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Thermal Properties of Concrete Slats During Preheating of Empty Swine Facilities

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Abstract

Providing appropriate thermal conditions for young piglets is critical to growth and welfare, especially during stressful periods after transportation and relocation. When preheating an empty facility prior to the arrival of piglets, raising the air temperature to the desired setpoint can be achieved relatively quickly but heating of other barn components, namely the concrete slat flooring, requires additional time and heat input. In this study, the heat transfer rates to concrete slats in a bench-scale model commercial facility environment were measured under high temperature heating conditions. Temperatures were recorded in multiple locations, including air above the slats, pit head space below the slats, and inside the slats. Results from this study can advise producers on the time and heating input required to preheat facilities prior to piglet arrival to reduce piglet stress and discomfort.

Keywords

Grow-finish, heat transfer, piglets

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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Thermal Properties of Concrete Slats During Preheating of Empty Swine Facilities

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ABSTRACT. ***Providing appropriate thermal conditions for young piglets is critical to growth and welfare, especially during stressful periods after transportation and relocation. When preheating an empty facility prior to the arrival of piglets, raising the air temperature to the desired setpoint can be achieved relatively quickly but heating of other barn components, namely the concrete slat flooring, requires additional time and heat input. In this study, the heat transfer rates to concrete slats in a bench-scale model commercial facility environment were measured under high temperature heating conditions. Temperatures were recorded in multiple locations, including air above the slats, pit head space below the slats, and inside the slats. Results from this study can advise producers on the time and heating input required to preheat facilities prior to piglet arrival to reduce piglet stress and discomfort.***

Keywords. *Grow-finish, heat transfer, piglets*

Introduction

The stress of transport for piglets, whether it is from farrowing to nursery or nursery to grow-finish, can have negative impacts on production. On average, piglets lose approximately 7% of their body weight during transportation events and take 3.5 d to gain the weight back (Lewis, 2008). Recovery time after transport can be managed by providing adequate conditions for piglets upon arrival at their new facility. This includes the provision of feed and water, but a key component to piglet success is the thermal environment (Le Dividich & Herpin, 1994).

As most US swine producers operate on a batch schedule, swine facilities are typically empty for a few days to a couple weeks prior to the arrival of new piglets. The facility is cleaned between batches, and during cold ambient conditions the temperature set point is usually lowered to reduce unnecessary fuel usage while the facility is empty. Prior to the arrival of a new batch of piglets, fresh feed and water is supplied and the temperature set point is raised to meet the thermal needs of the young piglets. In an effort to further reduce fuel usage, the set point is often only raised a few hours prior to piglet arrival. While only a few minutes may be required to heat the air in the facility to the desired temperature, other objects in the facility require much longer to warm up – namely, the concrete slat flooring. If the slats are not heated to the proper temperature, they will radiatively cool the piglets upon arrival, adding additional thermal stress to the piglets. Cold floors discourage cold piglets from lying on them to rest, which can prolong the recovery from transportation events. Brooders and rubber mats are often used to help mitigate some of these factors, but piglets must leave the brooder microclimate to feed and drink. Therefore, it is important that the entire facility is properly preheated.

Pig flooring slats are made predominately of concrete, with proprietary configurations of rebar supports within the slats. The thermal qualities of various types of concrete have been well studied, but with the unique slat composition and void spaces, it is unclear how well heat transfer values for flat concrete sections describe concrete slats (Huang et al, 1979; Guo et al., 2011; Sfikas et al., 2018). Kelly et al. (1964) and Pedersen and Ravn (2008) investigated heat transfer for swine slats specifically; however, both articles were evaluating conduction in relation to removal of pig body heat rather than convection in empty facilities. Other researchers have investigated heat transfer rates when modifying slats with water flush systems, also targeting body heat removal, but to the authors' knowledge there are no existing studies regarding slats in empty facilities (Newton et al., 1985; Huynh et al., 2004; Jacobson, 2011). Information is needed on convective heat transfer rates with concrete slats to understand how much preheating time is required to bring the slats up to temperature.

To address this gap in knowledge, a heating test was conducted in an environmental chamber to evaluate the heat transfer rates for the unique composition and configuration of concrete swine slats. The specific objectives were: (1) conduct a slat heating test in a controlled environment, (2) determine the empirical heat transfer coefficient, and (3) estimate the time required to preheat slats in common commercial facility configurations. These results enhance the understanding of heat transfer to concrete slats in empty swine barns. Results can aid producers in revising management strategies to better meet thermal needs of piglets, thereby reducing stress during relocations.

