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DESICCANT SYSTEM'S POTENTIAL FOR SWINE FACILITIES APPLICATIONS

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ABSTRACT

Heat stress associated with elevated temperatures and relative humidity (rh) has been shown to reduce the production levels of different swine facilities. Traditional cooling methods including evaporative pad cooling and misting have been used to lower temperature, but are not as effective in lowering relative humidity. Also, electric air-conditioning (AC) has been shown to be effective, but generally not as feasible an option due to more demanding cost and operational considerations. This study represents a first analysis of a space conditioning system that uses desiccants to control relative humidity and to enhance different cooling methods including evaporative pads. Desiccants have proved effective in human comfort applications when used in conjunction with traditional AC units. Results from this study suggest these systems could be used to effectively eliminate stress conditions in a swine facility or modified to enhance current cooling methods.

KEYWORDS. Swine housing, Heat stress relief, Dehumidification, Evaporative Cooling, Air conditioning, Computer simulation

INTRODUCTION

This report offers an initial evaluation of a novel application of desiccant systems for enhancement of the environment in swine breeding and genetic improvement facilities that can be retrofitted to existing systems or included in new facilities. Presented are the basic concepts of desiccant systems and design modifications to adapt the technology from human comfort applications to swine environmental control applications. A computer simulation gives the performance and economic analysis of a conceptual swine facility located in Charlotte, NC. The results suggest a system that could improve the thermal comfort of breeding swine, especially for climatic conditions associated with heat stress, and should enhance animal productivity and welfare.

Heat and Humidity Stress Background

On Dec 1, 1997 and 1998, there were 6.957M and 6.672M breeding animals in the U.S., respectively (USDA, 1998). Of these, 2.715M (1997) and 2.635M (1998) were in hot and humid south/southeastern states (MD, WV, VA, NC, SC, FL, GA, TN, MS, LA, TX, OK, KS, NE, MO, KY). For the farrowing sows, the total respective numbers for 1997 and 1998 were 11.5M and 12.1M total and 4.7M and 5.1M in the south/southeastern states. In addition, the fastest growing areas of swine production are in many of the hot and some of the humid areas of the U.S.

The fact that heat stress has a negative effect on intake and growth rate of pigs reared in hot, humid environments has been well-established (NRC, 1981; Close, 1978). It has been demonstrated that the growing-finishing pig closely regulates its feed intake with respect to the thermal environment. This led to the conclusion that there is a strong thermostatic regulatory mechanism in swine (Nienaber et al, 1994). At the biological engineering unit of the USDA-ARS Meat Animal Research Center (MARC), research completed in the environmental chambers showed that relatively large increases in tympanic temperature and heat production are associated

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with eating events. Under heat stress conditions, the decline in the rate of heat production is much more rapid than the decline in body temperature leading to heat storage within the body (increased body temperature) which effectively delays additional eating activity (Eigenberg et al, 1995).

Several researchers have shown that high temperatures adversely affect swine growth and feed intake. In a 21-day study of the effects of warm diurnal temperatures, Lopez et al. (1991) found that pigs raised in a hot environment [22.5 to 35 ^{o}C] gained weight at a 16.3 % lower rate and feed intake was 10.9% less compared to pigs raised under a constant temperature of 20 ^{o}C. Morrison et al. (1975) also observed a reduced growth rate for finishing pigs under a high temperature of 27.5 ^{o}C compared to those at a thermoneutral temperature. Roller et al. (1967) and Roller and Goldman (1969) found that daily feed consumption, average daily gain and reproductive performance were significantly reduced as dry bulb and dew point temperature increased. The results of these researchers clearly indicate that heat stress affects performance, and that some form of cooling would be beneficial in reducing animal heat stress under warm climates while improving the rate of milk production and piglet survival.

Although previous studies have emphasized the effects of high ambient temperatures on swine performance, the literature also indicates that humidity could negatively impact the development of pigs. This impact can be measured by THI's or temperature-humidity indices (Roller et al. (1967) and Roller and Goldman (1969), see Table 1 in Gates et al (1991a,b) for a listing of different THI values used by livestock researchers).

