Centre for Research and Development (CERAD)
The Federal University of Technology, Akure, Nigeria
JoST 2011

Development of an Automated Pig Cooling System

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ABSTRACT: The tropical environment constantly subjects heat-sensitive farm animals to stress under warm environmental conditions. Animals exhibit different behavioural patterns in an attempt to cope with the stress. However, the level of stress susceptibility varies from one animal to the other. The effects of heat stress are easily noticed in the physiology of the animal and it generally reduces productivity of the animal. In order to alleviate the problems associated with manual wallowing to reduce heat stress in pigs, an automatic showering system was designed, constructed and evaluated. The system is such that the movement of the pig through the entrance of the shower will trigger a pump with the aid of an infra-red electronic device. The pump will supply water to the shower head and subsequently effect cooling of the pig. The system is very efficient as the delay period only varied from 1.7 s to 2.59 s and the pump discharge was 0.2 litres/sec. The showering period to cool the pig was 4 minutes. It was concluded that the system could be adapted for use by pig farmers for reduction of heat stress and hence improve productivity.

Keyword: Showering unit, temperature, stress, wallowing, infrared sensor

JoST. 2011. 2(2): 101-111.
Accepted for Publication, August 1, 2011

INTRODUCTION

The zone of effective environmental temperature across which pigs survive is much wider than that in which the thermal environment has no effect on their health, growth, and reproduction. Pigs are vulnerable to low temperatures as neonates, but they become progressively more susceptible to warm surroundings as they grow older.

Environmental factors are a prime consideration in the maintenance of animal health. Steinbach (1987) underlines the essential need to manage the environment of the animal as much as the animal within its environment. A homoeothermic animal attempting to maintain core body temperature at a relatively steady value despite changes in its thermal environment must balance the rates at which heat is gained by and dissipated from the body. The heat gained originates primarily from metabolic conversion of the chemical energy stored in food. The rate of metabolic heat production in a thermoneutral environment ranges from 50 to 200 Wm^{-2}, depending on species and the level of production (Nienaber *et al*., 1989; Webster, 1974).

At high environmental temperatures, the rate of sensible heat loss may be lower than the rate of metabolic heat production in a thermoneutral environment. A animal relies on the evaporation of water to dissipate its excess heat, either from the skin surface as a result of sweating or from respiratory system by panting. This is necessary to prevent a rise in body temperature due to storage of thermal energy. The range of environmental temperatures outside which thermal strain causes a loss of productivity depends on the metabolic rate and on the thermal resistance to heat and mass transfer between the body core and surrounding. Thus this paper dwells mainly on the design and fabrication of an automated showering system for pigs.

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Stress Physiology in Farm Animals

Stress is a major underlying cause of animal health problems. It is a condition that is measurable both by blood analysis and physical effects. Although the immediate symptomatic recognition of stress is possible in many instances, e.g. excitability, apathy, aggression, perversion, shivering, erytherma, dyspnoea, prostration and exhaustion, these are more often accepted as part of the ensuing and resultant disease pattern.

Good health is a state of equilibrium, which will manifest itself in accepted normal patterns of behaviour. Anything destabilizing this condition constitutes stressor which will inevitably result in some physiological and behavioural changes, not least a reduction in immunological responses. This in turn enhances the prospect of disease. Although, stress susceptibility is a syndrome not widely understood at present, there is no doubt that some animals are more tolerant to stress than others.

Stresses factors examined by many researchers (Sainsbury, 1972) are seen to be intimately related to existing environmental, housing and husbandry systems. Indeed, anything impinging on the individual well-being of the pig can constitute a stress. Among the obvious stress factors are fear, pain, fatigue, noise, food, and water restriction or deprivation, and movement restraint.

Thermal Effects of various Environmental Factors

According to Steinbach (1987), the environment is an important influence on the animal's energy expenditure, and this is energy derived from nutrients in the feed. It follows that the thermal effects of the environment will have direct consequences for the partition of the animal's energy intake: between that retained as growth and that dissipated as heat. The primary influence of the environment on the productivity of animals is by way of their heat exchange. This is regulated so that heat produced within the body is equal to the heat loss from the body, enabling body temperature to be maintained within relatively narrow limits.

