Odour from Pig Production Facilities: Its Relation to Diet

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Report 115

Colophon

The authors are working at:

- Wageningen UR, Agrotechnology & Food Innovations B.V.
- Wageningen UR, Animal Sciences Group.

Title	Odour from Pig Production Facilities: Its Relation to Diet
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A&F number	Report nr. 115
ISBN-number	ISBN 90-6754-766-2
Date of publication	March 2004
Confidentiality	Non confidential
Project code.	N/A

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Abstract

Le PD, Becker PM, Aarnink AJA, Jongbloed AW & Van der Peet-Schwering CMC (2004) Odor from Pig Production Facilities: Its Relation to Diet, pp. 65. Wageningen: Wageningen UR, Agrotechnology & Food Innovations B.V.

Though bad odour has always been associated with animal production, it did not attract much research attention until in many countries the odour production and emission from intensified animal production caused serious nuisance and was implicated in the health problems of people living near animal farms. Odour from pig production facilities is generated by the microbial conversion of feed in the large intestine of pigs and by microbial conversion of pig excreta under anaerobic conditions and in manure stores. Assuming that primary odour-causing compounds arise from an excess of degradable protein and a lack of specific fermentable carbohydrates during microbial fermentation, the main dietary components that can be altered to reduce odour are protein and fermentable carbohydrates. In this paper we aim to give an up-to-date review of studies on the relationship between diet composition and odour production, with the emphasis on protein and fermentable carbohydrates. We hypothesise how odour might be changed and/or reduced by altering the diet of pigs. Research so far has mainly focused on the single effects of different levels of crude protein and carbohydrates on odour production. However, also important for odour formation are the sources of protein and carbohydrates. In addition, it is not only the amount and source of these compounds that is important, but also the balance between them. On the basis of our review of the literature, we hypothesize that odour nuisance from pig production facilities might be reduced significantly if there is an optimum balance between protein and fermentable carbohydrates in the pig's diet.

***Keywords**: Odour, diet, pig*

Contents

1 Introduction

Background odour problem in the Netherlands

The agricultural sector is an important source of odour nuisance in The Netherlands. Other sources are industry and traffic. Odour nuisance from agriculture is especially a problem in animal-concentrated areas, like in the southern and eastern part of the country. Eleven percent of the total population experienced more or less nuisance of odour from agricultural activities, while this was 10% for industrial activities and 7% from traffic (Anonymus, 2001). The objective of the government is to reduce severe nuisance of odour to zero level by 2010. From now on additional odour nuisance should be prevented in all cases.

Odour regulation in agriculture

Odour nuisance in agriculture is caused by two main sources: odour from application of manure on the field and odour from livestock buildings. From the ninety seventies onwards, regulations have been adopted to regulate odour emission from livestock buildings. In 1971, the first national regulation was put into force. This regulation was adapted in 1976, 1985 and 1996. At present, for livestock buildings the Guideline Livestock Production and Odour Nuisance is in force (Anonymous, 1996). This regulation aims to give an objective basis for local environmental measures and policy. The basis for this regulation is the relationship between odour emission and the minimum distance between the odour emitting farm and the odour sensitive object. The main elements of this regulation are:

- Odour emissions from all livestock farms are calculated based on a table with conversion values. Within this table the odour emission for all species and categories of livestock is converted to a standard emission per animal, expressed in a unit that corresponds with the odour emission of one fattening pig (one m.v.e.).
- A distance chart that gives the minimum distance between the farm, with a certain odour emission, and an odour sensitive object (e.g. a house).
- A separation in level of sensitivity of the different objects. For instance, another livestock farm has a lower sensitivity than a house. Four different sensitivity categories are distinguished.

Internationally different approaches can be distinguished to regulate odour (Mahin, 2001):

1. The use of specified setback distances between new or expanding livestock operations and sensitive receptors which are based only on the number and type of animals and the type of receptor (such as single house versus residential development / urban area).
2. Similar as under 1, but including additional factors that influence odour emission and odour dispersion, such as manure handling system, local landscape type, type of feed, type of ventilation system, etc.
3. The use of ambient air limits for individual compounds, such as hydrogen sulphide as used in certain states of the US and Canada.
4. Off site limits based on levels predicted by dispersion modelling and using dynamic olfactometry approach.

5. General regulatory schemes/statements that prohibit off-site nuisance or annoyance conditions as determined by field inspectors.

In The Netherlands, the first approach has been chosen. In Germany and Austria, the second approach is used. In this approach the number of animals first assesses the potential odour emission. Then the system used, e.g. manure handling, ventilation system, type of feed, the topography of the site, etc is evaluated. The separation distances are fixed by graphs. In Belgium and the UK, the fourth approach is in use. In Belgium 'sniffing units' are determined. The sniffing unit is defined as the maximum distance from the odour source at which the odour can be observed. The sniffing units of an odour source are determined by on site measurements. On basis of the determined sniffing units, the emission rates from the source are determined by dispersion modelling. In the UK, maximum levels of OU/m^3 of air are set, based on emission measurements at the odour source and dispersion modelling.

In Denmark and Norway, approach 5 is used. In Denmark, for new livestock facilities a minimum distance should be maintained to urban areas. There is also regulation on the way the manure should be applied on the soil. In Norway, an environmental impact assessment is required for large livestock facilities.

Actual odour situation

At the moment the Dutch Government develops new approaches. This means that in future regulation should be focused on nuisance and not on emissions standards. Targets for odour regulation are to limit odour nuisance to a maximum of 12% annoyed locations on the short term and no annoyed locations on the long term. Within the table with conversion values additional values have been included, e.g. for systems that proved to give low ammonia emission, also lower conversion values are given for odour emission. Recently an odour measurement program has been carried out to validate and modify the conversion factors in the conversion table (Ogink & Lens, 2001; Mol & Ogink, 2002).

The Dutch government wants to reconstruct the rural area in protected nature areas and in areas in which livestock production can develop. However, the present odour regulation might counteract the reconstruction. Also for this reason, production systems with low odour emission need to be developed. It's important to develop systems that can be easily used in practice, both in existing and newly build animal houses and that are not too expensive. At this moment the farmer has only minor choices to implement systems with low odour emission.

Possible solutions

Odour emission from livestock buildings can be prevented within the whole chain from feed and animals to manure and outgoing barn air. Odour emission can be reduced by preventing odorous components to be formed or by preventing odour to be emitted from the animal house, e.g. by washing the outgoing air. Even dilution of odorous outgoing air, by for instance discharging the

barn air through a high chimney, is a way to prevent nuisance to people living in the vicinity of the farm.

Experience in ammonia emission research has shown that tackling emission in the beginning of the chain generally has a higher efficiency (effect in relation to costs) than so-called end of pipe solutions. Research has shown that changing and optimising dietary composition can reduce ammonia emission considerably (Canh, 1998; Mroz *et al.*, 1999; Bakker & Smits, 2002). This approach might be successful for odour as well. Preventing odour components to be formed from undigested feed might be a very promising way to prevent odour emission from pig houses at reasonable costs and with easy implementation on existing and newly build farms.

Objective

The objective of this study is to determine the possible role of pig feeding and nutrition in reducing odour emission from pig production facilities. In The Netherlands, pig diets are formulated with a wide range of raw materials. These different raw materials will have an effect on digestion and utilization of nutrients of the pig, and thereby, on the formation of (pre-) odorous compounds. Within this study the state of the art is given on the influence of dietary composition on the formation of different odorous compounds within and outside the animal. On basis of this information the perspectives are presented to reduce odour emission from pig houses by dietary means.

In Chapter 2, an overview is given of the different groups of odorous compounds that have been identified in pig houses. In Chapters 3, the basics of the formation of odorous compounds within the animal and within the manure pit are described. In Chapter 4, the methods used at this moment to determine odour strength and offensiveness are described. In Chapter 5, the state of the art on the relationship between diet and odour production is presented. The perspectives of nutritional measures to reduce odour production from pig houses are reported in chapter 6. Finally, the main conclusions of this study are drawn in Chapter 7.

2 Odour compounds from pig production facilities

2.1 Odour groups

Odour generated in animal production facilities comes from (i) feed, (ii) animal body, (iii) urine and faeces or the mixture of both, the manure. The most significant source of odour is from the excreta: urine, faeces and manure, especially their decomposition during collection, handling, storage, and spreading. Odour is emitted into the air from buildings or external manure storage sites or from manure application in the field. There are a great number of odorous compounds present in animal production facilities. These compounds are not only responsible for unpleasant odour but also affect the comfort, health and production efficiency of animals, as well as the comfort and health of human workers (Tamminga, 1992). O'Neill and Phillips (1992) summarised 168 odorous compounds identified in various studies in animal production facilities. As already mentioned, they can be classified into sulphurous compounds, volatile fatty acids (VFAs), phenols and indoles, and ammonia and volatile amines. Thirty out of these 168 compounds have an odour detection threshold of 1μg/m^3 or less (Table 1). Recently, Susan *et al.* (2001) identified a total of 331 different compounds from pig production facilities in North Carolina.

Although a huge number of odorous compounds have been identified from animal production facilities, the sources from which they originate are poorly described. Geypens *et al.* (1997) isolated a total of 120 different volatile organic compounds from human faeces, of which 25 remained unidentified. Drasar & Hill (1974) found indole, 3-methyl indole (skatole), phenol, 4-methylphenol (p-cresol) and 4-ethylphenol in the urine of pigs. These compounds originate from the putrefactive decomposition of bacteria in the large intestine of the animal. They are then detoxicated by the liver and excreted via urine. According to Spoelstra (1976) phenol, p-cresol, and 4-ethylphenol are mainly present in urine as glucuronides. Glucuronides are rapidly and easily converted by glucuronidase in faeces to the compounds mentioned. Odour from the animal body, such as the cutaneous and oral odour, has not been well described. The main sweat compounds from the animal are thought to be propanoic and butanoic acid (Jackman, 1982). Volatile sulphur compounds, methylamine, dimethylamine, propanonic acid, butanoic acid, indole, skatole, and cadaverine are reported to cause oral malodour (Goldberg *et al.*, 1994; Goldberg *et al.*, 1997; Nakano *et al.*, 2002). Schaefer *et al.* (1974) detected more than 70 compounds, which they assumed to have originated from particles of feed rather than from animal manure.

Many authors have attempted to elucidate relationships between different odorous compounds or chemical odour groups and odour strength and offensiveness or have tried to find odour markers. Spoelstra (1980) recommended using p-cresol and VFAs as indicators of odour offensiveness from animal production facilities; Williams and Evans (1981) suggested VFAs, phenol, p-cresol and skatole as the main odour markers, while Barth *et al.* (1974) reported VFAs,

NH_3 and H_2S as the main odour markers from animal production facilities. According to Schaefer (1977) the primary malodour compounds from animal production facilities are associated with VFAs, phenol, p-cresol, indole, and skatole. Williams (1984) and Hobbs *et al.* (1997) produced a list of four major groups of odorants: VFAs, indoles, phenols and sulphides. According to Curtis (1993), the principal odour groups are ammonia and volatile amines, sulphurous compounds, VFAs, indoles and phenols, alcohols and carbonyls.

Table 1 Compounds with low odour detection threshold (Cod)* found in animal manure

Range of detection threshold (C_{od}, μg m^{-3})	Compound	Lowest detection threshold (C_{od}, μg m^{-3})
$C_{od} \leq 0.01$	Methanethiol	0.0003
	2-propanethiol	0.0025
	2-propene-1-thiol	0.005
	2,3-butanedione	0.007
$0.01 \leq C_{od} \leq 0.05$	Phenylethanoic acid (Phenyl acetic acid)	0.03
	Ethanethiol	0.043
	4-methylphenol (p-cresol)	0.05
$0.05 \leq Cod \leq 0.1$	Hydrogen sulphide	0.1
	1-octene-3-one	0.1
$0.1 \leq C_{od} \leq 0.25$	Benzenethiol	0.14
	2,4-decadienal	0.18
	3-methylbutanoic acid	0.2
	2,6-dimethylphenol	0.2
	3-methylphenol	0.22
	2,4-nonadienal	0.25
	Dacanal	0.25
$0.25 \leq C_{od} \leq 0.5$	Trimethylamine	0.26
	Octanoic acid	0.3
	Nonanal	0.3
	Methylthiomethane	0.3
	Ethyldithioethan	0.3
	2-phenylethanol	0.35
	3-methylindole (skatole)	0.35
	Butanoic acid	0.4
	2-methylphenol	0.4
	2-butene-1-thiol	0.43
	2-nonenal	0.5
$0.5 \leq C_{od} \leq 1.0$	Indole	0.6
	Petanoic acid	0.8
	Butanal	0.84

* Lowest odour detection threshold: The lowest concentration at which has a probability of 0.5 of being detected under the conditions of the test (CEN, 1999).

Source: O'Neil and Philips (1992)

2.2 Volatile fatty acids

VFAs are commonly reported as being major constituents of odour from animal production facilities. About 60% of the total VFAs in manure (w/w) are present as acetic acid. The next most dominant acids are propanoic, butanoic (n-butyric), 2-methylpropanoic (*iso*-butyric), 3-

methylbutanoic *(iso*-valeric), pentanoic (n-valeric), hexanoic and capric acids (McGill & Jackson, 1977; Cooper & Cornforth, 1978; Spoelstra, 1980). The odorous nature of VFAs progresses from the pungent smell of acetic acid to the distinctly unpleasant and offensive smell of valeric and caproic acids (Morrison, 1987; cited by Zhu, 2000). VFAs with high carbon numbers have a lower odour detection threshold (Mackie, 1994). A high concentration of VFAs in pig manure may not cause very offensive malodour because a large proportion of VFAs could be composed of short-chain VFAs that are potentially less offensive.

The detection threshold, concentration and odour nature of some important VFA compounds are listed in Table 2; their chemical structures and their potential precursors are listed in Table 5. Although all the researchers used the technique of gas chromatography (GC), it is surprising that concentrations of odorous compounds in general, and VFAs in particular, vary so widely among different studies and among different kinds of samples. The variation is probably created by different sampling and measuring methods, different sources of samples, etc. The exact source of samples of odorous air compounds is very important, but in many reports it is unclear. In addition, the studies cited in Table 2 were published from 1975 to 1997 and therefore an important reason for the variation of the concentration of odorous compounds could be the changes that have taken place in the last 30 years in animal production systems (e.g. in diet, animal breeds, and housing systems). Furthermore, the detection thresholds of odorous compounds also vary widely, probably due to the measuring methods and the accuracy of the equipment used.

2.3 Sulphur-containing compounds

Sulphur is present in numerous compounds at various states of oxidation. For example, sulphur has a +6 charge as sulphate anion, a +4 charge as gaseous sulphur dioxide and a sulphite anion, no charge as elemental sulphur, and a –2 charge as a sulphide anion. Several authors have reported that sulphurous compounds are important constituents of odour from livestock manure (Schaefer, 1980; Odam *et al.*, 1986; Ohta & Kuwada, 1998). The sulphur excreted in fresh manure is about 76 and 51g per 1000 kg animal mass per day for pig and dairy cattle, respectively (ASAE, 1998). Sulphur excretion is quantitatively similar in faeces and urine. When diets contain higher sulphur levels, the excretion ratio is shifted in favour of urine (Bouchard & Conrad, 1973). According to O'Neill and Phillips (1992) six of the ten compounds with the lowest odour detection threshold contain sulphur. In addition, Table 1 shows that the three compounds with the lowest odour detection threshold all contain sulphur. Furthermore, it has been shown that sulphurous compounds are the most offensive compounds. Table 2 shows that the odorous nature of sulphurous compounds progresses from the putrid smell of dimethyl disulphide and methanethiol to the rotten eggs smell of hydrogen sulphide.

Hydrogen sulphide is considered one of the most dangerous gases; it has been reported to be responsible for many animal and human deaths (Donham *et al.*, 1982; cited by Ji-Qin *et al.*, 2000).

