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BEFORE YOU BEGIN

We sincerely appreciate you taking the time to complete this Summary of Contributions (SoC). We will rely on the detailed information you provide here to prepare a strong case on your behalf. While we have legal expertise in presenting strong arguments for NIW petitions, any insight you can provide from your perspective as an expert in your field should be incredibly useful in informing our approach and ultimately lead to a stronger case.

The SoC is broken up into 3 sections:

I. **Background Information:** Here we will ask you to provide information regarding the field in which you work, your unique place in this field, your top accomplishments, your plans for continuing your work in the United States, and why those plans are of substantial merit and in the national interest. The more information you can provide here, the stronger we can make your case. **Please pay special attention to defining your proposed endeavor (Part 5), which will shape our overall approach to your case.**

II. **Research Contributions:** Here we will ask you to describe your key contributions to your field. We ask that you divide your body of work into **3 to 4 different projects** that we can discuss in your letters of recommendation and petition letter. Please make sure to discuss research related to **all of your highly cited papers** under one of your projects. Please be as specific as possible in describing your personal contributions to each of these projects, as well as in describing examples of how others have cited and/or implemented your work. **By providing more details specific to your work and its implementation in the field, your case should better stand out to the USCIS, significantly increasing its chance of success**. In the Summary of the Work sections in particular, statements such as "*Because of the need for _____, I studied _____ and found _____*" or *"I investigated/developed _____ and found _____"* are especially helpful.

III. **Additional Qualifications:** Here we will ask you to provide detailed records regarding any media coverage of your work, any accolades or memberships you hold in the field, your complete peer review record, and your complete publication record. Your completion of this section will help us ensure we have not missed discussing any of your important accomplishments or credentials.

We have done our best to provide prompts to guide you in completing this document. You should also see a sample in your client packet. If you have any questions, please let us know. We look forward to learning more about your work!

SECTION I

BACKGROUND INFORMATION

1) **Main Field/Industry:**

Please identify the main academic field or industry within which you conduct research. Ideally, this should be the most specific field that incorporates all of your major research projects.

Examples include: organic chemistry, materials science, electrical engineering, mechanical engineering, biochemistry, biomedical science, and geophysics.

My main field/industry is environmental engineering.

2) **Subfields/Specializations:**

Please identify the specific areas of your main field in which you specialize.

Examples include: An organic chemist may specialize in small molecule design and synthesis; a materials scientist may specialize in magnetic materials for power generation; a geophysicist may specialize in the seismic imaging of Earth's interior.

Within this general field, I specialize in wastewater treatment, bioremediation, and desalination.

My top skills include mathematical modeling, water resource engineering, sanitary processes engineering, and water resources design.

3) Your Place in the Field

Please discuss any experiences, skillsets, perspectives or accomplishments that you believe really set you apart from you peers (e.g. "Unlike the work of many of my peers in the field, my work directly addresses…)"

I have worked on different environmental issues like wastewater treatment, bioremediation, and seawater desalination over the past 6 years. Working on different aspects of environmental issues has helped me to come up with new solutions by combining techniques used in many different fields. During these years I have developed many skills, like how to design a project, how to design an experiment, working with different instruments, writing papers, etc. These skills will help me to be part of research team and design new solutions to common environmental issues. Further, I have recently won a John B. Hawley memorial fellowship from the American Society of Civil Engineers, and plan to begin work on a project funded by the National Science Foundation (NSF) in a few months.

4) Summary of Top Achievements in Field/Industry:

Please fill in the prompts below, briefly listing your top research projects and other achievements within your field/industry. Only one or two sentences is needed for each item, as you will be prompted to elaborate on these items later.

I am an environmental engineer who studies wastewater treatment, heavy metal remediation, and desalination. The overarching goal of my research is to remove pollutants from the environment and provide fresh water by brackish water or seawater desalination. My work has practical

applications in industrial wastewater treatment, polluted ecosystem remediation, and brackish and seawater desalination. These are my most significant research contributions so far:

- Synthesizing novel magnetic nanocomposites to remove dye and heavy metal from industrial wastewater
- Establishing the importance of microbial consortium as oppose to pure culture in heavy metal remediation
- Starting a new approach, simultaneous inhibiting of scaling and biofouling on reverse osmosis membranes, to improve water recovery in desalination plants
- Received John B. Hawley memorial fellowship from American Society of Civil Engineers

5) Plans for Continued Engagement in the Field:

Please clearly define your "proposed endeavor" by providing information regarding your plans for future work/research in your field as well as your plans for continued employment in your field. While it is not necessary for you to have an NIW or EB1A petitioner to have a job offer from a specific employer, the USCIS officers consider information about your prospective employment when determining whether you are well-positioned to conduct important work in your field.

If you are currently employed and expect the employment to continue, you may indicate how you will continue to engage in the same field and how your proposed endeavor has national importance based on your current position.

If you are currently a student, a visiting scholar, unemployed, or you are outside the U.S., please discuss any possible research-oriented job offers you intend to accept and/or any communications from employers expressing interest in hiring you in the future. If you have not received any such communications, please start to look for research-oriented positions in your field and, ideally, provide evidence of such a letter of intent from potential employers that will hire you for a research-oriented position.)

For my proposed endeavor, I intend to continue my research on wastewater treatment and bioremediation strategies with the goal of improving existing decontamination methods. I also plan on continuing my research on developing novel desalination techniques with the goal of improving access to drinkable water in areas where water scarcity is a significant issue. I believe I will be able to accomplish these research goals over the course of my current and future employment in the Department of Civil and Environmental Engineering at the University of Houston, where I am currently completing my Ph.D. and where I have been offered a permanent research position upon the completion of my degree. My supervisor is willing to sign a letter confirming their intent to hire me once I have completed my Ph.D. studies.

