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DEVELOPMENT OF AN AIR-FILTERED SWINE TRAILER FOR ENHANCED BIOSECURITY AND WELFARE DURING TRANSPORT

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ABSTRACT In response to industry demand for enhanced biosecurity and welfare during animal transport, a prototype air-filtered swine trailer was developed. The prototype trailer has a front compartment that houses the air filtration and ventilation system, and a 20-ft animal compartment with solid aluminum walls, two straight decks, and a hydraulic lift gate. This study aimed to evaluate the overall trailer performance, conduct an economic analysis, and implement modifications for optimization of the trailer design. The efficiency of the installed air filtration system (MERV 8 panel pre-filter and MERV 16 glass fiber V-bank filter) was evaluated in stationary tests with no pigs inside the trailer. Upstream and downstream monitoring of concentrations of aerosolized model virus (bacteriophage Phi X174) yielded an overall filtration efficiency of 96.9%. Moreover, two monitoring trips with market-sized pigs loaded in the trailer showed a general front to rear movement of air as evidenced by increasing trailer temperature, moisture, and CO_2 levels from front to rear end of the trailer. Conditions at the middle to rear portion of the animal compartment were within acceptable thermal limits. However, locations at the front end of the animal compartment experienced low temperatures (<10°C) during portions of the trips. Cost analysis for a 120-pig capacity air-filtered trailer yielded an estimated total cost of $109,900. Assuming an incremental revenue of $5 per head of biosecure pigs transported, the estimated payback period was about 2.41 years. Recommended modifications to the prototype include installation of water drinkers, misters, interior lighting, and improved ventilation control system.

Keywords: pig transport, biosecurity, animal welfare, mechanical ventilation

INTRODUCTION Transportation is an inevitable process in livestock production and subjects animals to unfamiliar surroundings, unfavorable or often times extreme environmental conditions. While in transit, pigs particularly breeding stocks transported from genetics companies whose nucleus and multiplier farms are located in various provinces in the country where disease pressure is low and biosecurity perimeters are wide, are inevitably exposed to risk of airborne disease contamination. Few of the emerging and re-emerging economically significant

and airborne transmissible swine diseases, particularly in North America, include Porcine Reproductive and Respiratory Syndrome virus (PRRSv) and *Mycoplasma hyopneumoniae* (*M hyo*) (Otake et al., 2010). Diseases caused by these pathogens can impact the swine industry through actual loss in animal productivity, added costs of medication and eradication measures, and even potential loss of access to markets for pigs from a PRRS-positive herd. A study in the U.S. estimated the annual financial impact of PRRS at US$664 million attributed to combined productivity losses in the breeding and grow-finish pig herds (Holtkamp et al., 2011). Similarly, a Canadian study estimated economic losses in a breeding facility affected by PRRSV to be from $250 to $460/sow/year for chronic PRRS or new acute outbreak (Mussell, 2010). Efforts have been made to develop control measures to prevent infection of animals during transport and consequently to close the biosecurity gap through which potential infection can be introduced to a commercial swine herd. Various studies provided evidences of the efficacy of incorporating air filtration systems (i.e., use of mechanical filters and antimicrobial filters) in swine barn facilities and eradication of loopholes in the said disease prevention strategy particularly on the North American swine production system (Alonso et al., 2012; Dee et al, 2012). However, no study has been published on evaluation of effectiveness of an air filtration system installed on a fully-operational mechanically ventilated swine transport trailer for prevention of disease infection via the airborne route during transport.

A study completed on this subject (Predicala and Alvarado, 2014) showed that the use of filtration systems using MERV 16 and Noveko bag filters can effectively capture bioaerosols in the air and prevent entry into the animal compartment of the trailer, thereby protecting the animals from potential infection by airborne transmissible diseases during transport. However, the study did not implement the final design in a commercial swine transport trailer loaded with pigs to determine the impact of the air filtration system on air quality and thermal environment inside the trailer.

The hypothesis for this study is that an efficient air filtration system in conjunction with an effective mechanical ventilation design fitted to a commercial swine transport trailer will prevent threats to animal health via airborne route and improve animal micro-environment during transport, both of which are among major concerns for existing swine transport trailers. The overall goal of this study was to develop a new and improved design for animal transport trailer that will facilitate control of airborne pathogen contamination and improve operational efficiencies. The specific objectives were to (1) evaluate the overall effectiveness of the air-filtered trailer in preventing airborne pathogen introduction to swine being transported; (2) assess the trailer's capacity to provide stable and acceptable thermal environment and air quality inside the trailer during transport (i.e., from loading to unloading); and (3) characterize cost and economic feasibility of the new trailer design for commercial swine production.

