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Design Alternatives for Effective Manure Removal and Storage for a Research Farm

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Scientific Abstract: The objective of this project was to create three design alternatives for manure removal and barn disinfection for a swine research farm. The research farm consists of several modular buildings, each capable of housing 40 wean-finish pigs, and all manure will be drained into and stored in the manure pit of an on-site former swine finishing barn. In order to create a suitable environment for controlled research, the manure removal and barn disinfection system must effectively inactivate swine pathogens, most notably Porcine Reproductive and Respiratory Syndrome virus, Porcine Epidemic Diarrhea virus, and African Swine Fever virus between turns of pigs.

In collaboration with the cooperator, design evaluation criteria were ranked according to importance; the most important factor was the simplicity of the disinfection method, followed by overall design cost, utilization of the existing storage system, and time it takes to perform sanitation between a turn of pigs. A combination of pressure washing above and below the slatted barn floor was proposed for surficial manure removal before disinfection. Considering the design evaluation criteria, the three proposed disinfection methods were heat treatment, formaldehyde fumigation, and commercial disinfection. The process for the three design alternatives combining manure removal and disinfection are provided in the paper. Cost analyses resulted in the following total design costs over ten years of operation for one modular building:

- Heat Treatment – $2,068
- Formaldehyde Fumigation – $5,242
- Commercial Disinfectant – $4,829

Each design alternative has their own set of positives and negatives in relation to the design criteria, and the final decision between alternatives will need to consider the importance of convenience versus cost of disinfection.

Introduction: Several viruses have been proven to persist in swine manure, including Porcine Reproductive and Respiratory Syndrome virus (PRRSv), Porcine Epidemic Diarrhea virus (PEDv), and African Swine Fever virus (ASFv). Each virus poses unique challenges, and there is growing literature on the persistence and eradication options. Rossow (2016) provides evidence of PRRSv in swine feces and urine. Linhares et al. (2012) shows the lifespan of PRRSv in manure over several ambient temperatures. Linhares et al (2012) concluded that the virus infectivity exponentially decreases as temperature increases; higher humidity can prolong the lifespan of PRRSv. Tun et al. (2016) suggests the fecal-oral route to be the major transmission of PEDv. In their study of two infected on-farm earthen manure storages, PEDv was determined to be highly viable for over 6 months, but the top layer of manure on both storage systems had almost no infective virus, potentially due to UV and sunlight exposure. According to Haas et al. (1995), ASFv can survive 60 to 100 days in liquid manure. Inactivation of the virus can be done through long-term storage, though it takes up to six months. Aside from heat, other viable alternative inactivation methods include pasteurization, anaerobic digestion, aldehyde and chemical treatments.

A research farm with reduced animal numbers provides some flexibility to manure storage design options, but systems must still consider regulatory requirements or limitations, cost, and siting. A key reason for the project is to reduce the risk of pathogen exposure between pigs and manure, ideally within a turn, but especially between groups of pigs.

Objectives: The student experience objectives were:

1. Exposure to the engineering considerations in swine housing that must balance functionality, operation and cost;
2. Design experience;
3. Stakeholder engagement; and
4. Translating science to a lay audience.

The engineering project goal was to identify alternative designs for effective manure removal and storage for a research farm. The project melded the engineering design process with stakeholder engagement and needs assessment, while providing the student with exposure to needs and considerations specific to the swine industry. In the process of visioning ideas for the cooperating production system, the student produced guidance supportive to all producers and the scientific engineering community.

Materials & Methods: The student and mentor met with the cooperator to document constraints of the design, and how design ideas would be evaluated relative to each other based on prioritized criteria. The student then reviewed literature on existing manure storage and manure disinfection methods, focusing on disinfection methods targeting PPRSv, PEDv, and ASFv. A lay-person summary was prepared to summarize the risks associated with these three diseases and proven disinfection methods to reduce those risks.

The student organized and convened a virtual meeting of stakeholders to brainstorm design alternatives for aspects of the desired system. The system constraints and criteria were presented before brainstorming, so stakeholders could evaluate how various ideas suited the design needs. The stakeholders were encouraged to be creative as the collaborator was open to new approaches and ideas. Stakeholders included researchers, Extension educators, regulatory engineers, building industry representatives, and the collaborator.

Based on the design constraints and ranked criteria, design alternatives generated from the brainstorming meeting were evaluated in a decision matrix, and the top three design alternatives were further developed, explored, and presented. For each alternative, a cost analysis estimating total capital and operational costs over ten years of operation was performed, and system drawings were created. A final report presenting all findings and recommendations was shared to the cooperator.

