Submission ID #: 68572
Scriptwriter Name: Pallavi Sharma
Project Page Link: https://review.jove.com/account/file-uploader?src=20914508

Title: Implementation of a Hyperbolic Vortex Plasma Reactor for the Removal of Micropollutants in Water

Authors and Affiliations:
Roman Klymenko[1,2*], Elmar C. Fuchs[1,3], Jakob Woisetschläger[4], Luewton L. F. Agostinho[1,5], Wilfred F. L. M. Hoeben[2]

[1]Wetsus - Centre of Excellence for Sustainable Water Technology
[2]Department of Electrical Engineering, Electrical Energy Systems group, Eindhoven University of Technology
[3]Optical Sciences Group, Faculty of Science and Technology (TNW), University of Twente
[4]Institute for Thermal Turbomachinery and Machine Dynamics, Graz University of Technology
[5]Water Technology Research Group, NHL Stenden University of Applied Sciences, Leeuwarden

Corresponding Authors:
Roman Klymenko (roman.klymenko@wetsus.nl)

Email Addresses for All Authors:

(elmarchristof.fuchs@wetsus.nl)
(luewton.agostinho@hvhl.nl)
(jakob.woisetschlaeger@tugraz.at)
(w.f.l.m.hoeben@tue.nl)
(roman.klymenko@wetsus.nl)

Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **No**

3. Filming location: Will the filming need to take place in multiple locations? **No**

Current Protocol Length
Number of Steps: 15
Number of Shots: 31

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

1.1. **Roman Klymenko:** The focus of our research is to optimize plasma discharge for the degradation of micropollutants in water, which is a growing environmental concern nowadays.

  1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B roll: 2.4*

What are the most recent developments in your field of research?

1.2. **Roman Klymenko:** We discovered that by optimizing the plasma discharge and carefully dosing a cationic surfactant, we can achieve nearly 100% degradation of PFAS—even at high concentrations—using only a moderate energy input.

  1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B roll: Figure 13*

How will your findings advance research in your field?

1.3. **Roman Klymenko:** Plasma treatment is typically an energy-intensive process; however, by applying pulsed plasma, energy consumption can be significantly reduced while improving performance, and in this study, we demonstrate how to achieve this optimization.

  1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Videographer: Obtain headshots for all authors available at the filming location.

Testimonial Questions (OPTIONAL):

Videographer: Please capture all testimonial shots in a wide-angle format with sufficient headspace, as the final videos will be rendered in a 1:1 aspect ratio. Testimonial statements will be presented live by the authors, sharing their spontaneous perspectives.

How do you think publishing with JoVE will enhance the visibility and impact of your research?

1.4. **Roman Klymenko, Postdoctoral researcher**: (authors will present their testimonial statements live)

   1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Can you share a specific success story or benefit you've experienced—or expect to experience—after using or publishing with JoVE? (This could include increased collaborations, citations, funding opportunities, streamlined lab procedures, reduced training time, cost savings in the lab, or improved lab productivity.)

1.5. **Roman Klymenko, Postdoctoral researcher**: (authors will present their testimonial statements live)

   1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Protocol

2. Different Types of Plasma Discharges

Demonstrator: Roman Klymenko

Author's NOTE: We recorded several additional shots — such as alternative angles or zoomed-in views — for specific steps of the protocol. These are marked in the script with notes like "2.3.1.1. Additional shot for 2.3.1." These extra shots are optional and were added to provide the editors with more flexibility during the editing process.

2.1. After setting up the hyperbolic vortex plasma **[1],** use the electrical circuit designed for the direct current arc discharge setup **[2]**. Connect the positive and negative high-voltage outputs from the bridge rectifier to the electrodes positioned above the surface of the water vortex **[3]**.

