A. COVER PAGE

Project Title: A Novel Approach of Quantifying Real-Time Aerosol Concentrations from Gravimetric Filter Collection	
Grant Number: 5K01OH011598-03	**Project/Grant Period:** 09/01/2019 - 08/31/2022
Reporting Period: 09/01/2021 - 08/31/2022	**Requested Budget Period:** 09/01/2021 - 08/31/2022
Report Term Frequency: Final	**Date Submitted:** 12/14/2023
Program Director/Principal Investigator Information: CHRISTIAN LORANGE , PHD **Phone Number:** 7208102215 **Email:** christian.lorange@colostate.edu	**Recipient Organization:** COLORADO STATE UNIVERSITY COLORADO STATE UNIVERSITY-FORT COLLINS 2002 Campus Delivery - Sponsored Programs FORT COLLINS, CO 805232002 **DUNS:** 785979618 **UEI:** LT9CXX8L19G1 **EIN:** 1846000545A1 **RECIPIENT ID:**
Change of Contact PD/PI: NA	
Administrative Official: WILLIAM W MOSELEY 600 S. Howes Street Colorado State University Fort Collins, CO 805232002 **Phone number:** 970-491-1541 **Email:** bill.moseley@colostate.edu	**Signing Official:** WILLIAM W MOSELEY 600 S. Howes Street Colorado State University Fort Collins, CO 805232002 **Phone number:** 970-491-1541 **Email:** bill.moseley@colostate.edu
Human Subjects: NA	**Vertebrate Animals:** NA
hESC: No	**Inventions/Patents:** Yes **If yes, previously reported:** No

B. ACCOMPLISHMENTS

B.1 WHAT ARE THE MAJOR GOALS OF THE PROJECT?

Aim 1: Develop a low-cost method for quantifying time-resolved aerosol concentrations based on filter pressure drop simultaneously with a time-integrated gravimetric measurement. Rapid prototyping techniques will be used to construct a new device for quantifying time-resolved aerosol concentrations based upon continuous monitoring of filter pressure drop. The Concentration via Pressure (CVP) device will incorporate a high-precision, low-cost differential pressure sensors. The CVP will be designed to interface with standard 37-mm cassettes (and similar size-selective personal samplers). The CVP device will be tested in the laboratory. Design considerations will include battery life, size and weight, operating range, and cost.

Aim 2: Develop a semi-empirical model that relates changes in filter pressure drop to filter media characteristics, aerosol properties, and environmental conditions. Factors such as flow rate, filter media, aerosol physical properties, and environmental conditions will be included. The model will take the form of a linear model and will leverage the simultaneously collected gravimetric filter as an in-situ calibration point. The device and model will be evaluated through laboratory testing. Performance data will include measures of accuracy, precision, limit of detection.

Aim 3: Evaluate both the model and the concentration via pressure device through field experiments. The CVP device will be deployed to three field sites: a dairy, a manufacturing facility, and an office space. The sites were selected to cover a range of aerosol types and concentrations. Area monitoring will be used to compare the prototype and reference samplers.

Impact: The technology developed here will provide health and safety researchers and practitioners with a valuable tool for quantifying and mitigating workplace aerosol exposures. The device will provide time-resolved aerosol concentrations while simultaneously collecting the gravimetric filter required for assessing OEL compliance at fraction of the cost of currently available technologies. By designing the CVP to interface with the commonly used 37-mm cassette, the device will be easy to integrate into many current state-of-the art instruments being used for workplace exposure assessment. I anticipate the simplicity and low cost of the CVP will aid in practitioner adoption and widespread usage. As part of a future R01 proposal, the core CVP technology will be adapted to fit with other size-selective inlets and instruments.

B.1.a Have the major goals changed since the initial competing award or previous report?

No

B.2 WHAT WAS ACCOMPLISHED UNDER THESE GOALS?

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B.3 COMPETITIVE REVISIONS/ADMINISTRATIVE SUPPLEMENTS

For this reporting period, is there one or more Revision/Supplement associated with this award for which reporting is required?

