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A Survey of VOC Emissions from Rendering Plants

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ABSTRACT

Rendering is a global industry that recycles by-products resulting from butchering operations, which process billions of animals per year. About 50% of the weight of livestock is not consumed by humans and must be processed by rendering operations, which cook and separate the material into its protein and fat components. These products serve as a sustainable food source for livestock, feedstocks for oleochemicals, and raw material for biodiesel refineries. Due to the scale and nature of the raw materials and the cooking process, rendering operations emit a significant, but as yet poorly quantified, VOC load. Assessing this VOC load is important in order to calibrate the industry's contribution to global VOC emissions, and to help address nuisance odor problems. We conducted VOC air sampling of two facilities in California, USA during the winter and summer seasons. VOC and reduced sulfur analyses were conducted using 8 h ambient air samples. Analyses for amines, ammonia, aldehydes/ketones, and volatile fatty acids were conducted using sampling pumps. These analyses detected 43 compounds at the facilities, and the number and concentration of detectable compounds were seasonally dependent. The compounds present at the highest concentrations included: ammonia (1600–2800 ppb, i.e., winter–summer levels), acetic acid (80–320 ppb, along with twelve other fatty acids ranging from ~0.5–140 ppb), acetone (55–241 ppb, along with nine other aldehyde/ketone products ranging from 0.4–60 ppb), and ethanol (15–81 ppb). These constituents have low odor thresholds and thus contribute to nuisance odor problems. Further, the overall VOC contribution arising from rendering facilities on a global scale is as yet very poorly characterized. This analysis will be useful to guide the development of new odor abatement strategies and strategies for the reduction of VOC emissions associated with this critical industry.

Keywords: Rendering; VOCs; Sulfur; Amines; Volatile fatty acids; Carbonyls; Environmental sampling.

INTRODUCTION

Rendering is global industry that efficiently processes and recycles the significant by-product stream of butchering and meat-packing operations including: hides, skins, hair, feathers, hooves, horns, feet, heads, bones, toenails, blood, organs, glands, intestines, extraneous muscle and fat tissues, egg shells, and whole carcasses (i.e., dead stock and slaughterhouse rejects)) (Meeker and Hamilton, 2006). The global scale of butchering a slaughterhouse operations are immense, and return exceedingly large volumes of by-product material that must be processed, sterilized, and ideally repurposed into value-added products. For example, approximately 28.7 million cattle, 115.4 million swine, 8.8 billion chickens, and 232.4 million turkeys were butchered in the USA alone in 2015 (Swisher, 2016). In the EU, 328 million cattle, swine, and sheep along with 6 billion chickens, turkeys and other poultry are processed annually (Caparella, 2016; EFPRA, 2016). While not readily available, the numbers from Asia, Africa, and South America are likely to be equally staggering. Indeed, roughly one third to one half of the live weight of these animals is not typically suitable for human consumption. Therefore, the rendering industry plays an important role in the global agricultural and food enterprise by providing for the efficient removal, decontamination, and repurposing of the large by-product stream from livestock and slaughterhouse operations. In

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fact, rendering operations process 49% of the live weight of cattle, 44% of the live weight of hogs, 37% of the live weight of broiler chickens, and 57% of the live weight of fish.(Meeker and Hamilton, 2006) In the US, the rendering industry processes greater than 22.7 million metric tons of by-product material annually (Swisher, 2016). In 2015, rendering operations in the EU processed approximately 22 million metric tons of animal by-product (Caparella, 2016; EFPRA, 2016).

The rendering process cooks, grinds, and separates these exceptionally large by-product streams and returns value-added products including: edible fats fit for human consumption, protein meals and fats suitable for livestock, fish, and pet feed, feedstock fats for the oleochemical industry, raw material for biodesiel refineries, and fertilizer for croplands (EFPRA, 2016). Further, the process provides an effective means to neutralize or deactivate biological contaminants associated with decaying raw material streams, such as bacteria, viruses, parasites and protozoa. Disposal alternatives in the absence of rendering would rely on environmentally and economically untenable solutions such as landfilling or incineration, which in either case would pose serious public health concerns and impractical energy requirements (Meeker and Hamilton, 2006). Indeed, rendering is more sustainable than alternative large-scale means for the disposal of animal carcasses and butchering by-products such as anaerobic digestion and composting (Gooding and Meeker, 2016).