The work I have completed at the University of Houston has left me well-positioned to achieve my proposed endeavor. The work I have published while conducting research at this institution has been widely cited within the field of environmental engineering. Further, my research possesses inherent benefits for the United States, especially within the context of environmental remediation and fresh water availability. I also believe I will be similarly well-positioned upon the completion of my Ph.D. degree, after which I intend to transition into a permanent research position in the same field at the University of Houston.

6) Substantial Merit and National Importance of Your Proposed Endeavor

In as much detail as possible, please clearly describe how your proposed research/work stands to benefit the United States. Please note that we will do our best to make these arguments based on our own research, but any insight you can provide would be extremely helpful!

A. How is your field or industry <u>inherently</u> beneficial to the interests of the United States and the overall field?

Generally, my work in the field of environmental engineering is related to cleaning up the environment, inhibiting contamination discharge to the environment, and providing a sustainable source of fresh water by desalinating sources of seawater and brackish water. The removal of contaminants from polluted water sources can help preserve the environment and prevent serious health outbreaks related to contamination from heavy metals and dyes. For instance, heavy metals such as cadmium are highly toxic, carcinogenic, and tend to accumulate within the body over time, resulting in devastating chronic symptoms. Dyes are equally dangerous and can act as neurotoxins in humans and animals when ingested. Thus, research within this field that serves to efficiently and cost-effectively remove these hazardous pollutants from wastewater is extremely important to public health within the United States.

Further, it has been reported that fresh water sources in the United States will eventually be unable to match the demand of the population for drinkable water, according to a study published in *Earth's Future* in 2019. These fresh water shortages are predicted to occur due to the country's increasing population totals as well as fewer rainfall density as a result of active climate change. Another aspect of my work is focused on providing sustainable sources of fresh

water through efficient desalination methods, demonstrating that the work conducted in my field is inherently beneficial to the United States.

B. How does your specific work directly benefit the United States?

Within the field of environmental engineering, my work specifically benefits the United States in multiple ways. First, the Environmental Protection Agency's (EPA) regulations on the limit of pollutants allowed to be released into wastewater sources has grown increasingly strict over the years, specifically due to the Clean Water Act. Therefore, many U.S. industries are in dire need of new techniques to both minimize contamination discharge and clean up heavily polluted sites. In one of my most-cited studies to date, I was able to introduce a novel method for removing harmful pollutants, such as heavy metals and dyes, using two series of magnetically-charged particles with polymer coatings. Our method proved to be extremely successful at removing the majority of the contaminants from the wastewater samples, especially in comparison to similar studies examining the same pollutants. Further, I designed these particles to be re-usable over several decontamination cycles for a long period of time, which improves the overall cost-effectiveness of my method for these industries.

As described above, another major problem in the United States is water scarcity, which is projected to worsen due to population growth and climate change. For instance, the state of California has been struggling with issues related to water scarcity over the past seven years. One solution they have actively pursued is desalination, primarily due to their proximity to the western coast and its unlimited supply of ocean water. One of my more recent works in the field has focused on improving large-scale membrane separation via reverse osmosis (RO), which is one of the most widely-used desalination techniques in use in the United States today. Even though RO desalination techniques have advanced significantly in recent decades, membrane fouling is still a common occurrence that hampers effectiveness. In my work, I examined the

benefits of applying a graphene oxide (GO) coating on an RO membrane prior to desalination. I found that the membrane coated with GO experienced less fouling compared to a membrane without coating and possessed higher water recovery over time, a discovery which will decrease both the cost and energy demands for desalination plants in the United States. Hence, my work in the field is directly beneficial to the country.

SECTION II

RESEARCH CONTRIBUTIONS

- **Please indicate and describe the <u>top 3 - 4 contributions</u> you have brought to the field or industry using the template below. Be sure to include <u>all</u> of your highly cited papers (including your most highly cited paper) in this section, even if you are not the first author.**

1. "Removing Pollutants, Dyes, and Heavy Metal Components from Industrial Wastewater Using Nanocomposites"

Dates of Project Initiation and Completion: 07/2013 – 03/2015

Resulting Publication(s) (if applicable): *(Please list <u>patents and full-length articles and note their current status: (Published Patent); (Filed Patent); (Published Journal Paper); (Published Conference Paper); (Accepted for Publication Journal/Conference Paper); (Submitted Journal/Conference Paper); (Under Preparation Journal/Conference Paper</u>].*

- O. Tavakoli, M. Khoobi, **A. Bardi**, M.A. Faramarzi, "Application of Novel Magnetic β-cyclodextrin-anhydride Polymer in Dye Removal from Aqueous Solution", *Journal of the Taiwan Institute of Chemical Engineers*, 2015, 80, 452-463 **(Published Journal Paper)**
- **A. Bardi**, S. Vahedi, O. Tavakoli, M. Khoobi, M.A. Faramarzi, "Novel Fe3O4/hydroxyapatite/ β-cyclodextrin nanocomposite adsorbent", *Applied Organometallic Chemistry*, 2018, 33, e4634 (**Published Journal Paper)**
- **A Bardi**, S. Vahedi, M. Khoobi, M.A. Faramarzi, "Fe3O4/hydroxyapatite/ β-cyclodextrin nanocomposite adsorbent, US 2019/532533 A1, filed Oct 2019 **(Filed Patent)**

Funding Sources, if applicable:

(*Please list here any independent entities that have funded this research, such as the National Science Foundation, National Institutes of Health, Department of Defense, etc. Please do not include funding from your own institution, as the USCIS does not consider such funding to be significant. Please upload any evidence you have of this funding when you upload your summary)*

- My second paper, **Bardi et al.**, was funded by the Iran Science Elite Federation (ISEF) and the Research Council of Tehran University of Medical Sciences (TUMS).

Conference Presentations/Invitations:

- 3rd International Conference on Membrane Science and Technology, September 2020. Invited based on interest in my paper in *Applied Organometallic Chemistry*. Presentation topic will be the same as my paper.

