Air Filtration in Swine Barns: Overview of the Current Situation

May 2013

Literature Review

Marie-Aude Ricard, Eng.
Elizabeth Gobeil Tremblay, B.Sc.
Valérie Dufour, M.Sc.
Francis Pouliot, Eng., MBA

CDPQ
Centre de développement du porc du Québec inc.

© Centre de développement du porc du Québec inc.
Legal deposit - 2013
Bibliothèque et Archives nationales du Québec
Library and Archives Canada
ISBN 978-2-92227876-63-3

Project Team

Project Director	Francis Pouliot, Eng., MBA, Centre de développement du porc du Québec inc.
Principal Investigator	Francis Pouliot, Eng., MBA, Centre de développement du porc du Québec inc.
Project Coordinator	Marie-Aude Ricard, Eng., Centre de développement du porc du Québec
Writing Team	Marie-Aude Ricard, Eng., Centre de développement du porc du Québec
	Elizabeth Gobeil Tremblay, B.Sc., Centre de développement du porc du Québec
	Valérie Dufour, M.Sc., Centre de développement du porc du Québec
	Françis Pouliot, Eng., MBA, Centre de développement du porc du Québec

This document is an update of the literature reviews of « Evaluation of an Air Filtration System Designed to Reduce or Prevent Airborne Transmission of the Porcine Reproductive and Respiratory Syndrome (PRRS) Virus in Swine Barns » and « Mise au point sur une ferme porcine d'un système de filtration d'air, muni d'agents virucides/bactéricides, afin d'éviter la transmission aérienne de pathogènes ».

Acknowledgements

A portion of project funding was provided by the sector councils of Quebec, Ontario, Alberta, Manitoba and Saskatchewan, who administer the Canadian Agricultural Adaptation Program (CAAP) for Agriculture and Agri-Food Canada. This study was also funded by the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ), under Section 3 of the Programme d'appui financier pour un secteur agroalimentaire innovateur, the Canadian Swine Health Board (CSHB), R.Robitaille et fils, inc., the Fédération des producteurs de porcs du Québec (FPPQ), Ontario Pork, Manitoba Pork, the Saskatchewan Pork Development Board (Sask Pork), Alberta Pork, the Centre de recherche de l'Institut universitaire de cardiologie et de pneumologie de Québec (CRIUCPQ) affiliated with Université Laval, JSR Genetics (Canada Ltd.), the Prairie Swine Centre Inc. (PSCI) and the Centre de développement du porc du Québec inc. (CDPQ).

Funding for this project has been provided in part through the Canadian Agricultural Adaptation Program (CAAP) on behalf of Agriculture and Agri-Food Canada. In Quebec, the portion intended for the agricultural-production sector is being managed by the Conseil pour le développement de l'agriculture du Québec (CDAQ).

Agriculture and Agri-Food Canada / Agriculture et Agroalimentaire Canada

Agriculture, Pêcheries et Alimentation Québec

Canadian Swine Health Board / Conseil canadien de la santé porcine

Fédération des producteurs de porcs du Québec

ONTARIO PORK

Sask PORK

ManitobaPork — Locally Grown. Globally Preferred.

ALBERTA PORK

PRAIRIE SWINE CENTRE — Research Profits Everyone

Robitaille

CENTRE DE RECHERCHE INSTITUT UNIVERSITAIRE DE CARDIOLOGIE ET DE PNEUMOLOGIE DE QUÉBEC — AFFILIÉ À UNIVERSITÉ LAVAL

CDPQ — Centre de développement du porc du Québec inc.

JSR Genetics

Table of Contents

1 Aerosol Transmission of Pathogens

Aerosols consist of finely divided matter, such as dust, suspended in the atmosphere (Hirst, 1995). Viruses do not survive well in a free state so they are often carried on aerosols (Dutertre, 1995). When aerosols contain particles of biological origin that can affect living organisms, such as viruses and bacteria, the term "bioaerosols" is used (Hirst, 1995). Bioaerosols have a diameter ranging from 0.5 to 100µm.

Viruses and bacteria known to spread from one pig farm to another via aerosol transmission are: foot-and-mouth disease virus, Aujeszky's virus (pseudorabies), influenza virus, *Mycoplasma hyopneumonia* (the cause of enzootic pneumonia), *Actinobacillus pleuropneumoniae* (the cause of pleuropneumonia), porcine reproductive and respiratory syndrome (PRRS) virus, *Bordetella bronchiseptica* and *Pasteurella multocida* (atrophic rhinitis), and respiratory coronavirus (Stärk, 1999; Baekbo and Mortensen, 2001; Desrosiers, 2004). Canada is free from foot-and-mouth disease and pseudorabies (Broes, 2002). However, influenza virus, *Mycoplasma hyopneumoniae*, *Actinobacillus pleuropneumoniae* and porcine reproductive and respiratory syndrome (PRRS) viruse are the most important pathogens in Canada's swine industry (Broes, 2002).

PRRS virus in the free state, has a diameter ranging from 0.050 to 0.065µm and *Mycoplasma hyopneumoniae* a diameter ranging from 0.3 to 0.9µm (Quinn et al., 2002, Zimmerman et al., 2006). But, these viruses are usually carried as bioaerosols.These pathogens are often found in viral-bacterial co-infection and result in significant economic losses for producers (Dee et al., 2009a). Studies have shown that the PRRS virus and *Mycoplasma hyopneumoniae* can be transmitted in the air over distances of up to 9.2 km (Dee et al., 2009b; Otake et al., 2010). Desrosiers (2011) reports that *Mycoplasma hyopneumoniae* can remain viable for four to eight days in dry air at room temperature. A recent study by Corzo et al. (2012) showed that pigs infected with influenza type-A can excrete aerosol-transmissible viruses that can travel outside the farm limits.

The possibility of PRRS aerosol transmission caused controversy for many years (Cho and Dee, 2006); however, it is now recognized and PRRS virus is included in the list of pathogens that can be aerosol-transmitted between farms. Many case studies support this statement (Stärk, 1999; Baekbo and Mortensen, 2001; Desrosiers, 2004).

1.1 Aerosol Transmission of PRRS Under Experimental Conditions

It has been demonstrated that infected pigs can transmit the PRRS virus to healthy pigs housed in adjacent room connected by a 1m long ventilation duct (Torremorell et al., 1997; Brockmeier and Lager, 2002; Kristensen et al., 2004). Torremorell et al. (1997) tested transmission of two different strains and concluded that virus aerosol transmission is possible but appears to be strain-dependent. In their study, when strain MN-1b was used, no pigs were infected by aerosol transmission, while pigs were infected when VR-2332 was used. Kristensen et al. (2004) used naturally infected pigs to test virus transmission, and 94% to 100% of pigs were infected by aerosol transmission.

Dee et al. (2005a) proved that the virus can be transmitted by aerosol over longer distances. Virus strain MN-30100 was sprayed with an atomizer and transported across a 150m long ventilation duct, into a room housing a healthy pig. The healty pig was infected by the virus three times out of six.

For their part, the results of a study by Trible and Rowland (2011) indicated that the risk of aerosols spreading the virus is low and they lent support to previous studies showing that the necessary distance for aerosol propagation of the PRRS virus is limited to a few meters. However, this contradicts the latest studies showing that the spread of a virus strain, such as MN-184, by aerosols can extend over several kilometers. In the study by Trible and Rowland (2011), 190 pigs infected with a strain with characteristics similar to MN-184 infected pigs about eight meters away. The reason for this discrepancy is unclear, but is possibly explained by the methodology used to determine the spread of the virus. In this study, transmission from one pig to another was used as an indicator of aerosol propagation, while earlier studies using the MN-184 strain measured the concentration of air sample contents at various distances from the source population.

1.2 Aerosol Transmission of PRRS in Field Studies

Transmission of PRRS has been tested under field conditions; however pigs in nearby facilities were not infected by aerosol when these experiments were performed (Otake et al., 2002a; Trincado et al., 2004a; Fano et al., 2005). Several explanations were proposed to explain this failure. First, Kristensen et al. (2004) stressed that the exposure period was really short in Otake et al. (2002a) experiment. Also, that the healthy pigs were only exposed to the virus for 72 hours, whereas in the experiment by Kristensen et al. (2004) the pigs were exposed to the virus for 28 to 35 days. Second, in experimental infections, physical signs such as secretion discharge, that favour aerosol transmission (cough and sneeze) and which might influence the results of these experiments, are not present (Lager and Mengeling, 2000). The third explanation, put forward by Cho and Dee (2006), concerns the virulence of the strains used. Cho et al. (2007) demonstrated that there is a significant difference in transmission between two viral strains: MN-30100 and MN-184. In this experiment, healthy pigs exposed to aerosols from pigs infected with isolate MN-184 strain became infected, while those exposed to aerosols from pigs infected with MN-30100 strain remained healthy. Cho and Dee (2006) emphasized that the use of the low virulence strain MN-30100 in the three field studies, could have influenced viral transmission.

2 Other Modes of PRRSV Transmission and Protective Biosecurity Measurements Against Them

Before installing an air filtration system, it is important to keep in mind that aerosols are not the only carriers of the PRRS virus and that adoption of a biosecurity program is vital to effectively protect a herd. According to Boutin (2001), biosecurity means “the set of measures taken to protect herds from the introduction of new pathogens.” While not totally eliminating risk, an adequate program can slow down herd infection.

Biocontainment and bioexclusion are two biosecurity concepts in reducing transmission of PRRSv. In the case of livestock infection by pathogens, bioconfinement consists in protecting neighboring farms by preventing airborne spread of the virus to the outdoors. In doing so, the virus is confined to the interior of the building. In the spring and summer of 2012 a new concept of biocontainment was also developed and tested in a quarantine unit as part of a project carried out by the CDPQ.The concept of bioexclusion can, for its part, reduce or prevent the introduction of pathogens into a herd. Example, by filtering intake air.

This section presents the different entry routes of the virus into a farm, as well as some biosecurity measures helping to control them. Figure 2.1 shows a diagrammatic summary of all possible routes of contamination.

2.1 Potential Contamination Sources

2.1.1 Introduction of Pigs

Introduction of replacement animals constitutes a direct contamination hazard for the farm. For this reason, recommendations are to deal with only one supplier, know the supplying herd’s health status (ensuring PRRS naïve status) and implement biosecurity strategies both at the farm and during animal delivery. It is also highly recommended to quarantine purchased animals before introducing them into the herd (Broes and Boutin, 2002).

A quarantine unit without a biocontainment system should be located more than 120 meters from the breeding herd and the animals should stay in quarantine for at least 30 days. Blood tests should be done on replacement animals from 24 to 48 hours after their arrival in quarantine and 5 to 7 days before their entry into the breeding herd (Pitkin et al., 2009a). The question remains: should exhaust air from the quarantine unit fans be filtered throughout the quarantine period, knowing that if there were any potential contamination, PRRSV can travel over 9.2 km?

2.1.2 Semen

Semen can also transmit the PRSSv. Consequently, it is crucial to purchase semen from insemination centers that offer a formal sanitary guarantee of PRRS virus naïve status (Broes and Boutin, 2002).