No

B.4 WHAT OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT HAS THE PROJECT PROVIDED?

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B.5 HOW HAVE THE RESULTS BEEN DISSEMINATED TO COMMUNITIES OF INTEREST?

NOTHING TO REPORT
B.6 WHAT DO YOU PLAN TO DO DURING THE NEXT REPORTING PERIOD TO ACCOMPLISH THE GOALS? Not Applicable

A. Specific Aims

There have been no modifications to the aims.

B. Studies and Results

Aim 1: Physical design and robustness testing of pressure sensing system.

Revisions to the design of the circuit board and housing was done to improve robustness as well as expand the applicability of the design to other uses. The primary alternative use for the design was to allow applying of much of the same component and elements to monitoring flowrate through a filter as opposed to loading onto a filter. This is a deviation to the original intent of the design, but one that we determined likely had substantially more viable usecases for. This pivot was initially considered as a method of determine flowrate, and throughout that leakrate, of air going through filters and filtering masks as part of lessons learned from the COVID19 pandemic.

*Aim 2: D*evelopment of mathematical models relating changes in filter pressure drop to filter loading, aerosol characteristics, and environmental conditions.

The the ability to quantify filter loading based on pressure drop was found to have mixed efficacy. We were able to demonstrate high accuracy in this approach when environmental conditions, such as temperature, humidity, and atmospheric pressure, remained relatively constant. However, when faced with varying environmental conditions, our ability to reliably differentiate between filter loading, changing aerosol type, and evolving environmental factors proved challenging.

Simultaneously, the cost and availability of compact optical particle sensors has significantly increased in recent years. These alternative measurement techniques often demonstrated equal or superior capabilities in determining real-time particle concentration compared to the proposed filter pressure drop approach. However, where the filter pressure drop approach excelled was in determining flowrate and leakage rates through filter media.

Given the maturing landscape of optical particle sensors and the promising results of using pressure to determine leakage, our efforts in the final months of the project shifted towards exploring this alternative application.

<u>Exploration of Alternative Use Case:</u>
Particle filtering masks filtering masks, respirators, and other face coverings can reduce aerosol intake (or emission in the case of infectious particles) and the associated health risks. A mask/respirator must achieve a sufficient level of fit, filtration, and breathability and be worn appropriately to provide adequate protection. Mask leakage, or the fraction of air bypassing the filtering piece, is especially problematic because leakage often depends on individual-level factors such as facial shape, donning procedure, and behavior. Current methods to quantify mask leakage (i.e., “fit testing”) are limited in that they test inhalation leakage only, result in the mask being irreversibly altered, and require expensive equipment and trained technicians. These limitations make fit testing impractical for members of the public and for workers outside of traditional workplace respiratory protection programs, as was often the case during the COVID19 pandemic.

There are two primary approaches for evaluating mask fit: quantitative fit testing and qualitative fit testing. Both approaches rely on exposing an individual to a test aerosol and determining if those particles leak inwards upon inhalation. Quantitative testing utilizes a particle measuring device, such as the Portacount (TSI Portacount 8038, TSI Inc Shoreview, Minnesota), which measures aerosol concentrations immediately upstream and downstream (i.e., inside) the mask. Qualitative fit testing is based upon the wearer’s sense of taste or smell, whereby if the test aerosol is detected inside the mask (by the wearer) then the mask leaks.

