EFFECTS OF BEEF HOUSING SYSTEMS ON GASEOUS CONTAMINANTS REMOVED BY VENTILATION

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INTRODUCTION

For many years the assumption was made that gases present in the atmosphere of total confinement livestock units tend to accumulate at different levels depending on their relative densities. Specific ventilation recommendations with regard to the effective removal of gases were based on this premise. However, Noren et al. (9), in a field study involving a range of livestock units, found that this stratification did not occur. Subsequent studies (3, 4, 10) have substantiated this finding. Heavy and light gases were shown to have similar distribution patterns whereas gas concentrations were dependant on the ventilation rate. Gas diffusion was found to take place as a consequence of temperature gradients, air movement, and diffusion.

Gases in confinement units result primarily from respiration of the animals, from fermentation in the case of ruminants, and from biological degradation of animal waste products. The gases commonly involved include carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S). As production of gases by the animals could be expected to remain fairly constant, any major variation in the gases generated within confinement units logically might be assumed to be due to the system of housing and waste-handling method employed.

With the possible exception of reports relating to the potential hazards associated with H_2S release from liquid wastes stored under anaerobic conditions, documentation on the effects of different housing systems with different waste-handling methods on noxious gas production is virtually nonexistent. Data also are lacking on how the level at which the exhaust air is removed from these confinement units affects gas concentrations.

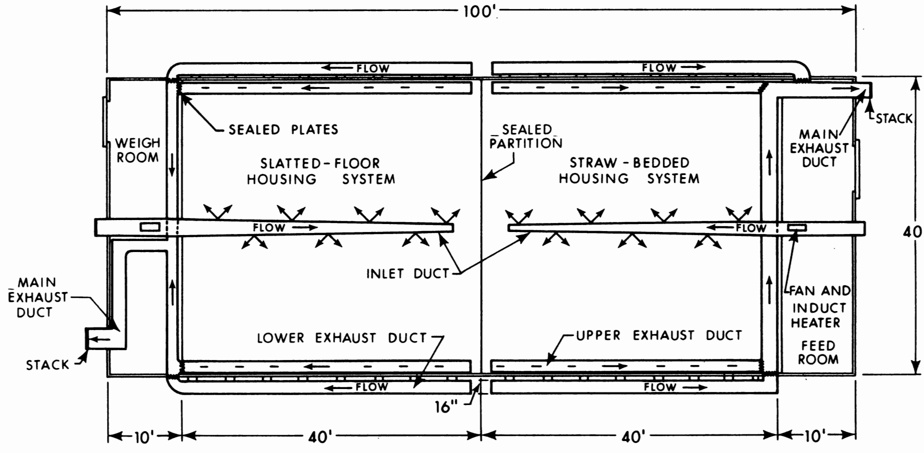

Figure 1. Location of inlet and exhaust duct systems within the two housing treatments.

The investigation reported here was initiated to ascertain such effects for the fully slatted and straw-bedded beef housing systems. The work was carried out concurrently with a study reported previously (5) on the moisture removed by ventilation at two exhaust levels or heights from these two housing systems. This moisture study included the effects of operating aeration rotors in pits below the slatted floor on the moisture load and hence provided an opportunity to include the effects of aeration rotors on noxious gas removal rates.

EXPERIMENTAL FACILITIES AND PROCEDURES

The facility in which this study was carried out has been described earlier (8). The 80 X 40-ft (24.4 X 12.2-m) livestock area is fully slatted with 10-ft (3.05-m) wide storage pits running across the building. The pressurized ventilation system consists of a duct running from each gable along the centerline towards the midpoint of the livestock area 11 ft (3.35 m) above floor level. Each half of the system is identical with the other, incorporating a centrifugal fan, an in-duct gas heater, and an equal number of diffusers.

For purposes of the experiment, the livestock area was divided equally in two (5). Plywood sheeting laid over the slats in one half provided a solid base for the manure pack in the straw-bedded treatment. In the other half or slatted-floor treatment, two toothed, 30-inch (76.2-cm) long rotors were placed in one pit and a similar rotor placed in a second, both pits having been modified as oxidation ditches.

