CONCENTRATION-TEMPERATURE RELATIONSHIPS OF ATMOSPHERIC GASEOUS CONTAMINANTS

P.G. Brannigan
Member CSAE
Department of Agricultural Engineering
University of Alberta
Edmonton, Alberta

J.B. McQuitty
Member CSAE
Department of Agricultural Engineering
University of Alberta
Edmonton, Alberta

INTRODUCTION

A laboratory study has been reported by Brannigan and McQuitty (2) on the influence of ventilation on the distribution and dispersal of atmospheric gaseous contaminants under confined conditions. An environmental chamber in which facilities were installed for the simulation of sensible heat and gas production of pigs was used in their experiments. One of the variables considered was heat condition involving an isothermal and a non-isothermal state. The variable 'heat condition' involved a study of ammonia (NH_3) and carbon dioxide (CO_2) concentrations and their distribution patterns with and without simulation of sensible heat production. Brannigan and McQuitty concluded that the sensible heat production of livestock, as simulated in their study, was a major factor in the diffusion of both gases within the atmosphere of the chamber.

Throughout the experiments, the temperature of the atmosphere was recorded at the same points from which gas samples were taken. The results of this aspect of the study including the influence of ventilation on temperature patterns and temperature – gas concentration relationships are presented here.

EXPERIMENTAL FACILITIES AND PROCEDURE

Details of the facilities and procedure used in this study have been reported (2). Four gas diffusion units to simulate sensible heat and gas production of 20 pigs of 120 lb (54.4 kg) liveweight were installed in a 20 feet x 8 feet x 8 feet high (6.096 m x 2.438 m x 2.438 m) environmental chamber. Total sensible heat output was 5140 BTU (1300 k cal) per hour. Ammonia at a rate of 27 litres per hour was diffused into the chamber in one experiment and CO_2 at a rate of 480 litres per hour in a second experiment. The two experiments differed only in the type and quantity of gas used. Each experiment was carried out for three ventilation rates of 165, 261 and 549 cfm (280, 443 and 932 m^3 per hour), two outlet heights of 19.0 and 75.5 inches (483 and 1917 mm) measured from floor level and the two heat conditions, isothermal and non-isothermal. An air-conditioner was used to cool the incoming air during the non-isothermal heat condition phase of the experiments. This was found to be necessary to limit temperature rise within the chamber as a result of the use of the heating elements. Each experiment was replicated three times. Gas concentrations were measured using two non-dispersive infra-red analyzers, one for NH_3 and the other for CO_2.

Copper-constantan thermocouples wired into a temperature recorder were used to sense temperature at both inlet and outlet. A further thermocouple, carried in a 4 feet (1.219 m) long probe of 1/4 inch (6.4 mm) O.D. copper piping, was inserted into the chamber to sense the temperature at the same point at which a gas sample had just been taken. Sampling was carried out in random order in a longitudinal vertical plane 3 feet (0.914 m) in from one sidewall of the chamber. The location of the 55 sampling points on this plane is shown in Figure 1. Due to a fault which developed in the temperature recorder, temperature data collected during one of the replicates in the experiment using NH_3 had to be discarded.

ANALYSIS AND RESULTS

The analysis of the data consisted of statistical procedures involving analyses of variance and multiple regressions using computer programmes (3,5).

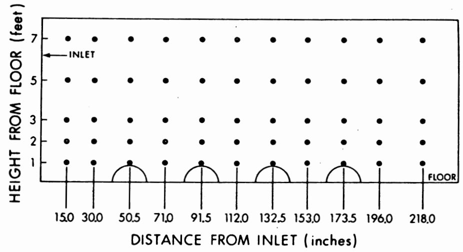


Figure 1. Location of sampling points on the longitudinal plane of the environmental chamber.