2.1.1. WIDE: Talent with the hyperbolic vortex plasma set up.

2.1.1.1. Additional shot for 2.1.1.

2.1.2. LAB MEDIA: Figure 3A

2.1.3. Talent connecting positive and negative high-voltage wires from the bridge rectifier to the electrodes above the water vortex. *Videographer: Please film multiple reusable takes to use them later*

2.1.3.1. Additional shot for 2.1.3. (for DC only) This shot cannot be reused in other sections.

2.1.3.2. Additional shot for 2.1.3.(for DC only) This shot cannot be reused in other sections.

2.1.3.3. Additional shot for 2.1.3 (for AC and DC).

2.2. Plug the variac into a 230-volt alternating current power outlet **[1]** and switch off the red safety switch to enable high voltage **[2]**. Using the variac, gradually increase the voltage from 0 to 250 volts **[3]** to ignite the plasma discharge **[4]**.

2.2.1. Talent plugging the variac into a 230-volt power outlet.

2.2.2. Talent switching off the red safety switch.

2.2.3. Talent turning the dial on the variac to increase the voltage and initiate plasma discharge. *Videographer: Please film multiple reusable takes to use them later*

2.2.3.1. Additional shot for 2.2.3.

2.2.4. Shot of the DC plasma discharge

2.2.4.1. Additional shot for 2.2.4.

2.2.4.2. Additional shot for 2.2.4.

2.2.4.3. Additional shot for 2.2.4.

2.3. Next, use the electrical circuit configured for alternating current arc discharge **[1]**. Then, connect both high-voltage outputs to the electrodes located above the surface of the water vortex **[2]**.

2.3.1. LAB MEDIA: Figure 3B.

2.3.2. *Reuse 2.1.3* NOTE: Only shots 2.1.3. and 2.1.3.3. CAN be reused.

2.4. After connecting the variac and disengaging the safety switch as shown earlier, gradually increase the voltage from 0 volts to 250 volts **[1]** to ignite the plasma discharge **[2]**.

2.4.1. *Reuse 2.2.3*

2.4.2. Shot of the AC plasma discharge.

2.5. Next, to perform a glow discharge in a helium atmosphere, use the electrical circuit shown here **[1]**. Connect the high-voltage outputs of the electrical circuit to the electrodes positioned above the surface of the water vortex **[2]**.

2.5.1. LAB MEDIA: Figure 4

2.5.2. *Reuse 2.1.3* NOTE: DON'T reuse 2.1.3. Use shot 2.5.2. that was filmed separately.

2.6. Once the variac is connected and the safety switch is disengaged, open the gas valve to introduce helium at the desired flow rate **[1]**.

2.6.1. Talent rotating a gas valve to release helium into the discharge chamber.

2.7. Then, using the variac, slowly increase the voltage to ignite the plasma discharge **[1]** until electrical breakdown occurs between the electrodes and the plasma shifts from glow discharge to arc discharge **[2]**.

2.7.1. Close-up of the talent turning the variac dial.

2.7.2. Shot of the moment when glow discharge forms and transitions into arc discharge.

2.7.2.1. Additional shot for 2.7.2.

2.7.2.2. Additional shot for 2.7.2.

2.8. Next, to initiate the bipolar flashover pulsed discharge, use the electrical circuit as shown in the schematic **[1]**.

2.8.1. LAB MEDIA: Figure 4.

2.9. Connect the high-voltage outputs to the electrodes, variac to a 230-volt alternating current power outlet, and disengage the safety switch **[1]**. Then, gradually increase the voltage from 0 to 250 volts **[2]** to ignite the plasma discharge **[3]**.

2.9.1. ~~Shot of the connected electrical circuit~~ NOTE: Reuse 2.5.2

2.9.2. *Reuse 2.2.3*

2.9.3. Shot of the flashover plasma discharge. NOTE: Use 2.9.3_restored.MOV. File is added in the folder

2.10. For monopolar pulsed streamer discharges, use the circuit shown in the schematic for positive or negative discharge as needed **[1]**.

2.10.1. LAB MEDIA: Figures 5 and 6

2.11. Connect the opposite terminal to a visible spark gap **[1]** and ground electrode **[2].** Attach the rest of the high voltage outputs to the electrodes situated above the water vortex surface **[3]**. NOTE: The VO is edited for the moved and additional shots

2.11.2. Talent attaching one terminal to a visible spark gap.

2.11.3. Added shot: Talent attaching corresponding high voltage channel output to a grounded electrode.

2.11.1 ~~*Reuse 2.1.3*~~ Talent attaching the rest of the high voltage outputs to the electrodes. NOTE: 2.11.1 is moved after 2.11.3, Do not use 2.1.3; instead use the shot filmed as 2.11.1

2.12. Then, open the gas valve and adjust the compressed air flow to 0.5 to 1 atmosphere to purge the spark gap **[1-TXT]**.