2.1.3 Transport Vehicles

Vehicles can also carry the virus. This is why a dead animal recovery container should be installed at a reasonable distance from the farm, thus preventing recovery trucks from coming close to the farm. Likewise, it is preferable that trucks are washed, disinfected and empty before their arrival at the farm (Broes and Boutin, 2002). Dee et al. (2004a) demonstrated that PRRS-contaminated transport can transmit the infection to naïve pigs. In that experiment, the only treatment that eliminated the virus was a combination of litter removal, washing, disinfection with phenol, and drying. In a second experiment, Dee et al. (2004b) evaluated the effectiveness of four sanitation protocols in eliminating the virus from transport vehicles. Protocols involving washing only, or washing followed by formaldehyde fumigation, were not effective while protocols involving washing and disinfection with glutaraldehyde-chloride and ammonium quaternaries, or washing followed by overnight drying, sanitized vehicles efficiently. Based on these experiments, Pitkin et al. (2009a) recommended this disinfection protocol: removal of organic matter; washing; disinfection using products with proven effectiveness such as Synergize (0.8% concentration) or Virkon (1% concentration) applied for a minimum of 2 hours; and drying. Drying is the most important step in this viral inactivation protocol. This same protocol is recommended for sanitizing facilities that have received animals infected with PRRS virus.

2.1.4 Inanimate Objects

Inanimate objects, such as shoes, clothing, material and equipment can also allow mechanical transmission of the virus. It is therefore vital to wash and disinfect inanimate objects before their introduction into the farm (Broes and Boutin, 2002). In 2007, Bernick stated that disinfection rooms to fumigate incoming material are often found in new swine constructions.

Synergize and Virkon are also recommended for their proven effectiveness against PRRS virus (Pitkin et al., 2009a). Dee et al. (2004c) demonstrated that the use of disposable plastic boots, use of footbaths containing hypochlorite, and implementation of the "bag-in-a-box" shipping method (a cardboard box into which is placed a plastic bladder containing the material to be shipped), were effective in preventing PRRS transmission. Clean coveralls should also be available in each building and washed regularly (Pitkin et al., 2009a). Dee et al. (2002, 2003) also showed, through a sequence of events reproducing the habits of farmworkers, that the mechanical transmission of PRRS virus happens more easily on cold days (<0° C) than on hot (10° C to 20° C).The sequence of events that were t ested involved boots, containers, cleaning of vehicles, transportation and staff movements.

2.1.5 Humans

Porcine reproductive and respiratory virus (PRRSv) can be transmitted via inanimate objects such as boots and clothes, but also by the hands (Otake et al., 2002b). Consequently, humans can act as mechanical vectors of this virus. Three biosecurity protocols were tested by Otake et al. (2002b) with the aim of preventing transmission. The first was a Danish entrance system (including change of boots and clothes, and hand washing), the second was a standard protocol (change of boots and clothes, showering and observation of a 12-hour withdrawal period), and the third was an alternate protocol (change of boots and clothes, and showering). All three protocols were effective in preventing transmission of PRRS virus. For this reason it is recommended that the farm entrance be equipped with a shower or a Danish entrance including three areas: a contaminated zone, a transition zone with a shower or a sink, and a clean zone (the herd area). Implementing strict control of incoming personnel is also suggested (Broes and Boutin, 2002).

2.1.6 Other Animals and Insects

Cats and dogs should not enter buildings and neither should rodents and birds, nor should they have access to feed bins (Broes and Boutin, 2002).

Zimmerman et al. (1997) showed that mallard ducks are susceptible to PRRS virus and that the virus is excreted in feces and can infect pigs. For their part, Trincado et al. (2004b) showed otherwise. Due to the experimental conditions of their study, they were unable to demonstrate transmission of PRRSv from pigs to mallard ducks, or vice versa. Their possible explanation for this is that there are two main differences between the two studies: researchers did not use the same strain of virus and the ducks were not all the same age. Pitkin et al. (2009a), support the fact stating that it has been demonstrated that PRRSv infects only pigs and that no other mammal, bird or insect can serve as a biological vector for the virus.

It is also necessary to maintain proper control of insects by installing mosquito screens on air inlets, applying insecticides and cleaning the exterior of buildings (Vansickle, 2007a). Flies (Otake et al., 2004; Pitkin et al., 2009b) and mosquitoes (Otake et al., 2002c) can act as mechanical carriers and transmit PRRS under experimental conditions. Under field conditions, Schurrer et al. (2004) showed that flies could pick up the virus from PRRS-infected animals and transport it over a distance of at least 2.3 km.

2.1.7 Disposal of Solid and Liquid Manure

Even if PRRSv transmission through manure has not been clearly proven (Desrosiers, 2007), the washing and disinfecting of manure spreading equipment used on other farms is recommended, as too is avoiding the spreading of manure close to buildings (Broes and Boutin, 2002).

2.1.8 Vaccines

It is preferable that only vaccines recommended by a veterinarian are used (Broes and Boutin, 2002).

2.1.9 Needles

Pigs in commercial herds receive multiple injections of vaccines and antibiotics and, because of time and cost constraints, producers rarely change needles between animals (Otake et al., 2002d).The results from their study suggest that PRRSv contaminated needles can serve as mechanical vectors of infection.

Changing needles between sows for third trimester injections, or using a needle-free technology is recommended, so as to prevent inter-animal virus transmission through contaminated blood (Pitkin et al., 2009a).

2.1.10 Water

Water can be a passive carrier of PRRS virus, so monitoring water quality and treating it, if need be, is important (Synthèse élevage, 2006).

2.1.11 Air

Air is also a vector of transmission for PRRSv. For this reason is important to pay particular attention to the airtightness of buildings with an air filtration system and to the equipment in the buildings.

2.1.11.1 Air Infiltration in Buildings With Filtered Air

The main drawback to a building with filtered air and a negative pressure ventilation system (the fans take up stale indoor air and expel it outside), comes from potential stray air inlets or hard to control leaks that may be the door frames and windows, building joints, fan shutters, the loading dock, feed lines that pass through the exterior walls, etc. When the fans expel air to the outside, it creates a partial vacuum inside the building, allowing the entry of fresh air through the air intake, but also through all other openings. The whole envelope of a building under filtered air becomes a barrier against the entry of viruses and should be as airtight as possible, because the efficiency of a building under filtered air depends not only on the efficiency of the filtration system, but also on the building's airtightness.

2.1.11.2 Air Infiltration Through Intermittently Operating Fans

Technical trials carried out on Quebec farms equipped with an air filtration system and that had been infected with PRRS virus, revealed a significant risk of contamination by way of stray air inlets, i.e. unfiltered air. Smoke tests showed that traditional shutters are not sufficiently airtight and allow infiltration of potentially infected stray air.The significant level of air infiltration through the traditional shutters on intermittently stopped fans creates a significant risk for airborne infection of the herd.

A study by Alonso et al. (2012) conducted in a negative pressure ventilated building showed a real risk of introducing PRRSv may exist when there is an air inflow with a minimum speed of 0.76 m/s through temporarily non-operating fans that are protected only by conventional plastic shutters. This situation represents a major risk for buildings with a negative pressure ventilation system.

The study by Alonso et al. (2012) also aimed to validate commercially available products designed to prevent this risk. Five commercial products designed to prevent air infiltration through non-operating fans were tested: conventional plastic shutters, plastic shutters with the addition of a canvas cover, a nylon air chute, aluminum shutters combined with an air chute, and last, a double shutter system of aluminum plus conventional plastic shutters. Infiltration of PRRSv-contaminated air was observed in the tests on conventional plastic shutters and also on the plastic shutters with added canvas cover. There was no introduction of PRRSv observed with the other treatments.This study demonstrates that some of the tested solutions do not offer complete protection against air infiltration, and consequently, against risk of PRRSv infection. On the other hand, a double shutter system or shutters combined with an air chute appears to eliminate this risk.

The *Centre de développement du porc du Québec inc. (CDPQ)* also showed that traditional shutters are not sufficiently airtight and that it is possible to effectively reduce the air leakage by installing an anti-backdraft damper. Traditional shutters as well as four products available on the market, including the motorized shutter manufactured by the company Trolec, the spring-loaded aluminum shutter from Automated Production Systems (AP), the air chute and the No Backdraft from Conception Ro-Main were laboratory and farm tested. The airtightness and air flow restriction provided by these products were evaluated on two different wind tunnels. Of the four anti-backdraft systems evaluated (for a fan running at full speed and a static pressure of 0.1 inches of water, assuming a double protection while keeping the traditional shutters), two stood out for their effectiveness in reducing air infiltration: the air chute and the No Backdraft damper which, in combination with a traditional shutter, reduced air infiltration by 84% and 96% respectively, compared to traditional shutters alone. Concerning restriction of air, the combination of air chute and traditional shutters (the double protection recommended) creates more air flow restriction, giving a 23% reduction compared to a fan with the traditional shutters, while the No Backdraft, with traditional shutters (double protection), represents a 15% decrease (assuming an on/off type fan operating at maximum flow and 0.1 in. water static pressure).

Nagorske et al. (2012) also reported obtaining interesting results during testing on the effectiveness of the new anti-backdraft damper, No Backdraft, for preventing the entry of stray air through non-operating fans in a negative pressure system.The anti-backdraft damper installed on a non-operating fan prevented the transmission of an artificial aerosol containing PRRSv that was misted directly toward the damper, whereas the PRRS virus was found inside the building when the damper was intentionally left open.The damper also prevented transmission of the virus when the fan on which it was installed was turned off and on while continuously misting virus at it.

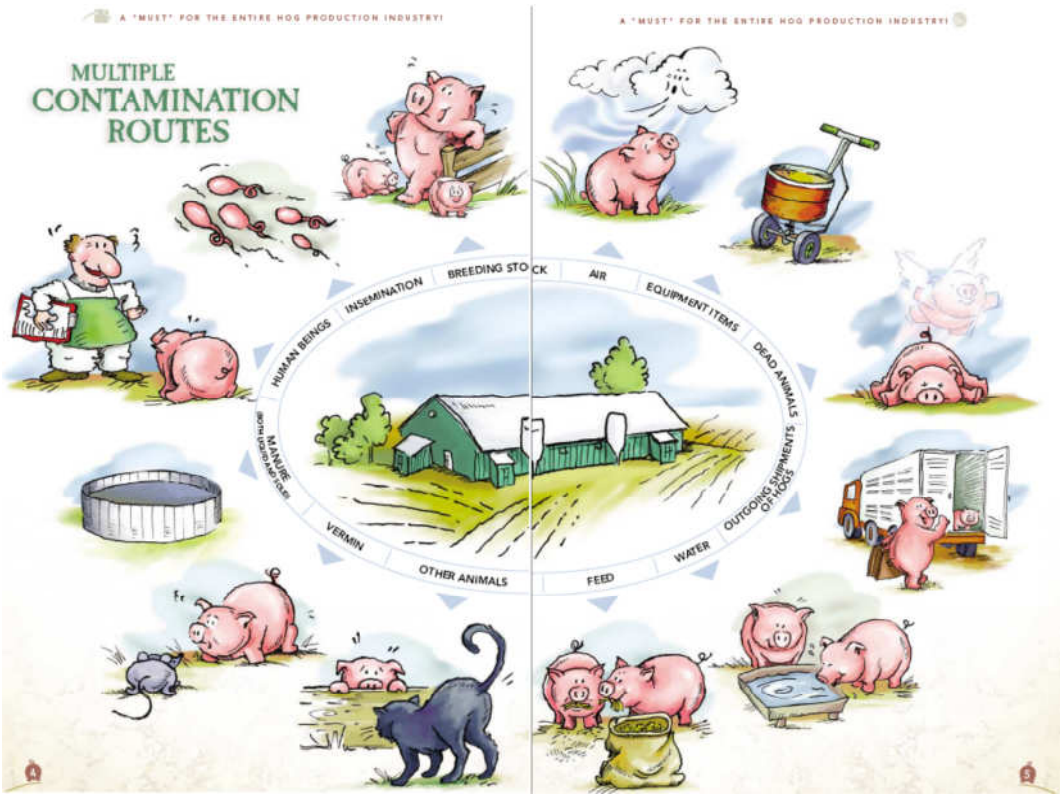


Figure 2-1. Multiples Routes of Contamination
(From : Biosecurity : A "Must" for the Entire Hog Production Industry)