The overall effect of ventilation rate on temperature (Figure 2) was similar for both gases and followed a similar trend to that found for gas concentration (2). The overall effects on temperature of outlet height and of heat condition are shown in Table I and Table II respectively. For either gas, little difference existed between the two outlet heights while the difference between the two heat conditions was only slightly over 2°F (1°C).

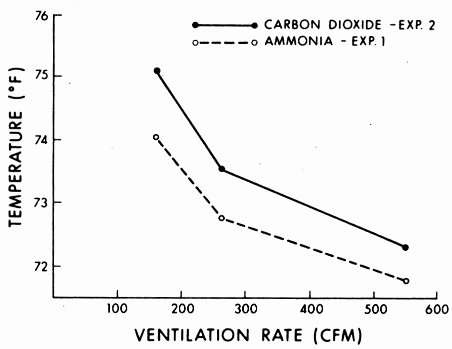


Figure 2. The effect of ventilation rate on temperature for both experiments with ammonia and carbon dioxide.

Figure 3 shows the overall effect of distance from inlet on temperature and Figure 4 the effect of height from floor. In both instances, as with the ventilation rate, the trends of temperature are very similar to those of both gas concentrations previously reported (2).

The analyses of variance of the temperature data for NH_3 and CO_2 experi-

RECEIVED FOR PUBLICATION JAN. 3, 1972

TABLE I MEAN TEMPERATURES AT BOTH LEVELS OF OUTLET HEIGHT FOR AMMONIA AND FOR CARBON DIOXIDE.

Outlet Height (inches)	Temperature, °F	
	Ammonia	Carbon Dioxide
19.0	73.0	73.8
75.5	72.9	73.5

TABLE II MEAN TEMPERATURES AT BOTH LEVELS OF HEAT CONDITION FOR AMMONIA AND FOR CARBON DIOXIDE.

Heat Condition	Temperature, °F	
	Ammonia	Carbon Dioxide
Isothermal	71.9	72.6
Non-isothermal	74.0	74.8

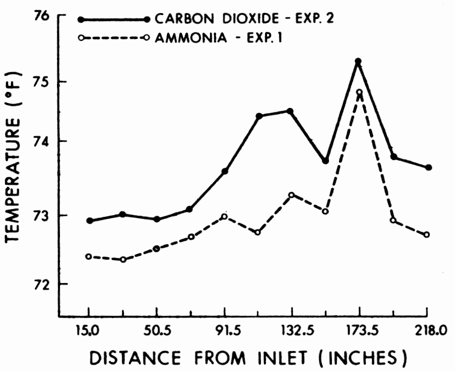


Figure 3. The effect of distance from inlet on temperature for both experiments with ammonia and carbon dioxide.

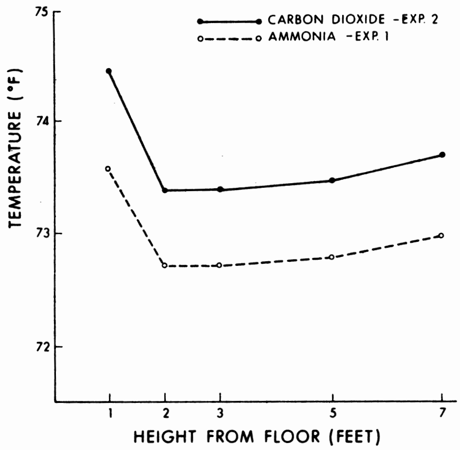


Figure 4. The effect of height from floor on temperature for both experiments with ammonia and carbon dioxide.

