RESEARCHREPORT

ENVIRONMENT

I. Identifying the Mechanism and Subsequent Remediation of Foaming in Swine Manure Management Systems. Project 15-136 - IPPA
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Iowa State University
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II. Industry Summary:

The typical Midwest deep pit swine grow out building design is very popular, but has experienced a significant, and unique, problem. Spontaneous foaming has been occurring in some facilities, and the foam itself presents serious potential dangers for both animals and workers in and around buildings. Methane gas is trapped in the foam's bubbles and creates a potential for fires and explosions, especially when the foam bubbles are rapidly destroyed in the presence of an ignition source. Conditions that are especially dangerous include pit agitation and pumping, as well as pressure washing or activities like welding, grinding, & drilling where slag or sparks might fall into the foam. If you are dealing with foam make sure you take the appropriate precautions to ensure safety for you, your employees, and your pigs. Below are a few best tips for working with foam.

If your facilities experience foam, make sure you take the appropriate precautions to ensure safety for you, your employees, and your pigs. Below are a few best practices for working with foam:

- Provide continuous ventilation to prevent gas build-up in the building.
- If disrupting the foam, increase ventilation to maximum for mechanical ventilation or wait until windy days for natural ventilation to quickly dissipate released gases. Never shut-off the fans nor close up the building.
- Turn off heater pilot lights and any other non-ventilation electrical systems, such as the feeding system), that might produce an ignition spark.
- When pumping pits that are close to being full, pump without agitation until manure is about 2 ft. below the slats.

Check out this video for a refresher on dealing with foam.

For more information contact:
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Research

Over the last three years, a collaborative research project to understand and mitigate the causes of foam has been conducted by Iowa State University, the University of Illinois, and the University of Minnesota. Substantial new of information has been learned about the foaming process, its potential causes, and the different methods of addressing it. That information is briefly shared below.

Farmer Survey

Information gathered from surveys suggests that in some production systems, 25% of the barns are experiencing some foaming problems with 10% of the barns seeing six inches of foam or more. Survey results also indicate there is no clear link between diet, genetics, barn construction, geography, drinking water, or management. Incidence of foaming seems to be confined to the upper Midwest region.

Gas Production

Methane is always produced during anaerobic breakdown of manure, so manure stored in deep pits generates methane. The danger is in the fact that the foam traps the methane, rather than allowing for it to continuously escape. Surprisingly, barns with foaming pits ("foaming barns") are consistently producing methane at faster *rates* than their non-foaming counterparts, often producing 2-3 times more methane per day. This led researchers to start asking why this might be happening. One explanation, based on several dietary feeding trials, is that diets higher in fiber tend to be less digested by the pig, which results in more carbon entering the manure storage. To microbes present in the pit, this carbon is a food source, it's the energy they need to grow and thrive. Consequently, it seems that recent dietary changes, such as feeding more DDGS (a feedstuff high in fiber and protein) effectively puts the fuel in the manure to build a more active microbial community. For example, a study of how diet impacted the amount of carbon in the manure found a diet with 35% DDGS inclusion resulted in 40% more carbon in the manure than pigs fed a corn-soybean meal based ration.