However, its concentration is usually low, unless the manure is agitated (Patni & Clarke, 1990). Schaefer *et al.* (1974) have reported that hydrogen sulphide in ventilation air has a concentration of about 4 μg m^{-3}. Hobbs *et al.* (1999) observed that the rate of hydrogen sulphide emission ratedecreased from 100 to 28 g m^{-2} d^{-1} during a 112-day study stored pig manure. They also reported that there was no correlation between hydrogen sulphide concentration and odour concentration. Clanton & Schmidt (2001), however, found that the Pearson correlation coefficient between odour concentration and hydrogen sulphide in the air from pig production facilities was 0.731; which is higher than that of 0.20 determined by Jacobson *et al.* (1997), also in air from pig production facilities.

Hydrogen sulphide and methanethiol (methylmercaptan) are the most commonly reported sulphurous compounds causing odour offensiveness in pig manure (Spoelstra, 1980). According to Bremmer (1975), hydrogen sulphide and methanethiol represented 70 to 97% of the total sulphur volatilised in manure. He also reported that for pigs and poultry, the amount of methanethiol produced exceeded the amount of hydrogen sulphide produced. Beard & Guenzi (1983) stated that most of the sulphur emanated in the form of hydrogen sulphide (39%), methanethiol (34%) and dimethyl sulphide (21%). According to Hobbs *et al.* (1997) the methanethiol concentration in the headspace air is about 36000 μg/m^{-3}. It is from 947 to 120 x10^{6} times higher than the detection threshold (Table 2). Therefore, methanethiol may be a very important compound causing odour nuisance.

Apart from hydrogen sulphide and methanethiol, the other sulphurous compounds identified in air from pig production facilities include carbon disulphide, 2-propanethiol, dimethyldisulphide, dimethyltrisulphide, 2-methylthiopropane, methaethiocyclopentane, 1-methylthiopentane, dimethyltetrasulphide and dimethylhexasulphide (Odam *et al.*, 1986).

The detection threshold, concentration and odour nature of some important sulphurous compounds are listed in Table 2; their chemical structures and their precursors are listed in Table 5. Like VFAs, they vary widely among studies and kinds of samples. In general, the concentrations of sulphurous compounds in the air are higher than the concentrations of VFAs. In addition, their detection thresholds are lower than VFAs. Furthermore, the nature of smell of sulphurous compounds seems to be more offensive. As a result, sulphurous compounds may cause much more odour nuisance than VFAs.

2.4 Phenoles and indoles

Phenol, p-cresol, 3-methyl phenol (m-cresol), and 4-ethylphenol are important representatives of phenolic compounds, whereas indole and skatole are indolic compounds. These two kinds of compounds are considered as the main compounds responsible for the smell in the ventilation air of pig houses (Schaefer, 1977; Williams & Evans, 1981; O'Neill & Phillips, 1992). The nature of the smell of indole and phenol compounds progresses from the aromatic smell of phenol to the

stench of indole and the nauseating smell of skatole. Schaefer *et al.* (1974) quoted by O'Neill & Phillips (1992) synthesised the smell of pig manure, in which phenolic compounds were represented in high concentrations (v/v): p-cresol (64%), phenol (26%). Other compounds e.g. n-butyric acid, skatole, and indole were present in lower concentrations. Williams and Evans (1981) reported an increase in concentrations of phenol, p-cresol and skatole, and a decrease in the concentration of indole during the accumulation of pig manure in a store. Spoelstra (1980) indicated that the phenol concentration increased during the 150-day measuring period, while indole, p-cresol and skatole concentrations increased initially but decreased after 40, 65 and 70 days, respectively.

Despite the great variation among studies, it can be seen from Table 2 that the concentration of p-cresol in headspace air ranges from 4600 to 7000 μg m^{-3}. This concentration is from 291 to 92000 times higher than its detection threshold. The concentration of p-cresol in ventilation air, wet slurry and stored manure is higher than that of other phenol and indole compounds listed in Table 2. In addition, it also has a lower odour detection threshold than the other compounds. Therefore, it seems safe to conclude that p-cresol is an important compound in terms of odour nuisance compared to other indole and phenol compounds. The next important compounds might be indole and skatole. Although phenol has a rather high concentration in headspace air (3700-4800 μg m^{-3}) it has a high detection threshold (22-4000 μg m^{-3}); in addition, the smell of phenol is aromatic, thus phenol may not cause more odour nuisance compared to other indole and phenol compounds.

Table 2 Nature of smell; odour detection threshold and concentration of important odorous compounds from pig production facilities

Groups	Odorous compounds	Nature of smell	Detection threshold (μg m^{-3})	Authors	Concentration (μgm^{-3})	Source	Authors
Volatile fatty acids Fatty acids	Acetic (Ethanoic) acid	Pungent/Vinegar	25-10000	2, 6-12, 15-17, 19, 21	0.0015-6700 1800-4700 1120-2690 2-15.7* 270	Ventilation air Headspace air Wet slurry Stored manure Air at 1.5 m above manure basin	7, 9, 12, 16 5 3 14 21
	Propanoic (propionic) acid	Faecal	2.5-890	2, 6-12, 15-17, 19, 21	0.002-1100 20-2500 148-400 1.2-6.6* 130	Ventilation air Headspace air Wet slurry Stored manure Air at 1.5 m above manure basin	7, 9, 12, 16 5 3 14 21
	Butanoic (butyric) acid	Faecal/Stench	0.25-42000	2, 6-12, 15-17, 19	0.001-617 1100-4000 250-350 0.4-3.1* 590	Ventilation air Headspace air Wet slurry Stored manure Air at 1.5 m above manure basin	7, 9, 12, 16 5 3 14 21

Groups	Odorous compounds	Nature of smell	Detection threshold (μg m^{-3})	Authors	Concentration (μgm^{-3})	Source	Authors
	3-Methyl butanoic acid	Faecal	0.017-6.9	8, 9, 12, 15-19, 20	0.0012-210 800-1100 50-200 0.2-1* 98	Ventilation air Headspace air Wet slurry Stored manure Air at 1.5 m above manure basin	7, 12, 16 5 3 14 20
	Pentanoic (n-valeric) acid	Faecal	0.26-120	8, 9, 12, 15-19	0.0012-80 200 70-90 0.1-1* 360	Ventilation air Headspace air Wet slurry Stored manure Air at 1.5 m above manure basin	7, 12, 16 5 3 14 20
	4-Methyl pentanoic acid	-	37	8, 12, 15, 19	0.001-160 0.2-1*	Ventilation air Stored manure	7, 9, 12, 16 14
	Hexanoic (n-caproic) acid	Pungent	20-520	8, 12, 15, 19, 20	10 110	Ventilation air Air at 1.5 m above manure basin	12 20
	Heptanoic (oenanthic) acid	Pungent	2.8-33	2, 8, 9, 12, 15, 20	3 8	Ventilation air Air at 1.5 m above manure basin	12 20
Ammonia and volatile amines	Ammonia	Sharp/Pungent	27-37800	6-9, 11, 12, 15, 17, 20	100-18000 3700	Ventilation air Air at 1.5 m above manure basin	6, 12 20
S-compounds	Hydrogen sulphide	Rotten eggs	0.1-270	1, 2, 7, 8, 10-12, 15, 20	4 90	Ventilation air Air at 1.5 m above manure basin	12 20
	Carbonyl sulphide	-	250	1, 15	-		
	Carbon disulphide	-	-		-		
	Methanethiol (Methyl mercaptan)	Garlic/Putrid	0.0003-38	1, 8, 11, 15	36000	Headspace air	5
	Dimethyl sulphide	Stench	0.3-160	1, 8, 11, 15	0.0022 14000	Ventilation air Headspace air	9 5
	Dimethyl disulfide	Putrid, decayed vegetable	1.1-610	1, 8, 9, 15, 20	12000 17	Headspace air Air at 1.5 m above manure basin	5 20
	Dimethyl trisulfide	Nauseating	7.3	8, 9, 15, 19	5000	Headspace air	5
	Ethanethiol (Ethyl mercaptan)	-	0.043-0.33	2, 11, 15	-		
Indoles and phenols	Phenol	Aromatic	22-4000	2, 6, 8-12, 17, 19, 20	0.0025 -5 3700-4800 16-47 0.007-0.055* 10-55 25	Ventilation air Headspace air Wet slurry Stored manure Stored manure Air at 1.5 m above manure basin	9, 12 5 3 14 4 20
	3-Methylphenol (m-cresol)	-	0.22-35	15	4	Ventilation air	7
	4-Methylphenol (p-cresol)	Faecal	0.05-24	2, 6, 8-12, 17, 19, 20	4600-7000 30-60 0.14-0.34* 10-55 90	Headspace air Wet slurry Stored manure Stored manure Air at 1.5 m above manure basin	5 3 14 4 20

Groups	Odorous compounds	Nature of smell	Detection threshold (μg m^{-3})	Authors	Concentration (μgm^{-3})	Source	Authors
	4-Ethylphenol	Pungent	3.5-10	21	500-4900	Headspace air	5
					0.3-6.4	Wet slurry	3
					0.006-0.072*	Stored manure	14
					4	Air at 1.5 m above manure basin	21
	Indole	Faecal/Stench	0.0.6-7.1	8, 11-13, 15, 17-20	3	Ventilation air	12
					100-500	Headspace air	5
					4-9.8	Wet slurry	3
					0-0.001*	Stored manure	14
					2	Air at 1.5 m above manure basin	21
	3-Methyl indole (skatole)	Faecal Nauseating	0.0.0005-6.4	8, 11-13, 15, 17-19, 21	3	Ventilation air	12
					100-400	Headspace air	5
					1.7-3.6	Wet slurry	3
					0.009-0.054*	Stored manure	14
					2	Air at 1.5 m above manure basin	21

*: g/kg wet weight

1: Banwart &Bremmer (1975)
2: Hammond *et al.* (1989)
3: Hobbs *et al.* (1996)
4: Hobbs *et al.* (1999)
5: Hobbs *et al.* (1997)
6: Klarenbeek *et al.* (1982)
7: Kowalewsky *et al.* (1980)
8: Lunn & van de Vyver (1977)
9: Miner *et al.* (1975)
10: Phillips *et al.* (1979)
11: Schaefer (1977)
12: Schaefer *et al.* (1974)
13: Spoelstra (1976)
14: Spoelstra (1979)
15: Spoelstra (1980)
16: van Geelen & van der Hoek (1985)
17: Williams (1984)
18: Williams & Evan (1981)
19: Yasuhara *et al.* (1984)
20: Zahn & DiSpirito (2001)
21: Zahn *et al.* (1997)

2.5 Ammonia and volatile amines

Ammonia has a sharp and pungent smell. The main source of ammonia is urea (Spoelstra, 1980). The ammonia concentration in air samples taken from animal houses, manure tanks and fields spread with manure has been found to correlate well with odour intensity ($r^2 = 0.72$) as measured by olfactometry (Kowalewsky *et al.*, 1980). Schulte (1985) and Miner (1995) found a high correlation between ammonia and odour emission from livestock facilities. However, Williams (1984), Oldenburg (1989), Liu *et al.* (1993) and Verdoes and Ogink (1997) found only a low correlation between ammonia and odour emission from pig houses. According to Oldenburg (1989), ammonia does not seem to be an important odorous compound. He also reported that mean ammonia concentrations were below 8 ppm in cattle barns, between 5 and 18 ppm in pig houses and between 5 and 30 ppm in poultry houses. Studies in the USA suggest that if ammonia levels exceed 7 ppm, workers may suffer clinical effects (Donham *et al.*, 1989). Wathes *et al.* (2002) reported that weaner pigs, broiler chickens and adult laying hens were significantly averse to ammonia at concentrations of 20 ppm and higher.

The volatile amines from animal production facilities may include methylamine (putrid smell), ethylamine (fishy smell), trimethylamine (ammoniac-like smell), cadaverine (foul smell), and putrescine (smell of putrefaction). Volatile amines take a very small part of the volatile

nitrogenous compounds. Concentrations of volatile amines from animal production facilities were rarely found in literature.

2.6 Concluding summary

A great number of odorous compounds have been identified in animal production facilities. However, the contribution of the different sources (e.g. animals, feed faeces, urine, and manure) to the formation of odorous compounds is not yet well determined. In order to be able to propose solutions for odour abatement, it is important to clearly identify the different sources of odorous compounds. Sulphurous compounds, indoles and phenols, and VFAs are important groups of odorous compounds from animal production facilities. The concentration, odour detection threshold, and the nature of the smell of specific compounds largely responsible for odour nuisance were mentioned in Table 2. Some authors have reported that compounds other than those in Table 2 (such as 2-butanol) are also important for odour nuisance. However, according to Zahn *et al.* (2001) the concentration in manure of 2-butanol (19 μgm^{-3}) was below the odour detection threshold value (110 μgm^{-3}). In addition, Van Gemert & Nettenbreijer (1977) reported that the odour detection threshold value of 2-butanol was 400 μgm^{-3}. According to Devos *et al.* (1990) the odour detection threshold value of 2-butanol was as high as 5025 μgm^{-3}. As these values are much higher than the measured air odour concentration of 2-butanol (Zahn *et al.*, 2001), it seems safe to conclude that 2-butanol is not an important compound causing odour nuisance from pig production facilities.

The huge variation among studies in the odour concentration and odour detection threshold of odour compounds (see Table 2) might be attributable to the fact that the determined odour concentration is related to many factors (e.g. dietary composition, environmental factors, measuring methods and standards, sources of sample). In addition, the relative importance of different compounds causing odour nuisance has seldom been described. In order to propose feasible and efficient solutions for odour reduction it is important to accurately identify the concentration, detection threshold and main source of each odorous compound, and the relative importance of different odorous compounds from animal production facilities. This requires further studies.

3 Production of odorous compounds from pig production facilities

When feed passes through the digestive tract, food nutrients are hydrolysed and fermented into smaller molecular structures that can be adsorbed and used for the growth and development of the animal. The non-utilised nutrients and endogenous compounds in the gastrointestinal tract are excreted via urine and faeces. The biological degradation process performed by micro-organisms, that starts in the intestine under anaerobic conditions, continues after excretion. This anaerobic microbial degradation process can be sketched as in Fig. 1. Different groups of odorous compounds are produced during anaerobic degradation. Most groups are produced from different precursors in different ways, which interact with the production of others.