Technical Summary of Work:

(*Please provide two paragraphs describing the work using the technical terminology and explanation of work that an expert would be able to understand and evaluate. The summary should be around 300 words in length.)*

We synthesized two sets of novel nanoparticles:

1) To remove Rhodamine B (RhB) and Methylene Blue (MB) from water by adsorption. The nanoparticles were: a) Fe3O4 coated with β-cyclodextrin (Fe@CD), b) Fe3O4 coated with β-cyclodextrin-succinic anhydride (Fe@CDA1), and c) Fe3O4 coated with β-cyclodextrin-Epiclon (Fe@CDA2).

2) To remove heavy metal ions, cadmium (Cd2+) and copper (Cu2+) from water by adsorption. The nanoparticles were: a) Fe3O4 coated with hydroxyapatite (Fe3O4@HA) and b) Fe3O4 coated with hydroxyapatite and β-cyclodextrin (Fe3O4@HA-CD).

For heavy metal removal Fe3O4@HA and Fe3O4@HA-CD were faster than dye removal as adsorption reached equilibrium in 60 min for removing Cd2+ and Cu2+. Fe3O4@HA-CD had higher adsorption than Fe3O4@HA for Cd2+ and Cu2+ as a result we chose Fe3O4@HA-CD for the rest of experiments.

We investigated the effect of pH on adsorption and based on that we suggested two mechanisms for dye adsorption: i) electrostatic attraction and ii) host-guest inclusion complex formation. For

RhB most likely the first mechanism is dominant i.e. negative sites of the adsorbent at high pH attract positively charged dye molecules. However, for MB the dominant mechanism can be the entrance of dye molecule into the βCD cavity and inclusion complex formation as by lowering the pH of solution.

We investigate the effect of the amount of adsorbents on the removal of the pollutants. For dyes, Fe@CDA2 was able to remove 80% of RhB and 96% of MB. For heavy metals, Fe3O4@HA-CD were able to remove 100% of Cd2+ and 80% of Cu2+.

We investigate the isotherms governing the adsorption for pollutants. For all the pollutants, adsorption was following the Langmuir isotherm. The maximum adsorption capacity predicted by Langmuir isotherm was 333.3 mg/g for RhB, which is higher than many other similar studies presented in our paper (**Vahedi et al.**), 250 mg/g for MB, 100 mg/g for Cd2+, which is higher than many other similar studies presented in our paper (**Bardi et al.**), and 66.66 mg/g for Cu2+ which is higher than many other similar studies presented in our paper (**Bardi et al.**).

We investigate the reusability of the adsorbents by desorbing the pollutants. After 5 cycles, Fe@CDA2 lost ~ 10% of its adsorption capacity and Fe3O4@HA-CD lost ~ 20% of its adsorption capacity. We characterized the adsorbents after 5 cycles, the results that the structure of the adsorbents have not changed. Based on the reusability and stability of the adsorbents we concluded these adsorbents can be used for a long term to remove pollutants from water.

Plain Language Summary of Work:

(*Please provide two paragraphs describing the work in layman's terms or plain language that an average person without special expertise would be able to understand and evaluate. The summary should be around 300 words in length.*)

In order to remove some pollutants like dye (rhodamine B and methylene blue) and heavy metal (cadmium and copper ions), which can be harmful for the environment, from industrial wastewater we made two series of particles with magnetic properties. The idea is to add these particles to the

wastewater, give them some time to attach to the pollutants and then remove the particles and pollutants from water by an external magnet. Fe_3O_4 is a magnetic material but it does not have enough sites on its surface to attach to pollutants. In order to provide more sites on the Fe_3O_4, we modified Fe_3O_4 by coating it with some polymers. The polymer coating provides more sites for pollutant attachment and is thin enough to not reduce the magnetic properties of Fe_3O_4 significantly i.e. the coated particles still can be removed from the water by external magnet.

At the best condition, we were able to remove 80% of rhodamine B, 96% of methylene blue, 100% of cadmium ions, and 80% of copper ions. The amount of the attached pollutant for each gram of the particles, known as capacity which is an important parameter to evaluate the performance of a particle, was pretty high compared to many similar studies especially for methylene blue, cadmium ions, and copper ions.

We also investigate if we can reuse these particles to remove pollutants over several cycles. In order to reuse the particles, first we have to remove the attached pollutants from the particles. We have tested different solutions to find the best solution to remove the pollutants. After that we used those solutions to remove the pollutants, we reused the particles to attach to the pollutants. We have tried this process 5 times. After 5 times, the particles that were used to attach the dyes lost only 10% of its capacity and the particles that were used to attach the heavy metals lost less than 20% of its capacity. All the particles keep their structure and there was no deformation. These results show that these particles can be used for pollutant removal from industrial wastewater for a long period of time

Summary of the Significance of the Work:

(*Please provide one paragraph describing the general significance of this work, why work in this area is important to the field and the nation, and how this project connects to your efforts to advance your proposed endeavor?*)

This project is important to my field because many industrial wastewaters contain dyes like textile, leather, cosmetics, paper and plastics and many contain heavy metals like textile, metal plating, pesticides production, oil refining, battery production, and mining. The release of these pollutants can significantly harm the environment. For instance, rhodamine B is a toxic carcinogenic dye which causes reproductive toxicity and neurotoxicity in humans and animals. Methylene blue may permanently injure the eyes of humans and animals. It may also cause breathing difficulties upon inhalation. Heavy metals are toxic, carcinogenic, non-biodegradable, and tend to accumulate in living organisms. Cadmium is highly toxic and mobile and copper may cause vomiting, gastrointestinal sickness, or even death.

