RESEARCH REPORT
ANIMAL WELFARE

Title: Depopulation of Swine by Inert Gassing Utilizing the Livetec Systems Nitrogen Foam Delivery System **NPB #20-099**

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Industry Summary:

The nitrogen foam delivery system is an alternative emergency depopulation system that uses high expansion water based foam bubbles to deliver nitrogen gas into a container, trailer, coral or barn. The integrity of the foam structure allows a blanket of foam to be maintained over the animal which is then exposed to, and maintained in anoxic conditions, effectively zero oxygen, until dead. The mode of death is intended to be by exposure to gas, not by the occlusion of the airway by the foam bubbles. Collaborative trials between the UK and US, to validate this process have been delayed by the exceptional circumstances we have found ourselves in over the past 12 months.

The system is made up from modular units which hold five key components, 1) Individual foam generator units, 2) Control and distribution platform, 3) Water supply, 4) Liquid nitrogen supply, 5) Gas Vaporiser. Water supply, liquid nitrogen supply and vaporiser are all elements that can be accessed from industrial suppliers at the time of a deployment operation therefore do not require capital investment nor additional maintenance requirement. The remaining components are incorporated onto a platform base in a shipping container which meets international standards for shipping and transport. Irrespective of the scale of the operation or deployment situation, there are several elements of the system that will be common to all situations. This core platform, built into the shipping container, houses a monitoring and control system to measure and record flow rates, pressures and temperatures of the gas and liquid supplies and can control the relative flows to ensure the correct delivery and rate and expansion ratio of the finished foam. The distribution pipe work manifold allows the connection of foam generator units and their respective gas and foam solutions hose supplies
The shipping container also holds 12 foam generators, supply hoses, the gantry support system and all ancillary equipment. The system provides for multiple deployment options whether on poultry or pig farms. A temporary gantry is assembled in front of the barn approximately 20ft high and span at least 10ft wide. Two foam generators and the associated supply hoses are suspended centrally from the gantry, above the parked trailer. An open topped trailer is backed up to the loading ramp and loaded with a single deck of pigs following industry standard operating procedures for the handling of swine.
The use of nitrogen filled water based foam is a feasible solution for emergency depopulation of

swine. It allows for the use of an alternative gas where carbon dioxide gas has been in short supply. The system has been designed for rapid deployment with a small number of operators. Standard operating procedures have been developed to allow the system to be used on smaller farms or on centralized sites to service a local area. It can be deployed and set up in a few hours, with the potential to depopulate over 8000 market weight pigs per day.

Key Findings:

- The systems was readily adapted to deliver short 2 minute bursts of high expansion gas filled foam bubbles into a coral
- In pre-deployment trials the average rate of delivery of finished foam with 2 foam generators was 3101 cuft per minute.

Keywords: depopulation, anoxia, nitrogen, foam, swine

Introduction:

The three key response goals to a disease outbreak are to: (1) detect, control, and contain the disease in animals as quickly as possible; (2) eradicate the disease using strategies that seek to stabilize animal agriculture, the food supply, the economy, and to protect public health and the environment; and (3) provide science- and risk-based approaches and systems to facilitate continuity of business for noninfected animals and non-contaminated animal products [1]

While prevention and bio-exclusion of a disease is everyone's goal, there is no doubt that depopulation is a necessary and effective means of response to protect the swine industry and pork supply. The American Veterinary Medical Association (AVMA) defines depopulation as the rapid destruction of a population of animals in response to urgent circumstances with as much consideration given to the welfare of the animals as practicable.[2] According to the National Animal Health Emergency Management System (NAHEMS) the goals of depopulation are to (a) provide humane treatment of animals at all times until they are culled; (b) select and use an acceptable form of depopulation to be executed as quickly, efficiently, and humanely as possible; (c) minimize the negative emotional and psychological impact on animal owners, caretakers, and the public; (d) prevent adulterated or potentially adulterated meat products from entering the food chain; and (e) prevent or mitigate disease spread within the country.[1]

However, there are multitude of factors that must be considered in selection and utilization of mass depopulation techniques. Historically it has proven extremely difficult to effectively and efficiently conduct even small depopulations of swine using traditional euthanasia methods for localized disease outbreaks such as H1N1, PED(v), TB, etc. Issues have included lack of equipment, supplies (cartridges, CO_2 tankers, etc.), trained labour, physical/mental exhaustion, psychological impacts (caring/killing paradox), disease spread, business continuity, etc. There is a need for equipment and techniques that have been scientifically validated, with robust, practical protocols developed in advance of an incident, to ensure safe and efficient deployment and fast resolution for the industry.

