2018-2019
Annual Professorship Report
A Note from the Provost:

To be named to an endowed professorship is one of the highest honors bestowed upon our faculty. Professors are appointed based on their demonstrated excellence in teaching, scholarly work and commitment to serving the Wentworth community. In collaboration with Institutional Advancement, Wentworth has established the following endowed professorships: the Blittersdorf Professorship, the Douglas C. Elder Professorship, the Henry C. Lord Professorship, the William E. Roberts Professorship, the Francis A. Sagan Professorship, and the Douglas D. Schumann Professorship. We acknowledge with deep gratitude the special gift of financial support that each of the sponsor/donors have given in recognition of our outstanding faculty recipients.

Please join me in congratulating our endowed professors for their many contributions to Wentworth. This annual report includes a summary of accomplishments over the 2018-2019 academic year.

With best regards,

Eric W. Overström, Ph.D.
Senior Vice President of Academic Affairs and Provost
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Impact:

The support of the HC Lord Professorship has contributed heavily to two of my primary responsibilities as an instructor at Wentworth Institute of Technology. These responsibilities revolve around my involvement in the first year engineering curriculum and the Electromechanical Engineering Senior Design. The funds have allowed me to grow in my role of coordinating and instructing the first year engineering courses ENGR1000 (Introduction to Engineering) and ENGR1500 (Introduction to Engineering Design). For the duration of the professorship I have utilized the HC Lord Professorship funds to attend and present at the annual ASEE conference: First Year Engineering Experience (FYEE). This conference has allowed me to serve on panels for discussions and attend workshops that greatly enhance my ability to develop and deploy curriculum for first year engineering courses. My presentations at these conference have focused on the development of the Interdisciplinary Design Course (ENGR1500) and on ways to improve student understanding of topics in the engineering design field. The discussions that followed these presentations have provided valuable insight that has been utilized for continued development of this course. My 2018 presentation at FYEE focused improving design course effectiveness by synthesizing design challenges.

My other teaching responsibility focuses on the capstone design course: Electromechanical Engineering Senior Design. In this course, the capabilities of the students is often never realized due to limitations in funds. The HC Lord Professorship Funds have allowed me to purchase items that can be used on these student projects that otherwise would be possible. These include multiple high powered multicore embedded platforms and sensors for autonomous vehicle systems, Virtual Reality headsets and support components for VR applications, and raw materials for manufacturing and student project development. All of the purchased components have continued to allow the student projects to go well beyond the expectations of prior iterations of the course and have produced some very impressive projects. All reusable components are also maintained as an inventory for
future iterations of the course. Funds have also allowed me to travel to the annual ASME IMECE conference and the annual ASEE conference to present both student work and work related to capstone design. In addition, funds have allowed me to purchase storage hardware for the purpose of maintaining an electronic library of student projects and files from prior years of BELM senior and junior design. This has been used as a depository of information for use in future projects, reduce redundancies in projects, and provide documentation for future ABET accreditations.

Along with the contribution to my teaching, the HC Lord Funds have also allowed for me to expand my scholarly work beyond that which would have been possible without the funds. I have been able to both return to the development of my previous work in using parameter signature for the purposes of model tuning and fault diagnosis and also begin a new initiative to use Virtual Reality Hardware as a medium for deployment of engineering laboratory instruction. Both of these areas of research are demanding on computer hardware and the funds have been used to purchase more powerful computer hardware and Virtual Reality Headsets. Funds have also been used to fund a Co-op student to work with me on this. In the first year of this new initiative one publication has already been generated and this work was presented at the 2018 ASEE national conference.

The Professorship funds have also allowed me to fund various initiatives for the Electrical and Computer Engineering Department. This included the purchase of soldering iron stations to allow for electrical circuit board fabrication. This involved the purchase of vent hoods, soldering irons, and a lab table. In addition, the funds were used to purchase a high voltage (10 kV) power supply that filled a need within the department. Lastly, the funds were used to support the MATE ROV team to purchase various prototyping supplies for the 2018 and 2019 entry into the international competition.
Use of Funds:

- In the 2017-2018 academic year, HC Lord Funds were used for the following:
  Total Expenses: ~$23875

  Component purchases:
  - HTC Vive VR Headset (~$400). This was used to allow for students to work in conjunction with me to continue the development of Virtual Reality Engineering Laboratories.
  - PNY P5000 Video Card ($750). Used in the development of virtual reality environments.
  - Miscellaneous sensors, cables, and components for student projects including MATE ROV components (~$2717.49).

  Travel:
  - ASEE FYEE conference July 2018 (Total cost with conference fee: ~$1000).
  - ASME CIE conference August 2018 (Total cost with conference fee: ~$1600 including membership dues to reduce cost of the conference).
  - Cost for ASEE 2018 annual conference (Total cost: ~$1800 including membership dues to reduce cost of the conference).

  Department Equipment purchases:
  - Soldering Irons (10x$90 = $900).
  - Fume hoods ($7143.50) Used in the setup of the Soldering Iron stations to vent the fumes away from the student.
  - 10kV Power supply ($6159.52).
  - Power Supply Cart ($155.99) Used for installing 10 kV power supply and for future supply needs.

Overall these funds have allowed me to greatly enhance student projects and contribute to future projects by purchasing current technologies and maintaining an inventory throughout. These items are to be added to over the subsequent years and I also worked with the department to identify equipment needs (like the 10kV power supplies and soldering iron stations).

The purchases that relate to the desktop computer in my office and the various virtual reality systems has allowed me to expand on my previous work to focus on the development of Virtual Engineering Laboratories. The initial work has proven to be very promising and will be greatly expanded in the coming months and years.
Impact

The primary goals for my HC Lord Professorship proposal surrounded helping student projects succeed where they otherwise may have had trouble succeeding without the funds. That has so far taken a few different forms: undergraduate research, senior design projects, MATE ROV student team travel, and student conference presentation funding.

- **Undergraduate Research:** In the spring of 2019, I was able to work with several junior co-op students on various research projects. In one particular project, the research involves Apple iPhone keyboard sound recording, in order to track the timing of the key presses and determine possible letter combinations for the recorded sound. This has revealed a possible side-channel attack that compromises the typed information, possibly revealing it to a third-party listener. In order to complete the research, which will continue in the short and long-term, we needed an up-to-date Apple device, in this case an iPod Touch, which mimics the mobile phone without the cellular service. This work was done by a BSCO student, John Solari.

Additionally, Professor Marisha Rawlins (my mentee) and I discussed the groundwork for her research project building a robot for STEM education and outreach to underprivileged children. Along with her co-op student (BSCO), Joshua Moorehead, they have designed the robot, and I helped purchase the parts for the prototype.

Without the funds, the students would not have had the necessary materials and tools to complete their co-op research. This would have weakened their experience and delayed forward progress on the overall project.
• **Senior Design Projects:** ENGR 5000 provides students with real-world hands-on project experience. As one of the instructors, I have made the funding opportunity provided me by the HC Lord Professorship available to all student groups (whether they are in my section, or the sections of the other instructors, Douglas Dow and Joe Santacroce). Students were required to fill out an application explaining how their project would benefit from the funds, why those parts were necessary, and they had to agree that I would keep their project prototype for advertising purposes at open houses. As these projects are typically self-funded by the students, it can place an unfair burden on the student groups to either lower their standards for materials or pay high costs out of pocket. The funding provided them with an outlet, allowing them to think about the right part for the project, not just part they could afford. So far, three teams have participated, and more are likely to participate in the summer semester as they build more of their project.

I plan to continue this practice of funding student projects at a micro-level (team by team, rather than single large purchases, which may also occur), as it gives students a much grander chance to make their dream project, regardless of the budget restrictions.

Additionally, since the department will now own the parts, they can either be repurposed for future teams and projects, or can be used to help recruit students that come to visit our campus. The HC Lord fund will thus have an direct impact on getting the best students to come to our department and be a part of our program.

• **Student Conference Travel:** As a faculty member, I strongly encourage students to get involved with professional societies and publishing their research in conferences. While some avenues are available for these students to receive travel funds, I have added to their budget through the HC Lord Fund. Alex Epstein and Azad Deihim are both BSCO seniors (in my ENGR 5000 course) with research publications in conferences in New Zealand and Ohio, respectively. They will each be presenting a paper at the conference that they may not have otherwise been able to afford. I am dedicated to helping research at WIT and the HC Lord fund has provided me with that opportunity.
Future Impact

In addition to continuing the efforts from the spring, there are additional plans for the summer and fall.

- **MATE ROV:** As the MATE ROV advisor and mentor, I know first-hand the budgetary constraints placed on the team. They compete at an international competition against teams with very large budgets from large universities. In addition, they need to travel with a team (they take 12 students) for four days to compete. The HC Lord Professorship funding has allowed me to give the team freedom to invest in their robot and their team travel without being overly concerned with their budget (although it is still carefully monitored). As my primary goal was to invest in student research and the MATE ROV represents a project of 30-40 students and faculty working on a single applied research project, the finds have had direct impact on the team and my participation in the team’s activities. In June, I will be traveling with the team, paid for in large part by the HC Lord funds, including flights, hotels, food, and other expenses.

- **Fall Co-op:** I have long been an advocate of availing paid research-style co-ops to our students. In the fall, I will hire a full-time co-op as a cybersecurity professional to continue the good work done by previous students regarding hardware security side-channels. The HC Lord fund will help fund this and will take a little over half of the yearly allocation.

- **IEEE Project Lab:** As IEEE advisor and senior design instructor, I would like to provide students with their own workspace and possible hardware and materials. I will partner with IEEE this summer to help do minor renovations on their project space (IEEE will also fund this) and then provide them with funds to populate the lab with equipment that members can borrow for student projects, both in and out of the classroom. These items will be shared between the ECE department and the IEEE student chapter and give students an opportunity to have a large library of items to use in their projects.

After the full funding year, I will likely have spent the total of the $15,000 for the year and helped further my goals. These goals were largely in student projects and related activities as well as promoting high-level research at Wentworth. All of these goals are still targeted and the HC Lord fund is having a direct impact on these pursuits. Without the funding, most, if not all, of these activities would go unfunded and unfulfilled.
Use of Funds

Table 1 shows the money already spent through April. An additional cost to the MATE ROV project may also be counted in the April budget, but that is not finalized yet.

Table 2 shows the planned expenditures for May through December (and possibly beyond).

<table>
<thead>
<tr>
<th>Table 1 – Funds used to date (Jan. 2019 – April 2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expenditure</strong></td>
</tr>
<tr>
<td>iTouch</td>
</tr>
<tr>
<td>Robot parts</td>
</tr>
<tr>
<td>Project components for senior design</td>
</tr>
<tr>
<td>Registration costs for student conference presentation</td>
</tr>
<tr>
<td>Poster printing</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
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</tbody>
</table>
TABLE 2 – Anticipated Use of Funds (May 2019-December 2019)

<table>
<thead>
<tr>
<th>Expenditure</th>
<th>Justification</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROV Competition Travel</td>
<td>The MATE ROV team (12 students) and I will travel to Tennessee for the annual competition</td>
<td>$3000</td>
</tr>
<tr>
<td>Project components for senior design</td>
<td>Provide various components for ENGR 5000 teams</td>
<td>$500</td>
</tr>
<tr>
<td>Costs for student conference presentation</td>
<td>Azad Deihim (BSCO senior) will be attending and presenting at an AI conference in Cincinnati; some travel costs will be covered</td>
<td>$500</td>
</tr>
<tr>
<td>Fall paid co-op</td>
<td>A student will be hired for the fall co-op and be paid for their efforts in the position (computer hardware and security related project) - $17/hour</td>
<td>$7616</td>
</tr>
<tr>
<td>Stipends for spring co-op</td>
<td>Students did an unpaid co-op in the spring; I am seeking a way to provide a small stipend to these students to do transitional work for incoming project students and other tasks</td>
<td>$2000</td>
</tr>
<tr>
<td>IEEE project lab</td>
<td>Remaining funds (if there are any) will be used to help renovate and equip the IEEE student project lab</td>
<td>TBD</td>
</tr>
<tr>
<td>Spring expenditures</td>
<td>See Table 1</td>
<td>$964.36</td>
</tr>
<tr>
<td></td>
<td><strong>Total:</strong> $15,000</td>
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</tbody>
</table>

In all the above cases, the Henry C. Lord Professorship is furthering my professional goals in regard to student projects, student research, and hands-on educational opportunities. I am grateful for the funds and I am sure they have a direct positive impact, for me and for the students involved.
Impact:

The support of the HC Lord Professorship has contributed heavily to two of my responsibilities as an instructor at Wentworth Institute of Technology. These responsibilities include my involvement in the first year engineering course ENGR1500 Introduction to Engineering Design and developing new Electrical Engineering elective courses Programmable Logic controllers (PLC) and Image Processing. The HC Lord Professorship funds were utilized to purchase soldering stations in Dobbs 202 and Wentworth 003. Soldering stations will be used for freshmen in Introduction to Engineering Design course, seniors in senior design course, and student projects for student clubs and competitions. The HC Lord Professorship Funds have also allowed me to purchase items that can be used on student projects in Introduction to Engineering Design. These include Arduino Uno R3 development boards, magnet speakers, ultrasonic sensors, pulse sensors, Adafruit MicroSD card breakout boards and support components. All of the purchased components allow the student to produce some very impressive projects. All reusable components are also maintained as an inventory for future iterations of the course.

My other teaching responsibility is developing new Electrical Engineering elective courses Programmable Logic controllers (PLC) and Image Processing. The PLC has evolved to become the central component of all automation systems today. The PLC course provides basic technical skills and knowledge necessary to work with electrical control systems typically found in an industrial environment. Image processing is used for detecting, counting, and measuring to help automate the process in manufacturing. It can also be used for detecting a target, tracking, recognizing objects in military and security. These courses could benefit Wentworth students in their job searching. The HC Lord Professorship Funds have allowed me to purchase textbooks for PLC and Image Processing.
Along with the contribution to my teaching, the HC Lord Funds have also allowed me to expand my scholarly work. I have been able to continue my research on pulsed voltage effects on cells and present my work “Molecular Dynamics Simulation Studies of Thermal Effects Created by Cell Membrane Electroporation” at 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society in July 2018.

The HC Lord Funds also support IEEE-Eta Kappa Nu student chapter at Wentworth. We conducted 10 new members last October and students organized weekly problem session for Network Theory I and network Theory II. Students plan to continue weekly problem session in the future.

**Use of Funds:**

In the 2018-2019 academic year, HC Lord Funds were used for the following:

Component purchases: Total Expenses: $8555.04

- Soldering station in Dobbs 202: $8468.22
- Arduino development boards, miscellaneous sensors, LEDs, and components for ENGR 1500 Introduction to Engineering Design student projects: $86.82

Textbooks: total expenses $453.04 (Programmable Logic Controllers and Image Processing)

Travel:

- 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, HI, July 17-21, 2018. (registration fee: $1005.00 + membership + travel cost: 3186.65)

IEEE Eta Kappa Nu student chapter: total expenses $848.95

- 10 student’s membership $700
- Student meetings $148.95
<table>
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<tr>
<th>Item</th>
<th>Vendor</th>
<th>Quan</th>
<th>Unit Price</th>
<th>Cost</th>
<th>Notes</th>
<th>Combined Cost</th>
<th>S&amp;H</th>
<th>Final Cost</th>
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<td>NI myDAQ - University Kit w/ 3-Yr Service</td>
<td>National Instruments</td>
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<td>$376.92</td>
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<td>EDGELEC 200pcs 10 Colors x 20pcs 5mm LED Light</td>
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<td>Emitting Diode Assorted Kit</td>
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Impact:

- How has the opportunity for this professorship impacted your teaching and research? What opportunities did you have that you would not have otherwise had?

I used the funds to work with an interdisciplinary team of 3 students to design a 3D Printer with unique capabilities. The team was comprised of Mechanical Engineering, ElectroMechanical Engineering, Electrical Engineering and Computer Science expertise.

The printer that we designed is still under construction. The goal is to have it operational by the start of the Fall, 2019 semester. The Roberts Professorship gave me the freedom to organize a team of my choosing and allowed me to roll up my sleeves and get my hands dirty on a topic that I am highly interested in.

Use of Funds:

- What have you done from April 2018-October 2018 with the funding you have received? How have the funds you received through this professorship complimented your teaching and scholarly work? What did you purchase with the funds and how was it used?

I used the funds to pay each of the students on the team and to purchase materials and components for the 3D Printer design. I am the sole faculty member who teaches Additive Manufacturing (3D Printing) at WIT. I could share my in-depth knowledge of this topic with my 25+ years of experience designing machines with a very talented and motivated team of students. The work on the project is ongoing and the learning continues.

I also used a portion of the funds to buy a license to software that allows me to explore Generative Design. This is a new design paradigm that uses the rules of mother-nature to generate forms based on applied stresses and material properties. The resulting forms are seldom manufacturable by conventional means but are well suited to Additive Manufacturing techniques. The underlying premise is that designs created by Generative Design use
far less material resulting in cost savings. Additive Manufacturing is able to produce these designs in small quantities but has a ways to go before it can compete economically in the mass manufacturing arena. Nonetheless, advancements in the field are being made on a weekly basis.
Use of Funds - Year 3

Essentially, my Summer Semester Studio Class for Junior Industrial Design students is built around the funding of a number of project-focused electronic components. Combined with a variety of high level prototyping materials, this allows the students to fully explore the potential of a product concept while building a working prototype. The studio focuses on Conceptual Robotics. Because of the William E. Roberts Grant, we were able to purchase a broader selection of parts, enabling my students to maximize their creative and experimental thinking while engaging in projects at a far deeper level.