Among different methods available to remove dyes and heavy metals from water, adsorption is a low-cost method and is a procedure of choice due to its simplicity and effectiveness in removing different types of dyes and heavy metals. An adsorbent should have high removal rate and high adsorption capacity. Moreover, it should be easily removed from water. In this project, we made different adsorbents that can practically be used to remove dyes and heavy metals.

This project is important to the United States because, as mentioned above, the nanoparticles we synthesized can be used to remove dyes and heavy metals from the wastewater of different industries. For example, we can take a closer look at textile industry which has both dyes and heavy metals in its wastewater. According to National Council of Textile Organization (NCTO) website, the U.S. textile industry supply chain employed 594,147 workers in 2018. U.S. textile and apparel shipments totaled $76.8 billion in 2018. U.S. textile mills have increased labor productivity by 60% since 2000. The U.S. textile industry invested $22.8 billion in new plants and equipment from 2006 to 2017. On the other hand, the textile plants produce wastewater containing different pollutants including dyes and heavy metals. As fresh water becomes scarcer in the U.S., the Environment Protection Agency (EPA) has put pressure on the industries to clean their wastewater. The Clean Water Act (CWA) is the main document determining the allowable

amount of different pollutants in the industrial wastewater which will be discharged to the environment. The EPA regulations become stricter over time. In order to follow the regulation, textile plants can benefit from our project to clean up their wastewater efficiently and with less expense. These regulations set by the EPA were one of the reasons that some dye manufacturers left the business in the 1976-1988 period. Sodyeco (now part of Clariant) had to install a $ 1.5 million wastewater treatment plant to purify water discharged into the Catawba river in South Carolina. However, our method stands to be a much cheaper and more effective alternative, which benefits industries looking for ways to meet EPA standards in wastewater treatment without investing large amounts of money.

This project is related to my proposed endeavor because they both are efforts to improve wastewater treatment using nanoparticles. My current work builds directly atop this past work.

Summary of the Implementation/Influence of the Work:

(*Please describe how this work has already been influential in the field. You should provide specific examples of where and how your work has been used by independent researchers, giving as much detail as possible. Examples of implementation/influence include (but are not limited to) notable citations of your articles, licenses or contracts, collaborations, technology transfer agreements, patent commercialization, clinical guidelines, clinical trials, or emails asking for your work. You should also include any notable funding or major media coverage this project has received, if applicable. Note that these examples are critical to the strength of your case.*)

- Zhang, W., et al., "One-bath one-step low-temperature dyeing of polyester/cotton blended fabric with cationic dyes via β-cyclodextrin modification." *Textile Research Journal*, 2018. **89**(9): p. 1699-1711.

  - This study is the only study not in the water treatment field that cited our paper (Vahedi et al.). They modified polyester fabrics by β-cyclodextrin to facilitate dyeing process of the fabrics. They cited our work at 3 different parts: i) in the materials and methods where they describe how they expect the dye and β-cyclodextrin will interact based on our proposed

mechanism. We suggested the dye and β-cyclodextrin form inclusion complexes. Based on this, they expected the dyeing process facilitates by modifying the polyester fabrics with β-cyclodextrin. ii & iii) in discussion where they justify how the modified polyester has better dyeing properties compared to unmodified fabrics. They use both our suggested mechanisms: formation of inclusion complexes and electrostatic attraction between negative and positive groups, to explain the improvement in dyeing process.

- Yang, X. and H. Liu, "Ferrocene-Functionalized Silsesquioxane-Based Porous Polymer for Efficient Removal of Dyes and Heavy Metal Ions." *Chemistry*, 2018. 24(51): p. 13504-13511.
  Yang, H., et al., "Rapid removal of anionic dye from water by poly(ionic liquid)-modified magnetic nanoparticles." *Journal of Molecular Liquids*, 2019. 284: p. 383-392.

  - These two studies, belonging to the same research group, used our work in discussion part to explain the difference in the amount of adsorbed dyes. In the first one they referred to our proposed mechanism of electrostatic interaction between the adsorbent and dye to explain why crystal violet adsorbed more than rhodamine B. In the second one, they cited our paper (**Vahedi et al.**) twice in the discussion. They mentioned how the size of the pores on the adsorbent and the size of the dye affect the amount of adsorption. We had the same discussion where we explain the pH test results. They also used our proposed mechanism based on the electrostatic attraction between the dyes and adsorbent to explain the amount of the adsorbed dyes.

- Pellicer, J.A., et al., "Removing of Direct Red 83:1 using α- and HP-α-CDs polymerized with epichlorohydrin: Kinetic and equilibrium studies." *Dyes and Pigments*, 2018. 149: p. 736-746.

Pellicer, A.J., et al., "Adsorption Properties of β- and Hydroxypropyl-β-Cyclodextrins Cross-Linked with Epichlorohydrin in Aqueous Solution. A Sustainable Recycling Strategy in Textile Dyeing Process." *Polymers*, 2019. 11(2).

– These two papers from the same research group cited our paper (**Vahedi et al.**) as an example of using β-cyclodextrin polymers for dye removal. They compared our reported adsorption capacity with their study and some similar studies. In the first manuscript, our adsorption capacity is the second highest number reported and in the second manuscript, our adsorption capacity is the highest number reported.

- Nasiri, J., et al., "Removal of crystal violet from water using β-cyclodextrin functionalized biogenic zero-valent iron nanoadsorbents synthesized via aqueous root extracts of Ferula persica." *Journal of Hazardous Materials*, 2019. **367**: p. 325-338.

  - This study cited our paper (**Vahedi et al.**) to explain the increase in the dye removal ability of their adsorbents based on our proposed mechanism, i.e. formation of inclusion complex.

- Zhou, Y., et al., "Recent advances for dyes removal using novel adsorbents: A review." *Environmental Pollution*, 2019. 252: p. 352-365.
  Mudhoo, A., et al., "Green synthesis, activation and functionalization of adsorbents for dye sequestration." *Environmental Chemistry Letters*, 2019. 17(1): p. 157-193.