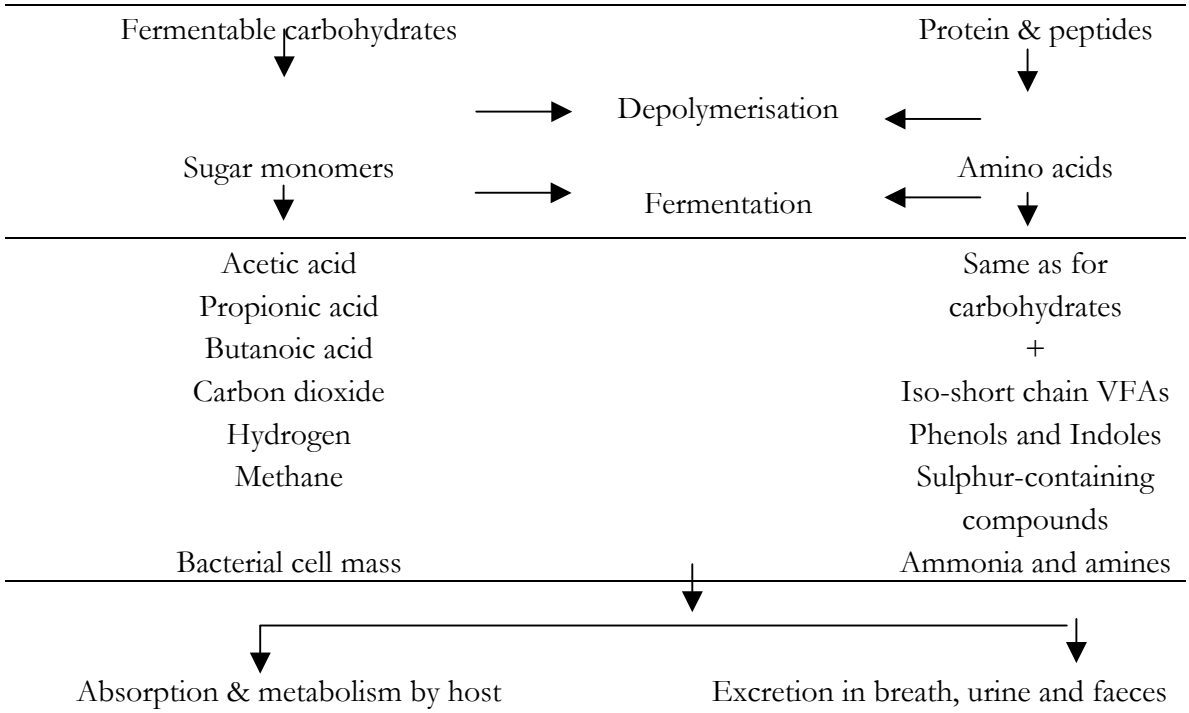


Figure 1 Major fermentation products formed by the micro-biota in the gastrointestinal tract of pigs (adapted from Jensen & Jørgensen (1994))

3.1 Volatile fatty acids

Volatile fatty acids are mainly formed by microbial conversions of plant fibre and protein residues in the large intestine and in manure under anaerobic conditions. During fermentation, energy is obtained from organic compounds that serve as electron donor and acceptor, replacing oxygen in the latter function.

Dietary fibre residues may include cellulose, hemicellulose and lignin. Lignin is very difficult to degrade under anaerobic conditions. Cellulose and hemicellulose are first hydrolysed by microbial

enzymes into oligomers and/or monomers. The latter are subsequently converted by the microbes into VFAs such as acetic, propanoic and butanoic acids. The proportion of acids produced can vary, depending on the type of substrate available, the composition of the anaerobic flora and the prevailing pH. Van Soest (1983) described different pathways of carbohydrate metabolism in general and of dietary fibre in particular in the rumen of cattle (Fig. 2.). The same pathways of carbohydrate metabolism are assumed in the large intestine of mono-gastric animals, although the amount and ratio of end products may differ.

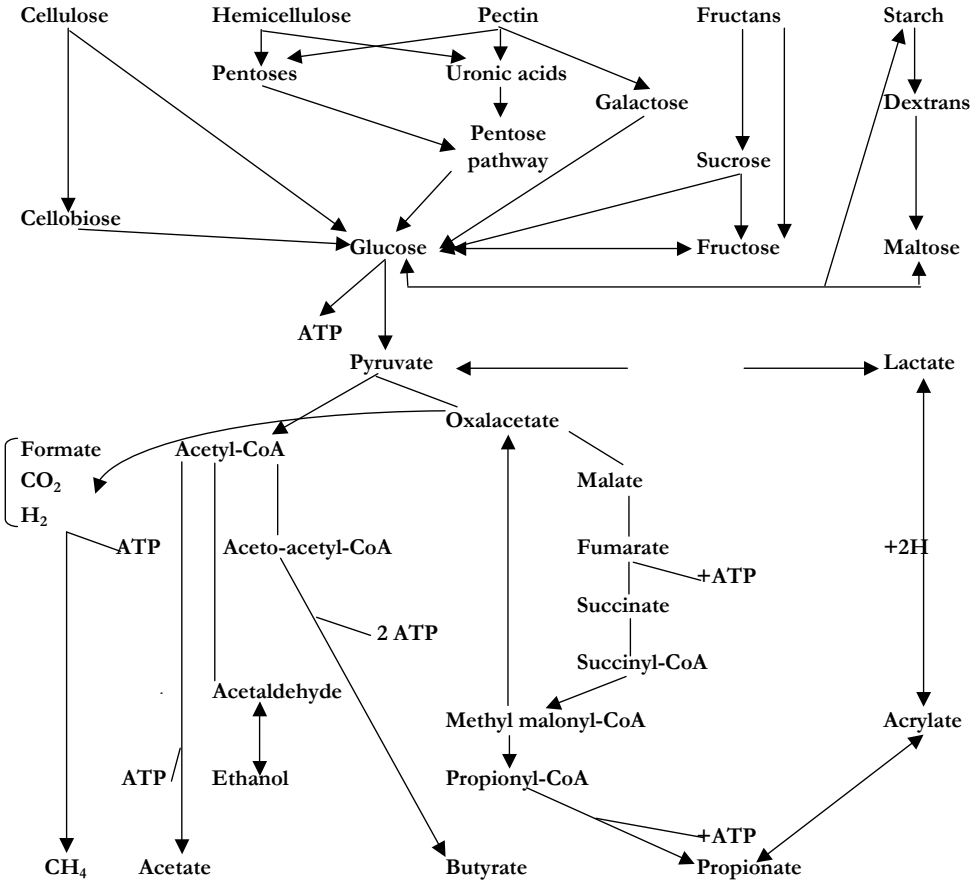


Figure 2 Pathways of carbohydrate metabolism in the rumen (Van Soest, 1983)

Apart from being formed from carbohydrates, acetic, propanoic and butanoic acids are also produced by deamination of amino acids such as L-glutamate, L-lysin, L-alanine. (Tables 3 and 5). Ammonia, CO_2 and [H] are additional end-products of this deamination-decarboxylation. The general mechanism of a deamination-decarboxylation is presented in equation 1.

$$R\text{-}\underset{\displaystyle NH_2}{\underset{|}{CH}}\text{-}COOH + 2H_2O \rightarrow R\text{-}COOH + NH_3 + 4[H] + CO_2 \qquad (1)$$

Table 3 Deamination reactions by anaerobic bacteria in the gastrointestinal tract and animal manure

Amino acid	Corresponding VFA produced
Alanine, glycine, serine	Acetic acid
Threonine	Propanoic acid
Glutamate, aspartate	Acetate, propanoic acid
Valine	*Iso*-Butanoic acid
Leucine	*Iso*-Pentanoic acid
Iso-leucine	2-Methylbutanoic acid
Phenylalanine	Phenylacetic acid
Tyrosine	*p*-Hydroxylphenylacetic acid
Tryptophan	Indoleacetic acid→skatole
Tyrosine	Phenylacetic acid, phenylpropanoic acid

Source: Adapted from Mackie *et al.*(1998)

According to Mortensen *et al.* (1987) and Rasmussen *et al.* (1988), carbohydrates are easily converted into acetic acid, propanoic acid, and butanoic acid in faecal incubation systems, but this has never resulted in the production of branched-chain VFAs such as *iso*-valeric acid, *iso*-butanoic acid. The latter VFAs originate from the breakdown of peptides. Peptolytic bacteria hydrolyse proteins into amino acids. The latter are then deaminated and decarboxylated to branched-chain VFAs. Examples are given in equations (2), (3) and (4).

$$\text{Valine} + 2H_2O \rightarrow \textit{Iso}\text{-butanoic acid} + NH_3 + CO_2 \quad (2)$$

$$\text{Leucine} + 2H_2O \rightarrow \textit{Iso}\text{-valeric acid} + NH_3 + CO_2 \quad (3)$$

$$\textit{Iso}\text{-leucine} + 2H_2O \rightarrow \text{2-methylbutanoic acid} + NH_3 + CO_2 \quad (4)$$

In the gastrointestinal tract of pigs, micro-organisms can synthesise short-chain VFAs (fatty acids with chain lengths of two to six carbon atoms) from unabsorbed nutrients (Giusi-Perier *et al.*, 1989). According to Müller & Kirchgessner (1985) and Engehard (1995), 66 to 99% of the short-chain VFAs produced in the large intestine can be absorbed and used as an energy source for the host animal. In addition, short-chain VFAs have a high odour detection threshold. Therefore, short-chain VFAs produced in the large intestine of animals are probably not a major concern in terms of odour nuisance.

Briefly, VFAs are produced from proteins and carbohydrates under anaerobic conditions in the large intestine of animals and in manure storage. Carbohydrates are transformed to straight-chain VFAs only. Proteins are transformed to both straight-chain VFAs and branched-chain VFAs. Short-chain VFAs in the large intestine can be used as an energy source for the host animal and thus are probably not a big problem in terms of odour nuisance. However, when they are in manure storages, VFAs may be volatilised and cause malodour.

3.2 Sulphur-containing compounds

There are two main ways of sulphide production: sulphate reduction and the metabolism of sulphurous amino acids.

(1) When manure is stored anaerobically, organic sulphurous compounds such as the amino acids methionine, cysteine and cystine are broken down to release sulphidic compounds. Various anaerobic bacteria perform this process, in which sulphurous amino acids are used as carbon and energy sources by the microbes. Some intermediates are produced that can volatilise and create odour. An example is the hydrolisation of methionine, from which methanethiol (methyl mercaptan) is formed, which can be further degraded to sulphide (ASAE., 1989), equations (5) and (6).

$$CH_3S(CH_2)_2CHNH_2COOH + H_2O \rightarrow CH_3SH \text{ (methanethiol)} + NH_3 + CH_3CH_2COCOOH \quad (5)$$

$$CH_3SH + H_2O \rightarrow CH_3OH + H_2S \quad (6)$$

Methanethiol as a product of L-methionine degradation can be chemically converted to dimethyl disulphide and dimethyl trisulphide in the presence of Cu(II) or ascorbate plus Fe(III), for example (Parliment *et al.*, 1982; Chin & Lindsay, 1994; Bonnarme *et al.*, 2001a).

(2) The other main source of sulphide formation is sulphate. In urine, sulphate is the primary form of sulphur excreted. Spoelstra (1980) stated that the primary origin of sulphide in manure is the reduction of sulphate into sulphide. Sulphate reduction proceeds via assimilatory or dissimilatory pathways. In the assimilatory process, bacteria produce enough reduced sulphur for the biosynthesis of cysteine and methionine. This is in contrast to the dissimilatory process, in which sulphate is used as electron acceptor for an anaerobic respiration comparable to the aerobic respiration with oxygen. During respiration with sulphate, copious amounts of malodour are generated. This process has been characterised by Clanton and Schmidt (2001) and Sawyer and McCarty (1978): equation (7). The bacteria that are sulphate-reducers belong to the genera *Desulfovibrio*, *Desulfotomaculum*, *Desulfobacter*, *Desulfococcus*, and *Desulfonema* (Schlegel, 1986).

$$SO_4^{2-} + \text{organic matter} \xrightarrow[\text{bacteria}]{\text{anaerobic}} S^{2-} + H_2O + CO_2 \quad (7)$$

Hydrogen sulphide might be transformed to carbonyl sulphide and carbon disulphide (Ren, 1999), although the respective reactions have not been described for gut bacteria.

$$H_2S + CO_2 \rightarrow COS + H_2O \quad (8)$$

$$COS + H_2S \rightarrow CS_2 + H_2O \quad (9)$$

According to Spoelstra (1980), sulphate-reducing bacteria also produce trace amounts of COS, CS_2, and methyl, ethyl and propyl mercaptans.

Briefly, sulphurous compounds are produced under anaerobic conditions from two main sources: sulphate in the urine and proteins or amino acids containing sulphur in manure. Various bacteria are involved in the production process.

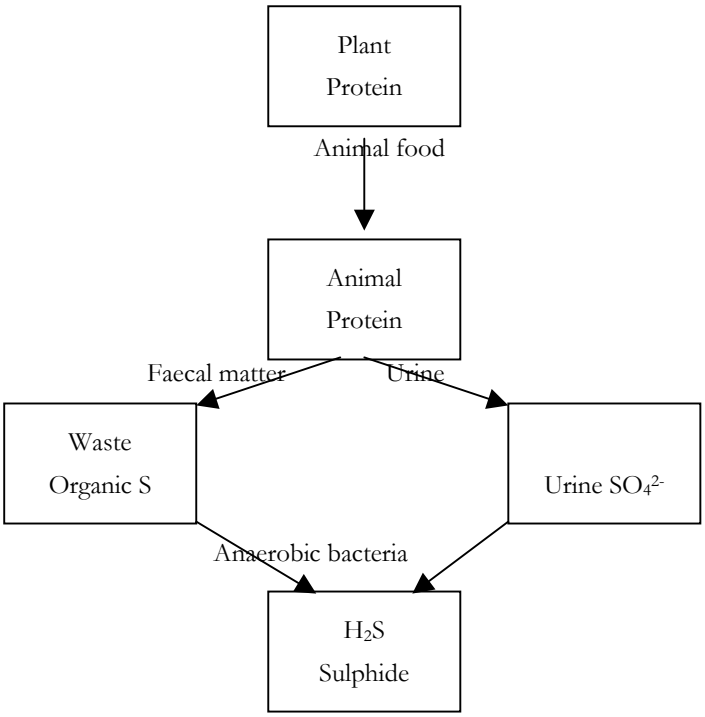


Figure 3 Sulphide formation in manure storage

3.3 Indoles and phenols

Phenolic compounds e.g. phenol itself, p-cresol and 4-ethylphenol originate from the microbial degradation of L-tyrosine in the intestinal tract of animals and in manure storage (Fig. 4).
L-tyrosine can be deaminated to 4-hydroxy-phenylpropanoic acid, which is either decarboxylated to 4-ethylphenol, or oxidised to 4-hydroxyphenylacetic acid. 4-Hydroxyphenylacetic acid is then either decarboxylated to p-cresol or further oxidised to 4-hydroxybenzoic acid. The latter is decarboxylated to phenol (Drasar & Hill, 1974). L-Tyrosine can also be split directly to release ammonia, phenol, and pyruvic acid by *Clostridium tetanomorphum* (Brot *et al.*, 1965) and *E. coli* ("*B. coli* phenologenes"; (Ichihara *et al.*, 1956).

Hammond *et al.* (1989) observed that p-cresol was formed from L-tyrosine and L-tryptophan when bacteria from pig manure were incubated with these amino acids in a synthetic medium. Hengemuehle and Yokoyama (1990) isolated an anaerobic Gram-positive bacterium from the caecal contents of weaning pigs, which produced p-cresol by decarboxylation of 4-hydroxyphenylacetic acid as described in Fig. 4.

Drasar and Hill *et al.* (1974) reported that 3-methylphenol (m-cresol) is one of the metabolites of the degradation of 3,4-dihydroxyphenylalanine (DOPA). DOPA is the precursor of neurotransmitters such as dopamine, norepinephrine, and epinephrine; it is produced by oxidation of L-tyrosine by the O_2-dependent enzyme monophenol monooxygenase (Dorland,

2003). DOPA is an amino acid, but is not in the group of 20 amino acids that are the building blocks of protein. Because only very small amounts of DOPA are expected to be available to intestinal bacteria, the reaction mentioned above cannot generate much 3-methylcresol.

