Effect of the age and season of fattening period on carbon dioxide emissions from broiler housing

M. Knížatová[1], Š. Mihina[1,2], J. Brouček[1], I. Karandušovská[2], G.J. Sauter[3], J. Mačuhová[4]

[1]Animal Production Research Centre, Nitra, Slovak Republic
[2]Faculty of Engineering, Slovak University of Agriculture, Nitra, Slovak Republic
[3]Agroscope Reckenholz-Tänikon ART, Ettenhausen, Switzerland
[4]Institute for Agricultural Engineering and Animal Husbandry, Poing, Germany

ABSTRACT: The quantification of emissions of greenhouse gases from human activities is of prime importance for determining the importance of their effect on the environment. The aim of this study was to test a hypothesis that the interior concentration and emission of carbon dioxide in chicken housing is impacted by the age of animals and season of fattening period. Carbon dioxide (CO_2) concentrations and emissions were assessed over six fattening periods in total. The major part of CO_2 seemed to have its origin in bird respiration with assumed production of approx. 147 kg of CO_2/h. CO_2 emission was most affected by chickens towards the end of the grow-out period ($P < 0.001$) taking dominance over the process of natural gas burning by heaters. The mean CO_2 emission from the chicken house ranged between 120 and 247 kg/h in the first quarter of periods and between 325 and 459 kg/h in the last ones. The heaters could be theoretically a possible source of approx. 39 kg each hour if they worked continuously. CO_2 emissions were considerably more affected by ventilation rate ($P < 0.001$) than by CO_2 concentration in the indoor air.

Keywords: carbon dioxide; broiler chickens; heating; natural gas; ventilation rate

Carbon dioxide (CO_2) is one of the major combustion products from burning fossil fuels. CO_2 is also a major contributor to the greenhouse effect and is therefore associated with climate change. Sources of CO_2 within a poultry house include fuel combustion, bird respiration and ambient air content (typically 550–900 mg/m^3) (Olanrewaju et al., 2008). The transformation of organic material in litter, especially by bedding moistening, or adjustments of ventilation systems are also accompanied by the release of carbon in the form of carbon dioxide (CO_2), methane (CH_4) and other gases (Jelínek et al., 2001; Nicks et al., 2003; Jelínek et al., 2004; Dolejš et al., 2006). It is generally recommended that CO_2 concentrations should be kept below 5 500 mg/m^3 (Council Directive 2007/43/EC, 2007). Modern poultry housing is designed and constructed to reduce a heat loss and to improve energy efficiency, however when coupled with reduced ventilation, it can result in elevated levels of CO_2, ammonia and other air contaminants, which may adversely affect the health and productivity of animals (Olanrewaju et al., 2008; Kolář et al., 2009). Vučemilo et al. (2010) give reasons for much lower values of air pollutants in summer months due to a higher ventilation level in this season. Lendelová and Botto (2009) documented that the pre-warming of incoming air could decrease a negative influence of reduced ventilation in winter months. The influence of season on the amount of produced emissions is in fact the influence of ventilation rate, depending on the need to cool the temperature in the interior environment (Knížatová et al., 2010).

The housing environment, including factors like CO_2 levels and oxygen levels, is known to influence the incidence of ascites (broiler pulmonary hypertension syndrome) in broiler chickens. The problem arises from a very high metabolic rate of rapidly growing broiler strains. Subsequently, in less well-ventilated poultry houses as well as at higher altitudes, oxygen becomes a limiting factor as far as their health, welfare and performance are concerned (Movassagh Ghazani et al., 2008; Niu et al., 2010). Both the gas furnaces and the broilers generate CO_2 and consume O_2. Consumed oxygen is equal to volumetric carbon dioxide produced by the birds and is assumed to be a double of carbon dioxide produced by open-flame natural gas furnaces (McGovern et al., 2001). It means that the combustion of one molecule of CH_4 generates one molecule of CO_2 and consumes two molecules of O_2.

The aim of this study was to test a hypothesis that the interior concentration and emission of CO_2 in chicken housing is impacted by the age of animals and season of the fattening period.

MATERIAL AND METHODS

The experimental study was carried out during 6 consecutive fattening periods specified below (Table 1). Individual flocks were evaluated in 10-days quarters of fattening periods for better differentiation of changes in CO_2 concentrations, emissions, ventilation rates and temperatures.