Materials and Methods

Data Collection

Empirical data were collected in a controlled environmental test chamber in the Mobile Lab for Euthanasia and Mortality Management Discoveries (MoLEMMAD; Figure 1). The chamber measured 2.4 × 2.4 × 2 m (L × W × H) and imitated a typical finishing barn environment, complete with a 0.5 m manure pit and metal gating. One 17.5 kW (60 kBtu h^{-1}) propane heater was suspended from the ceiling of the chamber. Two sections of 2.4 × 1.2 × 0.1 m concrete slats were used in the chamber.

Figure 1. Data were collected in a controlled environmental chamber that imitated a typical finishing barn environment.

For the data collection event the ventilation system of the chamber was not operating, inlets were closed, and the chamber fan opening was covered with plywood. Initial air temperature was approximately 24 °C and the internal slat temperature was 27 °C. The heater was turned on with a thermostat setpoint of 60 °C and maintained for 5 h. A temperature sensor on the heater recorded air temperature in the chamber 1.8 m above the slat surface. To measure temperature inside the slats, four holes were drilled. The holes were located in the slats near the center of the chamber, the back corner of the chamber, and near the wall halfway down the length and width of the chamber. In this configuration, one quad of the chamber was measured and assumed to be representative of the entire chamber. Each hole was approximately 6.3 mm in diameter and 51 mm deep, centered in the width of the slat. Approximately 6 mm of insulation was removed from the end of both wires of T-type thermocouples. The exposed thermocouple wires were twisted together and inserted into the drilled holes in the slat. Ready-to-use concrete mix (Quickcrete, Atlanta, GA, USA) was used to fill in the holes around the thermocouple wires and allowed to cure for at least 48 h prior to testing. Additional temperature readings were collected on the side and top of the slat surface using self-adhesive K-type thermocouples (OMEGA Engineering, Norwalk, CT, USA). A temperature probe was suspended 0.25 m below the slat surface to record head space air temperature. Temperatures were recorded every second for the duration of the heating event, except for air temperature, which was recorded once every 20 seconds.

Estimation of Heat Transfer Coefficient

To determine the empirical heat transfer coefficient, h, a subset of the data from 27 min to 305 min was used (Figure 2). The subset was selected when the heater began cycling on and off, so it could be assumed the air within the chamber had reached a uniform temperature. Linear interpolation was used to estimate air temperatures between measured time points.

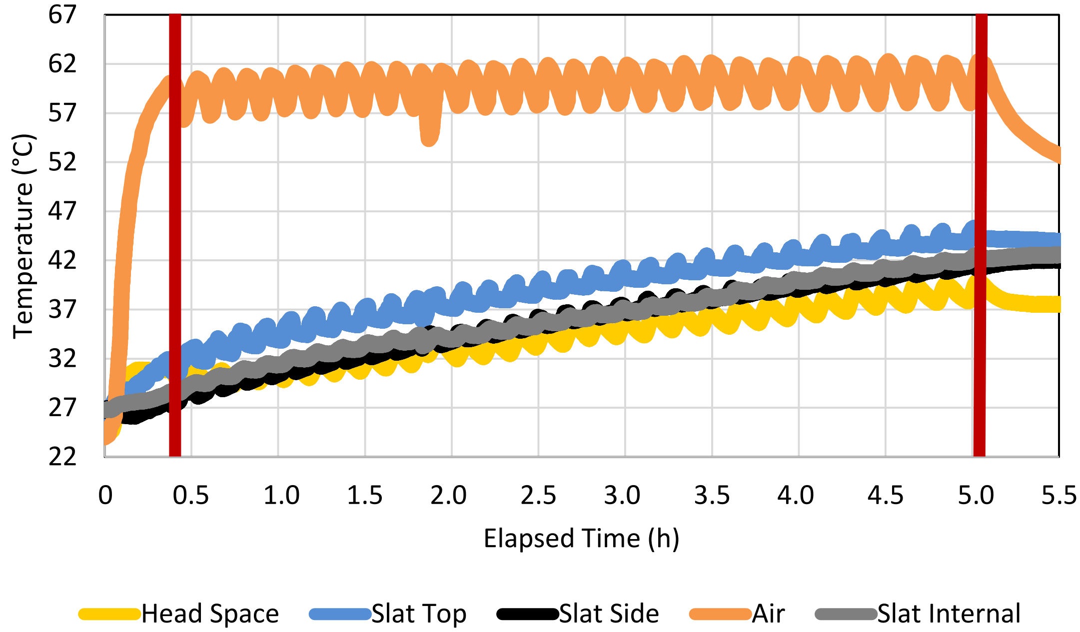

Figure 2. Temperature data collected during the heating event. A subset of data from 0.45 to 5.08 h (shown inside vertical bars) was used for subsequent calculations. Variation in temperature are due to the heater cycling on and off to maintain set point.