Two separate duct systems were constructed (5) in each housing system to facilitate monitoring of CO_2 and NH_3 in the exhaust air at two levels (Figure 1). The lower ducts collected the exhaust air from slots in the pit walls below slat level, a continuous opening being left between the external walls and the manure pack by means of planking in the straw-bedded treatment to these slots. The upper ducts removed the exhaust air 6.5 ft (1.92 m) above floor level. Every effort was made to ensure that each housing treatment and the respective duct systems were effectively sealed to ensure that air exchange was the result of the ventilation system and that no air exchange took

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place from one treatment to the other.

Two Beckman Model 315A nondispersive, infrared gas analyzers were used to measure CO_2 and NH_3 concentrations. A Sanborn two-channel hot-wire recorder was used to record these concentrations. The operation of the recorder was controlled by means of a time clock set to operate 5 min in each hour. Sampling sites were located in each inlet duct downstream from the fan and in each main exhaust duct. In addition, the two gases were sampled at animal level in each housing system, a 30-ft (9.14-m) length of tubing allowing this to be carried out at random locations.

A series of valves was incorporated in the gas sampling system to permit each sampling site to be sampled individually. Representative samples were obtained in the exhaust duct sampling sites by positioning horizontally three 1/4-inch (6.37-mm) OD copper pipes of different lengths. These three pipes had a common filter that was serviced weekly. Only one copper sampling pipe was inserted into each inlet duct since the turbulance created downstream from the fan was assumed to provide thorough mixing.

The copper pipes, filter and valves were interconnected by 1/4-inch (6.37-mm) plastic piping. A main plastic sampling line ran the length of the building to connect all the sampling sites to the gas analyzers located in an instrument station set up in the feed room (Figure 1).

During each trial run, the NH_3 concentrations of the fresh incoming air were checked twice. Preliminary tests had shown, as might be expected, that little variation occurred in NH_3 levels and that these were very low.

The CO_2 entering each housing system was determined from a calibration curve that was based on the temperature differential existing between the air upstream and downstream of the in-duct gas heater units. This temperature differential was found to vary directly as the CO_2 concentration entering the housing system because the CO_2 values increased with increasing heat output of the furnace. From the termperature data recorded in the concurrent moisture removal study (5), the hourly CO_2 concentration entering each housing system could be calculated.

During each trial run, the gas concentrations also were monitored twice in the zone of animal occupancy. Sampling was carried out at random locations to give a representative sample. For purposes of analysis, these mean concentrations were compared with the mean concentrations in the exhaust air at that particular time. The remainder of each trial run was allocated to sampling from the main exhaust ducts at hourly intervals.

The experimental design of this investigation was similar to that described in the moisture removal study (5). Five treatments were considered in the CO_2 and NH_3 experiments, namely, slatted-floor housing with three, two, one, and no rotors operating, and straw-bedded housing. For each treatment, the trial runs, based on a 48-h time interval, consisted of either lower or upper level exhausting.

In the moisture removal study, the three-rotor and straw-bedded housing trials were carried out simultaneously with each consisting of three replicates. As gas monitoring only could be carried out in one housing system at a time, the concentrations were collected in the straw-bedded system during the first and third replicates and in the slatted-floor system during the second replicate. The other rotor treatments that were carried out subsequent to the three-rotor treatment each consisted of one replicate. The order used was two, one, and no rotor operating, because any other sequence would have involved the risk of H_2S poisoning.

The study was conducted during the period December 10, 1970, to April 30, 1971, the animals having been housed in late October 1970. The slatted-floor and straw-bedded treatments housed 38 and 37 steers, respectively, their average initial liveweight on December 1 being 535 lb (242 kg). Details of pen layout, stocking densities, and rations fed were previously reported (5, 8).

The fan in the inlet duct of each housing system was adjusted to deliver 3,000 ft^3/min (5097 m^3/hour) by means of manually controlled dampering devices. This capacity was checked, using a 25-point traverse of velocity pressures, before and after each trail run. Some variation was found to occur as previously noted (5).