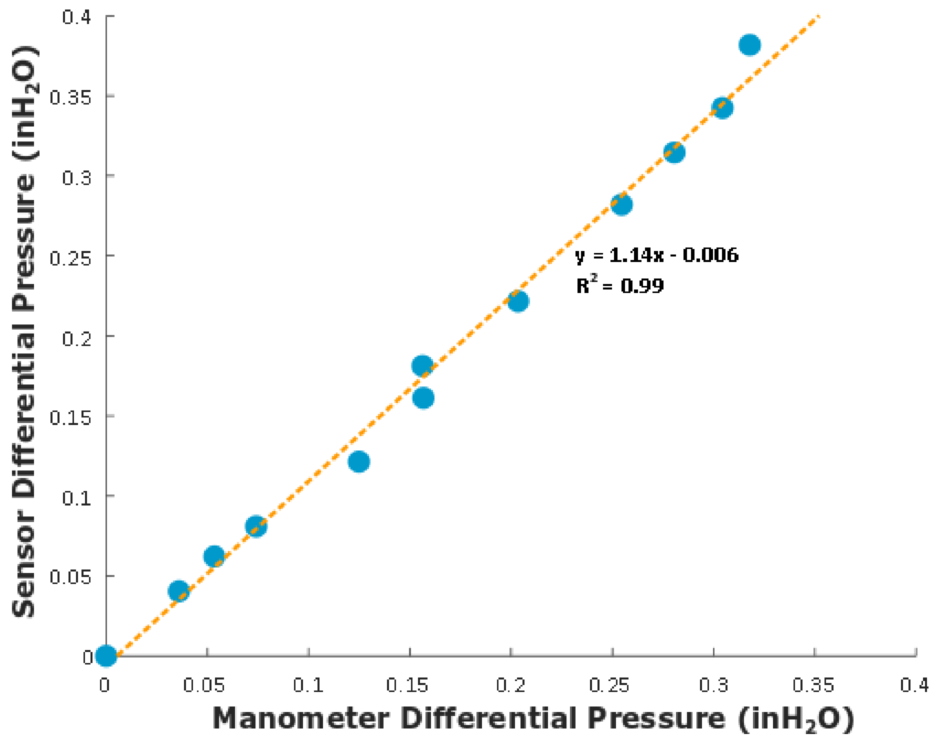
A potentially viable use case for time-resolved pressure measurements is to achieve an inexpensive, nondestructive, and scalable approach for quantifying airflow leakage around the periphery of a mask when worn. The method allows for quantifying leakage during inhalation and exhalation events and leverages the measurement of pressure drop across filter material during controlled inhalation/exhalation maneuvers.

As an individual breathes through a mask they will often notice some resistance. This resistance results in a pressure drop due to drag forces from air flowing past fibers in the mask. The relationship between pressure drop and flow through a material can be described using Darcy's Law (Equation 1), where κ represents the medium's permeability, μ is fluid viscosity, and $\partial P/\partial x$ is the pressure gradient across the material. By assuming the cross-section of a mask does not change and that a mask's material characteristics and the viscosity of the air are approximately constant, Darcy's Law can be rearranged to relate pressure drop to volumetric flow, Q (Equation 2). The constant C is mask-specific and captures factors such as material type, pore size, etc. A is the cross-sectional area of the mask and typically can be assumed to remain constant for a given mask. Darcy's Law can be employed to estimate mask leakage by first characterizing the relationship between flow and pressure drop for a mask.

$$v=\kappa/\mu\ (\partial P/\partial x) \qquad \text{(Equation 1)}$$

$$Q=C/\mu * A * \Delta P \qquad \text{(Equation 2)}$$

Thus, if one's breathing rate is relatively constant (or reproducible), and mask properties are well-known, then a measurement of mask pressure drop will be indicative of mask leakage. We describe three potential approaches below. The efficacy of this new approach was tested for a range of differential pressures. The differential pressure determined from the new approach (ambient minus gauge) was compared to that of a reference-grade liquid manometer (Model 400, Dwyer Instruments, Michigan City, IN). The new approach was found to have good linearity and accuracy as compared to the reference measurement.