2.2 The Importance of Biosecurity

Biosecurity must be part of every program designed to prevent introduction of PRRS into a herd. The importance of biosecurity was recently emphasized by Pitkin et al. (2007), who evaluated its influence on PRRS virus transmission. The model included three naïve buildings, with different biosecurity levels, all located 120m from a contaminated building. The first building (no intervention), represented a low biosecurity level, the second (applying a biosecurity protocol aimed at controlling insects, inanimate objects, employees and transport) represented a medium biosecurity level, and the third (equipped with an air filtration system and applying the same biosecurity protocol as the second model), represented a high biosecurity level. The study lasted one year and the protocol was repeated 26 times. Vansickle (2007a) reported that there was no virus transmission in the building with a high biosecurity level, while the building applying a medium biosecurity level was infected with PRRS in 31% of cases (aerosol transmission was identified as the source of infection). The building with no biosecurity protocol was infected via different sources in 66% of cases. These results clearly prove that implementation of biosecurity protocols reduces the risk of introducing PRRSv into a herd, and that an air filtration system provides additional protection.

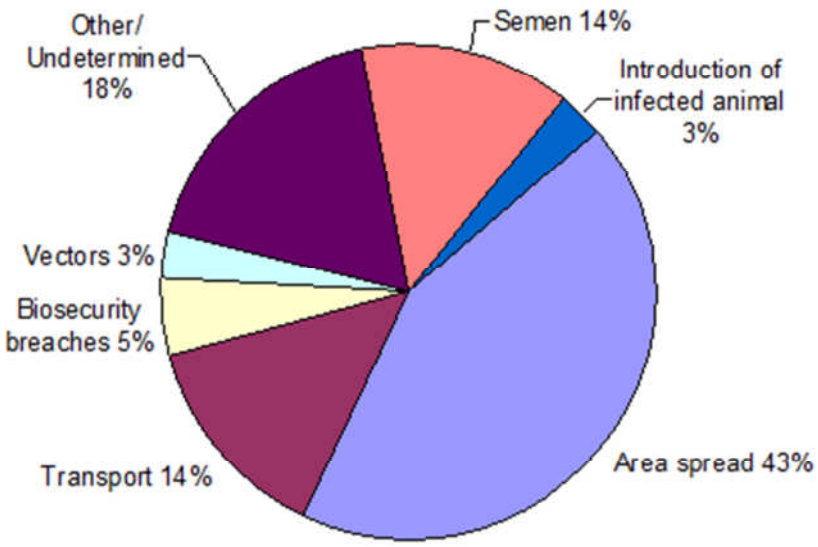
3 Epidemiological Studies on PRRS Transmission

Several epidemiological studies provided evidence of aerosol transmission of PRRS between pig farms.

Using a geographical information system, Zhuang et al. (2002) collected data from 344 herds participating in a PRRS surveillance program in Denmark; as well as from neighbouring herds. Analysis showed that the risk for PRRS infection of a herd increases with the density of infected neighbouring herds, and decreases with the distance between them. Mortensen et al. (2002) also conducted an epidemiological study on risk factors that can influence farm contamination. They showed that presence of infected neighbours within a 3 km radius increases infection risk, and that such risk depended on the distance to the infected farms, the size of the infected farms and the exposure period. They suggest that aerosol transmission is frequent, since infection risk was not affected by implemented biosecurity measures but was strongly influenced by factors affecting aerosol dispersion. Indeed, Stärk (1999) stresses that if risk factors such as herd size, distance between the closest infected herds, size of the nearest infected herds, and regional animal density influence disease transmission, it is very probable that airborne transmission is involved, since these factors play a crucial role in aerosol dispersion.

Other epidemiological studies that included virus sequencing, provided additional evidence of PRRS aerosol transmission between farms. Genomic characterization provides valuable information because the PRRS virus is highly variable. This technique amplifies and sequences the ORF5 region of the viral genome in order to compare information between strains and determine their homology percentage (D'Allaire, 2003). Lager and Mengeling (2000) were the first to identify similar or identical strains of the virus in different herds. Following the appearance of a case of PRRS in Iowa, they sequenced the ORF 5 region of samples taken from seven unrelated herds located in the same region (the farthest 33 km away). Six of seven herds were infected with identical strains (99.5 to 100% homology), and the seventh was infected with a similar strain (96.5 to 98% homology). These results led researchers to conclude that regional transmission, implying aerosol transmission, of the virus had taken place.

Torremorell et al. (2004a and 2004b) analyzed 35 cases of PRRS infection in negative herds in Iowa, Minnesota, Kansas, Wisconsin, South Dakota, Indiana and Colorado. The source of replacement animals and semen for those herds were PRRS-negative. During the study, the artificial insemination center became infected which explains the high infection ratio through contaminated semen (Torremorell, November 2007, personal communication). For each case, the virus genome was compared with other genomes present in the region to determine contamination source. It was concluded that introduction of contaminated semen (14% of cases) or infected animals (3% of cases) was not the main source of the virus, since 83% of the cases of infection were not associated with this mode of transmission (Figure 3-1). In 43% of cases, regional transmission was identified as the mode of transmission. Transport, pig movement, biosecurity breaches and carriers such as insects, were also evaluated as potential contamination sources. Torremorell et al. (2004b) concluded that herd location, animal transport and breaches in biosecurity protocols played a crucial role in herd infection. Their conclusions also indicated that the majority of infections occurred during the cold season, which indicates better survival of the virus under cold and humid conditions.



(Adapted from Torremorell et al., 2004a and 2004b)

Figure 3-1. Possible Causes of PRRS Virus Infection in 35 Naïve Herds

Larochelle et al. (2003) evaluated genetic variation among PRRS strains sourced from 250 Quebec herds and identified the relationships between strains to better understand propagation of the virus. They determined that the main relationship between strains of a similar group was regional propagation (33% of cases). Aerosol transmission was suspected when herds, infected with a similar strain, belonged to different owners dealing with different feed and animal suppliers, and with different technical advisory teams (about half of the cases). In 40% of cases where regional propagation was suspected, herds were separated by less than 3 km and, in 37% of the cases, distance was 3 to 10 km. The majority of cases occurred during fall and winter (between November and April), reducing the probability of insect transmission.

Other epidemiological studies demonstrate that genetic homology between PRRS strains decreases with distance between herds (Mondaca-Fernandez et al., 2006). However, the study by Goldberg et al. (2000) is the exception as it did not demonstrate any link between the genetic resemblance of the virus and geographic proximity of farms.

4 Importance of Porcine Reproductive and Respiratory Syndrome (PRRS)

Porcine reproductive and respiratory syndrome virus causes devastation across the world and generally infects 60 to 80% of swine herds when present in a country (Zimmerman, 2003). In 1990, 1995 and 2000, the United States Department of Agriculture (USDA) carried out three studies on PRRS prevalence in the US. Their results show that at least one animal was PRRS seropositive in around 36% of non-vaccinated breeding herds in 1990, 48% in 1995 and 62% in 2000 (USDA, 2005). The virus is also widespread in Canada. In 1999, Dewey reported that 80% of Canadian herds were considered infected with the virus, with a higher prevalence in swine dense areas of Nova Scotia, as well as south-western Ontario and Quebec. According to Mussell et al. (2011), there are no statistics on the prevalence of PRRS virus in Canadian pig farms; instead of official statistics, we reference experiments in connection with the PRRS virus to provide estimates of the general effect. For example, the *Fédération des producteurs de porcs du Québec (FPPQ)* found that 60% of farms are affected every two years by an outbreak of PRRS and 30% every four years (Pettigrew, 2011). The *Faculté de médecine vétérinaire* at the *Université de Montréal* (FMV, 2007) mentions that up to 90% of swine herds are PRRS-infected in areas with high animal density. In Quebec generally, 50% of finishers could be infected with PRRSV (Moore, 2006).

In its report to the *Commission sur l'avenir de l'agriculture et de l'agroalimentaire québécois*, the FMV stresses that PRRS is the most costly disease in the North American swine industry. It estimates losses for the Canadian sector at around $150 million per year (FMV, 2007). A single Canadian hog producer can incur losses of between $250 and $460 per sow per year if a herd is infected with chronic PRRS or affected by a new acute infection (Mussel, 2010). In Quebec province, losses are estimated at $322.89 per sow per outbreak (Surprenant, 2010). For American producers, economic losses from PRRS amount to approximately $664 million US per year or $1.8 million US per day (NPB, 2011). Malakowsky (2011a) mentions that in a farrow-to-wean herd, the cost of a PRRS outbreak is between $80-170 US per sow depending on the scale of the outbreak.

In their review on the potential financial impact of PRRS, Holck and Polson (2003) summarized several studies. Referring to Hoefling (1992), Polson et al. (1992) and Dee et al. (1997), they concluded that PRRS outbreaks in a breeding herd lead to losses of around $250 US per sow. They also determined that, according to the information provided by Dee and Joo (1993), Kerkaert et al. (1994), and Dee and Joo (1994), as well as Polson et al. (1994), losses due to persistent PRRS infection in farrowing and finishing herds vary from $6.25 US to $15.25 US per pig. Losses include, among others, financial losses due to increased mortality, decreased reproductive performance, significant increase in other diseases, purchase of antibiotics and vaccines, as well as increased cost for diagnosis.

Albina (1995) reported that PRRS has two phases and affects herds for a very long period. First, the virus spreads massively and affects animals severely. It then remains endemic within the herd and can persist for more than 16 months after the initial infection. It has devastating effects, especially as it predisposes pigs to contract opportunistic infections by altering their immune system defences (Châtillon et al., 2004). Among these secondary infections are *Streptococcus suis* and *Haemophilus parasuis*. Considering the less than adequate success of traditional PRRS control methods (Cho and Dee, 2006), many researchers are currently looking for methods to prevent the introduction of PRRS virus into swine herds.

Haden et al. (2012) confirmed that a combination of two pathogens has more impact on performance and generates greater losses compared to the impact these same two pathogens generate separately.The combination with the greatest economic impact is the PRRS-influenza combination, which causes losses of $10.41 US per space in the herd site.

5 Air Filtration in Swine Buildings

Insemination centres in Brittany (France) were the first pig farms to install air filtration systems. These barns were equipped with HEPA (High Efficiency Particulate Air) filter systems. Because of the significant pressure drops associated with HEPA systems, these buildings had to be ventilated under positive pressure. Toward the end of the 1990s, farrow-to-finish producers performing genetics selection began to introduce positive-pressure HEPA systems (Coudé, 2004).

The first air filtration systems in North American swine barns appeared in Canada, specifically in Quebec province, in 2003. Two artificial insemination centre sites were equipped with HEPA filters and ventilated under positive pressure. Today, HEPA filters are used in almost all major artificial insemination centres in Quebec. In 2004, a farrow-to-finish producer also adopted a HEPA system.