DESICCANT SYSTEM TECHNOLOGY FOR COOLING

Desiccant systems may be used to control humidity or to lower the wet bulb temperature of a process air stream (Kosar, 1998). However, until recently, the costs seemed to be prohibitive for many applications (Kosar, 1999). Desiccant technology in conjunction with a cooling system has been shown in non-agricultural applications to effectively control the humidity and temperature of an indoor environment. Applications have included corrosion prevention, condensation prevention, mold/mildew prevention, moisture regain prevention and product drying. Industries which have used desiccant technology include supermarkets, ice arenas, cold warehouses, hospitals, hotels, theaters, schools, restaurants, retail stores and nursing homes.

A desiccant system dries an inlet or process air stream by passing it through a portion of the matrix of a desiccant wheel, as shown in Fig. 1. Usually for comfort control, a cooling element has to be added to the dried but warmer process air stream to reduce the dry bulb temperature closer to ambient conditions.

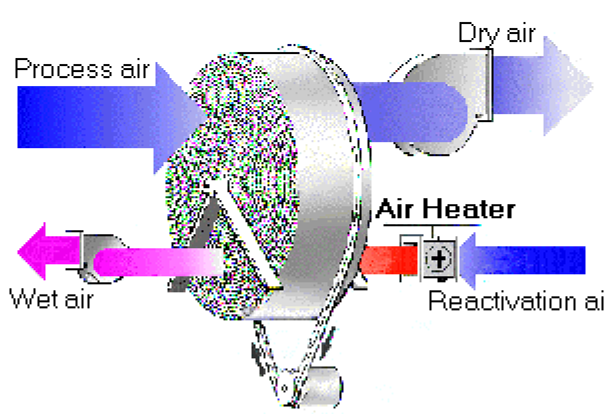

Figure 1. Schematic of desiccant wheel operation including process and reactivation air streams.

The matrix is either coated with or impregnated with a desiccant material, which removes the moisture from the air stream and thus lowers the relative humidity or wet bulb temperature. During operation, the wheel rotates, and thus prevents sections of the wheel from becoming saturated with water, and allowing for continuous operation. A counter-flow (to the direction of the process air stream) reactivation air stream regenerates the wetted section of the wheel. The reactivation stream is heated at the inlet of the wheel. The increased air temperature allows the air stream to "pull" the water off of the wheel matrix and regenerates the matrix for the process stream.

Desiccant System Designs

Desiccant technology in conjunction with a cooling system has been shown in different applications to effectively control the humidity and temperature of an indoor environment. The purpose of a desiccant system is to control humidity or lower the wet bulb temperature of a process air stream. The benefits of controlling the amount of moisture in the air include reduction of thermal stress (both humans and animals) and/or enhancement of evaporative cooling. The enhanced evaporative cooling effect can be beneficial both in the direct cooling of the swine by moisture evaporating off of their skin or in the use of evaporative cooling pads. Both processes are greatly enhanced by first drying the air because dryer air is able to absorb more evaporating moisture, and thus increases the capacity of the evaporative cooling effect. The capacity of evaporative pad coolers is dramatically reduced in high humidity climates.

Cooling loads are divided into latent loads associated with the control of humidity and sensible loads associated with the control of the dry bulb temperatures. Two common measurements for humidity are humidity ratio [g H_2O/kg dry air] or dew point temperature. Desiccant-based technologies have been shown (Kosar, 1998) to be effective for the precise controlling of moisture levels in air. Using desiccant systems, particularly those in a hybrid configuration with electric air-conditioning, results in a significant operating cost savings compared to a traditional air conditioning (AC) system, because the removal of the moisture from the air eliminates the latent load and thus significantly lowers the load on the AC system. Also, desiccant systems generally have a smaller operating cost because they operate using natural gas, propane or waste heat as compared to an electric AC. Generally, the cost/BTU for gas is significantly less than for electricity.

