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## **Multidimensional Gas Chromatography-Olfactometry for Identification and Prioritization of Malodors from Confined Animal Feeding Operations**

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**Abstract.** *Odor profiling efforts were directed at applying to high-density livestock operations, some of the lessons learned in resolving past, highly diverse, odor-focused investigations in the consumer product industry. Multidimensional-GC-Olfactometry was utilized in an attempt to define and prioritize the basic building blocks of odor character associated with representative cattle feedyard and swine feeding operations. Although scores of potential odorant volatiles have been previously identified in high-density livestock operations, the odor profile results developed herein suggest that only a very few of these may constitute the preponderance of the odor complaints associated with these environments. This appeared to be especially true for the case of increasing distance from the cattle feedyard facilities; with para-cresol consistently taking on the preeminent odor impact role with ever increasing distance. In contrast, at or near-site odor profiles were shown to be much more complex; with many of the traditional lower tier odorant compounds rising in relative significance. Surprisingly, for the at or near-site odor profiles, trimethylamine was shown to represent a significantly greater individual odor impact relative to hydrogen sulfide, the organic sulfides and volatile fatty acids; the more often cited target odorants.*

**Keywords:** malodor analysis, agricultural odor analysis, farm odor, GC-Olfactometry, GC-O, solid phase microextraction, SPME, multidimensional gas chromatography, livestock housing, volatile organic compounds, para-cresol.

## **Introduction**

Malodor characterization is among the most demanding of analytical challenges. This occurs because it is usually the case that aroma or odor critical components are present at very trace levels in a complex matrix of odor insignificant volatiles (Wright et al, 1986). A large body of excellent analytical work has been reported during the past three decades relative to the volatile compounds emitted by high density livestock operations. Scores of volatile compounds have been identified in these environments utilizing various concentrating and analytical techniques (Mosier et al. 1973; Hutchison et al. 1982; Oehrl et al. 2001; Keener et al. 2002; McGinn et al. 2003; Nielsen et al. 2004). Included among these volatiles are a large number of compounds which are known to be potent individual odorants (Devos et al. 1990). The challenge relative to the odor issue is to extract from this large field of 'potential' odorants, the compounds which constitute the primary odor impact relative to these environments. Given sufficiently comprehensive and accurate reference and analytical data regarding the volatile compounds present in these environments, it would seem to be possible to accurately predict and rank the primary odor impact compounds. However, from a practical standpoint, this does not produce satisfactory results in most cases. The factors working against such success are incomplete or imprecise odor threshold data in concert with the extremely low odor thresholds of many if not most of the key odorants present.

A practical alternative is to carry out GC-olfactometry (i.e. GC-O) based odor profile ranking studies relative to in-situ headspace volatiles collections taken directly from the target environment. This is the approach which we routinely take in investigating odor issues surrounding matrices for which limited volatiles compositional data is available. The general experimental approach is to develop a detailed odorant ranking profile for a sensory graded 'worst' case sample. Performing equivalent comparative odorant ranking profile analysis for equivalent sensory graded 'best' case samples will typically indicate which of the 'potential' odorant(s) present in the field account for the odor character differences between the two samples.

The necessity of prioritizing the individual odor carrying volatiles relative to a particular malodor issue is often overlooked in odor focused investigations. Over the past decade it has been our experience that such prioritization is essential to the resolution of the typical crisis-driven malodor problems. Scores of these investigations have been successfully effected during this period; ranging from aroma and flavor complaints in foods and beverages to malodors in packaging, consumer products and work environments. These current collaborative efforts undertaken with Texas A&M - Texas Agricultural Experimental Station, Amarillo and West Texas A&M, Canyon are directed at applying to high-density livestock operations some of the lessons learned in addressing these past, highly diverse odor focused investigations. In our experience, odor profiling by GC-O has proven to be an essential element required for defining, prioritizing and tracking the basic building blocks of odor character in complex matrices (Wright et al., 1986; Nielsen et al. 2001; Willers et al. 2003). This is the approach which we have attempted to take in this overview study.

## **MATERIALS and METHODS**

### ***Multidimensional Gas Chromatography-Olfactometry-Mass Spectrometry***

MDGC-O-MS is a novel approach combining olfactometry and multidimensional GC separation techniques with conventional GCMS instrumentation. An integrated AromaTrax™ system from Microanalytics (a MOCON Company) of Round Rock, Texas (Figure 1) was used for the

reported GC-O profiling work. This integrated system utilizes the Agilent 6890 GC / 5973 MS as the base platform. This basic GCMS platform is then optimized for the odor profile application by the addition of multiple detectors (i.e. flame ionization, photoionization and olfactory); multiple columns (i.e. precolumn = 12 m x .53 mm ID BP x 5 x 1.0  $\mu$ m from SGE; analytical = 25 m x .0.53 mm ID BP20 x 1.0  $\mu$ m from SGE); MDGC capabilities (i.e. heart-cutting, cryogenic trapping and back-flushing); system automation and data acquisition software (i.e. MultiTrax™ Ver. 6.00 and AromaTrax™ Ver 6.00 from Microanalytics and Chemstation™ G1701BA Ver. B.01.00 from Agilent).