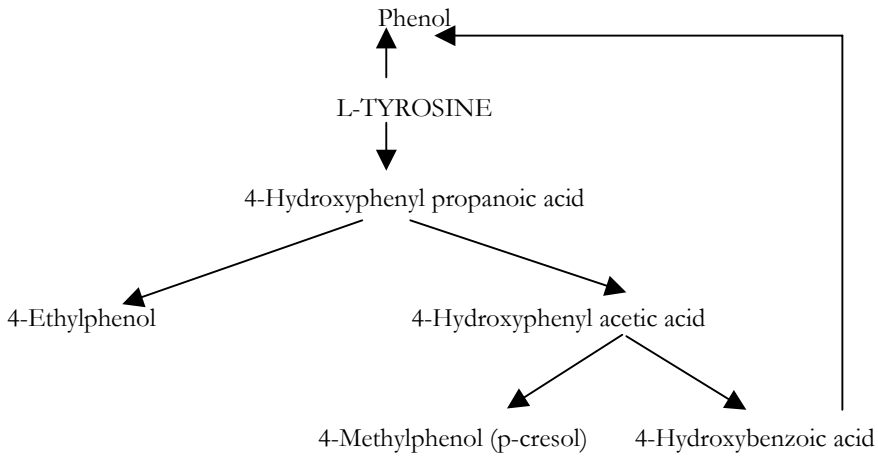


Figure 4 Breakdown of L-tyrosine in anaerobically stored manure

Phenolic compounds are absorbed in the large intestine by the host animal and detoxicated in the liver by conjugation with glucuronic acid, resulting in glucuronides, or sulphuric acid, resulting in sulphates (Smith & Williams, 1966). However, the sulphate conjugation is of minor importance in pigs (Capel *et al.*, 1974). In manure, urinary glucuronides are hydrolysed by faecal β-glucuronidase to release phenolic compounds, again as given in Fig. 4.

Indole production is shown in Fig. 5. Indole and skatole are produced in the large intestine of animals and in manure by microbial fermentation of L-tryptophan. Indoles are partly absorbed and detoxicated by the liver to glucuronides, e.g. 3-hydroxyindole, hydroxyskatoles and indole-3-carboxylic acid. Then, indolic detoxication products are excreted via the urine. The unabsorbed part of indole and skatole is excreted via faeces. Therefore, indole and skatole can be found in fresh faeces. Faeces contain a high level of β- glucuronidase of bacterial origin. This enzyme hydrolyses glucuronides. Therefore, it is expected that mixing faeces with urine causes the amounts of free indolic compounds to rise.

The ability to form indole from tryptophan is a taxonomic feature to distinguish between different enterobacteria. The following bacteria are able to form indole from tryptophane: *E. coli* and *Proteus* (except *Proteus mirabilis*), some *Shigella*, *Aeromonas liquefaciens*, some *Fusobacterium* species, *Bacteroides melaninogenicus,* some *Bacteroides fragilis* subspecies, *Bacteroides coagulans*, *Paracolobactrum coliforme*, *Photobacterium harveyi*, *Bacillus alvei*, some clostridia, *Propionibacterium acnes*, and *Micrococcus aerogenes* .

Tryptophan is converted to indole-3-acetic acid by *E. coli*, *Citrobacter* sp., *Bacteroides fragilis* subsp. *thetaiotamicron*, and *Clostridium* (Chung *et al.*, 1975; Elsden *et al.*, 1976). This conversion occurs by transamination of tryptophan to indolepyruvic acid and subsequent decarboxylation (Chung *et al.*, 1975). *Lactobacillus* strain 11201 and three unidentified isolates from the pig intestine have been shown to be able to degrade indole-3-acetic acid to skatole (Yokoyama & Carlson, 1974; Yokoyama *et al.*, 1977; Hengemuehle & Yokoyama, 1990; Honeyfield & Carlson, 1990). *Clostridium scatologenes* DSM 757 is capable of generating skatole directly from L-tryptophan (Mikkelsen & Jensen, 1996).

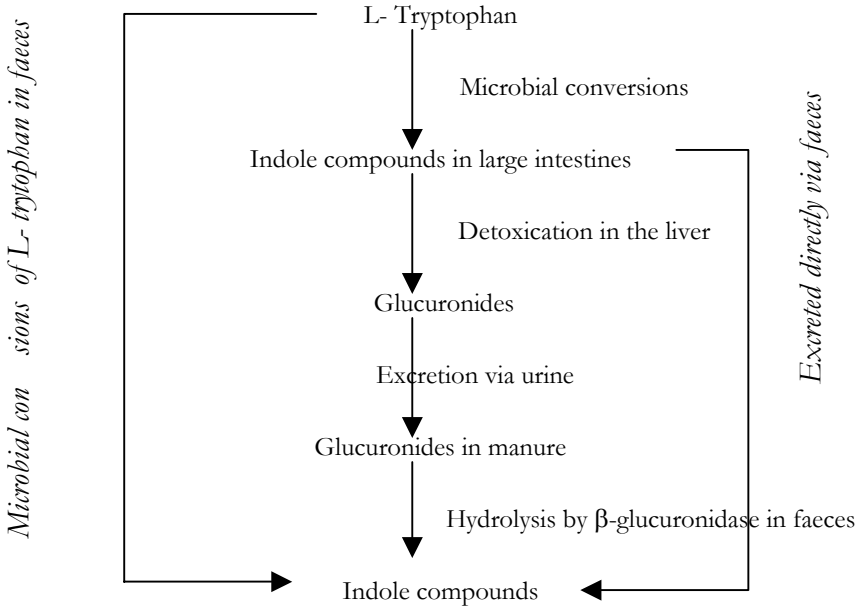


Figure 5 The production of indole compounds from L- trytophan

From in vitro experiments, Mogens *et al.* (1995) found that the production of indole and skatole is a pH-dependent process: the highest rate of production was observed between pH 6.0 and 7.0, and less than half of the maximum activity was observed at pH 5.0 or 8.0. The pH had dramatic effects on the relative production of indole and skatole from tryptophan. High pH values favoured the production of indole, while low pH values favoured the production of skatole.

Briefly, phenol and p-cresol are produced from L-tyrosine; indole and skatole are produced from L-tryptophan. There are three sources of indole and phenol compounds in manure:

(1) Degradation of the AA L-tryptophan and L-tyrosin in manure;
(2) Direct excretion from the large intestine of animals via faeces after being formed from Tryptophan and Tyrosine;
(3) Released from glucuronides in urine when placed in contact via faeces.

3.4 Ammonia and volatile amines

Ammonia and volatile amines are the main nitrogenous compounds produced during manure storage. When proteins and amino acids are used as an energy source, their deamination releases ammonia. In manure, Lehninger (1975) cited by Hobbs *et al.* (1999), found an enzymatic gateway used by bacteria to convert amino acids to L-glutamate and then oxidatively deaminate them into ammonia and the respective fatty acids or residual structures. However, the main source of ammonia is urea (Spoelstra, 1980; Aarnink *et al.*, 1993). Ammonia present in manure largely arises from the breakdown of urea. Urea is formed in the liver as the end-product of the protein-destroying metabolism of the pig and is excreted by the kidneys. Urea is quickly hydrolysed by urease present in faeces and fouled floors and converted into ammonium ions. Urease activity is ubiquitous among intestinal bacteria; it has been observed in strains of many species such as *Bacteroides multiacidus*, *Bacteroides ruminicola*, *Bifidobacterium bifidum*, etc. (Varel *et al.*, 1974; Wozny *et al.*, 1977; Suzuki *et al.*, 1979). Some of the ammonium ions will dissociate to form free ammonia. Ammonia emission into the air is a slow process, controlled by factors such as ammonia concentration, pH and temperature (Aarnink, 1997).

$$CO(NH_2)_2 + 2H_2O \xrightarrow{urease} 2NH_4^+ + 2OH^- + CO_2 \Leftrightarrow 2NH_3\uparrow + 2H_2O + CO_2 \qquad (10)$$

In manure, ammonia is in equilibrium with ammonium. The rate of ammonia emission depends on this equilibrium. The pH is one of the most important factors influencing ammonia emission. Ammonia volatilisation increases with increasing manure pH (Stevens *et al.*, 1989; Sommer & Husted, 1995; Aarnink, 1997). At a solution pH of 9.24, ammonia occurs equally in the form of NH_4^+ and NH_3(aq). Below a pH of 7, ammonia is almost exclusively present as NH_4^+, thereby reducing volatilisation as ammonia gas.

Under anaerobic conditions, volatile amines are often produced from protein-containing products. There are three possible mechanisms of microbial formation of volatile amines.

(1) Under certain conditions in the gastrointestinal tract and most likely during storage of fresh manure, amino acids undergo decarboxylation (Table 4). This mechanism was proposed by Bast *et al.* (1971), cited by Spoelstra (1980). Bacterial genera with decarboxylase activity include *Bacteroides, Bifidobacterium, Selenomonas, Streptococcus* and the enterobacteria.

(2) Bast (1971) cited by Spoelstra (1980) obtained experimental indication that the formation of hexylamine and ethylamine by *Sarcina* lutea, hexylamine by *Escherichia coli,* and *iso*-butylamine by *Aerobacter aerogenes* came about by amination of the corresponding aldehydes.

(3) Another source of amines in manure is urine. For example, the daily excretion of dimethylamine is estimated at 20 mg in humans, of which around 50% originates from choline by

the activity of gut flora Choline is degraded to either ethylamine plus ethanolamine or to trimethylamine which is easily demethylated (Drasar and Hill, 1974).

Briefly, ammonia is produced from deamination of amino acids when they are used as energy sources by bacteria, and by hydrolysation of urea in urine when it comes into contact with urease. Urea is the main source of ammonia from animal production facilities. Volatile amines are produced from amino acids by decarboxylation. In addition, they can be produced by amination of aldehydes and by demethylation of choline.

Table 4 Decarboxylation reactions by anaerobic bacteria in the gastrointestinal tract and manure

Amino acid	Corresponding amine produced
Glycine	Methylamine
Alanine	Ethylamine
α-Aminobutyrate	Propylamine
Orithine	Putrescine → pyrolidine
Arginine	Putrescine → pyrolidine
Norvaline	Butylamine
Lysine	Cadaverine→ pyrolidine
Histidine	Histamine
Tyrosine	Tyramine
Tryptophan	Tryptamine
Phenyl amine	Phenyl ethylamine

Source: Mackie *et al.*(1998)

3.5 Relationships among end products of bacterial fermentation in manure storage

There are interactive relationships between production and emission of different odorous compounds in manure storage. Hobbs *et al.* (1999) reported that there was a negative correlation between carbon dioxide and ammonia and positive correlations between carbon dioxide and phenol, p-cresol and hydrogen sulphide over a 112-day storage period. The methane emission rate correlated positively with the ammonia emission rate and negatively with the hydrogen sulphide emission rate. Skatole and indole production had a negative correlation with each other, because both have the same precursor, the amino acid tryptophane. An increasing methane production will reduce VFAs' concentration and vice versa: VFAs are converted into suitable substrates for methanogenesis such as hydrogen, carbon dioxide and acetic acid, and then methanogenic bacteria will convert these substrates to methane. Roustan *et al.* (1980) reported that phenolic compounds only began to be degraded after the disappearance of VFAs.

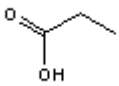
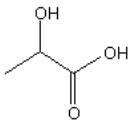
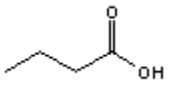
Under anaerobic conditions, there are three important microbially driven processes, i.e. acidogenesis, acetogenesis and methanogenesis. The acidogenesis is the process of producing acids, which cause malodour. Although some acetate and H_2 are directly produced by acidogenic fermentation, both products are primarily derived from acetogenesis and dehydrogenation of higher volatile fatty acids. Methanogenesis is the process of consuming acetic acid, carbon

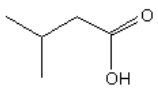
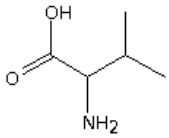
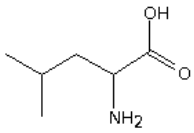
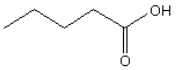
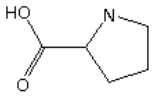
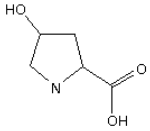
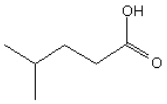
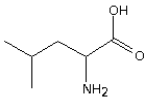
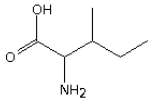
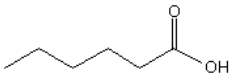
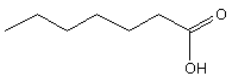
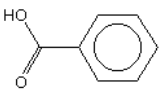
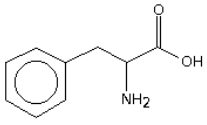
dioxide and H_2 to produce methane . Methane does not cause odour nuisance, however, it contributes significantly to the greenhouse effect. The key to preventing odour production without increasing methane emission is to maintain the balance between the two processes. Otherwise, either bad odour or greenhouse gas might be produced to an unacceptable level.

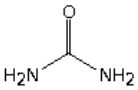
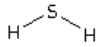
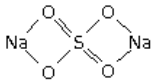
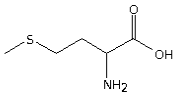
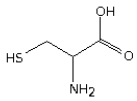
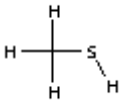
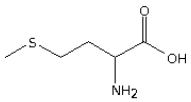
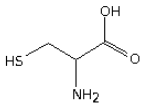
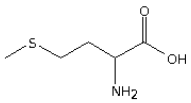
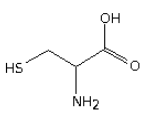
3.6 Concluding summary

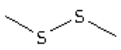
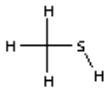
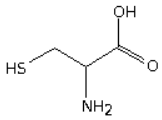
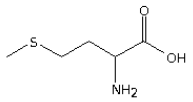
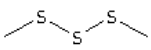
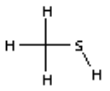
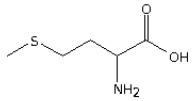
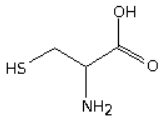
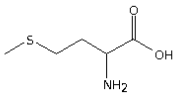
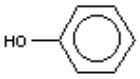
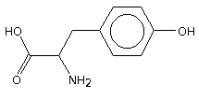
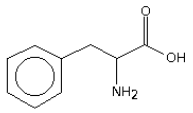
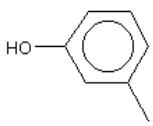
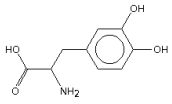
Microbial activities are responsible for odour generation in the large intestine of the animal and in manure storage. Odorous compounds are the intermediate or end products of microbial conversions under anaerobic conditions. The precursors of odorous compounds are non-utilised nutrients from the diet. Proteins and fermentable carbohydrates are the most important precursors of odorous compounds. Table 5 summarises different odorous compounds and their precursors. The odorous compounds included in this table are thought to mainly cause odour nuisance from pig production facilities.

