Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-318

Proposal Title: Efficient Filter and Sensor for Organic PAH Compounds

Project Manager Information

Name: Terrence Simon

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: We propose to develop a filter with an integrated sensor to remove airborne polycyclic aromatic hydrocarbons (PAHs). The filter advantages include low cost, high efficiency and real-time monitoring.

Funds Requested: $275,000

Proposed Project Completion: 2024-06-30

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Region(s): Metro

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Polycyclic Aromatic Hydrocarbons (PAHs) are a class of several hundred individual compounds composed of two or more fused aromatic rings. Unsubstituted PAHs are formed mainly by the incomplete combustion of organic materials. It has been proven that PAHs can cause carcinogenic and mutagenic diseases and are potent immune suppressants. They are the key components of 189 Hazardous Air Pollutants (HAPs) in the United States. PAHs are highly lipid-soluble and can be absorbed in the lungs, gut and skin of a human being. Once absorbed, the PAH mutagenic and carcinogenic biotransformation can lead to human fatality. Every year tons of PAHs are released in exhaust streams as pollutants from combustion in vehicles and industrial burners. There is no commercial filter that can efficiently remove PAHs, because of their very small size. Traditional airborne PAH detection techniques, such as gas chromatography-mass spectrometry (GC-MS) or high-performance liquid chromatography(HPLC), are laborious, relatively expensive and time-consuming. They require laborious pretreatment of the samples in order to increase the sensitivity and selectivity of the PAH analysis. As a result, the required time for testing is prohibitively long, such as several hours to a day.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

Proposed is a new waste treatment filter that decomposes PAHs from the sources integrated with a PAH sensor for real-time measurements. The PAH filter is formed by carbon nanotubes and a titanium dioxide composite fabricated using advanced manufacturing. It combines ultraviolet radiation to decompose PAHs, making the collected dust and discharge gases clean and safe. Titanium dioxide is a semiconductor with a desirable photocatalytic property when under ultraviolet light irradiation. Carbon nanotubes have enormous area/volume to support the reaction of catalyst, TiO_2, with PAH. The proposed PAH sensor is based on a Photoelectric Aerosol Sensor (PAS) concept. Compounds of PAH containing more than three aromatic rings are generally associated with Particulate Matter (PM) emission. The sensor employs UV light radiation to ionize PM-bound PAHs. Only PM, with PAH, adsorbed on the surface is ionized because of the PAH's low ionization potential. The charged particles are collected by the filter and are immediately converted into electrical current by a build-in electrometer. The sensor is located at the outlet of the filter to monitor PAH concentration. This technique for disintegrating, then sensing PAHs has following advantages: it is cheap, efficient and provides real-time monitoring.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

Success on PAHs remediation has been slow due to the numerous difficulties associated with decomposition. The proposed PAH reactor will address and overcome those difficulties and pave the way for a new technique for PAH remediation. Advanced manufacturing techniques at the University of Minnesota allow development of a suitable instrument for reliable and efficient PAH remediation at a very low cost. In addition, the PAH reactor with an integrated sensor can be assembled within a vehicle exhaust system or chimney to eliminate PAH contamination at its source thus providing valuable atmospheric cleanup in Minnesota and the nation.

Activities and Milestones

Activity 1: Development of a highly efficient filter and integrated sensor for removal and monitoring hazardous organic PAH compounds

Activity Budget: $137,000

Activity Description:
The objective of this activity is to develop a highly efficient filter which uses carbon nanotubes integrated with titanium dioxide, and to integrate it with a PAH pollutant sensor for real-time measurement. The integrated system is to be very cheap, efficient and reliable. The PAH filters are to be designed and fabricated to remove PAH material in airborne dust and gases. The shell of the reactor is transparent to allow ambient ultraviolet light radiation to pass. The reactor will reduce the concentration of PAHs to 10% of their original values. The cost is to be one-fifth of automobile exhaust catalytic converter cost or of chimney filter cost. The PAH sensors are to be designed, fabricated and integrated onto the outlet of the filters for detecting in real time PAH concentration of the gas being treated. Sensing is achieved by measuring the electrical current induced by ionized particles containing PAH, allowing real-time monitoring of the content of PAH bound in the particulate matter. The integrated sensor is to monitor the filter performance and indicate rise of such pollution in the ambient air.