Over the past three years, the generous grant has enabled the Department of Industrial Design to acquire equipment which has influenced our student outcomes immensely. For example, we bought a high resolution 3D printer (SLA), a small yet extremely valuable CNC wire bending machine, a large finishing tumbler for metal parts, and a large format vinyl cutter. In addition to the machines themselves, I bought a large selection of the applicable materials for these machines, including resins, 0.125 aluminum wire, abrasives, and rolls of vinyl.

The grant has also allowed me to supply an incredible amount of electronic componentry for my studio projects. The success of those projects could not have happened without that financial support. For example, I purchased 24 Makeblock Robots (one for each class student), numerous components including sensors and motors, micro vibrating motors, micro batteries, ABS print material, machinable wax for tooling test cutting and prototypes, OBO Modulan machinable heavy weight modeling board, and resins for casting parts.

In addition, something a little more unexpected happened. Because we were tackling content that was beyond our general scope of knowledge, we were able to involve professors from many other departments as essential partners. Therefore, we had sessions with experts in circuit building (Professor Yugu Yang-Keathley from the Department of Electrical Engineering) and programing (Professor Durga Suresh from the Department of Computer Science and Networking). This meant that my knowledge level grew too! After these sessions, I could advise seniors regarding the
electronic potential of their capstone projects and I was able to design a project for Peter Rourke’s engineering RP class that involved electronics. Neither would have happened without Ken Robert’s grant.

Finally, as a result of working with these components and materials, my students and I were given the freedom to creatively develop great ideas to prototype stage without the often-daunting constraints of cost. As I have written before, the results of these classes would not be the same without this endowment and I am extremely grateful.
Course Collaboration
Project: Create multi-configurable component kit for manufacture
CNC Milling - 3D Printed - Motors - Control Board
Impact:

- How has the opportunity for this professorship impacted your teaching and research? What opportunities did you have that you would not have otherwise had?

Over the course of my 11 years of teaching at Wentworth I have undertaken several design and fabrication projects due to my long standing belief that realizing ideas is an aspect of design that few students have an opportunity to do and at the same time it is profoundly important and impactful to do so. One of the greatest challenges of realizing ideas and transforming them into build work at full scale is the financial constraint placed on projects. The second challenge is finding the facilities to complete the work with a degree of craft and execution. The William E. Roberts Professorship has enabled me to reach new levels of what we can offer at Wentworth due to the financial support awarded to me. It has also allowed me to establish a connection with Boston’s Autodesk Build Space in South Boston’s Innovation District. The Build Space is one of three Technology Centers supported by Autodesk and as their website states, “hosts teams from industry, academic, and startup communities doing forward-looking work in the areas of construction, manufacturing, and emerging technologies.” Work conducted at the Build Space is at the cutting edge of design and manufacturing but is only possible with funding. We have spent the spring semester integrating into the space, receiving training in areas of CNC milling, 3D printing, woodworking, metal work and composites research and most importantly, testing ideas at large scale. Being able to offer this range of facilities all under one roof while surrounded by some of the best applied research teams in the area and beyond has been an incredibly
rewarding experience for me as a teacher and more importantly, to the students who will soon be entering into design practice.

Use of Funds:

• *What have you done this past year (2018-2019) with the funding you have received?*

My spring 2 & 3 year graduate architecture studio has been working with me as members of the residency team at the Autodesk Build Space and we are currently researching and testing the application of carbon fiber in architecture. Carbon fiber is a composite material emerging in the building industry and is known for its structural strength, lightness and its innovations in fabrication. We are using this residency to develop innovative ways to apply this new material to building facades. We are working through April and some of us will continue into the summer.

• *How have the funds you received through this professorship complimented your teaching and scholarly work?*

The material research conducted at Autodesk has allowed me to expand upon what I am able to do on campus. Autodesk provides a working environment for composites that is not found at the Institute. This allows me to not only expose students to innovative material research but will give me the opportunity to explore this research myself with a research assistant over the summer months. It is my hope that work conducted will lead to opportunities to publish in academic journals or conferences in the coming year.

• *What did you purchase with the funds and how was it used?*

Since receiving the professorship I have used the funding in large part to fund materials during my spring graduate studio. I have purchased supplies of pre-preg carbon fiber tow, a material used in manufacturing as well as necessary hardware for constructing jigs and assemblies for winding with the carbon fiber. Sturdy frames are needed in order to provide the proper resistance to tensile forces put on during the winding and curing processes.
• **How much total did you spend?**

I have spent approximately $2350.00 to date, these expenses provided materials, tools and equipment needed with no expense to the 6 graduate students working with me. More than half of the expenses have been towards hardware that can be used in future research.

• **What are your plans for the future for this professorship?**

This summer I plan to conduct my own research at the Autodesk Build Space with a focus on composites material research and fabrication.

Running parallel to this work, I plan to work with a research assistant to develop additive manufacturing end of arm tooling for our department’s industrial robot which will support clay extruding. This end of arm tooling will allow other faculty members in the department to explore opportunities in the area of additive manufacturing. Funding will support the cost of a research assistant and for the required hardware and software need for the project.

Looking ahead to the fall semester I hope to offer similar experiences to a senior design studio where we will build on the preliminary research. The students in the fall will further the applied research through a possible opportunity for a community focused design build project.

Thank you again for this amazing opportunity and I would be happy to forward images of the process from this spring’s research.

Best regards,

*Rob Trumbour*

William E. Roberts Professor

Associate Professor in Architecture
Impact:

- How has the opportunity for this professorship impacted your teaching and research? What opportunities did you have that you would not have otherwise had?

The Sagan professorship has had a positive impact on my teaching and research. It has given me the opportunity to work on a variety of projects and my teaching abilities have improved significantly as shown in the sections below. I have externally collaborated with faculty from other universities and organizations as listed below.

The funding has given me the opportunity to enhance undergraduate research at Wentworth Institute of Technology. Students have had exposure to working with graduate level instrumentation and material beyond the scope of undergraduate curriculum.

Use of Funds:

- What have you done this past year (2018-2019) with the funding you have received?

During the reporting period of 2018-2019, I worked with the following students and faculty.

Students:

1) Katherine Asciutto: Civil Engineering, 2018
2) Samantha Devincentis: Civil Engineering, 2018
3) Audrey Iodice: Civil Engineering, 2018
4) Catarina Figueiredo Mendes, 2019
5) Gabriela Kuran, 2019
6) Amanda Siciliano, 2020
Faculty:

1) Dr. Hajar Jafferji: Assistant Professor, Wentworth Institute of Technology, Civil Engineering
2) John Daniels: Professor, University of North Carolina
3) Dr. Rajib Mallick: Professor, Worcester Polytechnic Institute, Civil Engineering

Research with Audrey Iodice, Katherine Asciutto, and Samantha Devincentis: This research team consisted of three seniors from the civil engineering program and lab technician. In the spring and summer of 2018, the three students continued to evaluate the attenuation capacity of Cannabis Sativa (Hemp). Batch sorption and column testing was conducted, and the results proved positive. The students were able to model the results and could predict the contaminant fate and transport of the contaminants if a hemp filter were to be utilized in the field. The students presented the research in two different locations. The students presented in an international conference in Rome, Italy and won the best poster presentation award. The students continued their project till the day of graduation and the updated research was published again at the UMASS Soil and Sediment Conference.


Due to the lack of resources and support from the administration at Wentworth Institute of Technology this research will no longer continue at WIT.

Research with Catarina Figueiredo Mendes and Gabriela Kuran: This research team consisted of two seniors in the civil engineering program. In Summer and Fall 2018, the Catarina and Gabriela started to research the comingling single stream waste products into beneficial uses. It was determined that plastic bags originate from the same source as bitumen which is the primary constituent of asphalt. Ms. Kuran and Ms. Mendes conducted various acid digestion procedures to evaluate the contaminants leaching from plastic bags. They presented their research in the UMASS Soil and Sediment Conference

Research with UNC Charlotte: I started research with Dr. John Daniels who is the Department Chair and former NSF director from UNC-Charlotte. Dr. John Daniels is my former advisor and I have worked with him for the past 18 years. Our research was to evaluate the field leachability conditions of fly ash from Duke Power steam stations.

Fly ash is a waste product of the combustion of coal. It is produced at coal-fired power plants and blast furnaces. The United States produces 120 million metric tons (MT) of fly ash every year and most of it is simply deposited into landfills near each power plant. The Environmental Protection Agency (EPA) classifies fly ash as a hazardous product because it contains arsenic, chromium and boron (EPA, 2018). In Indiana, the coal plants generate a significant portion of the state’s electricity. The fly ash produced, are dumped into ash pits. These ash pits are toxic and are now contaminating groundwater as well as the state surface water, some of which provides the populations drinking water. In 2017, Duke Power was investigated and fined on numerous accounts for dumping toxic fly ash into natural water bodies. Dr. Daniels and I, from December 2017 to August 2018 evaluated the field leachability conditions of the toxic fly ash. Our results were published in the following journal publication.


How have the funds you received through this professorship complimented your teaching and scholarly work?

The funds obtained from the Sagan fund has enhanced my knowledge of sustainability and environmental remediation. Over the past few years I have gained a better understanding of my courses that I teach as shown in my student evaluations listed below of two courses environmental engineering and water and wastewater treatment.
Overall, my teaching has significantly improved my delivery and knowledge of the subject matter.
My scholarly work has improved significantly even though I have continued to teach 36 credits annually.

How much total did you spend?

The numbers listed below are approximate amounts spent as materials are still being purchased:

1) Materials for Research: 5500$: New equipment and laboratory material
2) Student Employment: 2500$
3) Travel for Conferences and Meetings: 8000$

See more of Gautham’s work in Appendix A
Impact:
I have been the Sagan Endowed Professor since January of this year. I have taken some initial steps towards implementing my plans for the Sagan Professorship.

- How has the opportunity for this professorship impacted your teaching and research? What opportunities did you have that you would not have otherwise had?

The opening of CEIS has allowed for greater opportunities in instrumental analysis of the products of the Biodiesel Laboratory. With funds from the Sagan professorship, I should be able to supplement material needs to conduct said analysis. As Shimadzu is currently installing and conducting training on new instrumentation, I am familiarizing myself with the options available for new analytical techniques. These will require some supplies, and some preparation which I can supplement from the Sagan funds.

I have also had a student, Jeff Urena, express interest in helping upgrade the pipework on the Biodiesel Processor. I am looking into the possibility of funding Mr. Urena’s work, an opportunity made possible by the Sagan fund.

Use of Funds:

- What have you done this past year (2018-2019) with the funding you have received? How have the funds you received through this professorship complimented your teaching and scholarly work? What did you purchase with the funds and how was it used? How much total did you spend? What are your plans for the future for this professorship?

My tenure as the Sagan Endowed Professor began in 2019. I plan to make use of the funds extensively to work on biodiesel analysis in the summer of this year, and potentially paying student workers in the summer and the fall.
These opportunities will enable me to do quality assurance on the biodiesel produced in our labs, and make it possible for the fuel to be used in campus equipment. It will give students engaged in the work a deeper understanding of the needs of chemical analytical techniques. It will also give me the opportunity to connect students at all levels directly with campus projects. I already give tours of the biodiesel lab to introductory chemistry classes, and this will give me the opportunity to tell a more compelling story. It will also increase the options for students to be able to participate actively in fuel production.

Funds are going to be used for purchasing supplies for analytical equipment. They will also be used to compensate students when and where possible for work that they do on the reactor. In addition, facilities will be consulted for some minor changes to the biodiesel space, and their costs can also be covered by the funds from the Sagan endowed professorship.
Introduction:

I was awarded the professorship in September of 2009. It was a great honor to have had the privilege of utilizing the professorship to advance the knowledge in the field of science and engineering in general, and the construction management field in particular. This endowed professorship enabled me to pursue several activities of significant academic and research importance. That included active participation in professional conferences; and expanding the scope of Wentworth’s EPIC program into the public sector. In addition, I was able to organize several symposia at Wentworth on topics such as: Climate Change and its impact on Infrastructure; Future of Public Transportation; Role of Technology in managing construction operation involving the use of drones etc.

Even though I am no longer in a position of endowed professorship, my overall mission continues to be guided by my core belief that in order to create excellence in students, an instructor must connect with the students in enhancing their understanding of the science and art of construction management, and its applications in solving the real world problems. We are seeing dramatic changes in the technologies being used in the CM field such as: use of drones in the inspection of bridge structures, monitoring construction progress, and delivering field data to project managers for decision making Building; Information Modeling (BIM); Integrated Project Delivery (IPD) systems, and risk analysis models. Below is a brief description of activities carried out as part of the Elders Professorship during this academic year under the title of impacts.
Impact:

- **Academic/Teaching Activities:**

  - **Symposium on New Infrastructure:** This was a major effort in organizing this symposium last October on campus. This symposium focused on: Transportation Policy, All Electronic Tolling (AET), Use of Drones specifically in the area of construction management, bridge inspections, and aviation safety, and Climate Change model developed by the Massachusetts Water Resources Authority (MWRA). The speakers on the panel were from the senior executive levels in state government. The symposium was well attended by students, faculty and engineering firms. I moderated the panel discussions, and Dean Chuck Hotchkiss gave the closing remarks.

  - **New Focus on the Elective, titled: Managing Public Infrastructure Projects, CONM 3800.** This course was developed by me in 2013 to provide an opportunity for our students to learn about our public infrastructure and its relationship to our nation’s economic well-being. This course has gone through some significant changes based on my dealings with public agencies such as Massachusetts Department of Transportation (MDOT), Massachusetts Bay Transportation Authority (MBTA), and the Massachusetts Water Resources Authority (MWRA). Students are asked to focus on a single public infrastructure project, examine and analyze its operational and management performance with view to enhance its service delivery. At the request of the General Manager of the MBTA students will be studying two new concepts – Value Capture and Public/Private Partnerships (PPPs or 3Ps) as a way of financing public infrastructure projects. This new focus exposes the students to the intricacies of managing construction projects in the public sector. High enrollment in the course indicates a strong student interest in learning about public infrastructure management. Juniors and seniors are registered in the course. The objective of the course is to prepare the students for working on publicly funded projects whether they are working in the public sector or in the private sector. The syllabus includes review and understanding of the requirements for compliance with state and federal laws in procuring services of contractors on public construction projects.

Professor Monica Snow and I have developed another elective titled: Bridges and Roadways, which we would be co-teaching. Some of the material for the course comes from the current state of the art technologies being used by the transportation agencies. On-going relationship and
collaboration with MDOT has been very helpful in this regard. Such activities are partly aided by the Elders Professorship.

- **Collaboration with WIT Public Relations Office:** Another part of my activities partly helped by the funds from the Elders Professorship has been to do research on current topics of public importance and to do interviews and provide comments to the media both in print and on camera. Keeping an active role in the professional community is important to stay abreast of the changes taking place regarding technology, new approaches to financing public projects, learning from failures in the construction area. I continue to participate publicly visible events such as being a speaker at professional societies, publication of letters related to infrastructure issues in the Boston Globe. Here is an example of such collaboration. Below is a message from Dennis Nealon, Director of Public & Media Relations:

For those tuned into NBC Boston this evening: at about 6 p.m. look for a promo for a story on deficient bridges featuring **Douglas C. Elder Professor** Ilyas Bhatti. He was interviewed on campus about a week ago for this special report. The full story/Bhatti interview airs on NBC Boston (Ch. 810 or 10) at 11 p.m. tonight.


Similarly, I conducted research into the topic of selection of street lighting systems by municipalities. I was interviewed by a reporter for Santa Fe, a newspaper based in New Mexico. According to our public relations office, I was quoted extensively in over 350 news outlets. These are a just a couple of examples of my on-going collaboration with our Public and Media Relations Office.

- **Role in Professional Societies (Research and Scholarly Activities):** This was quite a busy year in terms of collaborations with professional societies. The Elders Professorship funds have substantially contributed to my role in this area. I am an active member of several professional societies and organizations, such as the American Council for Construction Education (ACCE), American Society for Engineering Education (ASEE), American Society of Civil Engineers (ASCE) and its affiliate American Academy of Water Resources Engineers (AAWRE) to name a few. I am a Founding Diplomate of the Academy.
- For the ACCE, I serve as the Vice Chair of the Training Committee. This committee is charged with assessing training needs and organizing training sessions for future leaders of the ACCE. ACCE is the accrediting body for the construction management programs in the US. The changing criteria for program accreditation creates needs for training members for performing various responsibilities in the accreditation process.

The professorship funds were extremely helpful in enabling me to continue playing an active role in ACCE. Also, in recognition of my work for the ACCE, the Board of Trustees voted me in as a Trustee of ACCE.

I have served as a reviewer for scholarly papers submitted for presentations at the Annual Conference of the ASEE. I was the reviewer for the following papers: 1. Strategies to promote sustainability in courses and programs through student engagement with the United Nations Sustainable Development Goals. 2. Intercultural Competence at the Intersection of Engineering and Study Abroad.

My paper titled “Water – The next Frontier for International Conflicts” was accepted for presentation at the 2018 World Environmental and Water Resources Congress in Minneapolis in June. The paper examines the hot spots around the world where water conflicts have the potential of turning into armed confrontation. The paper also looked into actions that can prevent such conflagrations.

This participation was completely funded by the Douglas C. Elder Endowed Professorship. Similarly, my paper titled” A Perspective on History of Environmental Regulations – successes and challenges in reclaiming polluted waters” was accepted for presentation at the 2019 World Environmental and Water Resources Congress to be held in Pittsburgh in May.

