BIOMEDICAL ENGINEERING

Carnegie Mellon University

2021 Biomedical Engineering
Summer Undergraduate Research Abstracts

Biomedical Engineering at Carnegie Mellon University

Biomedical engineering education at Carnegie Mellon reflects the belief that a top biomedical engineer must be deeply trained in both a traditional engineering practice and biomedical sciences. The unique additional major program leverages extensive collaborations with sister departments in the College of Engineering and with major medical institutions in Pittsburgh. This collaborative approach, combined with a rigorous engineering education, confers unique depth and breadth to the education of Biomedical Engineering graduates.

Biomedical Engineering Summer Undergraduate Research Program (BME SURP)

This program allows students to spend a ten-week period on a project that combines translational research and clinical exposure at a local medical center. Hundreds of students have participated in BME-SURP since its introduction in 1980. The experience has played a major role in helping students choose their career paths and obtain positions in industrial or academia. This program is supported by grants from the CMU College of Engineering and the CMU University Research Office (URO).

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Towards Catastrophe in the Heart!

Roger Lacson*, Carnegie Mellon University; Robert Biederman, Allegheny Health Network

Introduction: The impedances between the left ventricle (LV) and the aorta and the right ventricle (RV) and the main pulmonary artery (MPA) describe blood flow efficiency through the reduced area of each blood vessel. Of importance is the observation that each impedance metric undergoes a periodic collapse (Fig. 1&2). This behavior suggests that the system is a complex nonlinear multi-node system with feedback. We aim to formulate and validate a model for the heart based on impedance metrics.

Methods: Data from 82 AHN patients with pulmonary hypertension underwent evaluation by cardiac magnetic resonance (CMR) to assess the LV and RV impedance: $Impedance = \frac{(End\ Systolic\ Ejection\ Time) \times (Mean\ Blood\ Velocity)}{(Vessel\ Diameter)}$. We measured MPA systolic blood pressure (SBP) and six-minute walk test distance (6MWTD). We validated two models in which impedance variables were fit by linear modeling to both MPA SBP and 6MWTD. To develop a formal model, the potential to use both pole-zero plots (PZP) using Levinson-Durbin recursion and catastrophe theory (CT) were explored.

Results and Discussion: The MPA SBP was modeled using left and right impedance metrics, $R^2 = 0.49$ (Fig. 3). The 6MWTD was modeled using impedance metrics, age, and height, $R^2 = 0.46$ (Fig. 4). These two associations form a validation of the impedance representation. A PZP was plotted (Fig. 5) but was inconclusive using currently available data on pulmonary hypertension. We proceeded to consider CT (Fig. 6). Critically important to the catastrophe model is the sudden collapse of the response variable in response to small changes in another variable. While the relationship of the impedance metrics to other physiologic variables is established, the axes of the control surface have not yet been identified. Potential variables to describe this surface include the slope of the end-systolic pressure volume relationship for the heart muscle (E_{Max}) and blood vessel (E_0).

Conclusion: LV and RV impedances have been shown to be predictive of MPA SBP and 6MWTD, providing insight into cardiovascular function. Further research is required to evaluate the applicability of the CT model.

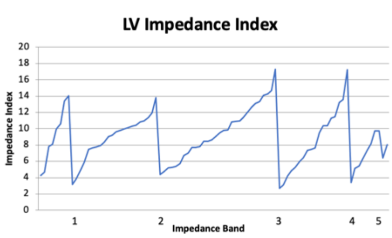


Fig. 1: LV Impedance Index against Impedance Bands. Impedance Index and Impedance Band are used to determine Ejection Fraction.

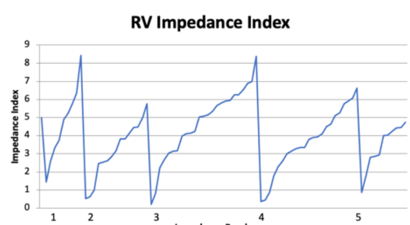


Fig. 2: RV Impedance Index against Impedance Bands.