Activity Milestones:

Description	Completion Date
Nanocomposite filter and PAH sensor modeling and simulation, with hardware development are conducted.	2021-11-30
Testing of decomposition efficiency and sensing performance to compare with conventional methods are conducted in the lab.	2022-04-30
Integration and improvement of the filter and sensor proceeds with continued development of the design, fabrication and testing methods.	2022-08-31
Comprehensive assessment of possible new techniques is conducted.	2022-12-31

Activity 2: Field tests of production filter and sensor assemblies in application settings such as chimneys and vehicle exhaust pipes

Activity Budget: $138,000

Activity Description:
Standard-size filters with integrated sensors are evaluated in chimneys and vehicle tailpipes. A test site will be set up for performance demonstration of the reactor (filter) and sensor assemblies. Field tests include simulating a chimney and applying to a vehicle tailpipe for field testing the efficiency of the filter and the accuracy of the sensor. Upon project completion, the performance will be demonstrated to the stakeholders and LCCMR committee members and officials.

Activity Milestones:

Description	Completion Date
Standard-size air filters with integrated sensors are designed and developed	2023-05-31
Test sites with chimneys and automobile tailpipes are set up.	2023-10-31
In-field tests of decomposition efficiency and sensing accuracy are conducted.	2024-03-31
Test data are published.	2024-06-30

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Tianhong Cui	University of Minnesota Mechanical Engineering Department	Co-Investigator and Researcher	Yes
Terrence W. Simon	University of Minnesota Mechanical Engineering Department	Principal Investigator and Research Coordinator	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this be funded?

This work will demonstrate an inexpensive, high-performance technique for treatment and monitoring of exhaust air pollutants from Minnesota chimneys and vehicles. The knowledge gained will provide a solid foundation for proposing further research and development leading to implementation. The Center for Disease Control notes that PAHs are produced when coal, oil, gasoline, wood, garbage and tobacco are burned, and in cooking under high temperature. The Minnesota Pollution Control Agency, the U.S. Environmental Protection Agency and like agencies would support bringing this technology to market. We plan to file patents on the filter and sensor technology.

Project Manager and Organization Qualifications

Project Manager Name: Terrence Simon

Job Title: Professor

Provide description of the project manager's qualifications to manage the proposed project.

Terrence W. Simon is the Ernst G. Eckert Professor of the Department of Mechanical. His major research interests include experiments, computation and visualization of heat, mass and momentum transfer in laminar, turbulent, transitional and unsteady flows, including flows through porous media and processes with phase change. Applications range from flow and heat transfer in plasma cutting tools and plasma flow actuators, electronics and optics, Stirling and gas turbine engines and MW-level grid energy storage systems. He is an active member of the American Society of Mechanical Engineers (including a past five-year term as the Senior Technical Editor of the Journal of Heat Transfer), the International Centre for Heat and Mass Transfer (in which he is now the President and has served on the Executive Committee), and the American Society of Thermal and Fluids Engineers (for which he co-chaired the International Workshop on Heat Transfer in 2017). Professor Simon has worked with his co-investigator, Professor Tianhong Cui for the last ten years on various projects of common interest. The first was a Micromechanical-Driven device for active enhancement of electronics cooling. This was a five-year project that successfully met the strict DARPA goals for enhanced heat transfer performance. Since, the Simon/Cui team has investigated the heat and mass transfer characteristics of a chemical vapor deposition cell for fabrication of the next generation solar cell using the material perovskite. The new fabrication method with perovskite promises to meet or surpass the performance of silicon cells but with a more carefully-controlled fabrication environment conducted at a lower temperature than with silicon. The low temperature allows using a polymer substrate which, in turn, allows fabrication of bendable and lower cost cells.