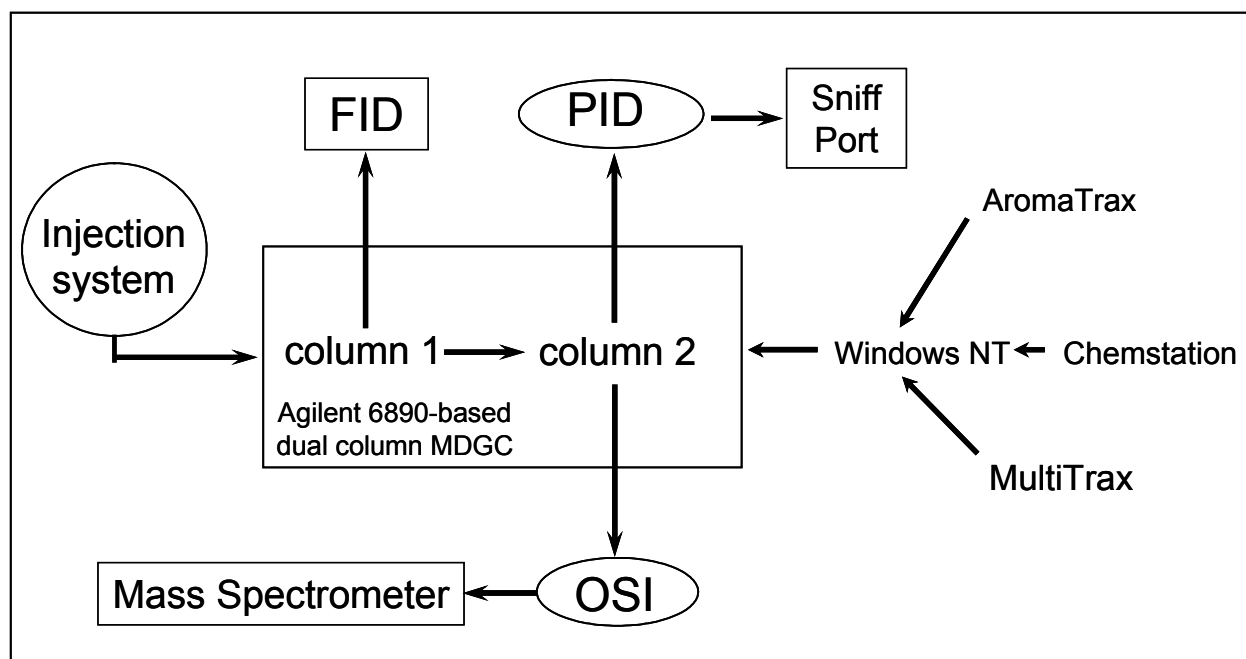


Figure 1. Schematic of AromaTrax™ MDGC-olfactometry system.

The general run parameters used during this project were as follows: injector, 240° C; detectors – FID, 270° C, PID, 240° C; column, 40° C initial, 3 min hold, 7° C / min, 220° C final, 10 min hold; carrier gas, helium.

For odor profile investigations the critical elements of the AromaTrax™ GC-O system pictured above are the following:

- Olfactory detector which enables the analyst to apply an odor tag to a peak or a region of the chromatographic separation. The odor tag consists of odor character descriptors, an odor event time span and perceived odor intensity.
- High sensitivity electronic signal (i.e. PID detector in series) and MS compound identification (i.e. MS detector in parallel); simultaneous with olfactory response.
- Dual column MDGC system with heart-cutting capability enables isolation of critical trace level odorants from complex background matrices (Wright et al. 1986; Gordon et al., 1988; and Willers et al. 2003). A cryotrap acting at the front of the second column further enhances these 'needle from the haystack' separations by enabling transferred heart-cut segments to be refocused prior to final separation and delivery to the PID-MS-O detector system.

- AromaTrax™ software facilitates the olfactory event notekeeping challenge of the analyst (i.e. human 'olfactory detector'). Utilizing a touchscreen monitor the analyst records the appropriate odor tag as odor notes are detected during the run.

### Sampling:

Solid Phase Microextraction (i.e. SPME) utilizing a 1 cm Carboxen-modified PDMS - 85 µm fiber was the primary field and headspace sampling technique utilized for this overview odor profiling study (Chai and Pawliszyn, 1995; Chai and Tang 1997; Spinhirne et al, 2002). SPME collections were carried out under a number of different conditions, including (a) direct sampling of the feedyard and swine barn environments – utilizing variations in downwind distance and exposure time for cross-comparison purposes and (b) indirect sampling of the feedyard environment exposed materials from 1 quart glass headspace vessels – utilizing variations in exposure time for cross-comparison purposes. All SPME collections were carried out under ambient conditions.

### Animal Feeding Facilities:

The air environments associated with two different high density livestock operations were sampled for purpose of this initial odor profile study series, including a 50,000-head capacity commercial cattle feedyard and a commercial swine barn in northwest Texas. An attempt was made to limit each of the direct - variable distance – downwind sampling series to periods of relatively stable straight line wind patterns. Meteorological conditions, general odor assessments and independent H<sub>2</sub>S concentrations (i.e. by multiple Jerome 631-X H<sub>2</sub>S monitors from Arizona Instruments, Tempe, AZ) were carried out to begin, during and to end the direct SPME sampling periods. In the case of the swine facility, exploratory direct SPME headspace samples were collected both from inside and outside the barns. Table 1 summarizes the basic environmental conditions and side-by-side H<sub>2</sub>S measurements during field events in this study.

Table 1. Environmental conditions and measured H<sub>2</sub>S concentrations during field air sampling.