Beginning in 2005, the high costs of HEPA systems resulted in negative-pressure ventilation research and development initiatives in both the US and Canada. To reduce costs and to facilitate retrofits, this research focused on negative-pressure ventilation.

To date in Canada, there are around 30 pig farms equipped with an air filtration system (thirteen boar farms, three farrow-to-finish sites, eight farrowing facilities and three gilt development units), most of them located in Quebec province. In the United States, 98 buildings are currently equipped with an air filtration system (including among others, 62 farrowing facilities and 26 boar studs) (Reicks, 2012, personal communication).

6 Air Filtration Systems

6.1 Methods of Filter Certification

In North America, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) established standards which enable measurement of filter efficiency and cross comparison among them (U.S. Environmental Protection Agency, 1997). In Europe, the European Committee for Standardization (CEN) sets the standards (Zhou and Shen, 2007). The International Organization for Standardization (ISO) is currently developing a standard that will be internationally recognized. However, the development of this international standard may take several years because there are many well-established national standards across the world and they have big differences in laboratory testing methods and classification systems (Tronville, 2008). In America and Europe, ASHRAE 52.2-2007 and EN779: 2002 are the most recent test methods. They measure the effectiveness of filters according to particle size (Zhou and Shen, 2007).

The EN779:2002 method determines the average efficiency of the filter for 0.4µm sized particles. Filters with an average efficiency of less than 40% for 0.4µm particles are called coarse filters (type G) and the rest are fine filters (type F). Coarse filters can be classified G1 to G4 while fine filters can be classified F5 to F9. Example, an F9 rated filter has an efficiency greater than 95% for particles of 0.4µm (Zhou and Shen, 2007).

The ASHRAE test method 52.2 measures filtration efficiency for three particle groups: 0.3 to 1µm (E_1); from 1 to 3µm; (E_2) and 3 to 10µm (E_3) .It provides an overall efficiency value expressed on a scale from 1 to 16, called the Minimum Efficiency Reporting Value (MERV) (Table 1). For example, MERV 14 rated filters have a 75% to 85% efficiency, MERV 15 rated filters an 85% to 95% efficiency and MERV 16 rated filters have an efficiency greater than 95%. In addition, MERV 8 rated filters have a >70% efficiency for particles from 3 to 10µm and MERV 12 rated filters have a >80% efficiency for particles from 1 to 3µm (Zhou and Shen, 2007).

Dutertre et al. (1995) presented different filter testing methods. The gravimetric ASHRAE method measures the efficiency against large particles of filters used as pre-filters. Caution should be exercised in interpreting values derived from this method, since the efficiency of a filter is calculated from the mass of dust not retained by the filter, so the higher the value less dust is retained. There is also the opacimetric ASHRAE method used for high efficiency filters. High efficiency filters rated MERV 13 to 16 have an efficiency of 80% to 95% for particles between 0.3 to 1µm in diameter; filters rated MERV 9 to 12 have a filtering capacity of 40% to 75% for particles between 1 to 3µm in diameter (Rosenthal, 2007). Finally, the dioctylphtalate (DOP) method enables performance evaluation of very high efficiency filters, such as HEPA filters. The European Committee of Aerial Material Manufacturers has defined a EUROVENT filter classification based on these three methods (Dutertre et al., 1995). Filters tested according to the gravimetric method are rated EU 1 to EU 4; filters tested according to the ASHRAE opacimetric method are rated EU 5 to EU 9, and filters tested according to the DOP method are rated EU 10 to EU 14.

Note that the ASHRAE classification is based only on mechanical filtration and does not take into account the antimicrobial properties of some filters. There is no standard rating for antimicrobial or antiviral filtration.

Table 1 MERV Ratings for Air Filters

MERV Rating	Average Efficiency			Filtration Capacity (ASHRAE 52.1)
	E1 0.3 – 1.0 µm	E2 1.0 – 3.0 µm	E3 3.0 – 10.0 µm	
1	-	-	< 20	< 65 %
2	-	-	< 20	65 – 69.9 %
3	-	-	< 20	70 – 74.9 %
4	-	-	< 20	75 % ≤
5	-	-	20 – 34.9	-
6	-	-	35 – 49.9	-
7	-	-	50 – 69.9	-
8	-	-	70 ≤	-
9	-	< 50	85 ≤	-
10	-	50 – 64.9	85 ≤	-
11	-	65 – 79.9	85 ≤	-
12	-	80 ≤	90 ≤	-
13	< 75	90 ≤	90 ≤	-
14	75 – 84.9	90 ≤	90 ≤	-
15	85 – 94.9	90 ≤	90 ≤	-
16	95 ≤	95 ≤	90 ≤	-

A filtration system must be able to effectively stop PRRS virus. It is important to fully understand how the virus presents itself, in order to select an appropriate filter. Reicks (2006) reported the diameter of four pathogens affecting swine and transmissible in air: porcine influenza virus (0.080 to 0.120 µm), PRRS virus (0.050 to 0.065 µm), porcine circovirus (0.0017 to 0.0022 µm) and Mycoplasma (0.3 to 0.9 µm). Because the size of influenza virus, PRRS virus, and porcine circovirus is less than 0.2 µm, they should, theoretically, pass through a HEPA filter. However, since viruses in the free state do not survive well, they are often transported by aerosols (Dutertre, 1995). Aerosols consist of finely divided matter suspended in the atmosphere, such as dust, smoke or fog (Hirst, 1995). When aerosols contain particles that can affect living organisms (e.g. virus) the term “bioaerosols” is used. According to Hirst (1995), bioaerosols have a diameter varying from 0.5 µm to 100 µm; therefore it is possible to intercept the transported virus with the aid of HEPA or other kind of filters.

Various types of filters were evaluated in terms of their effectiveness at preventing airborne infection of swine herds by PRRS virus and mycoplasma. These filters can have a mechanical or antimicrobial action.

6.2 HEPA Filters

According to Reicks (2009), swine influenza and PRRS viruses are both able to pass through HEPA filters, but the particles carrying them, usually bioaerosols of 0.4 to 0.7µm, cannot.

Dee et al. (2005b) evaluated the capacity of a HEPA-type filtration system to prevent aerosol transmission of PRRS virus. This HEPA filter (high efficiency filter against airborne particles) retains ≥0.3µm particles with a 99.99% efficiency rate. Two devices were set up for this experiment. The devices had two chambers connected by a 1.3m long rectangular duct. One of the devices had a filtration system from Fancom Agri-Computers adapted for this experiment, that filtered air between the two chambers while the second experimental device was not filtered. The filtration system had three filtration levels, a 20% passing gravimetric galvanized metal pre-filter to stop insects and debris, a 95% opacimetric filter bag rated EU 8, and a 99.99% DOP HEPA filter rated EU 13. Five pigs infected with the MN-184 virus strain were placed in the first chamber and a naïve pig in the second one. In the non-filtered setup, virus transmission occurred in six of 20 repetitions while in the filtrated setup, none of the 20 pigs became PRRS-positive, thereby proving that HEPA filtration significantly reduces airborne transmission of PRRS virus.

In 1996 Fancom Eurl was the first company to install a HEPA-type air filtration system in a swine farm (Innovet, 2006). In 1997, Cooperl proposed installation of this system to its breeding stock herds (Coudé, 2004). Fifteen farms in Brittany, France‘s most populated swine area, are now equipped with the system (Leriche, P., February 2008, personal communication). Eleven additional farms are equipped with similar filtration systems from other manufacturers and since then, none has lost their PRRS-negative status (Desrosiers, 2005).

To operate using this system, the building must be equipped with a positive-pressure ventilation system (Dee et al., 2005b). The *Centre d'insémination porcine du Québec* paid over $1 million for the acquisition and retrofitting required to install the system (550 boars in total) (Parent, 2004). In France, installation cost ranges between €1000 to €1,500 per sow in a farrow-to-finish facility, and €500 to €1,000 per boar for an insemination center (Desrosiers, 2005). Because of its high cost, most commercial herds cannot consider installing HEPA filtration. This is why research continues in order to find a less expensive filtration system (Desrosiers, 2004).

6.3 Antimicrobial Filters

The filter developed by the Quebec company, Noveko inc.,offers an innovative technology in the field of air filtration. A patented solution of virucides, bactericides and fungicides are incorporated into the polypropylene fibers of the filter during manufacturing (Noveko, 2008). The filter has several antimicrobial membrane layers enabling mechanical filtration combined with the antimicrobial action of the agents integrated in the fibers. These antimicrobial agents render viruses and bacteria inactive upon contact. This filter was developed specifically for easy adaptation of existing agricultural structures. It is available with either 10 or 15 layers for two levels of protection; the number of layers can also vary according to need. In addition, two models are offered with a different capacity and shape: a cube filter for use with ceiling inlets, and a curtain filter for use with exterior linear wall inlet vents or inlet baffles. This filter is washable. However, the manufacturer recommends the use of a pre-filter to limit filter clogging and reduce washing frequency.

Three physical mechanisms take place when particles pass through the filter and allow the blocking and sanitizing of PRRSv: inertial impaction, interception and diffusion (Noveko, 2008).

Dr.Batista of the *Université de Montréal* demonstrated the effectiveness of the Noveko antimicrobial filtration system in blocking the passage of PRRSv (Batista et al., 2008a). Dr Dee at the University of Minnesota confirmed its filtration efficiency and also demonstrated that the Noveko antimicrobial filter inactivated PRRSv (Dee et al., 2009c).

Dr. Batista also evaluated the effectiveness of Noveko filters after they had had 16 months of exposure to the environmental conditions of commercial swine production. Under the experimental conditions of this study, the results showed that Noveko technology maintains its performance in preventing airborne transmission of PRRSv for at least 16 months of continuous use in a swine building exposed to extreme climatic conditions (Batista et al., 2009).

The Noveko system can be installed on various types of air intakes on existing buildings under negative pressure ventilation (Noveko, n.d.). In such buildings, fans expel the air to the outside, creating a slight negative pressure and causing air to be drawn in through the air inlets (MWPS, 1990). The filter was designed to minimize air restriction and ensure the static pressure inside the building does not exceed 0.1 inches of water when the ventilation is operating at full capacity (100%) in summer.This precaution reduces air infiltration through unfiltered openings in the building (Bonneau et al., 2009).

In 2008, the costs of using Noveko antimicrobial filters in a farrowing building were estimated at around $2 per piglet weaned.These costs are calculated for a standard filtration system with 10 layers of antimicrobial filters, washed three times annually and replaced every two years (Batista et al., 2008b). Today these costs are significantly less.

6.4 Mechanical Filters

Mechanical filters capture airborne particles when they come into contact with the filter media and adhere to its fibres. There are currently two manufacturers of mechanical filters for swine barn installations: Camfil Farr and AirGuard®. Both have developed V-box pleated filters.

For swine barns, Camfil Farr offers its PathogenBarrier filter, available in L6 (MERV 14) and L9 (MERV 16). The L9 offers the best level of protection, while the L6 can be used in lower-risk situations. AirGuard® also makes a V-box filter, the Vari+Plus® AG, which has a MERV 15 rating. These mechanical filters are not washable, and use of an upstream pre-filter is necessary to eliminate coarse particles and extend the lifespan of the filter.

