Aerial VFA in Livestock Houses and Animal Waste Treatment Facilities

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Abstract A field survey on VFA from livestock facilities was carried out mainly on those of National Institute of Animal Industry and of two commercial pig enterprises to find out a countermeasure for reducing the evolution. VFA were analyzed by the alkali beads method of the Offensive Odor Control Law with modifications. Little odors were emitted from layer houses well managed and equipped with slats and improved watering systems and VFA were below 2.4 ppb. Whereas, in a broiler house with old newspaper bedding, the aerial VFA, especially n-butyric acid (C_4) increased remarkably to reach 97.4 ppb with accumulation of litter followed by the moistening, and the aerial ammonia concentrations also increased to 20.3 ppm. In dairy barns VFA in the air were on low levels except for silage feeding time, when propionic acid (C_3) and C_4 increased to higher levels. In general, aerial VFA in poultry and cattle houses are assumed to stay on low levels as long as proper waste management and silage handling is performed. Pig houses of partly slatted floor structures with pit scrapers and augers or with liquid manure systems were very odorous; in the latter, VFA in the air amounted to more than a hundred ppb. In pig houses with well managed sawdust floors, however, odors and VFA were in low levels, with C_3 and C_4 below 5.9, 2.2 ppb resp., both in summer and in winter. No offensive odors of VFA were emitted from the waste treatment facilities investigated, except a greenhouse for drying and composting swine manure, indicating biological treatments to be effective methods in controlling VFA from animal wastes.

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A recent trend toward large confinement livestock production in restricted areas, coupled with urban sprawl, is enhancing the risk of environmental problems, which suppress livestock farming. Among the problems, odor complaints are generated most frequently. Volatile fatty acids (VFA) are main components of malodors^{3,4,8,11,15,16)} emitted from

livestock farms, and are known to enhance offensive odors in the presence of other components, such as sulfur compounds, phenols, and indoles^{2,9,10,13,14)}. Recently, an extensive field survey was performed by the Environment Agency¹⁾ on aerial VFA in agricultural and food industries and it was confirmed that VFA are responsible for odors from livestock

facilities, especially swine houses, and from rendering plants, starch factories, *etc.* Upon these data, the Agency published the regulation of four VFA; propionic (C_3), n-butyric (C_4), n-valeric (C_5) and iso-valeric acids (i- C_5); in April 1990, by revising the Offensive Odor Control Law (OOCL)¹⁾. Since those VFA, especially the latter three, have lower thresholds for the olfaction, the regulatory standards on boundary lines have been established as low as ppb or sub-ppb levels according to the categories of the areas.

In order to establish countermeasures for controlling emissions of odors from livestock facilities, it is important to investigate the actual conditions of the odor emissions. This paper reports on the analyses of VFA in the air of livestock houses and of the waste treatment facilities.

Materials and Methods

1. Farms and waste treatment facilities investigated

During the past two years (1989-1990), animal and poultry houses and waste treatment facilities were investigated for VFA in the air. These houses and facilities were located in Ibaraki (3 poultry, 10 swine, and 2 cattle houses and 4 waste treatment facilities), Saitama (a waste treatment facility), Gunma (3 waste treatment facilities), Mie (2 cattle houses and a waste treatment facilities), and Aichi (2 poultry, and a swine houses and 2 waste treatment facilities) prefectures. Especially, detailed investigations were performed on those of the National Institute of Animal Industry (NIAI) and on farrow-to-finish swine farms O and M in Tsuchiura City, with 90 and 135 sows resp. Air samples were collected about 1 m above floors, and analyzed in duplicates unless otherwise stated.

2. Analytical methods

1) VFA determination

VFA, the four regulated acids as well as iso-butyric (i- C_4) and 2-methylbutyric (2-Me-

C_4) acids, were analyzed by gas chromatography, according to the method of OOCL¹⁾ and to those of Hoshica^{5,6)} and KATOU *et al.*⁷⁾ with the following modifications.