- **CM Semester Abroad Program:** Since my involvement in the Semester Abroad in Berlin (SAB) program in 2015, I have been working with our department chair, Professor Scott Sumner in effectuating changes to the program. This became necessary based on the feedback received from the students and my analysis of the program. Currently, I am working with Professor Sumner in providing a smooth transition to our new semester abroad program at the Waterford Institute of Technology in Ireland for the 2018 spring semester soon to be concluded. I visited our students and
faculty at the Waterford Institute in March this year and accompanied them for visits to project sites in London and Spain. I worked with Boston area firms doing international work in arranging these visits. Thus, students were exposed to learn about European construction technologies and their application on global stage. In this regard, professorship funds were helpful in doing the outreach to Boston area CM firms such as Skanska, AECOM/Tishman, and Louis Berger International who became partners in helping us with student visits in UK and Spain. It is likely that funds under the professorship may be utilized in further activities related to this program.

- **EPIC projects** – I have developed successful collaboration with two important public agencies in Massachusetts, MDOT and DCR. With MDOT, we just completed the second phase of a high-profile project known as Bowker Overpass. This project involved the participation of three departments: Department of Architecture, Civil Engineering, and Construction Management. Student work was displayed at the end of the 2017 spring semester. Plans developed by students were viewed by the MDOT officials and their consultant, Kleinfelder Associates. Another project that is underway is with DCR. DCR project entails looking at their camping facilities and developing designs for lodging and recreational activities in public parks in the state. Students from the Department of Architecture have developed some preliminary conceptual plans which were reviewed jointly with DCR. I'm currently working with both DCR and DOT to develop further action plans with the regard to the aforementioned projects.

These projects represent great opportunities for learning for our students under the EPIC program. I envision a very active role for me in this area.

Funds from the professorship provide for arranging discussion forums to develop curriculum activities. Working luncheon meeting were held with Massachusetts DOT

**Use of Funds:**

- **Equipment & Professional Activities:** As mentioned above, many activities have been funded completely or partially with the funds from the Douglas C. Elder Endowed Professorship. These funds have enabled me to keep an active role in the professional community to stay abreast of the changes taking place regarding technology, new approaches to financing public projects and lessons learned from project failures. In addition to the activities stated above, these funds allowed me to participate
in a two-day professional development seminar last June in Tampa organized under the auspices of the ASCE. The seminar focused on building failures – Investigation, and Remediation of Building Failures

- **Equipment Purchases:** Last year, the CM Department purchased two “iplan Tables” at an approximate cost of $25,000. These tables with screens provide access to data on estimation, project management, facility management, archiving and many other workstation solutions. This was a very good investment from the professorship fund. The availability of this equipment has helped our students greatly, and also been great for guest speakers to arrange their presentation materials for teaching purposes. Project files, drawings and specifications can be stored in these tables.

- **Purchase of Drones for Teaching:** Currently we are looking into purchasing of drones as a teaching tool for our students to understand the ever-expanding use of drones and related technologies in the construction field. The addition of such equipment to our labs would greatly enhance our lab’s capability.

**Concluding Remarks:**

It has been a privilege to have served as a Douglas Elder Endowed Professor in the CM Department. It enabled me to connect students with the external developments in the infrastructure arena by inviting speakers both from the public as well as private sectors. Hopefully, our students have benefitted from their exposure to the real-world challenges which will help shape their careers into leadership positions. The professorship funds were instrumental in accomplishing these goals that I set out with after receiving the award. I certainly would like to express my gratitude to Mr. Douglas C. Elder for his generosity and vision for advancing the cause of technology education. Also, a sincere thank you to Kelly Parrish, Director of Academic Operations, for being so helpful during the implementation period.
The Douglas C. Elder Endowed Professorship has provided me the opportunity to foster greater awareness of Boston transportation infra-structure, while advancing Wentworth's position with regard to local and regional transportation (rapid transit) infra-structure issues and needs. Since 2012, my efforts have been largely directed toward bringing greater awareness of the need for improved subway rapid transit service in Boston. This need for improved rapid transit service through Back Bay and the over-capacity conditions on the century old Green Line trolley were highlighted in the 2012 report by the Urban Land Institute. Over the past six years, I have worked with several groups of civil engineering students to develop the Blue Line to Riverside project idea, which the MBTA included in the 'short-list' of proposed transit extension proposals being considered in their FOCUS-40 process, envisioning the future of the MBTA.

The following describes the various efforts undertaken in the middle of final year of my participation in the Elder Professorship (summer 2018) on the Blue Line Extension project and other ideas for rapid transit improvement. Continued developing technical study on new subway line (Blue Line Extension) under a CIVE-3800 special study topic course taken by 8 students (3 juniors and 5 seniors). Five of the students focused on continuing development the Blue Line Extension of rapid transit line on the MBTA system. Three of these students participated in detailed studies of how to change the existing D-trolley at-grade stations into raised platform rapid transit stations for the Blue Line, with primary focus on stations from Reservoir Station to Fenway. With their study, we concluded that extension all the way to Riverside (i.e. beyond Reservoir) was probably not worth pursuing. Two other students (seniors) focused on a new idea to extend a Blue Line branch further along the Mass.Pike to Allston Landing and then on to Arsenal Mall in east Watertown. As part of these studies, we also contacted the Mayor’s office in Watertown and developer for Fenway Center regarding our ideas for the Blue Line into Fenway and to Arsenal Station.
In this same CIVE 3800 course, two other seniors investigated use of Mono-Rail and Bus Rapid Transit along the "Urban Ring" alignment from Orange Line Ruggles Station to Red Line Andrew Station, and then further to the Seaport District. A fifth senior student investigated use of Silver Line buses through the Seaport District and from Andrew Station along the South Boston Bypass Road into the Seaport.

By the end of the semester, four page 'brochure-type' summaries (se copies attached) were developed to illustrate workable plans that were developed for three of the projects and a technical report for the Mono-Rail option to the "Urban Ring' (which were then submitted to the MBTA's FOCUS-40 project coordinator).

At the conclusion of the efforts under D. Elder professorship, I took the group of 8 students in the CIVE 3800 summer course to the INNO-TRANS technical trade show in Berlin Germany in late Sept. 2018 (Monday through Saturday). These students had worked on the Boston Transit Improvements study course in Summer 2018. Funds for the trip came from the Elder professorship.

Although no longer funded by the Elder Professorship, I am continuing technical feasibility studies and needs analysis on new subway lines (Blue Line to Riverside, and Dudley Rail Rapid Transit) with student groups as CIVE-3800 Special Topics courses each semester through 2019.

Continuing to make presentations to political, civic, development interests in various forums. Planning to organize a forum in Summer to show results of various studies to selected group (20 to 35) local politicians, civic leaders, developers. Also planning to start a web-site for the Blue Line to Riverside and Dudley Rail Rapid Transit. Expect to also work with other CE student to further the preliminary work on the Rainbow Line.

Respectfully Submitted,

James Lambrechts, P.E., Professor, Civil Engineering and Technology
Impact:
The support of Elder professorship has been having a great impact on my teaching and research activities. While it has been only 4 months from the start of the professorship in January 2019, it has helped in different ways.

The funds provided the opportunity to hire an undergraduate student as a research assistant and conduct a literature review on automated earthmoving operations. This is an ongoing research study and the results are intended to be published in a peer-reviewed conference.

The use of lean concepts has been gaining more popularity in the recent years in the Construction Industry. The professorship funds have allowed me to attend a few webinars offered by the Lean Construction Institute. These webinars have been very helpful in enhancing my knowledge in this subject area and incorporating them into my teaching materials.

One of my goals for the professorship is to develop a new course on advanced Building Information Modeling (BIM) aspects. I am a member of the Virtual Design and Construction (VDC) committee at the Associated General Contractors of America, MA chapter (AGC MA). Recently, there was a conversation about the need for introducing different aspects of BIM in an intense course to construction management students. I am planning to develop a course as one of our construction management elective courses in which the students learn topics such as BIM fundamentals, coordination and clash prevention, scheduling with BIM, quantities and component tracking, etc. This will be a junior level course offered in summer; therefore, the participating students in this class know necessary subjects such as estimating, scheduling, and project management. To this end, networking and brainstorming with colleagues from other universities and industry professionals are essential. The professorship funds give the opportunity to buy necessary books and attend conference that bring many professionals from the Architecture, Engineering, and Construction (AEC) industry and academia together.
Use of Funds:

To this date, the Douglas C. Elder funds have been used for the following items:

- Paying an undergraduate research assistant for 12 hours
- Webinars: $275
- Books (building codes and regulations): $922.19
Impact:

The Elder professorship has had a positive impact on my teaching and research. It has given me the opportunity to work on a variety of projects and my teaching abilities have improved significantly as shown in the sections below. I have externally collaborated with faculty from other universities and organizations as listed below.

The funding has given me the opportunity to enhance undergraduate research at Wentworth Institute of Technology. Students have had exposure to working with graduate level instrumentation and material beyond the scope of undergraduate curriculum.

Use of Funds:

What have you done this past year (2019) with the funding you have received?

During the reporting period of 2018-2019, I worked with the following students and faculty.

Students:

1) Catarina Figueiredo Mendes, 2019
2) Gabriela Kuran, 2019
3) Amanda Siciliano, 2020

Faculty:

1) Dr. Abigail Charest: Assistant Professor, Wentworth Institute of Technology, Civil Engineering
2) Dr. Hajar Jafferji: Assistant Professor, Wentworth Institute of Technology, Civil Engineering
3) Dr. Rajib Mallick: Professor, Worcester Polytechnic Institute, Civil Engineering
I. Incorporation Plastic Products into Roadways

Research at WIT:
This research team consisted of two seniors and one junior from the civil engineering program. In Spring 2019, the students continued their research of comingling single stream waste products into beneficial uses. It was determined that plastic products originate from the same source as bitumen which is the primary constituent of asphalt. Asphalt which is the primary constituent of roadways. Ms. Siciliano, Ms. Kuran and Ms. Mendes conducted various environmental and strength testing at WIT.

- Ms. Mendes and Ms. Kuran will be presenting their research at 10th International Conference on Environmental Engineering and Applications (ICEEA 2019) on June 26-28th, 2019.
- Ms. Siciliano will be presenting her work at 7th International Conference on Bituminous Mixtures and Pavements on 12-14th June 2019.

Research with WPI:
Ms. Siciliano and I visited Worcester Polytechnic Institute (WPI) to meet with Dr. Rajib Mallick to discuss the field testing of the research we have been working on for the past one year. It was decided that Ms. Siciliano was going to conduct some strength testing at WPI labs later this year.

Dr. Mallick and I applied for a foundation grant. I was made aware of the RFP in October 2018. It should be stated that the white paper proposal for the foundation grant was submitted to the Department Chair Dr. Jack Duggan on November 16th, 2018 and the project notification form (PNF) got signed by all the academic leaders only on March 14th, 2019. This made it difficult for us to meet the deadline of April 1st, 2019. Dr. Mallick and I worked tirelessly on putting together the white paper proposal for this foundation grant, it was extremely discouraging for me that we could not submit a letter of inquiry (LOI) on time. WIT submitted the LOI on April 10th, 2019 and we got rejected on April 12th, 2019.

My future work is to apply for a National Science Foundation Grant and I am hoping that I have a better turn over on the approval of the PNF this time around.

II. Evaluating the Efficiency of Low-Cost Filtration
I started research with Dr. Abigail Charest to evaluate the efficiency of various low-cost water filters. The objective of this research is to identify a low-cost water filter which could be employed in areas affected by natural disasters and in developing nations. Dr. Charest is going to be doing all the microbiological while I am
going to be doing all the inorganic contaminant testing. Our hope is to submit our work to a journal publication.

III. Concrete and Fly Ash Research
Dr. Hajar Jafferji and I, have started investigating the strength properties of Fly Ash. We are currently working on incorporating 40% fly ash in concrete. This will potentially reduce 10% of fly ash placed in landfills. We are investigating various additives such as calcium stearate as potential additive which will reduce the leaching of fly ash.

How have the funds you received through this professorship complimented your teaching and scholarly work?
The funds obtained from the Elder Professorship fund has enhanced my knowledge of sustainability and environmental remediation. Over the past few years I have gained a better understanding of my courses that I teach

How much total did you spend?
The numbers listed below are approximate amounts spent as materials are still being purchased:

1) Materials for Research: 200$: New equipment and laboratory material
2) Student Employment: 1500$
3) Travel for Conferences and Meetings: 1000$

What are your plans for the future for this professorship?
My plans are to continue my research with:

a. Dr. Rajib Mallick from WPI on the incorporation of plastic products in roadways and apply for an NSF grant
b. Dr. Abigail Charest on identifying a low-cost water filtration product
c. Dr. Hajar Jafferji on incorporating various additives to fly ash and concrete
d. Dr. John Daniels from UNC-Charlotte on identifying innovative materials to attenuate heavy metals.

See more of Gautham’s Work in Appendix A
Impact:

Assess Impact – How has the opportunity for this professorship impacted your teaching and research?

The Blittersdorf Professorship has impacted my teaching and research in several apparent and imperceptible ways. The Professorship has allowed me to complete several quantifiable tasks including purchasing lab supplies and traveling with students to conferences. Additionally, the Professorship has provided me with a renewed excitement and empowerment for creating innovative research. This has resulted in an expansion of topics of sustainability in my coursework, and the creation of new lab groups.

What have you done in the past year?

Teaching:

Over the course of the past year, I have proposed several new courses and interdisciplinary EPIC projects. To date none of these proposals have been able to fit into my course load. I’ve moved on from incorporating new sustainability topics in new courses to have more of a focus on research due lack of support from the department. Hopefully, in future semesters there will be an opportunity to profess on these subjects.

Proposals included:

- Course - Global Sustainability Projects – Proposed a course which would combine civil engineering, architectural and construction management students in a projects-based course which would result in student posters to be presented at an Institute level. The project was drafted based on a discussion with Chuck Hotchkiss and Sharon Matthews and would compare and assess Sustainable Building in Boston, MA vs. Dubai, UAE. Additionally, there were preliminary discussions with the University of Sharjah to conduct a shared poster session at the University where a student team would be able to present at the University of Sharjah.
• Interdisciplinary work with Construction Management - Initiated by a draft with Scott Sumner to provide a pathway for Civil Engineers to get Construction Management minors. This included discussions of proposed interdisciplinary work at a department meeting for the Construction Management department.

• Course - Civil Research – Proposed a course to teach methods and ethics of research while combining faculty research projects in an attempt to work research into our existing course load, I submitted a syllabus and ICC paperwork to the department for a Civil Engineering Research course in Spring 2018.

• Sustainability Poster Contests for the Freshman Showcase and Capstone Presentations – I proposed providing funding for awards at the student showcases for projects that best incorporated themes of sustainability into their projects.

Research:

Over the past year, I have created and facilitated two new research groups. These groups have provided new opportunities for undergraduate research. My research includes themes of Sustainable Building and Water Quality. Over the past year, I have worked with several students to provide them with new opportunities.

1. Shivani Kumar
2. Marina Schmid
3. Tyler Cosma
4. Abby Morin
5. Sabrina Haarstick
6. Jamie Littlefield
7. Gabriela Kuran

Sustainable Building Research

In 2018, I created a sustainable building research group based on the topics of the professorship and interest from students. Shivani Kumar was the first student in the research group and she graduated in August 2018. The research was then continued by Tyler Cosma and Marina Schmid.

As global awareness of sustainability increases, the concept of net zero buildings is becoming more common place. These buildings use renewable energy resources, sustainable water practices, and energy efficient systems to achieve a zero energy difference. While documenting net zero is important, most buildings use
their own energy consumption from its annual data as a metric for comparison. Additionally, it is difficult to compare similar buildings in different locations and climates.

Our research investigates a methodology of assessing building envelopes for heat loss as a metric for comparison of sustainability. Traditionally, a building’s sustainability is measured by its individual energy production and requirements. The proposed model provides a metric of comparison between multiple net zero buildings. Using this model, the user will be able to compare various styles of net zero buildings in contrasting locations. Key features that will be applicable in the sustainability calculation include aspects of the buildings’ envelopes, thermal resistance of the walls, window selection, and roof strategy.

Outcomes

- “A Coast to Coast Analysis of Net Zero Energy Buildings - Building Envelope Comparison.” Abigail J. Charest, Ph. D., P.E. Shivani Kumar, Patrick Bussett
  - Published - *Journal of Architecture and Civil Engineering*
  - Architecture and Civil Engineering Conference (ACE 2018), Singapore May 2018
  - Accepted: International Conference for Building Materials & Construction Technologies “Commencing New Techniques for Efficient Structures & Dwellings”, June 20-21, 2019 Stockholm, Sweden *Received scholarship for student accommodations and conference fees
  - Abigail Charest – Presentation
  - Marina Schmid and Tyler Cosma – Poster Session
  - Drafted conference paper


Water Quality Research

My graduate research focused on the physical characteristics of viruses in water systems. I have been working on incorporating this research into my work at Wentworth. This work is more feasible now with the construction of the new labs and acquisition of new research quality instruments. I have started to create protocols for experiments in the lab and purchase new supplies to compliment the research.
This research examines indicators of viruses in water systems and environmental samples and then identify characteristics of indicators that are critical for predicting virus behavior. This research is unique in that it includes the investigation of viruses at multiple-scales, including full-scale water systems, lab scale batch analysis, and nanoscale particle analysis in order to investigate physical characteristics impacting fate and transport of viral surrogates in water systems.