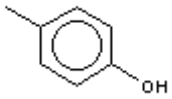
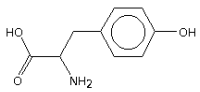
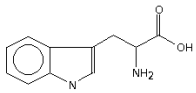
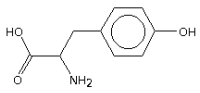
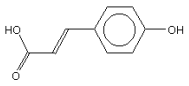
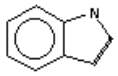
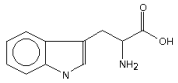
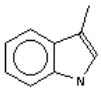
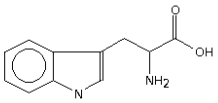
Table 5 Origin of odorous compounds

Groups	Odorous compounds/chemical structure	Main origin	Authors
Volatile fatty acids	Acetic (ethanoic) acid 	Dietary fibre, L-glycine, L-alanine, L-cysteine, L-lysine, L-serine, L-threonine, L-hydroxyproline, L-aspartate, L-glutamate, L-histidine	(Nisman, 1954; Stadtman, 1963; Loesche & Gibbons, 1968; Elsden & Hilton, 1978; Turton *et al.*, 1983; Mortensen *et al.*, 1987; Rasmussen *et al.*, 1988; Stryer, 1995; Sutton *et al.*, 1999)
	Propanoic (propionic) acid 	Dietary fibre, Lactate  L-Alanine, L-threonine, L-alanine + L-threonine, L-aspartate, L-methionine	(Nisman, 1954; Loesche & Gibbons, 1968; Elsden & Hilton, 1978; Schlegel, 1986; Rasmussen *et al.*, 1988; Sutton *et al.*, 1999)
	Butanoic (butyric) acid 	Dietary fibre, L-cysteine, L-hydroxyproline, L-lysine, L-serine, L-threonine, L-aspartate, L-glutamate, L-histidine	(Loesche & Gibbons, 1968; Elsden & Hilton, 1978; Turton *et al.*, 1983; Mortensen *et al.*, 1987; Rasmussen *et al.*, 1988; Hammond *et al.*, 1989; Sutton *et al.*, 1999)

Groups	Odorous compounds/chemical structure	Main origin	Authors
	3-Methyl butanoic acid 	Fibre L-Valine  L-Leucine 	(Elsden & Hilton, 1978; Britz & Wilkinson, 1983; Rasmussen *et al.*, 1988; Sutton *et al.*, 1999)
	Pentanoic (valeric) acid 	Fibre L-Proline  L-Hydroxyproline 	(Rasmussen *et al.*, 1988; Sutton *et al.*, 1999)
	4-Methyl pentanoic acid 	L-Leucine  L-Isoleucine 	(Nisman, 1954; Elsden & Hilton, 1978; Rasmussen *et al.*, 1988)
	Hexanoic (caproic) acid 	Ethanol, acetate, CO_2	(Smith *et al.*, 1985; Kenealy *et al.*, 1995)
	Heptanoic (enanthic) acid 	Benzoic acid  L-Phenylalanine 	(Bisaillon *et al.*, 1994; Schneider *et al.*, 1997; Gummalla & Broadbent, 2001)

Groups	Odorous compounds/chemical structure	Main origin	Authors
Ammonia and volatile amines	Ammonia 	Urea 	(Wozny *et al.*, 1977; Suzuki *et al.*, 1979; Aarnink *et al.*, 1996; Canh *et al.*, 1998)
		Deamination of amino acids	
S-compounds	Hydrogen sulphide 	Sulphate 	(Ohkishi *et al.*, 1981; Schlegel, 1986; Claesson *et al.*, 1990; Sutton *et al.*, 1999)
		L-Methionine 	
		L-Cysteine 	
	Carbonyl sulphide 	Hydrogen sulphide 	(Ren, 1999)
	Carbon disulphide	Carbonyl sulphide 	(Banwart & Bremmer, 1975; Ren, 1999)
	Methanethiol (methyl mercaptan) 	L-Methionine 	(Segal & Starkey, 1969; Kreis & Hession, 1973; Ferchichi *et al.*, 1985; Inoue *et al.*, 1995; Hori *et al.*, 1996; Mackie *et al.*, 1998) (Sutton *et al.*, 1999; Yoshimura *et al.*, 2000)
		L-Cysteine 	
	Dimethyl sulphide 	L-Methionine 	(Kadota & Ishida, 1972; Kelly *et al.*, 1994; Sutton *et al.*, 1999)
		L-Cysteine 	

Groups	Odorous compounds/chemical structure	Main origin	Authors
Indoles and phenols	Dimethyl disulfide 	Methanethiol  L-Cysteine  L-Methionine 	(Segal & Starkey, 1969; Chin & Lindsay, 1994; Sutton *et al.*, 1999; Bonnarme *et al.*, 2001b)
	Dimethyl trisulfide 	Methanethiol  L-Methionine  L-Cysteine 	(Segal & Starkey, 1969; Chin & Lindsay, 1994; Bonnarme *et al.*, 2001b)
	Ethanethiol (Ethyl mercaptan) 	L-Methionine 	(Akobe, 1936)
	Phenol 	L-Tyrosine  L-Phenylalanine 	(Ichihara *et al.*, 1956; Brot *et al.*, 1965; Bakke, 1969; Hammond *et al.*, 1989; Sutton *et al.*, 1999)
	3-Methylphenol (m-cresol) 	DOPA 	(Drasar & Hill, 1974)

Groups	Odorous compounds/chemical structure	Main origin	Authors
	4-Methylphenol (p-cresol) 	L-Tyrosine  L-Tryptophan 	(Bakke, 1969; Hammond *et al.*, 1989; Hengemuehle & Yokoyama, 1990; Sutton *et al.*, 1999)
	4-Ethylphenol 	L-Tyrosine  p-Coumaric acid 	(Drasar & Hill, 1974; Spoelstra, 1976; Hammond *et al.*, 1989; Hengemuehle & Yokoyama, 1990)
	Indole 	L-Tryptophan 	(DeMoss R & Moser, 1969; Drasar & Hill, 1974; Elsden *et al.*, 1976; Hammond *et al.*, 1989; Sutton *et al.*, 1999)
	3-Methyl indole (skatole) 	L-Tryptophan 	(Drasar & Hill, 1974; Yokoyama & Carlson, 1974; Chung *et al.*, 1975; Elsden *et al.*, 1976; Hammond *et al.*, 1989; Hengemuehle & Yokoyama, 1990; Honeyfield & Carlson, 1990; Jensen & Jørgensen, 1994; Sutton *et al.*, 1999)

4 Measurements of odour

Odour is the property of a chemical compound or mixture of compounds which, above a certain concentration activate the sense of smell and thus initiate an odour sensation (Winneke, 1994). A substance can create an odour impression if it meets certain preconditions e.g. volatility, water solubility, fat solubility and polarity (Jager & Kuchta, 1993).
Odour can be characterised in three different ways:

- By sensory evaluation;
- By chemical evaluation;
- By electronic sensor evaluation.

The sensory perception of odour can be characterised by three major parameters:

- Concentration;
- Intensity;
- Hedonic tone.

4.1 Olfactometry

The three sensory parameters of odour mentioned above are measured by olfactometry. Olfactometry is based on the use of human panels and an olfactometer, which is in essence a dilution device. The principle of the olfactometry is to establish an odour's characteristics in relation to its concentration, intensity and hedonic value.

There are two basic types of olfactometer: static and dynamic. The static olfactometer presents a set volume of diluted sample to the panellist for assessment. The dynamic olfactometer is an apparatus that mixes odorous air from the sample bag with a stream of odour free air. Because the apparatus produces a continuous stream of different air dilution it is called a dynamic olfactometer. As a result, in dynamic olfactometry a series of known dilutions of the odour sample is offered to a human panel.

Depending on the standard of odour measurement, the minimum numbers of persons on a panel may vary from 4 to 16. For example, the European standard requires at least 4 persons. Each individual of the panel is pre-selected on the basis of ability to detect odorants of known odour threshold such as hydrogen sulphide or n-butanol (C_4H_9OH). The objective of pre-selection of panel members is to reduce the variability in odour perception between panel members. Individuals who exhibit abnormal responses should be excluded.

Olfactometry is considered to be a standard method for measuring odour concentrations in odour units, because dynamic olfactometry has the best potential for high accuracy and repeatability. The accuracy and repeatability of the measurements are improved by selecting panel members with similar odour sensitivity based on a standard odorous gas, e.g. n-butanol.

4.2 Odour concentration

Odour concentration measured by olfactometry is expressed as odour units (OU) or odour units per cubic metre (OUm^{-3}). One odour unit is defined as the amount of odour-causing gases which, when diluted in 1 m^3 of air, can just be distinguished from clean air by 50% of the members of an odour panel. The definition of odour unit is rather complex, because it tries to quantify a physiological response to an odorous gas in which different components may be present.

Odour concentration is the most commonly used parameter for signifying the strength of odour. As the sense of smell is complex, it is not surprising that measuring odour is a complicated process and individual responses to odour vary greatly. Therefore, standards must be followed to ensure accuracy and consistency. In Europe, odour measurements have been made for more than 20 years based on various methods, different panel selections, a variety of olfactometers and different reference substances. Recently a working group from The European Standardization Organization (CEN) completed a new standard method EN 13725 to measure odour concentration by olfactometry (CEN, 2003).

The European odour unit (ou_E) is that amount of odorant(s) which, when evaporated into one cubic metre of neutral gas at standard conditions, elicits a physiological response from a panel equivalent to that elicited by one European Reference Odour Mass (EROM), evaporated in one cubic metre of neutral gas at standard conditions (CEN, 2003).

According to European standard (CEN, 2003 page 17), *one EROM, evaporated into one cubic metre of neutral gas at standard conditions, is the mass of substance that will elicit the D_{50} physiology response (detection threshold), assessed by an odour human panel in conformity with this standard, and has, by definition, a concentration of 1 $ou_E m^{-3}$. There is one relationship between ou_E for the reference odorant and that for any mixture of odorants. This relationship is defined only at the D_{50} physiological response level, where: 1 EROM ≡ 123 μg n-butanol (CAS-Nr. 71-36-3) ≡ 1 ou_E for the mixture of the odorants. This linkage is the basis of tractability of odour units for any mixture of odorants to that of the reference odorant. It effectively expresses odour concentration in terms of n-butanol mass equivalent.*

The odour concentration is expressed as a multiple of one $ou_E m^{-3}$ of neutral gas. The odour concentration can only be assessed at a presented concentration of 1 $ou_E m^{-3}$. The odour concentration, in $OU_E m^{-3}$, can be used in the same manner as mass concentration (kg m^{-3}).

Odour measurement in compliance with the European standard is described by CEN (2003). The mixed odorous air and the odour-free air are randomly assigned to the two air tubes. The panellist has to choose from which tube the odorous air is flowing, and has to indicate his or her certainty (certain, fairly sure, doubtful). In general, the first mixture has a very large volume of the diluent (odourless gas). As a result, the human panel cannot detect odour. In subsequent presentations, the volume of the diluent is reduced by a predetermined factor. The series is ended

at the dilution step at which all panel members have with certainty pointed out the correct tube in which the mixture of odorous air is flowing. Odour concentration can be calculated based on the volume of diluent at certain stage and the volume of diluent from the preceding step. The odour concentration in terms of odour units per m^3 of air is calculated as the geometric mean of the measured individual odour threshold of the panel members.

It is important to know that not all odours have the same ability to cause annoyance at a given concentration. It is not simple to account for differences in annoyance potential in quantitative terms. Therefore, most calculations used to predict the impact of odour use odour concentration only, ignoring different characteristics of odour. The odour concentration reduces the question "how strong and unpleasant is this odour?" to a detection threshold. However, measurements of odour concentration alone are insufficient to assess human perception of odour (Misselbrook *et al.*, 1993). The pleasant smell of one odour and the annoying smell of another odour may have the same odour concentration but certainly differ in offensiveness. Some odours judged acceptable or even pleasant at low concentrations could become annoying at higher concentrations (Punter *et al.*, 1986). Thus, odour can be more thoroughly characterised by also assessing the intensity and hedonic tone, as well as the odour concentration.

4.3 Odour intensity

Odour intensity (I) is the second parameter of the sensory perception of odorants. It refers to the magnitude of the odour sensation. The relationship between odour intensity and logarithm of odour concentration is expected to be linear.

There are two main methods of measuring odour intensity: the odour intensity referencing scale (OIRS) and the category estimation technique. A common OIRS method uses n-butanol as a standard reference odorant. The principle of this method is to compare the intensity of an odour to the intensities of different but known concentrations of n-butanol. As described in the previous section, there are two standard procedures for measuring odour intensity using n-butanol reference. These include dynamic-scale and static-scale procedures.

The category estimation technique method can be derived from the standard document of VDI Guideline 3882: 1997, part 1, Determination of Odour Intensity, Düsseldorf, Germany. The principle of its measurement is to vary the odour concentration and thus vary perceived intensity. At each concentration presented, human panellists are asked to indicate a value of perceived odour intensity from a seven-point scale that ranges from no odour to overwhelming odour. Odour intensity is then determined from the geometric mean of the different levels (intervals) of the category scales as perceived by a number of panellists. The values of I are then plotted against the logarithm of odour concentration. The regression line characterises the relation between perceived intensity and odour concentration. By comparing the intercept and slope of the regression lines, different odours can be characterised.

4.4 Hedonic tone

Hedonic tone is used to evaluate odour offensiveness. The odour offensiveness is a measurement of the unpleasantness or pleasantness of a perceived odour. The perception of hedonic tone varies widely among people and is strongly influenced by individual odour experience, personal odour preference, and the emotional context in which the odour is perceived. A method for measuring hedonic value is based on the standard document of VDI Güideline 3882: 1997, part 2, Determination of Hedonic tone, Dusseldorf, Germany. The principle of measurement is to vary the odour concentration and thus vary hedonic value. At each presentation, human panellists are asked to indicate perceived hedonic value, using a nine-point hedonic scale ranging from very pleasant to offensive. Pain *et al.* (1990) described a six-point scale only. The hedonic value of all panel members at each concentration level is calculated, and plotted against the odour concentration in $ou_E m^{-3}$. There should be a linear relationship between the logarithm of the odour concentration and the hedonic value at that concentration.

4.5 Chemical evaluation of odour

Odour from animal production facilities is usually comprised of a complex mixture of individual compounds. The mixture can be chemically characterised by determining which compounds are in the mixture of odour and at which concentrations. To analyse the mixture, three successive steps are essential: sampling and pre-concentration of the odour separation of components, and identification of the separated components. The basic technique for separating odorous compounds is gas chromatography. This technique separates mixtures of gaseous compounds into individual compounds by injecting them onto specific columns that partition these compounds according to vapour pressure and solubility. Because the various compounds of the sample interact with the absorbent to different degrees, compounds will be released from the tube at different and specific times. These elution times are compared to those of known compounds, for identification. In addition, peak areas and heights can be used to quantify the concentration of each odour compounds. The use of specific detectors, such as mass spectrometry, greatly improves the certainty with which compounds may be identified on the basis of their ionised molecular fragment patterns (Zahn *et al.*, 1997). The most sensitive technique for identifying volatile odorous compounds in combination with gas chromatography is mass spectrometry (Mellon, 1994). This combination of separation and identification is called GC-MS. With this method, volatile compounds can be quantified as well as identified.

4.6 Electronic sensor evaluation

Although olfactometry is considered the most precise method for quantifying odour at present, using a human nose as a sensor to measure odour concentration is labour intensive, time consuming and presents difficulty if on-site measurements are desired. In addition, sensory evaluation methods have a number of limitations. These include rapid saturation of olfactomtery senses by some odour compounds, individual variation in sensitivity to different odour, fatigue as a result of adaptation, etc. Currently, researchers are investigating the feasibility of an alternative

to olfactometry: using an electronic nose to measure odour concentration. An electronic nose is defined as an instrument consisting of an array of electronic chemical sensors with partial specificity and an appropriate pattern-recognition system capable of recognising odour. When presented with an odour, the electronic nose would initially classify the odour type. Then, using programmed knowledge about the relationship between sensor response and odour concentration for that odour type, the electronic nose would give an integrated response or value for odour concentration. The main application area of this device is quality control, especially in the food processing industry, but it is still far from implementation in livestock odour.

4.7 Concluding summary

Odour is mainly evaluated sensorily, and chemically. Using olfactometry, three parameters of sensory characterisation of odour e.g. concentration, intensity and hedonic value can be evaluated. Olfactometry is considered to be a standard method to measure odour concentration in odour units. Using GC-MS, mass concentration of different compounds of odour is quantified. Electronic sensor evaluation seems to be attractive; however, it is still far from implementation in livestock odour. Measuring odour is a complicated process and the measuring results vary greatly. Therefore, standards must be followed and strictly applied. A new and well-recognised standard of odour measurement is the European standard.

5 Odour from pig production facilities related to diets

The relationship between odour and diet can be considered in two ways: odour produced and released directly from diets, and odour produced and released indirectly from diets, which means odour from the animal, faeces, urine and manure after ingestion of food.

5.1 Odour production and emission directly from diets

In several experiments the effect of dietary manipulation on odour emission from manure was studied (Verdoes & Ogink, 1997; Gralapp *et al.*, 2002; Otto *et al.*, 2003). From these studies, there are indications that dietary crude protein and fermentable carbohydrates interfere with odour emission. Literature data on odour emission directly from diets or from dietary ingredients, however, are very scarce. Timmerman *et al.* (2004) investigated whether there is a difference in odour concentration and hedonic odour tone between dry feed and different combinations of liquid co-products. The used liquid co-products were mashed potato steam peel (MPSP), wheat starch (WS), whey (WH), beer yeast (BY) and onion juice (OJ). The dry feed was a commercial dry mixed diet for finisher pigs. Odour concentration and hedonic odour tone were determined in all possible combinations of the liquid co-products.