Several techniques (mechanical, electrical, pharmacological, gaseous and firefighting foam) have been employed for mass depopulation of swine and poultry in an emergency, each of which present practical challenges and raise welfare concerns. There is a requirement to depopulate large numbers of animals safely in as short a time as possible. As an example, for poultry, the use of a gas (e.g. bulk CO_2 delivered as a liquid that then sublimates) in houses has been advocated, as it eliminates the need to handle the animals, a vital advantage if worker health is at risk. However, unlike some other methods of killing, it is not instantaneous as research shows that birds remain conscious for significant periods and may experience respiratory distress. In addition, whole house gassing with free gas, requires significant preparations and is not applicable to much of the US industry with naturally ventilated barns.

An alternative method for whole house depopulation is the use of firefighting foam (Figure 1a), which has been tested and conditionally approved in the United States for use on some poultry species in specific circumstances.[2] Application of foam has several potential advantages including reducing the number of people in contact with the animals and as an alternative to the use of CO_2, which may be in

short supply in the event of a major disease outbreak. The firefighting foam used is medium density with small diameter bubbles. It operates as a euthanasia agent by rapidly occluding the airways of birds causing death by hypoxia. [3] However due to practical and welfare concerns surrounding this approach, use of firefighting foam for depopulation of larger animals is not considered acceptable. Hypoxia due to exposure to inert gases (Nitrogen, Argon, etc) for the euthanasia, slaughter and depopulation of swine and poultry has been evaluated and deemed acceptable worldwide. The AVMA states that inert gases are not detected by poultry and can be effective with containerized gassing methods or in whole-house situations.[2] However, inert gases have not traditionally been used for whole house gassing because of the practical impossibility of sealing the house or shed to the extent required to adequately eliminate oxygen (<2%). The use of high expansion gas-filled water based foam containing an inert gas presents a method of delivering gas into the shed or container where animals are held. It is a method of anoxic killing, since as the foam envelopes the animal, oxygen is effectively eliminated, and the animal will die by anoxia. The foam matrix contains a majority of bubble of a diameter of 0.75 inches or greater. The physical properties of the bubbles, by virtue of its high expansion ratio (greater than 250:1) and surfactant composition, means that it can effectively fill a space or open container without the need to seal it (Figure 1b).