This research was used to investigate the occurrence and physical characteristics of viruses which may impact treatment and survival in drinking water treatment. The outcomes of this research expand the current methodologies of nanoscale research by providing a time specific analysis of particle behavior. Determining the dynamic behavior of individual nanoparticles expands the current knowledge of viral transport in treatment processes, which is mainly based on size exclusion.

**Outcomes**

- Abby Morin and Sabrina Haarstick - Developed new lab protocols and standard operating procedures for methods in the new labs

**Additional Research Outcomes**

**Proposed – Summer 2019 – Student Speaker Series**

- Jamie Littlefield – LEED Certification and Sustainable Design
- Gabby Kuran – Living Building Institute and Sustainability Metrics
- Matt Medeiros- Stormwater Resiliency and Modeling

**How do the funds you received through this professorship compliment your teaching and scholarly work?**

The funds I have received contributed to my growth in teaching and scholarly skills in several ways. I was able to enhance my knowledge base in topics of sustainability and green building. These topics directly relate to the course outcomes and this has improved my ability to teach sustainability topics and relate them to real world events. This is evidenced by my course evaluations included in Figures 1 and 2.
The course evaluations show an increase in all three topics, including communicated the subject well, knows the subject matter and professor stimulated thought. The results are detailed in Table 1 and provide evidence that this professorship has significantly improved my ability to deliver the subject matter.

Table 1: Course Evaluation Comparison for Green Engineering prior to an after receiving the Professorship

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicated the Subject Well</td>
<td>3.6</td>
<td>4.1</td>
</tr>
<tr>
<td>Knows Subject Matter</td>
<td>3.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Stimulated Thought</td>
<td>3.6</td>
<td>4.4</td>
</tr>
</tbody>
</table>

My ability to share my scholarly work with students has greatly improved through this Professorship. I started while finalizing publications as a result of my dissertation but these did not include Wentworth students. Since
then, I have been able to work with more students, submit abstracts, publish papers and provide these students with the opportunities to attend peer-reviewed conferences.

Additionally, as an off-shoot of my water quality research I expanded by design project assignment to include methods of assessing water quality parameters, assessment of quality indicators and testing of point of use water treatment systems designed and built in ENGR 1500 Introduction to Design.

Several groups from this course presented on their projects at the Muddy River Symposium, College of the Fenway, April 2019. One the groups (Solar Still) placed in the top three in the student poster competition.

- A Salty Solution, Point of Use Solar Still, Helmand Province David Bauters, Jackson Nissen, Benjamin Zidelis
- Slow Sand Filter for Kayabwe Village Vincent Crudo, Jean Hache, Mary Matillano
- Point of Use Water Treatment for Cambodian Migrants Tyler Cosma, Brian Burns, Jared Gillett
- Maji Safi, POU: Water Quality in Outer Nairobi, Abigail Meyers, Sawda Mohamed, Emma Perry
- POU Filter for a Family Among Millions Kumbh Mela Festival, India, Maryalissa Hebden, Marina Schmid, Peter Travassos
- Clean water for Cuttack, India, Dylan Reilly and Matthew Saintus

**Use of Funds:**

Over the past year, I have allocated and expensed funds on lab supplies and conference attendance. The fund are represented in Table 2.

Table 2: Fund Allocation

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Location</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab</td>
<td>General Supplies</td>
<td>Fisher Sci</td>
<td>$800.88</td>
</tr>
<tr>
<td>Lab</td>
<td>Phage Enumeration</td>
<td>Sci Methods</td>
<td>$881</td>
</tr>
<tr>
<td>Lab</td>
<td>Coliform MPN</td>
<td>IDEXX</td>
<td>$5,694.59</td>
</tr>
<tr>
<td>Conference</td>
<td>Shivani Kumar</td>
<td>Singapore</td>
<td>$2,723</td>
</tr>
<tr>
<td>Conference</td>
<td>Gabby Kuran</td>
<td>Seattle</td>
<td>$1,025.57</td>
</tr>
<tr>
<td>Conference (Proposed)</td>
<td>Marina Schmid, Tyler Cosma</td>
<td>Prague</td>
<td>$6,768 (est.)</td>
</tr>
</tbody>
</table>
What are your future plans for this research?

My future plans for this research include continued expansion of sustainability topics in my coursework, and innovative undergraduate research.

This includes:

- Continued work with the Built Environment Committee on ideas and action items for a “Sustainability Center”.
  - Review draft proposal for a “Resiliency and Sustainability Center” based around themes of design and construction changes due to extreme weather events.
  - Conduct speaker series beginning in Fall 2018 with sub-group including Robbin Beauchamp and Phil Hammond. Proposed events include Massachusetts Building Commission (MBC) breakfast, and hosted speakers from MA CZM and US ACOE.

- Propose a “Sustainable Infrastructure Research Group”
  - The creation of a research group would allow researchers to build-off of each other’s successes and create more robust contributions to the scientific community.
  - Short term goals include coordination of research topics, expanded literature reviews into the combination of research and a proposal for the purchase of a Differential Scanning Calorimeter.
  - Long term goals include drafting of NSF REU application, coordination with NSF subject reviewers, and submission of NSF REU application package.

- Propose “International Experiences on Sustainable Infrastructure” with a Project Center based in Al Akhwayan University, Infrane, Morocco with Prof. Jafferji based on her experiences during her Fulbright
  - Create opportunities for students associated with Sustainable Infrastructure Research group to work with Profs. Elasi and Ouardaoui
  - Create “Project Center” relationship with Al Akhwayan University
  - Submit application for course with International Experience
  - Research steps and communication steps to submit a MOU for a co-sponsored program with Al Akhwayan University to support their Environmental Studies program.
  - Discuss future research co-op opportunities for students at Al Akhwayan University.
• Conduct research with student interns in Summer 2019 and Fall 2019
  o Summer part-time
  o Fall – Marina Schmid and Tyler Cosma – Work study

See more of Abby’s Work in Appendix B
The support of the Schumann Professorship helped enable much work and progress during the academic year of 2018-2019. The support of the Professorship directly has enabled buying of equipment for new elective courses and student projects related to Internet of Things (IoT), embedded microcontrollers and health monitoring. The professorship has also supported conference participation and professional development.

**Impact**

**Development of New Elective Courses for Internet of Things (IoT)**

A major effort being done with support of the Professorship is developing courses related to the emerging area of IoT. IoT is an extension of web and cloud to incorporate information from and to physical “things”. IoT related courses are being developed with the direct help of this Professorship. These courses open the concepts and skills of IoT to the participating students, opens new job opportunities, and helps meet industry demand for new workers with IoT knowledge and skills. Three courses have been offered as special topics courses related to IoT.

- ELEC 3800 Internet of Things
- ELEC 3800 Microcontroller Sensor Networks
- ELEC 3800 Therapy and Health Monitoring Systems

The labs for these courses utilize physical devices with embedded microcontrollers for the edge nodes of IoT, with function for sensor input, actuator output, wired and wireless communication protocols, and web communication. One application of IoT are development of systems to monitor human movement, physiology and health. Sensors and data acquisition systems for health monitoring were purchased and have started to be used in course labs.
Student Projects in IoT and Health Monitoring

The Professorship has supported several student undergraduate research projects. Equipment, material supplies, and conference travel has been supported. The student projects supported over this last year are listed.

- PhysioNet-LabView Interface – Andrew-Dave E. Simpson
- Force Profile of Physical Model of Thorax During Respiration – Matthew Dean, Joe Brown, Noah Martins
- Monitoring of Respiration with Sound and Chest Volume – Pattanawadee Winyarat
- Auscultation Analysis of Sound of Blood Flow for Detection of Stenosis – Sneha Maharjan, Ana Salas, Moheb Khalil
- Artificial Muscle Fabric for Exoskeleton Applications – Temour Raza, Jay Pusateri
- Smart Desk for Elderly Computer Interface – Miguel Villegas, Juan Carlos Torres Munoz, Abdulrahman Alrashidi
- Smart In-home Well-Water Monitor System – Nagy Brody, Sean Demers

Conference Participation and Professional Development

The Professorship has supported engineering conference fees and travel for both a student and me. The professorship has also supported professional development to attend an IEEE Workshop on embedded software development for medical devices.

The following is a list of conference publications made based on student undergraduate research projects.

Fenway Frankenstein Festival Showcase & Poster Session, College of the Fenway, Boston, MA, October 30, 2018.

- Tom Cleary, Matt Vartanian, Alex Kouris, Julio Estrada, Douglas E. Dow, "Impact of Frankenstein on Earl Bakken and Invention of Battery Powered Cardiac Pacemakers".
- Ryan Kearney, Tim McCusker, William Owens, Anthony Alves, Douglas E. Dow, "Historical Discovery of Bioelectricity for Life and Motion".
• Alexandra Genua, Pattanawadee Winyarat, Douglas E. Dow, "STEM Promotion using Frankenstein and Science Fiction".

• Andrew-Dave E. Simpson, Douglas E. Dow, "PhysioNet-LabView Interface".

• Douglas E. Dow, Marilyn Urrea, Irene Qin, Tung Pham, "Cloud Recording for Diabetes Regulation of Blood Glucose Concentrations".
Wentworth Spring 2019 Faculty Showcase, Boston, MA, March 14, 2019.

Proceedings of the ASME 2019 International Mechanical Engineering Congress and Exposition (IMECE2019), Salt Lake City, UT, Nov. 11-14, 2019. Submitted

• Douglas E. Dow and Pattanawadee Winyarat, "Monitoring of Respiration with Sound and Thoracic Volume".

Use of Funds

Professorship funds have been used during this last academic year in the areas of Internet of Things (IoT) and Health Monitoring, and of Conference and Professional Development. A total of $18,021.57 was used during the academic year.

IoT and Health Monitoring were supported with $14,526.95 primarily for equipment and component modules.

Internet of Things

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount</th>
<th>Vender</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/3/2018</td>
<td>$127.29</td>
<td>Walmart</td>
<td>SD Cards, 16 GB</td>
</tr>
<tr>
<td>8/2/2018</td>
<td>$70.25</td>
<td>AdaFruit</td>
<td>Bluetooth shield</td>
</tr>
<tr>
<td>8/8/2018</td>
<td>$516.25</td>
<td>Gibson Engineering</td>
<td>GX Works Software Development for PLC</td>
</tr>
<tr>
<td>8/13/2018</td>
<td>$391.64</td>
<td>Micro Center</td>
<td>Arduino Systems</td>
</tr>
<tr>
<td>3/27/2019</td>
<td>$1,088.90</td>
<td>Spark Fun</td>
<td>Arduino Systems</td>
</tr>
</tbody>
</table>

Sub-Total $2,194.33

During the prior year of 2017-2018, Professorship funds were used to build the IoT related elective courses with lab equipment, software, embedded systems and IoT courseware. This year a few more supplies, software and embedded systems were purchased. The GX Works Software Development is for Programmable Logic Controllers (PLC) that are a primary sensor-actuator embedded node in industrial and manufacturing applications. The Industrial IoT (IIoT) has been reported to currently account for 40% of IoT spending. We are evolving the IoT elective courses to also prepare students to contribute to IIoT projects and applications. The Arduino systems are a comparatively simple embedded platform that are ideal for introduction of students toward more serious embedded applications, such as IoT. The Arduino systems are being used for STEM promotion events at Wentworth for K12 students, within freshmen Introduction to Engineering Design course for projects, and within other student engineering projects.

Health Monitoring was also supported with professorship funds. Health monitoring includes sensors on the human body (Body Area Network), physiological measurements and activity monitoring for elderly people.
Health Monitoring

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount</th>
<th>Vender</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>9/4/2018</td>
<td>$1,810.37</td>
<td>Vernier</td>
<td>EKG and GSR Qbit modules</td>
</tr>
<tr>
<td>9/4/2018</td>
<td>$4,042.30</td>
<td>Vernier</td>
<td>Many Sensors</td>
</tr>
<tr>
<td>11/1/2018</td>
<td>$55.00</td>
<td>Vernier</td>
<td>EKG Pads</td>
</tr>
<tr>
<td>1/14/2019</td>
<td>$1,897.09</td>
<td>Vernier</td>
<td>Sensor DAQ modules; textbook; Microphones</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mouser</td>
<td></td>
</tr>
<tr>
<td>2/4/2019</td>
<td>$110.14</td>
<td>Electronics</td>
<td>Force Sensor Pads</td>
</tr>
<tr>
<td>2/11/2019</td>
<td>$77.90</td>
<td>McMaster-Carr</td>
<td>Power connector cables; plastic tubing</td>
</tr>
<tr>
<td>2/27/2019</td>
<td>$1,549.26</td>
<td>Vernier</td>
<td>Sensor DAQ modules</td>
</tr>
<tr>
<td>2/27/2019</td>
<td>$1,335.63</td>
<td>Vernier</td>
<td>Hand Dynamometer; Microphone; Temperature</td>
</tr>
<tr>
<td>3/27/2019</td>
<td>$1,406.65</td>
<td>Spark Fun</td>
<td>RFID UHF Systems</td>
</tr>
<tr>
<td>4/18/2019</td>
<td>$48.28</td>
<td>McMaster-Carr</td>
<td>Plastic barbed Y-Tube fitting</td>
</tr>
</tbody>
</table>

Sub-Total $12,332.62

The health monitoring sensors include electrocardiogram (EKG), skin conductivity, respiration chest belt, blood pressure, temperature, audio microphone, force measurements. Some of these sensors are already being used in student projects and course labs. The RFID systems were selected so the RFID UHF tag and reader could be further apart (more than a few cm) to enable applications like monitoring humans passing through doors or down hallways.

Conference and Professional Development were supported with $3,494.62 during this academic year by the Professorship.
### Conference Fees

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount</th>
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/10/2018</td>
<td>$350.00</td>
<td>ASME</td>
<td>IMECE Conference fee for student</td>
</tr>
<tr>
<td>11/4/2018</td>
<td>$930.00</td>
<td>reimburse</td>
<td>Airplane to Japan SCIS &amp; ISIS Conference</td>
</tr>
<tr>
<td>11/12/2018</td>
<td>$579.18</td>
<td>Kinky Nippon</td>
<td>SCIS &amp; ISIS 2018 Conference Fee</td>
</tr>
<tr>
<td>11/13/2018</td>
<td>$58.28</td>
<td>Super Shuttle</td>
<td>Shuttle bus Pittsburgh IMECE conference for student</td>
</tr>
<tr>
<td>12/5/2019</td>
<td>$277.46</td>
<td>Ryokan Hotel</td>
<td>Hotel in Japan for SCIS &amp; ISIS Conference</td>
</tr>
<tr>
<td>12/19/2018</td>
<td>$436.41</td>
<td>reimburse</td>
<td>Airplane to Pittsburgh IMECE conference for student</td>
</tr>
</tbody>
</table>

Sub-Total $2,631.33

One conference was the ASME 2018 International Mechanical Engineering Congress and Exposition (IMECE2018) held in Pittsburgh, PA in November 2018. A student came to this conference to present results from his project with a Poster presentation. I participated in several meetings related to Biomedical and Biotechnology Track of the conference. I am co-chair of the Clinical Applications of Bioengineering topic. There was also a meeting for the Associate Editors of the journal, ASME Journal of Engineering and Science in Medical Diagnostics and Therapy.

The other conference was the 10th International Conference on Soft Computing and Intelligent Systems and 19th International Symposium on Advanced Intelligent Systems (SCIS&ISIS) held in Toyama, Japan in December 2018. I presented work for a student projected related to Diabetes. During the conference I also met with several collaborators from the time I was on Sabbatical in Japan at Kansai University in 2016. We discussed future projects. Out of those discussions, one of my senior design teams is working on an intelligent desk for elderly people to function as a simpler and more understandable computer interface.

Professional Development was also supported with the Professorship.
Professional Development

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount</th>
<th>Vender</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/29/2019</td>
<td>$313.29</td>
<td>ASME</td>
<td>ASME Membership, annual</td>
</tr>
<tr>
<td>1/2/2019</td>
<td>$105.00</td>
<td>ASEE</td>
<td>ASEE Membership, annual</td>
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<tr>
<td>3/18/2019</td>
<td>$445.00</td>
<td>IEEE</td>
<td>IEEE Boston Spring 2019 Course, SW Development Workshop</td>
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</table>

Sub-Total $863.29

Annual membership fees were paid for the American Society of Mechanical Engineers (ASME) and the American Society for Engineering Education (ASEE).

The course fee was paid for an IEEE sponsored workshop in the Boston area about the process of software development for embedded medical devices, and the process of how to apply for approval of medical devices by the U.S. Food and Drug Administration (FDA) or the European Medicines Agency (EMA).

The Schumann Professorship functions as a powerful support and encouragement for these engineering activities. The support of the professorship has and will continue to strengthen activities toward helping students learn, develop and contribute to society.

Sincerely,

Douglas E. Dow, Ph.D.

The Douglas D. Schumann Professorship
Dept. of Electrical and Computer Engineering
Wentworth Institute of Technology
Appendix A-
Gautham Das’s Work
A.1

Influence of Flowrate on Leachability Signature

Gautham P. Das¹ and John L. Daniels²

¹Associate Professor, Department of Civil, Construction and Environment, Wentworth Institute of Technology, 550 Huntington Avenue, Boston, Massachusetts, 02115, USA.

²Professor and Chair, Department of Civil and Environmental Engineering, University of North Carolina, 9201 University City Boulevard, Charlotte, North Carolina 28223, USA.