TABLE III ANALYSIS OF VARIANCE-TEMPERATURE (AMMONIA)

Source of Variation	Degrees of Freedom	Mean Squares	F
V (Ventilation rate)	2	635.52	257.27**
O (Outlet height)	1	0.14	<1
H (Heat condition)	1	1469.40	594.85**
VO	2	8.97	3.63
VH	2	501.75	203.12**
OH	1	7.38	2.98
R (Replicates)	1	17.89	7.24**
ERROR (1)	11	2.47	
D (Distance from inlet)	10	52.64	80.43**
J (Height from floor)	4	32.00	48.93**
DJ	40	25.77	39.41**
DV	20	2.69	4.11**
JV	8	3.03	4.62**
DO	10	1.31	2.00*
JO	4	0.48	<1
DH	10	50.04	76.51**
JH	4	34.78	53.18**
ERROR (2)	956	0.66	

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

ments are shown in Table III and Table IV respectively. The error terms in both tables consist of the interactions with the replicates plus the four- and five - factor interactions. The three- factor interactions are not included for, although a number of these are significant, they are of little practical relevance. Of the main effects, only ventilation rate and heat condition were significant ($P<0.01$) during the NH_3 experiment while, with CO_2, the outlet height was also significant but at the 0.05 level of probability. The difference between the two replicates was significant in both cases; however, the recorded differences were very small. The significant interaction ventilation rate x heat condition, VH, for both gases simply indicates that the effect of ventilation rate on temperature is different at both heat conditions.

Brannigan and McQuitty (2) had noted that the non-isothermal heat condition resulted in higher mean concentrations for the two gases and different distribution patterns than with the isothermal

TABLE IV ANALYSIS OF VARIANCE-TEMPERATURE (CARBON DIOXIDE)

Source of Variation	Degrees of Freedom	Mean Squares	F
V (Ventilation rate)	2	1287.40	118.92**
O (Outlet height)	1	48.32	4.46*
H (Heat condition)	1	2311.40	213.52**
VO	2	8.78	< 1
VH	2	754.39	69.68**
OH	1	0.18	<1
R (Replicates)	2	42.27	3.90*
ERROR (1)	22	10.82	
D (Distance from inlet)	10	94.44	119.27**
J (Height from floor)	4	73.90	93.33**
DJ	40	33.51	42.32**
DV	20	6.22	7.86**
JV	8	2.65	3.34**
DO	10	1.11	1.41
JO	4	0.90	1.14
DH	10	86.36	109.07**
JH	4	61.88	78.15**
ERROR (2)	1604	0.79	

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

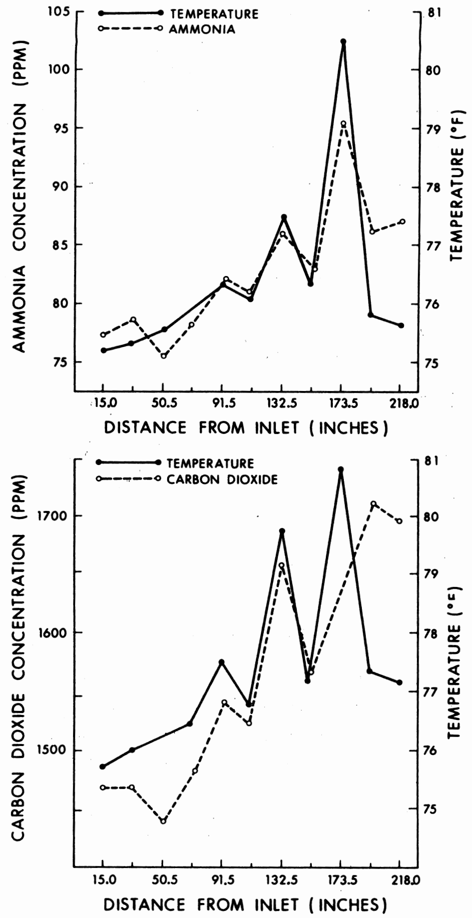


Figure 5. The relationship between temperature and gas concentration at the different distances from inlet for a ventilation rate of 165 cfm.

heat condition. The non-isothermal heat condition was an attempt to simulate conditions that would occur in practice. Consequently, a study of the relationship between temperature and gas concentrations under such conditions seemed appropriate.