Design of experiment

One-day-old chicks were placed in a tunnel-ventilated commercial broiler facility. The poultry owner performed the routine preparation of the house prior to bird placement (cleaning out the manure between periods, flushing, drying, gas disinfection). The housing area of the interior volume of 4 455 cubic meters (0.178 m^3/bird) was heated to a nominal temperature of 31–33°C by two gas furnaces of 70 and 120 kW or with 7.5 and 12.5 m^3 consumption of natural gas per hour, respectively (Table 2). The ambient temperature was reduced as the birds progressed in age by approx. 2°C each week to ensure their comfort. Six ceiling axial fans, each of maximum capacity 12 000 m^3/h, and four frontal fans of maximum capacity

Table 1. Monitoring schedule

Fattening period	Date	Duration (days)	Average number of chickens
Summer/autumn I	30.07.–07.09.	40	23 929
Autumn	23.09.–01.11.	40	24 310
Autumn/winter	18.11.–27.12.	40	24 502
Spring/summer	02.05.–10.06.	40	24 287
Summer	16.06.–25.07.	40	23 908
Summer/autumn II	10.08.–18.09.	40	24 016

Table 2. The parameters of gas furnaces

Model	GP 70	GP 120
Power output (kW)	70	120
Natural gas consumption (m^3/h)	7.5	12.5
Ventilation rate (m^3/h)	5 000	7 000
Heating distance (m)	50	50
Weight (kg)	36	64

35 000 m^3/h ensured the air exchange in the chicken house. Evaporative cooling pads were used in hot weather to cool the birds. Approximately 25 000 chicks were placed at a stocking density of 0.045 m^2 of area per bird. Feed and water were provided *ad libitum* during a 40-day production period, when broilers reached the market weight around 2 kilograms. New straw was used for each subsequent fattening period.

Sampling and calculation

Carbon dioxide (CO_2) and water vapour (H_2O) concentrations were measured with an infrared analyzer (Innova 1312). A self-contained pump draws air samples into the analyzer via sample tubes from five measuring points. Continuous monitoring operated automatically with one-hour sampling interval. Air samples were taken from the air stream close to the first and the third ceiling fan and the left and the right frontal fan (at a height of 1.8 m), as well as from outdoor environment, to allow the CO_2 emission calculation from the observed facility.

Air temperature was measured with a thermocouple probe at the same points. Two thermocouple probes were placed also into litter (30 mm deep), in the front part and at the opposite end of the house.

Emission factors were determined using the average concentration of CO_2 near the house exhaust fans reduced by the outdoor CO_2 concentration and multiplied by the volume of air that has passed through the building. The ventilation rate of exhausted air was based on the current ventilation capacity (%) and known rate of air flow at 100% efficiency (212 000 m^3/h).

A statistical analysis system (SAS ver. 9.1) and descriptive statistic were used for research data processing. Spearman correlation was calculated for the evaluation of relationships between CO_2 production and other observed parameters. The differences were declared significant when their probability levels were below 0.001.

RESULTS AND DISCUSSION

Carbon dioxide levels

CO_2 accumulation can occur when additional CO_2 is produced by direct heating systems (where

Table 3. CO_2 concentration range (mg/m^3) in 10-day quarters of fattening periods

Days of fattening period		Summer/ autumn I	Autumn	Autumn/ winter	Spring/ summer	Summer	Summer/ autumn II
1. to 10. (n = 960)	min	1 721	2 557	2 069	1 791	1 626	1 912
	$\bar{x}$	7 557	10 571	11 442	11 196	7 396	7 259
	max	17 280	18 453	16 294	18 015	19 226	18 763
11. to 20. (n = 960)	min	1 820	2 148	4 144	2 244	1 822	2 363
	$\bar{x}$	4 258	8 054	9 055	6 322	4 049	4 821
	max	9 664	13 089	13 599	11 541	7 997	9 006
21. to 30. (n = 960)	min	1 807	1 758	4 923	2 427	2 352	2 935
	$\bar{x}$	4 507	6 771	10 556	5 356	5 101	5 666
	max	9 257	14 010	16 785	12 340	9 931	11 572
31. to 40. (n = 960)	min	2 002	1 959	3 112	2 867	2 678	2 777
	$\bar{x}$	4 859	5 999	9 944	5 296	5 235	5 395
	max	9 460	10 435	15 527	11 203	10 180	9 852
1. to 40. (n = 3840)	min	1 721	1 758	2 069	1 791	1 626	1 912
	$\bar{x}$	5 296	7 849	10 250	7 042	5 446	5 785
	max	17 280	18 453	16 785	18 015	19 226	18 763