Abstract

The potential for leaching of coal fly ash is often approximated with laboratory-based methods that employ either columns of compacted material. While this procedure can simulate aspects of the field condition, it remains difficult to replicate site-specific thermodynamic and kinetic constraints on geochemical processes. This paper explores one parameter which contributes to the field/laboratory disparity, i.e., flowrate in column tests. Seven column based leaching experiments were conducted with the same ash but with different flowrates and intermittency (i.e., infiltration pulsing). Results indicate that effluent concentration vs. time (leachability signature) is a function of the flowrate and degree of intermittency. For a flow rate of 41.7 mL/hr, concentrations of 170 mg/L of calcium and 20 mg/L of sodium were observed in the effluent after one pore volume; at a flow rate of 4.2 mL/hr, the corresponding concentrations at one pore volume were 55 mg/L of calcium and 4 mg/L of sodium. Chemical transport modeling was conducted and the numerical simulations indicated that the leaching signature was dependent on both flow rate and the apparent chemical reactions occurring within the material while it is being leached. The results are discussed in the context of ash weathering.
Introduction

There are many leach tests available and codified by such organizations as the U.S. EPA, ASTM, ANSI and so on. Sorini (1997) summarized more than 60 different leaching procedures that have been in different forms, while LaGrega et al. (2001) presented those most commonly used for waste matrices. For coal fly ash (CFA) there is an emerging inventory of data being developed with US EPA Methods 1311, 1312, 1313, 1314, 1315 and 1316. A summary of these EPA methods, along with an approach to field leaching is provided as Appendix 1.

Appendix 1. Summary of Leaching Methods (meant to serve as useful addendum rather than traditional journal table/figure, consistent with online access)

In general, leaching data indicate that CFAs tend to leach various contaminants, including trace metals, boron, sulfates and chlorides, at concentrations above applicable standards. However in virtually any leaching test, the leaching solution composition, liquid: solid ratio (L/S), residence time, temperature and level of effective stress has little in common with the field condition. In addition, CFA is subject to weathering reactions which can change the governing geochemical processes as a function of time. For example, Zevenbergen et al. (1999) compared fresh and weathered fly ash samples from both India and Denmark, and observed that after 8 years and 14 years, respectively, ash contained appreciable amounts of newly formed allophane, a type of amorphous clay mineral. Similar behavior was observed for both the Indian and Danish ash, where the source coal, combustion process and weathering conditions were completely different. There are a variety of chemical processes relevant to weathering, many of which are sensitive to residence time, as summarized in EPRI (2006). Daniels et al. (2006) identifies a need to consider residence time in leaching experiments and provides data on the influence of column leaching flowrate on effluent pH, Eh and solution conductivity. The
objective of this contribution is to extend the focus of that work, while exploring a wider range of flow rates in column-based leaching tests.

**Background**

Data for the leaching of CFA is vast, with a summary provided by the EPA (2009). Relevant examples of column-based leaching of CFA are discussed as follows. Ghosh and Subbarao (1998) used rigid wall permeameters with tap water at a pH of 7 as influent and a hydraulic gradient of 10 for column leach tests. The concentration of various metals and the pH was measured in the effluent. The metals leached from fly ash were cadmium, chromium, copper, iron, manganese, lead and zinc whose maximum concentrations were 0.060, 0.68, 0.260, 0.120, 9.530, 1.3 and 0.135 mg/l respectively. Deed (1981) performed column leach tests with columns of 150 mm diameter and 400 mm height, with one column containing precipitator ash and one column with a ratio of 1:1 of ash and ash excavated from a disposal pond and placed within a low moisture environment. Effluent from the mixed column demonstrated a reduction in leachate concentration over 22 days.

The leachability of ash mixtures was investigated with columns by Black (1990a & 1990b). Samples were collected from both the electrostatic precipitators (fly ash) and the respective ash disposal ponds. Black (1990b) also included some modeling of the migration of the leachate in the groundwater system beneath the ash disposal site. The solute transport model used was MYGRT (EPRI, 1986), a semi-analytical model, applied in one-dimension. The author concluded a general trend that could be observed in the behavior of most major and trace elements for both ashes was a significant initial release followed by a rapid decrease in the rate of leaching towards a steady state concentration.

Yong et al. (1993b) investigated the leaching of ash using three different methods. The three methods included the field cell test, the batch or shake tests and column leaching tests. The ash samples were leached
with deionized water and the pH was adjusted to 5 using 0.5 N acetic acid. For the column tests, the flow rate was maintained at about 20 to 30 mL/min. The total leached quantities (TLQ) from all the tests resulted in mercury concentrations ranging from 5 to 30 µg, lead concentrations up to 1 to 2 mg, arsenic values ranged from 90 to 140 µg and selenium averaged 45 mg.

Bin-Shafique et al. (2002) conducted water leach tests (WLTs), column leaching tests (CLTs) and field tests on class C fly ash and “off specification” ash. During the WLTs, 70g of the ash were agitated in a tumbler with 1400 ml of deionized water in a 2-L sealed container for 18 hrs. During the WLTs the class C ashes leached about 3.6µg/l, 2.3µg/l and 0.7 µg/l of Cd while the other ashes leached 3.2 and 1.7µg/l of Cd. For chromium the class C ashes leached 95.0, 84.6 and 91.2 µg/l while the off-specification ash leached 123.2 and 59.0 µg/l. Selenium leached 26.0, 18.0 and 20.1 µg/l for class C ash while 41.0 and 82.0 µg/l for the off-specification ash. Elution curves for metals from CLTs were conducted on various mixtures of fly ash (10 and 20%). These compared to the analytical solutions of the advection-dispersion retardation equation (ADE) with instantaneous sorption described in van Genuchten (1981). The noticeable trend from the tests was that the leachate concentration diminished with increasing pore volumes of flow. The rate at which the concentration diminished was consistent.

The foregoing examples illustrate that the variability in techniques used to evaluate leachability. To understand the effects of field relevant leaching conditions (e.g. low flow, intermittent) on a laboratory scale, different types of column leaching tests have been evaluated, including vertical (van der Sloot et al. 1997; Huang et al. 1998; Jang and Townsend 1998; O’Grodnick et al. 1998; Jang et al. 2001; Georgakopoulos et al. 2002) and horizontal (Elzahabi and Young 2001) column designs. The dimensions of the columns have varied considerably. Inner diameters have ranged from 2 to 33 cm, while length has varied from 10 cm to 1.9 m. Typically, length has been approximately four times the inner diameter. Columns have been constructed out of acrylic, PVC or some other ostensibly inert material; however, some columns have been constructed with glass (Vegliò et al. 2001)
and stainless steel (Jang et al. 2001). Some columns had a silicone sealer bead or ridge on the sides to stop water movement down the side of the pipe and to prevent “edge flow” or “boundary flow” conditions along the material-wall interface (Futch and Singh. 1999).

Flow rates for the column studies performed have varied from 2 mL/h to 6000 mL/h. The solution passing through the columns, or leachant, has usually been deionized water, although there have been experiments using a low pH solution (Wasay 1992), a simulated rain solution (Stewart et al. 1997), EDTA (Sun et al. 2001), different concentrations of an oxalic acid solution (Ubaldini et al. 1996), a solution with sulfuric acid and glucose (Vegliò et al. 2001) and tap water (Hanson et al. 1993). Tests have been performed doing extractions with several leachants, such as HNO₃, H₂O₂, NaOAc, DTPA, H₂CO₃, and H₂O. Each leachant extracted different metals. However, the ash samples were taken from different locations and at different aging stages, and therefore, it presented a different chemistry. Therefore, it was not possible to conclude if there was one leachant that was better than the rest of them and in any case, they did not approximate natural field conditions (Sawhney et al. 1991).

The flow through the columns has varied between up-flow and down-flow. Most of the column studies have been under saturated conditions, and to accomplish this, up flow is usually required to maintain a constant saturated environment. To prevent channeling, up flow is used (gravity is used to oppose flow) (Daniels et al. 2005). Duration of the column experiments previously mentioned ranged from 48 hrs. to 7 yrs. The duration of test is usually selected so it can represent a period of time when the material would become stable. Another way of determining the duration of the test has been by cumulative LS ratio or pore volume flowing through the column combined with the flow rate. Column tests are usually carried out from ½ pore volume to 10 pore volumes. In some studies, the columns were not leached for specific periods of time to simulate drought conditions (Stewart et al. 1997). In the cases where the columns did not have a constant flow rate (Modi et al. 1994), the leachant solution would be added at the beginning of the test and then, depending on the experiment
time, a sample would be taken before adding more leachant solution. The controlled amounts of leachate were usually based on an average monthly or yearly rainfall amount.

Column tests have been studied as closed systems (Jang et al. 2001) and open systems (Lu 1996). In closed systems, the material in the column has no contact with the atmosphere, so carbonation of the sample and evaporation and transpiration losses from the column do not represent an extra variable to consider. In open systems evaporation and transpiration, as well as carbonation, cannot be prevented. Some column studies have involved the use of a controlled baths varying from 60°C to 70°C (Ubaldini et al. 1996; Vite et al. 1997) and a water-jacketed glass column connected to a controlled bath at 80°C (Vegliò et al. 2001). Temperature had a positive effect on the extraction of some of the heavy metals in the early stages of the leaching process (e.g., Mn, Fe).

The packing of the column also has varied between experiments. In most cases, a layer of glass beads or ceramic material is placed underneath and above the material of interest. The top layer, usually consisting of glass beads, helps distribute the flow above the column evenly (Stewart et al. 1997; Huang et al. 1998). The bottom layer, usually consisting of sand or glass beads, nylon mesh, filter paper, glass wool or synthetic cloth, helps filter the leachate and prevent the material inside the column from exiting the system (Wasay 1992; Ubaldini et al. 1996; Stewart et al. 1997; Huang et al. 1998; O’Grodnick et al. 1998; Sun et al. 2001). The packing of the columns has not followed a specific method, and only a couple of studies mentioned tapping the column to pack the material (O’Grodnick et al. 1998; Vegliò et al. 2001).

The sampling times for column studies have ranged from hourly to daily for columns that are running continuously. Hassett et al. 2003 attempted to effectively simulate field conditions by conducting column tests for longer periods of time. Their research also indicated that long term testing would result in weathering of fly ash which would in turn result in secondary mineral formation. Their results suggest column testing should be
conducted for at least 3 months, at a very low flow rate to simulate field leaching of ash and the weathering process (Hassett et al. 2004). If the flow rates were to replicate natural settings then the flow the through the column should be about $10^{-5}$ to $10^{-7}$ cm/s. This would be impractical at laboratory settings even if the columns were 50 to 100 centimeters long (Hassett et al. 2003), and thus enters potential disparity.

For some of the studies simulating drought conditions, the samples are only taken before adding more leachant to the columns. The leachate samples are usually analyzed for pH, conductivity and concentrations of metals by atomic absorption spectrometry or ICP-AES and ICP-MS and anions by IC. For some studies, after the leaching phase of the experiment has ended, the columns are cut open and examined for evidence of oxidation and weathering features (Stewart et al. 1997). Results from leaching column tests have shown that heavy metals solubility is highly pH dependent, usually increasing as the pH of the material decreases (Farrah and Pickering. 1977).

The scale up from laboratory-based leaching tests to field predictions is generally achieved through a consideration of “pore volumes” (Daniels and Das 2005). In a laboratory-based column test, a pore volume represents the pore space available to flow. It may be calculated as the effective porosity multiplied by the total volume of the sample. Presenting results in terms of pore volumes provides an indication of liquid: solid exchange however it indicates nothing about time-dependent geochemical reactions. Any researcher or practitioner interested in conducting a column based leaching evaluation is directed to standardized and validated test methods, e.g., U.S. EPA Method 1314; (U.S. EPA 2017). That said, there remain gaps in the literature as to how to connect laboratory results with field behavior as well as the significance of flowrate on leaching results.
Materials and Methods

Leaching of fresh fly ash was conducted under two flow conditions: intermittent unsaturated and continuously saturated. Four types of intermittent unsaturated flow and three types of continuous unsaturated flow were studied in this research. The intermittent column tests were conducted for a period of three months as previous research had indicated that there is a higher probability of the secondary minerals forming in the ash over this period (Hassett et. al 2004, EPRI 2006). Column tests were conducted on fresh ash samples which were obtained from a local power station in the southeast U.S. The ash was compacted in the columns at the optimum moisture content (OMC) and maximum dry density (MDD), as defined by the compaction curve defined by standard Proctor effort (ASTM D698) (ASTM 1991). The OMC and MDD were previously determined as 23% and 12.41 kN/m³, respectively (Daniels, 2005). This density was achieved by hand tamping the required amount into the column with a rod. The ash was compacted in three layers. The columns were acrylic tubes that had an inner diameter of 14 cm and a length of 7.6 cm. The top and bottom plates were made of plastic, it was necessary to use inert materials for the construction of the columns as it was necessary to prevent adsorption of the metals. Glass filter papers and glass wool were placed at the top and bottom of the plates to distribute the flow and to prevent particle migration. The columns were fitted to the plates using ‘O’ rings and silicone beads as a sealant. Threaded rods with wing nuts were used to fit the plates to the columns. The solution was delivered to the columns through ¼” flexible tubing. The leaching behavior of materials in general and fly ash is quite sensitive to the nature of the leaching solution (leachant), specifically as reflected by pH and ionic strength. For this research, the water used was deionized water (DI) where the pH was maintained at 4.0±0.1. The influent was introduced into the column from the bottom to ensure full contact between the ash and the water. Flow was initiated by a peristaltic pump at varying intermittent and continuous flow rates. The infiltration capacity for the ash was obtained using the double ring infiltrometers from previous research conducted on the same type of ash (Daniels 2004). The infiltration capacity was 1.9x10^-4 cm/sec. As the area of the column was known,
the product of area and infiltration rate gives the volume of water to be added to the column which was 
approximately 100 cubic centimeters per hour. Now the water added to the columns were based on 1 hour, 4 
hour, 8 hour and 24 hour storm events. The flow was intermittent and the water added to the columns was 
based on precipitation records in the southeast U.S. (USGS 2007). These intermittent infiltration schedules are 
labeled as IR1 to IR 4. For the continuous saturated flow through the columns the flow was 1000 mL/day, 100 
ml/day and 10 mL/day. These flow rates are labeled as IR 5 to IR 7, as shown in Table 1.

Table 1: Infiltration Schedules and Representative Flow Rates

<table>
<thead>
<tr>
<th>Flow Rate ID</th>
<th>Flow Rate(Q)</th>
<th>mL/day</th>
<th>mL/Hr</th>
<th>mL/Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR1</td>
<td>2400</td>
<td>100</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td>IR2</td>
<td>600</td>
<td>25</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>IR3</td>
<td>300</td>
<td>12.5</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>IR4</td>
<td>100</td>
<td>4.2</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>IR5</td>
<td>1000</td>
<td>41.7</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>IR6</td>
<td>100</td>
<td>4.2</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>IR7</td>
<td>10</td>
<td>0.4</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

A similar pattern to that of the precipitation was used for wetting the column and is shown in Table 2.

Table 2: Water added to Intermittent Columns (pause indicates intentional cessation of flow)

<table>
<thead>
<tr>
<th>Days</th>
<th>IR1( mL/1 Hr)</th>
<th>IR1(mL/4 Hrs.)</th>
<th>IR3( mL/8 Hrs.)</th>
<th>IR4(mL/24 Hrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
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<td>2</td>
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<tr>
<td>3</td>
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<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Days</td>
<td>IR1 (mL/1 Hr)</td>
<td>IR1 (mL/4 Hrs.)</td>
<td>IR3 (mL/8 Hrs.)</td>
<td>IR4 (mL/24 Hrs.)</td>
</tr>
<tr>
<td>------</td>
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<td>-----------------</td>
</tr>
<tr>
<td>5</td>
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<td>100</td>
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<tr>
<td>23</td>
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<td>pause</td>
<td>pause</td>
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<td>100</td>
<td>100</td>
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<td>100</td>
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<td>28</td>
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<td>29</td>
<td>100</td>
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<td>100</td>
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<tr>
<td>30</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
After collection, samples were measured for pH, Eh and conductivity and then acidified to a pH < 2 and refrigerated until analysis using an Atomic Absorption Spectrophotometer (AAS).

**Results and Discussion**

A premise of this research is that it is necessary to conduct column leach tests at field relevant flow rates, with rates adjusted to reflect anticipated field conditions.

**INSERT FIGURES SHOWING LEACHING RESULTS AS A FUNCTION OF FLOWRATE, FOR WHATEVER SPECIES (Na, Ca, Cr) WE HAVE**

Figure 1. Plot of Sodium vs. Pore volume for IR 5 (1000 ml/day), 6 (100 ml/day) and 7 (10 mL/day)

Figure 2. Plot of Calcium vs. Pore volume for IR 5 (1000 ml/day), 6 (100 ml/day) and 7 (10 mL/day)

Figure 3. Plot of Chromium vs. Pore volume for IR 5 (1000 ml/day), 6 (100 ml/day) and 7 (10 mL/day)

Figure 4. Plot of Sodium vs. Pore volume for IR 1,2,3 and 4

Figure 5. Plot of Calcium vs. Pore volume for IR 1,2,3 and 4

Figure 6. Plot of Chromium vs. Pore volume for IR 1,2,3 and 4

For example, the concentration of chromium after one pore volume would be 3.5 mg/L at 100 mL/Hr flow rate, while it would be 0.06 mg/L at 25 mL/Hr flow rate.