The standard used on the pig farms used to correspond to the MERV 16 classification, but for the past three years and for reasons related to cost, some U.S. farms have started to use MERV 14 classified filters (Devries, 2012). Some studies have shown that this type of filter significantly reduces the risk of airborne infection of livestock (Dee et al., 2010; Dee et al., 2011).

6.5 Evaluation of the Potential of Different Filters to Intercept the PRRS Virus

Dee et al. (2006a) tested other types of filters with the potential to stop PRRS virus transmission. The same experimental model was used, but this time, a mister aerosolizing the virus replaced the infected pigs. Three filtration methods were tested: HEPA type filtration, an ultraviolet (UV) irradiation system and a system containing a mosquito screen (prefilter), a

fibreglass furnace filter (MERV 4) and a furnace electrostatic filter (MERV 12) rated EU 3. The HEPA filter was significantly more efficient than the others, since none of the ten pigs became PRRS-positive. Nine out of ten pigs became PRRS-positive when no filter was used, eight out of ten for the UV irradiation system, and four out of ten for the mosquito screen-furnace filter combination.

In a subsequent experiment, Dee et al. (2006b) used the same model to test four filtration methods: HEPA type filtration; a HEPA-like system (Cho and Dee, 2006) containing a pleat-in-pleat V-bank disposable 95% DOP filter with an efficiency for particles ≥0.3µm in diameter, and an EU 9 and MERV 15 rating; a system composed of a 20% passing gravimetric galvanized metal pre-filter and a 95% opacimetric bag filter rated EU 9 and MERV 15, and finally a system with a mosquito screen (pre-filter), two fibreglass furnace filters (MERV 4) and two furnace electrostatic filters rated EU 3 and MERV 12. In the first phase of the experiment, none of the 10 pigs became PRRS-positive when the HEPA filter or the HEPA-like filter were used, while two out of ten pigs became PRRS-positive when the bag filter was used, four out of ten when furnace filters were used and all ten became PRRS-positive when no filter was used.

In the second phase of the experiment comparing the HEPA filter to the HEPA-like filter, only the HEPA filter prevented virus transmission completely (all pigs remained PRRS-negative for all sixty-six repetitions), while two of sixty-six pigs became PRRS-positive in the system with the HEPA-like filter. Since the HEPA-like filter usually retains particles from 1.0 to 10.0 µm with an efficiency rate of 90%, it should have shown better efficiency with 0.5 to 100µm diameter sized particles, as reported by Hirst (1995). Dee et al. (2006b) pointed out that the particles aerosolized by the mister were between 0.3 µm to 3.0 µm in diameter. Accordingly for Dee (2006b), the 95% DOP for ≥0.3 µm filter can represent an interesting option, considering its installation cost, its compatibility with a negative pressure ventilation system, and the level of risk that producers are willing to accept.

The 95% DOP for ≥0.3 µm filter tested by Scott Dee and his team has been installed in some farms in the US and it appears to prevent introduction of the PRRS virus, influenza virus, as well as *Mycoplasma hyopneumoniae* (Dee, 2007). According to Dee (2006), it has the advantage of working in negative pressure ventilation system buildings and costing 10% of a HEPA type filtration system. Pohl (2007) reports satisfying results with no recurrence of disease in any of four insemination centers of 200 to 250 head. One of these insemination centers had a PRRS episode in 2005, when PRRS broke out on a farm situated about 1.25 km away. In 2006, Dr. Reicks reported having worked for a 13 month period with nine insemination centers that had installed a 95% DOP for 0.3 µm filtration system. He established that the cost of a 95% DOP negative pressure system ranged from less than $30 to $100 US per boar space without air conditioning or from $330 to $430 US with air conditioning. The equivalent cost of a positive pressure HEPA system ranged from $300 to $600 US per boar space without air conditioning, or from $1000 to $1200 US with air conditioning. Vansickle (2007b) reported that after two and a half years of work with 15 enterprises located in high density swine areas in Minnesota that had installed different filtration systems, Dr. Reicks did not observe any PRRS appearance during complete filtration periods. Three PRRS episodes occurred during the summer when air was not filtered; about 75% of these farms had gone through previous PRRS episodes.

6.6 Air Filtration System Performances

Since the primary objective of a filtration system is to purify the air, filtration efficiency is the first factor to take into consideration when selecting a filter (Eurovent/Cecomaf, 2005). Once the necessary level of protection has been established, the second important factor to consider is the filter air resistance, and thus, the pressure drop caused by the filter (Pearson and Owen, 1994). The loss of pressure represents the energy required to overcome the frictional forces of the filter impeding the free flow of air. It is equal to the difference between the static pressures measured on each side of the filter (Pearson and Owen, 1994). Even though the filter is a passive element and does not consume energy directly, the pressure loss it creates directly affects the energy consumption of the fans (Eurovent/Cecomaf, 2005).

These two elements, efficiency and pressure loss, vary according to: filter structure (e.g. degree of clogging), operating conditions (e.g. air velocity) and type of filtered aerosol (e.g. particle size) (Thomas et al., 2001). In general, operating conditions and the type of aerosol filtered, remain largely the same throughout the life of the filter. However, as it gradually becomes clogged, filter structure itself evolves. This is why the gradual clogging of the filter, because of its large influence on the performance of the filtration system and filter lifespan, is a major factor in the evolution of the performance of a filtering system (Penicot et al., 1999).

For this same reason, when the time comes to select a filter, calculations should not be limited to purchase price only, but rather the total costs accrued over the whole time that the filter is in use (Burroughs, 1998). The total cost of a filter's lifespan includes the initial investment for purchase and installation, plus the amounts invested in energy, maintenance and disposal (Eurovent/Cecomaf, 2005). Amounts invested in energy dominate the cost analysis and depend very much on the loss of pressure brought about by the filter (Burroughs, 1998).

Therefore, if the air flow remains constant, resistance and filtration efficiency will gradually increase as the filter clogs (Kowalski and Bahnfleth, 2002). However, even if the behavior of clean filters is well known, how they behave during clogging is still not fully understood (Penicot et al., 1999). Thomas et al. (2001) compiled a table of events that occur during the clogging of a HEPA filter. At first, when the filter begins to absorb particulate matter, efficiency increases dramatically until a crust, called filter cake, is formed. From this point on, the increase in efficiency is reduced. It then becomes more difficult to predict the filter behavior and the evolution of its performance. According to Burroughs (1998), filters that show a less pronounced evolutionary curve of pressure loss, or that are changed at an earlier point during the increase in their resistance, show a more positive energy use.

Filter lifespan depends on the evolution of its resistance, which can vary from three to five years. Usually pre-filters are washed or replaced every six or twelve months. This is why installation of electronic gauges that indicate the level of filter contamination and control the loss of pressure generated by the filter during its use, are recommended (Burroughs, 1998). For optimization of the overall cost of a filter's lifespan, the time to replace it should not exceed the moment at which it reaches twice its initial pressure loss or three quarters of the distance between the initial and the final recorded pressure loss (Burroughs, 1998).

In cases where the air filter contains excessive amounts of large particles, the addition of pre-filters to the filtration system can be shown to be quite cost-effective (Burroughs, 1998). Davis and Kim (1999) studied the effect of prefiltration on the performance of HEPA filters and found that the presence of pre-filters was beneficial for each scenario assessed. Pre-filters increased the lifespan of the HEPA filters from 58% to 78%.They also resulted in savings of

20% to 29% on filter purchase cost, including the amounts for purchasing pre-filters.They also reduced the volume of used filters from 24% to 33%, thereby lowering disposal costs. Burroughs (1998) cautions however, that pre-filters are not recommended in all situations. As they are part of the filtration system, the pressure loss that they cause plus their purchase costs, maintenance and disposal should be taken into account when calculating the overall cost of the filtration system. In certain cases, even if they increase the life of the main filter, they can double energy costs, double filter purchasing cost and increase the labor and disposal costs by up to eight times. In addition, by preventing clogging of the main filter, they hinder improvement of its efficiency.

One other factor can also influence the performance of a filtration system: microbial growth. It has been shown that the filters are susceptible to fungal colonization (Price et al., 1993, Kemp et al., 1995, Simmons et al., 1997).Viruses do not multiply in the environment (Kuehn et al., 1991), but bacteria and fungi can use both the filter and the filter cake as a growth substrate (Verdenelli et al., 2003). The accumulation of organic matter on the surface of the filter does not need to be sizeable for mold to develop (Simmons et al., 1997). According to Price et al. (1993), organic matter on the surface of the filter appears to have little influence on the development of mold. High humidity is the environmental factor with the greatest influence on development of mold in an air filtration system.

Microorganisms growing on the surface of a filter can affect its integrity (Verdenelli et al., 2003). They can also produce volatile organic compounds that pass through the filter and contaminate the air (Ahearn et al., 1997). Colonized filters can even become a source of pathogens (Verdenelli et al., 2003).

Given that bacterial spores and fungi can survive for long periods on new and used filters (Maus et al., 2001) and live through periods of low humidity, Simmons et al. (1997) recommend that facilities that are periodically exposed to high humidity, use filters resistant to fungal colonization. The effectiveness of antimicrobial treatments incorporated in the air filter itself remains, however, a controversial topic. Several studies have demonstrated the efficacy of antimicrobial treatments in reducing microbial colonization, the deterioration of the filters by mold and the release of microorganisms downstream from the filters (Price et al., 1993; Simmons and Crow 1995; Foarde et al. , 2000; Verdenelli et al., 2003; Cecchini et al., 2004). On the other hand, the antimicrobial must be applied evenly to prevent parts of the filter from being colonized and the filter losing its effectiveness (Simmons and Crow, 1995). In addition, a nonvolatile antimicrobial, linked to or embedded in the filter fibers, is recommended (Price et al., 1993). It is also necessary to be aware that there are different types of antimicrobial agents and not all have the same degree of effectiveness, and that certain parameters can affect their efficiency (Foarde et al., 2000). Following a study on the ability of various antimicrobial agents to inhibit the growth of microorganisms on filters, Foarde et al. (2000) reported that, although they are effective on clean filters, the antimicrobial treatments evaluated were not effective on filters clogged with dust. Foarde et al. (2000) also stressed the importance of testing the efficacy of the products after they enter the filter, in order to take into account the interactions that occur between the antimicrobial and the filtering medium.

6.7 Efficiency of Air Filtration

It is not only herds free from PRRS virus that would benefit from the installation of an air filtration system; herds already infected with the virus would also benefit since they would be protected against airborne introduction of new strains of the virus (Dufour, 1995). Several studies have shown that air filtration reduces significantly the risk to a herd of infection.

According to Reicks (2010), on 38 selected farms (21 boar sites, 12 farrowing sites, 3 research farms and 2 finishing sites), air filtration reduced the annual outbreak rate from 34% before filtration to 8% after partial filtration, and 4% for 100%-filtered farms. These statistics are based on the number of farm-years, i.e. the number of years of the farm's existence in the five years before implementation of air filtration, since some farms were in existence for less than five years at the moment of filtration.

Dee et al. (2010) reported the results of a pilot study conducted on a commercial scale for a period of one year (September 2008-August 2009) at seven herd sites located in high pig density areas of southern Minnesota and northwest Iowa.Two farms were equipped with an air filtration system (negative pressure), one using a MERV 16 filtration system and the other a MERV 14 (Camfil Farr), while the five other farms were not air filtered. During the study, the two farms with filtered air showed no clinical evidence of infection and no introduction of virus. For their part, the five farms without air filtration systems were infected with new strains of PRRSv.