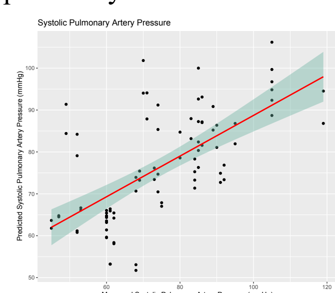


Fig. 3: Plot of predicted pulmonary artery pressure using LV and RV impedance against measured pulmonary artery pressure

Fig. 4: Plot of predicted 6MWT distance using impedance metrics, age, and height against measured 6MWT distance

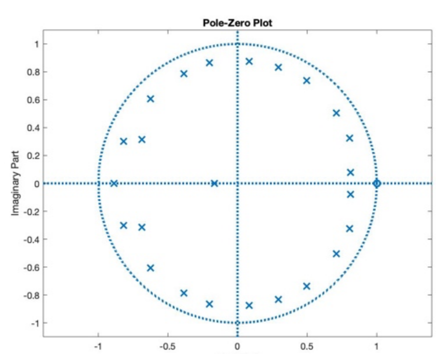


Fig. 5: Pole-Zero Plot fitted using Levinson-Durbin Recursion using 25 poles.

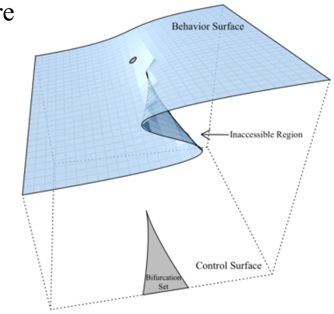


Fig. 6: Catastrophe theory cusp model representing the behavior space and jumps that occur through an inaccessible region from one equilibrium state to another.

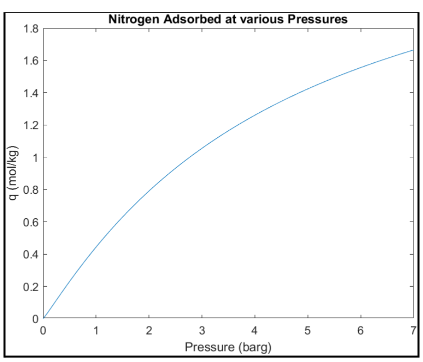
Mathematical Modeling of a Prototype Oxygen Concentrator

Authors: Daniel Thomeer - Carnegie Mellon University Department of Biomedical Engineering

Introduction: Increased number of COVID19 patients in hospitals has shown the demand for a more affordable, portable oxygen concentrator to provide respiratory failure patients a constant supply of supplemental oxygen. Portable oxygen concentrators were developed to remove the need for large oxygen tanks. However, current portable concentrator technology is heavy and unable to produce sufficient flow. Our lab has developed a prototype oxygen concentrator that will weigh less than current alternatives, and have a flow rate of at least 5 lpm. The prototype utilizes zeolite, a material that removes nitrogen from air producing concentrated oxygen, packed into tanks. The goal of our lab this summer was to create a mathematical model of air flow through our prototype in order to best optimize the weight and performance.

Materials and Methods: A literature review was performed in order to create MATLAB models for pressure drops and flow rates through the prototype, as well as adsorption of Nitrogen into the zeolite. The literature review focused on mathematical equations used to model gas adsorption and flow through a molecular sieve. The Sips equation, used to model adsorption of a gas, in mol/kg, by a molecular sieve, at various input pressures, was used to model nitrogen adsorption by zeolite. Using the Bernoulli and head loss equations, we were able to model flow and pressure through the tubes of the concentrator. Additionally, we utilized the Ergun equation to model the flow through a packed column of zeolite. Combining the Bernoulli, head loss, and Ergun equations allowed us to examine inlet pressure and flow conditions to produce our desired oxygen output of 5-10 lpm.