After one day, odour concentration of the dry feed was significantly lower than the odour concentration of the most important combinations of liquid co-products. The odour concentration of the combination of MPSP, WS and WH was significant lower than that of the combination of MPSP, WS, WH and OJ and of the combination of all liquid co-products. After 8 and 15 days, odour concentration of the combination of MPSP, WS and WH did not differ from the odour concentration of the dry feed. The odour concentrations of the combinations with BY and/or OJ, however, were significant higher than the odour concentration of dry feed and of the combination MPSP, WS and WH.

The hedonic odour tone of the dry feed was higher than the hedonic odour tone of the combinations of liquid co-products. After one day, hedonic odour tone of the combination of MPSP, WS and WH was significantly higher than the hedonic odour tone of the combination of all liquid co-products. After 8 days, hedonic odour tone of the combination of MPSP, WS and WH was higher than the hedonic odour tone of the combinations of liquid co-products with BY. After 15 days, there was no difference in the hedonic odour tone between combinations of liquid co-products.

From the study from Timmerman *et al.* (2004), it can be concluded that in general, there are no differences in odour concentration between dry feed and the combination of the liquid co-products MPSP, WS and WH. The hedonic odour tone, however, is higher in dry feed. The combinations of liquid co-products with BY and/or OJ give higher odour concentrations than the combination of standard liquid co-products (MPSP, WS and WH) but the hedonic odour tone is not different in most cases.

5.2 Odour production and emission indirectly from diets

The availability, type and level of odour precursors in the large intestine of animals and in manure determine the production of odorous compounds. To alter odour production, one may reduce the availability of precursors for odour formation and/or alter the pH in the large intestine of animals, in urine and in manure. Altering the level and source of proteins and fermentable carbohydrates may be used as important means to implement these strategies, because proteins and fermentable carbohydrates are the main precursors of odour formation. Other possible ways of altering odour production that have been considered are feed additives and other feeding strategies e.g. feed processing, phase feeding and liquid and dry feeding.

5.2.1 Odour from pig production facilities related to protein in diets

Attempts to reduce odour production and emission by altering diets have focused on protein. Research so far has focused on two areas: reducing ammonia emission and reducing the emission of other odorous compounds. Although the relationship between ammonia and odour is still debatable, there is a relationship with protein intake. An excessive protein intake will increase both ammonia emission and odour emission. An excessive intake of protein or of amino acids – or both – has a big effect on faecal and urinary nitrogen excretion and thus on ammonia emission. In addition, excessive protein from the diet is excreted in three forms: (1) urea, glucuronides and sulphate in urine, (2) non-digested proteins in faeces, and (3) bacterial proteins in faeces. These excreta are major precursors for odour formation. Blair *et al.* (1999) reported that with traditional dietary practices (14% CP), growing-finishing pigs may retain less than 40% of the nitrogen fed. According to Aarnink (1997) nitrogen retention of growing-finishing pig was 30% of the nitrogen in feed (Fig. 6). Therefore, a good base for reducing nitrogen excretion and odour production is by reducing the amount of protein in the diet.

The principle of reducing nitrogen excretion and ammonia emission through protein is to ensure that the amount of protein in a diet matches the protein requirement and to increase the efficiency of the animals' protein utilisation. There is abundant literature on the impact of the reduction of dietary protein supply to pigs on the reduction of nitrogen excretion and ammonia emission (Kerr, 1995; Hobbs *et al.*, 1998; Zijlstra *et al.*, 2001; Zervas & Zijlstra, 2002). Nitrogen excretion and ammonia emission can be reduced appreciably by reducing the crude protein content in diets. Diets with reduced protein content are often supplemented with essential amino acids. Reduced CP diets, supplemented with crystalline AA, have been shown to reduce faecal nitrogen excretion by 25 to 30% (Cromwell & Coffey, 1993; Jongbloed & Lenis, 1993). According to Sutton *et a*l. (1999) and Shriver et al. (2003), reduced CP diets supplemented with AA decrease not only nitrogen excretion but also manure pH and thus ammonia emission. Generally, as a guide, for each 1% unit reduction in dietary CP combined with AA supplementation the estimated ammonia losses are reduced by 10% in pig and poultry (Aarnink *et al.*, 1993; Jacob, 1994; Kay & Lee, 1997; Sutton *et al.*, 1997).

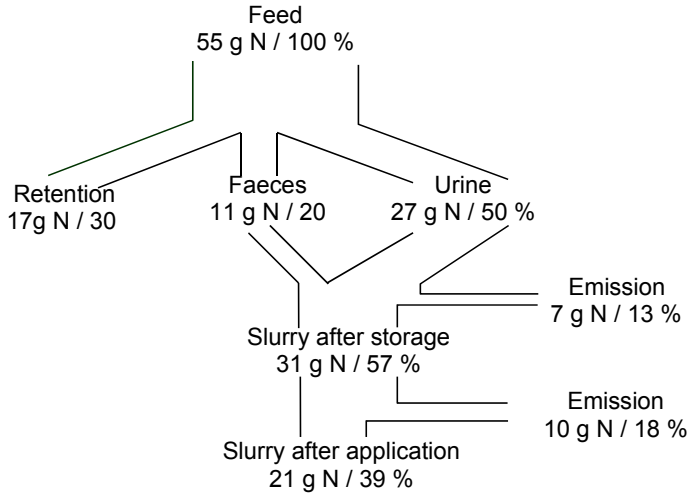


Figure 6 Nitrogen flow in growing-finishing pigs (Aarnink, 1997)

The impact of feeding a reduced CP and AA supplemented diet on reducing odorous compounds is, however, small and inconsistent. Hobbs *et al.* (1996) showed that five out of 10 odorous compounds in the manure of growing pigs and nine out of 10 odorous compounds in the manure of finishing pigs declined when pigs were fed reduced CP diets with supplemented AA, compared with pigs fed commercial diets. They also reported reductions of VFAs, branched-chain VFAs, p-cresol, indole and skatole in manure from pigs fed low protein diets (14 and 13% CP for grower and finisher diets, respectively) compared to pigs fed high protein diets (21 and 19% CP for grower and finisher diets, respectively). Sutton *et al.* (1998) reported a 62% reduction of volatile organic sulphur compounds (dimethyl sulphide, dimethyl disulphide, dimethyl trisulphide, dimethyl sulfoxide and carbon disulphide) in 53 kg gilts when their diet of 13% CP diet was compared to a 8% CP and AA supplemented diet. According to Stevens *et al.* (1993) increasing the protein content of diets increased the excretion of sulphurous compounds capable of producing sulphide under anaerobic conditions. In addition, in rats, the amounts of phenol, p-cresol, and 4-ethylphenol in the caecum was found to be reduced when the amount of dietary protein was reduced (Bakke, 1969).

However, Sutton *et al.* (1999) found that the concentration of volatile organic compounds in the headspace air of manure stored anaerobically did not differ between pigs fed a 10% CP and AA supplemented diet and pigs fed a standard 13 % CP diet. They also observed no differences in concentration of phenolic or sulphurous compounds in the faeces from pigs fed 10, 13 or 18% CP diets. In addition, neither Obrock *et al.* (1997) nor Cromwell *et al.* (1999) found a difference in aerial sulphide concentration after feeding a reduced CP and AA supplemented diet compared to a standard one. Futhermore, Obrock *et al.* (1997) reported no difference in odour concentration between pigs fed 13% and 9% CP with AA supplemented diets.

Moreover, Otto *et al.* (2003) showed an increase in total VFA concentration in the manure and a tendency to increase odour offensiveness from pigs fed reduced CP and AA supplemented diets. In addition, Cromwell *et al.* (1999) reported higher levels of butyric and valeric acid but lower acetic acid in manure when pigs were fed a reduced CP and AA supplemented diet, while Shriver *et al.* (2003) reported lower VFA concentrations in manure from pigs fed the reduced CP but AA supplemented diet.

Types of protein have effects on odour nuisance. According to Van Heugten and Van Kempen (2002) diets containing fishmeal and a high sulphur content from adding up to 12% feather meal showed a high odour concentration. They also reported that including feather meal up to 8% increased concentrations of butanoic, pentanoic, and *iso*-valeric acids in faeces, although concentrations of m-cresol, p-cresol, indole and decane were reduced.

A logical concern arising from reducing protein level in diets is the possible effect on animal productivity. Oldenburg and Heinrichs (1996) found no negative effects on performance and leanness of pigs between 50 and 110 kg when protein levels in diets were reduced from 17% to 13.5%. According to Canh *et al.* (1998) lowering dietary CP (16.5, 14.5 and 12.5%) and supplementing AAs could reduce ammonia emission up to 50% from manure of growing–finishing pigs while maintaining a normal growth rate. In an experiment in which dietary protein was reduced from 19% to 15% in starter diets, from 16% to 12% in grower diets and from 14% to 11% in finisher diets, with or without amino acid supplements, Kerr *et al.* (1995) found that a reduction in pig performance and carcass muscle can be prevented by supplementing with the proper AAs. According to Lopez *et al.* (1994) and Hahn *et al.* (1995) pigs fed reduced crude protein diets (a reduction of 3.5 to 4%) supplemented with AAs had similar carcass characteristics to pigs fed diets with a normal CP.

Briefly, diets generally contain a larger amount of proteins than the animals require. Only a proportion of dietary protein is used for growth or other production activities of the animal. Usually a large part is excreted via urine and faeces. Proteins and their metabolites in the excreta are precursors for odour formation. Reducing the amount of proteins in the excreta will decrease the available substrates that microbes can metabolise to odour compounds. It is clear from the literature that ammonia from animal production facilities can be decreased considerably by reducing the amount of protein in the diet. However, in the case of other odorous compounds the situation is not so straightforward. Ammonia is a single compound and the techniques and equipment for measuring it has already been standardised. Total odour, however, is a complex mixture of various compounds, which interact each other. Its measurement techniques and equipment still require standardisation. This may have contributed to the inconsistency in the measured effect of reduced CP and AA supplemented diets on odour. However, based on basic knowledge, we believe that feeding animals diets with reduced CP and supplements of AA can decrease odour. To maintain normal growth rate, AAs should be supplemented.

5.2.2 Odour from pig production facilities related to fermentable carbohydrates in diets

In common with protein, the type and level of fermentable carbohydrates have received much attention in dietary approaches to reduce odour production and emission. Researchers, however, have mainly focused on ammonia; few have examined odour concentrations as measured by olfactometry. The principle of reducing ammonia production and emission through fermentable carbohydrates is to shift nitrogen excretion from urine to faeces and to reduce the pH of manure. Increasing the fermentable carbohydrates in diets can result in bacterial proliferation due to an increase in the source of energy for bacteria in both the gastrointestinal tract and in the manure. Bacteria will use ammonia as a source of N for protein synthesis, thus reducing ammonia absorption into blood and urea excretion via urine. Fermentable carbohydrates in the gastrointestinal tract shift urinary nitrogen excretion to faecal nitrogen excretion in the form of bacterial protein (Younes *et al.*, 1997), which is less susceptible to rapid hydroxylation. Therefore, inclusion of fermentable carbohydrates in diets can reduce ammonia emission. Other researchers who have observed this phenomenon include Morgan & Whittemore (1998) and Cromwell *et al.* (1999).

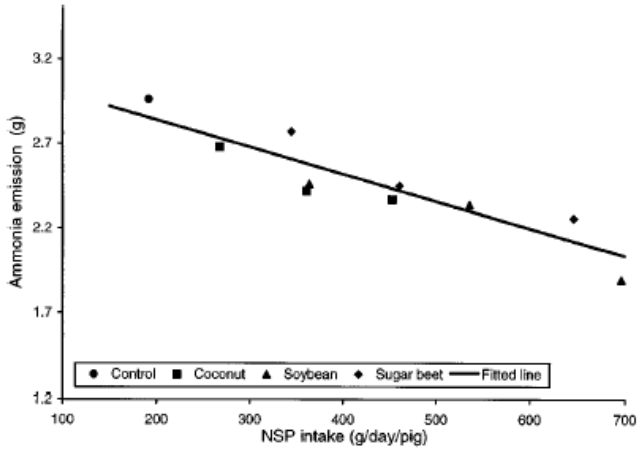


Figure 7 Ammonia emission from manure during a 16-d storage period related to the daily intake of non-starch polysaccharides (Canh *et al.*, 1998c)

Generally, the inclusion of fermentable carbohydrates in pig diets will increase VFA concentration in faeces and manure storage and thereby will reduce pH and thus ammonia emission (Sutton *et al.*, 1997; Canh *et al.*, 1998c; Kendall *et al.*, 1999). Sources of fermentable carbohydrates have an impact on nitrogen excretion and ammonia emission, because of the different components in these carbohydrates (Bakker, 1996; Canh *et al.*, 1997; 1998c Fig.7; Mroz *et al.*, 2000; Zijlstra *et al.*, 2001; Zervas & Zijlstra, 2002).

Although increasing fermentable carbohydrates in diets has a reducing impact on ammonia loss, it clearly increases manure VFA concentrations (Canh *et al.*, 1997; 1998b; 1998c; Sutton *et al.*, 1999; Shriver *et al.*, 2003). This increase may impact on manure odour concentration, because VFAs are important odorous compounds in manure storage (Schaefer, 1977; Williams, 1984;

Chen *et al.*, 1994; Zahn *et al.*, 1997). However, the relationship between the concentration of each odorous compound and odour concentration measured by olfactometry is still unknown. The increase of VFA concentration may increase and/or reduce the concentration of other compounds and odour concentration. Decamp *et al.* (2001) reported a 32% increase of total VFA concentration in 6-week-stored manure of pigs fed 10% soybean hulls when compared to no soybean hulls added. In the headspace gases there was a 20% reduction in aerial ammonia, a 32% reduction in hydrogen sulphide and an 11% reduction in odour concentration when soybean hulls were added. Goa *et al.* (1999) reported a trend to decrease excretions of p-cresol and skatol in fresh faeces (Fig. 8) by adding fibres to the basal diet. Moeser *et al.* (2001) fed soybean hulls to pigs not adapted to high fibre diets and noted a decrease in odour. However, Gralapp *et al.* (2002) reported no difference in odour concentration when 10% distillers dried grain was added to the diets of finishing pigs. Moreover, Hawe *et al.* (1992) reported increased excretions of indole and 3-methyl indole in the faeces of pigs fed diets containing sugar beet pulp as a fermentable fibre source. Knarreborg *et al.* (2002) observed a significant reduction in the production of indole and skatole in the proximal and distal part of the hindgut in pigs fed a diet rich in sugar-beet pulp. They believed that easily fermentable carbohydrates such as sugar-beet pulp stimulate microbial growth and hence the demand for amino acids for protein synthesis, leaving less tryptophan for conversion to 3-methyl indole.