A four-year study by Dee et al. (2011) at the University of Minnesota's experimental farm, representing a model of regional production, was used to assess the ability of commercial air filters to protect livestock against airborne transmission of PRRSv and *Mycoplasma hyopneumoniae (M. hyo.)*.This study was used to simulate the contamination of naive farms. Four buildings were involved: Building 1 was the source of bioaerosols in the vicinity (PRRSv and *M. hyo.*-infected pigs) and was located 120m away from the other buildings.The other buildings contained naïve pigs. Building 2 was not filtered as a control, while Buildings 3 and 4 were filtered using different types of filters, mechanical and antimicrobial respectively (Table 2). Several repetitions were held during the study; a repetition comprised one batch of 10 to 20 pigs for a period of 2 to 4 weeks.

Table 2 Summary of Tests Performed During the Four-Year Study

Year	Pathogens Tested	Types of Filters Tested
1	PRRSv	Building 1: infected Building 2: not filtered Building 3: MERV 16
2	PRRSv and *M. hyo.*	Building 1: infected Building 2: not filtered Building 3: MERV 16
3	PRRSv and *M. hyo.*	Building 1: infected Building 2: not filtered Building 3: MERV 14 Building 4: antimicrobial
4	PRRSv and *M. hyo.*	Building 1: infected Building 2: not filtered Building 3: MERV 15 electrostatic Building 4: previously used antimicrobial filter (2 years of use on pig farm)

Airborne transmission of PRRSv and *Mycoplasma hyopneumoniae* was found in 43% and 34% of the repetitions done in Building 2 (unfiltered).However, no infection was found in Buildings 3 and 4, irrespective of the type of filter used (Table 3). All the types of filters tested reduced the risk of airborne transmission of these pathogens in equal measure.

Table 3 Summary of Episodes of Animal Infection During a Four-Year Study by the University of Minnesota, According to Pathogen and Type of Filter Used

Pathogen	Without Filtration	Type of filter				
		MERV 16	MERV 14	Antimicrobial (new)	Antimicrobial (previously used)	MERV 15 Electrostatic
PRRSv	28/65	0/39	0/13	0/13	0/13	0/13
Mycoplasma hyopneumoniae	17/39	0/13	0/13	0/13	0/13	0/13

To analyze the occurrence of new PRRSv infection, Dee et al. (2012) conducted a study of 38 selected herd sites between September 2008 and January 2012. The effect of air filtration over the long-term on reduction in occurrence of new PRRSv infections was demonstrated. This study included the likelihood of infection in filtered herds (under negative pressure ventilation and using Camfil Farr or Clarcor filters) and in non-filtered herds, as well as the likelihood of infection before and after implementation of filtration.The results showed that the rate of new infections in filtered herds was significantly lower than in the non-filtered herds.The odds of a new infection in the herds before filtration was approximately eight times greater than after implementation of filtration. During the study, eight new introductions of PRRSv occurred in the filtered herds while there were 89 new introductions in the non-filtered herds.

According to Reicks (personal communication, 2012), in September 2012, the annual infection rate for all types of production on 98 American farms rose to 61% before the installation of air filtration systems and fell to 13% following the implementation of air filtration. For 62 farrowing units, the infection rate was 80% and fell to 25% after implementation of air filtration systems.

In February 2013, following implementation of air filtration, the number of episodes of PRRS on 20 Canadian farms was 14, based on 51 farm-years (an annual infection rate of 27%). At the end of 2011, 16 farms in the United States were found to be infected within the space of five to six weeks (Reicks, 2012, personal communication). This situation raised questions as to whether these infections had been brought about by the lifespan of filters, viral load, the construction and finishing of the buildings (airtightness) or backdrafting through the fans.

6.8 A Summary of the Costs

The costs of implementing air filtration may vary depending, among other things, on changes made to the building and the level of filtration that is wanted. Return on investment will vary considerably from one case to another and depends on the frequency and intensity of outbreaks.

In 2006, Dr. Reicks reported having worked for a period of 13 months with nine insemination centers that had installed a 95%-DOP, 0.3-µm-filtration system. He found that the cost of a negative pressure 95%- DOP system ranged from less than $30 to $100 USD per boar space without air conditioning or $330 to $430 USD with air conditioning. The cost of a HEPA positive pressure system ranged from $300 to $ 600 per boar space without air conditioning or $1,000 to $1,200 US with air conditioning.

In Canada, for a 15 layer antimicrobial filter installation, the costs associated with filtration (cost per sow in inventory), based on four farrowing units (or 7,500 spaces) and assuming filtration is operating during all four seasons, are as shown in Table 4.

Table 4 Estimated Costs for an Air Filtration System in Canada

	Farrowing Facility	
Investment costs by space[1]	$48–$98	
Annual payment per space[2]	$6–$13	
Frequency of filter change	**3 years**	**5 years**
Maintenance costs /space/year	$18–$31	$12-$21
Total annual operating costs	**$25–$45**	**$18–$35**

[1] Does not include starting and replacement filters and prefilters. These are included in the maintenance costs.
[2] For a 10-year loan at an annual interest rate of 6.5%.

According to Malakowsky (2011b), in the United States (AgStar clients) (installation of MERV 14 and MERV 15 mechanical filter) based on 33 farrowing sites[1] (or 116,000 spaces), and looking at four-season filtration, the costs of filtration ranged from $120 to $170 US per sow in inventory, or an average of $150 per sow in inventory.

6.9 Disposal of Filters

The amounts put into the disposal of the filters are often overlooked, but they should also be taken into consideration (Burroughs, 1998). Eurovent (2009) recommends disposing of the filters or incinerating them to burn trapped impurities, reduce waste and recover a form of energy .However, burning certain materials can be difficult (Tronville, 2008). Concerning the long-lasting and sturdy filters, it might be interesting to recover the particles filtered by suction and dispose of them separately, rather than leaving them inside the filter (Chadwick, 2006).

[1] Considering a conventional ventilation, i.e., ceiling air inlets only

References

Ahearn, D.G., Crow, S.A., Simmons, R.B., Price, D.L., Mishra, S.K. and D.L. Pierson. 1997. Fungal colonization of air filters and insulation in a multi-story office building: Production of volatile organics. Current Microbiology, 35(5) : 305-308.

Albina, E. 1995. Epidemiology of PRRS : an overview. Second international symposium on porcine reproductive and respiratory syndrome (PRRS), August 9-10, p. 23.

Alonso, C., Otake, S., Davies, P. and S. Dee. 2012. An evaluation of interventions for reducing the risk of PRRSV introduction to filtered farms via retrograde air movement through idle fans. American Association of Swine Veterinarians : 45-46.

Baekbo, P. and S. Mortensen. 2001. Airborne transmission of swine pathogens. Allen D. Leman Swine Conference : 30-36.

Batista, L., Urizar, L. and F. Pouliot. 2009. Évaluation de l'efficacité du filtre à air antimicrobien commercialisé par Noveko après 16 mois d'utilisation dans un bâtiment porcin commercial. Québec : Centre de développement du porc du Québec inc., 6 p.

Batista, L., Pouliot, F., Dufour, V. and M. Morin. 2008a. Evaluation of commercial filters to avoid or reduce reproductive and respiratory syndrome virus aerosol transmission. 20th IPVS Congress : P01.138.

Batista, L., Dufour, V., Pouliot, F., Gobeil-Tremblay, E. and M. Morin. 2008b. Évaluation d'un système de filtration d'air visant à réduire ou à éviter la transmission par voie aérienne du virus du syndrome respiratoire et reproducteur porcin (SRRP) à l'intérieur des bâtiments d'élevage : rapport final. Québec : Centre de développement du porc du Québec inc., 39 p.

Bernick, K. 2007. Disinfectant chambers improve biosecurity. National Hog Farmer, November 15. Available at: http://nationalhogfarmer.com/health-diseases/disinfectant-chambers-improve-biosecurity/ [Accessed 2008].

Bonneau, M., Batista, L. and F. Pouliot. 2009. Noveko introduces a new filtration concept that fits air filtration needs of existing production facilities in the swine industry. American Association of Swine Veterinarians : 275-282.

Boutin, R. 2001. La biosécurité à la ferme : un « must » pour tous les élevages! 22e Colloque sur la production porcine, 31 octobre, Saint-Hyacinthe, p. 57-81.

Brockmeier, S.L. and K.M. Lager. 2002. Experimental airborne transmission of porcine reproductive and respiratory syndrome virus and Bordetella bronchiseptica. Veterinary Microbiology, 89(4) : 267-275.

Broes, A. 2002. Les mesures de biosécurité dans les élevages porcins québécois. Journée : « De la démarche hygiène à la biosécurité », 24 avril, Ploufragan, 10 p.

Broes, A. and R. Boutin. 2002. Biosécurité : un « must » pour tout le secteur porcin! Québec : Centre de développement du porc du Québec inc., 11 p.

Burroughs, H.E.B. 1998. The art and science of air filtration management in health care. Heating, piping and air conditioning, 70(10) : 79-86.

Cecchini, C., Verdenelli, M.C., Orpianesi, C., Dadea, G.M. and A. Cresci. 2004. Effects of antimicrobial treatment on fiberglass-acrylic filters. Journal of Applied Microbiology, 97(2) : 371-377.

Chadwick, C. 2006. Filtering out waste. Nuclear Engineering International, 51(624) : 16-20.

Châtillon, G., Godreau, C. and É. Hamelin. 2004. SDRP : pathologie et épidémiologie. Un virus encore mystérieux. Porc Magazine, juin(378) : 58-61.

Cho, J.G., Deen, J. and S.A. Dee. 2007. Influence of isolate pathogenicity on the aerosol transmission of Porcine reproductive and respiratory syndrome virus. The Canadian Journal of Veterinary Research, 71(1) : 23-27.

Cho, J.G. and S.A. Dee. 2006. Porcine reproductive and respiratory syndrome virus. Theriogenology, 66(3) : 655-662.

Corzo, C.A., Torremorell, M., Gramer, M., Dee, S. and R. Morrison. 2012. Detection of airborne swine influenza A under field conditions. American Association of Swine Veterinarians : 65-66.

Coudé, N. 2004. La filtration de l'air est en marche. Le Courrier, 8(1) : 3-4.

D'Allaire, S. 2003. Épidémiologie du syndrome reproducteur et respiratoire porcin (SRRP) dans les élevages québécois. 24e Colloque sur la production porcine, 4 novembre, Saint-Hyacinthe, p. 121-131.

Davis, W.T. and G.D. Kim. 1999. Effect of prefilters on the performance of HEPA filters. Filtration and Separation, 36(3) : 51-56.

Dee, S., Cano, J.P., Spronk, G., Reicks, D., Ruen, P., Pitkin, A. and D. Polson. 2012. Evaluation of the long-term effect of air filtration on the occurrence of new PRRSV infections in large breeding herds in swine-dense regions. Viruses, 4 : 654-662.

Dee, S., Pitkin, A., Otake, S. and J. Deen. 2011. A four-year summary of air filtration system efficacy for preventing airborne spread of porcine reproductive and respiratory syndrome virus and Mycoplasma hyopneumoniae. Journal of Swine Health and Production, 19(5) : 292-294.

Dee, S., Otake, S. and J. Deen. 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 : 177-184.