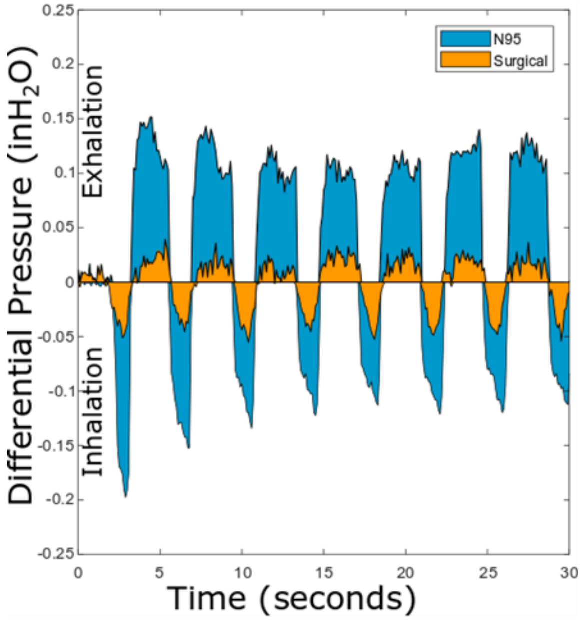


Figur

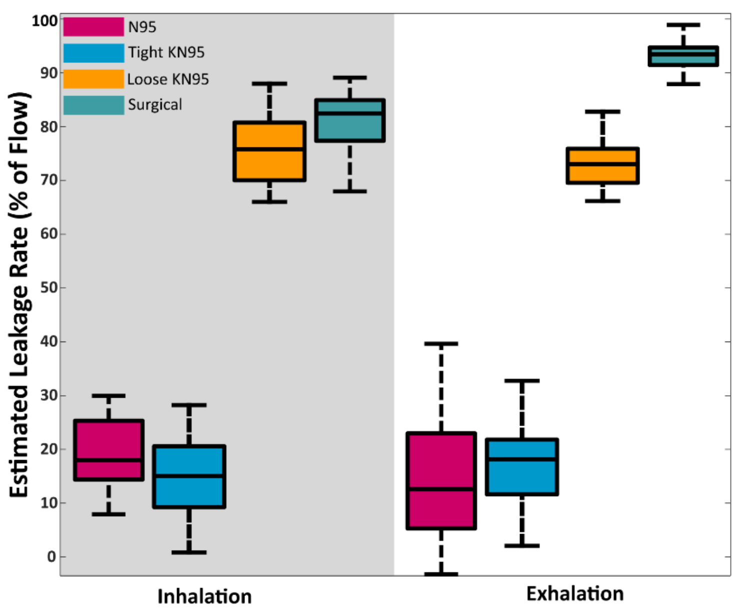
Comparison between the new approach and a reference liquid monometer. The dashed line presented a linear regression between the two method.

Aim 3: Testing of Proposed System

The new approach was tested by comparing mask leakage using convention fit testing and monitoring time resolved changes in pressure. Time-resolved pressure traces were collected by placing the pressure sensor inside the mask while it is being worn. The resulting real-time pressure traces could then be used to determine an estimation of mask leakage rate by assuming a breathing rate and knowledge of the mask being worn. The combination of this information can inform the user of the estimated leakage rate of the mask both during inhalation (a consideration for personal protection) and exhalation (important for understanding community protection).



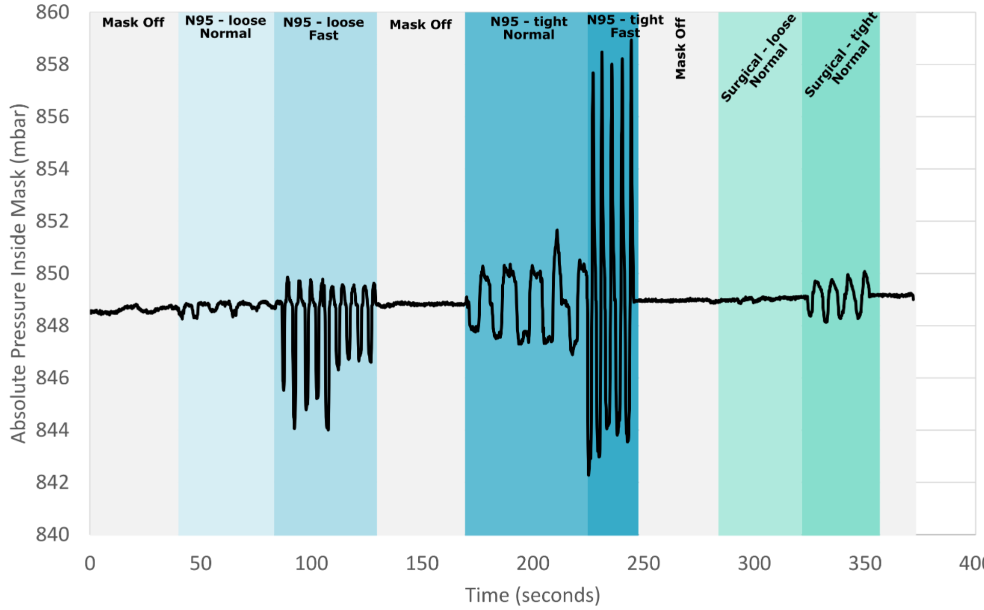
Examples of time-resolved pressure traces that can be collected using the new sensor. Example data for an N95 mask and a poorly fitting surgical mask are included. The pressure traces above were collected while using the electronic metronom to achieve a consistent breathing pattern.