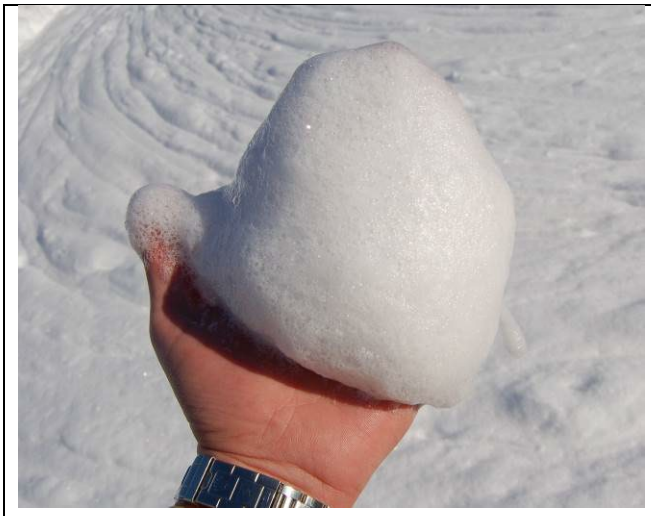

FIGURE 1a Medium density firefighting foam

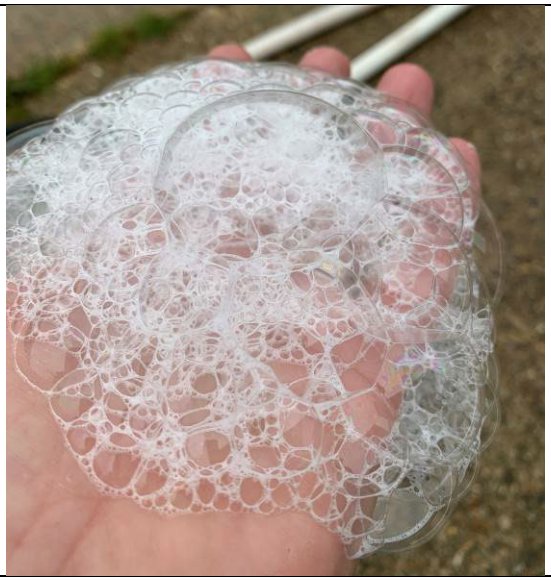

FIGURE 1b High expansion nitrogen gas filled foam

Livetec Systems have been involved in research and development of high expansion gas filled foam systems since 2007 and are currently leaders in the field. Our original work with the University of Glasgow Veterinary School and the Royal Veterinary College, London established the principle that exposure of poultry to inert gas delivered to the bird in a high expansion water-based foam, had potential to be an acceptable method of depopulation.[4] These initial trials with individual birds provide proof of principle that submersion in nitrogen filled high expansion foam provides a highly effective and humane method of euthanasia. Physiological observations and measurements of oxygen in the foam show that unlike previous application of medium expansion foam in the US, the method of killing is anoxia with nitrogen gas, not occlusion of the airway. This is corroborated by post-mortem examinations in which no evidence of tracheal occlusion with foam was found.

Immersion in high expansion foam filled with nitrogen achieved a rapid death, with broadly similar responses in all poultry species tested. Evidence showed that death was due to anoxia from to exposure to nitrogen gas within the foam bubble matrix and there was no occlusion of the airways. There was little behavioral response to immersion in air filled high expansion foam as a control. Once submerged exposure to less than 1% oxygen is immediate. Behavioral responses included headshaking, loss of posture and vigorous wing flapping characteristic of anoxic death. Mean time to

loss of consciousness was 30s in hens and 18s in broilers and death resulted between 50 and 65 seconds.[4]

Following this initial work larger scale systems were developed, capable of whole house gassing of poultry in their sheds using nitrogen gas instead of traditional carbon dioxide. The prototype system was completed in 2013 with industry funded trials. Demonstration trials and active deployments have been carried out in multiple facility types and production systems. The Livetec Systems Nitrogen Foam Delivery System (NFDS) produces 5000 – 6000 m^3 (176,573-211,888 Cu ft) of finished foam per hour delivered though patented nitrogen foam generators. Each generator produces 50 m^3/1765 Cu ft per minute, the residual oxygen within the foam matrix is less than 1%.

Deployment for Pigs

The use of inert gasses for euthanasia, slaughter and as a depopulation method for pigs has been extensively studied and has been approved by the European Union since 2009. Likewise, the AVMA has deemed that hypoxia resulting from exposure to inert gas mixtures is acceptable with conditions for euthanasia of pigs, however highlighting that it is typically not practical in farm situations.[5] Research into the use of nitrogen filled foam for the euthanasia of pigs, (weaners, slaughter weight and adult) is being currently being conducted by institutions in Europe. Our own collaborative work in the USA funded by the NPB was unfortunately delayed due to COVID travel restrictions.

Preliminary research from Sweden indicates that pigs exposed to nitrogen foam lose posture within 60 seconds and are motionless around 131 seconds and showed no strong aversion to the foam.[7]

Objectives:

The aim of this project was to systemically evaluate the potential of the Livetec Systems NFDS as a depopulation tool for swine. The use of inert gases to effectively stun and kill pigs is well documented [7-8]. This would have be achieved by completion of the following objectives:

1) Assessing the effectiveness of Livetec Systems NFDS for killing swine.
2) Validation of the Livetec Systems NFDS for depopulating swine on a commercial scale.

Materials & Methods:

The NFDS system had originally been designed for deployment of large quantities of foam into poultry barns, running continuously for 1-2 hours per barn, depending on its size. It was proposed that an alternative method of application be found for the depopulation of swine.

