2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation
DOI: https://doi.org/10.13031/aim.201701639
Paper Number: 1701639

Development, validation and application of a mobile air filter testing unit

Benjamin C. Smith[1,2], Graduate Research Assistant, **Brett C. Ramirez[1],** Graduate Research Assistant, **Steven J. Hoff[1],** Professor, **Jay D. Harmon[1],** Professor, **John P. Stinn[2],** ASABE Member

[1]Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA USA

[2]Iowa Select Farms, Iowa Falls, IA USA

Written for presentation at the
2017 ASABE Annual International Meeting
Sponsored by ASABE
Spokane, Washington
July 16-19, 2017

ABSTRACT. The recent shift in commercial swine breeding-gestation-farrowing facilities to incorporate filtered ventilation systems raises numerous questions about system performance and longevity of filters. It has been shown that air filtration with ASHRAE standard MERV 14, 15 and 16 type filters are effective at reducing the aerosol spread of PRRSV and *Mycoplasma hypopneumonia*. The areas that are lacking in current literature is relevant filter testing methodology and criteria for determining filter end of life in an agricultural setting. To address this, a mobile air filter testing unit (MAFT) was developed to address the testing needs for the swine industry to evaluate on-site filter performance. The test duct is capable of measuring pressure drop and airflow for a pre-filter and main V-bank filter combination. The unique feature of this system is the ability to test filters on site and to test the same filter at different points in time. It was shown through validation that MAFT was accurate at measuring the airflow through the filter combinations in comparison to an ASHRAE 52.2 standard lab.

Keywords. disease prevention, positive pressure, swine, ventilation.

Introduction

The swine industry has recently seen a shift towards air filtration technologies on commercial breeding-gestation-farrowing sites. The use of filtration has been well-documented as an effective tool at reducing the aerosol transmission on many common diseases (Alonso, Murtaugh, Dee, & Davies, 2013; Dee, Otake, & Deen, 2010). Two of the most common aerosol transmitted diseases are Porcine Reproductive and Respiratory Syndrome virus (PRRSv) and *Mycoplasma hypopneumonia* (Myco) (Stark, 1999). It has been estimated that PRRSV costs the industry around an average $114.71 per sow per year (Holtkamp et al., 2012). Myco is commonly found as a respiratory issue and can be a factor in chronic respiratory illness during all stages of production (Neumann, Ramirez, & Schwartz, 2009).

The utilization of air filters to prevent aerosol disease transmission has been proven effective in recent literature using MERV rated HVAC type filters (Dee et al., 2010). The common categories seen in literature include MERV 8 pleated pre-filters for stage 1 filters and MERV 14, 15 and 16 pleated v-bank filters as second stage filters (Dee et al., 2010).

Outside of the agricultural industry air filtration is common in many different ventilation systems. Many commercial HVAC systems in the United States use similar filters to the swine industry (Fisk, 2013). Although these systems differ greatly in the equipment used and in the equipment's performance. The typical design value for airflow in an industrial HVAC situation is 0.94 $m^3 s^{-1}$ (2,000 CFM) with a pressure drop of 99.5 Pa (0.40 in. wc). ASHRAE standard 52.2 mandates that for resistance testing the airflow through the filter, typical rated airflow for commonly used filters is 0.94 $m^3 s^{-1}$ (2,000 CFM)(ASHRAE, 2012). This standard poses immense issues for the swine industry to easily relate standard testing results to on-farm performance.

Even with recent breakthroughs in agricultural fan performance technology, common commercial swine farm ventilation systems cannot perform near the level of common HVAC systems for total pressure across the fans, thus creating an issue with the evaluation of filter performance. The objectives of this study were to design a portable test duct specifically designed to measure filter resistance at filter pressure drops typical of the swine industry *in situ*, validate the test duct, and develop the application methods for the results gathered from the duct.

Methods

MAFT's design was based on the ASHRAE 52.2 standard (2012), without the section needed for mixing orifices, particle counters, and particle generators. To further shorten the overall duct length, computational fluid dynamics modeling was used to qualitatively compare different duct lengths between the entry transition and the filter and then the filter and the downstream precision nozzle at 1.22 m, 1.52 m, 1.83 m, and 2.13 m (48, 60, 72 and 84 in.). Based on visual inspection of velocity profiles and turbulence intensity contours, the length of the duct sections were selected. The duct sections for entry transition to filter measured 1.83 m (72 in.) section 1, the filter housing section measured 0.610 m (24 in.) section 2, the section for filter to upstream of precision nozzle measured 1.52 m (60 in.) section 3, and the downstream section from the precision nozzle measured 1.22 m (48 in.) section 4 (fig 1). The duct cross sectional dimensions were 0.610 m by 0.610 m (24 in. by 24 in.) over the entire length.