(a) Air sampling tube: A pyrex tube 5.8-mm in *i.d.*, 15 cm long, with a tapered end to fit a syringe needle, was packed with about 2.5 g of alkali glass beads, which were prepared from 100 g of glass beads (about 0.63 mm d.) by addition of 0.3 g of $Sr(OH)_2 \cdot 8H_2O$ in 100 ml of distilled water and subsequent evaporation with a rotary evaporator. After conditioning by heating for 10 min at 280-300°C in a stream of nitrogen gas, it was sealed with a Teflon cap and a silicone septum, and wrapped with Parafilm M to store until use.

(b) Gas chromatography: It was conducted on a JEOL 20 K chromatograph fitted with a flame ionization detector and a switching valve for nitrogen carrier gas. The column was prepared as follows; a glass column, 1.6 m $\times$ 3 mm *i.d.*, was packed with Carbowax B (60/80 mesh). Each 30 mg of FFAP (free fatty acid polyester) and phosphoric acid were dissolved in 30 ml of methanol, and the solution was passed through the column in 10 hours. During the coating, the column was treated with ultrasonic wave for 5 min. Then, the column was conditioned overnight at 220°C in a stream of nitrogen gas. The chromatographic conditions were as follows; carrier gas was nitrogen, 43 ml/min. Injection and detection was operated at 200°C and the oven heating was programmed from 100°C to 200°C at 6°C/min.

(c) Analytical procedure: Using a portable air pump, Sibata MP-50 WT, 12.5 l of the air in the field was passed through the sampling tube in 6 min. Before the GC analysis, the tube was heated in a nitrogen gas stream at 180°C for 5 min to expel contaminants. Then, the tube was fitted with a syringe needle, and added with 5 μ l of formic acid (GR MERK, the earlier main distillate), while being held in horizontal position. Immediately after the

addition, the tube was connected to the carrier gas by a Swagelok fitting and the needle was inserted to the injection port of the gas chromatograph. At the same time the carrier gas was allowed to pass through the tube by the switching valve and the tube was heated to 200°C in 2 min to start chromatography. After each analysis, the chromatograph was injected with 4 μ l of 5% formic acid to remove any residual VFA.

2) Ammonia determination

In addition to VFA analyses, ammonia concentrations in the air were determined by detection tubes (Gastec, 3 L).

Results and Discussion

The results of VFA and ammonia analyses on livestock facilities are shown in Table 1-4, as the averages of duplicate determinations.

In the layer houses of NIAI (Table 1, Sample No. 1, 2; August), aerial VFA were on low levels, ranging from trace to 1.4 ppb, in accord with daily removal of the waste. Thus, air sample (No. 5) taken at 30 cm above droppings on the floor was found to contain less than 5.8 ppb VFA. Odors from layer houses (No. 3, 4; December) of poultry enterprises in Aichi were also below a few ppb. These houses were equipped with slats under the cages in addition to improved waterers to keep droppings dry. In accord with low odors, VFA and ammonia

levels in the air were low. Whereas, in the windowless broilerhouse in NIAI, where old newspapers were used as a bedding material, aerial VFA increased with accumulation of the waste on the bedding, and at two weeks of age C_4 reached to a peak of 15.7 ppb (No. 6). The VFA, then, decreased gradually in accord with increase of ammonia concentration in the air.

The air samples from the dairy barn of NIAI had VFA in small amounts (Table 2, No. 1, 6). Near a silo attached to the barn, or during delivery of silage, however, VFA in the air of the barn, especially C_3 and C_4 increased up to 30.8 and 13.4 ppb resp. (No. 5, 2). These large values were observed for C_3 in winter (No. 3-6) and for C_4 in summer (No. 2).

In the air of a beef cattle barn with sawdust bedding (No. 7, March) in Mie only traces of VFA were detected, but in the barn of NIAI with old newspaper bedding (No. 9, 10) the atmospheric VFA were on higher levels, and especially C_4 concentrations were about 10 ppb in June. The differences in C_3 and C_4 concentrations in the cattle barns appear to be seasonal fluctuations and assumed to be due to the quality of silage.