the exhaust gases remain inside the broiler house) and when the ventilation rate is operated at an extremely low level (EC, 2000). The highest concentrations of CO_2 were detected in fattening periods "autumn/winter" (10 250 ± 1 795 mg/m^3) and "autumn" (7 849 ± 2 669 mg/m^3) ($\bar{x}$ ± SD). The intensity of ventilation, working at a low capacity during cold weather (16% and 24%, respectively), could cause these increased levels ($P < 0.05$, $P < 0.001$). The maximum permitted CO_2 concentration of 5 500 mg/m^3 (Council Directive 2007/43/EC, 2007) was regularly exceeded in both fattening periods. Relatively lower concentrations were measured in fattening periods "summer/autumn I" (5 296 ± 2 621 mg/m^3) and "summer" (5 446 ± 2 814 mg/m^3), but only in the period "summer/autumn I" was there a statistically reliable difference ($P < 0.001$) with ventilation rate. The critical values of CO_2 were reached in all observed periods and the CO_2 level was sometimes even tree times higher than it is permitted. Particularly during the first and the fourth quarter of periods, chickens were exposed to very high levels of CO_2 (Table 3). However, it is important to point out that the concentrations were not measured at the level of chickens' heads. In a study of Vučemilo et al. (2008) examining the air quality in an intensive broiler breeding facility, the level of CO_2 was between 3 850 mg/m^3 in the fourth week and 5 860 mg/m^3 in the first week of study.

Carbon dioxide sources

There are two main sources of CO_2 in general. The first one is supposed to be heaters, however, as the birds approach market age, they become the primary CO_2 source (McGovern et al., 2001). A speculation can be accomplished if it is assumed that natural gas typically consists of 97.6% CH_4, 1.5% ethane, propane, butane, 0.1% CO_2, and 0.8% nitrogen. The gas furnaces used for heating in the chicken house (Table 2) had the natural gas consumption of 7.5 and 12.5 m^3/h and the power output of 70 and 120 kW. If 20 m^3 of natural gas are burnt completely and if we assume that it is pure CH_4, this equation holds good:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_20$$

As 1 mole of gas takes up 22.4 litres at STP (Standard Temperature and Pressure, i.e. temperature of 0°C and pressure of 101.325 kPa), 20 000 litres of CH_4 contain 20 000/22.4 = 892.86 moles of CH_4.

As for each mole of CH_4 we get one mole of CO_2 (see the equation above) and one mole of CO_2 has a mass of approx. 44 g, 892.86 moles of CO_2 have a mass of approx. 892.86 × 44 or 39.3 kg of CO_2. It means that the complete combustion of 20 m^3/h of natural gas at STP results in the production of about 39.3 kg/h of CO_2.

Just for a recheck, if we use the CO_2 emission factor for natural gas combustion related to the net calorific value of 56.1 tons CO_2/TJ (IPCC, 2006; Commission Decision 2007/589/EC, 2007) and power output of both gas furnaces

$$70 + 120 = 190 \text{ kW}$$

then we obtain a similar result:

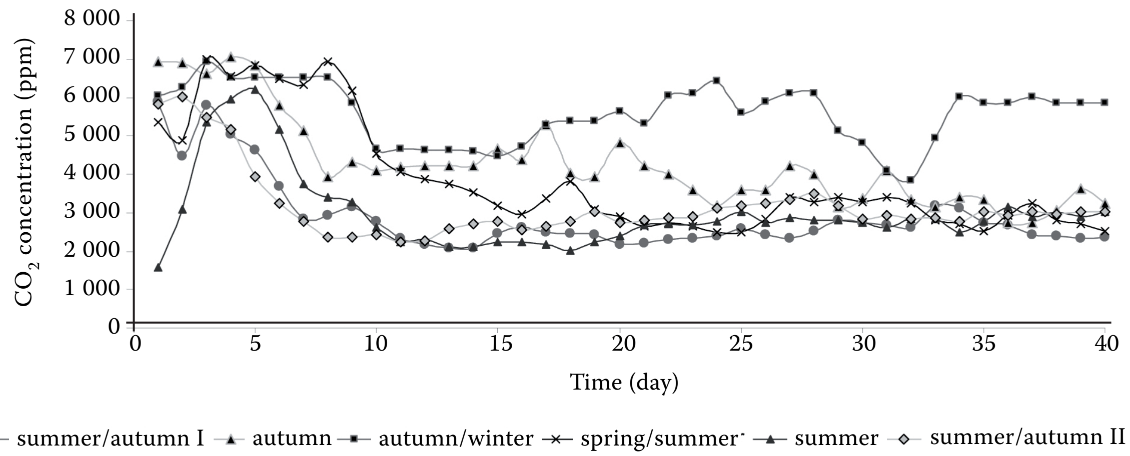

Figure 1. Time behaviour of carbon dioxide concentrations

Table 4. Correlations between studied parameters and CO_2 production

Parameter	Fattening period	CO_2 emissions	Air temperature	Litter temperature	Age of chickens	Ventilation rate
CO_2 concentration	summer/autumn I	NS	NS	NS	–0.4*	–0.5***
	autumn	NS	0.7***	0.4**	–0.8***	–0.8***
	autumn/winter	0.4**	NS	NS	NS	–0.4*
	spring/summer	0.5***	0.6***	–0.5***	–0.8***	–0.7***
	summer	NS	NS	NS	NS	NS
	summer/autumn II	0.4*	NS	NS	NS	NS
CO_2 emission	summer/autumn I		–0.7***	0.9***	0.8***	0.7******
	autumn		NS	NS	0.5***	0.5***
	autumn/winter		–0.7***	0.7***	0.7***	0.6***
	spring/summer		NS	0.7***	0.6***	0.8***
	summer		–0.4**	0.8***	0.9***	0.9***
	summer/autumn II		–0.7***	0.8***	0.9***	0.9***

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; NS = not significant

190 kW = 190 000 J/s = 684 MJ/h

684 MJ/h × 56.1 g/MJ = 38.4 kg of CO_2 per hour. Both heating units did not work continuously. Thus we cannot say that this amount of CO_2 was produced each hour.

Carbon dioxide levels in the broiler house atmosphere tend to increase over time with bird growth and respiration (Miles et al., 2006). Corresponding to intensive heating at the beginning, CO_2 concentrations decreased from placement to mid-fattening and then increased slightly towards the end of periods (Figure 1). It means that one source of CO_2 (gas burning) was replaced with another one (bird respiration). This effect is not very evident, since more intensive ventilation entered this process and CO_2 was diluted in fresh air from the outdoor environment.

The amount of CO_2 produced by respiration of chickens can be explicated in a similar manner like the fuel combustion mentioned before. The amount of CO_2 produced by birds is proportional to the heat production by the animal (1 litre CO_2 per each 24.6 kJ of total heat produced). This corresponds approximately to 1.5 l/h/kg live weight (EC, 2000). Since 1.5 l of CO_2 corresponds to 0.06696 moles (1 mole CO_2 = 22.4 l at STP) and one mole of CO_2 has a mass of 44 g, then a chicken exhales approx. 0.06696 × 44 or 2.946 g CO_2/h/kg. At the market age of 2 kg and the capacity of 25 000 chickens kept in this broiler house, 50 000 × 2.946 g or 147.3 kg of CO_2 are emitted per hour as a consequence of bird respiration. If we take into consideration the first day of just hatched chicks with live weight of 40 g, 2.9 kg of CO_2/h is produced by their respiration. However, it is also important to point out that the breathing frequency changes with age markedly. The production of CO_2 in the experiment carried out by Para et al. (2003) decreased with increasing weight of broilers from the mean weight of 0.25 kg/bird always up to the final weight of 1.5–2.0 kg/bird; the initial value reaching 1.85 l/h/kg and the final one 1.23 l/h/kg. A great influence ($P < 0.001$) of chicken age on CO_2 emissions can be deduced from the data in Table 4.