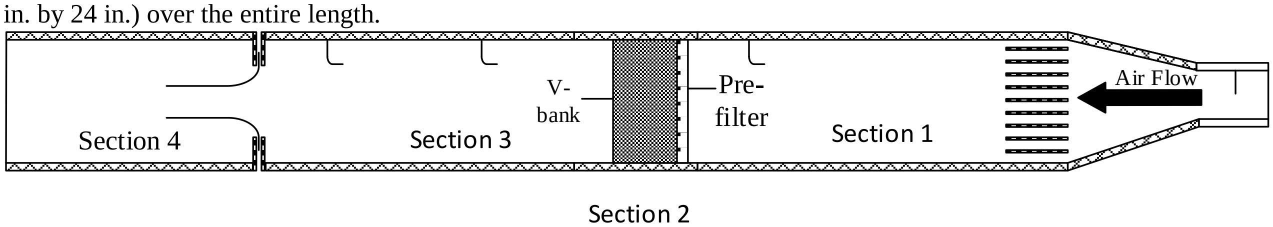

Figure 1. MAFT duct sections as assembled.

MAFT was mounted inside a 7.32 m (24 foot) long enclosed trailer. The intake side of the blower was connected to the trailer with an 0.203 m (8 in.) diameter flex hose to a PVC pipe through the trailer nose with two filter grids located on the inside of the trailer so that the radial blower only pulled air through the filter grids. A 3 hp radial blower and generator was mounted in the back of the truck pulling the trailer. The exhaust side was also attached to the trailer with 0.203 m (8 in.) diameter flexible duct to a PVC pipe to the trailer. The PVC pipe was connected to a custom entry transition from 0.203 m (8in.) diameter pipe to a 0.610 m by 0.610 m (24 in. by 24 in.) duct using a duct boot adapter and clear acrylic. The four duct sections were constructed out of clear acrylic with an angle-iron frame for support. A flow straightener was constructed out of 0.051 m (2 in.) diameter Schedule 80 PVC pipe in the upstream side of the entry duct section. The filter containing section had a stainless steel single filter grid with spring clips installed four inches from the upstream side. A precision nozzle was mounted between the third and fourth duct sections using a custom built sheet metal flange.

For instrumentation, a custom interface was developed in visual basic for applications (VBA) to read temperature and relative humidity (HMP 110, Vaisala) upstream of the entry section in the 8 in. diameter pipe, barometric pressure (Model 276 Setra Inc.) inside the trailer, differential pressure across the filter using three pitot tubes 0.305 m (12 in.) upstream and 0.660 m (26 in.) downstream of the filter (Model 267, Setra Inc.), and differential pressure drop across the precision nozzle with pitot tubs 0.305 m (12 in.) upstream and taps in the nozzle (Model 267, Setra Inc.). A 16-bit data acquisition board (16082AO, Measuring Computing Corporation) was used to read in each sensor input and to control the actuator on the dampener valve that controlled flow through the duct (M9108-GGA, Johnson Controls).

The interface used a PI loop to control the flow through the duct until the pressure drop across the filter reached the set point (0.15 in. wc). The custom code recorded all sensor data at 4 Hz for 15 s at that flow. The average of each input was used to calculate the flow through the duct eq. 1 (equation 38; ASHRAE, 2013). This flow value was then corrected to standard operating conditions, eq. 2, before the calibration equation to reference value was applied.

$$Q' = C_d \times (\pi d^2/4) \times \left(\frac{2\delta p}{\rho(1-\beta^4)}\right)^{1/2} \quad (1)$$

Where

- Q' = predicted air flow, $m^3 s^{-1}$
- C_d = discharge coefficient (0.98)
- d = nozzle diameter, m
- D = duct hydraulic diameter, m
- δp = differential pressure across nozzle, Pa
- ρ = moist air density, kg m^{-3}
- β = d/ D

$$Q_{std} = \frac{Q'}{\left(\frac{P_{std}}{P - Pws \times Rh} \times \frac{T}{T_{std}}\right)} \quad (2)$$

Where,

- Q_{std} = corrected air flow to standard conditions, $m^3 s^{-1}$
- P_{std} = Standard barometric pressure (101325 Pa)
- P = actual barometric pressure, Pa
- Pws = saturation water vapor partial pressure, Pa
- Rh = relative humidity of actual conditions. %
- T = actual dry-bulb temperature, K
- T_{std} = standard dry bulb temperature conditions (294.25 K)

Before validation testing was started with MAFT, the entire duct section with precision nozzle was calibrated against BESS Labs (University of Illinois Urbana Champaign). Duct sections 2, 3, and 4 were taken for the calibration of the nozzle in the duct. A filter combination was also taken to create experimental flow conditions for the calibration. A total of 16 flows were recorded and used to create a calibration curve.

To validate MAFT, 34 filter combinations were tested in MAFT and then shipped to an ASHRAE 52.2 standard lab. For each testing, the pressure drop across the filters was set to 0.15 in. wc. The v-bank and pre-filters tested were of varying age on farms and varying flows rates.

Results

A unique calibration curve was created for MAFT based on the results of calibration at BESS Labs. The calibration curve resulted in an R^2 value exceeding 0.99 and when comparing the slope to unity it was found to be significantly different ($p = 0.0021$). The validation testing resulting in a 4% difference from the ASHRAE 52.2 standard lab with no trend on the differences noted across the wide range of flows measured, fig 2.