2.12.1. Talent opening the gas valve and fine-tuning the flow meter while monitoring the spark gap setup. **TXT: Ensure a stable internal atmosphere and consistent temperature** NOTE: This shot is filmed in two takes, 2.12.1 talent opening the gas valve and 2.12.1.2 Talent tuning the flow meter

2.13. After connecting the variac and engaging the safety switch **[1],** ignite the plasma discharge as shown earlier **[2]**.

2.13.1. ~~Close-up of the variac dial being turned slowly.~~ NOTE: This short is not filmed. Reuse 2.2.3.

2.13.2. Shot of the positive plasma discharge

2.13.2.2. Aditional shot for 2.13.2.

2.14. To terminate the experiment, reduce the variac voltage **[1]**, switch off the power supply **[2]**, and engage the safety switch **[3-TXT]**.

2.14.1. Talent rotating the variac dial back to 0 volts.

2.14.2. Talent powering off the main switch on the electrical circuit.

2.14.3. Talent flipping the red safety switch back to the engaged position. **TXT: If used, stop the dosing pump for the cationic surfactant**

2.15. Then, close all gas valves for helium and compressed air if they were used during the experiment **[1]**. Using a grounding stick, touch all metallic components to verify that they are properly grounded **[2]**.

2.15.1. Talent manually turning off both the helium and compressed air valves.

2.15.2. Talent systematically touching exposed metal parts of the setup with a grounding stick.

Results

3. Results

3.1. Among the three discharges, flashover generated the highest concentrations of hydrogen peroxide at approximately 450 milligrams per liter **[1]**, nitrite at around 90 milligrams per liter **[2]**, and nitrate at about 340 milligrams per liter **[3]**.

3.1.1. LAB MEDIA: Figure 10 top left panel. *Video editor: Highlight the tallest blue-striped bar under "Flashover" labeled H_2O_2.*

3.1.2. LAB MEDIA: Figure 10 top left panel. *Video editor: Highlight the orange-striped bar under "Flashover" labeled NO_2^-.*

3.1.3. LAB MEDIA: Figure 10 top left panel. *Video editor: Highlight the green-striped bar under "Flashover" labeled NO_3^-.*

3.2. The flashover discharge caused the most pronounced drop in pH *(P-H)*, reducing it from approximately 5.5 to 2.3 **[1]**. Electrical conductivity was highest in the flashover-treated samples, reaching about 2300 microsiemens per centimeter **[2]**. Oxidation-reduction potential increased most significantly in the flashover discharge, reaching approximately 600 millivolts **[3]**.

3.2.1. LAB MEDIA: Figure 10, top right panel. *Video editor: Highlight the gray bar labeled "Influent" and the purple-striped bar labeled "Flashover" to show the drop.*

3.2.2. LAB MEDIA: Figure 10 bottom left panel. *Video editor: Highlight the tallest purple-striped bar under "Flashover".*

3.2.3. LAB MEDIA: Figure 10 bottom right panel. *Video editor: Highlight the tallest purple-striped bar under "Flashover".*

3.3. Flashover discharge achieved the fastest and most complete PFOS *(P-F-O-S)* degradation for both initial concentrations, reaching nearly 100% conversion by 60 minutes **[1]**, outperforming the positive **[2]** and negative discharges **[3]**.

3.3.1. LAB MEDIA: Figure 11. *Video editor: Highlight the purple line labeled "Flashover" at the 60-minute mark in both graphs.*

3.3.2. LAB MEDIA: Figure 11. *Video editor: Highlight the red dashed line labeled "Positive" at the 60-minute mark in both graphs.*

3.3.3. LAB MEDIA: Figure 11. *Video editor: Highlight the blue dashed line labeled "Negative" at the 60-minute mark in both the graphs.*

3.4. In the PFAS *(P-F-A-S)* matrix without surfactant, long-chain compounds like PFDA *(P-F-D-A)*, PFNA *(P-F-N-A)*, and PFOS exhibited degradation above 90% after 75 minutes **[1]**. In contrast, short-chain species such as PFBA *(P-F-B-A)* remained largely undegraded or increased in concentration due to byproduct formation **[2]**.