Estimated leakage rates for an N95 mask, a well sealed KN95, and poorly sealed KN95, and a surgical mask using the new analysis technique. The leakage rate estimates were determined by collecting pressure traces for each mask (see Figure 10) and applying knowledge of the pressure drop vs. volumetric flowrate for each mask.

While not initially the primary design focus of the device, this new approach demonstrates potential as an ultra-low-cost method for evaluating mask fit and detecting leakage. Currently, we are conducting further testing and refinement of this new approach, concurrently seeking additional dedicated funds to continue this work.

B.2 (Research Accomplishments close out.pdf)



Example data from the FitCheck sensor when worn in loose and tightly fitting masks

C. Outputs, Outcomes, and Research to Practice (R2P)

Outputs:

Published manuscripts

One publication was published in the last year related to this work (see below). This publication is related to high-throughput methods of analysing filters.

L'Orange, C., Neymark, G., Carter, E., & Volckens, J. (2021). A high-throughput, robotic system for analysis of aerosol sampling filters. Aerosol and Air Quality Research, 21(11), 210037.

In addition to the publications, two patent applications have been submitted the build upon technologies, techniques, or knowledge that came out of the work supported by this grant.

Outcomes:

Nothing new to report.

R2P:

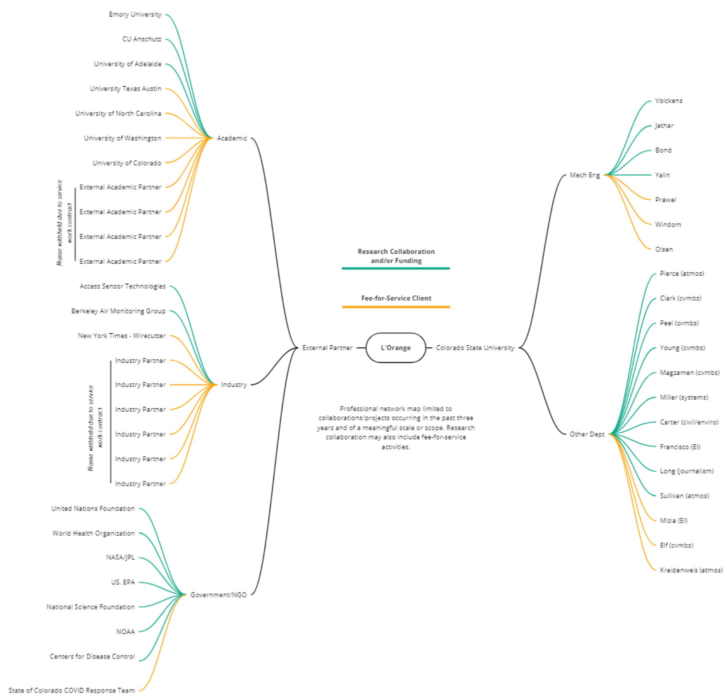
Nothing new to report.