A program was developed in MATLAB (R2020b, MathWorks, Inc., Natick, MA, USA) to calculate the heat transfer to the slats.

$$HT_i = m \times C_p \times (T_{slat,i} - T_{slat,i-1}) \quad (1)$$

Where HT was the heat gained or lost from the slats in J, m was the mass of the slats, and C_p was the specific heat capacity, and T_{slat} was the average internal slat temperature. The time step i was in seconds. Based on manufacturer specifications, it was estimated that one 2.4 × 1.2 m section of slats weighed 508 kg. Though slats typically have an internal support system with a proprietary configuration of rebar, the majority of the slat is made of concrete. Therefore, a C_p value of 880 J kg^{-1} C^{-1} was selected based on data presented by Albright, 1990. Once the HT was known for each timestep, the empirical heat transfer coefficient, h, could be calculated.

$$h_i = \frac{HT_i}{(T_\infty - T_{slat,i})A} \quad (2)$$

Where h is the empirical heat transfer coefficient, T_∞ was the air temperature, T_{slat} was the average internal slat temperature, and A was the total surface area of the slats. One section of slats contained ten individual concrete sections, each 102 mm wide, and eight 25 mm wide void spaces. The surface area was calculated as the total width of the 10 concrete sections multiplied by the length of the slat section (2.4 m), then multiplied by two as two slat sections were in the chamber. This resulted in a surface area, A, of 4.9 m^2. The values of h_i were then averaged over all timesteps to determine h_{avg}.

Estimation of Required Heating Time

Estimates of required heating time were simulated using common 2,400 hd grow-finish barn configurations, presented in Table 1.

Table 1. Facility configurations used to calculate required heater run time to raise internal slat temperature.

Metric	Value
Facility dimensions	84 × 21.3 × 2.3 m (L × W × H)
Capacity	2,400 hd
Number of slat sections[a]	594
Weight of a single slat section	508 kg
Single heater capacity	733 kW (250 kBtu h^{-1})
Number of heaters	1, 2, or 3

[a] Assuming 2.4 × 1.2 m slat sections

Equation 1 was modified to estimate the time required to raise the internal temperature of slats to a desired set point.

$$HT_R = m \times C_p \times (T_{set\ point} - T_{initial}) \tag{3}$$

Where HT_R was the amount of heat in J required to raise the initial internal slat temperature, $T_{initial}$, to the desired set point temperature, $T_{set\ point}$. The specific heat capacity was represented by C_p, while m was the total mass of the slats. $T_{set\ point}$ was constant at 23.3 °C based on the desired room temperature for 12 kg piglets (PIC, 2019). The $T_{initial}$ ranged from 10 to 22 °C at 2 °C increments. Equation 4 was used to determine the heater run time needed to produce the HT_R.

$$t_R = \frac{HT_R}{HC \times N_H} \tag{4}$$

Where t_R was the required heater run time, HT_R was the amount of heat required to raise the initial internal slat temperature to the desired set point temperature, HC was the capacity of a single heater (733 kW), and N_H was the number of heaters present for the given facility configuration.

Results and Discussion

Estimation of Heat Transfer Coefficient

The values for h at each individual time step varied widely, from -968 to 990 W C^{-1} m^{-2} (Figure 3). Much of the variation in the raw data could be explained by the cycling of the heater on and off. As the heater cycled on, the air temperature measurements responded nearly immediately as the air probes were very close to the heat source. It took some time for the heat to mix within the bulk of the air mass in the chamber and conduct through the slats to influence the internal slat temperature.