MATERIALS AND METHODS The prototype air-filtered trailer was assembled and the evaluation of its performance was conducted in two parts: (1) stationary tests, and (2) road tests. The stationary test was aimed to test the capacity of the trailer's air filtration system to prevent airborne introduction of pathogens inside the animal compartment. The road test, on the other hand, was intended to assess the resultant environmental condition inside the air-filtered trailer during an actual journey with the trailer loaded with pigs to capacity. A preliminary cost analysis was done based on actual costs incurred in the assembly and evaluation of the prototype trailer.

Description of the prototype air-filtered trailer The assembled prototype trailer was comprised of two main compartments, the front compartment and the animal compartment, both installed on a flatbed trailer. The front compartment held components of the trailer air filtration and ventilation systems. A 10-kW, single-phase generator set (PowerLine™ Model KS1000-T4, Frontier

Power Products, AB, Canada) was installed in the front section of the compartment. Two 2' × 6.25' (w × h) openings on both sides of the compartment secured using steel mesh and detachable pre-filters served as main air inlets for the livestock trailer. The air filter wall, sealed on all sides, held 6 filter sets each composed of a 24" × 24" × 1" MERV 8 pre-filter (30/30®, Camfil Farr, AB, Canada) and a 24" × 24" × 12" MERV 16 filter (Durafil® ES, Camfil Farr, AB, Canada). According to manufacturer, the MERV 8 pre-filter was made from "proprietary blend of fibers" with a mechanical principle of particle capture. The MERV 16 filter, on the other hand, was made from microfine glass fibers to form mini-pleats assembled into multiple V-banks. Two 18-inch diameter axial fans, each powered by 2 HP, 3-phase electric motor (Sukup, Sheffield, IA USA) were installed at the downstream side of the filters to pull fresh air through the air filter sets and onto the animal compartment at a controlled flow rate. A commercially available centralized electronic control system, Maximus System (Maximus Systems, Saint-Bruno-de-Montarville, QC, Canada) was utilized to control the mechanical ventilation system of the prototype trailer.

The animal compartment is a 20' × 7.25' × 7' (l × w × h) box of aluminium 5754 H111 construction (Figure1). It has solid walls, in contrast to the walls of conventional livestock trailers where side vents are present throughout the entire length of the trailer. It has two decks (top and bottom) each divided into two pens (front and rear) by a gate. Both top and bottom decks are 3'5" in height. The middle portion of the upper deck floor is hinged and can be lifted open to allow easier loading, unloading or other human activities (i.e., trailer cleaning, washing, inspection) in the bottom deck. Figure1 shows the features of the livestock container that was custom-built for this study. The ventilation fans were installed in the front compartment such that each fan supplied air to the animal compartment through openings located at the top center of the front wall of the top and bottom decks of the animal compartment. On the other hand, exhaust air openings are located on both sides at the rear of each deck. To address animal handling and welfare issues faced with use of ramps in conventional livestock trailers, a 1,000-kg capacity hydraulic lift gate was added to the prototype trailer (Figure 1E). Its control system composed of a hydraulic motor powered by two automotive batteries and a push-button type remote as shown in Figure 1F.

Figure 1. Photos of the animal compartment showing (A) its lower and upper decks, (B) hinged roof, (C) gate that partitions each deck into two pens, (D) air exhaust damper, (E) hydraulic lift gate, (F) hydraulic lift controller and (G) compartment exterior.

Stationary test In this test, bacterial virus or bacteriophage Phi X174 (ATCC 13706-B1) together with its host *Escherichia coli* (ATCC 13706) was used as surrogate for common viral swine pathogens. Phage Phi X174 is tailless, non-enveloped, 25 - 27 nm in capsid size, and contains single-stranded DNA (ssDNA) as its genomic material. The bacteriophage and its host were obtained from the American Type Culture Collection (www.atcc.org). Preparation and storage of the amplified phage stock (2.78×10^{10} ssDNA copies/ml) were done by trained personnel at the Microbiology Laboratory of Western College of Veterinary Medicine (WCVM), University of Saskatchewan. This method of viral stock preparation was adopted from Broyles et al. (2002).