3.4.1. LAB MEDIA: Figure 12A. *Video editor: Highlight the purple bars for PFDA, PFNA, and PFOS.*

3.4.2. LAB MEDIA: Figure 12 A and B. *Video editor: Highlight the PFBA bars and the rising green and blue lines for PFHxA and PFPeA.*

3.5. With surfactant addition, all long-chain PFAS compounds were degraded above 95% **[1]**, and degradation of short-chain compounds like PFBA improved from minus 19% to approximately 53% **[2]**, and PFBS from 22% to about 95% **[3]**.

3.5.1. LAB MEDIA: Figure 13A.

3.5.2. LAB MEDIA: Figure 13A. *Video editor: Highlight the bars under PFBA.*

3.5.3. LAB MEDIA: Figure 13A. *Video editor: Highlight the bars under PFBS*.

3.6. The concentration of PFHxA *(P-F-H-X-A)* started decreasing after 20 minutes **[1]**, and PFPeA *(P-F-P-E-A)* dropped after 30 minutes of treatment with surfactant dosing, indicating progressive breakdown of PFAS byproducts **[2].**

3.6.1. LAB MEDIA: Figure 13B. *Video editor: Highlight the green line for PFHxA after 20 minutes and show its decline*.

3.6.2. LAB MEDIA: Figure 13B. *Video editor: Highlight the blue line for PFPeA after 30 minutes and show its decline.*

1. hyperbolic
Pronunciation link (Merriam-Webster):
https://www.merriam-webster.com/dictionary/hyperbolic [Merriam-Webster]
IPA: /ˌhaɪpərˈbɑlɪk/
Phonetic spelling: hy-per-BAHL-ik

---

2. vortex
Pronunciation link (Cambridge Dictionary):
https://dictionary.cambridge.org/dictionary/english/vortex [Cambridge Dictionary]
IPA (US): /ˈvɔrˌtɛks/
Phonetic spelling: VOR-teks

---

3. plasma
Pronunciation link (Britannica/Wikipedia audio): https://www.britannica.com/science/plasma-state-of-matter (**click speaker icon**) Encyclopedia Britannica

IPA: /ˈplæz·mə/
Phonetic spelling: PLAZ-muh

---

4. variac
No dedicated pronunciation entry on Cambridge or Merriam-Webster, but the term appears in technical sources.
Pronunciation link: No confirmed link found
IPA (standard American): /ˈvɛəriˌæk/
Phonetic spelling: VAIR-ee-ak

---

5. arc discharge
No single dictionary entry for the phrase, while "arc" and "discharge" are conventional words.
Pronunciation link for arc (dictionary.com): No specific link found for "arc discharge"
IPA: /ɑrk dɪsˈtʃɑrdʒ/
Phonetic spelling: ark diss-CHARDJ

---

6. streamer discharge
No dedicated pronunciation entry, but based on standard terms.
Pronunciation link: No confirmed link found
IPA: /ˈstri·mər dɪsˈtʃɑrdʒ/
Phonetic spelling: STREE-mer diss-CHARDJ

---

7. monopolar
Pronunciation link (HowToPronounce.com): https://www.howtopronounce.com/monopolar Word Panda+6Word Panda+6Cambridge Dictionary+6media.iupac.org+7abcpcb.com+7ScienceDirect+7
IPA: /ˌmoʊnəˈpoʊlər/
Phonetic spelling: MOH-nuh-POH-ler

---

8. bipolar (as in bipolar flashover pulsed discharge)
Pronunciation link (Cambridge Dictionary):
https://dictionary.cambridge.org/pronunciation/english/bipolar Cambridge Dictionary
IPA: /ˌbaɪˈpoʊlər/
Phonetic spelling: BY-POH-ler