Based on the extremely large scale of global rendering operations and the unique nature of the associated raw materials, we contend that the global VOC load associated with worldwide rendering operations could be significant. Nonetheless, a comprehensive global assessment of the nature and concentration of VOC emissions associated with rendering operations has never been undertaken. Only a few studies of rendering emissions have been conducted previously (Van Langenhove *et al.*, 1982, 1983; Defour *et al.*, 2002; Bhatti *et al.*, 2014). Additionally, these previous efforts have focused mostly on VOC emissions in the context of odors. Some were qualitative in nature (i.e., concentrations of the emissions were not analyzed) (Van Langenhove *et al.*, 1982), while others focused only on quantifying certain classes of VOC emissions (Van Langenhove *et al.*, 1983). One study has utilized GC-MS analyses to estimate concentrations of odorant molecules emitted from biofilter effluents associated with rendering operations (Defour *et al.*, 2002). Finally, just one other study has been conducted that aims to assess the total VOC emission load of a rendering plant (Bhatti *et al.*, 2014).

Our study differs from the previous assessments in several important ways: 1.) unlike the previous study, our sampling was conducted at an open-air facility, where the cookers and raw material piles are not confined within an enclosure; 2.) our study samples a continuous flow cooking system instead of a batch-cooking system; 3.) our study takes into account seasonal changes in VOC emissions associated with rendering operations, and 4.) our study also includes an assessment of an ancillary operation, the dead-stock processing plant that generates the raw material for the rendering operation. As such the study described herein complements the previous, groundbreaking assessment of rendering VOCs and thus serves to further clarify the VOC emission profile of this important and global industry.

In the US, state and federal agencies closely regulate the rendering industry with routine inspections of the facilities. Among the different agencies responsible for regulated inspections is the Food and Drug Administration (FDA) responsible for inspecting rendering facilities for compliance to Bovine Spongiform Encephalopathy (BSE) related regulations and chemical residues tolerance. The Animal and Plant Health Inspection Service (APHIS) is responsible for issuing export certificates and therefore also inspects rendering facilities for compliance to restrictions that may be imposed by the importing country. Finished products are inspected and tested by state feed control officials to ensure quality, and compliance to feed safety and adulteration policies. Other federal and state agencies also play important roles by issuing air quality permits and feed and rendering licenses (Meeker and Hamilton, 2006).

The rendering industry invests significant efforts and capital into controlling odor emissions that result from the processes. Modern facilities, for instance, are equipped with sophisticated mechanisms for controlling particulate and odor emissions. Malodorous emissions from rendering processes are controlled by a variety of strategies, including combustion/incineration, chemical oxidation, and wet or biological scrubbing (Bethea *et al.*, 1973; Shareefdeen *et al.*, 2002; Shareefdeen *et al.*, 2005; Sindt, 2006). Despite all of the technological advances applied to the rendering process, the industry still suffers from nuisance odor problems that can contribute to public relations issues and make site selection for new operations difficult.

Thus, a thorough investigation of the VOCs emitted from the rendering process, at different sites of the plant, and during different seasons of the year, might help researchers better understand the constituent molecules responsible for nuisance rendering odors. In this manuscript, we describe the results of a series of on-site air sampling studies at a dead-stock skinning plant and a rendering facility in California, USA in both winter and summer.

MATERIALS AND METHODS

Sampling Sites

We conducted on-site ambient air sampling at two plants in the Central Valley region of California, USA. The first site, herein referred to as the "dead-stock facility", was dedicated to processing mostly dead stock cattle along with some swine. Specifically, this plant (Fig. 1(A)) was an open-air facility that processed fallen cattle and calves from regional dairy operations by removing the hides and then quartering the carcass. The resultant carcass sections were then passed through an auger and loaded via a conveyer into a tractor-trailer for transport to a rendering plant for further processing. Simultaneously, the hides were collected, rinsed, salted, and stacked onto pallets for shipment to tanneries. Odor streams for this operation include those associated with the dead and decomposing animals, rumen fluid and manure from the opened carcasses, and the substantial wastewater stream associated with the process, which is pumped into a series of settling ponds on site.

The second facility was an open air rendering plant located within 50 miles of the dead-stock facility. This plant (Fig. 1(B)) rendered material from the dead-stock facility, as well as other sources. In this plant, raw material was fed via front-end loader into a large screw auger/grinder (known as a "hogger") that feeds into high-pressure cookers and grinders. The cooked material is then pressed in order to separate the fats from the protein meal, which is further ground and dried. The rendered products (protein meal or fats) are then loaded into tractor-trailers for shipment off-sight. Odor streams for this plant included those associated with the raw material pile, cooking vapors, and the significant wastewater stream associated with the operation. Similar to the dead-stock facility, the wastewater was processed via a series of settling ponds on the property.