Heat Production and Loss in Pigs

Extreme warm conditions can result in death of animals if attention is not given to providing a means of stress control within animal houses. Farm animals produce a lot of heat as a result of various physical activities. In pigs, the quantity of heat typically produced varies as a function of their live weight (Nienaber, 1996). All animals have their tolerable temperature limit under stress and the need to reduce this effect is necessary when heat stress becomes rather severe.

Thermoneutral Heat Production Model

The thermoneutral zone is defined as that within which the heat production of a pig is independent of the temperature and it may be identified with the zone of best productivity. Within this zone, the heat produced by the pig is determined by its live weight and feed intake. The zone is bounded by a lower critical temperature and an upper critical temperature. A model based on the commonly used concepts of maintenance and efficiency of utilization of metabolizable energy has been developed by Bull *et al.* (1997). In this model, the thermoneutral heat production in Watts is given by;

$$Q_{tn} = 11.57 \{ F_m + (1 - k)(F - F_m) \} \qquad (1)$$

Where, k is the efficiency of utilization of feed increment above maintenance. For pigs of weight W e" 20 kg, the maintenance energy requirement F_m (MJ/day) is $0.44W^{0.75}$ and for W Â 20 kg, F_m is $0.64W^{0.66}$. The efficiency of utilization of metabolizable energy, k in the above equation is a dimensionless value of less than unity. For W Â 20 kg and W Ã 100 kg, k is 0.75, while for 20 d" W e" 100 kg; k is given by (0.625 + 0.00142W). The metabolizable energy intake F is in MJ/day. This model has been validated only for pigs of live weight between 20 and 90 kg fed on barley-based diets. The root-mean-square error of prediction for 62 measurements was 5.7W.

Heat Loss Model

A model was also developed which allows the heat loss from the pig to be calculated as a thermal demand by the environment (Bull *et al.* 1997). The model variables are air temperature, air velocity, floor type, live weight and the number of pigs in the group, and the model can accommodate huddling and postural behavior. The total heat loss from the pig, Q (in Watts) is given by;

(2)

The other symbols in the above model are defined as follows: for pigs, the surface area A (in m^2) is given by $0.09W^{0.67}$, A_f and A_c are the areas of the pig's surface (in m^2) in contact with the floor and with other pigs respectively. The insulation of air interface I_a (in m^2kW^{-1}) is given by $(5.3 + 15.7u^{0.67}W^{0.13})^{-1}$, where u is the air velocity in m/s. The body tissue insulation I_b (m^2kW^{-1}) is given by $0.02W^{0.33}$. The effective floor insulation I_f in the same units is given by $I_{f45}(W/45)^{0.33}(5A_f/A)N^{0.5}$, where N is the number of pigs in a group. In calculations, T_b is taken as 39°C. T_a is the air temperature in degrees Celsius. The latent heat flux, E, is in Wm^{-2}. A_f/A is taken as 0.2 for I_f e" I_a, or 0.1 for I_f Â I_a, A_c/A is given by 0.15(N - 1)/N. For heat loss below the critical temperature, this model has been validated for pigs of between 20 and 80 kg live weight in group of 1 to 9. The floors had range of I_{f45} from 0.07 to $0.5m^2kW^{-1.}$ The root-mean-square of prediction for 78measurements of heat loss was 8.9W (Bull et al.1997).

Minimizing Heat Stress in Farm Animals

In time past, various means have been employed to achieve adequate stress control in farm animals, some of which include evaporative cooling, wet skin cooling and use of ventilation fans, air cooling and zone cooling.