Dee, S., Otake, A. and J. Deen. 2009a. Use of a production region model to address issues regarding the aerobiology of PRRSV and Mycoplasma hyopneumoniae and to investigate alternative protocols of aerosol biosecurity. American Association of Swine Veterinarians : 111.

Dee, S.A., Otake, S., Oliviera, S. and J. Deen. 2009b. Evidence of long distance airborne spread of porcine reproductive and respiratory syndrome virus and Mycoplasma hyopneumoniae. Veterinary Research, 40 : 39.

Dee, S., Pitkin, A. and J. Deen. 2009c. Evaluation of alternative strategies to Merv 16-based air filtration systems for reduction of the risk of airborne spread of porcine reproductive and respiratory syndrome virus. Veterinary Microbiology, 138(1/2) : 106-113.

Dee, S.A. 2007. Indirect transmission of PRRSV: Let's take it out of the equation! International Pigletter, 27(2b), 2 p.

Dee, S.A. 2006. The Next 10 years in animal health. International Pigletter, 26(10b), 2 p.

Dee, S.A., Batista, L., Deen, J. and C. Pijoan. 2006a. Evaluation of systems for reducing the transmission of Porcine reproductive and respiratory syndrome virus by aerosol. The Canadian Journal of Veterinary Research, 70(1) : 28-33.

Dee, S.A., Deen, J., Cano, J.P., Batista, L. and C. Pijoan. 2006b. Further evaluation of alternative air-filtration systems for reducing the transmission of Porcine reproductive and respiratory syndrome virus by aerosol. The Canadian Journal of Veterinary Research, 70(3) : 168-175.

Dee, S.A., Deen, J., Jacobson, L., Rossow, K.D., Mahlum, C. and C. Pijoan. 2005a. Laboratory model to evaluate the role of aerosols in the transport of porcine reproductive and respiratory syndrome virus. The Veterinary Record, 156(16) : 501-504.

Dee, S.A., Batista, L., Deen, J. and C. Pijoan. 2005b. Evaluation of an air-filtration system for preventing aerosol transmission of Porcine reproductive and respiratory syndrome virus. The Canadian Journal of Veterinary Research, 69(4) : 293-298.

Dee, S.A., Deen, J., Otake, S. and C. Pijoan. 2004a. An experimental model to evaluate the role of transport vehicles as a source of transmission of porcine reproductive and respiratory syndrome virus to susceptible pigs. The Canadian Journal of Veterinary Research, 68(2) : 128-133.

Dee, S.A., Deen, J., Burns, D., Douthit, G. and C. Pijoan. 2004b. An assessment of sanitation protocols for commercial transport vehicles contaminated with porcine reproductive and respiratory syndrome virus. The Canadian Journal of Veterinary Research, 68(3) : 208-214.

Dee, S.A., Deen, J. and C. Pijoan. 2004c. Evaluation of 4 intervention strategies to prevent the mechanical transmission of porcine reproductive and respiratory syndrome virus. The Canadian Journal of Veterinary Research, 68(1) : 19-26.

Dee, S.A., Deen, J., Rossow, K., Weise, C., Eliason, R., Otake, S., Joo, H.S. and C. Pijoan. 2003. Mechanical transmission of porcine reproductive and respiratory syndrome virus throughout a coordinated sequence of events during warm weather. The Canadian Journal of Veterinary Research, 67(1) : 12-19.

Dee, S.A., Deen, J., Rossow, K., Wiese, C., Otake, S., Joo, H.S. and C. Pijoan. 2002. Mechanical transmission of porcine reproductive and respiratory syndrome virus throughout a coordinated sequence of events during cold weather. The Canadian Journal of Veterinary Research, 66(4) : 232-239.

Dee, S.A., Joo, H.S., Polson, D.D. and W.E. Marsh. 1997. Evaluation of the effects of nursery depopulation on the profitability of 34 pig farms. Veterinary Record, 140 : 498-500.

Dee, S.A. and H.S. Joo. 1994. Factors involved in successful eradication of PRRS virus using nursery depopulation. American Association of Swine Practitioners : 239-243.

Dee, S.A. and H.S. Joo. 1993. PRRS clinical management and control: Eradication from herds. Allen D. Leman Swine Conference : 93-97.

Desrosiers, R. 2011. Transmission of swine pathogens: different means, different needs. Animal Health Research Reviews, 12(1) : 1-13.

Desrosiers, R. 2007. Indirect transmission of the PRRS virus (Part 7). International Pigletter, 27 (8a), 2 p.

Desrosiers, R. 2005. Aerosol transmission of swine pathogens: overview of the subject and evaluation of suspected field cases. American Association of Swine Veterinarians : 405-416.

Desrosiers, R. 2004. Epidemiology, diagnosis and control of swine diseases. American Association of Swine Veterinarians : 9-38.

Devries, S. 2012. Air filtration for swine operations. 31st Annual Centralia Swine Research Update : I-25 à I-26.

Dewey, C. 1999. History, occurrrence, dynamics and current status of PRRS in North America, Latin America, and Asia. Proceedings PRRS and Aujeszky's Disease, June 21-23, p. 189-193.

Dufour, J. 1995. Mesures de biosécurité. Available at: http://rechamakayajo.qc.ca/medecine/biosecur/biosecur.htm [Accessed 2008].

Dutertre, C. 1995. La filtration d'air pour protéger la sélection. Porc Magazine, avril(277) : 30-31.

Dutertre, C., Risson, K. and P. Rousseau. 1995. La filtration d'air appliquée à la protection sanitaire des élevages. Techni-Porc, 18(1) : 15-27.

Eurovent. 2009. Recommendation concerning air filters for better indoor air quality. Available at: http://212.123.1.105/web/eurovent/web/Recommendations/REC06.pdf [Accessed 2012].

Eurovent/Cecomaf. 2005. Recommendation concerning calculating of life cycle cost for air filters. Available at: http://212.123.1.105/web/eurovent/web/Recommendations/REC10.pdf [Accessed 2012].

Faculté de médecine vétérinaire de l'Université de Montréal (FMV). 2007. Formation et recherche en santé animale : Préparer l'avenir de l'agriculture et de l'agroalimentaire québécois. Mémoire présenté par Jean Sirois, doyen, à la Commission sur l'avenir de l'agriculture et de l'agroalimentaire québécois, 14 p.

Fano, E., Pijoan, C. and S. Dee. 2005. Evaluation of the aerosol transmission of a mixed infection of Mycoplasma hyopneumoniae and porcine reproductive and respiratory syndrome virus. The Veterinary Record, 157(4) : 105-108.

Foarde, K.K., Hanley, J.T. and A.C. Veeck. 2000. Efficacy of antimicrobial filter treatments. ASHRAE Journal, 42(12) : 52-58.

Goldberg, T.L., Hahn, E.C., Weigel, R.M. and G. Scherba. 2000. Genetic, geographical and temporal variation of porcine reproductive and respiratory syndrome virus in Illinois. Journal of General Virology, 81(1) : 171-179.

Haden, C.D., Painter, T., Fangman, T. and D. Holtkamp. 2012. Assessing production parameters and economic impact of swine influenza, PRRS and Mycoplasma hyopneumoniae on finishing pigs in a large production system. American Association of Swine Veterinarians : 75-76.

Hirst J.M. 1995. Bioaerosols; introduction, retrospect and prospect. Bioaerosol Handbook. Boca Raton, Florida : CRC Lewis Publishers, p. 5-14.

Hoefling, D.C. 1992. Overview and history of SIRS. Proceedings of the Annual Meeting of the Livestock Conservation Institute : 239-242.

Holck, J.T. and D.D. Polson. 2003. The Financial impact of PRRS virus. PRRS Compendium Producer Edition, chapter 6 : 46-54.

Innovet. 2006. Yvon Lintanff. Available at: http://www.innovet.ca/2006/cv/8_fr.html [Accessed 2008].

Kemp, S.J., Kuehn, T.H., Pui, D.Y.H., Vesley, D. and A.J. Streifel. 1995. Growth of Microorganisms on HVAC Filters Under Controlled Temperature and Humidity Conditions. ASHRAE Transactions, 101(1) : 305-316.

Kerkaert, B.R., Pijoan, C. and G. Dial. 1994. Financial impact of chronic PRRS. Allen D. Leman Swine Conference : 217-218.

Kowalski, W.J. and W.P. Bahnfleth. 2002. Airborne-microbe filtration in indoor environments. HPAC Heating, Piping, Air Conditioning Engineering, 74(1) : 57-69.

Kristensen, C.S., Bøtner, A., Takai, H., Nielsen, J.P. and S.E. Jorsal. 2004. Experimental airborne transmission of PRRS virus. Veterinary Microbiology, 99(3/4) : 197-202.

Kuehn, T.H., Pui, D.Y.H., Vesley, D., Berg, C.D. and M. Peloquin. 1991. Matching to health filtration requirements. ASHRAE Transactions, Part 2, 3505 (RP-625) : 164-169.

Lager, K.M. and W.L. Mengeling. 2000. Experimental aerosol transmission of pseudorabies virus and Porcine Reproductive and Respiratory Syndrome Virus. American Association of Swine Practitioners : 409-410.

Larochelle, R., D'Allaire, S. and R. Magar. 2003. Molecular epidemiology of porcine reproductive and respiratory syndrome virus (PRRSV) in Québec. Virus Research, 96(1/2) : 3-14.

Malakowsky, S. 2011a. A lenders evaluation of PRRS filters. Allen D. Leman Swine Conference : 43-44.

Malakowsky, S. 2011b. Lenders views of PRRS filters. Leman Conference, September, 33 p.

Maus, R., Goppelsröder, A. and H. Umhauer. 2001. Survival of bacterial and mold spores in air filter media. Atmospheric Environment, 35(1) : 105-113.

Midwest Plan Service (MWPS). 1990. Mechanical ventilating systems for livestock housing. MWPS-32, 69 p.

Mondaca-Fernandez, E., Murtaugh, M.P. and R.B. Morrison. 2006. Association between genetic sequence homology of Porcine reproductive and respiratory syndrome virus and geographic distance between pig sites. The Canadian Journal of Veterinary Research, 70 : 237-239.

Moore, C. 2006 Résultats de l'enquête épidémiologique sur le SDPS et quelques moyens de contrôle. Expo-congrès du porc du Québec, 12 et 13 avril, Saint-Hyacinthe, p. 15-23.

Mortensen, S., Stryhn, H., Søgaard, R., Boklund, A., Stärk, K.D.C., Christensen, J. and P. Willeberg. 2002. Risk factors for infection of sow herds with porcine reproductive and respiratory syndrome (PRRS) virus. Preventive Veterinary Medicine, 53(1/2) : 83-101.

Mussell, A., Oginskyy, A., Grier, K., Morin, M., Lachance, M.P., Whittington, L. and R. Friendship. 2011. A Risk, Benefit, Strength, Weakness, Opportunity and Threat Analysis for the Control and Possible Eradication of Porcine Reproductive and Respiratory Syndrome (PRRS) Virus Within the Canadian Swine Herd. Guelph : George Morris Centre, 122 p.

Mussell, A. 2010. Pour une stratégie d'éradication du SRRP. George Morris Centre. Forum canadien sur la santé porcine, 25 et 26 octobre, Québec.

Nagorske, M., Pitkin, A., Kurt, J. and S. Dee. 2012. Investigation of a novel retrograde air movement intervention to prevent aerosol transmission of PRRSv. American Association of Swine Veterinarians : 83-84.