Proposed Conceptual Design of Desiccant System

Current commercially available options for cooling of finishing swine include evaporative pad cooling, direct sprinkling, and misting systems. Bridges et al. (1992a) indicate that for Kentucky and much of the Southeast, most cooling for finishing swine is done using direct sprinkling systems. Desiccant based systems work best in conditions where removal of moisture from the air is as important as lowering the air temperature. The removal of moisture could be applied in two ways for this project: as a tool to enhance evaporative cooling or removal of latent load to reduce the overall cooling load.

A desiccant system is plotted on a psychometric chart in Fig. 2.

As shown in Fig. 2, the outside air passes through the desiccant wheel (A-B) and follows a path that diverges slightly upward from a constant enthalpy line. The cost of removing moisture to the conditions at point B is an increase in temperature. Some of this temperature can be recovered using a heat exchange wheel in the desiccant system that shifts the conditions at point B along a sensible heat line to point C. Additional sensible cooling, including electric air-conditioning would continue to shift C along a horizontal axis. If the air at point C is passed through the evaporative pad, the resulting air temperature at point D is lower than at A and the absolute humidity of the air is less, thus lowering or eliminating thermal stress on the animals.

The enhancement to the evaporative cooling of the pad occurs because point C is at a lower rh then point A, which represents outside air that would have been pulled through for evaporative pad only applications.

The stress levels at point D are also lower than at E, which could be reached by a process (A➔E) of using non-dehumidified air passing through an evaporative pad. The main concern of this method is whether the reduction in stress levels leading to increased production levels offsets the investment costs of the desiccant system. The basic concept of the system along with points A through D from Fig. 2 is shown in Fig. 3.

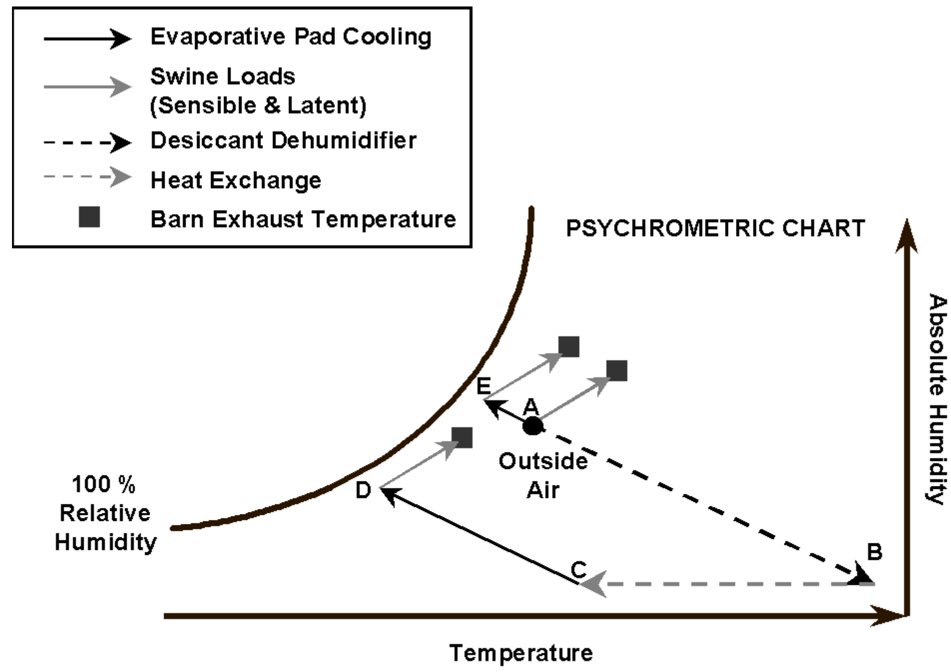

Figure 2. Psychometric chart plotting the operational conditions for a desiccant-based system using an evaporative pad. Each path between points in the chart is as follows: Path A-B: outside air passes through the desiccant wheel; Path B-C: sensible heat recovery from heat exchange wheel; Path C-D: evaporative pad cooling.