However it is also important to evaluate whether this change in leachability signature is a mere function of velocity and dispersion, or if there are other variables (e.g. weathering reactions) in operation. Because if it is a simple function of velocity or dispersion, then one can conduct column tests to determine leachability at a fast rate that is convenient for quick test results but not representative of field conditions. Then to determine the correct leachability signature, one can modify the equation which fit the data under fast flow rate conditions to reflect actual field conditions.
Figures 6.1 and 6.2 are plots that show the difference between the predicted leachability signature and the observed leachability signature. The predicted plots were constructed with velocity being the key component which governed the flow through the columns. On observing Figures 6.1 and 6.2 it is clearly evident that velocity is not the only governing factor in obtaining a leachability signature. Hence it can be stated that changing the velocity of the flow through the column will have a direct impact on dispersity as shown in equation 5-10, and have relative impact on dispersion and diffusion. The actual leachability signature will depend on other factors explained in following sections or a combination of velocity, dispersion and diffusion which are discussed in this section.

Figure 1: Comparing Continuous Flow Rates using Modified Van Genuchten Equation for Calcium

![Graph showing Comparing Continuous Flow Rates using Modified Van Genuchten Equation for Calcium](image-url)
For purposes of analyzing the results better “Peclet Numbers, (Pe)” were calculated. Peclet numbers are dimensionless numbers and a Pe number relates the effectiveness of advective mass transport to the effectiveness of diffusive/dispersive mass transfer. It has been used to analyze column tests, as reported in Daniels et al. 2000 and Ogunro and Inyang 2003. The formula to calculate the Pe number is given below

\[ Pe = \frac{V_s L}{D^*} \]  \hspace{1cm} (6-1)

Where \( V_s \) is the seepage velocity in cm/s, \( L \) is the length of the given column and \( D^* \) is the soil diffusion coefficient given in cm\(^2\)/s. In some tests, \( L \) is used to determine the average particle diameter (Freeze and Cherry, 1979). As the soil diffusion coefficient varies for different contaminants, varying peclet numbers will be obtained for different infiltration schedules as shown in Table 6.1.
Figure 6-3 to 6-6 show Peclet numbers for calcium, these figures illustrate the relationship between Peclet numbers and varying infiltration schedule, seepage velocity, discharge velocity and flow rates. Mass transport in column tests is usually dominated by advection when the column Peclet number is higher than 50, and by diffusion when the column Peclet number is lower than 1 (Shackelford 1994). The estimated column Peclet number in this study suggests that both advection and diffusion played a significant role in solute transport in different columns and this will be explained further in following paragraphs.

Upon examining Figures A1 to A3 which corresponds to IR 1 where the flow rate was 100 mL/hour and upon examining the Peclet number for all the contaminants was >50 indicating advection the main reason for solute transport. The concentration for the three contaminants studied dropped quite significantly from the first flush. The concentration of sodium decreased from 6.8 mg/L to 0.9 mg/L but continued to remain constant while the concentrations calcium and chromium showed an initial increase in concentration (0.5 mg/L to 3.5 mg/L for chromium, 40 mg/L to 150 mg/L for calcium) and then a substantial drop in concentration (concentration less than 0.1 mg/L in both cases). This could be explained as sodium and calcium are part of the

Table 6.1: Peclet numbers for different infiltration schedules for varying contaminants

<table>
<thead>
<tr>
<th>Infiltration Schedules</th>
<th>Calcium</th>
<th>Chromium</th>
<th>Sodium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1094</td>
<td>1743</td>
<td>778</td>
</tr>
<tr>
<td>2</td>
<td>273</td>
<td>435</td>
<td>194</td>
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<td>3</td>
<td>136</td>
<td>217</td>
<td>97</td>
</tr>
<tr>
<td>4</td>
<td>46</td>
<td>72</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>455</td>
<td>725</td>
<td>324</td>
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<td>6</td>
<td>46</td>
<td>73</td>
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</tr>
<tr>
<td>7</td>
<td>4.6</td>
<td>7.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>
basic composition of ash (i.e. lime and water soluble alkalis) and some of the initial leaching could be associated with the presence of these cations on the surface of the material itself. As the water passed through relatively fast, surficial sodium ions were washed out of the surface quicker than the other analytes measured as observed by Mc Carthy et al. 1999. Peclet numbers were calculated as described earlier and shown Table 6-1, which indicated that the flow through this column was advection dominated and this could also explain why the leaching pattern for this column.

Figures A4 to A6 corresponds to the IR 2 where the flow rate was 100mL/4 hours (25 mL/Hr), Here the results varied from each contaminant. The Peclet number in this case was 6 indicating that the solute transport was a combination of both diffusion and advection but a greater portion was diffusion dominated. The concentration of sodium decreased and continued a similar trend upon further leaching but this was not the case for calcium. The calcium concentration decreased from 60mg/L to 30 mg/L in the first pore volume and then increased to 130 mg/L. The calcium concentration then dropped to 60 mg/L in the next pore volume. The leachate concentration of calcium over the next 5 pore volumes followed a sinusoidal pattern until at pore volume 7.0 where the concentration of calcium reached 50mg/L. The delayed release of calcium with respect to fly ash leaching was explained by Iyer (2002), where he concluded that the release of calcium ions in leachates is controlled by the solubility of minerals like calcium oxide and calcium hydroxide. Iyer (2002) argued that chemical equilibrium models can be used to predict leachate concentration of elements whose dissolution is controlled by reaction kinetics. The release of chromium in this infiltration schedule also varied as the concentration decreased from 0.19 mg/L to 0.04 mg/L and then again increased to 0.08 mg/L and then decreased to 0.05 mg/L all in the flushing of the first pore volume (Figure A5). On further observation, leachate concentrations of chromium remained at about 0.04 mg/L up to 3 pore volumes. It then climbed to 0.09 mg/L and gradually declined to 0.06 mg/L through 7 pore volumes. The overall resultant leaching pattern in this column could be attributed to the wetting and drying phases within the column itself. As the deionized (DI)
water was passed through the column at an intermittent flow rate, it is hypothesized that the flow through the column was advection dominated when the water was pumped into the column. When the pumps were switched off, however the flow through the column was diffusion dominated. This continual transition between transport mechanism likely explains the sinusoidal leaching pattern.

Figures A7 to A9 indicate the leaching patterns of the three analytes with respect to the Infiltration Schedule 3 where the flow rate was 100 mL/8 hours. Though the flow rate was different the Peclet numbers were similar to that of IR 2, indicating a combination advection and diffusion were the main mechanisms for solute transport. The concentration of sodium reduced from 5.5 mg/L to 2.0 mg/L over the first 3 pore volumes and remained roughly constant for the pore volumes 3 through 5 (Fig. A7). The concentration of calcium again followed a sinusoidal pattern as seen in IR 2, where the initial concentration was 140 mg/L and the final concentration was 80 mg/L. On examining the chromium results, the concentration of chromium first dropped close to zero by the first pore volume but increased to 0.1 mg/L by the third pore volume which was greater than the initial flush concentration. It then fell to 0.04 mg/L for pore volumes 4 and 5 (Fig. A8). Sanchez et al. (2003) conducted similar intermittent leaching tests on cemented matrices and they explained the sinusoidal pattern as the product of intermittent leaching, where the release flux of chromium during the first leaching interval of each cycle was higher than subsequent intervals. In addition to this Kosson et al. (2002) and Garrabrants et al., 2002a concluded in intermittent leaching the release pattern of these elements was highly dependent on the solubilities of the elements. It should be noted that the solute transport through the columns was alternately dominated by both advection and diffusion according to the intermittent pulsing of flow which explains the sinusoidal behavior.

Figures A10 to A12 correspond to the leaching patterns for the infiltration schedule IR 4 which was 100 mL/day (4.2 mL/Hr). The flow through the column here was again intermittent and on further examining Figures 6-3 to 6-6 it is evident that the solute transport through the column was diffusion dominated as the Peclet
number was close to 1. The chromium concentrations decreased quite rapidly from 0.3 mg/L to less than 0.05 mg/L over the first two pore volumes. It then rose slightly to 0.1 mg/L showed a decreasing trend. The sodium concentration dropped from 5.5 mg/L in the first pore volume to 3 mg/L and remained steady for the last three pore volumes (Fig. A10). The trend for calcium had a concentration 35 mg/L increased to 55 mg/L, the concentration then dropped to 25 mg/L and then increased to 40 mg/L remained steady for 3 and 4 pore volumes and then again increased to 70 mg/L (Fig A12). Experiments conducted by Iyer (2002), showed similar results as achieved in this research. Iyer (2002) then stated that the leaching of elements like calcium and sodium from fly ash takes an indefinite period to attain steady state. The dissolution of ions from charged fly ash particles as solid liquid mass transfer of ions across the diffuse double layer provides insights into the prolonged delay to achieve a steady state. Iyer (2002) developed a mass transfer model for explaining the leaching behavior of these elements from fly ash. He stated that the novelty of the mass transfer model is that it accounts for the accumulation of ions in the diffuse double layer around the charged fly ash particle. The leached ions traverse two spherical shells surrounding the particle, e.g. the diffuse double layer and bulk convective layer (see Fig. 6.7). This has been experimentally shown by exchange of ions, where the ions namely calcium as Ca(OH)$_2$ is retained in the diffuse double layer. The retention of ions coupled with the resistance of the diffuse double layer provides an explanation for the delayed achievement of steady state.

Figures A13 to A15 represent IR 5 where the flow rate was 1000 mL/day and the DI water was passed continuously. The Peclet number was calculated to be greater than 300 for all contaminants and it was determined that the flow was advection dominated. On examining the results, the concentration of sodium dropped significantly from 23 mg/L to 5 mg/L and similar results were noticed for calcium where the concentration dropped from 130 mg/L to 60 mg/L. This could be explained as the flow through the column was advection dominated and hence accounted for drops in concentration for elements like calcium and sodium. As explained in previous sections that the calcium and sodium are cations and are associated with the surface of
the fly ash and hence when a constant flux was supplied to the columns the ions were washed away (McCarthy et al. 1999). While the concentration of sodium and calcium dropped significantly it was observed that the concentration of chromium dropped from 0.3 mg/L to 0.2 mg/L after 5 pore volumes and then remained constant. For this particular infiltration schedule approximately 17 pore volumes were collected while for the other columns the concentration of chromium dropped significantly within the first 5 pore volumes itself. Yalcin et al. (2006) explained the leaching behavior of chromium stating that the kinetics of chromium dissolution was controlled by the difference between aqueous phase concentration and saturation concentration (effective solubility), by the mass fraction of dissolvable chromium remaining in the solid phase, and finally, by the contribution of a constant dissolution rate manifested as a steady-state tailing behavior. Yalcin concluded that intermittent leaching could be 65 and 35% more effective than continuous leaching for total Cr and Cr(VI) removal. Yalcin stated that Cr tends to remain in the solid phase rather than the liquid phase and hence a pulsating flow enabled the dissolution kinetics to be more effective than a steady or continuous flow.

Figures A16 to A18 represent IR 6 which corresponds to a flow rate of 100 mL/day (4.2 ml/Hr). The Peclet number in this case was < 50 but >1.0 which indicates the solute transport being a combination of advection and diffusion. As stated earlier the flow through the column was continuous and as in the previous column the concentration of calcium and sodium dropped from significantly. The sodium concentration dropped from 15 mg/L to 5 mg/L after 1.0 pore volume. The calcium concentration dropped from 100 mg/L to 80 mg/L after 1.5 pore volumes. The chromium concentration in this case showed slight variations but remained roughly constant at about 0.18 mg/L. The concentration and leaching patterns of the IR 6 were similar to those of IR 5.

Figures A19 to A21 represent the IR 7 which corresponds to a continuous flow rate of 10 mL/day. The Peclet number in this case was close to 1.0 indicating the solute transport was diffusion dominated. The concentration of sodium dropped in a linear fashion from 25 mg/L to 14 mg/L. The concentrations of calcium and chromium dropped rapidly for 2 pore volumes as seen in Figures A20 and A21 but remained constant for
later pore volumes. Voegin et al., 2003 conducted column tests with low flow rates similar to the one followed in this particular infiltration schedule. Voegin concluded that the release of heavy metals and elements like calcium are much slower at lower flow rates due to the occurrence of slow desorption or dissolution reactions. He noted that the kinetics of release of heavy metals like chromium was 5 times slower at lower flow rates as compared to the faster flows.

Conclusion
One of the main objectives of this research was to establish that the flow rate played an integral role in the leaching of fly ash. On completion of this research it can be stated that on examining the results from the different infiltration schedules, leaching of contaminants varies from one flow rate to another.

On examining the infiltration schedules it was noticed that the release of contaminants varied quite considerably with respect to flow rates. For example comparing the IR 1 and IR3, it was noticed that the concentrations calcium and chromium showed an initial increase in concentration (0.5 mg/L to 3.5 mg/L for chromium, 40mg/L to 150 mg/L for calcium) and then a substantial drop in concentration (concentration less than 0.1 mg/L in both cases) for IR 1 while for IR 4, the concentration of calcium followed a sinusoidal pattern where the initial concentration was 140 mg/L and the final concentration was 80 mg/L. On examining the chromium results, an increasing trend was noticed, the concentration of chromium first dropped close to zero by the first pore volume but increased to 0.1 mg/L by the third pore volume which was greater than the initial flush concentration itself. The above infiltration schedules represented the intermittent flow rates that were applied to the column. Now on comparing IR 5 and IR 7 which represented the continuous flow rates it was noticed that the concentration of sodium and calcium dropped significantly from 23 mg/L to 5 mg/L and 130 mg/L to 60 mg/L respectively while the concentration of sodium dropped in this infiltration schedule, the concentration of calcium remained constant throughout. Hence it is concluded that the leaching of contaminants varies with flow rates primarily because the leaching is highly dependent on the existing peclet
number which defines whether the flow through the column is either advection dominated or diffusion dominated or a combination of both.

To highlight the difference between the chemical reactions occurring within the column and role of flow rate influencing the leachability signature analyses were done comparing the mass transfer coefficient and the observed average flux and the Peclet numbers. It was concluded that the leachability signature was dependent on both these factors but is more dependent on chemical reactions rather than flow rate. Though it is stated that flow rate does play a role in the leachability signature. Bin Shafique et al. (2002) indicated that flow rate does not play a role in the leaching of contaminants in fly ash but this research along with research conducted by Marqa (2001) indicate that the leaching of contaminants is dependent on flow rate.

After conducting the chemical transport modeling, it was further corroborated that the leachability signature was influenced by both the chemical reactions and flow rate. It was determined that the mass transfer coefficient as developed in the Van Genuchten’s analysis and the ‘$k_b$’ (dissolution rate) & ‘$a$’ as developed in the Yalcin’s analysis were chemically driven parameters that influenced the shape of the curve and hence the leachability signature. HYDRUS modeling simulations indicated that it took 41 years to deplete the contaminant concentrations if IR 7 and IR 3 were used to conduct column tests. However it would take 14 years to deplete all the contaminant concentration from the column if IR 5 was used. It is concluded after conducting all the laboratory tests and chemical transport modeling that IR 3 is the field relevant infiltration schedule.

References


Influence of Flow Rate on Leachability

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ABSTRACT

The leaching potential of coal fly ash is often approximated with laboratory-based methods that expose columns of compacted material to synthetic precipitation. While this procedure can simulate aspects of the field condition, it remains difficult to replicate site-specific thermodynamic and kinetic constraints on geochemical processes. This article explores one aspect that contributes to the field/laboratory disparity, namely, the influence of flow rate and intermittency. Seven column-based leaching experiments were conducted with the same ash but with different flow rates and intermittency (i.e., infiltration pulsing), and results were evaluated in terms of aqueous sodium, calcium, and chromium concentrations in the effluent. Flow rates ranged by three orders of magnitude, encompassing advection- and diffusion-dominated conditions as determined by Peclet number calculations. With few exceptions, the results revealed diminishing leachate concentrations with continued flushing, consistent with a declining source model. Notwithstanding differences in effluent concentration as a function of pore volume, general mass release followed similar patterns that likely reflected solubility control. Higher liquid-to-solid ratios revealed potentially nonequilibrium behavior at the highest flow rate (2400 mL/day) during intermittent flow conditions for chromium and calcium, and to a modest extent for sodium. The primary conclusion from this work is that for the constituents and ash tested, there was relatively little effect of flow rate or intermittency on leachability patterns.

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ARTICLE INFO

Article history: Received 8 February 2018; Received in revised form 17 April 2018; Accepted 18 April 2018

Keywords: leachability; leaching; weathering; coal fly ash; equilibrium

1. Introduction

Leachability testing has long been conducted to experimentally evaluate the extent to which trace contaminants can be mobilized from the solid phase to the aqueous phase for a variety of waste materials, industrial by-products, and coal combustion products (CCPs). Such experiments can be conducted with batch (material shaken in a suspension of leachant) or column (material compacted and subjected to permeation in a rigid- or flexible-wall cylinder) configurations. Column configurations are often used when there is a desire to simulate a field-relevant level of material density and porosity. Investigators have used many project-specific and standardized methods to evaluate leaching, as noted by Kosson et al. (1996) and Hassett et al. (2003). Such wide variability served as inspiration to a significant effort by the U.S. Environmental Protection Agency (US EPA) and several research groups to develop an integrated framework, as proposed by Kosson et al. (2002). That work, also known as the Leaching Environment Assessment Framework (LEAF), ultimately became the basis for four US EPA Methods, namely 1313, 1314, 1315, and 1316 (US EPA, 2017a,b,c,d). Example CCP leaching results using these methods may be found with those method references, as well as in US EPA (2009) and Thorneloe et al. (2010).