Although it was feasible to deliver foam into a swine barn and euthanize all animals in the barn, there was concern about the difficulties in removing the carcasses, however this was the approach taken by Ventilation Shut Down (plus), therefore perhaps not an insurmountable problem.

The proposed alternative method of application was to load pigs in groups into open topped trailers and deliver foam over the top of the trailer. This created a new challenge as rather than running the system continuously for an hour or more, a 53 foot trailer would fill in 60 seconds and the system would then have to be shut down again until the next vehicle is in place to foam.

The NFDS was reconfigured with an attached gantry which supported two foam generators 16 ft in the air. (Figure 2)

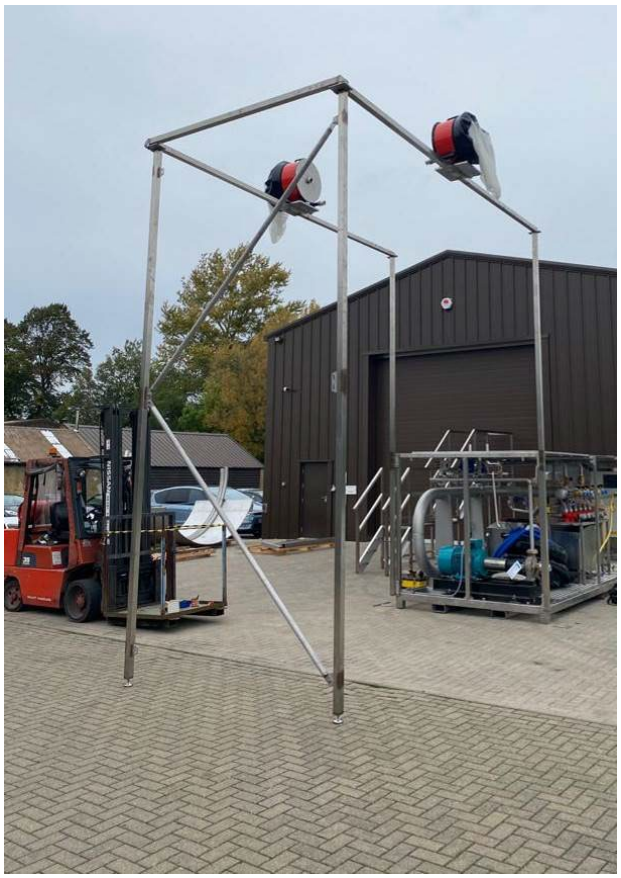

Figure 2 NFDS Foam system with drive through gantry

Results: Although all the planning and preparation was completed, the travel ban to the USA prevented UK personnel traveling to the US at the last minute, although initially approved for travel. . The team therefore had to cancel the planned trials, attempts were made to complete the trials in the UK but the required ethical review and license application could not be completed in the time available.
We were able to complete dry run testing. (Figure 3)