Location	Start	End	H <sub>2</sub> S (ppb)	Odor description	Wind speed at 2 m (m/s)	Wind speed at 10 m (m/s)	Wind direction (deg)	T <sub>air</sub> (C)	RH (%)	P (kPa)
Exhaust fan at swine finish barn (December 8 – 10, 2003)										
	12 noon	12 noon	404 (374)	Characteristic swine barn odor	n/a	7.35 (3.14)	247 (76)	16.0 (3.90)	52.0 (7.27)	88.0
20 m downwind from commercial cattle feedyard (January 28, 2004)										
	10:20 A.M.	2:20 P.M.	3.75 (1.5)	Feedyard odor and "burnt crop field" smell	6.84 (0.47)	9.14 (0.62)	239 (15)	8.95 (2.38)	22.5 (3.11)	88.2 (0.05)
2,000 m downwind from commercial cattle feedyard (January 28, 2004)										
	11:55 A.M.	3:55 P.M.	3.4 (0.55)	Faint feedyard odor and "burnt crop field" smell	6.25 (0.77)	8.19 (1.14)	251 (9.6)	12.0 (1.71)	19.7 (0.96)	88.1 (0.08)
Adsorption to common materials inside a commercial cattle feedyard (January 28 – February 18, 2004)										
	12 noon	12 noon	n/a	Characteristic feedyard odor	3.23 (1.13)	n/a	197 (57)	2.50 (3.60)	n/a	n/a

Note: values in ( ) signify standard deviation around mean; n/a = not available

## RESULTS and DISCUSSION

The odor profiling investigative process is basically the same regardless of whether attempting to define the major odor carriers in a plastic packaged food product or in a work environment. This process essentially involves collecting, concentrating and analyzing the volatile odorants directly from the field or target headspace, ranking the individual odorants relative to odor character and intensity and correlating to a sensory panel gradation of the composite sampled environment. Working with investigators at TAMU in Amarillo, this process was carried out under a variety of conditions relative to the commercial cattle feedyard and a swine barn in northwest Texas. These efforts, as summarized below, reconfirm (i.e. as previously reported) the overall complexity of these environments; both in terms of total volatile compounds produced and the number of significant potential odorants among those volatile compounds.

Among the lessons we have learned using a GC-O based approach to malodor investigations is that it is possible to look too closely at the volatiles / odorant composition of any matrix. Utilizing appropriate volatiles concentration techniques it is always possible to generate a 'forest' of chromatographic peaks and corresponding odor notes. From a practical standpoint (i.e. relative to long distance odor impact) most of that data is little more than background clutter or noise with negligible contribution to the primary sensory gradation difference. An example of this from this current study is shown in Figure 2 below; a 48 hour SPME fiber exposure taken from inside a test swine barn at a point near the exhaust fan.

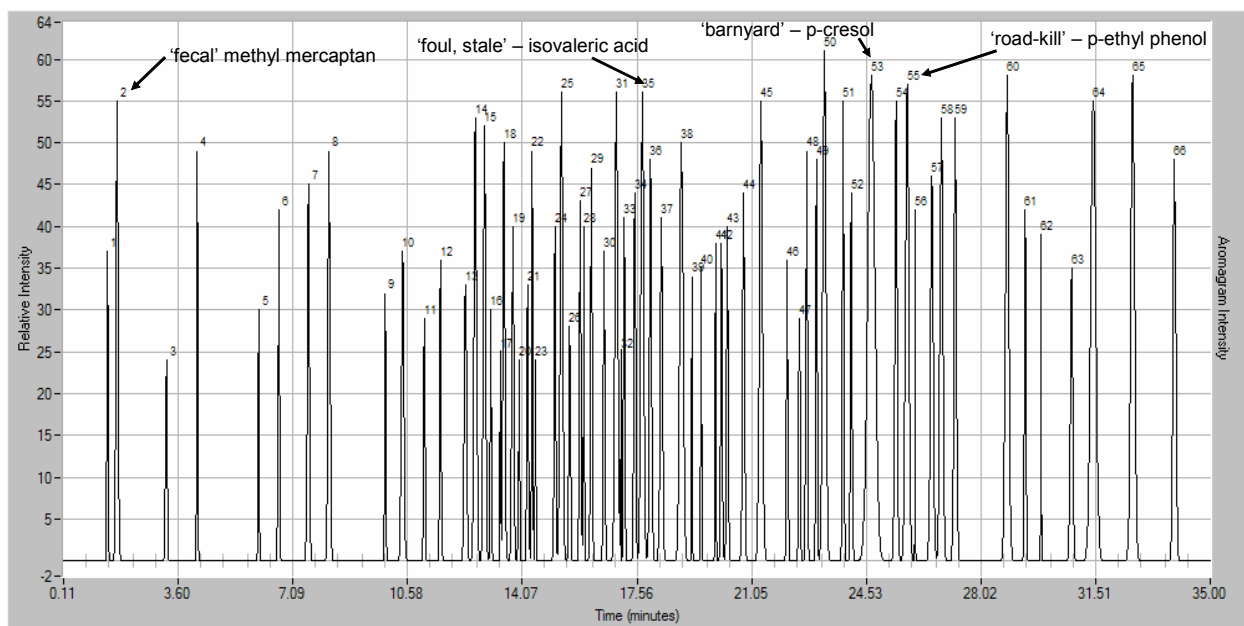


Figure 2. Aromagram from 48 hr SPME collection at the exhaust fan of a swine finish barn.

Figure 2 is an aromagram which was generated by the GC-O investigator monitoring the odor impact of the individual compounds as they elute from the chromatographic column. The retention time span of the peaks reflect the start and end time for the individual odor responses while the peak height reflects the perceived intensity of these responses. By overlaying these

sensory responses with the PID and MS signals, it is possible to correlate the sensory responses with corresponding electronic signals and odorant identification respectively. At least 66 discrete odor notes were detected under the conditions of collection and many of these reflected intense to overwhelming odor intensities. The full range of previously reported swine farm odorants were detected, including: H<sub>2</sub>S and its organic homologs; trimethylamine; VFA's, ranging from acetic to octanoic; phenolics, including phenol, p-cresol and p-ethyl phenol; indole, skatole and a wide variety of ketones, diones and aldehydes among others. A summary of a few of the major odorants from this odor profile analysis is presented in Table 2.