Results and Discussion: Figure 1 shows the results of the Sips equation applied to the prototype parameters. The graph shows that a higher pressure over the zeolite results in more nitrogen being adsorbed and therefore a higher concentration of oxygen. The model graphed in Figure 2 shows that in order to achieve a higher pressure, a higher input flow is also needed. Putting these two models together shows that increasing input pressure and input flow will result in more nitrogen being adsorbed and therefore, a higher output oxygen concentration. Additionally, a higher adsorption means we can reduce the weight by decreasing the amount of zeolite needed.



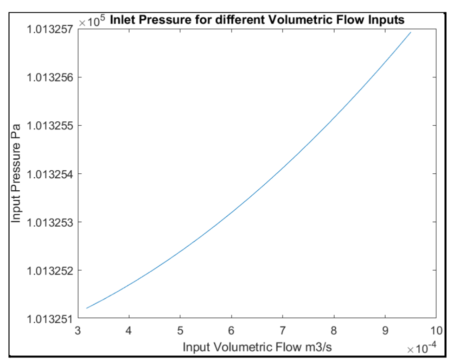


Figure 1 (Left): Model of Nitrogen absorbed by the zeolite at ranging pressures
Figure 2 (Right): Model of prototype inlet conditions to yield 5 lpm output

Conclusions: Examining the models, we can observe that increasing the input flow rate, increases the pressure which increases the adsorption and therefore allows us to decrease the weight of the prototype by using less zeolite. Moving forward, the model should be run through an optimization formula in order to best predict the optimal inlet conditions for our prototype.

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Virtual Clinical Immersion: Developing Project Ideas for BME Senior Design Capstone
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Introduction: The purpose of the Clinical Immersion Fellowship (CIF) is to uncover problems in the biomedical engineering field that can be transformed into project ideas for the BME senior design capstone course. Clinical immersion provides first hand experience of the problems that are faced by medical professionals in the industry and uncovers gaps in the field. Due to restrictions brought upon the university and hospitals in response to the COVID-19 pandemic this experience was performed virtually through online meetings and correspondence with clinicians and individuals in the field. This year had an intended focus on military medicine so some project ideas have possible military applications. A final write up consisting of four project ideas was created and will be distributed to students in the BME design course in the upcoming fall semester.

Methods: Due to the virtual setting, in person shadowing opportunities were limited. Instead, meetings were set up virtually with a clinician at Allegheny Health Network and a contact in the United States Army Reserves Medical Corps in order to understand how they each interact with and help patients who have varying needs. Background research was conducted before these interviews in order to gain basic knowledge and understanding about the specific fields. Notes were taken during the meetings so that they could be referenced later on during subsequent needs finding on the topics mentioned during the interviews. The fellow asked each clinician questions about their background, specialization, and experience in their respective field. Research was then conducted online to find potential project ideas either relating to the interviews or on alternate topics. Needs statement development was studied in order to outline the problem, population, and desired outcome in the write up for each project idea.

Results and Discussion: Clinical immersion was successfully accomplished through virtual interactions. A total of four project ideas and write ups were created, with the potential for some ideas to be shared among different teams to uncover multiple approaches to the same problem. The project ideas consist of the following: improving upon the Veress needle to prevent incorrect or dangerous placement, designing a garment to reduce fluid buildup for individuals with lymphedema, creating an endotracheal tube that can be detected non-invasively in order to check for correct placement of the tube in real time, and producing an assistive technology device for patients with mental illnesses that tracks physiological symptoms of one or more mental illnesses to aid in the mitigation and treatment of these conditions. Due to restrictions, experiences were limited which led to less exposure than previous iterations.

Conclusions: Although remote, clinical immersion is still possible though alternate online methods and allows for the development of project ideas. Interviews were a limiting factor since they consisted of what problems clinicians recalled at the time and wanted to share. In person shadowing allows for a less biased exposure to the field of biomedical engineering but it is difficult to replicate virtually.

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