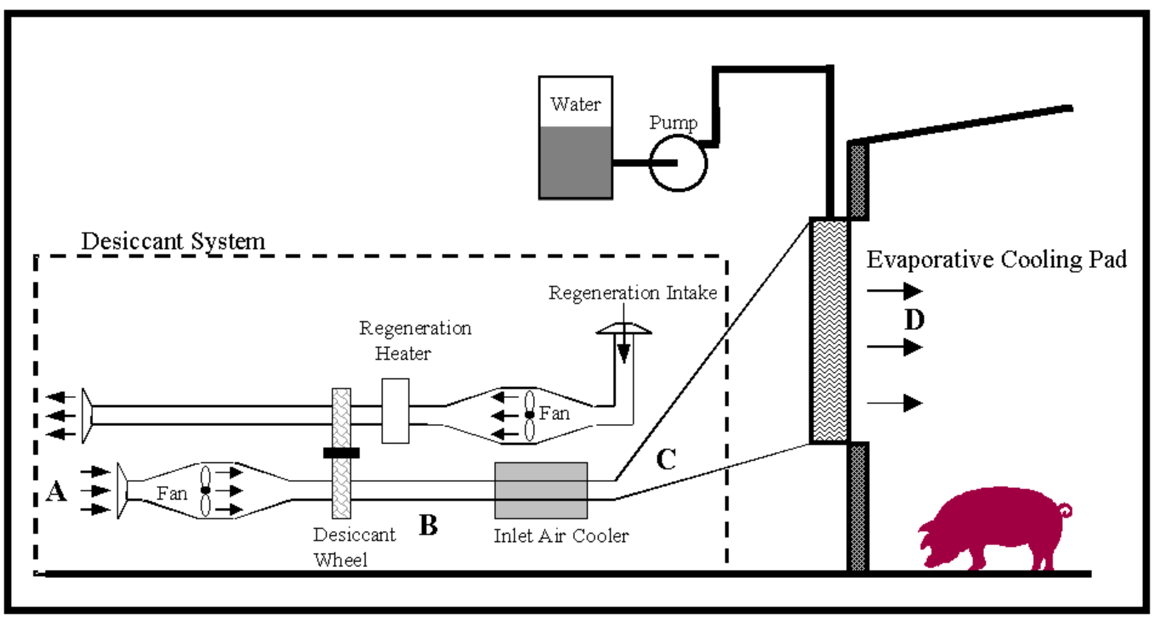

Figure 3. Design concept for swine facility desiccant system with evaporative cooling pad.

The success of this process depends greatly on the heat recovery along path B to C in Fig. 2. The further to the left point C is positioned, the cooler the inlet air to the barn is after the e-pad. This also results in less cooling required from an electric AC.

DesiCalc® Simulation and Economics

For this analysis, the proposed design uses the desiccant hybrid system consisting of a desiccant unit and small AC system to provide sensible cooling. Ideally, the simulation would avoid the use of electric cooling, but DesiCalc® was developed for human applications where electric AC is the standard. However, the use of electric AC with a desiccant system has the potential to eliminate some of the disadvantages that electric cooling has experienced in agricultural applications, including cost and reliability. A future hope on improving methods of sensible heat recovery includes evaporative pads to eliminate electric costs. The purpose of this simulation is to investigate the potential of the desiccant system, not the sensible cooling method.

The potential overall savings benefit of using a desiccant system can be determined using a software package developed by the Institute of Gas Technology (IGT) and the Gas Research Institute (GRI) entitled DesiCalc®. DesiCalc® models the environment within a building using desiccant technology to supplement a traditional air-conditioning system. The DesiCalc® software includes templates for 11 commercial building types and weather conditions for 236 cities and can be modified for specific cases. DesiCalc® calculates the energy loads and costs using the DOE 2.1E computational engine. The versatility of the software facilitates the fine-tuning of the modeling and design of a system to utilize the wasted heat from the generator system. The DesiCalc® software first and foremost will allow us to determine the feasibility of using the extra thermal energy for the purpose of dehumidification in a light commercial building. The results using DesiCalc® allow us to compare the operational costs of a generator cogeneration system with traditional air-conditioning methods, including the reduction in costs of house loads. Another benefit of the DesiCalc® software is that we will be able to determine other building applications where the cogeneration system could be applied.