Table 2. Representative odorants from inside tunnel-ventilated swine finish barn collected for 48 hrs with SPME near the exhaust fan.

Peak Number	GC Column Retention Time (min)	Odor Descriptor	Preliminary Odorant Identification
1	1.42	foul, fecal	hydrogen sulfide
2	1.68	fecal	methyl mercaptan
3	1.70	fishy	trimethylamine
4	4.15	buttery	diacetyl
6	6.60	amine	unknown amine or diamine
7	7.60	grassy	hexanal
10	10.30	buttery	pentanedione
14	12.60	savory, nutty	dimethyl pyrazine
18	13.45	musty, vinegar	acetic acid
20	13.85	fecal	dimethyl trisulfide
25	15.20	vomitus, body odor	propionic acid
27	15.85	cardboard, musty	? nonenal
31	16.80	vomitus, body odor	butyric acid
35	17.60	body odor, foul	isovaleric acid
38	18.80	foul, characteristic	valeric acid
45	21.30	medicinal	guaiacol
50	23.14	medicinal, floral	phenol
52	24.10	beet, vegetable	geosmin
53	24.40	barnyard, characteristic	para-cresol
54	25.80	roadkill, decay, foul	para-ethyl phenol
58	27.15	taco shell, bat cave	2'-aminoacetophenone
60	28.70	outhouse	para-vinyl phenol
62	29.83	outhouse	indole
63	30.70	outhouse, naphthalenic	skatole
64	31.26	floral, honey	phenyl acetic acid
65	32.50	taco shell, bat cave	1-(2-aminophenyl)-1-butanone

For purpose of reducing this mass of data and focusing on the most important odorants in the field it was necessary to adopt a strategy of reduced collection time and/or increasing distance from the odor source. Figures 3 and 4 reflect such a series; generated at increasing distance from the commercial beef cattle feedyard source and under shorter collection times (i.e. 4 hr) relative to that adopted for Figure 2.

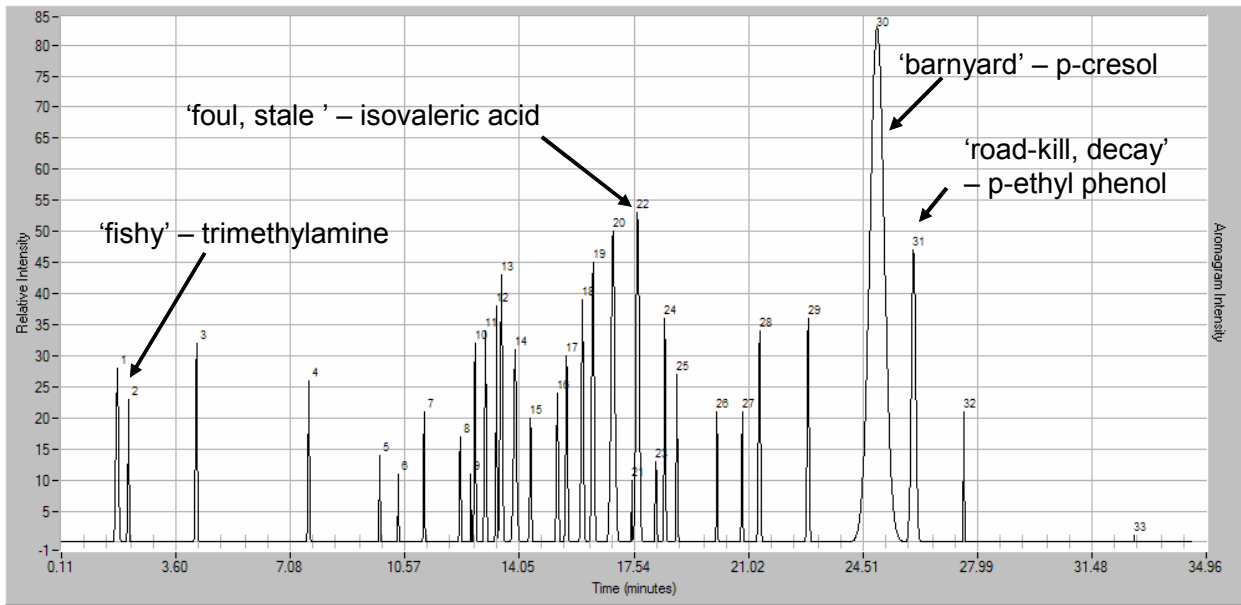


Figure 3. Aromagram for 4 hr SPME fiber collection at 20 m downwind (“near” site) from commercial beef cattle feedyard.