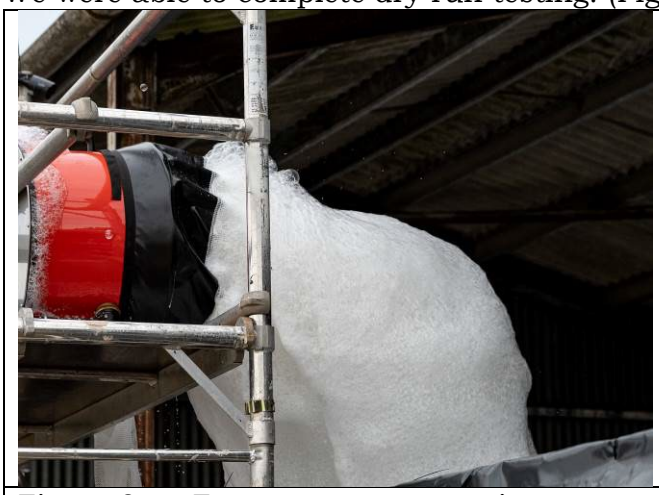

Figure 3 a. Foam generator running

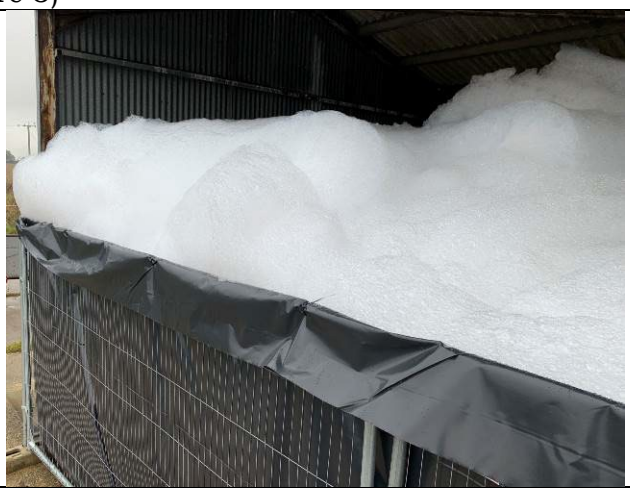

Figure 3b. Open pen filled with high expansion foam

The foam generators were set up to fill an open topped pen with 8ft walls. The average rate of filling was 3101 cubic feet per minute.

Discussion:

Unlike poultry, who can be depopulated in the barn, mass depopulation for pigs requires the movement of the pigs out of their housing prior to depopulation to facilitate carcass disposal. Livetec Systems has designed a NFDS protocol to utilise containers or trailers to hold pigs outside of their housing which could then be filled with nitrogen foam.
A temporary gantry is assembled in front of the barn approximately 20ft high and span at least 10ft wide. Two foam generators and the associated supply hoses are suspended centrally from the gantry, above the parked trailer. An open topped trailer is backed up to the loading ramp and loaded with a single deck of pigs following industry standard operating procedures for the handling of swine. Once loaded the trailer moves under the gantry system and foam delivery is initiated. A standard 53 foot trailer with a volume of 3390 Cu ft could be filled with dual foam generators mounted on the gantry in about one minute. It is expected that pigs would enter a convulsive stage 60 seconds after submersion in the foam, and additional foam could be added if required to ensure the pigs remain sufficiently submerged and not exposed to atmospheric air. Foamed trailers would be staged to allow for a minimum 7-minute exposure period to the nitrogen gas to ensure death. It is expected that the total cycle time from backing up, loading, foaming and moving off again to be approximately 20 minutes. However by shuttling trailers from the loading ramp, to the foaming station, disposal point and back to the loading ramp it is expected that a load could be depopulated every 10 to 15 minutes.

The foam delivery system can be set up by 4 people and operated by 2 technicians and the nitrogen supply, including the vaporiser and liquid nitrogen, will be managed by 2 gas engineers provided through the gas supply company. The swine production operation will provide personnel to handle, sort and load swine destined for depopulation in accordance to industry standard operating procedures. To maintain target throughput, sufficient personnel will be required to load the trailer in approximately 10 minutes.

The following throughputs are based on loading a 53ft trailer with pigs at a stocking density 15% above the normal transport density. [7]

Table 1. Estimated depopulation throughput rates for different pig weights.

Pig Type	Weight (lbs)	Number of head per load	Total per hou 4 cycles per h	Total per operational day (20 Hrs)
Isowean	12	767	3070	61,400
Grower	150	169	676	13,520
Market	275	109	436	8,720
Sow	450	71	285	5,700

If sufficient trailers are available and the site layout allows, the nitrogen foam system can support up to 6 coordinated depopulation efforts. Running multiple pairs of generators consecutively is the most efficient operational process and will increase throughput.