Because DesiCalc® is designed for human application to commercial buildings, modifications to the inputs and assumptions were required to simulate a swine facility. This simulation will focus on a boar study facility, but other barn types including farrowing and nursery could be used. The annual climatic and energy rate data for Charlotte, NC were used and the space area was set to 1820 sq. feet (26' x 70'). A retail building was used because it more closely simulates a concrete floor boar barn with insulated walls and ceiling. A barn this size holds about 36 boars, with heat and moisture production assumed to be 490 Btu/hr and 0.32 pounds of water/hr respectively. The latent and sensible loads are about double for the boars as compared to humans. Because the latent and sensible loads of the occupants cannot be changed, the occupancy was set at 72 persons to simulate 36 boars. The simulation results are based on the desiccant system maintaining a desired temperature and relative humidity within the barn. For our example, assumed ideal conditions for boar productivity of 20 ^{O}C and 60 % relative humidity were used. At these ideal conditions, the minimum required ventilation rate for this barn is 20 CFM/pig or 720 CFM to satisfy the building's sensible and latent loads. However, most barns do not ventilate at the minimum rate, so for this simulation a ventilation rate of 1500 CFM was used.

For this analysis, the rate schedule used was NC: CPL MGS85/PSCNC for Charlotte, NC. This schedule includes:

- Miscellaneous Charges

  $12 Monthly Charge

  3% Taxes/Surcharges

- Electricity

  Stepped Charge: 4.7¢ per kWh

  Demand Charge: $4.89 per kW

- Gas (1 therm = 100,000 BTUs)

  48.2¢ per therm summer

  51.4¢ per therm winter

  39.1¢ per therm cooling

Analysis using DesiCalc® was performed for three types of systems compared to a desiccant hybrid system: a single AC system, two AC system and AC system with no humidity control. A single AC system uses a standard electric, vapor compression system to control the air temperature and humidity. A two AC system uses one AC system to lower the air temperature and a smaller AC system to remove moisture from the air before entering the second AC. An AC system with no humidity control uses one AC system to lower the air temperature to a set value without concern for the air humidity levels. All three types have advantages and disadvantages and will be discussed in the results.

The results for the three types of systems compared to the desiccant hybrid system focuses on three calculated values: Design Cooling Capacity (in units of tons of refrigeration), Annual Energy Costs and Occupied Hours above 60% relative humidity. Table 1 gives these values for the conditions stated above.

Table 1. Simulation Results from DesiCalc®.

System	Design Cooling Capacity (tons refrig.)	Annual Energy Cost ($)	Occupied Hours > 60 % rh (Days)
One Larger AC System	11.22	$5,315	86.0
Two AC System	10.3	$2,679	131.9
AC System without Humidity Control	5.7	$2,398	148.0
Desiccant Enhanced Hybrid System	4.6	$2,884	0.00

In terms of cooling capacity, the size of the cooling unit decreases 59% from the one AC system to the desiccant hybrid system, the reason being the desiccant system handles the latent load of removing water (thus lowering humidity) from the air. The AC systems have progressively smaller required cooling capacities because the removing of the water from the air is handled more efficiently or ignored. The difference in annual energy costs ($2,431/year) is due to the difference in the cost of electricity and natural gas in the Charlotte area. The one AC system is using electric energy to control air humidity while the desiccant system using natural gas energy. The annual energy costs were less for the two AC and AC without humidity control systems compared to the one AC system, but this savings is offset by reduced humidity control. Table 1 and Fig. 4 shows that the AC only systems attempt to control air rh to levels below 60%, but all three systems still result in room conditions where the relative humidity is above 60% for greater than 2,000 hours or 86 days. In comparison, the desiccant system never allows the room humidity to rise above 60%. This result shows one of the failings of using electric AC only for swine barn cooling. Due to increased heat and moisture production of a boar compared to a human, the AC system has to be larger in terms of tons of refrigeration to keep the interior barn temperatures below stress levels. The system, however, is still unable to maintain the barn humidity below 60% rh.