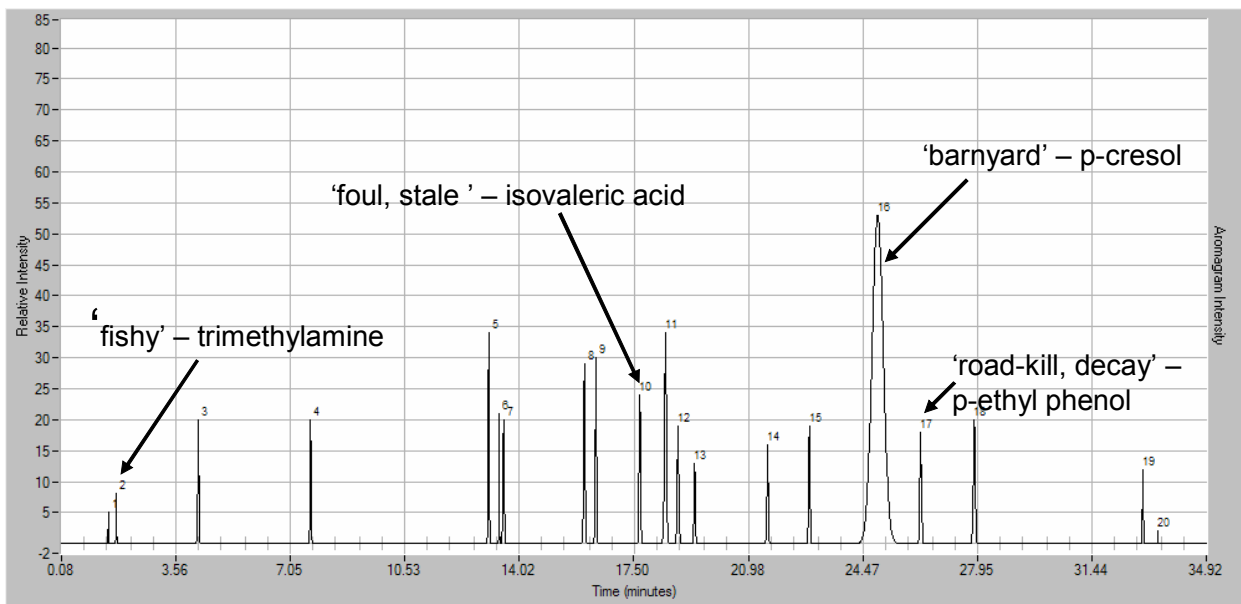


Figure 4 Aromagram for 4 hr SPME fiber collection at 2,000 m downwind (“distant” site) from commercial beef cattle feedyard.

The reduced sample loadings reflected in this pair of aromagrams presents a much more useful profile of the key individual odorants within these environments. Key observations which can be extracted from this sample series are the following:

- Increasing distance from the source results in a significant reduction in the total number of detectable odors as well as corresponding reductions in odor impact intensities for those odors that are detectable. Most noteworthy is the fact that, of the most commonly cited feedyard odorants, only para-cresol was shown to carry a significant individual olfactory

response for the approximate 2000 meter distance sample. Although the olfactory response for para-cresol was shown to be reduced by approximately 50% relative to the near-site equivalent, this response was still recordable as 'strong' and 'characteristic barnyard'. In contrast, all other primary focus odorants were shown to be below their respective odor thresholds with the exception of isovaleric acid, which was only faintly detectable.

- The near-site collection resulted in strong-to-intense odor responses for most of the commonly cited feedyard odorants. Particularly prominent was an intense 'barnyard', 'urinous' or 'characteristic' response for para-cresol. A second tier of strong to intense responses were shown for para-ethyl phenol (i.e. 'foul', 'road-kill'); isovaleric acid (i.e. 'body odor', 'musty'); butyric acid (i.e. 'vomitus'); and trimethylamine (i.e. 'fishy').
- Relative to the near-site collection, only the dimethyl trisulfide homolog of the sulfide series presented with a significant individual odor response (i.e. strong 'fecal'). There were no significant odor responses for H<sub>2</sub>S or its lower MW organic homologs. Parallel H<sub>2</sub>S concentration determinations carried out with two calibrated Jerome 631-X H<sub>2</sub>S analyzers at the near-site sample point confirmed that the approximate 3 ppb H<sub>2</sub>S levels were too far below the published odor threshold of approximately 10 ppb (Devos et al. 1990) to 130 ppb (MSDS, 2002) to contribute significantly to the strong composite odor perceived at that position and time of sampling.
- The near-site collection resulted in a surprisingly strong to intense 'fishy' odor note corresponding to trimethylamine. This strong response is particularly noteworthy considering the aforementioned absence, in this chromatographic region, of odor responses for H<sub>2</sub>S, methyl mercaptan or dimethyl sulfide.

The goal of these odor profile studies was to develop an approximate qualitative priority ranking of the individual odorants as emitted by the source. In this current study there were distinct differences in the odor profiles which existed at or near the source relative to the profiles which existed upon increasing distance (i.e. and increasing dilution) from the source. Table 3 below summarizes the approximate top odor profile rankings for these two regions as extracted from the preliminary odor profile study of the commercial feedyard.

Table 3. Approximate odor profile priority rankings for a commercial cattle feedyard.

Odor Priority Ranking	Near Source	Distance From Source
1	trimethylamine	para-cresol
2	para-cresol	isovaleric acid
3	butyric acid	para-ethyl phenol

There are a number of factors which are taken into consideration in developing this initial priority ranking profile. These include odor character as well as detectability and perceived intensity. However, these results must be interpreted within the context of the characteristics and limitations of the SPME sampling approach taken in this preliminary study. Sensitivity of SPME technique to solubility constants and volatility-driven rate constants is well recognized (Pawliszyn, 1997) and must be considered relative to these preliminary assessments. Repetition of the GC-O based profile assessment with alternative approaches such as sorbent tube or cryogenic concentrating will be critical for confirmation of this critical assessment.

A second lesson learned from previous investigations of this type is that special considerations should be carried when the key odorants are shown to be compounds of low volatility and high odor potency (e.g. para-cresol). Under such conditions these compounds will be slow to diffuse from the source and as a result will tend, over time, to accumulate and increase in concentration at the source; adsorbing onto, permeating into and reemitting from structural or incidental

materials at or near the source. This is analogous to indoor environments where, in extreme cases, it has been necessary to remove structural and incidental materials (i.e. sheetrock, boxes, paper, fiber and carpet etc.) from these source areas for effective site odor remediation, since even forced ventilation effects can be too slow under these conditions. Figures 5 and 6 below illustrate this effect relative to two types of material specimens (10 × 5 × 0.6 cm plates) which were exposed to air inside a 50,000-head cattle feedyard for 3 weeks. Samples were collected from closed headspace of clean jars holding these specimens after 3 week collection period.