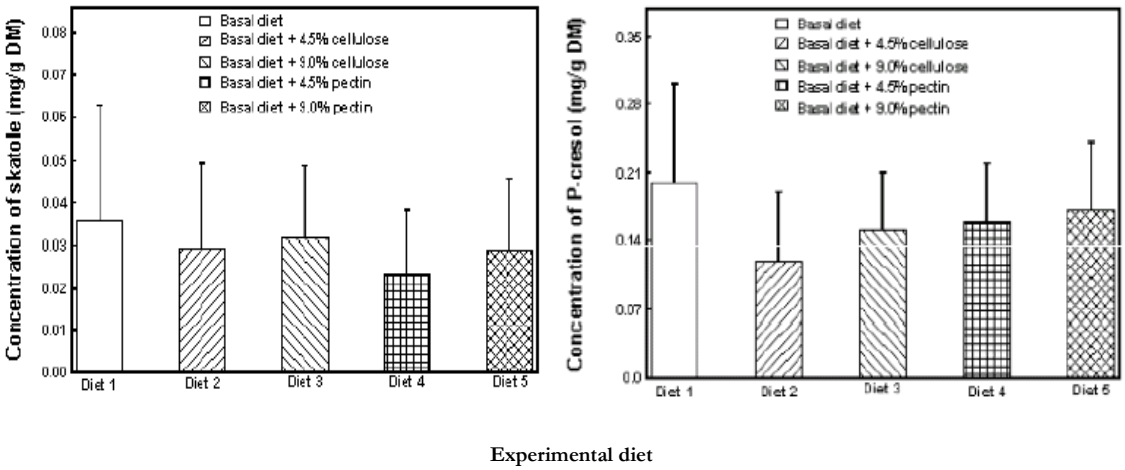


Figure 8 Effect of adding cellulose and pectin to a corn and soybean meal based diet on skatol and p-cresol in faeces (Goa *et al.*, 1999)

The literature contains very little information on the effect of sources of fermentable carbohydrates on the production and emission of odour compounds other than ammonia. Different sources of fermentable carbohydrates are fermented differently by pigs. Thus, different sources of fermentable carbohydrates provide different precursors for odour formation. The effect of fermentable carbohydrate sources depends on the composition of components. Microbial activity in the large intestine is generally increased when diets contain a high concentration of soluble fibre (Jørgensen & Just, 1998). The enhanced microbial activity in the

digestive tract means an increase in the excretion of microbial substances, thus a reduction in the proportion of very volatile compounds such as urea in total excretion.

Apart from their effects on environment, adding fermentable carbohydrates to pig diets has some controversial disadvantages. They can reduce the apparent ileal and total tract digestibility of protein (Shi & Noblet, 1993; Bakker, 1996), of fat (Dierick *et al.*, 1989), of minerals (Jongbloed, 1987) and of energy. The principles that cause these changes are: a reduced absorption of nutrients, which reduces the true nutrient digestibility; an increased secretion of digestive juices; an increased microbial synthesis of fat and protein, which reduces apparent nutrient digestibility; a reduced retention time of the digesta in the gastrointestinal tract, causing reduced nutrient digestion.

In brief, fermentable carbohydrates have been studied as a means to reduce both ammonia and other odorous compound production and emission from animal production facilities. It is clear from the literature that including fermentable carbohydrates in diets can reduce ammonia emission from animal production facilities considerably. However, the effect on other odorous compounds is inconsistent and not yet clear. Further studies are required before conclusions can be drawn and the application can be used to reduce odour from animal production facilities.

5.2.3 Odour from pig production facilities related to additives in diets

Feed additives are one of the biochemical and chemical agents that can reduce odour from animal production facilities (1989). The principles of using feed additives to reduce odour formation and emission are to:
(1) Alter the micro flora in the large intestine of animals and in manure;
(2) Change the pH into one less favourable for odour formation;
(3) Bind odour.
Microbial activities in the large intestine of the animal both produce odorous compounds and provide precusors for odour formation in manure; thus it is expected that altering the microflora and nutrient supply has the potential to change one or more groups of odorous compounds.

Altering the pH of urine and manure has received the most attention in efforts to use feed additives to reduce ammonia emission. At a low pH, ammonia is protonated to ammonium (NH^+_4), which remains in solution due to its charge. Some kinds of acid salts have been added into diets to reduce ammonia emission based on the principle of pH reduction. According to Canh *et al.* (1998a) the addition of calcium salts including $CaSO_4$, $CaCl_2$ and Ca-benzoate to diets decreased urinary pH; as a result, ammonia emission was reduced by 30, 33 and 54%, respectively.

A change in pH may also change the release of other odorous compounds such as hydrogen sulphide. For example, at a high pH, hydrogen sulphide will be reduced but ammonia release will

be enhanced. Sutton (1999) reported that manure with a higher pH emitted in more odour. The literature contained very little further information on the relationship between pH and other odorous compounds from animal production facilities.

Some feed additives are reported to bind ammonia or inhibit urease. Amon *et al.* (1995) reported a 26% reduction in ammonia emission when fattening pigs were fed De-Odorase (a yucca extract). Some other investigations have also observed reduced ammonia emission after adding yucca extracts to pig diets (Cromwell *et al.*, 1999; Colina *et al.*, 2001). However, at present, its inclusion in pig diets to reduce odour is not strongly supported by research. No information on the use of feed additives to bind odour other than ammonia was found in the literature.

In brief, like the two other means of reducing odour (proteins and carbohydrates), the use of feed additives has mainly focused on reducing ammonia emission. Acidifying additives has proved to be effective in reducing ammonia emission. However, its impact on odour has not been evaluated yet.

5.2.4 Other feeding strategies

In addition to using proteins, fermentable carbohydrates and feed additives strategically to curtail odour formation, liquid and dry feeding, phase feeding, and feed processing have also been studied in this context. According to Hobbs *et al.* (1997) the odour concentration from the manure of pigs fed a 4:1 (water: dry feed) diet was significantly less than that of pigs fed dry feed and 3:1 diets. H_2S was the major odorant in the 3:1 and dry feed diets. The organic nitrogen in manure declined concomitantly with an increase in the water content of the diets. Nahm (2002) reported that in growing and finishing pigs, phase feeding can reduce N excretion by 10-13% and odour from manure by 49-79%. He also observed that a 27% reduction of N excretion in finishing pigs and a 22-23% reduction of N excretion in piglets can be achieved when pigs are fed with proper ground feed. Van der Peet-Schwering *et al.* (1996) reported that moving from a 2-phase diet system to a multi-phase programme with optimal housing resulted in a 17% reduction in ammonia emission.

5.2.5 Concluding summary

Dietary composition and odour production and emission have a cause and effect relationship. Altering dietary composition, especially the sources and levels of proteins and fermentable carbohydrates seems a promising approach to reduce odour nuisance. The attempts made so far to alter diets to reduce ammonia emission have achieved much; the approach can reduce ammonia emission considerably. One shortcoming of most studies to date is that odorous compounds are considered in isolation, i.e. relative changes are measured only in single compounds or in one group of compounds. Only a few studies have used olfactometry to assess the effect of altering dietary composition on odour emission.

6 Perspectives of nutritional measures to reduce odour emission from pig production facilities

In Chapter 5, it has been discussed how manipulation of dietary composition may reduce odour emission. Three strategic dietary means were described:

- Proteins;
- Fermentable carbohydrates;
- Feed additives.

Results of some experiments were described on altering dietary CP and fermentable carbohydrates and using feed additives.
This chapter aims to give perspectives of nutritional measures to reduce odour emission. The following main directions for odour reduction by nutritional means are discussed:

- Protein level and type;
- Carbohydrate level and type;
- Interaction between protein and carbohydrate;
- Feed additives.

6.1 Main odorous compounds that can be influenced by diet

Table 6 summarises a list of the most important odorous compounds from animal production facilities. These compounds are produced from non-utilized nutrients in the diet. Proteins and carbohydrates are the main precursors for their formation. Therefore, the concentrations of these odorous compounds can probably be altered by changing the level and type of dietary compositions.

Phenol and indole compounds are typical most highly correlated with odour nuisance. Although sulphur-containing compounds are extremely malodorous, varying from putrid -like smell of dimethyl disulfide and methanethiol to the smell of rotten eggs of hydrogen sulphide, their role in odour nuisance is controversial. Sulphur-containing compounds are only formed under strict anaerobic conditions such as in deep pit manure storage, but it is not the case in pit recharge or pit flush systems (Mackie *et al.*, 1998). Volatile fatty acids are important odorous compounds. Branched-chain VFAs are thought to be more offensive than straight-chain VFAs. Ammonia is of environmental concern, as well. However, its relationship with odour nuisance is still debatable.

Table 6 Main odorous compounds in pig production facilities

Odorous compounds	Main origin	Odour group
Phenol	L-Tyrosine, L-Phenylalanine	Phenols
3-Methylphenol	DOPA	Phenols
4-Methylphenol (p-cresol)	L-Tyrosine, L-Tryptophan	Phenols
4-Ethylphenol	L-Tyrosine, p-Coumaric acid	Phenols
Indole	L-Tryptophan	Indoles
3-Methyl indole (skatole)	L-Tryptophan	Indoles
Hydrogen sulphide	Sulphate, L-Methionine, L-Cysteine	S
Carbonyl sulphide	Hydrogen sulphide	S
Carbon disulphide	Carbonyl sulphide	S
Methanethiol	L-Methionine, L-Cysteine	S
Dimethyl sulphide	L-Methionine, L-Cysteine	S
Dimethyl disulfide	Methanethiol, L-Cysteine, L-Methionine	S
Dimethyl trisulfide	Methanethiol, L-Methionine, L-Cysteine	S
Ethanethiol	L-Methionine	S
Acetic acid	Dietary fibre, L-glycine, L-alanine, L-cysteine, L-lysine, L-serine, L-threonine, L-hydroxyproline, L-aspartate, L-glutamate, L-histidine	VFAs
Propanoic (propionic) acid	Dietary fibre, Lactate, L-Alanine, L-threonine, L-alanine + L-threonine, L-aspartate, L-methionine	VFAs
Butanoic (butyric) acid	Dietary fibre, L-cysteine, L-hydroxyproline, L-lysine, L-serine, L-threonine, L-aspartate, L-glutamate, L-histidine	VFAs
3-Methyl butanoic acid	Dietary fibre, L-Valine, L-Leucine	VFAs
Pentanoic (valeric) acid	Dietary fibre, L-Proline, L-Hydroxyproline	VFAs
4-Methyl pentanoic acid	L-Leucine, L-Isoleucine	VFAs
Hexanoic (caproic) acid	Ethanol, acetate, CO_2	VFAs
Heptanoic (enanthic) acid	Benzoic acid, L-Phenylalanine	VFAs
Ammonia	Urea, Amino acids	NH_3

6.2 What can be done by protein

With current dietary practices, animals are not able to retain more than 40% of total nitrogen in the diet (Lenis, 1989; Kerr, 1995; Blair *et al.*, 1999). The non-utilized nitrogen and those from animal secretions are excreted via manure. They provide precursors for bacteria to produce odour. It is clear that many odorous compounds are produced from the breakdown of proteins/AAs. Almost all odorous compounds in Table 7 can be produced from proteins. Therefore, to reduce odour, reduction of total protein supply to the pig is promising. This offers less nitrogenous substrates for the microbes in the large intestine of animals and in manure. Amino acids such as methionin, cystein, tryptophan, tyrosine, etc should be as low as possible. In many cases, some of them e.g. methionine, typtophan are added into pig diets, because they are limiting amino acids. From dietary point of view, we can realise this by:

(1) Formulating diets closer to protein requirements of animals;
(2) Reducing protein amounts in the diet and supplementation with essential AAs to allow a normal growth;
(3) Using highly digestible and highly qualitative proteins.

6.3 What can be done with fermentable carbohydrates

Like protein, fermentable carbohydrates play an important role in odour production. They can directly produce odour, mainly short and straight-chain VFAs or/and alter pH in the large intestine of animals and in manure, which indirectly influence odour production. For example an increase in acidity reduce the conversion of tryptophan to skatole (Hammond *et al.*, 1989). In addition, the inclusion of fermentable carbohydrates in diet can shift nitrogen from an easily volatile form, urea in urine to a stable form, bacterial protein in faeces. This reduces ammonia emission. The use of fermentable carbohydrates has been proved to be an effective means to reduce ammonia formation and emission, but their role in odour nuisance is not straightforward. From dietary point of view, odour production could probably be altered by:

- Changing the type of fermentable carbohydrates in the diet;
- Changing the level of fermentable carbohydrates in the diet.

6.4 Protein and fermentable carbohydrates, a matter of optimisation

The role of different feed compositions on odour formation should not be considered independently, because they interact with each other. According to Sutton *et al.* (1999) odour compounds are produced from excess degradable protein and lack of specific fermentable carbohydrates during microbial fermentation. Fermentable carbohydrates such as sugar-beet pulp can stimulate microbial growth and hence the demand for AAs and ammonia for protein synthesis, leaving less AAs and ammonia for odour production. During anaerobic fermentation in the large intestine of animals or in manure; bacteria use protein as a nitrogen source and fermentable carbohydrates as an energy source, both proteins and fermentable carbohydrates should therefore be considered simultaneously when odour production should be reduced by dietary approach. Excess of proteins in comparison with fermentable carbohydrates and vice versa can increase odour production. Therefore, the optimisation of proteins and fermentable carbohydrates in the diet can be considered the best dietary approach to reduce odour production from animal production facilities.

6.5 What can be done with feed additives

Section 5.2.3 described the use of feed additives to reduce odour, mainly by the way of reducing pH of urine and manure. It can be seen that feed additives e.g. $CaSO_4$, $CaCl_2$ and Ca-benzoate can reduce ammonia substantially (Hendriks *et al.*, 1997; Canh *et al.*, 1998a; Mroz *et al.*, 1998). It is, however, speculated that addition of these salts will hardly affect microbial fermentation in the large intestine of animals; it may have no effect on other odorous compounds than ammonia. Generally, the effects of feed additives should always be studied in a broaden scope. An additive might be a solution for one problem, but might generate another problem. However, measurements are necessary to confirm this hypothesis.

6.6 What are the knowledge gaps

It is obvious that proteins and fermentable carbohydrates in diets can be considered as strategic means to interfere in odour production and emission from pig production facilities. Some authors exploited this strategy. The results are, however, inconsistent. In addition, studies were implemented by using either proteins or fermentable carbohydrates. Optimising levels of proteins and fermentable carbohydrates with respect to odour production only received little attention. Furthermore, also little attention was paid to different types of proteins and fermentable carbohydrates in relation to odour production. New studies should focus on the effect on odour production of:

(1) Protein level and type

The approach described in 5.2.1 i.e. reduction of the total protein concentration is promising. This offers less nitrogenous substrates for the microbes inside and outside the animal, hence reducing odour. The studies so far have focussed on some specific odorous compounds. The effect of protein level on odour production measured by olfactometry got little attention. Moreover, studies of the effects of protein types on odour production were scarily found in literature.

(2) Level and type of fermentable carbohydrates

The role of fermentable carbohydrates and odour production is not straightforward. Dependent on the type and amount of fermentable carbohydrates, different populations of bacteria can be favoured; some of them may reduce odour while the others may increase odour. In general, the more fermentable carbohydrates are offered to pigs, the higher the production of VFAs in manure is expected. The effects of same studies on other odorous compound e.g. phenols, indoles, and sulphur-containing compounds were inconsistent. Like protein, studies on the effect of fermentable carbohydrates on odour production mainly focussed on certain groups of odorous compounds, while the relationship between each odour group with odour nuisance measured by olfactomtery was not yet clear. The effect of fermentable carbohydrate concentration on odour concentration measured by olfactometry was rarely found in literature. In addition, the role of specific components in fermentable carbohydrates on odour nuisance was not evaluated.

(3) Interaction between protein and carbohydrate

The type and amount of carbohydrates entering the large intestine have a substantial effect on nitrogen metabolism. However, the interactive effect of proteins and carbohydrates in the diet on odour production got only little attention in previous studies. Although some studies were found in the area of ammonia emission, the same results may not be expected for odour, because ammonia is just a single compound of odour; and the relationship between odour and ammonia is still debatable. In addition, a specific dietary means such as proteins or carbohydrates can only alter certain groups of odour compounds while odour is a complicated mixture of all individual

compounds. Up to date, the relationship between each odour group and odour concentration measured by olfactometry was not yet clear. Therefore, we think optimisation of fermentable carbohydrates and proteins in the diet is a very promising dietary approach to reduce odour production and emission. It, however, requires further studies before a general principle can be drawn to reduce odour.