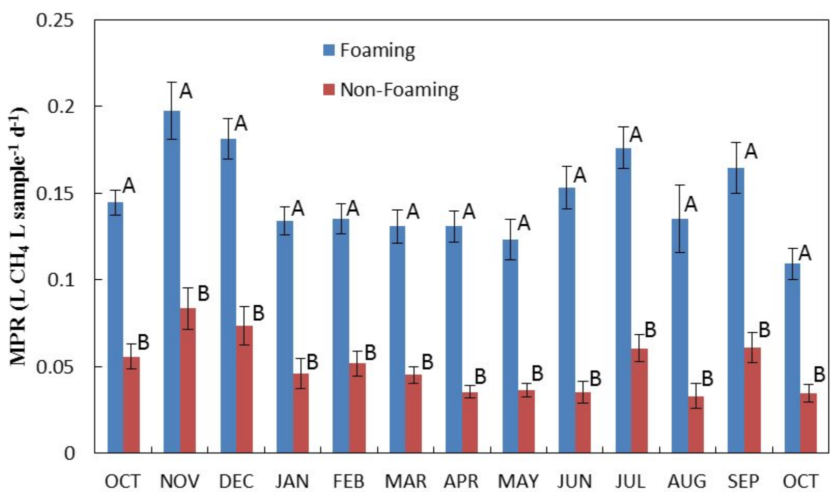

Figure 1. Methane Production Rate (MPR) for foaming and non-foaming manures.

However, simply getting the extra carbon into the pit doesn't guarantee foam, a microbial community needs to develop that breaks it down quickly. A comprehensive field assessment of foaming and non-foaming pits conducted during this work showed that very different microbial communities develop and thrive. The similarities in microbial communities for foaming barns (or non-foaming barns) greatly outweigh the differences between barns with like conditions. This demonstrates that microbial action is at least in part responsible for foam production, by converting the extra energy in pits into a set of conditions that make foam development possible.

What's this mean for mitigation? Finding ways to reduce methane production should lead to less foam. Rations which reduce carbon in the manure can lower the chances of foam by reducing the microbial food supply. This suggests that dietary changes towards more digestible feed ingredients (typically those lower in fiber content) or finding ways to make currently utilized ingredients more digestible (including finer grinding or feed treatments to improve digestion and incorporation in the pig) are appropriate. This also indicates that pit or feed additive treatments, such as ionophores (narasin and monensin), that impact methane production pathways, can be effective treatments as they lower methane production rates.

Stabilization

The second important ingredient for foam generation is the need for something to stabilize the generated bubbles and allow foam to develop. Research has found the stabilizing agent appears to be fine sized particles (2-25 μm) that are enriched in proteins, but it takes something to bind those proteins together. What's that something? At this point researchers aren't 100% certain, but best data suggests it is a microbially produced poly-liposaccharide, aka "microbial exudates." These microbial exudates cause the foam to be very viscous, keeping the bubbles wet and making them last longer.

One way of thinking about the chemistry of this stabilization is like comparing it to making meringue for your lemon meringue pie. In that case you take some egg whites (just the white, we want the proteins which have hydrophobic-water hating, and hydrophilic-water loving, areas or ends) and then start whipping it to entrain air. This alone isn't enough though; something needs to stabilize the meringue. That's where sugar comes in. Slowly add sugar and keep whipping and you'll end up with a tasty meringue that's light and fluffy and will persist for a long time. The sugars bond with the proteins and hold it all together.

What's happening in the manure is surprisingly similar to making a meringue. The biogas bubbles ascending up through the manure brings those bits of protein towards the surface (just like when we separate the whites from the yolk to make meringue) and also provides the light whipping effect, churning the protein and causing them to orientate themselves so their hydrophobic areas are towards the bubble and the hydrophilic areas to the manure. When the proteins react with some of that microbial poly-liposaccharide, stabilized foam results.

Summary of Mitigation Strategies

What's this mean for foam mitigation? This tells us there are two parts we can focus on to destabilize the foam, the protein or the microbial poly-liposaccharide. Research has shown that treatments that destabilize the proteins, such as proteases, can greatly reduce foaming capacity and foaming stability. Other treatments that seed microbes, especially microbes known to produce proteases, into the manure may be a viable treatment and are being tested both at the laboratory-scale and in-the-barn. As proteins are an important component of the stabilized foam, diets that lead to more protein excretion (typically higher protein contents) would seem to have greater potential for foam formation. A swine feeding trial focused on how different levels of protein and sources of protein impacted manure foaming properties. The results of this trial showed that higher protein diets led to manures that had higher foaming capacity, greater foam stability, and higher methane production rates – all characteristics of foaming manures.