Anyhow, in poultry houses and cattle barns, the aerial VFA will be estimated not to be a nuisance, so long as the accumulated manure and silage are managed properly. However, one should not assume from these data that

Table 1. VFA in the Air of Poultry Houses (1989-1990*)

sampling No.	Date	temp °C	wind m/s	NH ₃ ppm	C ₃	i-C ₄	C ₄	2-Me-C ₄ ppb	i-C ₅	C ₅	description on sampling place
1	Aug 11	24.3	0.0	3.3	1.4	—	0.6	—	0.1	ND	WL, L, NIAI
2	Aug 11	27.8	1.3	0.1	ND	—	ND	—	ND	ND	L, NIAI
3	Dec 12	16.0	0.6	ND	2.4	0.4	0.7	0.2	0.2	0.2	L, slat, nipple D, Aichi
4	Dec 12	16.2	0.3	ND	0.8	0.1	0.2	0.1	0.3	0.4	L, slat, trough D, Aichi
5	Aug 21*	24.2	0.03	3.5	3.5	5.8	3.5	0.4	0.7	0.6	WL, L#, NIAI
6	Nov 9*	25.3	0.05	0.1	7.4	1.5	15.7	0.9	2.5	1.0	WL, B##, 2 w of age, NIAI
7	Dec 21*	20.4	0.08	20.3	61.5	10.1	97.4	6.4	6.7	3.3	WL, B##, 8 w of age, NIAI

C₃: propionic acid; i-C₄: iso-butyric acid; C₄: n-butyric acid; 2-Me-C₄: 2-methylbutyric acid; i-C₅: iso-valeric acid; C₅: n-valeric acid; ##: old newspaper bedding; ND: not detected WL: windowless; L: layer house; B: broiler house; #: 30 cm above feces on the floor; D: drinker

higher levels of VFA could not or did not occur ; in the case of the floor-reared broiler in NIAI, VFA concentrations in the air increased again and aerial C_4 amounted to 97.4ppb, afterwards, with increasing moisture of the litter with spilled water, irrespective of

presence of very high aerial ammonia of 20.3 ppm, as the waste was accumulated and moistened severely (Table 1, No. 7).

VFA of higher concentrations of several decades ppb were frequently found in the air of pig houses (Table 3). In the fattening house in

Table 2. VFA in the Air of Cattle Barns (1989-1990*)

sampling No. Date	temp °C	wind m/s	NH ₃ ppm	C ₃	i-C ₄	C ₄	2-Me-C ₄ ppb	i-C ₅	C ₅	description on sampling place
1 Aug 11	27.2	0.0-0.1	0.1	0.2	—	0.4	—	ND	ND	D [#] , NIAI
2 Aug 11	27.0	0.0-0.3	0.1	1.7	—	13.4	—	0.7	ND	D [#] , FS, NIAI
3 Nov 27	13.9	0.1-1.5	—	17.8	0.6	0.7	0.1	0.2	0.1	D, end of passage, NIAI
4 Nov 27	10.5	—	—	11.3	0.3	0.5	0.1	0.2	0.3	D, mid passage, NIAI
5 Nov 28	18.9	0.1-0.2	—	30.8	0.9	1.4	0.2	0.4	0.3	D, end of passage, NIAI
6 Nov 28	14.5	0.0-0.1	—	6.5	0.3	0.6	0.2	0.2	0.3	D, mid passage, NIAI
7 Mar 19*	17.1	0.1-0.7	—	0.1	0.1	0.2	ND	ND	ND	B, sawdust bedding, Mie
8 Mar 20*	19.6	0.0-1.6	—	0.8	0.6	0.6	0.2	0.2	0.3	D, Mie
9 Jun 20*	26.0	0.03	2.0	2.4	0.6	9.2	0.3	0.8	0.7	B, before SM & FS, NIAI
10 Jun 20*	26.6	0.2-1.5	2.5	3.9	0.7	10.8	0.8	0.6	ND	B, during SM & FS, NIAI

D : dairy barn; B : beef cattle barn; # : most cows were in a paddock; ** : FS : feeding with silage
SM : scraping & removal of manure; end of passage : at the end of passage near a silo