In general, leaching data indicate that uncedmented CCPs tend to leach various contaminants, including trace metals, boron, sulfates, and chlorides, at concentrations above applicable standards (e.g., Daniels and Das, 2006; US EPA, 2009; Komonweerak et al., 2015). Yet, despite the US EPA leaching framework and expanding
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Table 1
Infiltration schedules and flow rates

<table>
<thead>
<tr>
<th>Flow rate ID</th>
<th>Flow rate (Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ml/day</td>
</tr>
<tr>
<td>IR1</td>
<td>2400</td>
</tr>
<tr>
<td>IR2</td>
<td>600</td>
</tr>
<tr>
<td>IR3</td>
<td>300</td>
</tr>
<tr>
<td>IR4</td>
<td>100</td>
</tr>
<tr>
<td>IR5</td>
<td>1000</td>
</tr>
<tr>
<td>IR6</td>
<td>100</td>
</tr>
<tr>
<td>IR7</td>
<td>10</td>
</tr>
</tbody>
</table>

fore compaction in a landfill. It had a loss on ignition of 2.8 and a specific gravity of 2.4. The ash was compacted in the columns at the optimum moisture content (OMC) and maximum dry density (MDD), as defined by the compaction curve defined by standard Proctor effort (ASTM D698 [ASTM International, 2002]). The OMC and MDD were determined as 23% and 12.41 kN/m³, respectively. This density was achieved by hand tamping the required amount into the column with a rod. The ash was compacted in three layers. The columns were acrylic tubes that had an inner diameter of 14 cm and a length of 7.6 cm.

The pore volume represents the pore space available for flow in a column test. It may be calculated as the effective porosity multiplied by the total volume of the sample. For this work, the effective porosity was not measured; however, based on the total porosity, one pore volume would not exceed 525 ml. The water used was deionized water (DI), where the pH was maintained at 4.0 ± 0.1. This pH is relatively low and was not selected to represent a specific field site. The intent was to constrain pH while focusing on the effect of flow rate. That said, a pH of 4 is not that dissimilar from previous field observations, where a pH of 4.44 was appropriate (Daniels and Das, 2014). Likewise, data available from recently characterized impoundments indicate ash pore fluid pH as low as 2.5 (Synterra, 2018).

The influent was introduced into the column from the bottom. Flow rates were selected based on previous infiltration data (Daniels and Das, 2008), as well as variable-length storm events, i.e., 1-hour, 4-hour, 8-hour, and 24-hour events. These intermittent infiltration schedules are labeled as IR1 to IR4. For the continuous saturated flow through the columns, the flow was 1000 ml/day, 100 ml/day, and 10 ml/day. These flow rates are labeled as IR5 to IR7. Table 1 provides a summary of all continuous and intermittent flow rates, while Table 2 indicates how intermittency was introduced over a 30-day time period. Each column was conducted for one schedule without replication.

After collection, samples were acidified to a pH < 2 and refrigerated until analysis using an atomic absorption spectrophotometer (AAS).

2. Materials and Methods

Leaching of fresh fly ash was conducted under two flow conditions: intermittent unsaturated and continuously saturated. Four types of intermittent unsaturated flow and three types of continuous unsaturated flow were studied in this research. Column tests were conducted on coal fly ash samples obtained from a local power station in the southeast United States, with details as provided in Daniels et al. (2006). Coal samples were not analyzed to determine their source; however, the plant typically uses Appalachian Basin bituminous coal. The plant had a moisture conditioning unit that added moisture to dry handled ash to approach optimum moisture content. The sample was taken after moisture conditioning but be-
source model. Edil et al. (1992) differentiated between “first flush” and “lagged response” for constituents. Following that description, sodium generally displayed first flush behavior, while calcium and chromium exhibited hybrid behavior, i.e., aspects of both first flush and lagged response when plotted as a function of pore volume. The results may also be considered in terms of cumulative mass vs. L/S ratio, as described in US EPA (2017b), which in turn can be used to obtain insight on release mechanisms. For example, Kosson and Van der Sloot (1997) summarized general mechanisms in terms of solubility control, availability control, desorption control, and matrix interaction, as seen in the slope of the data as presented on a log-log scale. Because such plots lend themselves to a clearer presentation of the data, all seven infiltration rates were plotted on one graph, as shown for Figures 7, 8, and 9 for sodium, calcium, and chromium, respectively.

Because much of the data approach a slope of one on the log-log plots, a review of Figures 7, 8, and 9 indicates that all three constituents may be at least partially solubility controlled, consistent with the study by Van der Sloot et al. (2001) and example data shown in US EPA (2017b). Calcium, for example, could be

![Fig. 2. Calcium vs. pore volume for infiltration rates 1, 2, 3, and 4 (intermittent flow).](image)

![Fig. 1. Sodium vs. pore volume for infiltration rates 1, 2, 3, and 4 (intermittent flow).](image)

![Fig. 3. Chromium vs. pore volume for infiltration rates 1, 2, 3, and 4 (intermittent flow).](image)
Fig. 4. Sodium vs. pore volume for infiltration rates 5, 6, and 7 (continuous flow).

Fig. 6. Chromium vs. pore volume for infiltration rates 5, 6, and 7 (continuous flow).

Pe number is given by:

$$Pe = \frac{V_s L}{D^*}$$

where $V_s$ is the seepage velocity in cm/s, $L$ is the length of the given column in cm, and $D^*$ is the soil diffusion coefficient given in cm$^2$/s. A constituent-specific soil diffusion coefficient was calculated as the aqueous-phase diffusion coefficient as listed in Thibodeaux (1996), modified by tortuosity and porosity as described in Fetter (2001). In some tests, $L$ is used to determine the average particle diameter (Freeze and Cherry, 1979). The calculated column Peclet number varied considerably among the column tests, as shown in Table 3.

Mass transport in column tests is usually dominated by advection when the column Peclet number is higher than 50, and by diffusion when the column Peclet number is lower than 1 (Shackelford, 1994). The calculated column Peclet numbers in this study indicate that IR1, IR2, IR3, and IR5 were all likely advection dominated, and IR7 was diffusion dominated, while IR4 and IR6 were influenced significantly by both advection and diffusion. The overall leaching pattern in Figures 1–3 (intermittent flow) is less consistent than
that in Figures 4–6 (continuous flow), and this is attributed to the process of infiltration pulsing, which leads to localized reductions in the concentration gradient and overall mass flux. These reductions occur during flow interruption, at which point mass transfer within the pore space occurs only by diffusion, rather than advection and hydrodynamic dispersion. For this reason, flow interruption has been used by other investigators to decouple diffusive and advective processes (Brusseau et al., 1989). This continual transition between transport mechanisms manifests in terms of variable effluent concentration data. The significance of advection vs. diffusion appears to be masked by the ease with which sodium, calcium, and chromium leach from the ash. Moreover, these results indicate that while different concentration vs. pore volume results will emerge depending on the flow rate, the general trend in terms of mass release remains similar. A similar observation was observed by Garrabrant et al. (2002), Sanchez et al. (2003), and Dijkstra et al. (2008). To illustrate this observation, Tables 4 and 5 present a summary of the average constituent mass released per unit pore volume.

In reviewing Table 4, the least variability was found for sodium, followed by calcium and chromium. Variability in chromium was principally a function of the highest flow rate, IR1, which resulted in approximately ten times the mass released compared with the average of IR2, IR3, or IR4. Overall variability was considerably less for the continuous flow rates, as shown in Table 5. In this case, sodium displayed the greatest variability, at the lowest continuous flow rate, IR7. There are no reports on the coefficient of variation (CV) as a function of column flow rate on ash leachability, although Kim and Hesbach (2009) provided a comparison of leaching methods for several ash types. An analysis of their results from a class F ash for sodium, calcium, and chromium for element extraction revealed CV values of 44%, 23%, and 100%, respectively, which compare well with the values shown in Tables 4 and 5. The authors noted that overall agreement was found, frequently within a similar order of magnitude. Indeed, an order of magnitude is reasonable for many natural and environmental samples; the extent to which the CV can be used as an indicator of variability depends on what is being measured. By way of example, Duncan (2000) provided a summary of CV values for an array of geotechnical properties. Properties such as unit weight have common ranges of 3–7%. Other properties have much higher ranges, including hydraulic conductivity, which may range from 1300% to 2400%. Overall, the leaching data presented reflect the inherent heterogeneity of coal fly ash, with relatively low variability as a function of flow rate.

4. Conclusions

This work evaluated a broader range of intermittent and continuous flow conditions for column-based leaching than has been previously reported, i.e., three orders of magnitude. In terms of cumulative release, the results indicate that for the ash tested and the constituents considered (sodium, calcium, and chromium), reasonably consistent data can be obtained regardless of the flow rate and extent of intermittence. These constituents may be influenced

---

**Table 3**

<table>
<thead>
<tr>
<th>Infiltration Schedules</th>
<th>Calcium</th>
<th>Chromium</th>
<th>Sodium</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR1: 2400 mL/day, intermittent</td>
<td>1094</td>
<td>1743</td>
<td>778</td>
</tr>
<tr>
<td>IR2: 600 mL/day, intermittent</td>
<td>273</td>
<td>435</td>
<td>194</td>
</tr>
<tr>
<td>IR3: 300 mL/day, intermittent</td>
<td>136</td>
<td>217</td>
<td>97</td>
</tr>
<tr>
<td>IR4: 100 mL/day, intermittent</td>
<td>46</td>
<td>73</td>
<td>33</td>
</tr>
<tr>
<td>IR5: 1000 mL/day, continuous</td>
<td>455</td>
<td>725</td>
<td>324</td>
</tr>
<tr>
<td>IR6: 100 mL/day, continuous</td>
<td>46</td>
<td>73</td>
<td>33</td>
</tr>
<tr>
<td>IR7: 30 mL/day, continuous</td>
<td>5</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

---

**Table 4**

<table>
<thead>
<tr>
<th>Infiltration schedule</th>
<th>Standard deviation</th>
<th>Mean</th>
<th>Coefficient of variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyte</td>
<td>IR1</td>
<td>IR2</td>
<td>IR3</td>
</tr>
<tr>
<td>Sodium</td>
<td>1.26</td>
<td>1.70</td>
<td>1.70</td>
</tr>
<tr>
<td>Calcium</td>
<td>12.68</td>
<td>41.57</td>
<td>55.9</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.37</td>
<td>0.04</td>
<td>0.02</td>
</tr>
</tbody>
</table>

1: Representing values as entire population (e.g., STD/√P).
by solubility-controlling phases, although this mechanism may be different at large L/S ratios or high flow rates with intermittency. The extent to which nonequilibrium processes, including weathering reactions, influence the leachate signature was not evident in the data. The mass released for chromium and calcium was more susceptible to changes in flow rate than that for sodium, and it is expected that a broader suite of constituents could likewise yield different behavior. These results add to the database of leachability testing and may be used for additional geochemical or mass transport modeling. A limitation of this conclusion is the use of one type fly ash and evaluation of only three constituents.

References


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Evaluating the Adsorption Capacity of Heavy Metals by Hemp (Cannabis Sativa L.)

Katherine Asciutto, Samantha DeVincentis, Audrey Iodice, Dr. Gautham Das
Wentworth Institute of Technology, Boston, MA USA

Abstract

Hemp Seeds (Cannabis sativa L.) was used to examine its capability as a renewable resource to decontaminate heavy metals. The analysis of heavy metal content was determined using an atomic absorption spectrophotometer (AAS). The goal of this research was to evaluate the attenuation capacity of hemp seeds. It was concluded that hemp is an efficient adsorbent for the attenuation of heavy metals.

Introduction

The aim of this research is to combine phytoremediation with a crop of commercial interest, to achieve low price decontamination. The plant of focus for this research was Cannabis Sativa L. (hemp). Previous research indicated that hemp was effective while implementing phytoremediation. For the purpose of this research, hemp seed was used as an adsorbent to evaluate the attenuation capacity through batch and column testing.

Sample Preparation

Hemp seeds were bought through a commercial source and were dried for about 30 mins (each batch) at a temperature of roughly 176°C. Seeds were then passed through a No. 10 sieve to guarantee uniformity.

Methods and Discussion

Batch Sorption Experiments

These experiments were carried out to determine the adsorption isotherms of metal ions onto the adsorbents. The solution volume was kept constant and the amount of metal absorbed per unit mass was calculated as

\[ Q_e = \frac{(C_i - C_f) \cdot V}{M} \]

where \( C_i \) and \( C_f \) are the initial and equilibrium concentration (mg/L), \( Q_e \) is the mass of the adsorbent (g) and \( V \) is the volume of the solution (mL).

Introduction

Isotherms were then created for Cadmium, Chromium and Nickel.

The Ogata-Banks equation was then used to predict the long-term attenuation of the heavy metals by hemp. The equation is given as:

\[ C_e = C_i \cdot \left( 1 + \frac{V}{V_c} \cdot \frac{K_d}{n} \right) \cdot \frac{R}{\sqrt{D+1}} \cdot \exp \left( \frac{R}{\sqrt{D+1}} \right) \]

The retardation factor makes use of the experimentally-determined \( K_d \) value and is computed but the following equation:

\[ R = \frac{V}{V_c} = 1 + \left( \frac{P}{n} \right) \cdot K_d \]

The data is presented in the following graphs:

Table 1: Summary of Batch Testing Results

<table>
<thead>
<tr>
<th>Hemp Seeds (Gallium Solvent)</th>
<th>Cadmium (mg)</th>
<th>Chromium (mg)</th>
<th>Nickel (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear</td>
<td>Freundlich</td>
<td>Linear</td>
</tr>
<tr>
<td>258</td>
<td>0.0866</td>
<td>0.0866</td>
<td>0.0866</td>
</tr>
<tr>
<td>150</td>
<td>0.0855</td>
<td>0.0855</td>
<td>0.0855</td>
</tr>
</tbody>
</table>

Column Testing

Column testing was performed in accordance with ASTM D 1557 to obtain a density of 0.58 g/cm^2. The seed was then compacted into the columns and solution was delivered through flexible tubing.

Conclusion

Based on laboratory testing, Hemp is an extremely good adsorbent for heavy metals as presented in this research. Batch testing revealed favorable distribution coefficients such as 48.52 L/g for cadmium, 8.34 L/g for chromium and 0.022 L/g for nickel. The column testing data revealed that the Ogata Banks equation could be used to predict the fate and transport of heavy metals using Hemp seed.
Using Plastic Bags in Roadways  
Dr. Gautham Das, Phillip Curtsmith, Catarina Figueiredo Mendes, and Gabriel Kuran  
Wentworth Institute of Technology, Boston, MA USA

Abstract
Mass production of plastics, which began just six decades ago, has accelerated so rapidly that it has created 8.3 billion metric tons, which exists mostly as disposable products that end up as trash. Adding flexible materials to strengthen tar roads is not a new idea. Commercially made polymer-modified asphalts first became popular in the 1970s in Europe. Now, North America claims 35% of the global market. Modified asphalts are made from virgin polymers and sometimes crumb rubber (ground tires). They are highly versatile: Illinois uses them to build high-traffic truck roads, Washington State uses them for noise reduction and in rural Ontario they are used to prevent roads from cracking after a harsh winter. Polymerized asphalts also tend not to buckle in extreme heat the way conventional roads do – plastic roads will not melt unless the temperature goes beyond 66°C (150°F), compared to 50.2°C (122.5°F) for ordinary roads – and are frequently used on roads in the Middle East. The objective of the investigation was to characterize the leaching potential of plastics by conducting an acid digestion procedure and to evaluate the overall strength of pavement by using 6% plastic.

Methodology
Sample Preparation
Total 20 plastic bags (PB) samples were collected from several super markets in Boston, MA based on used polymer types and colors. All the selected samples were repeated and also triplicated when the first obtained values were not close. Here, samples were chosen to reflect a broad range of used polymer matrix and colors that may represent overall scenarios of daily consumed bags. Seven widely used polymers in PB manufacturing were selected, i.e., (a) Polyethylene – PE, (b) High density polyethylene – HDPE, (c) Low density polyethylene – LDPE, (d) Polyvinyl chloride – PVC, (e) Polypropylene – PP (f) Polystyrene – PS, and (g) Polyamide (nylon) – PA. Six types of PBs with commonly used colors were selected from PE, HDPE, LDPE and PVC polymers. But 3 types of PBs were selected from PP, PS and PA polymers due to their comparatively lower usage in PB production. At first, all the bags were cut into small pieces (3.5 inches) with scissor (stainless) to reduce and bring homogenous size, then dried at 25°C for 24 h before further analysis.

Introduction
Mass production of plastics, which began just six decades ago, has accelerated so rapidly that it has created 8.3 billion metric tons, which exists mostly as disposable products that end up as trash. Even the scientists who set out to conduct the world’s first tally of how much plastic has been produced, discarded, burned or put in landfills, were horrified by the sheer size of the numbers (National Geographic, 2018; Greenleaf 2018). Of the 8.3 billion metric tons that has been produced, 6.3 billion metric tons has become plastic waste. Of that, only nine percent has been recycled. The vast majority about 79 % is accumulating in landfills or leaching off in the natural environment as litter. Meaning: at some point, much of it ends up in the oceans, the final sink. If present trends continue, by 2050, there will be 12 billion metric tons of plastic in landfills. That amount is 35,000 times as heavy as the Empire State Building. Adding flexible materials to strengthen tar roads is not a new idea. Commercially made polymer-modified asphalts first became popular in the 1970s in Europe. Now, North America claims 35% of the global market. Modified asphalts are made from virgin polymers and sometimes crumb rubber (ground tires). They are highly versatile: Illinois uses them to build high-traffic truck roads, Washington State uses them for noise reduction and in rural Ontario they are used to prevent roads from cracking after a harsh winter.