The second component that could be targeted as a mitigation approach is the microbially produced poly-liposaccharide. Efforts to extract and better characterize this substance are underway; however, at this time not enough is known about material, or the microbe that produces it, to target this specific aspect of foaming.

Microbes

How does all of this explain when you have two barns that are treated the same; same pigs, same diets, they are as similar as they can be, but one foams and one doesn't? It's all about the microbial community that develops in the manure. Certainly the dietary ingredients can influence microbial community, but other factors seem to make as much of a difference. This was true both in the field and with the feeding trials that were conducted; however, based on the feeding trials it is clear that certain properties do influence the microbial community that develops. In particular, our study showed that manure carbon contents (microbial food energy) led to differences in microbial communities. Our field evidence suggests that where higher fiber diets are encountered, such as with DDGS, there tends to be microbes associated with foaming rather than with crusting surface conditions.

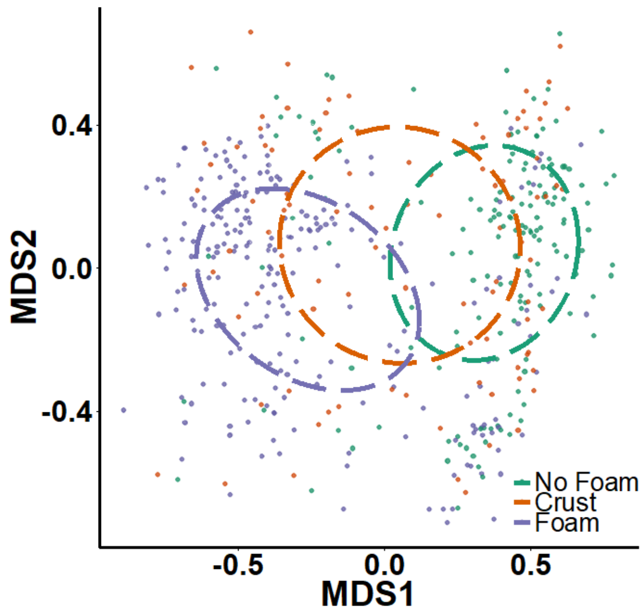

Figure 2. Microbial community analysis showing distinct differences between non-foaming barns and foaming barns indicating distinct microbial communities have formed.

In the case of non-foaming manures, the microbial community tended to be focused on lactobacillus and volatile fatty acids (VFA) processing. Within these barns the slurry showed an accumulation of VFA, which slightly reduces surface tension in the manure and methane production rates. Foaming barns exhibited microbial communities that were slightly correlated to higher added oil in the diets and exhibited increased presence of ruminococcaceae, ruminococus, and bateroidales and had a higher portion of the methanogens from unclassified methanogens, which seemed to be correlated to the higher methane production rates.

In terms of mitigation we are currently working to better correlate why these microbes become more prevalent as well as methods to alter and modify the microbial community. In particular, we initiated a study to evaluate if increasing lactobacillus in the manure can alter the amount of volatile fatty acids in the manure and upset the unclassified methanogens in the manure to alleviate foaming.

Leon's Safety Message:

September 15th, 2014: This past year Leon Sheets, Past-President IPPA/IPB shared the story, his story, of a flash fire/explosion at his swine barn. His important message reminds us all the importance of safety. "Farmers need to be careful whether they are pumping, power washing, or doing maintenance, when it comes to these accidents, we want no more, nobody else." **Do not become complacent.** Take the time to hear Leon's message.

Figure 3. Leon Sheets talking about foaming manure and the need to be conscious about safety.