6.7 Methodology

To fill the gap of knowledge or to realise the objective of reducing odour production at source by dietary approach, we propose to follow two successive steps.
(1) Conducting experiments on metabolism cages: pigs will be provided different diets with varying amounts of proteins and carbohydrates and with different types of proteins and fermentable carbohydrates. Their urine and faeces are collected, mixed, and then injected in a laboratory set up to sample odorous air. Odour characteristics (strength and offensiveness) and manure characteristics are determined.

- Experiment 1: Odour concentration, emission and hedonic value from pig production as affected by types and levels of crude protein in diets
  - Independent variables: types and levels of protein in diets;
  - Dependent variables

Characteristics of manure;
Odour concentration, emission and hedonic value of manure measured by olfactometry;
Odour compounds and emission from manure measured by GC-MS.

- Experiment 2: Odour concentration, emission and hedonic value from pig production as affected by dietary protein and fermentable carbohydrate levels in diets
  - Independent variables: levels of protein and fermentable carbohydrates
  - Dependent variable: The same as experiment 1

- Experiment 3: Odour concentration, emission and hedonic value from pig production as affected by types and levels of fermentable carbohydrates in diets
  - Independent variables: Types and levels of fermentable carbohydrates
  - Dependent variables: The same as experiment 1

(2) Validating the results in a practical situation of the farm: The most promising treatments for odour reduction will be validated at farm scale.

7 Conclusions

Odour nuisance from animal production is especially a problem in densely concentrated livestock farming areas, like those in The Netherlands. It results from the intensification of animal production in the vicinity of a dense population. Such intensive animal production can cause serious nuisance and can even lead to health problems as a result of odour production and emission.

Livestock odour does not come from an individual compound but from a complex mix of various compounds. Numerous odorous compounds from animal production facilities have been identified in various studies. However, to date, odorous compounds from different sources e.g. feed, animal body, urine, faeces and manure, have not been well described. The main source of odour from animal production facilities is excreta. The odorous compounds that mostly cause nuisance can be classified into 4 main groups: sulphurous compounds, indoles and phenols, VFAs, and ammonia and volatile amines.

Odour production is mainly based on microbial conversions involving many bacteria. Odorous compounds are the intermediate or end products of microbial conversions of nutrients in the diet that are not utilised. The main precursors of odour formation are proteins and fermentable carbohydrates. The different odorous compounds interact with each other: an increase of one compound may cause others to increase or decrease – or both.
Odour is evaluated sensorily and chemically. Using dilution apparatus, the sensory characteristics of odour strength and offensiveness can be quantified by human noses. This technique is called olfactometry. The chemical characteristics of odour can be evaluated by using GC-MS equipment to determine the concentrations of different odorous compounds. Electronic sensor evaluation appears to be promising, but it is still a long way from being applied in research on livestock odour.

Despite inconsistencies between studies, it proved possible to compile a list of around 20 important odorous compounds from animal production facilities. The odour concentrations of these compounds from animal production facilities vary widely, depending on diet, climate factors, housing system, pig breed, sampling and measuring methods, etc.
Studies on altering diets to reduce odour production have tended to have two distinct aims: to reduce ammonia emission and to reduce the emission of other odorous compounds. Though there are many reports on ammonia emission being successfully altered by adjusting diets, reports of the impact of altering diets on the emission of odorous compounds other than ammonia are scarce and inconsistent.

It is clear that many odorous compounds are produced from the breakdown of proteins. Therefore, a promising approach to reducing odour is to reduce the total protein concentration so that less nitrogenous substrate is available to the microbes inside and outside the animal. Up

to now, studies have focused on certain specific odorous compounds and have tended to ignore the effect of protein level on odour production measured by olfactometry. Moreover, there are hardly any published studies on the effects of protein sources on odour production.

The role of fermentable carbohydrates in odour production is not straightforward. Depending on the type and amount of fermentable carbohydrates, different populations of bacteria can be favoured; some of them may reduce odour, while others may increase odour. In common with studies on protein, studies on the effect of fermentable carbohydrates on odour production have tended to focus on certain groups of odorous compounds, though the relationship between each odour group with odour production measured by olfactometry is not yet clear. The literature contains hardly any reports of the effects of fermentable carbohydrates on odour production measured by olfactometry. Nor has the role of specific sources of fermentable carbohydrates on odour production been evaluated.

It is clear that feed additives can reduce ammonia substantially. It remains speculative, however, whether adding these salts will affect microbial fermentation in the large intestine of animals; additives may have no effect on other odorous compounds than ammonia. Generally, the effects of feed additives should always be studied in a wider context. An additive might solve one problem but generate another. This hypothesis remains to be tested, however.

Dietary proteins and fermentable carbohydrates offer the means to reduce odour strength and offensiveness at source, because they are main precursors of odour production. Research has so far tended to focus on single effects of different levels of CP or fermentable carbohydrates on odour production. However, it is not only the amount and source of these compounds that is important but also the balance between them, because microflora in the large intestine and manure storage use fermentable carbohydrates as a source of energy and N for protein synthesis. On the basis of our review of the literature, we hypothesise that odour nuisance from pig production facilities can be reduced significantly by achieving an optimum balance between proteins and fermentable carbohydrates in the diet. However, more research must be done in order to specify this optimum balance.

8 Samenvatting

De agrarische sector is een belangrijke bron van geurhinder in Nederland. Geurhinder komt vaak voor in gebieden met hoge dierconcentraties, zoals in het zuiden en oosten van Nederland. Elf procent van de bevolking heeft wel eens last van stank als gevolg van activiteiten in de landbouw. De doelstelling van de overheid is om ernstige geurhinder in 2010 volledig uit te bannen en vanaf nu te voorkomen dat er lokaal meer geurhinder ontstaat.

Internationaal kunnen verschillende benaderingen worden onderscheiden om geurhinder door emissie uit veehouderijgebouwen te reguleren. In Nederland wordt de systematiek van minimale afstanden tussen nieuw te bouwen stallen en geurgevoelige objecten gehanteerd. De minimale afstand is afhankelijk van de bronsterkte, gebaseerd op het aantal dieren op het veebedrijf en sinds kort tevens op het huisvestingssysteem (wel of niet emissiearm). In Duitsland en Oostenrijk worden ook andere factoren meegenomen die de geuremissie en –verspreiding beïnvloeden, zoals mestverwijderingsssyteem, lokaal landschap, voersoort, ventilatiesysteem, etc. In België en Engeland zijn maximale geurconcentraties vastgesteld voor geurgevoelige objecten. Onder- en overschrijdingen worden bepaald door het meten van de bronsterkte en het gebruik van verspreidingsmodellen. Op dit moment worden door de Nederlandse overheid nieuwe strategieën ontwikkeld. De regelgeving zal in de toekomst meer gericht worden op geurhinder en minder op emissiestandaarden.

Geuremissie uit stallen kan in de hele keten worden aangepakt, van voer en dier naar mest en uitgaande stallucht. Geuremissie kan worden gereduceerd door er voor te zorgen dat minder geurcomponenten worden gevormd of door te voorkomen dat de gevormde geurcomponenten de stal kunnen verlaten, b.v. door het wassen van de uitgaande lucht.
Ervaringen in het ammoniakemissie onderzoek hebben geleerd dat het voorkomen van emissies bij de bron in het algemeen efficiënter is (effect in relatie tot kosten) dan de zogenaamde end of pipe oplossingen. Onderzoek heeft aangetoond dat de ammoniakemissie belangrijk kan worden gereduceerd via voermaatregelen. Deze aanpak zou ook voor geur succesvol kunnen zijn.

De doelstelling van deze deskstudie was te bepalen wat de rol van voeding is bij de vorming van geurcomponenten in de darm van het varken en in de mestopslag en op welke manier voeding bij zou kunnen dragen aan een reductie van de geuremissie uit varkensstallen. In Nederland worden diervoeders geformuleerd op basis van een heel scala aan grondstoffen. Deze verschillende grondstoffen hebben ieder een effect op de vertering en de benutting van voedingsstoffen door het dier en beïnvloeden daarmee tevens de vorming van geurcomponenten in het dier en in de mest. In deze deskstudie is de huidige stand van kennis weergegeven ten aanzien van het effect van voersamenstelling op de vorming van geurcomponenten in het dier en in de mest. Op basis hiervan zijn de perspectieven geschetst voor een sterke vermindering van geuremissie uit stallen via voedingsmaatregelen.

Urine, feces en mengmest zijn de belangrijkste bronnen van geur in varkensstallen. Er zijn een groot aantal geurcomponenten geïdentificeerd in stallucht. Voor varkensstallen kunnen ca. 20 belangrijke geurcomponenten worden onderscheiden. Deze componenten kunnen in 4 hoofdgroepen worden ingedeeld: 1) zwavelhoudende componenten, 2) indolen en fenolen, 3) vluchtige vetzuren, 4) ammoniak en vluchtige aminen. De bijdrage van een geurcomponent aan de geurconcentratie wordt vooral bepaald door de concentratie van de component in de lucht en van de geurintensiteit van de betreffende component. Het voorgaande zegt nog niets over de aard van de geur. De hedonische waarde van geur bepaald of deze als hinderlijk wordt ervaren. De score varieert hierbij van zeer onaangenaam tot zeer aangenaam.

Met behulp van olfactometrie kan de concentratie, de intensiteit en de hedonische waarde van een geur worden bepaald. Het meten aan geur is een complexe zaak en meetresultaten vertonen in het algemeen een grote variatie. Daarom is het zeer belangrijk dat standaard procedures worden gevolgd. Recentelijk is een Europese standaard ontwikkeld voor olfactometrische bepaling van de geurconcentratie. De concentraties van de verschillende geurcomponenten in een luchtmonster kunnen bepaald worden met behulp van GC-MS (Gas Chromatography – Mass Spectofotometry).

Verschillende onderzoekers hebben getracht een relatie te leggen tussen de concentratie van bepaalde geurcomponenten in de stallucht en de olfactometrisch bepaalde geurconcentratie van die lucht. Voor varkensstallen worden p-cresol, fenol, indole and skatol vaak genoemd als indicatoren voor geur. Het onderzoek is hier echter niet eenduidig in.

Geurcomponenten worden vooral gevormd door microbiële activiteit in de dikke darm van het varken en in de mengmest gedurende de opslag. Het zijn tussen- of eindproducten van de microbiële omzetting van onbenutte voedingsstoffen. De omzettingen vinden plaats onder anaërobe condities. Onverteerd en endogeen eiwit en onverteerde fermenteerbare koolhydraten zijn de belangrijkste precursors van geurcomponenten.

Vluchtige vetzuren worden vooral gevormd door microbiële omzetting van fermenteerbare koolhydraten en onverteerd en endogeen eiwit in de dikke darm van het varken en in de mengmest. Fermenteerbare koolhydraten worden alleen omgezet naar onvertakte vluchtige vetzuren, terwijl eiwitten zowel naar onvertakte als naar vertakte vluchtige vetzuren kunnen worden omgezet. In het algemeen veroorzaken vluchtige vetzuren met langere en/of vertakte ketens een sterkere stank dan vluchtige vetzuren met korte rechte ketens.

Zwavelhoudende geurcomponenten worden vooral uit twee bronnen geproduceerd: 1) sulfaat in de urine; 2) eiwitten en zwavelhoudende aminozuren. Alhoewel zwavelhoudende componenten een zeer sterke geur hebben, is hun rol in de geuremissie uit varkensstallen niet eenduidig.

Zwavelhoudende geurcomponenten worden alleen gevormd onder strikt anaërobe omstandigheden, zoals in diepe mestkelders. Bij o.a. spoelsystemen worden deze geurcomponenten vrijwel niet gevormd.

Er zijn drie bronnen van fenolen en indolen in de mest: 1) afbraak van de aminozuren L-tryptofaan en L-tyrosine in het varken en directe uitscheiding van deze componenten via de feces; 2) afbraak van de aminozuren L-tryptofaan en L-tyrosine in de mest; 3) omzetting van glucuroniden in urine, wanneer de urine in contact komt met feces. Fenol en p-cresol worden gevormd uit het aminozuur L-tyrosine. Indole en skatole worden gevormd uit het aminozuur L-tryptofaan. Fenolen en indolen zijn in het algemeen zeer sterk gecorreleerd met stank uit stallen. Ammoniak wordt vooral gevormd uit afbraak van ureum in urine. Vluchtige aminen worden gevormd door decarboxylatie van aminozuren. In het algemeen wordt gesteld dat ammoniak slechts een beperkte bijdrage levert aan de geurconcentratie in varkensstallen.

In het algemeen bevat varkensvoer veel meer eiwit dan het dier nodig heeft om te groeien. Gemiddeld wordt slechts 30 à 35% van het voereiwit aangezet in het dier. De rest wordt uitgescheiden als onverteerd eiwit in de feces of wordt in het lichaam afgebroken en in de vorm van ureum uitgescheiden via de urine. Onbenutte eiwitten en de afbraakproducten daarvan zijn belangrijke precursors van geurcomponenten. Daarom kan het verminderen van de hoeveelheid eiwit en het aanpassen van de eiwitbronnen een belangrijke weg zijn om de geuremissie te reduceren. Voor ammoniak is reeds aangetoond dat het beperken van het eiwitgehalte in het voer de ammoniakemissie belangrijk kan reduceren zonder dat dit, indien limiterende aminozuren worden toegevoegd aan het voer, ten koste gaat van de productie.

Het effect van niveau en bron van fermenteerbare koolhydraten op de ammoniakemissie is uitgebreid onderzocht. Het blijkt dat het toevoegen van fermenteerbare koolhydraten aan het voer een belangrijke weg kan zijn om de ammoniakemissie uit stallen te reduceren. Het effect van fermenteerbare koolhydraten op de emissie van andere geurcomponenten is echter nog onduidelijk. Onderzoek op dit gebied is niet eenduidig.

Voersamenstelling en geurproductie hebben een sterke oorzaak en gevolg relatie. Het veranderen van de voersamenstelling zal daarom een direct effect hebben op de geurproductie en de geursamenstelling. Vooral het niveau en de bron van eiwitten en fermenteerbare koolhydraten lijken een belangrijke invloed te hebben op de geurproductie. Hoe hoog uiteindelijk de emissie van geur uit de stal is hangt tevens af van omgevingsfactoren als temperatuur, ventilatiedebiet, verdunning met water, huisvestingssysteem etc. Tot dusver is het internationale onderzoek vooral gericht geweest op het effect van voersamenstelling op specifieke geurcomponenten. Meer aandacht is nodig voor bepaling van het effect van voersamenstelling op de geurconcentratie, bepaald met behulp van olfactometrie. Echter, chemische analyses met behulp van GC-MS zijn

ook nodig om inzicht te krijgen in de manier waarop het voer invloed heeft op de verschillende geurcomponenten.

De conclusie van dit rapport is dat via aanpassing van het gehalte en de samenstelling van eiwitten en fermenteerbare koolhydraten de geurproductie en –emissie belangrijk kan worden beïnvloed. De onbenutte bestanddelen van deze voedingsstoffen zijn namelijk de belangrijkste precursors van geurcomponenten. Het weinige onderzoek dat tot nu toe is gedaan op dit gebied heeft zich voornamelijk beperkt tot enkele geurcomponenten en afzonderlijke effecten van deze voerbestanddelen. Belangrijk in het toekomstige onderzoek op dit gebied is om niet alleen te kijken naar de afzonderlijke effecten van deze voerbestanddelen, maar tevens naar de interactie tussen deze twee. Onze hypothese is namelijk dat de geuremissie uit varkensstallen drastisch kan worden terug gedrongen wanneer het voer een optimale, op het dier afgestemde, balans heeft tussen eiwitten en fermenteerbare koolhydraten.

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