Evaporative Cooling

In evaporative cooling, the temperature of air is reduced by the transfer of heat from air to evaporating water (that is, a reduction in dry air enthalpy coupled with a sire in air moisture enthalpy). Evaporative cooling of animal environment is used for relief of heat stress in cattle, pigs, poultry, and horses mostly in hot-dry climates (Petherick *et al*., 1981). Forced evaporation from a wetted coat may be seen as an alternative form of evaporative cooling (Hill and Sainsbury, 2007). There is little or no information on the relief that evaporative cooling may offer in environments other than hot-dry climates. A warm climate is typified by moderately high temperatures, coupled with variable relative humidity, greater in littoral areas and decreasing inland. This implies that evaporative cooling needs to be used selectively according to the environmental conditions. However, little is presently known on the range of ambient temperature and relative humidity at which the evaporative cooling will effectively relieve stress of heat in animals kept in the shade. Evaporative cooling involves the transfer of the enthalpy from dry air to water vapour so that the change in dry air enthalpy equals the change in water vapour enthalpy. According to Lucas *et al* (2000), evaporative cooling may be equated as:

(3)

Where ρa and ρva are the dry air density in ambient and cooled air (kg/kg of air), and are the water vapour density in ambient and cooled air (kg/kg of air), 1.01 and 1.88 are the specific heat of dry air and water vapour (kJ/kg), and 2502 is the latent heat of water (kJ/kg).

Cooling efficiency is affected by several factors, such as pad design, location and material, area and thickness of the pad, water temperature, water and airflow rates and outside air temperature and relative humidity (Close, 1971). Cooling efficiency, $ç_c$ in %, can be defined as follows (Lucas *et al.* 2000):

(4)

Where *td* and *tw* are the dry and wet bulb temperatures of the ambient air and *tc* is the dry bulb temperature of the cooled air in ^{0}C.

Wet Skin Cooling

Pigs, under natural conditions outdoors, wallow in mud to cool themselves. The mud itself does not provide significant cooling directly, but instead evaporative cooling occurs as the mud dries, while it also provides a protective shield against sun-burn. In confinement systems, water sprinkler systems and drip coolers can also provide effective supplemental evaporative cooling. In shower units, sprinkling water in 1 to 2 minute intervals every 20 – 30 minutes allows moisture to evaporate off the pig's skin before wetting and starting the cooling process over again, and is more effective than leaving waterers on continuously. Larger water droplets are the most effective, as fogging increases the humidity of the surrounding air and therefore indirectly reduce the evaporative rate for heat loss on the pig. For sows individually housed in gestation or farrowing stalls, dripping water on the necks and shoulders combined with air movement also provides direct evaporative cooling. Water drips should be set such that water is nearly or completely evaporated before reaching the flooring.

Ventilation Fans, Air-conditioning and Zone cooling

In environmentally regulated swine buildings, mechanical ventilation is one method used to keep pigs cool. The movement of air produced by the fans causes the transferred of heat away from the animal's body. Air conditioning is used by a few swine producers to cool the animals in completely confined breeding buildings.

Zone cooling directed towards the head of the animal can be effective when animals are housed in crates or individual pens. A supply of a high-velocity air around the animal's head enables it to lose more heat and remain cooler. Zone cooling can use cooled or uncooled air. In farrowing houses, zone cooling helps to maintain a cool environment for the sow while allowing higher temperatures for piglets in the creep area.

Justification for the study

Pig is a unique animal and different from other livestock animals in the way they react to changes in the environmental conditions. Pigs have the advantage that they can easily be raised and they develop very fast. Shade and temperature control are both extremely important when caring for a pig. Pigs do not sweat like humans do so they are very limited on ways to cool down. Heat can be dangerous to a pig causing sunburn, heat stress, and possibly even death. Pigs exposed to high temperatures suffer heat stress. When the body temperature of pig rises beyond its normal limits it becomes heat stressed and the first sign of this is panting. If the body temperature does not decrease, the pig may collapse and die. Heat stress not only causes suffering but it also affects fertility and productivity. When it is too hot a pig will not eat or drink. For a pregnant sow this could mean reduction of milk. The existing method of taking care of the problem of heat stress in pig is the provision of wallowing system which has its attendant problems of wasting water and ineffective control of the heat stress. An automatic showering unit will ensure a better reduction in heat stress and better management of water.

MATERIALS AND METHOD

Location

The study was carried out at the Federal University of Technology, Akure. Nigeria, It is located in the south western part of Nigeria. It is located on Latitude: 7.250 N and Longitude: 5.200 E. It covers a land area of about 923,768.