Table 3. VFA in the Air of Pig Houses (1989-1990*)

sampling No. Date	temp. °C	wind m/s	NH ₃ ppm	C ₃	i-C ₄	C ₄ ppb	2-Me-C ₄	i-C ₅	C ₅	description on sampling place
1 Jul 7	28.3	moderate	—	6.0	—	0.5	—	0.5	0.3	F house, NIAI
2 Jul 14	29.0	moderate	—	4.4	—	1.6	—	0.6	0.9	F house, NIAI
3 Jul 21	30.5	0.1-0.5	3.0	58.7	—	41.4	—	3.0	8.2	F house-1, scraper, O
4 Jul 21	30.5	0.0-0.1	1.0	20.2	—	12.0	—	1.9	2.5	FR house, scraper, O
5 Jul 21	30.5	0.2-1.1	1.0	38.6	—	33.9	—	3.1	4.8	F house-2, scraper, O
6 Jul 21	30.5	0.6-1.6	1.5	39.9	—	48.5	—	2.9	6.2	Outside, O
7 Jul 28	31.0	0.2-1.0	6.0	170	—	131	—	10.3	22.9	N house, liquid, M
8 Jul 28	29.0	0.2-1.3	2.0	20.7	—	21.1	—	2.5	5.5	FR house, liquid, M
9 Jul 28	29.5	0.2-1.0	3.0	28.2	—	18.6	—	2.5	3.0	F house-1, scraper, M
10 Jul 28	29.5	0.3-1.2	5.0	48.7	—	33.3	—	3.7	5.3	F house-2, scraper, M
11 Nov 30	13.8	0.5-1.4	1.0	23.3	2.9	16.2	1.4	1.1	2.3	Outside, O
12 Nov 30	19.0	0.1-0.3	6.5	5.9	1.5	2.0	0.5	0.7	0.5	F house-3, SD floor, O
13 Nov 30	14.6	0.1-0.5	2.5	0.7	0.7	0.9	0.2	0.2	0.4	F house-4, SD floor, O
14 Dec 13	19.2	0.0-0.2	6.0	77.6	10.0	35.4	4.9	4.3	5.4	WL FH, scraper, Aichi
15 Jul 27*	31.2	0.39	0.3	3.8	1.4	2.2	0.6	1.7	0.7	F house-3, SD floor, O
16 Jul 27*	28.8	1.11	ND	2.1	0.6	1.5	0.6	0.7	0.7	F house-4, SD floor, O
17 Jul 27*	29.3	0.59	0.1	43.1	3.9	37.9	2.6	3.5	5.6	F house-2, scraper, O
18 Jul 27*	30.7	1.02	0.1	13.6	1.3	11.1	0.9	1.5	2.2	Outside, O

F : fattening; N : nursery; FR : farrowing; O : O farm; M : M farm; SD : sawdust; WL : windowless
Outside : 10 m downwind from the exhaust fan of F house-2, O

NIAI (No. 1, 2), the aerial VFA were below several ppb due to lower housing density and better management.

In contrast, intense malodors were emitted from the nursery and fattening houses of pig enterprises, O and M farms (No. 3, 5 ; 7, 9, 10) and the VFA of C_3 , C_4 , $i-C_5$ and C_5 were extremely high (28-170, 19-131, 2.5-10.3, 3.0-22.9 ppb resp.) in summer. In these farms, even the atmospheres of farrowing houses were malodorous (No. 4, 8). Especially in the nursery house that were constructed by underslat liquid manure systems, the odors were more offensive to record the highest values of the aerial VFA, when aerial ammonia concentration amounted to 6 ppm (No. 7). Similarly, both aerial VFA and ammonia were high (C_4 35.4 ppb ; ammonia 6 ppm), when determined in winter, in a windowless fattening building (No. 14) with partly slatted floors in Aichi, whereas the outside of the building was not odorous, suggesting the exhaust odors to be allowed to diffuse effectively.

Those pig houses that evolved large amounts of VFA were of partially slatted floor structures and equipped with scrapers and augers in the pits, or with liquid manure pits, where excreta became anaerobic during scraping or storage to give rise to malodors. Thus, even in the air outside of the fattening house-2 of O farm (No. 6, 11, 18 ; 10 m downwind of the exhaust fan), VFA were beyond the levels regulated by OOCL.