  - Our paper (**Vahedi et al.**) has been cited in two review articles. The first manuscript presented the regeneration method we used for the adsorbents. The second manuscript cited our work as one of the magnetic nanostructured adsorbents for dye removal (sequestration).

- Núñez, D., et al., "Heavy metal removal from aqueous systems using hydroxyapatite nanocrystals derived from clam shells." *RSC Advances*, 2019. 9(40): p. 22883-22890.

  - This study synthesized hydroxyapatite (HA) nanocrystals from clam shell for heavy metal removal. Based on the reusability of our adsorbent which contained HA, they justified why HA nanocrystals can be a good choice for long term heavy metal removal.

2. "Bioremediation of Heavy Metals"

Dates of Project Initiation and Completion: 01/2017 – 11/2017

Resulting Publication(s) (if applicable): *(Please list patents and full-length articles and note their current status: (Published Patent); (Filed Patent); (Published Journal Paper); (Published Conference Paper); (Accepted for Publication Journal/Conference Paper); (Submitted Journal/Conference Paper); (Under Preparation Journal/Conference Paper].*

- IE. Mejias Carpio, **A. Bardi**, DF. Rodrigues, "Relationship of biodiversity with heavy metal tolerance," *Environmental Science & Technology,* 2016, 52 (1), 184-194. **(Published Journal Paper)**

Funding Sources, if applicable:

- No funding for this project. It is a review and statistical analysis.

Conference Presentations/Invitations:

- International Congress on Membranes & Membranes Processes 2019, July 2019. Invited based on interest in my paper in *Environmental Science & Technology*. My presentation was titled "Heavy Metal Tolerance: The Role of Biodiversity."

Technical Summary of Work:

Bioremediation is a technique utilizes the biological inherent in microbes and plants to restore the ecosystem to its original condition. The basic principles of bioremediation involve reducing

the solubility of these environmental contaminants by changing pH, the redox reactions, and adsorption of contaminants from a polluted environment.

In this study, we collected 930 values from other literature studies that comprise common cells used for metal sorption and metal tolerance, with aims to (i) correlate microbial metal tolerance, in terms of minimum inhibitory concentration (MIC), with the type of metal; (ii) correlate microbial metal tolerance, in terms of MIC, with the microbial Kingdom; (iii) correlate microbial metal tolerance, in terms of MIC, with the bacterial genus; (iv) determine if growth medium influences MIC; (v) determine if type of culture, pure culture or consortium, affects MIC; (vi) link microbial metal sorption capacity with microbial Kingdom; (vii) link microbial metal sorption capacity with the types of metal; and (viii) determine if biodiversity has a significant effect on maximum adsorption capacity (qmax) by considering values of consortia and pure cultures. This approach will allow us to gain a better understanding of the role of microbial diversity, metal resistance, and metal sorption in bioremediation processes.

1st analysis: We found that there is a statistically significant difference between the different metals and the overall microbial tolerance under the same redox conditions (aerobic), with a p-value <0.001.

2nd analysis: We found that Fungi has the highest metal tolerance probably because it has both prokaryotes and eukaryotes metal detoxification mechanisms. After Fungi Eubacteria and Plantae had the highest MIC.

3rd analysis: We found that the difference between the genera is significant as Bacillus, Cupriavidus, Klebsiella, and Paenibacillus are the most resistant genera.

4th analysis: We found that there is no significant difference between minimum and rich media. This could be due to the production extracellular polymeric substances (EPS) by bacteria, which makes the chemistry of minimum and rich media the same.

5th analysis: We found that consortium has higher metal tolerance than pure culture. This result may be explained by the communication between cells through which they can trigger changes in gene expression in response to high levels of metal.

6th analysis: We found that Eubacteria has the highest sorption capacity, as there was no difference between Fungi and Plantae. This result clearly shows that tolerance is not directly related to the bioremediation ability of a group of microorganisms since Fungi has the highest tolerance (2nd analysis) but not the highest adsorption capacity.

7th analysis: We found that there is statistically significant difference between adsorption capacity for each metal.

8th analysis: We observed that consortium had higher qmax compared to pure culture. This result demonstrates the importance of investigating complex microbial communities for metal sorption applications.

Plain Language Summary of Work:

Heavy metals can be harmful to the environment. Researchers have used different approaches to remove heavy metals from aquatic environment or soil. One of these approaches is to use microorganisms to remove the heavy metals, which is called bioremediation. We analyzed the data from other researchers using statistical tools to determine the important parameters in designing a bioremediation process. There are two important characteristics of microorganisms that play a vital role in bioremediation: (1) the tolerance of microorganisms to heavy metal, since heavy metals can be toxic to them, and (2) the amount of heavy metals microorganisms can adsorb from the environment. We correlated these two parameters to different microorganisms and conditions. Our main findings are that we found that Fungi has the highest tolerance to heavy metals, but they do not have the highest heavy metal uptakes. Eubacteria showed the highest metal uptake which make them the best candidate for bioremediation considering they grow faster that Fungi and easier to work with. We also observed that when a mixture of microorganisms has been used for bioremediation the amount of metal uptake is significantly

higher and a group of microorganisms has higher tolerance to heavy metals compared to a single microorganism. We believe, based on these results, despite that most previous studies have used a microbial isolate for bioremediation, researchers should focus more on using mixture of microorganisms for metal removal. Besides, we should also consider that using an isolate is not practical for real applications since the isolate can easily get contaminated by other microorganisms present in the environment. This contamination can negatively affect the bioremediation property of the isolate, but for a mixture of microorganisms it is less likely that the other microorganisms present in the environment affect their performance.