Results:

Objective 1. *Exposure to the engineering considerations in swine housing that must balance functionality, operation and cost*

Based on conversations with the cooperator, a specific design objective emerged. The objective was to develop three design alternatives for manure removal and barn disinfection for a swine research farm. To create a farm suitable for controlled research, effective inactivation of novel swine viruses is critical. The viruses of concern considered in this project were Porcine Reproductive and Respiratory Syndrome virus (PRRSv), Porcine Epidemic Diarrhea virus (PEDv), and African Swine Fever virus (ASFv). Each design alternative need to be capable of inactivating these three viruses between each turn of pigs. A specific research farm was the base for this project, however aspects of the design alternatives, especially disinfection procedures, have application on other farms.

The research farm site for this project consists of several modular buildings, each capable of holding 40 wean-finish pigs. Manure from all buildings will be drained into and stored in the pit of an on-site former swine finishing barn. The design alternatives proposed include specifications based on one modular building, and product amounts and costs will need to be scaled up to account for several buildings. From conversations with the cooperator, the student put together lists of constraints and criteria, and the cooperator ranked the relative importance of each criterion. Table 1 is a needs assessment for the specific design objective, providing the basis for evaluating designs based on functionality, operation and cost.

Table 1. Constraints and criteria for the proposed management system. The number in parentheses following each criterion denote the relative importance with (1) being the most important and (7) being the least important. Multiple criteria followed by the same number in parentheses are of equal importance.

Constraints	Criteria
- On-site manure storage for 250 wean-finish pigs for at least six months. Storage may include multiple areas. - Barns must demonstrate an absence of PRRS and PEDv contamination between turns.	- Sanitation techniques or processes should be simple for people to perform, requiring little manual effort. (1) - The manure management system cost should be less than 1/3 of the total barn cost. (2) - The system should ideally utilize the existing storage system in place at the site. (3) - Sanitation process should take less than a week. (4) - Sanitation system should be adaptable for novel pathogens. (4) - The floors should ideally be fully slatted cement. (6) - The system should include short-term room manure storage, through a turn of pigs. (7)

Objective 2. *Design experience*

In consideration of criteria (1) and (2), a combination of manual pressure washing above and below the slatted floor was proposed. Equipment necessary for this washing included a commercial pressure washer and an undercarriage cleaner with an extension wand (i.e. Waterbroom & Undercarriage w/ Ext Wand, Davidson's Pressure Washers & Supplies). This method of cleaning would be performed between each turn of pigs, using the following steps as a guide:

1. Use a power washer to wash the floor and walls of each pen.
2. Lift all pull plugs and allow all pit manure to drain out.
3. Lift one section of flooring per pen, ideally on the opposite side of the nearest pull plug.
    a. During steps 4 and 5, only open the pull plugs for the pen being sprayed, keeping all other plugs closed.
4. Lower undercarriage sprayer onto the pit floor and spray upwards across the bottom on the flooring.
5. Use the water broom function of the undercarriage sprayer to spray any residual manure on the pit floor toward the pull plug.

Table 2 displays the ten year cost analysis for the proposed washing method. Both the pressure washer and undercarriage cleaner were assumed to have an operation life of ten years, with no end of life salvage value. Yearly maintenance cost for the pressure washer was assumed to be ten percent of the initial capital cost.

Table 2. Manure removal and washing ten year cost analysis.

	Items	Cost Over Ten Years
Capital Cost	Pressure Washer - $1,000[1] Waterbroom & Undercarriage w/ Ext Wand - $50	$1,050
Operating Cost	Pressure Washer Yearly Maintenance - $100	$1,000
	Ten Year Total Cost	**$2,050**

[1] Estimated based on average commercial pressure washer prices on the market

Table 3 shows the decision matrix created to evaluate disinfection methods, with the three highest weighted totals resulting for heat treatment, formaldehyde fumigation, and commercial disinfectant. Total scores were weighted based on the criteria importance ranking (Table 1).

Table 3. The decision matrix for disinfection methods. Percentages in brackets indicate the relative weight of each criterion.

	Score for each criterion (1-10)				
Disinfection Method	Simplicity [36%]	Cost [28%]	Required Time [18%]	Adaptability [18%]	*Weighted Total*
Lime Treatment	5	7	8	3	*5.73*
Formaldehyde Fumigation	**8**	**8**	**7**	**10**	***8.18***
Heat Treatment	**9**	**9**	**9**	**8**	***8.82***
UV Treatment	10	6	10	5	*8.00*
Commercial Disinfectant	**8**	**8**	**8**	**9**	***8.18***

Tables 4 through 6 summarize ten year cost analyses for each of the three disinfection methods, including all capital and operating costs. For each method, a disinfection frequency of six weeks was assumed, or nine rounds of disinfection per year.