On the contrary, the piggeries with saw dust floors of O farm (No. 12, 13, 15, 16) were not so odorous and the VFA (C_3 , C_4 , $i-C_5$, and C_5) in the air were below 5.9, 2.0, 0.7 and 0.5 ppb resp., whereas the aerial ammonia was rather higher, in winter when the windows were almost closed. In these piggeries, the acids stayed in below several ppb even in summer, though all the windows were open and the exhaust fans were working. The reason for less odors in these piggeries lies in management of the sawdust floors : The sawdust floors were

black in color and properly moistened to allow in-house composting of the accumulated manure to decompose VFA. Here, resultant ammonium ion is assumed to serve for suppressing the vaporization of VFA by forming the salts.

In contrast to these piggeries, the VFA in the air of the above house-2 (No. 17) were found again in high levels and C_3 , C_4 , $i-C_5$, and C_5 were 43.1, 37.9, 3.5 and 5.6 ppb resp. on the same day in summer.

The waste treatment facilities including plastic covered greenhouses for composting and drying wastes (Table 4, No. 3, 8, 13), composters (No. 1, 10), compost storage (No. 2, 4, 5, 6, 9) and waste water treatment systems (No. 7, 11, 12, 13) were also investigated for the VFA in the air. Since biological degradation of organic materials is involved in the most waste treatment processes and results in producing a large amount of ammonium ion as envisaged on composting of manure, evolution of VFA from the wastes can be expected to be suppressed by neutralization with abundant ammonium ion and by vigorous microbial decomposition.

Expectedly, the treatment facilities investigated had no acidic odors of VFA (below 2.9 ppb), except the greenhouse containing an aerated composter for swine feces (Table 4, No. 8) in Saitama, where C_4 in the air at the entrance amounted to 35.5 ppb, though aerial ammonia was considered to be in high levels. In this case, the VFA were assumed to arise mainly from storage of raw swine feces scraped out from pits and not from the compost product.

In addition to the treatment facilities, both VFA and ammonia were simultaneously released from some livestock houses, including the above broiler house (Table 1, No. 6, 7) and pig houses, in high concentrations, though they are readily reactive to give salts.

Formerly, we reported that odors in the exhaust from composting of pig feces were

Table 4. VFA in the Air of the Waste Treatment Facilities (1989-1990*)

sampling No.	temp Date	°C	wind m/s	NH ₃ ppm	C ₃	i-C ₄	C ₄ ppb	2-Me-C ₄	i-C ₅	C ₅	description on sampling place
Poultry wastes											
1	Aug 11	31.4	0.1-0.6	1.0	0.3	—	ND	—	ND	ND	composter room, NIAI
2	Aug 11	30.0	0.1-0.2	1.0	0.9	—	0.6	—	0.2	ND	compost storage, NIAI
3	Dec 12	18.4	0.6-0.7	>30	0.4	ND	ND	0.2	0.2	0.2	PL#, Aichi
Cattle wastes											
4	Aug 9	34.5	0.1-1.5	—	1.1	—	0.5	—	0.1	ND	compost storage##, NIAI
5	Nov 21	22.2	0.1-1.0	—	2.9	ND	1.5	ND	ND	1.7	compost storage##, NIAI
6	Mar 20*	18.4	0.1-1.8	—	0.2	0.1	ND	ND	ND	ND	compost storage, Mie
Swine wastes											
7	Aug 9	34.5	0.1-1.4	—	0.1	—	0.3	—	ND	ND	near aerator, WWTF, NIAI
8	Nov 14	15	moderate	—	40.8	7.7	35.5	5.1	3.3	5.1	PL#, Saitama
9	Dec 13	13.2	0.1-0.3	—	0.3	0.4	0.4	0.2	0.4	1.0	compost storage#, Aichi
10	Dec 13	11.8	0.3-0.7	7.0	0.1	ND	ND	ND	0.2	0.2	SD filter*** for E, Aichi
11	Mar 22*	19.1	0.0-1.4	—	0.1	0.2	0.1	ND	ND	ND	near aerator#, WWTF, Gunma
12	Mar 22*	12.8	0.9-1.0	—	1.0	0.3	ND	0.2	0.1	0.2	near lagoon#, WWTF, Gunma
13	Mar 22*	17.6	0.0-1.0	—	0.3	0.2	0.1	ND	0.1	0.3	PL#, ES, WWTF, Gunma