Another joint activity of the Simon/Cui team has been in hot embossing of polymers allowing fabrication with rigid control of tolerances.

Organization: U of MN - College of Science and Engineering

Organization Description:
University of Minnesota
College of Science and Technology
Department of Mechanical Engineering
Thermodynamics and Heat Transfer research group (Simon) and Sensing and Controls research group (Cui)

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Terrence W. Simon		Principal Investigator			36.5%	0.06		$27,250
Tianhong Cui		Co-Investigator and Researcher			36.5%	0.06		$24,952
Research Assistant		Researcher			76%	1.5		$156,021
							Sub Total	**$208,223**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Gases, metals, combustors for testing, fans, ducts, fasteners, pollution measure lab use fee and machine shop. Use of the characterization facility and MN Nano Center for fabricating the filters	To build the device and verify its performance					$51,777
							Sub Total	**$51,777**
Capital Expenditures								
		Testing Facility, Fabricated in-house	For evaluation of techniques					$12,000
							Sub Total	**$12,000**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	To visit potential users to introduce the filter and to gain feedback	To have a developed product that can be accepted and used					$3,000

							Sub Total	**$3,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$275,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
In-Kind	University of Minnesota indirect cost	In general support of the proposed work	Secured	$124,146
			State Sub Total	**$124,146**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$124,146**

Attachments

Required Attachments

Visual Component

File: 175bce4f-663.pdf

Alternate Text for Visual Component

The visual shows the reactor and sensor (instrument) in its microfabrication state, then assembled with a fan and duct. It also shows it in place within a truck or car exhaust pipe of at a factory stack. Shown are some of the filter geometries.

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

- Patent, Copyright, or Royalty Potential

Does your project include research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

PI/PD: Terrence Simon, University of Minnesota

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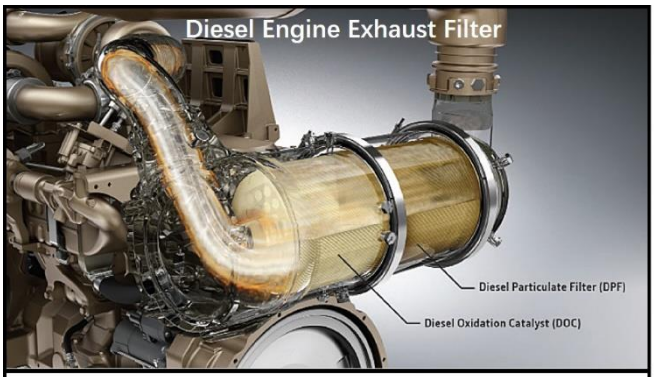
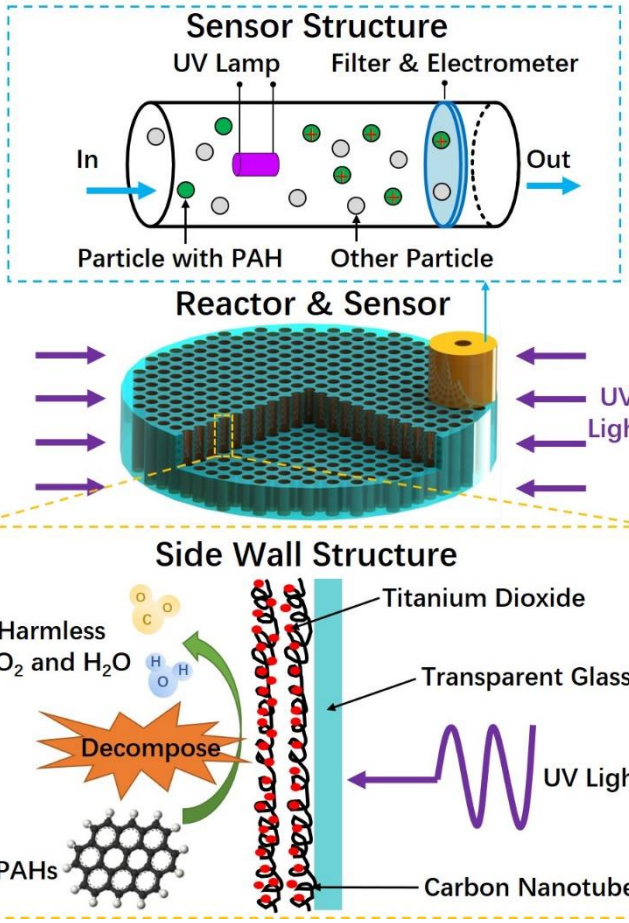