Aerosol generation and viral load sampling On the day of testing, a nebulization solution composed of 1 mL phage lysate diluted in 39 mL ultra pure water was prepared. A cold fog mister (Hurricane ULV/mister, Curtis Dyna-Fog Ltd. Westfield, IN, USA) was then used to generate aerosol at an average liquid use rate of 37.5 mL/min. Aerosol produced was directed into a foil-lined cardboard chamber installed upstream of the air filter set directly in front of the fan. The same foil-lined cardboard material was used to create a duct that connects the downstream side of the air filter set to the inlet side of the fan, to ensure that all air entering into the chamber upstream of the filter set passes through the filter and all the way through the fan. A smoke test was done prior to testing to locate and seal leaks all over the testing setup. Each filter set change represented a replicate. Figure2 shows the schematic diagram of the test set-up.

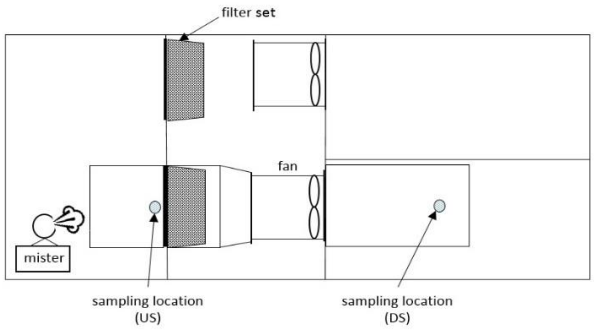

Figure 2. Diagram of the testing setup during the stationary test. US and DS stand for upstream and downstream, respectively.

Polycarbonate filters (PC) (SKC Inc., Eighty Four, PA) with 0.4 µm porosity and 37 mm in diameter placed in clear styrene 3-piece cassettes (Sureseal, SKC Inc.) were used to monitor phage concentration in aerosols upstream and downstream of the air filter set and fan assembly. Aerosolization and sample collection duration was 10 minutes. After each test, the filter samples were stored individually in 15 ml conical centrifuge tubes at -80°C for subsequent quantitative polymerase chain reaction (qPCR) analysis. Extraction of viral particles from filter samples and qPCR were carried out by trained personnel at WCVM, University of Saskatchewan, using their laboratory facilities and equipment.

Calculation of filtration efficiency Filtration efficiency in terms of viral load was estimated using Equation 1 (Ardkapan et al., 2014):

$$\eta_{i,filter} = \frac{L_u - L_d}{L_u} x\ 100 \qquad (1)$$

where $\eta_{i,filter}$ is the air filter efficiency (%) and L_u and L_d are the average viral loads (ssDNA copies/L of air) upstream and downstream of the air filtration system, respectively.

Road test Two monitoring trips from a pig farm in Saskatoon, Saskatchewan, Canada to an abattoir in Moose Jaw, Saskatchewan with market pigs loaded inside the trailer were carried out under mild winter conditions. The travel time was at least 5 hours excluding time allotted for

loading, wait time in the yard of the abattoir and unloading. The average live weight of the market pigs, stocking density, time of start of loading, travel interruptions on the road and time until end of unloading in the abattoir were recorded. The mechanical ventilation system was turned on before start of loading and was kept operating until end of unloading.

Data collection Over two monitoring trips, several parameters including temperature, relative humidity (RH), carbon dioxide (CO_2), as well as ammonia (NH_3) and hydrogen sulfide (H_2S) were monitored. Temperature and RH were logged every 30 seconds using OM-EL-USB-TP-LCD and OM EL-USB-2 data loggers (Omega Environmental, Laval, QC, Canada). Concentration of CO_2 measured every 30 seconds using SE-0018 sensors (CO2Meter.com, Ormond Beach, Florida) and were logged continuously in a data logger (Campbell Scientific Canada, Edmonton, AB). H_2S and NH_3 concentration monitoring were done using Dräger Pac® 7000 (Draeger Safety Canada, Ltd, Mississauga, Ontario). Figure 3 shows the distribution of sensors and data loggers inside the trailer during the trip. The monitoring devices were installed at the ceiling of each deck approximately 1 m (≈ 40 in) above the floors which was approximately 0.3 m above the pig level. This was done to ensure the devices were kept from animal damage.