CO_2 is also a product (at several stages) of the aerobic breakdown of uric acid (Carlile, 1984). The enzymatic degradation of uric acid is supported by warmer temperatures (Coufal et al., 2006). The temperature of litter increased in spite of the decreasing air temperature during the particular fattening periods (Table 5).

Miles at al. (2006) also noticed in their research that CO_2 is an important component of the litter gas flux. Their gas flux picture showed an increase

Table 5. Parameters of indoor environment during 10-day fattening periods

Days of fattening period		Ventilation rate (m³/h)					
		summer/ autumn I	autumn	autumn/ winter	spring/ summer	summer	summer/ autumn II
1. to 10. (n = 240)	$\bar{x}$	39 079	28 284	25 581	22 711	27 322	30 873
	SD	27 921	7 503	5 029	7 580	19 426	13 656
11. to 20. (n = 240)	$\bar{x}$	73 361	34 159	32 330	39 061	68 105	66 877
	SD	49 373	4 173	2 525	14 191	44 233	41 550
21. to 30. (n = 240)	$\bar{x}$	114 772	46 349	35 060	126 458	98 819	124 594
	SD	49 642	10 328	2 227	58 806	55 572	64 793
31. to 40. (n = 240)	$\bar{x}$	130 725	90 524	39 406	102 387	128 764	145 785
	SD	58 893	18 899	2 287	41 257	47 680	55 652
1. to 40. (n = 960)	$\bar{x}$	89 484	49 829	33 094	72 654	80 752	92 032
	SD	59 724	27 001	5 970	56 594	57 714	66 165
Air temperature (°C)							
1. to 10. (n = 960)	$\bar{x}$	29.2	29.7	32.5	29.3	29.2	28.6
	SD	1.6	1.8	3.9	2.2	3.8	2.3
11. to 20. (n = 960)	$\bar{x}$	26.5	26.1	24.7	23.5	25.2	24.9
	SD	2.0	2.1	1.6	2.3	2.1	1.7
21. to 30. (n = 960)	$\bar{x}$	25.1	21.3	21.7	24.3	23.7	24.4
	SD	1.8	1.6	1.4	2.7	1.8	2.7
31. to 40. (n = 960)	$\bar{x}$	24.7	23.7	19.7	22.8	23.8	23.3
	SD	1.8	2.5	1.4	2.3	1.8	2.5
1. to 40. (n = 3 840)	$\bar{x}$	26.4	25.2	24.7	25.0	25.5	25.3
	SD	2.5	3.7	5.4	3.5	3.4	3.1
Litter temperature (°C)							
1. to 10. (n = 480)	$\bar{x}$	26.7	30.7	25.2	26.9	26.2	28.7
	SD	0.49	1.52	1.26	1.76	2.09	1.04
11. to 20. (n = 480)	$\bar{x}$	27.9	27.1	28.1	27.1	27.7	28.1
	SD	0.89	1.96	1.04	1.76	1.42	1.78
21. to 30. (n = 480)	$\bar{x}$	31.1	25.3	30.5	30.3	30.0	30.8
	SD	1.56	1.58	0.85	2.12	1.76	2.12
31. to 40. (n = 480)	$\bar{x}$	34.4	29.0	33.3	32.9	33.5	32.2
	SD	0.97	0.89	0.72	1.05	1.35	1.01
1. to 40. (n = 1 920)	$\bar{x}$	30.0	28.0	29.3	29.3	29.3	29.9
	SD	3.19	2.56	3.15	3.03	3.24	2.27

Table 5 to be continued

Days of fattening period		Ventilation rate (m^3/h)					
		summer/ autumn I	autumn	autumn/ winter	spring/ summer	summer	summer/ autumn II
H_2O concentration (mg/m^3)							
1. to 10.	$\bar{x}$	12 812	12 656	9 494	13 125	12 443	13 064
(n = 960)	SD	2 317	1 737	856	1 736	2 398	1 788
11. to 20.	$\bar{x}$	10 373	10 441	9 944	9 635	10 571	12 201
(n = 960)	SD	1 095	1 643	649	1 244	1 168	898
21. to 30.	$\bar{x}$	10 565	9 122	9 440	9 392	11 747	11 630
(n = 960)	SD	1 178	1 038	745	1 222	1 373	1 027
31. to 40.	$\bar{x}$	10 074	11 134	9 092	9 680	11 693	12 537
(n = 960)	SD	1 034	588	808	1 133	1 518	995
1. to 40.	$\bar{x}$	10 956	10 838	9 492	10 458	11 613	12 358
(n = 3 840)	SD	1 852	1 845	825	2 053	1 808	1 334

