UMSAEP UM-UWC: Project Report

Mobile Hydrodynamic Cavitation System at UMKC

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Project Summary

The growth of chemically-based industries has led to environmental contamination from persistent pollutants like Persistent Organic Pollutants (POPs) and Per- and Polyfluoroalkyl Substances (PFAS), threatening ecosystems and human health. Current strategies to treat contaminated water suffer from high cost and low portability, among other limitations. This research proposes a portable hydrodynamic cavitation (HC) system for degrading these pollutants and enhancing water treatment and reuse. Aligned with UN SDGs, the project aims to replicate and downscale the University of the Western Cape's UWC cavitation system into a mobile unit at the University of Missouri, Kansas City UMKC. Key milestones include constructing a mobile system with optimisation efforts for possible future application in contaminated water samples. Collaboration between UWC and Missouri promotes innovation in water treatment, with ongoing work focusing on refining the system for real-world applications.

Key milestones include building a mobile unit with an acoustic device for cavitation verification and optimising pollutant breakdown by adjusting orifice sizes and pump capacity. Initial experiments showed these factors significantly influence cavitation, though further improvements are needed for consistent pollutant degradation. The project builds on the existing partnership between UWC Chemistry and UMKC Civil and Mechanical Engineering related to waster resiliency and water treatment technologies and promotes cross-cultural collaboration between the two institutions for developing new advances in water treatment innovation. Ongoing work will refine the system by exploring additional variables such as pressure and pipe diameter, to enhance pollutant degradation in real-world settings.

Background

The collaboration between the University of Missouri and the University of the Western Cape on the development of a hydrodynamic cavitation system (HC) resonates with several global Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs), particularly regarding environmental sustainability and water quality. One of the key global Millennium Development Goals (MDGs) is ensuring environmental sustainability which includes the improvement of access to clean water and sanitation. Hydrodynamic cavitation systems contribute to these efforts by offering a method for the degradation of organic pollutants in water aiming to enhance water quality. Worldwide it is becoming an issue to address pollution, especially in the State of Missouri where industrial and agricultural activities challenge the state of freshwater sources. The project fits into Goal 6: Clean Water and Sanitation of the SDGs, which targets improved water quality by reducing pollutants and minimizing hazardous chemical exposure. The hydrodynamic cavitation system developed in this project is focused on pollutant degradation such as dyes such as Methyl Orange and other organic contaminants. This demonstrates a potential offering of a valuable tool for water treatment in areas suffering from water pollution.

Kansas City in the state of Missouri faces water quality challenges related to stormwater runoff, industrial discharge and agricultural activities. The combined effect adds towards pollution in the Missouri River and other local water bodies. The HC system under the development of the University of Missouri derived from the UWC design and seeks to address water quality issues by breaking down pollutants at a reasonable scale. South Africa is a water-scarce country and technology to improve water quality is always welcoming. This technology can aid in mitigating water pollution by offering an adaptable and mobile solution for the environment and could contribute to cleaner water sources in both rural and urban settings and potentially in larger municipal systems. This forged partnership between the two universities is a testament to the power of cross-cultural academic collaboration, where researchers from different parts of the world come together to address global challenges in water-related challenges and draw on knowledge bases to develop solutions for the future. The project’s focus on sustainability and water quality improvement ties into both local and international challenges for environmental conservation.

Introduction

A mobile cavitation system was constructed at the University of Missouri (Kansas City) based on the University of the Western Cape's (UWC) pilot plant design. The system comprises a pump, reservoir, temperature gauges, and several ball valves to control water flow direction. To enhance the UWC design, an acoustic listening device was incorporated to monitor the audio output for cavitation verification. The UWC system has a 2.2 kW pump capacity, while the mobile unit features a hydraulic head of 25 m but was later upgraded to a 2.5 Hp. Both systems utilise stainless steel piping to maximise corrosion resistance. The mobile cavitation unit has a maximum volume capacity of approximately 10 L, whereas the pilot plant can exceed this volume depending on the experiment objectives. In addition, the reservoir of the mobile unit is fitted with a cooling unit to control the temperature of the water.

Figure 1 Researchers checking the cavitation system for leaks and functionality.

Figure 2 Mounting the system to the platform during the assembly stages.