Summary of the Significance of the Work:

This project is important to my field because heavy metal pollution has adversely affected the natural ecosystem. These pollutants arise from natural and anthropological sources. Heavy metals are toxic, carcinogenic, non-biodegradable, and could accumulate in agricultural soils and get into the food chain thereby becoming a major threat to food security. Bioremediation is an eco-friendly and cost-effective method compared to the conventional chemical and physical methods, when metal concentrations are low. Our study guides future studies in the developing approach of bioremediation, by determining and highlighting the main findings of the previous studies. We believe our results can facilitate the way for bioremediation to become a practical method for heavy metal removal.

This project is important to the United States because heavy metal pollution is an environmental problem in the United States as well as across the world. Different projects have been organized by environmental protection agency (EPA) over the past decades for metal removal from the environment. For instance, at Dearing Smelter site, Kansas, the concentration of zinc and lead in the surface soil is extremely high, or the concentration of arsenic is quite high at the Whitewood Creek site, South Dakota. The health hazard from these sites would be by the

exposure routes of wind-blown dust and ingestion by children. Bioremediation can effectively be used for heavy metal removal from contaminated sites.

This project relates to my proposed endeavor because this represents one of the bioremediation strategies I mention in my proposed endeavor. This work resulted in new ideas for approaches to bioremediation (such as relying on a variety of microorganisms rather than only one to maximize metal uptake), which is directly in-line with my proposed endeavor.

Summary of the Implementation/Influence of the Work:

- Liang, Y., et al., "Characterization of Cu and Cd biosorption by Pseudomonas sp. strain DC-B3 isolated from metal mine soil." *International Journal of Environmental Science and Technology*, 2019. **16**(8): p. 4035-4046.

  - This paper has cited our paper 6 times. They cited three of our findings, i) MIC depends on genus, ii) metal resistant is not positively related to adsorption capacity, and iii) metal adsorption capacity depends on the type of metal, in discussion to explain their results.

- Mitra, S., et al., "Three-dimensional graphene for electrochemical detection of Cadmium in Klebsiella michiganensis to study the influence of Cadmium uptake in rice plant." *Materials Science and Engineering: C*, 2019. **103**: p. 109802.

  - This paper has cited our paper in discussion when they are describing the detection techniques for bioaccumulation of cadmium, they cite one of our findings that Eubacteria is the second most tolerant microorganism.

- Chang, J., et al., "Cr(VI) removal performance from aqueous solution by Pseudomonas sp. strain DC-B3 isolated from mine soil: characterization of both Cr(VI) bioreduction

and total Cr biosorption processes." *Environ Sci Pollut Res Int*, 2019.

- This paper used two of our findings in discussion on the metal resistance of their isolate. First that the metal resistance is different among different genera. Two that metal resistance is not positively related to adsorption capacity.

- Castro, C., et al., "Metal biorecovery and bioremediation: Whether or not thermophilic are better than mesophilic microorganisms." *Bioresour Technol*, 2019. 279: p. 317-326.

- This paper is a review on metal biorecovery and bioremediation. They cited our work where they say many biosorbents have been used for heavy metal removal.

- Liu, K., et al., "Macro and Microelements Drive Diversity and Composition of Prokaryotic and Fungal Communities in Hypersaline Sediments and Saline-Alkaline Soils." *Front Microbiol*, 2018. 9: p. 352.

- They cited our paper in discussion. They mentioned our finding that consortium has higher tolerance than pure culture to explain that micronutrient are not toxic to the consortia and drives the change in prokaryotes diversity.

3. "Inhibiting Inorganic Fouling on Reverse Osmosis Membranes by Surface Modification"

Dates of Project Initiation and Completion: 01/2017 – 08/2018

Resulting Publication(s) (if applicable): *(Please list patents and full-length articles and note their current status: (Published Patent); (Filed Patent); (Published Journal Paper); (Published Conference Paper); (Accepted for Publication Journal/Conference Paper); (Submitted Journal/Conference Paper); (Under Preparation Journal/Conference Paper].*

- B. Cao, **A. Bardi**, X. Yi, DF. Rodrigues, Y. Hu, "Gypsum scale formation on reverse osmosis membrane", *Journal of Membrane Science*, 2019, 552, 132-143.

Funding Sources, if applicable:

- This work was supported by the Qatar National Research Fund (QNRF) – National Priority Research Program under contract number NPRP9-318-1-064 to the University of Houston.

Conference Presentations/Invitations

N/A

Technical Summary of Work:

Graphene oxide (GO), a well-known antimicrobial material, coatings on membranes can improve antifouling performance against a variety of microorganisms and organics. However, the effects of GO coatings on mineral scaling were not investigated. In this study, we first coated a commercially available reverse osmosis (RO) membrane with GO and proved the coating with different characterization techniques. We showed that by coating the bare membrane with GO, transport properties of the membrane like water permeability and salt rejection did not decrease while surface properties like hydrophilicity, measured by water contact angle method, and charge, measured by zeta potential, changed in favor of less fouling.

Second, we investigated the gypsum scaling on bare and GO-modified thin-film polyamide membranes followed by cleaning with deionized (DI) water with a bench-scale reverse osmosis setup. We observed that flux decline caused by gypsum scaling on GO coated membrane was slightly reduced than on bare membrane. This is because the GO coated membrane is more hydrophilic than bare membrane, indicating a higher energy barrier for heterogeneous nucleation and/or the deposition of gypsum on it. Moreover, the more negatively charged GO coated membrane lead to stronger electrostatic repulsive forces between the membrane and the negatively charged gypsum particles and thus further inhibiting gypsum deposition onto membranes. We characterized the precipitates formed on both membranes. The results showed that GO coating does not affect the type of precipitation.

Interestingly, during the cleaning process, we observed smaller flux recovery for GO coated membrane. This is because GO coated surfaces have higher densities of carboxyl (–COOH) groups, which form complexes with Ca^{2+}, building strong bonds between GO coatings and gypsum. Our study provided unique insights on the physicochemical interactions among membrane, the scaling mineral, and aqueous species, which can help the rational design of coatings for better simultaneous anti-scaling and antifouling performances.