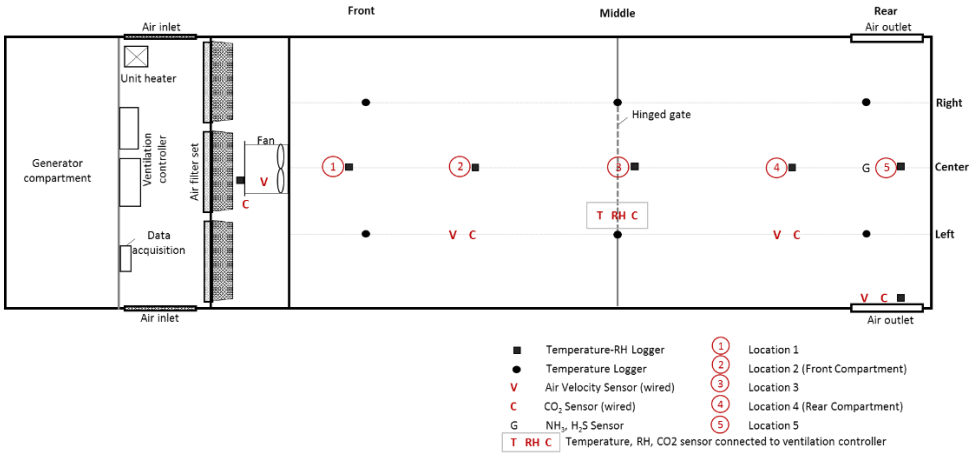

Figure 3. Trailer schematic diagram showing the plan view of locations of sensors and data loggers used to measure temperature, relative humidity, air velocity, CO_2 and other gases (NH_3 and H_2S) inside the trailer. Similar layout was followed for both top and bottom decks of the animal compartment.

Data analysis Mean comparison between upstream and downstream phage concentrations were carried out using paired sample t-test. On the other hand, processed data sets for the different environmental parameters monitored were descriptively analyzed using means, standard deviations, ranges and frequencies. To compare means of the temperature, humidity ratio, and CO_2 levels across all monitoring locations inside the trailer, General Linear Model - Univariate analysis was performed using SPSS (IBM SPSS Statistics, Version 24.0. Armonk, NY: IBM Corp.), with each environmental parameter analyzed separately. Tests of normality and homogeneity of variances were carried out by Shapiro-Wilk and Levene's tests, respectively. Overall level of significance was defined by $p<0.05$.

Cost analysis Record of actual expenditures for this project were used in carrying out a cost analysis for an air-filtered trailer with a 120-pig capacity (i.e., approximately double the size of the prototype trailer assembled). Estimation of annual operational costs were based on a 10-hr journey (pig transport) done at a maximum of two times per week, with the trailer being used

90% of the year. Various other assumptions particularly in carrying out payback period analysis are also described.

RESULTS AND DISCUSSION

Filtration efficiency test (stationary test) Prior to the filtration efficiency tests, the integrity of the sampling method and set-up was evaluated through a smoke test coupled by two 10-minute each of positive and negative control tests. Smoke test was done to ensure there was no leak around the air filter set and the testing chambers (from upstream of the filter set to downstream of the fan). Table 1 summarizes the results of the filtration efficiency tests including the positive and negative control tests. No significant difference (p = 0.341) between the upstream and downstream phage concentrations was found from the positive tests conducted. The positive control test indicated that no false negative results were obtained in the four trials conducted, i.e., no viral genome detected or below qPCR detection limit, as a consequence of factors other than the relative effectiveness of the air filtration system installed. The negative control tests, on the other hand, yielded no Phi X174 genome detected on both upstream and downstream sampling locations (Table 1). This means that the obtained positive viral genome results, i.e., all quantifiable genome counts, were primarily due to actual concentration of the test virus in the air captured in the sampling device and not due to contamination from uncontrolled sources.

Table 1. Filtration efficiency determined from reduction of bacteriophage Phi X174 concentration downstream of the air filters tested, n = 4.

Trial*	Repetition	Nebulization solution phage concentration, copies/ml	Average bacteriophage concentration, copies/m^3 of air		Filtration efficiency, %	Mean filtration efficiency, %	Standard deviation, %
			Upstream of the filter	Downstream of the filter			
1	1	3.60E+08	2.35E+08	5.17E+06	97.8	97.9	1.3
	2		6.54E+07	1.98E+06	97.0		
	3		3.93E+08	2.31E+06	99.4		
	4		1.39E+08	2.00E+06	98.6		
	5		1.14E+08	4.63E+06	95.9		
	6		2.75E+08	4.21E+06	98.5		
2	1	3.60E+08	1.01E+08	5.05E+06	95.0	96.9	2.0
	2		1.00E+08	2.59E+06	97.4		
	3		1.53E+08	3.68E+06	97.6		
	4		8.79E+07	5.21E+06	94.1		
	5		3.86E+08	2.06E+06	99.5		
	6		1.40E+08	2.91E+06	97.9		
3	1	2.40E+08	3.70E+08	1.20E+07	96.8	95.7	4.9
	2		4.09E+07	5.82E+06	85.8		
	3		3.47E+08	7.40E+06	97.9		
	4		4.21E+08	5.52E+06	98.7		
	5		1.77E+08	3.55E+06	98.0		
	6		1.45E+08	4.39E+06	97.0		
4	1	2.40E+08	1.20E+08	1.56E+06	98.7	97.2	1.7
	2		5.71E+07	1.70E+06	97.0		
	3		1.52E+07	8.61E+05	94.4		
	4		1.83E+08	3.06E+06	98.3		
	5		5.56E+07	2.07E+06	96.3		
	6		1.25E+08	2.08E+06	98.3		
+ Control	1	3.60E+08	8.66E+07	1.64E+07	na	na	na
	2	2.40E+08	1.77E+08	1.24E+07			