Design Consideration

In the course of the design analysis and construction, the following factors were considered in order to achieve a functional and suitable system.

i. The total cost of the components and assembly of the showering system is quite cheap and affordable.

ii. The system is capable of eliminating human fatigue in filling the bath with water; this is achieved by installing a sensor to detect the presence of the pig. Once the sensors senses the presence of the pig, it sends a signal to the microcontroller , which then trigger open the valve for flow of water

iii. Suitable locally available materials were used in the construction of the system. such as wood for the body work, PVC pipes for the showers, e.t.c

iv. The system unit is such that is it easy to install, handle and operate with little or no maintenance cost

v. The sensor is located at a strategic point in the system to sense the presence of the pigs and it was protected against water splash.

The Design of Component units

The Automated showering system consists of the controlling unit, microcontroller, power circuit, bath tub, water tank, showering head, pipes, sensors and pump.

Design for the Controlling unit

The component units of the controlling unit consist the microcontroller (Sensors i.e. for the transmitter and receiver), bath tub, pump, sensors, storage tank, pipes and fittings, and shower heads The microcontroller is designed such that there are two sensors that are carefully placed, the transmitter and the receiver. However, both the transmitter and the receiver were aligned to be adjacent to each other and to be in straight line since the infrared waves is a straight line wave. The transmitter sends an infrared signal which is being received by the receiver. As the pig passes through, it sends the signal to the microcontroller and then triggers the pump on, to cause a flow of water. The pump would run through the relay for four minutes, for the pig to shower. However, if the pig leaves the shower before the 4minutes elapsed, the pump would be triggered off. The layout of the microcontroller is shown in figure 1, while the block diagram of the system of electronics is shown in figure 2

The Microcontroller

The microcontroller comprised the power circuit, infrared (IR) transmitter circuit (microcontroller) and infrared (IR) receiver controlling circuit (microcontroller)

Power circuit

In the design of the circuit to power the sensor and enable sending of signal, the sensing device monitors light from the Light emitting diode (LED) when the LED is blocked by any means. It enables the sign amplifier to be modified by boosting signal strength and send it to the microcontrollers which then send a signal to the relay circuit to switch on the pump or solenoid valve. The microcontroller also enables timing of the pumping for a specific time regime for pumping o water.

Design Considerations for the bath tub

The bath tub takes into consideration three main parameters which include:

i. Material**:** The material selected for this purpose is a wood of different sizes, this is because of its easy accessibility, easy carriage of the whole unit from place to place and affordable. However, since wood is not water friendly, the floor of the tub is covered with an aluminum foil which also allow for easy flow of water down the drainage

ii Size: The size for the bath tub is a function of the pig size; however for this study, the largest pig in the school farm, The Federal University of Technology, Akure (FUTA), which has the length: 180 cm, width: 90 cm, height: 86 cm was used. This size is used to justify design for the worst condition.

iii Location: The entrance location of the bath tub is such that would aid easy entrance of the pig and to restrict the pig access to the tub from all sides, however, allowance was made to allow for drainage by slightly tilting the floor of the bath tub. By design and construction the tilting angle was fixed at two degrees (2°).

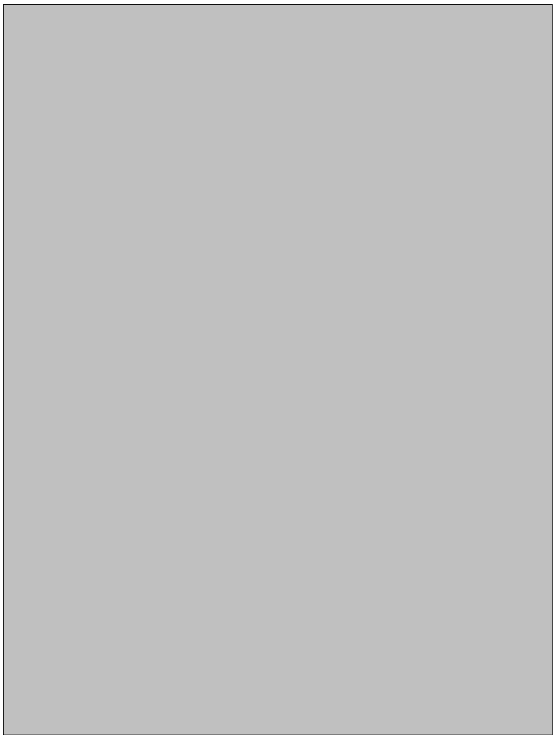

Figure 1 Layout of the microcontroller

Figure 2: block diagram of the system of electronics

Design for the tank and volume of water required by the pig

The following considerations were taken into considerations for the tank design.