SD = standard deviation

in CO_2 flux from litter in the broiler house brood area from 6.190 mg/m^2/h on day 1 compared with 5.490 mg/m^2/h in the non-brood area to 6.540 and 9.684 mg/m^2/h on day 21 for the brood and non-brood area, respectively. Variable ventilation rates made it impossible to assess the relationship between temperature and CO_2 concentration in this study.

Carbon dioxide emissions

The mean carbon dioxide emission increased over time with bird age, ranging between 120 and 247 kg per h in the first 10-day quarter of fattening periods and between 325 and 459 kg/h in the last quarters (Table 6). It can be concluded from the above-mentioned calculations that the process of natural gas

Table 6. Summaries of CO_2 emission data (kg/h)

Fattening period	Days of fattening period					EF[1] (kg/bird)	EF[2] (kg/bird)
	1. to 10.	11. to 20.	21. to 30.	31. to 40.	1. to 40.		
					total emission (kg)		
Summer/autumn I	155.75	137.91	270.09	338.60	216 563	9.05	
Autumn	240.21	212.57	232.31	348.55	248 075	10.20	
Autumn/winter	247.02	238.70	311.21	325.07	269 280	10.99	73.11
Spring/summer	198.11	169.18	445.82	338.93	276 497	11.39	
Summer	120.29	130.72	284.22	398.31	224 050	9.37	
Summer/autumn II	131.96	177.71	398.38	459.27	280 156	11.67	

[1]partial emission factor calculated from the average number of chickens in individual flocks represents CO_2 emission per bird and 40 days of fattening period
[2]annual emission factor, i.e. CO_2 emission converted into seven fattening periods in one productive year

burning is responsible for a substantial part of CO_2 emissions during the first days of periods, and later, the respiration of animals takes dominance. From the seasonal aspect, CO_2 emissions reached the highest values in the fattening period "summer/autumn II" (280 t). This was attributed to an increased ventilation rate of the building ($P < 0.001$). Relatively high emission levels were also determined in the fattening periods "autumn/winter" (269 t) and "spring/summer" (276 t). This was significantly affected not only by ventilation rate but also by increased CO_2 concentrations ($P < 0.01$; $P < 0.001$). There was also a moderate correlation between ventilation rate and CO_2 concentration – the higher the ventilation rate, the lower the concentration of CO_2. No statistically significant relationship was found between the concentration of CO_2 and air temperature or litter temperature. Moreover, there was no statistically significant correlation between CO_2 concentration and CO_2 emission in three fattening periods (Table 4).

CONCLUSION

CO_2 production from heaters (approx. 39 kg/h) and CO_2 production from bird respiration (approx. 147 kg/h) were compared with total CO_2 emission from the building ranging between 120 and 247 kg/h in the first quarters, and between 325 and 459 kg/h in the fourth quarters of fattening periods.

CO_2 emissions were considerably more affected by ventilation rate ($P < 0.001$) than by CO_2 concentration in the indoor air. CO_2 emission was most affected by chickens towards the end of the grow-out period ($P < 0.001$) taking dominance over the process of natural gas burning by heaters.

Carbon dioxide in poultry houses does not rise to dangerous concentrations since the ventilation rate which is required to remove moisture exceeds the ventilation rate to remove CO_2 production of the birds, heaters and litter. CO_2 accumulation occurs only when the ventilation rate is operated at an extremely low level.

This evaluation of CO_2 emission sources could be complete if also CO_2 release from litter decomposition were taken into consideration.

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Corresponding Author

Ing. Monika Knížatová Ph.D., Animal Production Research Centre Nitra, Hlohovecká 2, 951 41 Nitra, Slovak Republic
Tel. +421 376 546 250, fax +421 376 546 483, e-mail: knizatova@cvzv.sk