Figures 5 and 6 show the relationships between temperature and the mean gas concentrations for both gases at different levels of distance from inlet and height from floor for a ventilation rate of 165 cfm (280 m^3 per hour). These relationships were also plotted for ventilation rates of 261 and 549 cfm (443 and 932 m^3 per hour). Similar trends were found to occur. The temperature and gas concentration data plotted here are means for the non-isothermal heat conditions over both levels of outlet height. It is clear from these graphs that the general trend for gas and temperature is similar. An interesting point to note is that the gas concentrations (Figure 6) are slightly higher at the 7 feet (2.133m) height than at 1 foot (0.305 m).

Since temperature and gas concentration varied in a similar manner, multiple regression analyses were carried out to determine the degree of relationship between these two variables for both gases at the three ventilation rates. The general form of the equation considered in the analyses was:

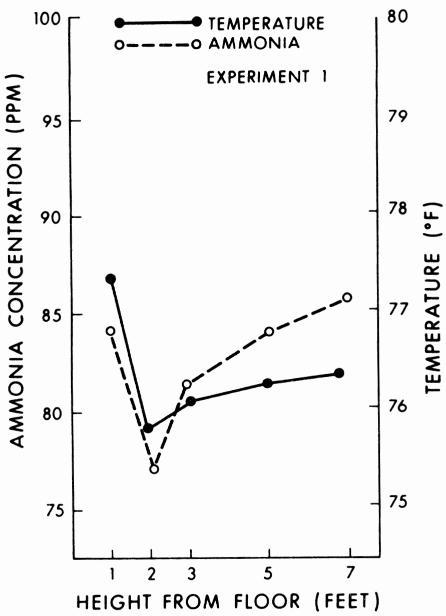
$$Y = A_o + A_1T^3 + A_2T^2 + A_3T$$

where Y = dependent variable (concentration of NH_3 or CO_2),
T = temperature (°F),
A_o = constant, and
A_1, A_2, A_3 = multiple partial regression coefficients.

Results of the regression analyses are presented in summary form in Table V. All the correlation coefficients were significant at the 0.01 level of probability.

DISCUSSION

The effects of the independent variables on the mean temperature followed the anticipated course. Both heat condi-



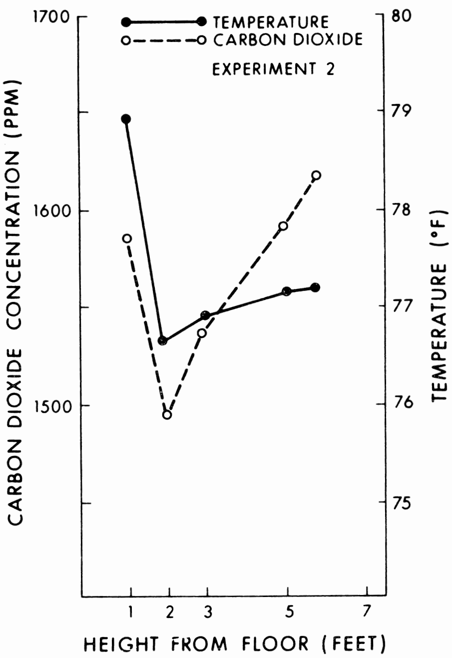


Figure 6. The relationship between temperature and gas concentration at the different heights from floor at a ventilation rate of 165 cfm.

TABLE V DETAILS OF TEMPERATURE GAS CONCENTRATION REGRESSION ANALYSES FOR BOTH GASES AT THREE VENTILATION RATES.

Gas	Ventilation Rate (cfm)	Multiple Correlation Coefficient	Standard Error of Estimate (ppm)	Equation
Ammonia	165	0.779	6.05	$-115.38 + 2.58T$
Ammonia	261	0.771	5.56	$-707.71 + 17.15T - 0.0932T^2$
Ammonia	549	0.863	3.14	$142.42 + 0.06558T^2 - 6.37T$
Carbon Dioxide	165	0.758	105.5	$-17760 + 337.62T - 0.01461T^3$
Carbon Dioxide	261	0.743	99.3	$-12324 + 307.53T - 1.73T^2$
Carbon Dioxide	549	0.741	57.8	$-6444 + 148.27T - 0.7327T^2$

tion and ventilation rate had the most significant effect on temperature. Under non-isothermal heat conditions, differences in temperature existed at different levels of height from floor and distance from inlet.