Table 4. Heat treatment ten year cost analysis, including costs for manure removal and washing.

	Items	Cost Over Ten Years
Capital Cost	Pressure Washer - $1,000 Waterbroom & Undercarriage w/ Ext Wand - $50	$1,050
Operating Cost	Pressure Washer Yearly Maintenance - $100 Propane - $2.25 per gallon[2]	$1,018.26
	Ten Year Total Cost	**$2,068.26**

[2] Estimated based on average weekly U.S. propane prices over the past year (U.S. Energy Information Administration, n.d.)

Table 5. Formaldehyde Fumigation ten year cost analysis, including costs for manure removal and washing.

	Items	#	Cost Over Ten Years
Capital Cost	Pressure Washer - $1,000	1	$1,131.20
	Waterbroom & Undercarriage w/ Ext Wand - $50	1	
	2-cup Glass Bowls - $4[3]	4	
	8’ x 20’ Plastic Tarp - $32.60[4]	2	
Operating Cost	Pressure Washer Yearly Maintenance - $100		$4,111.16
	37% Formalin (1 gallon) - $32[5]		
	Potassium Permanganate (100 g) - $12.95[6]		
	Ten Year Total Cost		**$5,242.36**

[3] Price from (Pyrex, n.d.)
[4] Price from (Sigman, n.d.)
[5] Price from (Premier 1 Supplies, n.d.)
[6] Price from (Science Company, n.d.)

Table 6. Virkon S ten year cost analysis, including costs for manure removal and washing.

	Items	Cost Over Ten Years
Capital Cost	Pressure Washer - $1,000 Waterbroom & Undercarriage w/ Ext Wand - $50	$1,050
Operating Cost	Pressure Washer Yearly Maintenance - $100 Virkon S Tablets (50 tablets) - $45.50[7] Water (per 6,000 gallons) - $25[8]	$3,779.28
	Ten Year Total Cost	**$4,829.28**

[7] Price from (Lanxess, n.d.-b)
[8] Price estimated from average city water costs in Minnesota (City of Bloomington, MN, 2014)

In order to effectively inactivate PPRSv, PEDv, and ASFv in a room using heat treatment, the room must be heated to 60ºC for at least 30 minutes (Kessel, 2021; Pospischil, 2002; Turner et al., 1999). To implement this into the manure management system, room heating should occur after the room is allowed to dry following pressure washing. Assuming no animals or humans will be in the room, all ventilation systems should be turned off during the heat treatment, and the building's heating system should be used to increase and hold the room temperature at 60ºC for 30 minutes. Assuming the building had a propane heater, the only additional cost for this method would be the supplemental propane necessary to increase the room temperature. Some notable detriments to this method included the additional time necessary to allow the room to dry after pressure washing, and the time it would take to let the room cool back down after disinfection, during which time a new turn of pigs would not able to be moved into the room. Furthermore, any items that would not be able to withstand temperatures up to 60ºC would need to be removed from the building and stored elsewhere during disinfection.

Formaldehyde is capable of inactivating PRRSv, PEDv, and ASFv, along with several other pathogens and bacteria (Pospischil, 2002). The simplest way to expose formaldehyde to all surfaces in a room is through fumigation. Fumigation can be performed using a formalin solution with solid potassium permanganate. Each cubic meter of space required 35 mL of formalin and 10 g of potassium permanganate (Grimes et al., 2002). All surfaces must be wet prior to fumigation, so fumigation should occur immediately after pressure washing. To reduce the space necessary to fumigate, large tarps should be placed overtop the walls each pen (Figure 1), pull plugs should be closed, and the ventilation system turned off to create as sealed of an area as possible. A bowl containing 70 g of potassium permanganate should be places in the center of each pen (Figures 1 and 2), then add 240 mL of formalin to each bowl. Formaldehyde is a potential carcinogen, causes burns, and vapors irritate the eyes and respiratory tract, so protective clothing, gloves, a mask, and safety glasses must be worn, and those carrying out the procedure must do so as quickly as possible and then exit the room to reduce exposure. Allow 24 hours for the vapor to penetrate all surfaces, then turn the ventilation system back on and allow sufficient time for the fumigant to dissipate before reentry to the room. Some detriments with this method include difficulties sealing the pen areas with the tarps and requiring multiple people (i.e. a buddy system) to initiate the fumigation for safety reasons.