National Pork Board (NPB). 2011. Pork Checkoff Study : PRRS cost industry $664 million annually. Available at: http://www.pork.org/News/1265/PRRSCostsIndustry664Million.aspx [Accessed 2008].

Noveko. 2008. Filtre antimicrobien noveko : présentation technique et utilisation recommandée dans les bâtiments de ferme. Québec : Noveko inc., 4 p.

Noveko. n.d. La filtration de l'air : élément essentiel de tout programme de biosécurité : développé par et pour les professionnels de l'industrie porcine. Québec : Noveko inc., 4 p.

Otake, S., Dee, S., Corzo, C., Oliveira, S. and J. Deen. 2010. Long-distance airborne transport of infectious PRRSV and Mycoplasma hyopneumoniae from a swine population infected with multiple viral variants. Veterinary Microbiology, 145 : 198-208.

Otake, S., Dee, S.A., Moon, R.D., Rossow, K.D., Trincado, C. and C. Pijoan. 2004. Studies on the carriage and transmission of porcine reproductive and respiratory syndrome virus by individual houseflies (Musca domestica). The Veterinary Record, 154(3) : 80-85.

Otake, S., Dee, S.A., Jacobson, L., Torremorell, M. and C. Pijoan. 2002a. Evaluation of aerosol transmission of porcine reproductive and respiratory syndrome virus under controlled field conditions. The Veterinary Record, 150(26) : 804-808.

Otake, S., Dee, S.A., Rossow, K.D., Deen, J., Joo, H.S., Molitor, T.W. and C. Pijoan. 2002b. Transmission of porcine reproductive and respiratory syndrome virus by fomites (boots and coveralls). Journal of Swine Health and Production, 10(2) : 59-65.

Otake, S., Dee, S.A., Rossow, K.D., Moon, R.D. and C. Pijoan. 2002c. Mechanical transmission of porcine reproductive and respiratory syndrome virus by mosquitoes, Aedes vexans (Meigen). The Canadian Journal of Veterinary Research, 66(3) : 191-195.

Otake, S., Dee, S.A., Rossow, K.D., Joo, H.S., Deen, J., Molitor, T.W. and C. Pijoan. 2002d. Transmission of porcine reproductive and respiratory syndrome virus by needles. The Veterinary Record, 150 : 114-115.

Parent, M.J. 2004. Aux grands maux, grands moyens. Le Bulletin des agriculteurs, 87(3-4) : 66-70.

Pearson, C.C. and J.E. Owen. 1994. The resistance to air flow of farm building ventilation components. Journal of Agricultural Engineering Research, 57(1) : 53-65.

Penicot, P., Thomas, D., Contal, P., Leclerc, D. and J. Vendel. 1999. Clogging of HEPA fibrous filters by solid and liquid aerosol particles : An experimental study. Filtration and Separation, 36(2) : 59-64.

Pettigrew, R. 2011. Des nouvelles technologies ou approches en production porcine. Expo-Congrès du Porc du Québec, 13-14 avril : 28-38.

Pitkin, A., Otake, S. and S. Dee. 2009a. Biosecurity protocols for the prevention of spread of pocine reproductive and respiratory syndrome virus. American Association of Swine Veterinarians : 17 p.

Pitkin, A., Deen, J., Otake, S., Moon, R. and S. Dee. 2009b. Further assessment of houseflies (Musca domestica) as vectors for the mechanical transport and transmission of porcine reproductive and respiratory syndrome virus under field conditions. Canadian Journal of Veterinary Research, 73(2) : 91-96.

Pitkin, A., Deen, J. and S. Dee. 2007. Aerosol transmission of PRRSV : Application to the field. Allen D. Leman Swine Conference : 85.

Pohl, S. 2007. Engineering air filtration systems of swine facilities. Allen D. Leman Swine Conference : 86-88.

Polson, D.D., Gorcyca, D. and R.B. Morrison. 1994. An evaluation of the financial impact of porcine reproductive and respiratory syndrome (PRRS) in nursery pigs. Proceedings of the International Pig Veterinary Society Congress : 436.

Polson, D.D., Marsh, W.E., Dial, G.D. and W.T. Christianson. 1992. Financial impact of porcine epidemic abortion and respiratory syndrome (PEARS). Proceedings of the International Pig Veterinary Society Congress : 132.

Price, D.L., Simmons, R.B., Ramey, D.L., Crow, S.A. and D.G. Ahearn. 1993. Assessment of air filters treated with a broad spectrum biostatic agent. Proceedings of indoor Air '93, vol. 6, p. 527-532.

Quinn, P.J., Markey, B.K., Carter, M.E., Donnelly, W.J. and F.C. Leonard. 2002. Mycoplasma. In: Veterinary microbiology and microbial disease. Ames, IA : Iowa State University Press, p. 189.

Reicks, D. 2011. Operation and maintenance of barn filtration for disease control. Available at: http://www.mnpork.com/FileLibrary/States/MN/Workforce%20Development%20Seminars/2011/Air_Filtration_Workforce_2011.pdf [Accessed 2012].

Reicks, D. and D. Polson. 2011. A financial evaluation of PRRSv introduction risk mitigation attributed to air filtration of pig production sites. Allen D. Leman Swine Conference : 37-42.

Reicks, D.L. 2010. Using air filtration to reduce the risk of PRRS introduction. Proceedings of the International Pig Veterinary Society Congress : 271.

Reicks, D.L. 2009. Application of air filtration systems in swine operations. Advances in Pork Production, 20 : 163-171.

Reicks, D.L. 2006. Alternative filters for boars. Allen D. Leman Swine Conference : 99-100.

Rosenthal, J. 2007. Understanding MERV or the minimum efficiency reporting value : How the ASHRAE 52.2 helps you select an air filter. Available at: http://www.allergyclean.com/article-understandingmerv.htm [Accessed 2008].

Schurrer, J.A., Dee, S.A., Moon, R.D., Rossow, K.D., Mahlum, C., Mondaca, E., Otake, S., Fano, E., Collins, J.E. and C. Pijoan. 2004. Spatial dispersal of porcine reproductive and respiratory syndrome virus-contaminated flies after contact with experimentally infected pigs. American Journal of Veterinary Research, 65(9) : 1284-1292.

Simmons, R.B., Price, D.L., Noble, J.A., Crow, S.A. and D.G. Ahearn. 1997. Fungal colonization of air filters from hospitals. American Industrial Hygiene Association Journal, 58(12) : 900-904.

Simmons, R.B. and S.A. Crow. 1995. Fungal colonization of air filters for use in heating, ventilating, and air conditioning (HVAC) systems. Journal of Industrial Microbiology, 14(1) : 41-45.

Stärk, K.D.C. 1999. The Role of infectious aerosols in disease transmission in pigs. The Veterinary Journal, 158(3) : 164-181.

Surprenant, C. 2010. Vivre avec le SRRP, peut-on encore se le permettre? Le rendez-vous porcin AQINAC, 23 novembre, Drummondville : 25-33.

Synthèse élevage. 2006. SDRP : les règles « clés » de la biosécurité. Porc Magazine, février(396) : 102-103.

Thomas, D., Penicot, P., Contal, P., Leclerc, D. and J. Vendel. 2001. Clogging of fibrous filters by solid aerosol particles experimental and modelling study. Chemical Engineering Science, 56(11) : 3549-3561.

Torremorell, M., Geiger, J.O., Thompson, B. and W.T. Christianson. 2004a. Evaluation of PRRSV outbreaks in negative herds. Proceedings of the International Pig Veterinary Society Congress : 103.

Torremorell, M., Geiger, J.O., Thompson, B. and W.T. Christianson. 2004b. Evaluation of potential sources of PRRS virus infection in negative herds. Allen D. Leman Swine Conference : poster.

Torremorell, M., Pijoan, C., Janni, K., Walker, R. and H.S. Joo. 1997. Airborne transmission of Actinobacillus pleuropneumoniae and porcine reproductive and respiratory syndrome virus in nursery pigs. American journal of veterinary research, 58(8) : 828-832.

Trible, B.R. and R.R.R. Rowland. 2011. Is aerosol transmission an important risk for PRRSV transmission? An example of how simple biosecurity procedures can prevent virus spread within a barn. Swine Day : 6-11.

Trincado, C., Dee, S., Jacobson, L., Otake, S., Rossow, K. and C. Pijoan. 2004a. Attempts to transmit porcine reproductive and respiratory syndrome virus by aerosols under controlled field conditions. The Veterinary Record, 154(10) : 294-297.

Trincado, C., Dee, S., Rossow, K., Halvorson, D. and C. Pijoan. 2004b. Evaluation of the role of mallard ducks as vectors of porcine reproductive and respiratory syndrome virus. The Veterinary Record, 154 : 233-237.

Tronville, P. 2008. Developing standards: Global standards for air cleaning equipment. Filtration and Separation, November : 28-31.

United States Department of Agriculture (USDA). 2005. Swine 2000 : Part IV: Changes in the U.S. Pork Industry, 1990-2000. Available at: http://www.aphis.usda.gov/vs/ceah/ncahs/nahms/swine/swine2000/swine2kPt4.pdf [Accessed 2008].

U.S. Environmental Protection Agency. 1997. Overview of ASHRAE Standard 52.2 : Research triangle institute, 5 p.

Vansickle, J. 2007a. Reducing The Area Spread of PRRS. National Hog Farmer, November 15. Available at: http://nationalhogfarmer.com/health-diseases/reducing-spread-prrs/ [Accessed 2008].

Vansickle, J. 2007b. Filtering out viral pathogens. National Hog Farmer, November 15. Available at: http://nationalhogfarmer.com/health-diseases/filtering-viral-pathogens/ [Accessed 2008].

Verdenelli, M.C., Cecchini, C., Orpianesi, C., Dadea, G.M. and A. Cresci. 2003. Efficacy of antimicrobial filter treatments on microbial colonization of air panel filters. Journal of Applied Microbiology, 94(1) : 9-15.

Zhou, B. and J. Shen. [2007]. Comparison of general ventilation air filter test standards between America and europe. Available at: http://www.inive.org/members_area/medias/pdf/inive/iaqvec2007/zhou_5.pdf [Accessed 2011].

Zhuang, Q., Barfod, K., Wachmann, H., Mortensen, S. and P. Willeberg. 2002. Serological surveillance for PRRS in Danish genetic pig herds and risk factors for PRRS infection. Proceedings of the International Pig Veterinary Society Congress : 406.

Zimmerman, J., Benfield, D., Murtaugh, M., Osorio, F., Stevenson, G. and M. Torremorell. 2006. Porcine reproductive and respiratory syndrome virus. In: Diseases of Swine, 9th Ed. Ames, IA : Iowa State University Press, p. 387-417.

Zimmerman, J.J. 2003. Epidemiology and Ecology. PRRS Compendium Producer Edition, chapter 4 : 26-34.

Zimmerman, J.J., Yoon, K.J. Pirtle, E.C., Wills, R.W., Sanderson, T.J. and M.J. McGinley. 1997. Studies of porcine reproductive and respiratory syndrome (PRRS) virus infection in avian species. Veterinary Microbiology, 55 : 329-336.

Centre de développement du porc du Québec inc.
Place de la Cité, tour Belle Cour
2590, boulevard Laurier, bureau 450
Québec (Québec) G1V 4M6
☏ 418 650-2440 • 🖷 418 650-1626
cdpq@cdpq.ca • www.cdpq.ca