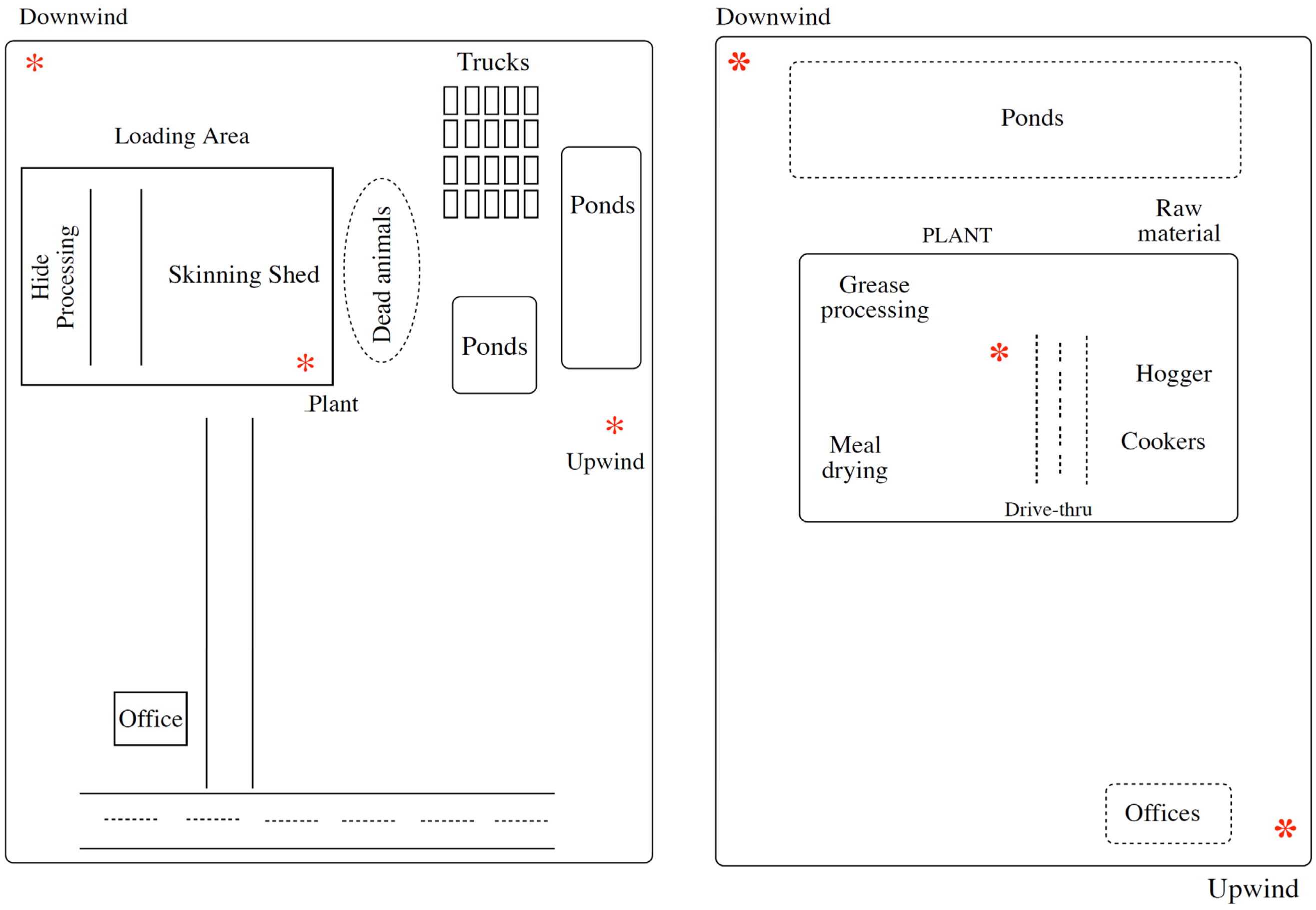
We conducted extensive ambient air sampling at both facilities at three different sites on each property (highlighted with a red star), as depicted in Fig. 1. Further, the sampling was conducted both in the winter (early January) and summer (early August) seasons. At each plant, three different areas were sampled: up-wind or down-wind of the operation and directly in the plant area.

Sample Collection

We collected samples at each site using a combination of sampling equipment and standardized analyses to assess the VOCs in the two plants (Fig. 1). In all cases, the field samples were analyzed by means of standardized methods by one of two contract environmental analysis laboratories in California, USA.

First, we set out to obtain a broad survey of detectable VOCs by collecting 8-hour ambient air samples using evacuated 6 L silicon-coated summa cans (i.e., Silonite^{TM}). These samples were then analyzed for Volatile Organic Compounds and Tentatively Identified Compounds (TICs) by contracting with an environmental laboratory that employed EPA method TO-15 for the analysis. Briefly, the samples were prepared for analysis by the contract laboratory by bringing the canister to positive pressure with ultra-high purity helium. Next, up to a 500 mL aliquot of the canister contents was collected and concentrated, passed through a water/CO_2 management system, and cryofocused prior to injection into a GC/MS for analysis following the EPA TO-15 protocol. By means of a similar protocol, the summa canister samples were also utilized to conduct an analysis for Total Reduced Sulfur via GC/SCD analysis following the ASTM D-5504 method.