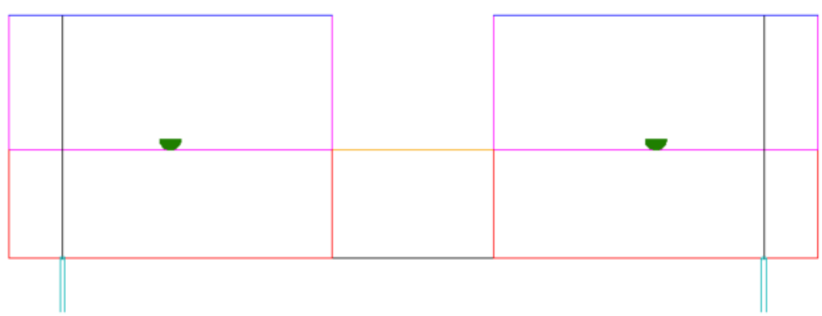

Figure 1. Shows locations of tarps (blue) and bowls (green) for formaldehyde fumigation in a side view of the building.

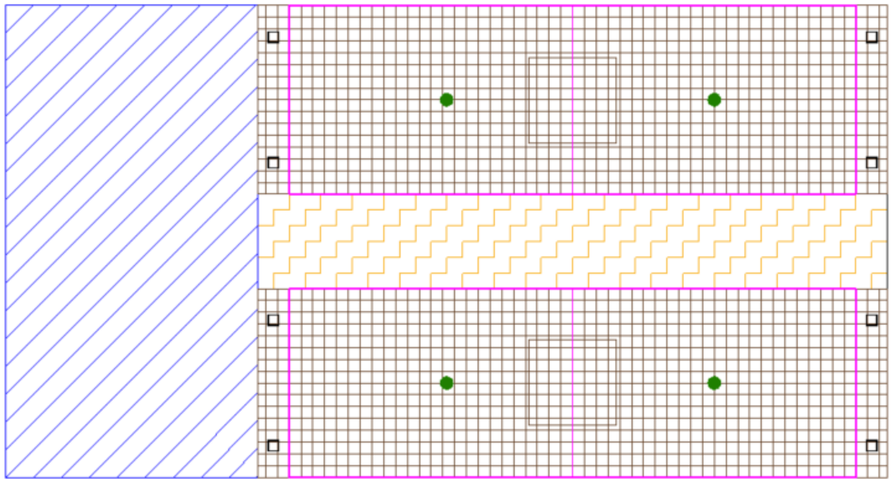

Figure 2. Shows locations of fumigation bowls (green) for formaldehyde fumigation in a top view of the building.

The commercial disinfectant Virkon S (active ingredients potassium peroxymonosulfate and sodium chloride) has been shown as effective in inactivating PRRSv, PEDv, and ASFv when applied to contaminated surfaces as a 1% solution (De Lorenzi et al., 2020; Pitkin, n.d.; Pospischil, 2002). One gallon of solution is sufficient to treat approximately 135 square feet of surface (Lanxess, n.d.-a). The 1% solution can be made by dissolving four tablet of Virkon S per gallon of water. After initial pressure washing, the 1% solution can be fed through the pressure washer and undercarriage sprayer and all pen and pit surfaces should be thoroughly soaked with solution. After spraying the solution, the room should be allowed to completely dry before introducing a new turn of pigs. Some drawbacks of this method are the additional manual labor necessary to spread the disinfectant and the additional time necessary for drying.

Objective 3. *Stakeholder engagement*

The stakeholder meeting was important to provide a broader set of perspectives and ideas. The meeting was virtual per the COVID-19 restrictions in place at the time. The student led the participants through two brainstorming exercises, focused on storage options and disinfecting technique. The participants' ideas expanded beyond the existing modular structures. Deep pit storage, shallow pit storage, and high-rise style housing, and applicable manure transfer systems were discussed in terms of regulatory requirements, ability to separate the manure from the animal area (short and long-term), and ease of use. Sprinkler systems were also considered with power washing for cleaning the storage area. Nine disinfection techniques were listed, based on participant's experiences and also novel research areas. Four long-term storage options were put forward for consideration; regulatory requirements was a key factor in winnowing this list. Simply considering the lists of storage – transfer – cleaning – disinfection and long term storage options, there were 675 possible combinations. However, the discussion between stakeholders identified feasible ideas to focus on for a manageable analysis moving forward.