The highest mean temperatures for both gases for each level of ventilation occurred at the lowest sampling height of 1 foot (0.305 m). The probability, of course, is apparent that lower temperatures would have occurred nearer the floor level as a result of cooler air moving in to replace that warmed by the heating elements. The existence in actual practice of a marked temperature gradient within a few inches from floor level has been noted for example by Gordon (4) who stressed the adverse effects this may have on pigs. The trend of increasing temperature with increasing distance from inlet has practical implications in that livestock furthest from the inlets (closest to the outlets) may be subjected to stress conditions.

In these experiments, both heat and gas production occurred at the same site. Transfer of heat in a still atmosphere by the process of heat conduction involves the transfer of energy by molecular movement. The diffusion of gases in a still atmosphere follows a similar pattern. This movement of a gas through the atmosphere is caused by a concentration gradient and is explained by Fick's Law. This, however, is a much slower process than convective or eddy diffusion. Convective diffusion involves macroscopic or particle mixing compared to microscopic or molecular mixing by Fickian diffusion (1). Any diffusible component of the atmosphere such as heat can be similarly transported by eddy diffusion.

The temperature and gas concentrations in this study followed the same general trends for the three ventilation rates. Therefore, both noxious gases and heat would appear to diffuse in a similar manner. The regression analyses indicated the degree of relationship that existed between these two variables. Thus, temperature variations may be used to predict the pattern of gas concentrations at any point with a fair degree of accuracy in situations where heat and gas production occur at approximately the same site.

CONCLUSIONS

Under the conditions of the experiment described, the following conclusions are drawn:

1. The distribution and dispersal of sensible heat within an enclosed ventilated chamber followed patterns similar to those of concentrations of gases when the production site of both heat and gases are the same.
2. Correlation coefficients between temperature and the concentrations of ammonia and carbon dioxide were significant ($P<0.01$).
3. Ventilation rate had a significant effect ($P<0.01$) on mean temperature but the effect of outlet height had little practical importance.
4. There was a general trend of increasing temperature from inlet to outlet.

SUMMARY

Facilities were installed in an environmental chamber to simulate the production of gas and sensible heat from 20 pigs. The chamber represented a full scale section of a pig barn. The study investigated the effects of ventilation on temperature distribution patterns and temperature – gas concentration relationships. The gases used were ammonia and carbon dioxide.

The independent variables were ventilation rate, heat condition (isothermal and non-isothermal), outlet height, height from floor and distance from inlet. Procedures involved measurement of gas concentrations and temperatures in a longitudinal vertical plane within the chamber.

Results showed that the distribution and dispersal of sensible heat followed patterns similar to those of both gases. Significant ($P<0.01$) correlation coefficients between temperature and gas concentration were obtained. An increase in temperature from inlet to outlet was noted. Outlet height had little practical importance.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Canada Department of Agriculture for their financial support of this study.

REFERENCES

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1967. Handbook of Fundamentals. A.S.H.R.A.E., New York, p. 65-78.

2. Brannigan, P.G. and J.B. McQuitty. 1971. The influence of ventilation on distribution and dispersal of atmospheric gaseous contaminants. Can. Agr. Eng. 13(2): 69-75.

3. Easton, M. 1968. Analysis of variance library programme, C.S. 017. Department of Computing Science, University of Alberta, Edmonton.

4. Gordon, W.A.M. 1962. Environmental studies in pig housing. I. Air velocity. Brit. Vet. J., 118: 171-205.

5. Grobben, G. 1970. Stepwise multiple regression library programme, C.S. 101. Department of Computing Science, University of Alberta, Edmonton.