- Control	1	na	ND	ND	na	na	na
	2		ND	ND			

*Each replicate trial represents one filter set, i.e. MERV 8 pre-filter and MERV 16, tested;
na – not applicable; ND – none detected by qPCR

For the filtration efficiency tests, significant ($p < 0.001$, $n = 4$) reduction in bacteriophage concentration was observed between upstream and downstream of the air filter sets with mean bacteriophage concentrations of 1.8×10^8 (95% CI: 1.2×10^8 - 2.3×10^8) genome copies per m^3 of air and 3.8×10^6 (95% CI: $2.8 \times 10^6 – 4.8 \times 10^6$) genome copies per m^3 of air, respectively. The air filtration system installed in the trailer yielded an approximately 96.9 ± 2.8% reduction in the concentration of bacterial virus Phi X174 relative to upstream concentration as measured in the animal compartment of the trailer (Table 1). Although bacteriophage Phi X174 is a very small virus, the air filter combination tested performed close to the expected 95% filtration efficiency for MERV 16 filters at test particle sizes ≥ 0.3 µm based on ASHRAE Standard 52.2 - 2007 testing. This may be partly due to the bigger aerosol droplets produced by the aerosol generator used in the study; manufacturer information for the Dyna-fog Hurricane ULV/mister reports droplets produced are within the 5 to 50 µm size range. However, the Dyna-fog mister has been satisfactorily used in previous studies in generating test aerosols (Batista et al., 2008; Otake at al., 2010; Alonso et al., 2012). Finally, the determined percent reduction in bacteriophage concentration by the installed air filtration system implies that if the system is challenged under normal field conditions (as previously determined by Corzo et al., 2013 and Alonzo et al., 2015), significant risk reduction from infection will be achieved.

Environmental condition inside the air-filtered trailer during transport (road test) A total of 60 market-sized pigs with an average weight of 125.5 ± 6.2 kg (115 – 140 kg) were loaded in the four compartments of the livestock container at 15 pigs/compartment during the first monitoring trip. For the second trip, a total of 61 pigs with an average weight of 122.8 ± 6.4 kg (114 – 140 kg) were loaded. Space allowance for both trips was 0.40 m^2/115 kg pig following the recommendations of Correa (2011) for winter transport of pigs. Duration of different events throughout the two journeys were synonymous except that waiting period at the plant took longer during the first trip than the second trip. Moreover, journey started earlier during the first trip (loading at 4:15 am) while second journey started at around 5:15 am. Duration of the entire transportation process was approximately nine hours for both monitoring trips.

Temperature distribution and overall thermal conditions during transport The trend in temperature for the top and bottom deck levels were similar for both trips. Temperature from start of loading to early period of the trips ranged from -7 to 22°C and from -0.5 to 23°C for the first and second monitoring trips, respectively. Temperature for both decks started to stabilize approximately one hour after leaving the farm, except for some minor peaks, such as during slow down and during a stop at the abattoir. Similar observational studies on thermal condition inside swine trailers during transport corroborate most observations in this study. For instance, Kettlewell at al. (2001) and Ellis et al. (2008) found that greatest temperature extremes were observed during stationary periods such as during loading and waiting at the abattoir and during travel interruptions such as slow downs and short stops. Periods of thermal equilibration approximately an hour after start of travel may suggest that the animals have adapted to vehicle motion. According to Kettlewell et al. (2001), the animal compartment structure also equilibrates during this stationary transport period. However, during travel interruptions, especially if prolonged, the thermal equilibration is disrupted as a consequence of the animals getting agitated

and resulting to increased movement. Equilibration is usually re-established after the vehicle starts moving again.