ANALYSIS AND RESULTS

The CO_2 and NH_3 removed by ventilation were determined from the concentrations recorded in the incoming and exhaust air. The hourly removal rates were averaged for each trial run. As the treatments considered were not studied for the same time interval within the course of the experiment, and hence liveweights were not constant, and as the ventilation rates differed somewhat for each exhaust level and each housing system due to external influences, the gas removed was expressed in terms of cubic feet per minute and animal liveweight. For CO_2, the units were 1,000 ft^3/min (1,699 m^3/h) and 10,000 lb (4,536 kg) liveweight, whereas NH_3 was expressed in terms of 10,000 ft^3/min (16,990 m^3/h) and 10,000 lb (4,536 kg) liveweight.

The data collected for both gases were analyzed on the basis of a split-plot design with a 2 X 2 latin square within the whole plots. A 2 X 2 latin square was selected as a subplot since only one subtreatment was considered, namely, two exhaust levels. The effects of two consecutive trial runs followed by another set of trial runs of opposite order, referred to as "period," were included in the analysis. The effects of one trial run followed by another, referred to as "sequence," also were considered.

Ammonia concentrations recorded throughout the experiment proved to be low. Although the overall mean differences between the five treatments were very small in the practical sense, the analysis of variance indicated that highly significant differences ($P < 0.01$) for NH_3 removal existed in the exhaust levels, the lower exhaust level removing more NH_3 than the upper (Figure 2). The differences between treatments were not significant ($P < 0.05$). The interaction treatment X exhaust level also was not significant.

The analysis of variance for CO_2 removal indicated no significant differ-

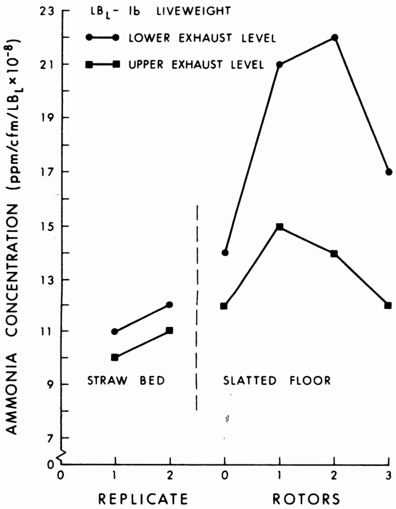

Figure 2. Effects of rotors in the slatted-floor housing system and of the straw-bedded housing system on ammonia removal rates at two exhaust levels.

ences ($P < 0.05$) existing between treatments or between exhaust levels. Period was found to be highly significant ($P < 0.01$), whereas the interaction treatment X exhaust level was significant at the 0.05 probability level. Removal rates for CO_2 tended to be higher in the straw-bedded system than in the slatted floor (Figure 3).

Multiple regression analyses were used to determine which of the measured parameters accounted for the major portion of the variation within the gas concentrations. These parameters included ventilation rate, total animal liveweight, number of rotors operating and inside ambient temperature and relative humidity. The interactions and linear transformations of these variables also were considered. The linear transformations of the independant variable X were $(X)^{1/4}$, $(X)^{1/2}$, $(X)^2$, $(X)^3$, and $(X)^4$. The general model considered for the analysis, with only the main effects included here, had the following form:

$$Y = A_0 + A_1V + A_2T + A_3R + A_4RH + A_5A \quad \ldots\ldots (1)$$

where

Y = dependant variable (concentration of NH_3, ppm, or concentration of CO_2, ppm X 10^{-2});
V = ventilation rate (ft^3/min X 10^{-3});
T = indoor temperature (°F X 10^{-1});
R = number of rotors operating;
RH = relative humidity (percent X 10^{-1});
A = total animal liveweight (lb X 10^{-4});
A_0 = intercept; and
$A_1 - A_5$ = multiple partial regression coefficients.