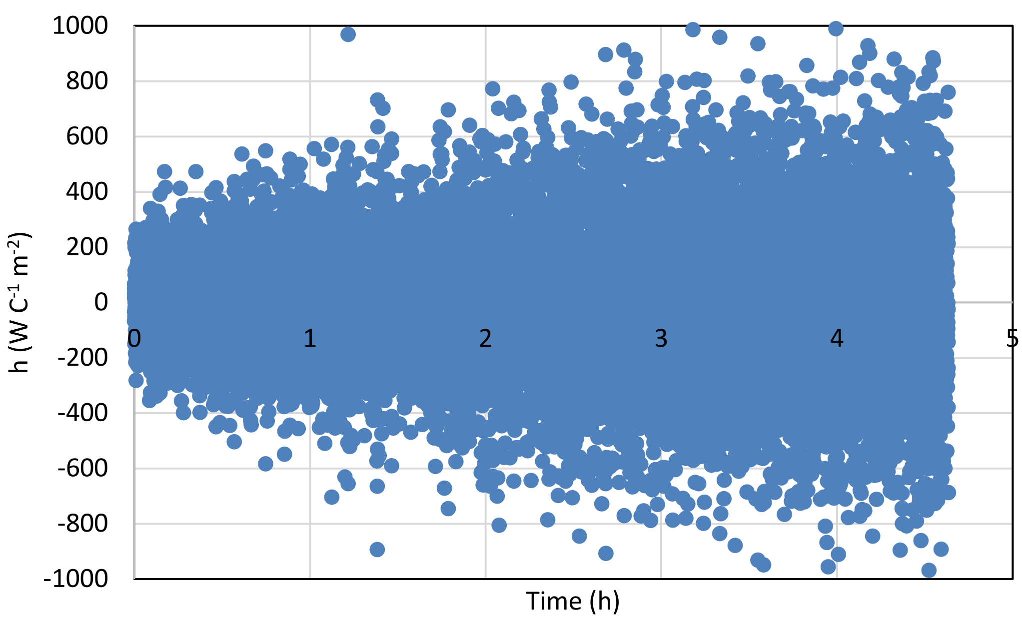

Figure 3. Raw values for h, the heat transfer coefficient of the slats, calculated at 1 s time steps.

When averaged over all time steps, h_{avg} was 7.25 W C^{-1} m^{-2} (SD = 242.6 W C^{-1} m^{-2}). This value is lower than the common value of 12 W C^{-1} m^{-2} for flat concrete slabs (Guo et al., 2011). The lower empirical value was somewhat surprising, as it was expected that the void spaces in between the slats would increase the value of h. A potential reason this was not realized could be thermal stratification. Though it was a relatively small chamber, and only 2 m in height above the slats, the actual air temperature near the slats would have been lower than the average 59 °C measured 1.8 m above the slat surface. Another potential reason for the lower than expected h_{avg} could be that more heat was being lost to heat the head space air than anticipated. It is shown in Figure 2 that head space temperature closely followed the internal slat temperature. Future studies with more detailed measurements of thermal stratification could be used to help determine causation.

Required Heating Time

Required heating times for the 1, 2, and 3 heater configurations are show in Figure 4. Increasing the initial temperature and number of heaters both reduced the amount of time required to reach an internal slat temperature of 23.3 °C. A facility of the specified dimensions would commonly have two or three heaters when located in climates that require heating. Even with three heaters, an initial temperature of 15.5 °C (60 °F) would require approximately 3.5 h to warm the slats. With only two heaters, this time was extended to approximately 5 h. These results highlight the need to preheat for an extended period of time prior to placing a new batch of piglets in the facility. Turning the heaters on for only two hours prior to piglet arrival is not sufficient if the initial temperature is less than 18 °C for three heaters, or less than 20 °C for two heaters or 22 °C for one heater. Proper preheating of the facility requires time and extra fuel; however, it is an important step to reduce stress and thermal discomfort of piglets after transport.

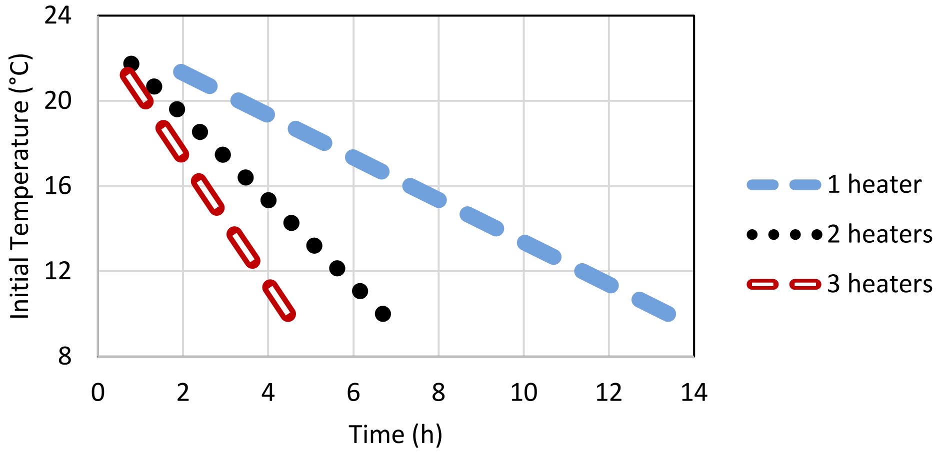

Figure 4. Time required for slats to reach the desired setpoint of 23.3 °C for a range of initial temperatures. Values are shown for a typical 2400 hd, 84 × 21.3 × 2.3 m finishing barn, assuming a single heater capacity is 733 kW (250 kBtu h^{-1}).

Conclusions

Data were collected in a controlled environmental chamber to evaluate the heat transfer rate of concrete slats for swine in empty facilities. Approximately 4.5 h of heating data was used to empirically determine the average heat transfer coefficient, h_{avg}, as 7.25 W C^{-1} m^{-2}. Additional calculations estimated the time required to reach an internal slat temperature of 23.3 °C, the recommended temperature for 12 kg pigs. Time to reach desired temperature varied with number of heaters and initial temperature. Results can be used to estimate the time needed to preheat swine facilities to ensure proper thermal environment prior to the arrival of a new batch of piglets.

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