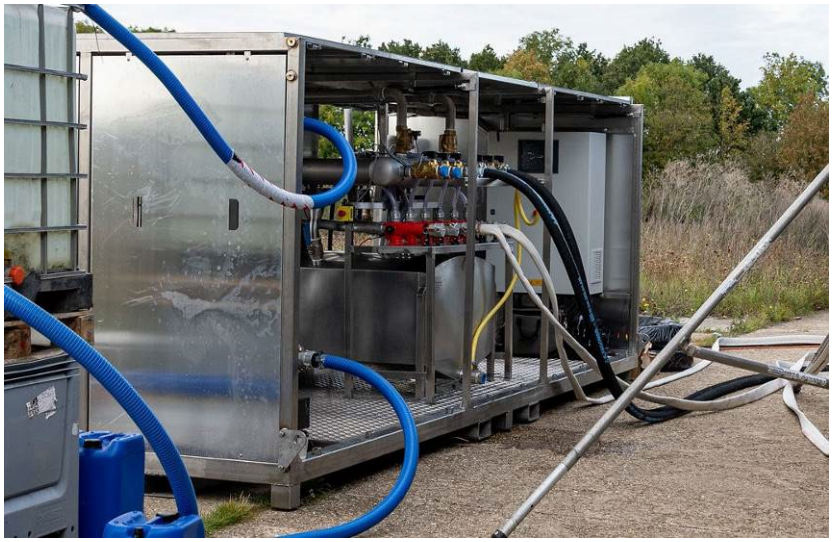

Figure 4. Nitrogen foam system

Throughout the research and development process projects, we have designed, developed and evolved improved foam generators. The latest generation are highly efficient units that can generate up to 50 m3/1765 Cu ft of finished nitrogen filled foam per minute when supplied with gas and foam solution to the correct pressure and flow rates. Livetec have patented the technology and principle of design of the foam unit.

Water supply capacity is determined by the scale of the operation as each cubic metre of water will produce up to 350 m^3/12,360 Cu ft of foam. For instance, to fill a 96 m^3/3390 Cu ft container or trailer would consume 273 litres/72 US gal water and approximately 5.75 litres/1.5 gal of foam concentrate. The foam concentrate used in the system is propriety to Livetec Systems. It is tolerant of different water qualities, working with hard, soft, fresh, brackish or sea water, and breaks down fully within the environment.

The flow rate of nitrogen gas required by the system is determined by the number of generators that will be in use simultaneously. The supply requirement to fill a trailer or open topped container utilizing dual foam generators is no more than 7000 normal cubic meters (Nm) per hour if the system was in use continuously. To depopulate one trailer of pigs it is estimated to take a maximum of approximately 100 m3 of nitrogen gas. Therefore as 1000 litres/264 gal of liquid nitrogen (LIN) create 682 m3 /24,084 Cu ft of gas, each depopulation cycle would require 68.2 liters/19 gal LIN. There are several options for supply of nitrogen gas and the scale of the operation will determine the supply mode as all are readily available for rental through industrial suppliers.

Once the unit is on site it is possible to re-fill them from a supply tanker that can stay outside the demarcated biosecurity perimeter, this reduces the need for taking additional equipment onto a farm.

Integration with Carcass Disposal

To ease carcass handling the containers should have a floor conveyor or other moving floor mechanism to be able to remove the pigs. Once it has been determined that the pigs are dead, the foam can be destroyed by application of compressed air jets if necessary due to disposal method selected. If the disposal site is close by (local or on farm burial/composting) and sufficient trailers available, the trailer can simply be driven away for disposal of the carcasses. Alternatively, the carcasses from multiple foaming trailers could be combined by utilizing an elevating conveyor to lift and deposit the carcases into a secure bulk disposal vehicle which could carry in excess of 25 tonne/55,000 lbs of carcases (depending on local commercial load weight restrictions). Trials of the system including alternative carcase disposal techniques such as above ground burial and composting are scheduled for later in 2021.

Summary

The nitrogen foam delivery system is an alternative emergency depopulation system that uses high expansion foam bubbles to deliver nitrogen gas into a container or trailer. The integrity of the foam structure allows a blanket of foam to be maintained over the animal which is then exposed to anoxic conditions until dead. The mode of death is intended to be by exposure to gas, not by the occlusion of the foam bubbles. Collaborative trials between the UK and US, to validate this process have been delayed by the exceptional circumstances we have found ourselves in over the past 12 month, but progress will be made in the first half of 2021. The use of nitrogen filled water based foam is a feasible solution for emergency depopulation of swine. It allows for the use of an alternative gas where carbon dioxide gas has been in short supply. The system has been designed for rapid deployment with a small number of operators. Standard operating procedures have been developed to allow the system to be used on smaller farms or on centralised sites to service a local area with the potential to depopulate over 8000 market weight pigs per day.

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