i The volume of water designed for the system to shower is 47.92litres for a period of 4min

ii The intended flow rate designed for the system to function is 0.199 l/s

iii The number of times the tank would be put into use is given by

$$y = \frac{[5\times 60]-[4X]}{30}. \quad (5)$$

Since the shower was meant to shower within the interval of 4 min for 30 min, Therefore, $y = \frac{300-4x}{30}$ and $x \approx 9\ times.$

The maximum volume of water to be used could be expressed as $V_t = V_w \text{ x } x$ (6)

Where = the volume of water and x is the no of times

= 47.92 x 9 = 431.28 litres.

The height for which the tank would be elevated above the ground was calculated using the Bernoulli theorem;

(7)

Where = pressure of the overhead tank at the point of attaching the pipe (N)

= velocity of the shower head at the point of attaching the pipe)

H = height of the shower head at the point of attaching the pipe (m)

= velocity of the shower head)

= pressure just before the shower head (N)

= height of the shower (m) and = density of water (kg/m^3

the value of H was 1.50 m.

The Required quantity and flow rate of shower

From the concept of heat, the heat gained is equal to the heat loss

Heat lost from pig = heat gained by water

$M_p C_p$ □ = $MwCw\theta w$ (8)

Cp= specific heat capacity of pig (3477.7J/kg/k)

□= change in pig temperature (°C)

Mw= mass of water (kg)

Cw= specific heat capacity of water (4200 J/kg/k-)

θw= sum of change in pig temperature and initial temperature of water (°C)

According to Petherick (1983), large pig is most prone to heat stress hence the design for the quantity of water suitable for cooling the temperature of any pig size would be related to large size.

Mp= mass of the pig (in the research farm) = 62 kg

Cp= 0.83cal|g| = 3477.7J/kg/k (Hart, 1951)

□= 7.15 =7.15 + 273.15 = 280.3 K

Mw= mass of water (kg)

Cw= 4200J|kg|k

θw= initial temperature of water change in temperature of pig

= 20°C+ 7.15°C = 27.15°C = 27.15°C+ 273.15 = 300.3K

Using equation 2, and or

The shower was meant to run for a period of 4 min

Flow rate (Q) $= {V_w}/{time}$

$= \frac{47.92 litres}{4 min} = 11.98\ litres/min = 0.199 l/s$

$\approx 0.2 l/s$.

Pipe design

The design parameters of pipes include;

i. Pipe type: an appropriate polyvinyl chloride pipe (PVC) is selected, this is because of its easy handling, and it is cheap and readily available.

ii. Pipe sizing: According to Kentish (1982), the pipe diameter required for a velocity of about 0.2m/s is given as D (mm) = 8.4 (9)

While substituting Q, which is the discharge, Q = 11.98 lit/min

D_1=8.4 = 29.07 mm

This implies that a 31.75 mm diameter pipe is adequate.

Considering the fact however that pipe diameter size for shower heads is 0.5 inch (Kentish, 1982), therefore, D_2=0.5inch, since it is most suitable pipe.

Now, from the continuity expression of discharge, Q = A_1V_1=A_2V_2 (10)

Therefore, V_2=

A_1= Area of the pipe for shower head in ms^2

V_1= Velocity of the pipe carrying the shower head in ms^{-1}

A_2= Area of the pipe supplying the water to the shower in ms^2

V_2velocity of the pipe carrying the water to the shower in ms^{-1}

V_2= = 1.875ms^{-1} .