#: single determination; ##: compost from mixtures of cattle manure and swine manure

** : 30 cm above; SD : sawdust; E : exhaust from a vertical composter; PL : plastic covered greenhouse for composting & drying; ES : excess sludge; WWTF : waste water treatment facility with activated sludge process

mostly removed when the moisture in the exhaust was allowed to condense^{12,16)}. This indicates that odors from animal wastes can be removed readily if a proper medium for mutual reactions is provided, since the most components of odors have reactive functional groups. In the piggeries with sawdust floors, the sawdust is regarded as such a medium for adsorbing and degrading malodorous substances physicochemically and biologically.

In livestock farms, odors are formed from readily biodegradable organic materials in manure mainly by the action of putrefactory bacteria. Since activities of the bacteria depend on the climatic and atmospheric conditions for the manure, such as temperature, humidity and the redox potential, the seasonal effect in terms of amounts of emitted odorous compounds was expected to occur and evidenced in the determinations of VFA.

However, the effect was not so pronounced

on the air of several houses, such as the piggeries with sawdust floors. The reason for preventing the houses from affecting the environment during the hot season may be attributed to the structures and the accommodations in the houses and to the well managed waste treatment, in addition to dilution due to increased ventilation rates in the season.

In this investigation it was shown that emissions of VFA from livestock farms were especially important in swine farms as compared with those from poultry and cattle farms in terms of the regulation by OOCL and that the odors had a close relationship with house structures and facilities, and with the waste management systems; scraping of manure was liable to emit VFA, whereas in-house drying and on-site composting of manure was effective in reducing VFA emission. The facts that ammonia and VFA were frequently found at the same time in the air of

animal houses and of the waste treatment systems, and that in the latter aerial VFA were mostly negligible, indicate a collection of odors from the source by local ventilation and subsequent biological deodorization to be a promising countermeasure for odor complaints. This work was partly supported by a grant from MAFF in 1989.

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畜舎および処理施設における低級脂肪酸の発生状況

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畜産の悪臭の主要成分の一つである低級脂肪酸（VFA）の畜産業からの発生状況を把握し，悪臭対策を確立するために現地調査を実施した。

VFA の分析は環境庁制定のアルカリ・ビーズ法を一部改変して行なった。現地調査は畜試の畜舎，家畜排泄物処理施設および周辺の養豚場 2 箇所を主とし，適宜一般の畜舎施設の調査を加えた。管理がよく，スノコ，ニップル飲水器等を備えた採卵鶏舎内の VFA はプロピオン酸（C₃）でも 2.4 ppb 以下と低く，環境も良好であった。ブロイラー鶏舎（新聞故紙敷料）では糞の堆積，湿潤化に伴い 20.3 ppm のアンモニアと共存して多量の VFA（n-酪酸，C₄ で 97.4 ppb）がみられた。搾乳牛舎ではサイレージ給飼時に C₃ や C₄ が増加したが糞尿由来は少なかった。これに対し，肉豚舎では管理がよくても VFA はやや高めであった。さらに周辺の豚舎の仔豚舎，肥育舎などでは C₃，C₄ は数十 ppb，ときには各々 170，131 ppb に達し夏期ばかりでなく冬期でも高濃度であった。これらの豚舎構造は部分スノコ床構造でスクレーパ，オーガー搬送又は糞尿混合処理であった。一方床の管理のよいオガ屑豚舎では夏冬期とも VFA は C₃，C₄ で 5.9，2.2 ppb 以下と比較的低濃度であった。処理施設では豚糞発酵乾燥施設入口で高い例がみられたが，豚糞急速堆肥化物置場，堆肥化排気，堆肥盤，鶏糞発酵機室，同堆積場，同発酵乾燥施設，污水处理施設等では処理物を含めて VFA は僅かで C₃，C₄ で 2.9，1.5 ppb 以下であった。

以上，VFA 等の臭気の発生には舎内管理だけでなく畜舎構造および施設が特に関連が深いという結果がえられた。同時に，生物学的処理過程で容易に除去されることも示唆された。

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