Career Development Progress

My career development efforts to date can be broken into two broad categories: (1) education and (2) professional development. Approximately 5% of my time in the past year has been devoted to education and training. These educational efforts have spanned a number of formats and topics. An extensive component of my training focus in the past year has been sent on building my mentorship skills in preparation for building a successful independent research team. One of the key avenues for this training has been the Colorado State University Center for Inclusive Excellence.

I have been working to increase my professional portfolio and build collaborations both within my department and with external colleagues. I am a member of the Diversity and Inclusion committee. The committee has provided me valuable opportunities to network with my colleagues.

I have actively worked to build my broader professional network over recent months. This network has been built based on a combination of research collaborators and groups who have contracted my group for analysis services. A visual representation of this network is show below.



I have been pursuing avenues of supplemental and future funding. Since receiving my K-Award, I have lead or played a key role in the submission of over 10 grant proposals. To date, we have received >$8 million in support from these grants with over $5 million in funding currently

C. PRODUCTS

C.1 PUBLICATIONS

Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication, monograph) during the reporting period resulting directly from this award?

Yes

Publications Reported for this Reporting Period

Public Access Compliance	Citation
N/A: Not NIH Funded	L'Orange C, Neymark G, Carter E, Volckens J. A high-throughput, robotic system for analysis of aerosol sampling filters. Aerosol and Air Quality Research. 2021;21(11):210037.

C.2 WEBSITE(S) OR OTHER INTERNET SITE(S)

Not Applicable

C.3 TECHNOLOGIES OR TECHNIQUES

Not Applicable

C.4 INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES

Have inventions, patent applications and/or licenses resulted from the award during the reporting period? Yes

If yes, has this information been previously provided to the PHS or to the official responsible for patent matters at the grantee organization? No

C.5 OTHER PRODUCTS AND RESOURCE SHARING

NOTHING TO REPORT

D. PARTICIPANTS

D.1 WHAT INDIVIDUALS HAVE WORKED ON THE PROJECT?

Commons ID	S/K	Name	Degree(s)	Role	Cal	Aca	Sum	Foreign Org	Country	SS
CHRISTIAN.L	Y	L'Orange, Christian	PHD	PD/PI	7.3	0.0	0.0			NA

Glossary of acronyms:
S/K - Senior/Key
Cal - Person Months (Calendar)
Aca - Person Months (Academic)
Sum - Person Months (Summer)
Foreign Org - Foreign Organization Affiliation
SS - Supplement Support
RS - Reentry Supplement
DS - Diversity Supplement
OT - Other
NA - Not Applicable

D.2 PERSONNEL UPDATES

D.2.a Level of Effort

Not Applicable

D.2.b New Senior/Key Personnel

Not Applicable

D.2.c Changes in Other Support

Not Applicable

D.2.d New Other Significant Contributors

Not Applicable

D.2.e Multi-PI (MPI) Leadership Plan

Not Applicable

E. IMPACT

E.1 WHAT IS THE IMPACT ON THE DEVELOPMENT OF HUMAN RESOURCES?

Not Applicable

E.2 WHAT IS THE IMPACT ON PHYSICAL, INSTITUTIONAL, OR INFORMATION RESOURCES THAT FORM INFRASTRUCTURE?

Not Applicable

E.3 WHAT IS THE IMPACT ON TECHNOLOGY TRANSFER?

Not Applicable

E.4 WHAT DOLLAR AMOUNT OF THE AWARD'S BUDGET IS BEING SPENT IN FOREIGN COUNTRY(IES)?

NOTHING TO REPORT

G. SPECIAL REPORTING REQUIREMENTS SPECIAL REPORTING REQUIREMENTS

G.1 SPECIAL NOTICE OF AWARD TERMS AND FUNDING OPPORTUNITIES ANNOUNCEMENT REPORTING REQUIREMENTS

NOTHING TO REPORT

G.2 RESPONSIBLE CONDUCT OF RESEARCH

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G.3 MENTOR'S REPORT[CDA]

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G.4 HUMAN SUBJECTS

G.4.a Does the project involve human subjects?

NA

G.4.b Inclusion Enrollment Data

NOTHING TO REPORT

G.4.c ClinicalTrials.gov

Does this project include one or more applicable clinical trials that must be registered in ClinicalTrials.gov under FDAAA?