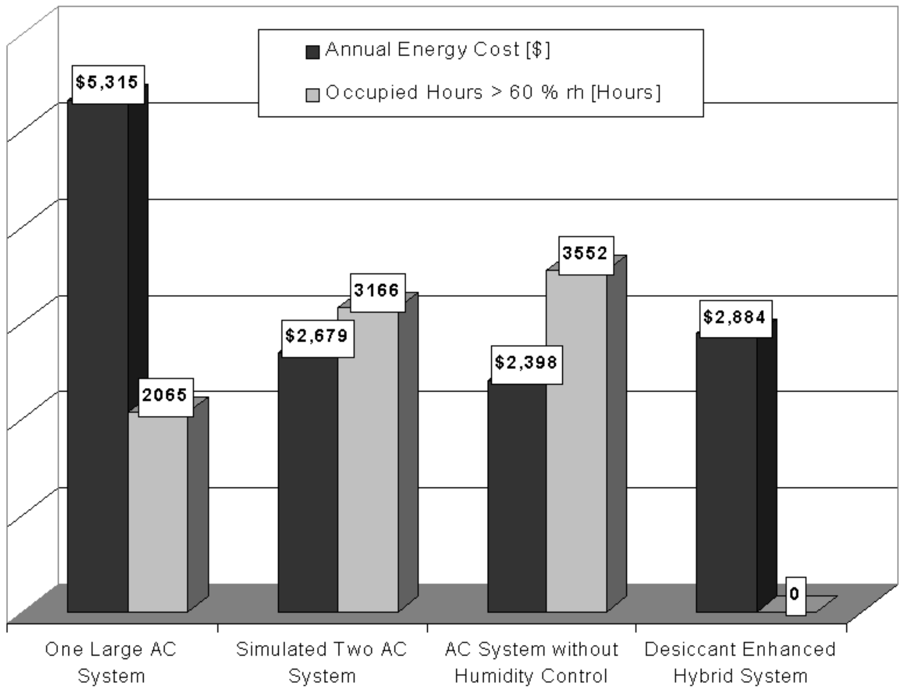

Figure 4. Simulation performance results for AC cooling systems compared to desiccant system.

SUMMARY

Previous studies have shown that improvements in swine production and potential economic savings can be realized by reducing the thermal stress experienced by swine. This study focused on not only reducing stress related to temperature, but also reducing humidity. Areas like the southeastern United States that frequently experience relative humidity of over 80% in the summer are particularly affected. This area not only deal with the negative effect high humidity has on the pig, but the negative impact that high humidity has on some cooling methods. An example is evaporative cooling to lower the barn temperature. At higher relative humidity, the evaporative cooling effect's capacity is reduced such that the system is unable to lower the barn temperature to below stress conditions. Desiccant dehumidification mitigates such effects by lowering the inlet humidity when used with an evaporative pad. Simulation results showed that a hybrid desiccant-AC could eliminate all thermal stress conditions (both temperature and humidity) and result in increased swine production levels. An AC only system is capable of controlling stress related to temperature, but cannot eliminate stress related to humidity like a desiccant hybrid system. The simulation also shows that the desiccant system represents potential annual energy savings over the AC only system because of the cost difference between electricity and natural gas. Thus in terms of application to swine barn facilities, a hybrid desiccant-AC cooling system has the potential to eliminate all thermal stress conditions within a barn without the fallbacks associated with AC only systems or to enhance the performance of evaporative pad cooling.

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