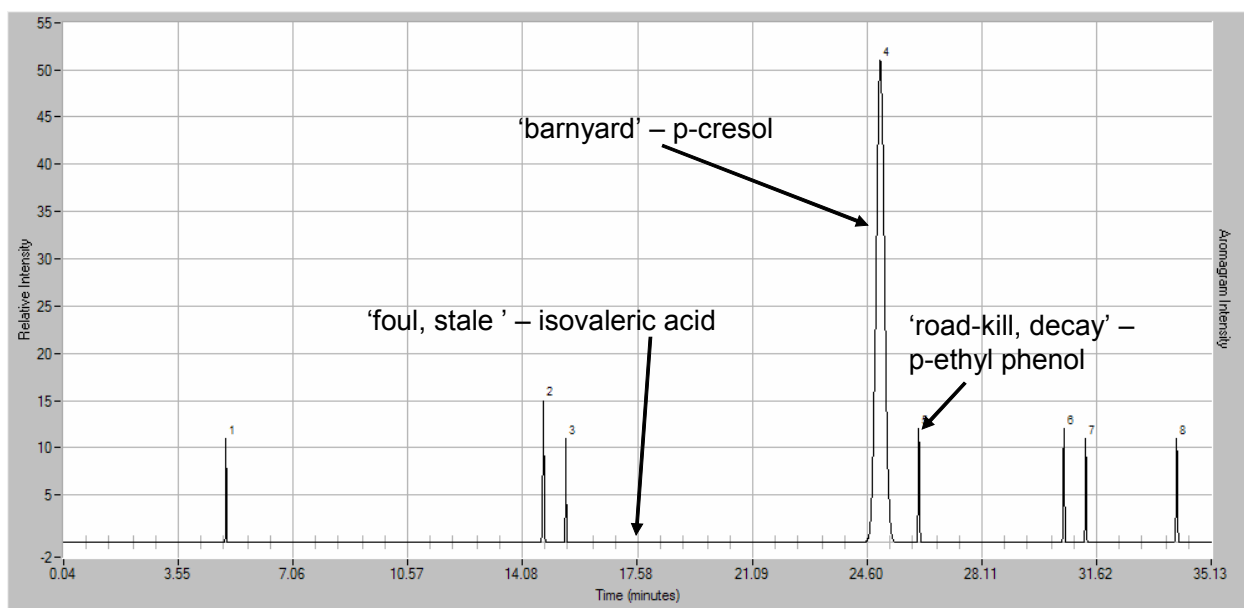


Figure 5. Aromagram for plastic plate exposed for 3 weeks at a large cattle feedyard.

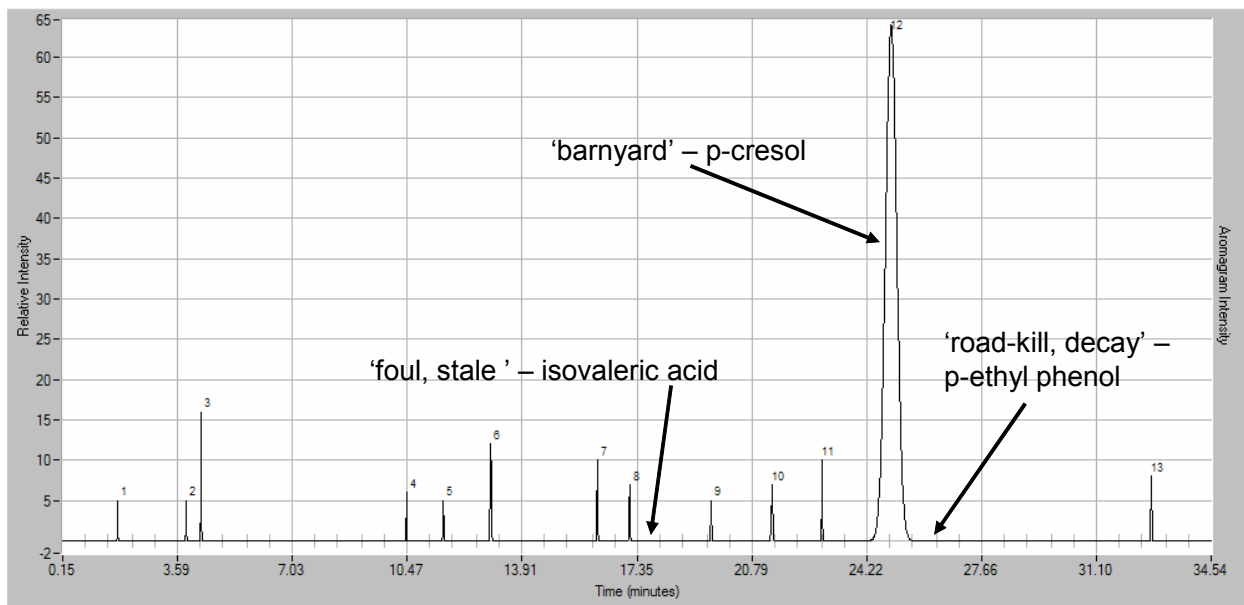


Figure 6. Aromagram for carbon steel plate exposed for 3 weeks at a large cattle feedyard.