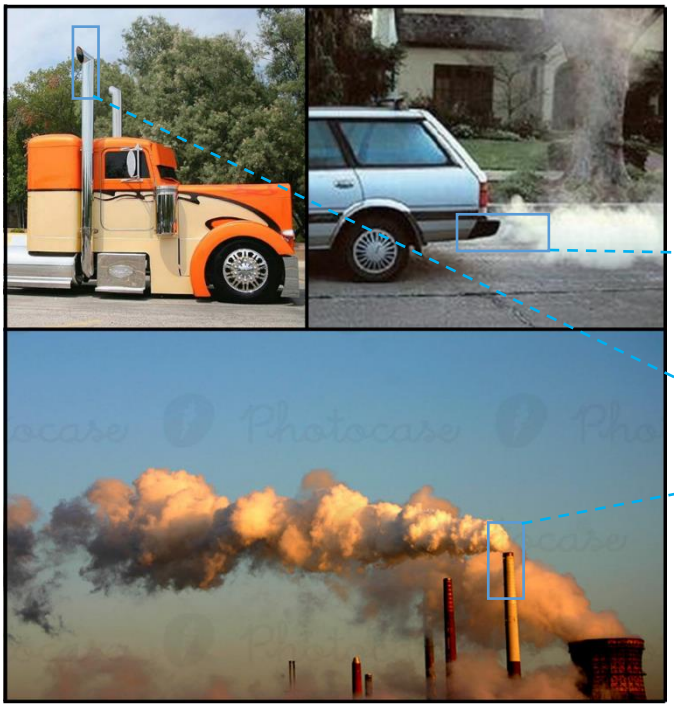
Current Technology

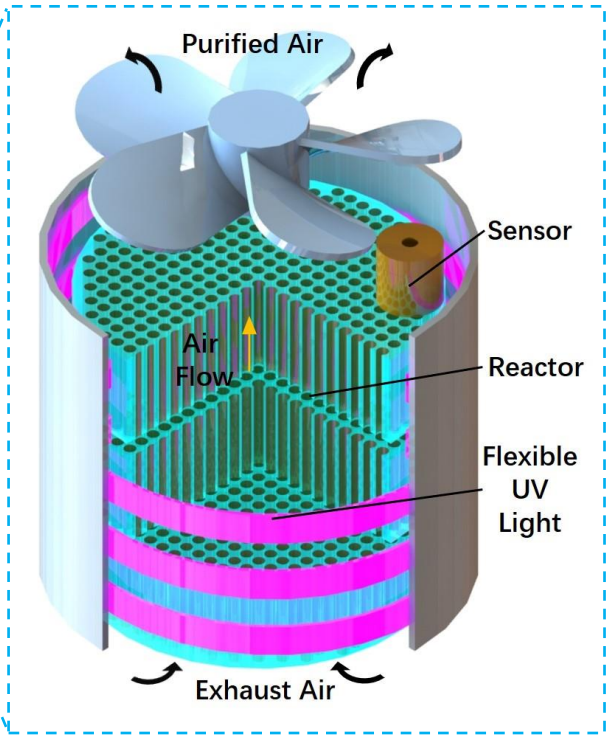
New Technology Proposed

★Low Cost ★High Efficiency

★Real-time Monitoring







Reactor Applications to Decompose Toxic Organic Compounds from

Diesel Trucks, Old Cars and Chimneys of Wood Burners