Plain Language Summary of Work:

Desalination is one of the most promising technologies to provide an infinite, uninterruptable, and reliable source of clean water, by converting salty water to fresh water. Today, membrane separation via reverse osmosis (RO) accounts for over 50% of the installed capacity in the world. In the past two decades, large-scale RO desalination has advanced significantly, mainly because of the development of more robust thin-film composite polyamide membranes, but such membranes still suffer from fouling. Membrane fouling by inorganic materials (scaling) and microorganisms (biofouling) have been the subject of many studies since membrane fouling will decrease clean water production levels, increase energy consumption due to clogging of the membrane pores, and potentially damage equipment. Coating RO membranes with different materials is one approach to reduce fouling, but most studies have focused on the effect of a coating on either biofouling or scaling. We believe the simultaneous prevention of mineral scaling and biofouling on RO membranes can give a boost to RO expansion worldwide.

In this study, we used graphene oxide (GO) coating on an RO membrane. GO coating is known to reduce biofouling, but its effect on scaling has not studied. We used a bench-scale RO system to test the performance of GO coated membrane and compare it with a commercially available non-coated membrane. We used salty waters with different amount of salts to investigate different conditions since the amount of salt in seawater or brackish water is not the same worldwide. First of all we observed that although we add a layer of GO to the membrane the

amount of clean water that can pass through the GO coated membrane is the same as membrane without coating. Second, we used different kind of salty waters as feed to the RO system. We observed that membrane coated with GO has less scaling thus more clean water production compared to the membrane without coating. However, removing scales formed on the membrane was harder for GO coated membrane compared to the membrane without coating.

Summary of the Significance of the Work:

This project is important to my field because we believe a new approach for enhancing the reverse osmosis desalination is required, by dealing with biofouling and scaling at the same time. Most, if not all, studies on using surface modification for decreasing fouling on RO membranes focus on either biofouling or scaling. However, it is possible a surface modification which decreases the scaling increases the biofouling or vice versa, but researchers do not investigate that. We believe in order to achieve this goal, first we must understand the complex physical-chemical-biological interactions in the RO systems. By doing that we might be able to provide coatings that can reduce both biofouling and scaling.

This project is important to the United States because technological breakthroughs have led to desalination expansion in the US in recent years. More than 300 municipal-level seawater and brackish water desalination plants with the ability to produce at least 25,000 gallons of potable water per day exist in the United States, with countless projects in the pipeline. Florida takes the lead for municipal desalination by volume, with 282 million gallons of potable water produced per day from both ocean and brackish water treatment, according to the South Florida Water Management District. Ranking second in the country is California: the state's Department of Water Resources reported that 140,189 acre-feet per year or 125 million gallons per day were treated in 2013. The Claude "Bud" Lewis Carlsbad Desalination Plant, the largest in the United States, was completed in 2015 and can produce up to 50 million gallons of fresh water a day.

Municipal desalination plants in Texas can produce about 142 million gallons per day, according to the Texas Water Board, all from brackish groundwater and surface water treatment (there are, as of yet, no municipal seawater desalination plants in Texas). We believe our finding can pave the way for faster expansion of RO desalination in the US.

This project relates to my proposed endeavor because we discovered a new approach to desalination that I am building on in my current devising of new methods for inhibiting fouling in the reverse osmosis membrane desalination strategy. This is one piece of that puzzle.

Summary of the Implementation/Influence of the Work:

- Cha-Umpong, W., et al., "Effect of oscillating temperature and crystallization on graphene oxide composite pervaporation membrane for inland brine desalination." *Journal of Membrane Science*, 2019. **588**: p. 117210.

  - This study has cited our paper in the introduction as the only study on inorganic fouling on GO coated membranes.

- Matin, A., et al., "Scaling of reverse osmosis membranes used in water desalination: Phenomena, impact, and control; future directions." *Desalination*, 2019. **455**: p. 135-157.

  - This is a review paper on different aspects of scaling on RO membranes. In the "promising future directions" section, under "surface modification" they presented our results. They also said the following: "The above study with graphene oxide was useful in providing unique insights on the physicochemical interactions between the three different components: the RO membrane, the mineral salt that deposits on the surface, and the ions in solution. These insights can be of great value for the design of coatings with resistance to both organic and inorganic foulants. There is a need for further studies

of a similar nature with other antifouling coatings and materials that have shown promise against other fouling types e.g. organic and biofouling. An effective surface modification strategy can only be devised after the development of a mechanistic understanding of the role played by membrane materials in inorganic fouling."

- Tong, T., et al., "Mineral scaling in membrane desalination: Mechanisms, mitigation strategies, and feasibility of scaling-resistant membranes." *Journal of Membrane Science*, 2019. **579**: p. 52-69.

  - This is a review paper on different aspects of scaling on RO membranes. Under describing the importance of surface properties on scaling, they presented our results as one of the few studies on using surface modification on reducing scaling.

SECTION III

ADDITIONAL QUALIFICATIONS

Please indicate any major media coverage you have received related to this research project:

(Note: *Please only include media coverage of your work by nationally or internationally recognizable media sources. Please include only coverage that mentions you by name or that references your published work. If the media coverage does not mention you by name or your published work, please provide the name of the person who can write a letter attesting to your contributions to the research. Fill out the following information for each piece of media coverage. You should also upload or provide a link to the actual article*.)

1. "New advances in cleaning up water pollution on the horizon"

Date Published: October 1, 2016

Author: Scott Brown

Name of Journal/Magazine/Newspaper/Website: *The Guardian*

Circulation/Number of People who Read the Publication: 135,000

Summary of Article's Focus: This article summarizes various new approaches to cleaning up water pollution.