Objective 4. Translating science and engineering to a lay audience

The culmination of a literature review resulted in Table 7, a summary of proven methods of PRRSv, PEDv and ASFv inactivation specific to manure. The table is currently under review. The intent is to disseminate the table to a broader audience via Extension portals.

Table 7. Quick guide of proven methods of PRRSv, PEDv, and ASFv inactivation.

	Method and Dose or Application Rate		
Disinfection Method	PRRSv	PEDv	ASFv
Chemical Treatment – inactivation of viruses on surfaces by physical application of a chemical		Hydrated lime to maintain pH ≥ 10 for 1 hour.[1] • 50 lb per 1,000 gallons	$Ca(OH)_2$ at ≥ 0.5% (w/v) for 30 min at ≥ 4℃[2] NaOH at ≥ 0.5% (w/v) for 30 minutes at ≥ 4℃[2]
Fumigation – inactivation of viruses on surfaces by aerial dispersion of a chemical	Paraformaldehyde • 5 g per cubic meter of building, heated on an electric pan at 204 C, sealing building for 24 hours[3]		
	Formalin and Potassium Permanganate • 35 mL formalin (40 percent formaldehyde) and 10 g potassium permanganate per cubic meter of building, sealing building for 24 hours[3]		
	Synergize and glycol solution. • 30 mL of Synergize in 3,840 mL of 10% propylene glycol, sealed for 60 minutes[4]		
	Ortho-phenylphenol fumigation for 15 hours[5]		
UV Treatment – inactivation of viruses on surfaces by exposure to UV light	Inactivation by UV_{254} exposure for at least 10 minutes[6]	Exposure to sunlight in earthen manure storage[7]	
Commercial Disinfectants – inactivation of viruses on surfaces by physical application of a disinfectant	Synergize (0.8-1%) – dry for 2 hours[8]	Virkon S (1:100 dilution)[9]	Virkon S – soak for 10 minutes[11]
	Virkon (0.8-1%) – dry for 2 hours[8]	Clorox bleach (1:32 dilution)[9]	Clearon Bleach Tablets – soak for 30 minutes[11]
		1 Stroke Environ (1-2%)[9]	Klor-Kleen – soak for 30 minutes[11]
		Tek-Trol (1-2%)[9]	Klorsept – soak for 30 minutes[11]
		Roccal-D Plus (1.5:128)[10] Synergize 1:256[10]	Klorkleen 2 – soak for 15 minutes nonporous surfaces, 30 minutes porous surfaces[11]

[1] (Stevens et al., 2018)
[2] (Bicudo & Goyal, 2003; Turner et al., 1999)
[3] (Grimes et al., 2002)
[4] (Dee et al., 2005)
[5] (Cha et al., 2016)
[6] (Dee et al., 2011)
[7] (Tun et al., 2016)
[8] (Pitkin, n.d.)
[9] (Pospischil, 2002)
[10] (Bowman et al., 2015)
[11] (De Lorenzi et al., 2020)

Discussion: Manure storage can harbor pathogens, including viruses. For any barn, effective pathogen removal between turns is critical.

Table 8 summarizes the results for each of the three design alternatives, including costs and limitations. When determining the most appropriate design alternative, the final decision would need to consider the importance of convenience versus cost of disinfection.

Table 8. Summary of results for the three design alternatives.

Design Alternative	Ten Year Total Cost	Limitations
Heat Treatment	$2,068.26	- Additional time necessary for drying and cooling - Removal of items unable to withstand heat
Formaldehyde Fumigation	$5,242.36	- Difficulties sealing pen areas - Need multiple people to initiate disinfection
Commercial Disinfectant	$4,829.28	- Additional manual labor required for disinfection - Additional time necessary for drying

Student Statement: The Swine Research Experience & Education experience has helped me grow in both my knowledge of the engineering design process, and my skills in communication, leadership, and independence. Through this project, I have learned and performed the steps necessary to complete an engineering design for a client and how to communicate and collaborate with the client about goals for the design and what they are looking for. This project has also helped me gain skills in leadership and independence, especially through planning and executing a stakeholder meeting. Through the funding of this project, I was also able to do a site visit of the buildings these designs surrounded, and that experienced greatly increased my knowledge of swine systems and livestock buildings through simply seeing the buildings in person and getting a better understanding of how everything connects. My experience from this project has encouraged me to pursue graduate studies focusing on greenhouse gas air quality work, including swine and other livestock systems. I plan on completing an Integrated Degree Program, where I will obtain a master's degree one year after finishing my bachelor's degree in Bioproducts and Biosystems Engineering at the University of Minnesota.

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