Optimisation of the system

The methodology of this project spanned several phases, starting with assembly and initial testing in the first three weeks, where ball valves, pressure gauges, and pipes were installed, and the system ran successfully for 6 hours. In week 4, the system underwent dye testing using Methyl Orange, revealing no cavitation and a blockage in the flowmeter, which was later resolved through cleaning. Week 5 focused on learning system fundamentals and demonstrated the siphoning cavitation process without a mechanical pump, although issues arose with cavitation formation due to height restrictions governed by Bernoulli's Equation. In week 6, system errors were corrected and various orifice sizes were fabricated for optimization. During weeks 7 and 8, experiments using different orifice plates (0.5 mm to 8 mm) showed that the 6 mm orifice performed best in generating cavitation-like conditions. However, sustained cavitation necessary for pollutant degradation was not achieved. A new, more powerful pump was introduced in weeks 9-12, significantly increasing system capacity and pressure. Testing with the new pump demonstrated better cavitation conditions, particularly with a sharp-edged 4 mm orifice. Overall, the study showed that orifice size and pump capacity are crucial for optimizing cavitation in pollutant degradation, although further work is needed to refine the system for long-term effectiveness.

Cavitation fundamentals

Figure 3 An attempt to demonstrate syphoning cavitation using the overhead crane, 16 mm pipe and two 25-litre buckets.

The fundamentals for cavitation occur under certain conditions and it was demonstrated at Missouri University in the High Bay Laboratory which is equipped with an overhead crane. Syphoning cavitation occurs under certain boundary conditions and approximately 50 feet of 16 mm diameter pipe and 2 buckets was used to demonstrate this phenomenon. To improve our understanding of this concept, the task at hand was to create a flow of water from one bucket to another without the addition of a mechanical pump. At a certain height, water flow is disrupted, and bubble forming occurs when natural cavitation occurs. However, the syphoning is deterred by the bubble forming at a certain height restriction which is governed by Bernoulli's Equation as follows:

$$P1 + (1/2)\rho v_1^2 + \rho g h_1 = P2 + (1/2)\rho v_2^2 + \rho g h_2$$

Where:
P1, P2: represents different pressures at points 1 and 2 in the system
v1, v2: represents the velocities at points 1 and 2
h_1, h_2: represents the heights at points 1 and 2

Activities in Kansas City, USA

Figure 4 One of several outdoor excursions Mr Denzil Bent had the opportunity to visit the local World War II Museum, accompanied by Professor John Kevern (right) and UMKC PhD candidate Mr. Evral Ntsa (left).

The collaboration between the University of Missouri in Kansas City, USA and UWC in Cape Town, South Africa also highlights cultural exchanges that can contribute to the global academic and environmental community. Kansas City's rich history as a Midwest city in the USA and diverse population gives a strong sense of community making it an ideal location for fostering such international partnerships. The multicultural landscape of Kansas City offers a variety of perspectives and solutions to environmental problems from an engineering perspective to this project. Denzil`s experience of Kansas City`s unique combination of urban innovation and rural agricultural setting offers a daily life in particular sporting codes, art and music.

The outcome of the project

The collaboration between the two institutions successfully merges skills from a multidisciplinary perspective. The development of the mobile cavitation system has progressed through assembly, initial testing, and certain optimisation phases. Challenges related to pump capacity and pressure have been identified and were addressed through system reconfiguration and the production of varying orifice sizes. In addition, leaks and blockages have been addressed to minimize the pumping efficiency.

The adaptation of orifice plates in hydrodynamic cavitation systems is crucial for optimizing cavitation effects. Amongst all experiments, the 6 mm orifice was identified as the most effective size so far that showed the ideal conditions for cavitation. The findings highlight the importance of selecting appropriate orifice dimensions to achieve desired cavitation characteristics to degrade pollutants. Given the limited variables in the system, the edge of the orifice will be explored to facilitate the rapid change in the pressure drop. These findings have given visiting researcher, Denzil a great perspective on the capabilities of the HC system and how can this knowledge further be explored in his research at UWC.

Upcoming activities

The 3 months of research have paved the way forward for a stronger relationship between the two institutions in particular the Department of Chemistry at the University of the Western Cape and the Civil Engineering Department at the University of Missouri, Kansas City. The work conducted at UMKC is ongoing and documented along the way. The prospects of a publication in a peer-reviewed journal are highly likely based on further collaboration.

Additional research could explore the effects of varying initial and downstream pressures, as well as the number of holes to accommodate the surface area of the orifice on the system`s behaviour. The parameters of the system are strong grounds to be investigated along with the UV-VIS analysis of the selected dyes. Verifying that free radicals are being produced such as OH radical and hydrogen peroxide during cavitation utilising various detection methods.

Acknowledgement

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