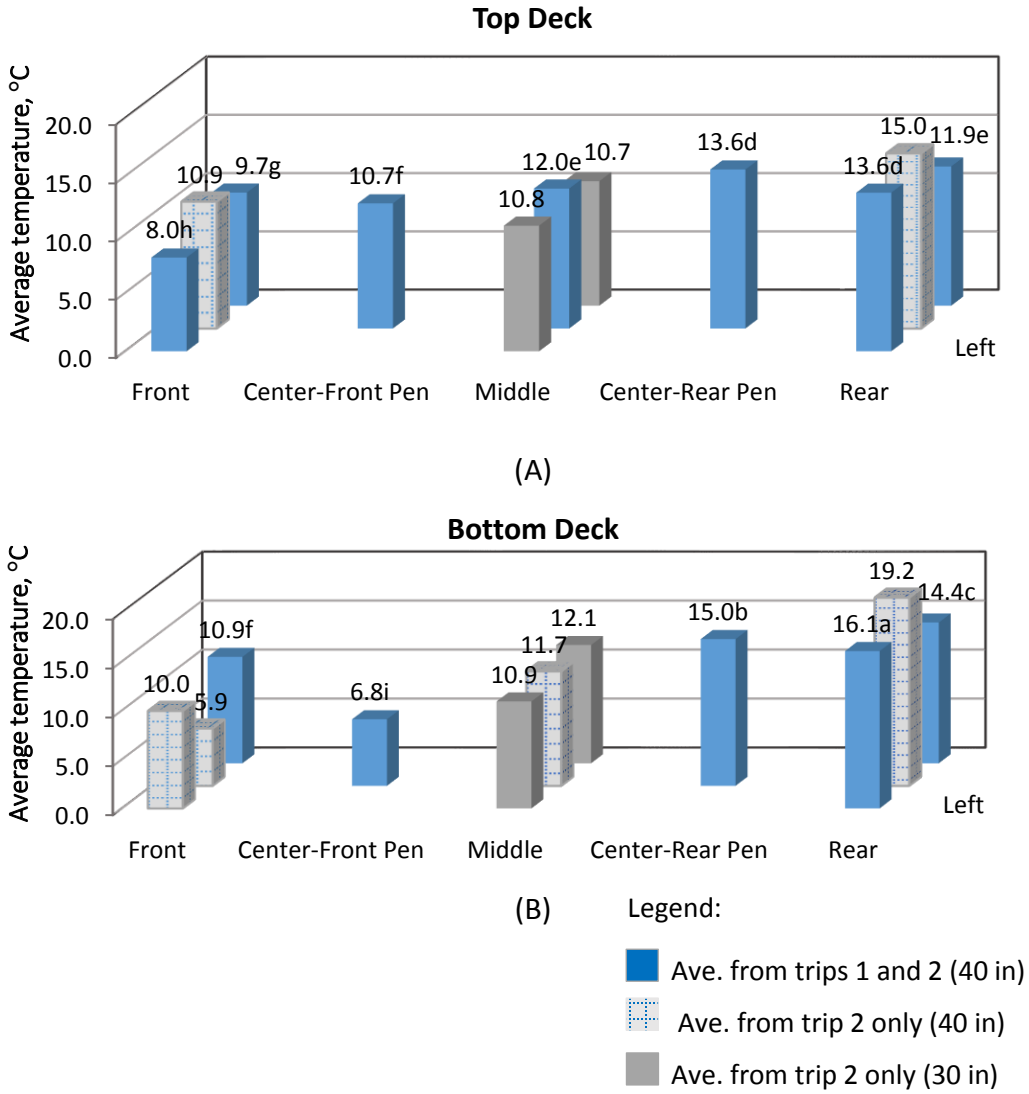

Figure 4. Average air temperature during the stable transport period at different monitoring locations approximately 1 m (≈ 40 in) above the floor of the (A) top deck and (B) bottom deck of the animal compartment monitored during two monitoring trips, n = 2. Data labels followed by the same letter (a to i) for top deck and bottom deck combined are not significantly different ($p<0.05$). Data labels with no letter groupings were computed from monitoring trip 2 only thus were excluded in the analysis.

Figure 4 shows the distribution of average temperature inside the trailer at several locations during the stable period of the two trips. This period was defined as starting from the time the trailer had travelled for approximately one hour (after loading). The stable transport period covered the longest duration in the transport process (around four hours for both trips) and was chosen to minimize the effect of travel interruptions and stationary periods in further analysis to assess the general overall trends in the resultant thermal conditions in the trailer. Generally, temperature inside the animal compartment of the prototype trailer increased from front to rear. Moreover, the temperature at the center of the trailer was significantly higher ($p<0.05$) than the average temperatures at the corresponding peripheral areas (left and right side of the trailer).