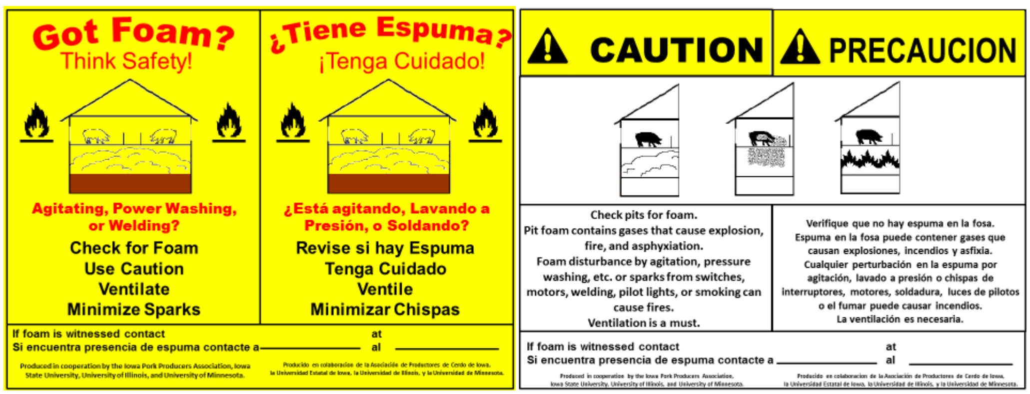

Figure 4. Safety sticker distributed throughout the Midwest developed in conjunction with the Iowa Pork Producers Association.

III. Keywords: swine, manure, methane, foam, pump-out, agitation

IV. Scientific Abstract:

Manure samples were collected monthly from October 2012 to October 2013 from 58 commercial swine finishing facilities with deep-pit manure storages in Central and Eastern Iowa. These samples, along with manures obtained from dietary feeding trials, were evaluated for a plethora of manure characteristics to provide insight into what may be causing foam formation.
Key summaries of the data:

Gas Phase (biogas production):

- Non-foaming manures had more than double the concentration of volatile fatty acids (VFA), precursor compounds used in methanogenesis, than foaming manures.
- Biological methane potential (BMP) of non-foaming manure was 23% higher than foaming manure much of it related to differences in VFA concentrations.
- Methane production rates (MPR) from foaming manure was on average 200% higher than MPR of non-foaming manure.
- The higher methane flux from foaming manure potentially also operates as an aerator causing fine particles in the manure entrained on bubbles to accumulate at the surface.

Liquid Phase (surfactant):

- Surface tension of non-foaming manure were significantly lower than foaming manure, which is opposite of what is expected if foaming manure was acting like a surfactant.
- Foaming manure had a higher foaming capacity than non-foaming manure; foam layers had higher foaming capacity than either manure presumably due to the accumulation of particles in the foam layer.
- Viscosity of the foam layer was significantly greater than underlying manure layers and this was true for both whole and centrifuged material indicating there was an accumulation of some substance in the foam layer present in either manure.

Sold Phase (particles):

- Foam was enriched in total and volatile solids and foaming manure tended to have a slightly higher solids concentration over non-foaming barns.
- The half-life of the foam for foaming manure was hours compared to minutes for non-foaming manure; half-life of the foam layer was an order of magnitude higher than manure.
- Average particle size of the foam material is significantly smaller than manure material.
- Foam layer enriched for particle size fraction between 2-25 μm with underlying foaming manure being depleted of particles in that size fraction.
- Foam stability enhanced by significantly higher viscosity keeping the foam layer wet and stable.
- Stabilizing molecules (i.e., tannins) that interact with proteins when added to non-foaming manures created stable foam indicating all manures have the capacity to form stable foam.
- Protein and carbohydrate concentrations were significantly higher in the foam layer of whole manure than either non-foaming and foaming manures.

Microbial Phase:

- Distinct manure surface texture (no-foam, crust, foam) was associated with specific microbial consortia.
- Indigestible fiber and protein were significantly abundant in crust and foaming sample diets.
- Free long chain fatty acid (LCFA) and Clostridia were one of the strongest correlations found in foaming samples.
- Different methane producing pathways were likely involved in no-foam, crust, and foam samples.