Acid Digestion

The heavy metal proposed to be used for this research was Pb, Cr, Cd and Mn. Due to time constraints this poster will reflect results on for Pb. The analysis was conducted using a Perkin Elmer PinAAcle 900T Atomic Absorption Spectrometer graphite furnace.

Conclusion
Heavy metals tested for this research were Pb, Cr, Cd and Mn. However the results that were obtained were for any Pb. The results demonstrated that PVC bags leached Pb concentrations within permissible standards (ASTM F963); i.e., Pb in black LDPE (2.01 µg/l), White LDPE (2.21 µg/l) and brown LDPE (2.62 µg/l). As this was within permissible limits, it justified the use of plastics in roadways. Further testing will be conducted to evaluate the strength characteristics of plastics when 6% PBs are added to roadways instead of bitumen.
Appendix B-
Abby Charest’s Work
Net Zero Residential Building Envelope Energy Calculation

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Wentworth Institute of Technology, Boston, MA 02115, USA

As global awareness of sustainability increases, the concept of net zero buildings is becoming more common place. These buildings use renewable energy resources, sustainable water practices, and energy efficient systems to achieve a zero energy difference. While documenting net zero is important, most buildings use their own energy consumption from its annual data as a metric for comparison. Additionally, it is difficult to compare similar buildings in different locations and climates.

Our research investigates a methodology of assessing building envelopes for heat loss as a metric for comparison of sustainability. Traditionally, a building’s sustainability is measured by its individual energy production and requirements. The proposed model will provide a metric of comparison between different net zero buildings. Using this model, the user will be able to compare various styles of net zero buildings in contrasting locations. Key features that will be applicable in the sustainability calculation will include aspects of the buildings’ envelopes, thermal resistance of the walls, window selection, and roof strategy.

Biography

Abigail Charest holds the endowed Blittersdorf Professorship in sustainability at Wentworth Institute of Technology, Department of Civil Engineering. She received a B.S., Environmental Engineering from Rensselaer Polytechnic Institute and her Ph.D., Civil Engineering from Worcester Polytechnic Institute (WPI). She was consulting engineer at AECOM and received her professional engineering (PE) license. At WPI, she researched viral pathogen fate and investigated the sustainability of water resources. At Wentworth, Dr. Charest teaches civil engineering design courses and in the past year, she developed and taught a new course in Green Engineering. Recently, she was awarded a fellowship from the American Society of Civil Engineering for Excellence in Civil Engineering Education (ExCEED).

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Category: Oral or Poster Presentation
Clean water for Cuttack, India
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Abstract
- Given the challenge to provide a clean and safe drinking water source for any struggling city in the world
- Selected the city of Cuttack in eastern India
- Design must be:
  - cost efficient
  - Simple
  - easy to maintain
  - provide drinking water for 1,000 individuals

Synthesis
- SODIS (Solar Water Disinfection)
- Filtration
  - UV-rays kill viruses, bacteria, and parasites
  - Separation of total suspended solids from a liquid

Design & Materials
- A stand
  - Wood or hard pvc plastic
  - Solar oven
    - Reflective film and plywood
  - Corrugated wavy steel
  - Water tank
  - 3 Liter water bottles
  - WAPI

Results
- Need 2,000 L for 1,000 people
- Provide 2,400 L with 4 units
- Units are 10ft x 10ft with 200 bottles each
- Each tank holds 1,136 L
- Total tank storage would be 4,544 L

Current water quality
- pH: 6.97 - 7.95
- TSS: 37.8 mg/L
- Turbidity: 89.2 NTU
- BOD: 32.3 mg/L

Clean water quality
- pH: Approximately 7
- TSS: 1.5 mg/L
- Turbidity: 5 NTU
- BOD: <1 mg/L

Conclusions
- Design for clean drinking water is extremely low in cost and operating cost
- Simple to operate
- System may not be compact but built to last
- Supply clean water without power and little to no maintenance
- Believe this is the best solution for Cuttack and other developing and third world countries

Bibliography
1. Figure 1 - Location of Cuttack, India - Google Maps
2. Figure 2 - SODIS Bottles - Google images
3. “SODIS METHOD,” SODIS: SODIS METHOD
4. WHO | Emergency treatment of drinking-water at the point of use. (n.d.)
5. WHO | Arsenic. (n.d.)
Slow Sand Filter for Kayabwe Village
Vincent Crudo, Jean Hache, Mary Matillano
Abigail Charest, Asst. Prof., Intro to Engineering Design
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Abstract
- Kayabwe Village lacks access to clean water
- Located in Uganda, Africa
- Goal is to build a filter
- Drinking Quality
- Sustainable
- Easy to use
- Inexpensive

Introduction
- Water Quality at Lake Victoria
  - Alterations of water temperature
  - Higher temperatures lead to higher conductivity
  - Thermal pollution is detrimental to water supply
- Persistent outbreaks of algal blooms
  - Increases mass occurrences of cyanobacteria
- Pollution
  - Leads to biodegradation of phytoplankton and macrophytes
  - Impacted by industrialization of cities like Kampala City

Materials
- Outlet Tube
  - PVC Tubing (3/8" ID, 5/8" OD, Vinyl Tubing)
- Stand
  - Wood
- Filter Media
  - Stainless Steel Woven Wire Mesh
  - Bamboo Charcoal
  - Sand
  - Gravel
  - Filter Fabric

Expected Results
- Produces enough drinking water for each family
- Easy to use, easy to replace filter media
- A solution that is sustainable
- Must be free of micro-organisms, chemical substances, and radiological hazards that threaten a person’s health (WHO)

Testing Protocols
- Conductivity meter
- Measures salts and minerals of water
- DO meter
- Measures dissolved oxygen in the water
- pH meter
- Measures the pH of the water on a scale of 1 to 14
- A pH of 7 is desirable
- Turbidity meter
- Measures cloudiness of a fluid caused by microscopic particles
- Detects biological contaminants

Next Steps
- Create an efficient way of using water
- Develop boreholes
- Building a sustainable water storage tank
- Deriving a way to collect rainwater during the wet seasons
- Expanding filter use for each family and other villages

Considerations
- Knowledge about filter technology
- Education on clean water
- 950 people (200 families)
  - Each family lives off of 10L per day
- Water is retrieved through a 2km trek to Lake Victoria
- Poverty
- Current problems include water diseases:
  - Cholera
  - Typhoid
- Dysentery
- Skin Infection

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United Nations Department of Economic and Social Affairs. (20 May 2014). Human right to water and sanitation. Retrieved from
Figure 1 – Location of Kayabwe Village – Google Maps
Figure 2 – Location of Kayabwe Village – Google Maps
Figure 3 – Water Quality of Lake Victoria – Akint
Figure 4 – PSO Slow Sand Filter – Milstein
Figure 5 – Prototype (Solidworks)
Clean Water for Students: Arsenic Removal from University Water
Emma Loughlin and Lo-Badal Burch
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Abstract
- Dangerous levels of arsenic
- Water quality concerns in student hostels at University of Punjab Lahore
- Methods meet WHO Standards of arsenic in drinking water

Needs Analysis
- Hostels:
  - 10 for women, 16 for men (Shahid, N., et al., 2015)
  - Approximately 250 people per hostel
- Quantity of Water
  - WHO Standard: 7.5-15 L/day/person (Mihelcic, 2012)
  - Each hostel should treat 2,000-3,750 L/day
- Final Water Quality
  - WHO Standard: .01 mg-L^-1 (Mihelcic, 2012)
  - NSDWQ Standard: .05 mg-L^-1 (Duad, 2017)
  - EPA Standard: .01 mg-L^-1 (EPA via Mass.gov, 2001)

Introduction
- 26 hostels with approximately 6,000 people each
- Source water is deep wells with municipal delivery system
- Water stored in overhead tanks
- Design intercepts contaminated water before tank
- SkyHydrant Filtration System with pre-filtration
- Goal: Arsenic levels within WHO standards

Materials List
- Filter fabric
- Gravel
- Iron-Modified Activated-Carbon
- Coarse Sand
- Activated Alumina

Materials and Methods

Conclusions
- Combination of iron-modified activated-carbon & activated alumina
- SkyHydrant pump from SkyJuice Foundation
- Goal is to produce plenty of adequately filtered water
- Testing will determine next design iteration
- Other water quality standards to be addressed once arsenic is within WHO standards

Acknowledgements
We would like to thank the Department of Civil Engineering. We would specifically like to thank Professor Charest for her guidance with the project & Professor Das for his consultation in filtering methods & materials.

Bibliography
Point of Use Water Treatment for Cambodian Migrants

Tyler Cosma, Brian Burns, Jared Gillett
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Abstract
- Estimated 36% of the Cambodian population lacks access to drinking water.
- Equipped to 7.6 million people.
- Drinking water from different sources contain varying amounts of E. coli.
- Point of use treatment systems used to increase overall drinking water quality.
- Focused on 5 households in the peri-urban community of Veal Stov.

Background
- Water:
  - Weather: Cambodia transitions from torrential downpours to several months of drought.
  - Community: Ave. of 47 people in each temporary household.
  - Contact: Due to urbanization, the poor population is constantly being pushed farther away from the city.
- Water sources:
  - Each water source has varying amounts of E. coli, as seen in Table 1.

Water Treatment Design
- Method Used: Slow Sand Filtration
- Contaminated Water
- Layer 1: Sand
- Layer 2: Rock
- Layer 3: Flat Stone
- Materials:
  - Plastic 5 Gallon Bucket
  - Gravel: for the third layer of the filter
  - Sand: placed above the gravel
  - Perforated PVC pipe with valve
  - Flat Stone: above all layers for even distribution of water across filter

Consumption Demand
- Per Person: 3L/day
- Estimated Water Demand
- 5 gallon bucket dimensions and velocity from page 251 of the Final Guide to Environmental Engineering for Development Workers - used to determine the expected flow rate of the filter

Anticipated Results
- Point of use slow sand filtration system is the best method.
- Materials needed to create the filter are readily available and cost-effective, and are easily replaced if necessary.
- Actual flow rate of our filter will be significantly lower than the theoretical flow rate that was calculated.
- Biological layer that forms at the top of the system will help to reduce, but not eliminate, the total E. coli concentration.
- Decrease in diarrheal disease

Acknowledgements
Dr. Abigail Charest - For assisting us through every step of the design project.
Professor Gautam Dey - For teaching us more about flow rate and the importance of reading in the design process.

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- WHO: water sanitation and hygiene
- "World weather & climate information." Climate and Average Monthly Weather in Phnom Penh, Cambodia. Weather and climate average monthly weather temperature - sunshine, pressure, wind, Cambodia.
Maji Safi
POU: Water Quality in Outer Nairobi
Abigail Meyers, Sawda Mohamed, Emma Perry
Abigail Charest, Asst. Prof., Intro to Eng. Design (Class Of 2021)
Wentworth Institute of Technology

Abstract
- Outer Communities of Nairobi Kenya have very little access to clean water
- Create a way for the people to obtain clean drinking water
- Uncontaminated and accessible water as defined by World Health Organization
- Contaminated by waterborne diseases

Introduction
- Langas Slums of Eldoret, Kenya
- Kenya is struggling with an increase in population
- Informal settlements
- No government aid
- Most common source of water is shallow wells
- Wells are being contaminated due to their proximity to pit latrines
- All the shallow wells tested positive for coliform bacteria
- Coliforms are an indicator that disease-causing pathogens may be present
- 97% tested positive for thermotolerant coliforms

Analysis
- Study conducted in the Langas Slum
  - 40 samples
  - 31 were from shallow wells
  - 100% coliforms, 97% thermotolerant coliforms
  - 4 from deep wells
  - 75% coliforms, 50% thermotolerant coliforms
  - 5 were taken from taps
    - Few coliforms
    - 91% don’t have access to clean water

Methods/Materials
- Biogas Pump
- 2 Five Gallon Buckets
- Small Container
- Petri dish
- Cloth- 2cm
- Sand and Gravel- 10cm each
- Cotton Balls-5cm

Design
- Source Selection
  - Covering the wells, will prevent the waste from entering
- Filtration
  - Filtering existing pathogens from the water
- Education
  - Teach the people about the dangers and ways to farther clean the water

Conclusions
In conclusion our project is not only the design of our project but is a combination of source protection, filtration, and education. Clean water is a human necessity for survival. This project could be the change so that citizens have access to clean water.

Acknowledgments
Professor Abigail Charest, for guiding and assisting us throughout the design process

Bibliography
A Salty Solution, Point of Use Solar Still, Helmand Province

David Bauters, Jackson Nissen, Benjamin Zidelis
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Abstract
- The people in Helmand, Afghanistan need clean drinking water.
- Sun’s heat to evaporate the water
  - Lower behind the sail
  - Removable sail
- Evaporate water to collect with tarp
- Implement for each household

Background
- Simple filtration system that can be easily maintained
- 20% of rural population has access to improved water source
- Water sources directed for flood water (Human Production)
- Open defecation often leads to contamination of water supply
- Major Problems
  - Most drinking water obtained from groundwater wells - groundwater level sinking
  - Saline and Brackish water is unsuitable for drinking
- Salinity Value to aim for
- Taste thresholds for chloride anions in the range of 200-300 mg/l for sodium, potassium, and calcium chloride

Water in Afghanistan
(McKay, Holle)

<table>
<thead>
<tr>
<th>Quality of Water</th>
<th>Low (ppm)</th>
<th>High (ppm)</th>
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<tbody>
<tr>
<td>Fresh Water</td>
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<td>1000</td>
</tr>
<tr>
<td>Slightly Salty Water</td>
<td>1000</td>
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</tr>
<tr>
<td>Moderately Salty Water</td>
<td>5000</td>
<td>10000</td>
</tr>
<tr>
<td>Highly Salty Water</td>
<td>10000</td>
<td>30000</td>
</tr>
</tbody>
</table>

Karaze Diagram
(Khan, Baba Sher)

Existing conditions
- Helmand region is mainly a warm desert climate
- 100 mm of rainfall per year
- Saline Water
- Allowed Water
  - Shared with neighbors
- Tarp is controlled water
- Water although saline can be obtained from abandoned Karaze

Function/Materials
Materials for Prototype
- 1-1/2"x12"x12"
- 1-1/2"x4"x6" tarp
- 14 square meter black tarp
- 14 square meter clear tarp
- 50 meters of PVC piping
- Insulation (ex. wood chip)
- Container for final collection (can be plastic, metal, or clay)

Function: How the still works
- Saline water is placed in bottom chamber with insulation
- Sunlight heats water through clear tarp
- Evaporation occurs
- Salt is left behind on insulation and potable water collects on tarp
- Water flows with help of gravity into trough surrounding tarp
- Water flows through tubes and collects in container.

Equations: Amount of Water Treated Per Day

\[
\text{Amount of Water Treated Per Day} = \frac{4000 \text{ ml}}{1 \text{ day}} = 364 \text{ l/day}
\]

1000 people

\[
1 \text{ l/day} = 3.78 \text{ l/day}
\]

Need 3708l.

Conclusions
- Education and implementation
- 5 people receive
  - Knowledge to treat water in a new location
- Wide range of naturally available materials
  - Both local and global
- Potable water yield based on research
- Effective means of education
- Widespread access to clean water in rural areas of Afghanistan

Acknowledgements

Selected Bibliography

1.重点关注 (Focus on)
2. 其他 (Other)
3. Selected Bibliography

Professor Charest
Professor Das
Lab Technician Philip Gunsmith
The Nissen, Zidelis and Bauters family
POU Filter for a Family Among Millions
Kumbh Mela Festival, India
Maryalissa Hebdon, Marina Schmid, Peter Travassos
Prof. Abigail Charest, Intro to Eng. Design (Class of 2021)
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Abstract
- At the crossroads of the Ganga and Yamuna Rivers in Allahabad, India, the world’s largest religious festival occurs.
- This design provides potable water for a family of four at the festival.
- The water filter will clean at least 16 liters per day.
- Uses cheap and local materials to create a 3 bucket slow sand filter system.

Background
- Religion: For Hindus all around the world, the Kumbh Mela in Allahabad, is the largest sacred pilgrimage of faith.
- More than 27 million daily visitors.

Ganges and Yamuna Rivers
- Ganges river becomes heavily impacted.
- River serves as a place to wash clothes, gather water, dispose of the dead, and defecate.
- Waterborne illnesses kill 600,000 Indians per year, such as Cholera, Malaria, and Typhoid.
- Polluted waters cost Indian’s a collective $4 Billion per year.

Considerations
- Transportation
- Handling of materials
- Ease of storage
- Availability
- Acceptability
- Affordability
- Clean
- Inexpensive

Water Filter Design
- Three bucket slow sand filter connected through a series of PVC pipes.
- Filters by water pressure through a sequence of varying materials.
- Water rises through filters to provide slower but more thorough filtration.
- PVC piping assists in water’s flow from one bucket to next.

Materials
- Type: Slow Sand Filter
- Approximate Cost: $79 single unit
- Various PVC connections and fittings

Testing Protocol
- PH Meter - Ecolyser pH2
- Spectrophotometer - Hach DR 3800
- Conductivity Meter - Hanna HI98304
- Turbidity Meter - Oakton - T-100
- Dissolved Oxygen Meter - Hach LDO
- Data collected using a handheld device.

Recommendations
- Design cost would be cheaper if materials are bought in bulk.
- Many of materials can be found locally in India.
- Due to material absorption and other imperfections, it would take more than 16L of water to supply daily 16L needed.
- To mitigate clogging of first valve, cover top of first bucket in wire mesh and pour water through mesh.

Bibliography