Similarly, power rating is the product of the pressure and discharge

Power rating (W) = pressure × discharge
1hP = 746 watts
0.5 hP = 0.5 × 746 = 373 watts
Pressure = power D discharge = 373 D 0.167 = 2233.5 ND m²

Design Consideration for the Sensors

i. Some assumptions were made in the design of the sensor, they include:

ii. The sensor would be placed or positioned very close to the ground so as to make room for different pig sizes, however, care should be taken to prevent the pigs from damaging the sensors

iii. They are installed in such a way that it would not interfere with water splash

iv. The sensors are made to be in alignment with each other and along a straight line, since the propagation of the infra red wave is a straight line.

v. The sensors are firmly placed for easy sensing of the pigs, this would also ensure that the microcontroller does not trigger off before its designed time regime

Pump design and Considerations

In the design for pumps, the pump type and capacity were considered. A centrifugal pump was considered because of its easy and continuous water discharge in spite of the unsteady flow and the capacity was calculated from the equation;
Capacity (C) = *Flow rate (Q) X Hydraulic head (h)* using *Flow rate (Q) of 20litres/min or 0.33litres/s* and hydraulic head of 1.5 m
C=0.29955 or or 0.224 kW, hence 0.50 Horse power or 0.37 kW centrifugal pump was selected.

Description of the showering unit

The showering unit comprised two sensing devices, which are the transmitter and receiver. The transmitter senses the presence of the pig as it enters from the entrance and the receiver picks the signal and sends it to the microcontroller, the microcontroller then triggers on the centrifugal pump which runs for 4 min and makes water to flow from a tank to the shower head. Other accessories incorporated in the unit include the pipes fittings, pipe clip to hold the pipes firmly to the body work and the aluminum foil on the floor of the tub for easy flow of water. Figure 3 shows the essential features of the unit.

Testing

A pig was trained at the University Research Farm to visit the showering unit for cooling purpose. The time of response of the sensors at the entrance sensors (transmitter and receiver) was recorded. The time of flow of water and volume of water discharged before being triggered off was also noted. The data collected were subjected to appropriate statistical analysis.

RESULTS AND DISCUSSION

Delay period of discharge

There was delay period experienced before the pump could deliver water to the showering head, which is dependent upon the efficiency of the sensors. The delay periods varied from 1.7 s to 2.59 s as shown in Figure 4. An analysis of variance (ANOVA) carried out on the data showed that there is no significant difference in the set of values recorded at 95% level of significance ($F_{cal} < F_{crit}$ at 0.005) as shown in Table 1. The sensors trigger the pump and supplied water for about four minutes which was similar to the work of Kunavongkrit *et al* (2000)

Figure 3: Isometric view of the automatic showering system

Figure 4: Relationship between the delay periods and no of trials

Table 1: Analysis of variance (ANOVA) of delay period

SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Column 1	10	21.25	2.125	0.105161		
Column 2	10	21.96	2.196	0.123671		
ANOVA						
Source of Variation	**S S**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	0.025205	1	0.025205	0.220292	0.644452	4.413863
Within Groups	2.05949	18	0.114416			
Total	2.084695	19				

Quantity of water discharged

The results of quantity of water discharged and measured at different time intervals are shown in Figures 5 and 6. An average flow rate of 0.2 litres/sec was observed which agreed with the designed flow rate of 0.1997litres/sec. This observation implies that the system is very efficient in terms of discharge as reported by Lucas *et al.* (2000).

Figure 5: Relationship between average volume and time

Figure 6: Relationship between average flow rate and time

CONCLUSION

A low cost automated showering system utilizing locally available materials was developed to reduce heat stress in pigs. The system has proven to be very efficient in delivering adequate quantity of water to the pig at the required time. The various components of the system which included the electronic control unit, the pump and water tank worked according to specification. The sensors upon sensing the entry of stressed pig, triggered pump which allowed water to shower on the pig for about four minutes as stated in literatures. The water flow rate of 0.2 litres/sec was adequate to cool a heat stressed pig.

The system is beneficial as it reduces waste of water, reduced handling and ensures a cleaner and better sanitation for the pig.

ACKNOWLEDGEMENT

The author wishes to acknowledge Mr. O.T. Ogini, Mr. C.P. Monye and Miss A.A. Fagbemi of Agricultural Engineering Department, the Federal University of Technology, Akure (FUTA) for their technical assistance.

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