A significant consideration relative to these odor profiles is the fact that the environment exposed specimens were thoroughly flushed with tap water and blotted dry prior to inserting into clean headspace vessels for sampling. It is noteworthy that in spite of this pre-wash sample preparation step, a very strong response for para-cresol was still detected; even with relatively short sample collection periods. Although this effect was expected for the plastic chip specimen it is somewhat surprising that it also appeared to hold for the steel plate equivalent. Also noteworthy relative to this sampling series is the fact that, for both plastic and steel, the other commonly targeted odorants were not detected under conditions where the para-cresol response was very strong. The tendency for para-cresol to tenaciously adsorb onto surfaces may account for a tendency to increase in concentration at the source over time; thereby also increasing the odor impact of the source over time.

Figures 7 and 8 below illustrate another interesting analytical effect which may have practical significance to the field of livestock odor analysis. It is the 'flooding out' effect which is often utilized to increase the headspace concentration of target volatile organics, including the trace level odorants. The addition of an excess of water to a dry solid sample matrix has the effect of displacing adsorbed organics, and in the case of volatile compounds increasing their relative concentration in the headspace.

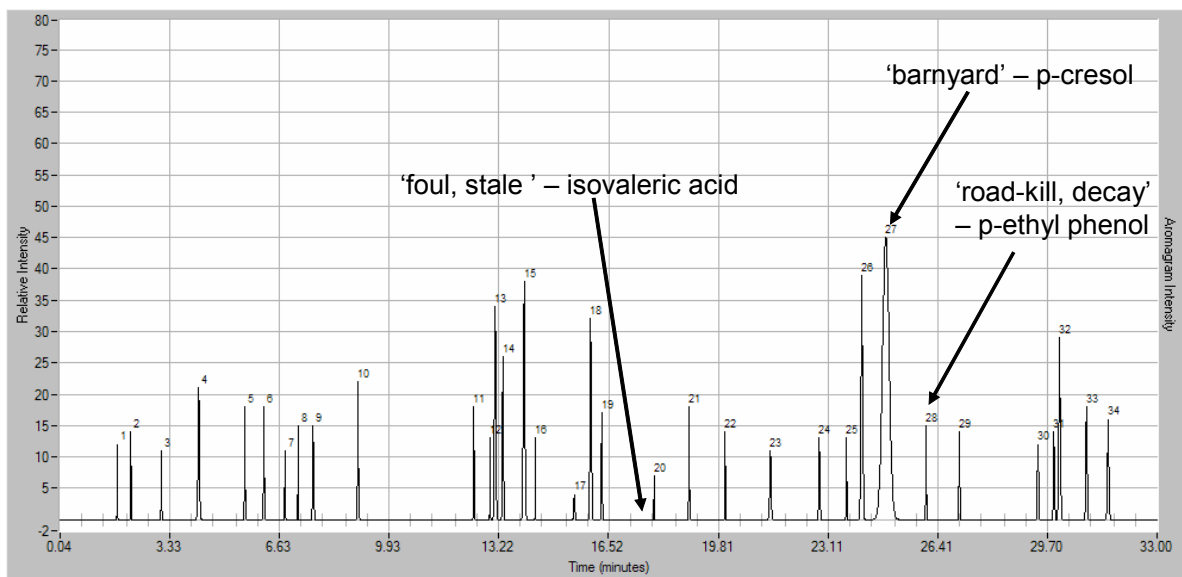


Figure 7. Aromagram for top 3 cm of surface soil taken at 50 m downwind from commercial feed-yard. Sample collected using 1.5 hr SPME fiber collection before water added.

These two aromagrams illustrate this 'flooding out' effect relative to a sample of surface soil (i.e. ~top 3 cm) collected a distance of @ 50 meters downwind of the commercial feedyard. Figure 7 is the aromagram which was generated for the sample as originally submitted while Figure 8 was generated from the same sample subsequent to water saturation. Shown is a dramatic increase in the odorant composition of the sample headspace; both in terms of the numbers and relative intensities of the individual odorants. Key observations which can be extracted from this sample series are the following:

- Significant increases relative to several key odorant compounds; including: peak #40 ( para-cresol - 'barnyard', 'characteristic'); peak #41 (para – ethyl phenol – 'foul', 'road-kill'); peak #38 (unknown – 'musty'); peak #39 (geosmin - 'beet', 'vegetable'); peak #30 (isovaleric acid

– 'musty', 'body odor'); peak #22 (dimethyl trisulfide – 'fecal') and others. The peak numbers referenced are taken from the post-flood aromagram (i.e. Figure # 8).

- Detectable but relatively insignificant responses for the lower molecular weight volatile fatty acids (i.e. peak #24 - propanoic and peak #29 - butyric). Acetic acid was not odor detectable for either sampled condition.