G.5 HUMAN SUBJECTS EDUCATION REQUIREMENT

Are there personnel on this project who are newly involved in the design or conduct of human subjects research?

G.6 HUMAN EMBRYONIC STEM CELLS (HESCS)

Does this project involve human embryonic stem cells (only hESC lines listed as approved in the NIH Registry may be used in NIH funded research)?

No

G.7 VERTEBRATE ANIMALS

Does this project involve vertebrate animals?

G.8 PROJECT/PERFORMANCE SITES

Not Applicable

G.9 FOREIGN COMPONENT

No foreign component

G.10 ESTIMATED UNOBLIGATED BALANCE

G.10.a Is it anticipated that an estimated unobligated balance (including prior year carryover) will be greater than 25% of the current year's total approved budget?

G.11 PROGRAM INCOME

Not Applicable

G.12 F&A COSTS

Not Applicable

I completed a CITI Good Clinical Practices course in the last year of the project. I have continued to have discussions with my advisor and mentors related to how human subjects considerations might be involved in my project as well as how I could apply these skills to projects in the future. These discussions occurred to some degree at many of my bi-weekly update meetings and occurred verbally with my advisor and mentor. A specific focus of my personal/career development has been training in diversity and inclusivity and how it might impact my studies. As part of this effort, I have severed on the Mechanical Engineering Department's Diversity, Equity, and Inclusion committee for the past two years.

Colorado State University

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13 December 2023

To Whom It May Concern

This mentor's report documents a summary impression of Dr. Christian L'Orange's career progression and professional development over his K01 award. I am satisfied with Dr. L'Orange's professional progress in recent years. He has successfully transitioned to an independent researcher over the period of performance for his K01 award. Evidence for this independence and growth includes securing of independent funding, participating in research that extends beyond that being done by myself or his other mentors, and his recent promotion to Associate Professor in the Department of Mechanical Engineering at Colorado State University.

Dr. L'Orange's funding has not only enabled him to achieve research independence but has also provided him the opportunity to mentor undergraduate and graduate students – one graduate student will matriculate in Spring 2024 and another in Summer 2024. Since receiving his K-award, he has led or played a major contributing role in submitting more than 10 grant proposals, resulting in awarded amounts exceeding $8 million in support.

The K-Award career development opportunity has allowed Christian to advance both professionally and as a researcher, laying a solid foundation for future success. I am confident in his ability to contribute to the field of occupational and environmental health as independent researcher moving forward.

Sincerely,

John Volckens, PhD
Professor of Mechanical Engineering
Professor of Environmental and Occupational Health
Director, Center for Energy Development and Health

I. OUTCOMES

I.1 What were the outcomes of the award?

Exposure to aerosols is associated with numerous adverse health effects. Current options for measuring real-time aerosol concentrations typically utilize optical methods such as light scattering or light transmittance. The accuracy of optical aerosol measurements depends on the size and optical characteristics of the particles being measured and, although low-cost optical methods are becoming increasingly available, these low-cost devices can have questionable accuracy.
This work sought to establish the potential efficacy of changing filter pressure drop as a proxy measure to determine time-resolved particle loading on a filter. The approach is based on the principle that flow through a filter must overcome the pressure drop from drag forces. Filter pores become clogged as particles are deposited, and air drag increases, increasing pressure drop.

These were some of our main findings:
• We established that low-cost pressure sensors were capable of detecting the minute changes in resistance that occur as a filter begins to load.
• Under ideal conditions, the sensors were capable of detecting loading of only a few micrograms of loading.
• Where the proposed new approach struggled was to compensate for rapidly changing environmental conditions such as temperature, relative humidity, and barometric pressure. In cases of low-concentration air pollution, changes in filter drag were greatly dominated by changes in environmental conditions, leading to unreliable predictions of aerosol concentrations.
• Where the technology was shown to be highly effective was in the determination of real-time changes in flow rate through filter media. This approach has great potential to be used to determine filter leakage rate.