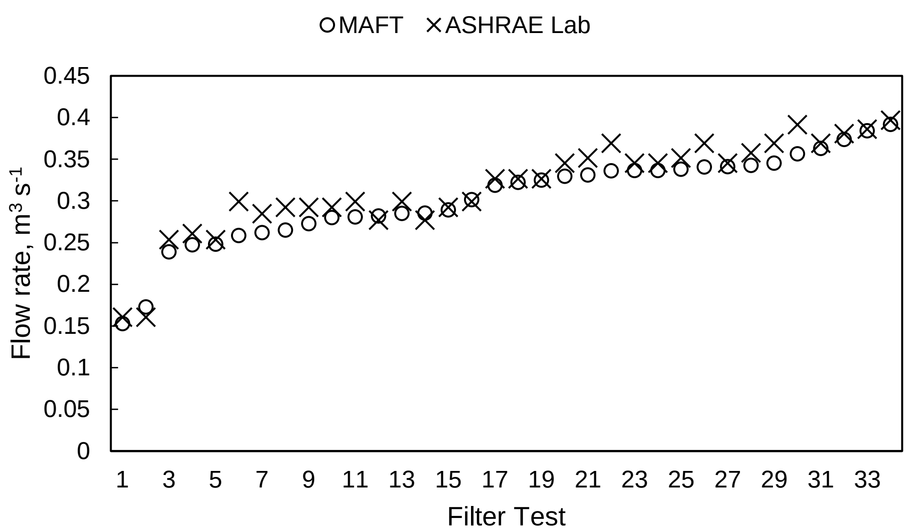

Figure 2. MAFT flowrates and ASHRAE 52.2 certified lab flowrates for validation filter tests.

Application

The driving factor for constructing and building MAFT was to reduce the total cost of testing filters for producers. MAFT is able to travel to a site and test multiple filter combinations at a given time. MAFT has tested used pre-filters on site using a new v-bank to determine the loading of the pre-filter. This reduces the total cost and increases the number filters tested. The alternative option for filter resistance tests is to pull the set of filters, replace them on farm, and send to an ASHRAE 52.2 certified lab for testing. MAFT is able to test on site and eliminate the cost of replacing filters and give instant feedback for the data collection. Recent uses for MAFT have been testing on 4,000 head breeding-gestation-farrowing farms, with over 2,000 filters installed on site. MAFT is used to test 5% of the pre-filters with a new v-bank in the test duct, 104 to 112 filters per farm. The new v-bank is used to standardize the pre-filter test results for comparison. For these sites MAFT is testing filters for an average of 6 hours, 18 filter tests per hour. MAFT has also been used to test every filter within one specific size of filter wall, 144 filters in total in one day of testing. Since its commissioning in March 2017 to current, July 2017 MAFT has tested 2,114 filters consisting of used pre-filters and new v-banks and used pre-filters and used v-banks. As the v-banks on site load they will also be tested with MAFT.

Conclusion

A mobile air filter test duct was designed and constructed to meet the requirements set forth by swine producers. MAFT has been calibrated to BESS Labs to ensure high quality flow predictions and has been validated to an ASHRAE 52.2 lab for filter resistance tests. Future use of MAFT include complete filter wall testing to observe spatial variation within the wall, sub-sample testing of sites for barn to barn variation and study's into the mitigation of peak loading times during the year (planting and harvest seasons for farms near row crop fields and grain handling facilities).

Refernces

Alonso, C., Murtaugh, M. P., Dee, S. A., & Davies, P. R. (2013). Epidemiological study of air filtration systems for preventing PRRSV infection in large sow herds. *Preventive Veterinary Medicine*, *112*(1), 109–117.

ASHRAE. (2012). *ANSI/ASGHRAE Standard 52.2-2012: Method of testing general ventilation air-cleaning devices for removal efficiency by particle size*. Atlanta, GA.

ASHRAE. (2013). *ASHRAE Handbook Fundamentals*. Atlanta, GA: ASHRAE.

Dee, S., Otake, S., & Deen, J. (2010). Use of a production region model to assess the efficacy of various air filtration systems for preventing airborne transmission of porcine reproductive and respiratory syndrome virus and Mycoplasma hyopneumoniae: results from a 2-year study. *Virus Research*, *154*(1), 177–184.

Fisk, W. J. (2013). Health benefits of particle filtration. *Indoor Air*, *23*, 357–368.

Holtkamp, D., Kliiebenstein, J., Neumann, E., Zimmerman, J. J., Rotto, H., Tiffany, Y., … Haley, C. (2012). Assessment of the economic impact of porcine reproductive and respiratory syndrome virus on United States pork producers. *Journal of Swine Health and Production*, *21*(2).

Stark, K. D. C. (1999). The role of infectious aerosols in disease transmission in pigs. *The Veterinary Journal*, *158*, 164–181.