The NH_3 regression analysis considered only the two exhaust levels in the slatted-floor system, whereas the CO_2 analysis considered both exhaust levels in the slatted-floor system and exhaust levels in the straw-bedded system as one treatment. The exhaust levels were combined in the latter analysis because of the fact that no significant differences existed between the two exhaust levels. This combination had the effect of increasing sample size. As no significant part of the variation occurring in the NH_3 concentrations could be accounted for within the straw-bedded system, no regression analysis was undertaken for this system. Results of the regression analyses are presented in summary form in Table I.

The results of the comparison between CO_2 and NH_3 concentrations during each trial run at animal level and in the exhaust ducts for both housing systems indicated several trends (Table II). The NH_3 concentrations at animal level were quite similar to those in the exhaust air except at the lower exhaust level in the slatted-floor system when they were less than in the exhaust air.

With regard to gas production, the mean NH_3 and CO_2 concentrations produced by the animals and their wastes tended to be higher in the slatted-floor than in the straw-bedded system. The fact that the CO_2 concentrations monitored in the straw-bedded system were somewhat higher than in the slatted floor (Table II) was due to higher concentrations of CO_2 being introduced via the inlet duct. The reason for this was the slightly higher mean room temperature that prevailed for this housing system for the period of the study; thus there was a greater CO_2 output from the in-duct gas heater because of the additional supplemental heat required. For each housing system, the CO_2 concentration at animal level tended to exceed the quantity of CO_2 in the exhausted air.

The CO_2 input to both housing systems increased with decreasing outside air temperatures. At −25°F (−31.7°C), for instance, a heater would release approximately 1,700 ppm to maintain a room temperature of 60°F (15.6°C). This figure included the 300 ppm of CO_2 in the outside air. The CO_2 concentration within each housing system, therefore, approached 3,000 ppm during cold periods.

Because the CO_2 monitored in each housing system included that of the animals and their wastes, an attempt was made to provide some indication of the relative importance of these production sources. A carbon balance was used to estimate the CO_2 output of a steer. Balances were calculated for the steers in the slatted-floor system for a 40-day period (March 18-April 28) and for a 20-day period (February 4-24) in the straw-bedded system. The parameters used to calculated the CO_2 respired were obtained from standard references (2, 7, 11). Animal livewights, gain per day, feed intake, ventilation rates, and monitored CO_2 values were averaged for each period.

The results of these carbon balances

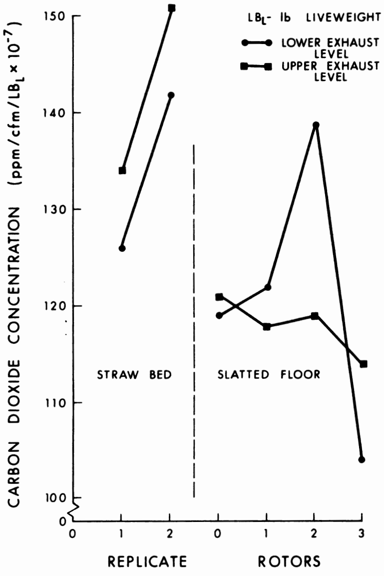

Figure 3. Effects of rotors in the slatted-floor housing system and of the straw-bedded housing system on carbon dioxide removal rates at two exhaust levels.

TABLE I DETAILS OF CARBON DIOXIDE AND AMMONIA REGRESSION ANALYSES FOR EACH TREATMENT

Gas	Treatment	Multiple correlation coefficient	Standard error of estimate (ppm)	Equation
NH_3	Lower exhaust – slatted floor	0.860	2.1	$-4.78 - 0.195CO_2 \times RH + 9.46R^{1/4} + 0.83CO_2 \times A$
NH_3	Upper exhaust – slatted floor	0.735	2.2	$-5576.9 - 0.0592R^4 + 4711.5RH^{1/4} - 297.3RH$
CO_2	Lower exhaust – slatted floor	0.880	98.7	$2.50 - 0.04R^4 + 0.230T \times RH$
CO_2	Upper exhaust – slatted floor	0.899	65.0	$12.43 - 0.336V \times R$
CO_2	Straw-bedded	0.900	85.5	$-55.76 + 52.91A^{1/4}$