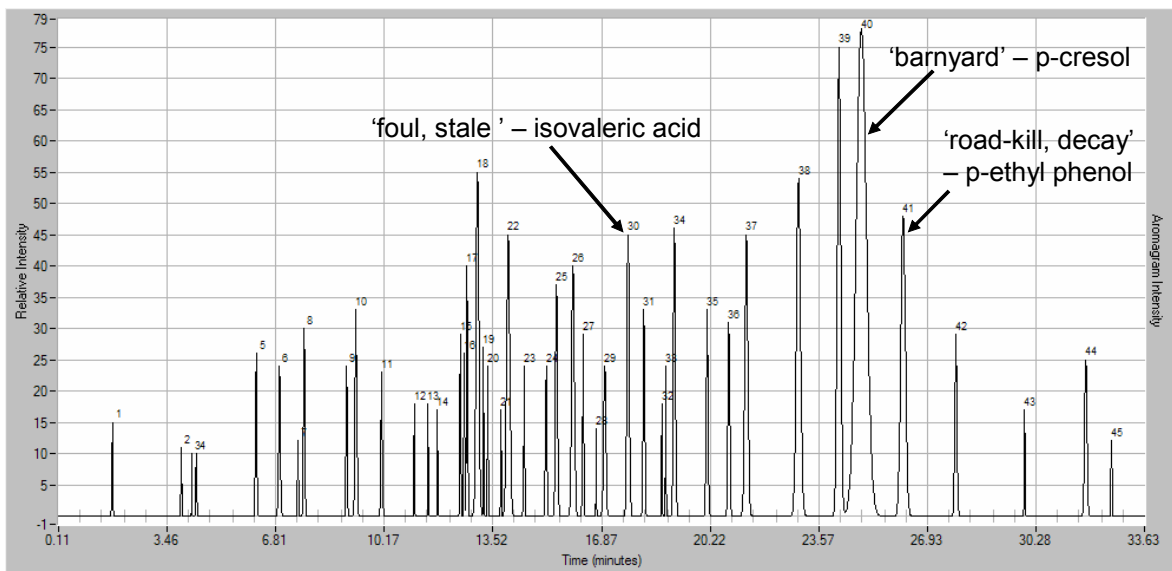


Figure 8. Aromagram for top 3 cm of surface soil taken at 50 m downwind from commercial feed-yard. Sample collected using 1.5 hr SPME fiber collection after water added.

It is this 'flooding-out' effect which likely accounts for reported increased odor complaints surrounding commercial high-density livestock operations subsequent to rain events. It is possible, although unproven at this point, that extended periods of dry weather followed by a rain event may magnify the odor impact of this 'flooding out' effect.

Based upon this preliminary odor profile survey study, para-cresol appeared to constitute the single most prominent odorant emission from both cattle feedyard and confined barn swine operation samples. However, there also appeared to be significant differences between these two sampled environments relative to some of the secondary odorants. This is illustrated in Table 4 below relative to indole and skatole, two other relatively high boiling odorants that have been previously identified in commercial livestock environments.

Table 4. Comparison of high molecular weight odorant ratios – cattle feedyard vs. swine barn.

	Swine Finish Vent	Feedyard Position 1	Feedyard Position 1
distance from source	10 m	20 m	20 m
collection time	1 hr	4 hr	24 hr
para-cresol peak area (ion 107)	526,290	394,769	1,055,076
indole peak area (ion 117)	3,157	405	506
skatole peak area (ion 130)	4,673	<100	<100
ratio para-cresol/indole	~170:1	~1,000:1	~2,000:1
ratio para-cresol/skatole	~110:1	>4,000:1	>10,500:1

Comparison of the ratio values for the one hour swine barn vent and four hour feedlot samples indicated higher swine house vent concentration levels of both indole and skatole relative to para-cresol. Although these odor profile experiments were not approached as a rigorous cross-comparison of these two environments these results are believed to be sufficiently dramatic and consistent to warrant further investigation. Shown to be consistent across a wider cross-section of commercial facilities, such ratio differences between primary and secondary odorants can explain perceived odor character differences between these two types of operations. Previous efforts have shown that although the list of potential odorants may be very similar between animal species in high-density settings, there may be relatively dramatic differences between them regarding the designation of primary and secondary odorant status and corresponding concentration ratios. Based upon this current odor profile effort, para-cresol appears to be the key odor character defining compound relative to distance separation from either the high density swine or livestock operations. In contrast, previous odor profile efforts relative to the Mexican free-tail bat colonies in central Texas (Nielsen et al. 2001) have shown the key odor character defining compound to be 2'-aminoacetophenone; a compound of extreme odor potency carrying an odor character which is often described as 'taco shell'. Interestingly, current odor profile efforts relative to the confined barn swine operation have shown 2'-aminoacetophenone to be present in these environments also but only as a minor odor contributor relative to para-cresol. Conversely, para-cresol was also found to be present in the high-density bat cave environments but only as a minor odor contributor relative to the character defining impact of 2'-aminoacetophenone.

## CONCLUSIONS

These current collaborative efforts were directed at applying to high-density livestock operations, some of the lessons learned in utilizing GC-Olfactometry to resolve past, highly diverse odor-focused investigations in the consumer product industry. Past experience has proven GC-O based odor profiling to be an essential technology for prioritizing the individual odor contributors to any malodor issue. The prioritization of the individual odor contributors has proven, in turn to be an essential element of rapid response to crisis-driven malodor issues. Based upon these current overview odor profile efforts, para-cresol appears to be the key odor character defining compound relative to distance separation from the target high density cattle feedyard and swine barn facilities. As expected, at or near-source odor profiles were much more complex; with the full range of previously reported livestock odorants detected, including: hydrogen sulfide and its organic homologs, trimethylamine and VFA's, ranging from acetic to octanoic. However, a surprising odor impact prominence for trimethylamine was shown for the near-source feedyard samplings. If these priority rankings can be proven consistent across a broader sampling of similar environments it will be essential that sampling, analytical and odor abatement strategies be developed or modified to reflect these priority rankings (Wright, 1997). Particular attention appears to be warranted for para-cresol due to several factors; including:

- Odor impact prominence over great distances from the source
- Relatively low volatility and high polarity; factors which may result in slow diffusion and at-source concentration build-up over time
- Surface adsorption propensity; 'stickiness' which may magnify the near-source concentration build-up and odor impact effect through adsorption, permeation and re-emission effects from organic, structural or incidental materials at or near the source.
- Sensitivity to the 'flooding out' effect in concert with the above defined volatility, polarity and surface adsorption factors may serve to induce or magnify weather related odor excursions

The observations presented above do not purport to represent a definitive qualitative assessment of the complex field of high-density livestock odor impact. However, these observations are believed to be sufficiently compelling to warrant a more comprehensive GC-olfactometry based odor profiling investigation.

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