This is in agreement with the prediction done using computer simulations during the design phase of the project. In addition, the variability in temperatures across different locations inside the animal compartment at a specific time reached as high as 12°C during the first trip and had a maximum of 9°C during the second trip. These high temporal differences in temperature were observed between the bottom deck front compartment and rear compartment of both bottom and top decks. This is a direct consequence of the general front-to-rear air flow pattern inside the trailer as dictated by the ventilation system configuration, i.e., positive ventilation fans located at the front end of the trailer while exhaust openings are found at the rear. This is in contrast to the reported air flow pattern in conventional livestock transport trailer where differences in external pressure fields while the vehicle is in forward motion causes rear-to-front air movement inside the trailer (Kettlewell, et al., 2001; Ellis et al., 2008; Brown et al., 2013). This led to generally rear-to-front increase in temperature and other environmental parameters (e.g. moisture and CO_2 levels) in conventional trailers.

Moisture levels and distribution To provide a more useful measure of the moisture level inside the trailer during transport, relative humidity (%) measured were converted into humidity ratio (g/kg of dry air) (Albright, 1990). Figure 5 shows the average humidity ratios along five monitoring locations for both top and bottom decks of the trailer during the stable transport period. Moisture level increased from front to rear for both decks which further attest to the general front-to-rear air movement inside each trailer deck compartment. In contrast to temperature distribution, moisture level inside the trailer was significantly higher ($p<0.05$) at the top deck compared to the bottom. This can be explained by the lower ventilation rates maintained at the top deck (at 10% of fan capacity during the stable transport period) compared to the bottom deck for the entire duration of the study. Although the ventilation control system has relative humidity and CO_2 compensation feature, this feature is only activated when detected temperature by the control system is equal or higher than the 16.5°C set-point.

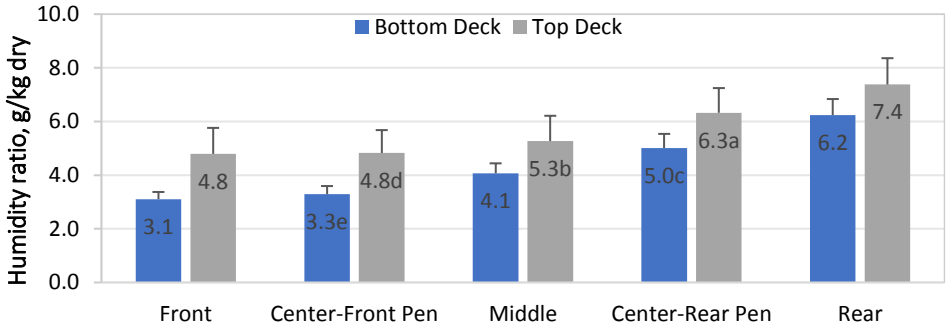

Figure 5. Average humidity ratio during the stable transport period measured in different locations approximately 1 m (≈ 40 in) above the floor along the center of the trailer top and bottom decks during the two monitoring trips, n = 2. Data labels followed by the same letter (a to e) for top deck and bottom deck combined are not significantly different (p<0.05). Data labels with no letter grouping were computed from monitoring trip 2 only, thus, were excluded in the analysis.

Carbon dioxide levels and distribution Carbon dioxide (CO_2) level was used as an indicator of overall air quality inside the trailer during the two monitoring trips. CO_2 concentration inside the pig-filled trailer followed the general trend exhibited by temperature and humidity ratio throughout the monitoring trips. During the stable period of the trips, average CO_2 concentrations were 850 ± 277 and 1,999 ± 422 ppm for the front and rear pens of the bottom deck, respectively. Corresponding values for the top deck were 1,533 ± 427 and 2125 ± 518 ppm, respectively.