V. Introduction:

In 2009, the emergence of spontaneously produced foam on deep-pit manure storages became a major concern for swine producers. If the foaming is severe, this can lead to increased frequency of manure removal events (typically from once to twice or more times per year) due to reduced storage volumes. However, given the major crop cycles used in the Midwestern U.S. this makes these additional land applications (in off seasons) challenging. There are also serious safety concerns with this issue; the foam captures the biogas produced by microbial activity in the manure slurry. Foam collapse or breakage can release significant quantities of the trapped gasses, leading to potentially hazardous concentrations of hydrogen sulfide or explosive concentrations of methane in the barn (Moody et al., 2009). In general, foam observed in deep-pit storages is a dark-brown or gray, solids-rich, viscous fluid (Robert et al., 2011) with mid-sized bubbles entrained throughout.

We hypothesized that storages with existing foam accumulation would exhibit significantly different physical, chemical, and biogas production characteristics compared to non-foaming storages when evaluated using the three-phase approach. Specifically, the rate of biogas production, the concentration of critical substrates including short- and long-chain fatty acids, and the solids distribution within the deep-pit were evaluated. In addition, we used the lab-scale foaming capacity and stability test to evaluate if proper physical properties were present to allow foam generation and stabilization, but that non-foaming manures were not achieving sufficient gas production rates to cause foam. Better understanding of the causes and mechanisms of foaming will lead to the development of viable treatment and mitigation techniques.

The microbial consortia that develops within these storages is another key area to investigate. Previous research has often indicated that the presence of specific microbes is a cause in foaming in municipal wastewater treatment plants. To evaluate this area three objectives were formulated, these were:

Objective 1: ***Confirm foam production is correlated to differences in microbial communities.*** Our *working hypothesis* is that differences in the composition of microbial assemblages are correlated to the onset of foam production in deep-pit manure storages.

Objective 2: ***Identify specific microbial populations correlated with manure foaming.*** Our *working hypothesis* is that foaming and non-foaming deep-pit manure storages have different dominant microbial species that may be the cause of foaming or an indicator of foam production.

Objective 3: ***Identify any on-farm factors correlated to the onset of foaming.*** Our *working hypothesis* is that the presence and abundance of the dominant microbes identified above will be correlated to various on-farm factors that alter microbial communities and lead to foam production in deep-pit manure storages.

Although improved understanding of the microbial consortia may not lead directly to mitigation techniques, the potential to link them to operational changes and manure characteristics provides potential mechanisms by which the microbial community that develops could be altered.

VI. Objectives:

The goal of this research is to determine the mechanisms of and remediation for foaming in swine deep-pit manure management systems. This research was conducted by three Midwestern universities: Iowa State University (with subcontracting to USDA), University of Illinois at Urbana-Champaign, and the University of Minnesota-Twin Cities (specific investigators listed in separate final report document). The specific umbrella project objectives were to:

a. Review and update of the document **Literature Review: Deep Pit Swine Facility Flash Fires and Explosions: Sources, Occurrences, Factors, and Management** funded by the National Pork Board and dated December 21, 2009.
b. Identify individuals to serve on a Project Advisory Panel for the overall project subject to approval by IPPA and serve as chair of that advisory panel once formed during the duration of the project.
c. Convene a meeting or teleconference of persons and institutions who have been or currently are engaged in research efforts related to foaming in animal manure storage facilities and if appropriate municipal or industrial waste management facilities.
d. Based on findings derived from objectives #2 & #3 above, identify additional areas of research needed to achieve the goal of identification of the causes and solutions to foaming in swine manure storage facilities and prioritize those research efforts identified.
e. Develop a draft "Request for Proposal" (RFP) for each of the additional areas of research identified in Objective #4 above and a list of institutions or researchers believed to possess the resources and qualifications to successfully complete the efforts outlined in the RFP for consideration by the IPPA.
f. In conjunction with the Project Advisory Panel identified in Objective #2 above review proposals received in response to RFP's issued by IPPA as a result of Objective #5 above and make recommendations to IPPA relative to funding the proposals received.
g. Provide coordination and oversight on the additional research efforts approved and funded by IPPA as a result of the above Objectives on behalf of IPPA.
h. Provide IPPA periodic update presentations/discussions as requested by IPPA.
i. Provide IPPA written project status reports on an annual basis during the project period.
j. Upon completion of the overall project and additional research efforts compile the individual findings and reports from the coordinated research efforts into a single cohesive report which will

include an "Industry Summary" of conclusions and recommendations written for a non-technical audience.