TABLE II SUMMARY OF MEAN AMMONIA AND CARBON DIOXIDE CONCENTRATIONS

	Ammonia				Carbon dioxide			
Housing system:	Slatted		Straw-bedded		Slatted		Straw-bedded	
Exhaust level	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Inlet, ppm	4	4	3	3	1100	1060	1500	1300
Outlet, ppm	21	16	11	11	1970	1960	2300	2150
Animal level, ppm	15	17	12	13	2150	2150	2500	2500
Animals and waste, ppm	17	12	8	8	860	900	800	850
Animals and waste, ft^3/day	74	53	34	34	3760	3930	3400	3630
Animals and waste, ft^3/animal/day	2	1	1	1	100	105	90	99

indicated that the CO_2 production from the animal wastes in this experiment were very small relative to that of the animals. The recorded and calculated CO_2 production rates were found to be approximately equal, irrespective of whether the wastes were in the form of a manure pack or liquid slurry.

DISCUSSION

On the basis of the results of this experiment, the concentrations of two common atmospheric gaseous contaminants, namely, NH_3 and CO_2, appear to be relatively unaffected by use of either the slatted-floor or straw-bedded total confinement beef housing systems. The manure pack in the latter system was removed every 4-6 wk during the period of the experiment and this may have had some influence, as a maximum rate of decomposition in the pack may not have been achieved. The amount of bedding used, which was quite generous in this experiment, also may contribute to this result.

The higher NH_3 concentrations found in the exhaust air when removed below slat level in the slatted-floor system than at the upper level indicated that NH_3 is most effectively removed at its primary site of production. That this was the case is supported by the fact that NH_3 concentrations at animal level were less than in the exhaust air when removed at the lower level. If the rates of NH_3 production were the same for both exhaust levels, the NH_3 concentration in the exhaust air should have been similar. The reason why this was not the case is not readily apparent. One possible explanation may be that, with upper level exhausting, the vapor pressure of the NH_3 above the pits was greater than at lower level exhausting, this tending to suppress NH_3 release or diffusion from the slurry. This does not explain, however, the fact that the differences between upper and lower exhaust concentrations (Figure 2) were appreciably greater when one or more rotors were in use than when no rotors were operating, even though rotor action might be expected to increase the rate of air exchange between the air spaces above and below the slats.

Agitation of slurry in oxidation ditches normally facilitates the escape of NH_3 to the atmosphere (1). In this experiment, NH_3 concentrations in the exhaust air did not continue to increase with increasing numbers of operating rotors (Figure 2) as might be expected. Again, the reason for this is not apparent. Changes in the nature of the decomposition in the two ditches as a consequence of increasing loading rates as the experiment progressed possibly may have had some bearing in this regard. Such changes might influence the rate of either NH_3 production or diffusion from the slurry.

In the straw-bedded system and in the slatted floor with no operating rotors, the lower exhaust level proved more effective in NH_3 removal than the upper level. The differences in the NH_3 concentrations, however, were small and, in practice, the exhaust level in these circumstances would not appear to be of importance. A similar situation occurred with regard to the efficiency of CO_2 removal. In this case, CO_2 concentrations were slightly higher in the air exhausting at the upper level than at the lower. Again, the location of the exhaust outlet had little practical effect.

These findings further discount the theory of gaseous contaminants tending to accumulate in confinement livestock buildings according to their relative densities. Since the location at which moisture was removed by ventilation also was found to be unaffected by exhaust level under these same circumstances (5), NH_3, CO_2 and water vapor must have similar distribution patterns in the atmosphere of the confinement systems.

The trends in CO_2 removal displayed in the interaction exhaust level X treatment (Figure 3) are difficult to explain. One reason might be that the organic loading of the pits increased as the experiment progressed due to increasing animal liveweights. At the same time, the number of rotors operating was decreasing from two in one pit and another in the second to one in each pit and finally to one in one pit. The CO_2 concentrations at the lower level exhaust fluctuated to a greater extent than at the upper level with a change in treatments but again the reason for this is not apparent. The general trend of increasing CO_2 concentrations recorded as the experiment progressed is indicative of the increase in CO_2 respired by the animals. The fact that no significant differences existed between the exhaust levels implies that exhaust levels did not effect CO_2 production as was the case with NH_3.