Relevance to Your Original Work: The article cites my 2015 paper from project #1 as one of the new approaches being considered in the industry.

Which of your above projects does this coverage report on? Project #1

Please list and describe any nationally or internationally-recognized prizes or awards for excellence you have received in the field/industry.

(Note: *Please include only nationally or internationally recognized prizes and fill out the following information for each one. Do not include scholarships, student awards, travel grants, or fellowships, as the USCIS is unlikely to find these significant. You should also upload evidence of this information. If the award was given to a sponsoring institution or supervisor, please provide the name of the person who can write a letter attesting to your contributions on the award-winning project.*)

1. Exceptional Work in Environmental Clean-Up

Award Recipient: Me and my co-authors of "Novel Fe3O4/hydroxyapatite/ β-cyclodextrin nanocomposite adsorbent"

Awarding Institution: EPA

Who is Eligible to Compete: Anyone who has published a paper in the last 3 years related to the topic in a peer-reviewed journal.

Number of Competitors/Winners: 3 teams

Selection Criteria: The author or authors of the paper must have completed work that is particularly original and nationally beneficial.

Who are the Judges: Senior members of the EPA

Notable Past Award Winners: Not sure

➢ **Please list and describe any notable memberships or professional organizations to which you have been specifically nominated.**

(Note: *Please fill out the following information for each organization of which you are a nominated member. You should also upload a certificate or letter as evidence of your membership and provide the relevant sections of the organization's bylaws or constitution that discuss the requirements for membership. Examples of eligible memberships include Senior IEEE Fellow or American Physical Society Fellow. Please do not include paid memberships, including student memberships, as the USCIS does not generally consider these significant.*)

1. Water Environment Federation

Level of Membership: Distinguished Member

Requirements for Membership: Evidence of major contributions to the field and nomination by 3 Distinguished Members.

Who Judges Membership Eligibility: Distinguished Members of the organization.

➢ **Please indicate and describe any occasions where you have served as a judge of the work of other experts in the field/industry.**

(Note: *Please fill out the following information for each instance of judging that you have actually completed. Invitations to judge are not sufficient. You should also upload evidence that you actually completed this work, which can include thank you emails. If you are not able to provide thank you emails or similar evidence, we can draft a letter for the organization to sign accordingly*).

- Journal of Drug Delivery Science and Technology – 15
- Journal of Macromolecular Science, Part A: Pure and Applied Chemistry – 5
- Journal of Controlled Release – 1
- Nature Reviews: Drug Discovery - 4

- **Please describe any leadership roles that you have held in prominent organizations in the field/industry.**

  (Note: *Leadership roles include, but are not limited to, editorial board service, guest editor positions, conference session chairs, and technical program committee membership. Please provide as much detail about your roles and responsibilities as you can so that we may discuss the significance and importance of these contributions to your field.)*

1. Editorial Board

Name of Organization: *Journal of Drug Delivery Science and Technology*

Dates of Service: 2015 - Present

Brief Summary of Organization's Prestige/Reputation in Field: From website: "The Journal of Drug Delivery Science and Technology is an international journal devoted to drug delivery and pharmaceutical technology. The journal covers all innovative aspects of all pharmaceutical dosage forms and the most advanced research on controlled release, bioavailability and drug absorption, nanomedicines, gene delivery, tissue engineering, etc. Hot topics, related to manufacturing processes and quality control, are also welcomed."

Brief Summary of Role and Responsibilities: Meet monthly with other editors to discuss newest submissions, news, and new trends in the field. Help decide which papers will be published by personal evaluation and querying authors.

➢ **Please describe any conference presentations and/or conference invitations:**

(Note: *Please provide as much detail as possible about your conference presentations, the conferences where they occurred, and why you were invited to present (based on a published paper, based on your employment, based on your expertise, etc.), if applicable.*

1) 3rd International Conference on Membrane Science and Technology, September 2020

Presentation Topic/Title: Novel Fe3O4/hydroxyapatite/ β-cyclodextrin nanocomposite adsorbents

Reason for Invitation (if applicable): Organizers were impressed with my paper in *Applied Organometallic Chemistry*.

Additional Details: N/A

2) International Congress on Membranes & Membranes Processes 2019, July 2019

Presentation Topic/Title: Heavy Metal Tolerance: The Role of Biodiversity

Reason for Invitation (if applicable): Organizers were impressed with my paper in *Environmental Science & Technology.*

Additional Details: I won a top ten award for my presentation.

➢ **Please provide a complete list of your <u>full-length</u> journal articles, books, chapters, or articles in conference proceedings under the relevant headings below.**

(Note: *Please include the title of article, name of publication, date, credited authors, and any relevant publication information. If this list with the related information is readily available on your resume or curriculum vitae, you may copy and paste this information or note such below*.)

Journal articles:

- O. Tavakoli, M. Khoobi, **A. Bardi**, M.A. Faramarzi, "Application of Novel Magnetic β-cyclodextrin-anhydride Polymer in Dye Removal from Aqueous Solution", *Journal of the Taiwan Institute of Chemical Engineers*, 2015, 80, 452-463

- **A. Bardi**, S. Vahedi, O. Tavakoli, M. Khoobi, M.A. Faramarzi, "Novel Fe3O4/hydroxyapatite/ β-cyclodextrin nanocomposite adsorbent", *Applied Organometallic Chemistry*, 2018, 33, e4634

- IE. Mejias Carpio, **A. Bardi**, DF. Rodrigues, "Relationship of biodiversity with heavy metal tolerance", *Environmental Science & Technology*, 2016, 52 (1), 184-194.

- B. Cao, **A. Bardi**, X. Yi, DF. Rodrigues, Y. Hu, "Gypsum scale formation on reverse osmosis membrane", *Journal of Membrane Science*, 2019, 552, 132-143.

- **Please indicate your annual salary or equivalent remuneration for services:**

$29,000