Summary of Objectives and Completions

a.	Review and update of the document **<u>Literature Review: Deep Pit Swine Facility Flash Fires and Explosions: Sources, Occurrences, Factors, and Management</u>** funded by the National Pork Board and dated December 21, 2009.	Completed and attached as a separate file
b.	Identify individuals to serve on a Project Advisory Panel for the overall project, subject to approval by IPPA and serve as chair of that advisory panel once formed during the duration of the project.	An advisory panel of twelve members and two support staff was formed in late January 2012. The panel met in February 2012 to discuss direction of the project, possible interested parties, and a timeline. In June 2012, the panel selected three universities to receive funding to investigate the causes and remediation of pit foaming.
c.	Convene a meeting or teleconference of persons and institutions who have been or currently are engaged in research efforts related to foaming in animal manure storage facilities and if appropriate municipal or industrial waste management facilities.	Three conference calls with project researchers were held to discuss updates on the direction of the project during the Spring of 2013. A meeting was held in Ames, IA on June 4, 2013 to give research teams and advisory panel members an opportunity to discuss ideas, modify project direction if needed, and to continue a climate of collaboration between universities.
d.	Based on findings derived from objectives #2 & #3 above, identify additional areas of research needed to achieve the goal of identification of the causes and solutions to foaming in swine manure storage facilities and prioritize those research efforts identified.	After the June 4, 2013 meeting, researchers believed that more information needed to be gathered with respect to soluble and insoluble fiber content, long chain fatty acids, and the particle size within the manure samples collected.
e.	Develop a draft "Request for Proposal" (RFP) for each of the additional areas of research identified in Objective #4 above and a list of institutions or researchers believed to possess the resources and qualifications to successfully complete the efforts outlined in the RFP for consideration by the IPPA.	Completed and issued to ISU, UMN, U of NE, UIUC, and Cranfield University in April 2012.
f.	In conjunction with the Project Advisory Panel identified in Objective #2 above, review proposals received in response to RFP's issued by IPPA as a result of Objective #5 above and make recommendations to IPPA relative to funding the proposals received.	Completed June 29th, 2012. It was determined that an initial two-year contract was to be issued to UIUC, U of MN, ISU, and USDA sub-contracted with ISU. Third year funding and direction of research would depend on Year 1 & 2 findings.
g.	Provide coordination and oversight on the additional research efforts approved and funded by IPPA as a result of the above Objectives on behalf of IPPA.	Coordination and oversight has been provided through guidance during development of research objectives and by support staff efforts.
h.	Provide IPPA periodic update presentations/discussions as requested by IPPA.	Updates via email, teleconference, and on-campus meetings have been undertaken several times since the start of this project. Most recent update presented to the IPPA Research Committee on July 10th, 2015 and to the Project Advisory Panel on August 17, 2015.
i.	Provide IPPA written project status reports on an annual basis during the project period.	Mid-year and annual final reports were submitted as required by this project.

j.	Upon completion of the overall project and additional research efforts compile the individual findings and reports from the coordinated research efforts into a single cohesive report which will include an "Industry Summary" of conclusions and recommendations written for a non-technical audience.	Completed and included at the end of this final report.

VII. Materials & Methods:

Please see the attached final report for individual projects, including objectives, materials and methods, and results and discussion.

VIII. Results:

Please see the attached final report for individual projects, including objectives, materials and methods, and results and discussion.

IX. Discussion:

Please see the attached final report for individual projects, including objectives, materials and methods, and results and discussion.

Included in a separate and attached files:

Project Final Report
Updated Literature Review as per objective (a)
Safety Sticker via original PPT file