The significant differences found in the CO_2 analysis of variance between the periods in which the overall mean of the CO_2 removed for the first set of consecutive runs exceeded that for the second set of consecutive runs implies that equilibrium of the CO_2 being removed did not occur. The overall mean CO_2 removal of the first trial run in period 2 apparently was reduced, as the exhaust level operating in the second trial run of period 1 was the first trial run of period 2 plus the fact that this was the exhaust level operating during the 1-d break period. As a result, this exhaust level operated for 5 d. When period 2 was followed by period 1, this effect would not occur, as the last trial run in period 2 was not the same as the first trial run in period 1.

The use of a carbon balance as a means of calculating the CO_2 respired by the animals, and hence to arrive at the CO_2 production of the wastes by subtracting the respired value from the measured CO_2 removed from each housing system, served only as an estimate. In the balance calculation, the values for the CO_2 production of the steers were most sensitive to a variation of the carbohydrate fraction of the feed and its carbon content. Hence, an accurate quantitative analysis would be necessary to attain a high degree of precision. In the apparent absence of data citing CO_2 production from liquid and solid wastes, however, the indication that the CO_2 production of the wastes as calculated by this method is very small relative to that of the animals is of interest. Some confirmation of this with respect to liquid wastes was obtained by calculation using data on CO_2 production from dairy bull wastes (6) and on volatile solid production from beef cattle (1).

Monitored CO_2 concentrations showed that approximately one-half of the values recorded during cold weather in the environment of the facilities used in this experiment entered via the incoming air as a result of CO_2 release from the in-duct heaters. This type of heating system might have limitations under severe cold conditions in certain situations with ventilation reduced to a minimum. Even though CO_2 tolerance limits for livestock may not be reached, there is the possibility that, in combination with other atmospheric contaminants, the levels may impose an environmental stress condition.

CONCLUSIONS

On the basis of the results of this study, the following conclusions are drawn:

(1) In total confinement beef housing, the concentrations of ammonia and carbon dioxide removed from the slatted-floor and straw-bedded systems by ventilation, at similar rates, are not significantly different.

(2) The location at which exhaust air is removed from the slatted-floor system with anaerobic waste storage and from the straw-bedded system has little practical effect on the ammonia and carbon dioxide removed by ventilation.

(3) Ammonia and carbon dioxide production are only slightly greater in the slatted-floor system than in the straw-bedded system. The production of carbon dioxide by the animal wastes is negligible compared with that produced by the animals in either housing system.

(4) Exhausting air below slatted floor level when rotors are used significantly increases the ammonia removed by ventilation but not the carbon dioxide removed.

(5) The major portion of the variation in ammonia and carbon dioxide removed by ventilation from the slatted-floor system is accounted for by the number of aeration rotors operating, relative humidity, and ventilation rate. In the straw-bedded system, animal liveweight accounted for the major portion of the variation of carbon dioxide.

SUMMARY

This study investigated the effects of slatted-floored and straw-bedded beef housing systems on ammonia and carbon dioxide removal by ventilation. Two exhaust levels were included within each housing system to study the influence of outlet height on the removal rates of the two gases. The effects of operating aeration rotors in pits below the slatted floor on the gas removal rates also were investigated.

The five treatments considered for both exhaust levels were three, two, one, and no rotors operating in the slatted-floor system and the straw-bedded system. Sampling procedures involved monitoring the ammonia and carbon dioxide concentrations of the air entering and leaving each housing system. The air also was sampled at animal level.

Results show that the housing systems had no significant effects on the concentrations of the two gases removed for similar rates of ventilation. With no rotor operating and in the straw-bedded system, outlet location had little effect on gas removal rates. Exhausting air below slat level increased the rate of ammonia removal but not that of carbon dioxide. Carbon dioxide produced by the wastes in either system was neglible compared with that respired by the animals.

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