Moreover, inlet CO_2 levels for the two trips were 462 ± 55 ppm while outlet CO_2 levels were 1,888 ± 322 and 2,209 ± 508 for the bottom and top decks, respectively. These values are comparable to CO_2 levels (≈ 1,900 - 2,300 ppm) observed inside a pig gestation room during cold weather trial when ventilation rates were lower (Predicala et al., 2017). In the study of Ellis et al. (2008), CO_2 concentration inside the trailer was used as an indication of the ventilation rate in different trailer compartments considering ventilation in existing commercial livestock vehicles is driven by external pressure fields and the pattern of boarding of side openings. Reported mean CO_2 concentrations from their study during one of their summer trips ranged from 878 to 2,746 ppm. These values were comparable to the CO_2 levels in this current study despite the trailer ventilation system running at winter flow rates. Finally, CO_2 concentrations significantly increased ($p<0.05$) as the air stream reached the rear portion of the trailer. Moreover, the outlet CO_2 level suggests that the ventilation system under the given operating condition was able to remove stale air from inside the trailer.

Monitoring of other gases, H_2S and NH_3, during the 2nd monitoring trip yielded zero ppm readings throughout transport for both gases. These gases are not anticipated to be a concern in pig transport due to the limited time the animals were held in the transport compartment; hence, duration is too short to generate measurable levels of these gases under normal transport circumstances.

Cost analysis The cost analysis focused on the incremental costs associated with the assembly and operation of an air-filtered swine transport trailer, relative to a conventional non-air-filtered commercial trailer. Table 2 summarizes primary cost elements in the assembly of a hypothetical 120-pig (market pigs or gilts) capacity air filtered trailer. Actual costs incurred in the construction of the 20-ft prototype air filtered trailer (60-pig capacity) were used as baseline in the estimation of cost for the full-scale air-filtered trailer. Annual operational costs, on the other hand, were estimated based on a 10-hr journey (pig transport) conducted at a maximum of two times per week. Major incremental expenses for using an air-filtered livestock vehicle over an ordinary commercial trailer are related to purchase of equipment and associated installation cost amounting to $109,900, operational cost per year of $9,520, and annual cost for replacement of filters distributed over an assumed 10-year filter lifespan amounting to $600 per year.

Simple payback period was used as final criterion in the financial analysis for this project. Payback period computations were based on the assumption that cash inflows will accrue solely from the premium received for each pig delivered using the air-filtered trailer (with mechanical ventilation). The estimated premium values ranged from $1 to $10 for every weaned pig that was PRRSV-negative based on the financial impact study of air filtration in swine barns conducted by Alonso et al. (2013). For example, receiving a premium of $5/pig delivered, with two journeys served per week (personal communication) and allowing extra downtime for trailer maintenance, thus transporting only 90% of the total number of weeks in a year (total of 93 journeys in a year) at 120 pigs per journey, this would translate to an annual net cash inflow of approximately $45,680 after subtracting the annual operational and air filter replacement costs. Thus, the payback period at this rate of premium is 2.41 years. Other modest rates of premium at $3/pig and $4/pig will yield payback periods of 4.70 and 3.18 years, respectively.

Table2. Costs associated with the assembly and operation of an air filtered trailer.

Type of Expense	Estimated Cost
Total equipment cost (filters, fans, generator, ventilation system, etc.)	$43,600
Total installation cost	$11,500
Total of other capital costs (animal container body, hydraulic lift gate, control compartment, trailer flatbed, etc.)	$66,300
Total equipment and installation cost	**$109,900**
Fuel for genset*, $/yr	$8,320
Hydraulic oil for lift gate and WiFi data charges, $/yr	$1,200
Total operational cost, $/yr	**$9,520**
Assumed lifespan, yr	10
Filter cost, $	$2,000
Total replacement cost per lifespan, $	$6,000
Total replacement cost per year, $/yr	**$600**

All costs are in Canadian dollars.

*Diesel fuel cost estimated at $1.120/L. Consumption based on a 5-month heating period (i.e., space heaters are utilized) and 7-month cooling period (i.e. no heater used, but no supplemental cooling system assumed in analysis) per year.

CONCLUSIONS The air filtration system (MERV 8 panel pre-filter and MERV 16 glass fiber V-bank filter) installed in the prototype trailer showed great potential in preventing airborne entry of pathogen to the livestock compartment, with the concentration of aerosolized bacteriophage inside the animal compartment reduced by 96.9% compared to initial levels upstream of the filtration system. During the road tests, acceptable thermal condition was maintained only at selected locations inside the animal compartment. Extended low temperatures at the front locations near the ventilation fans and the overall thermal and air quality heterogeneity owing to the ventilation configuration are areas for improvement in future design modifications. Cost analysis showed financial feasibility of an air-filtered trailer. Reasonable premium for every biosecure pig transported with air-filtered trailer can offset cost of investment and significantly reduce payback period. Recommended modifications to the prototype include installation of water drinkers, misters, interior lighting, and improved ventilation control system.

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