We also collected 100 min samples using a series of sampling cartridges and pumps to assay for volatile



(A) (B)

Fig. 1. Schematics of rendering facilities. A) "Dead-stock facility" and B) open-air rendering plant.

amines, ammonia, volatile fatty acids, and carbonyls (i.e., aldehydes and ketones), respectively. For example, the carbonyls analysis was conducted by pumping plant air through a commercially available cartridge of 2,4-dinitrophenylhydrazine (DNP) impregnated silica gel at a flow rate of 1000 mL min^{-1}. This sample was then extracted and a 10 mL aliquot of the extract was analyzed by HPLC/UV using EPA method TO-11A. Similarly, amines were sampled using a silica gel cartridge (250 mL min^{-1} flow rate) and analyzed using the NIOSH 2010 method. Ammonia was sampled utilizing a sulfuric acid coated Anasorb® cartridge (250 mL min^{-1} flow rate) and analyzed using the OSHA ID-164 method. Volatile fatty acids (VFAs) were sampled using a sodium hydroxide-coated silica gel cartridge (700 mL min^{-1} flow rate) and were analyzed by GC/MS according to standard operation procedures of one of the contract laboratories. In the obtained reports for all samplings, the results were presented in relation to the Method Reporting Limit (MRL) value.

RESULTS AND DISCUSSION

Winter Sampling

In January of 2015, we collected VOC/TIC and sulfur analysis of 8-hour summa can samples at both the dead-stock facility and the rendering plant. Additionally, we collected 100 min ammonia and VFA analyses at both sites. At both plants, we collected air samples in three different locations: up-wind from the plant, inside the plant, or down-wind from the facility (See Fig. 1(B) for sampling sites indicated by red stars). A qualitative summary of the results from these experiments appears in Table 1. Sulfur sampling experiments showed no detectable reduced sulfur compounds at either plant at any of the sampling sites. VFAs and ammonia were detected in both facilities in the plant region. VOCs were detected at all plant regions in the rendering facility whereas at the dead-stock plant, VOCs were detected up-wind and in the plant site regions but not down-wind.

Ammonia experiments were conducted during a 100 min sampling period, and the results show that the detected concentration was 730 ppb at the rendering facility and 1600 ppb (1.6 ppm) at the dead-stock facility during the winter sampling.

The results for the VFAs analysis during the winter visit are depicted in Fig. 2(A). At the dead-stock facility the only VFA detected was butanoic acid at a 0.77 ppb concentration. On the other hand, at the rendering facility another 6 VFAs were detected. The butanoic acid concentration was significantly higher, 19 ppb, when compared to the dead-stock facility. Acetic acid was the compound present at the highest concentration, 78 ppb, followed by propionic acid (25 ppb). Compounds present in smaller concentrations included 2-methylpropanoic acid (1.4 ppb), 3-methylbutanoic acid (1.3 ppb), pentanoic acid (2 ppb), and 2-methylbutanoic acid at 1.1 ppb.

Similar to the VFA results, winter VOC sampling at the rendering plant revealed a larger variety of compounds than the dead-stock facility. The only VOCs detected at the dead-stock facility were ethanol (4.73 ppb up-wind and 53.9 ppb in the plant), acetone (14.4 ppb in the plant) and 2-propanol (7.73 ppb). At the rendering facility, ethanol was also detected up-wind (4.08 ppb) and in the plant (14.8 ppb). Acetone was also detected in the plant (13.8 ppb) and also down-wind (3.98 ppb). Additionally, 2-propanol was only detected up-wind (5.66 ppb), and thus may not be associated with the plant emissions. Other compounds detected inside the plant included methanol (11.8 ppb) and 2-butanone (2.88 ppb). Furthermore, propene, benzene and toluene were detected down-wind at 19.3 ppb, 1.44 ppb and 1.34 ppb, respectively. Chemical compounds detected in the winter VOC air sampling analyses are depicted in Fig. 2(B).

Summer Sampling

We conducted similar analyses at the same sites in both plants the following summer (August 2015). In addition to the analyses described above, we also conducted 100 min amine and carbonyl (i.e., ketones/aldehydes) analyses as well. The results of these studies are summarized in Table 2. The sulfur and amine sampling experiments showed no detectable reduced sulfur or amine compounds at either of the plants at any of the sampling sites. The ammonia analysis shows that the compound is detectable at the rendering facility both inside the plant and down-wind. Interestingly, ammonia was not detected at the dead-stock facility during the summer sampling, despite being present during the winter sampling visit. The reason for this discrepancy is not immediately apparent. VFAs were detected both at the rendering and at the dead-stock facility but only in the plant, not up or down-wind. Furthermore, carbonyls and VOCs were detected at all three sampling regions in both facilities (Note: down-wind carbonyl sampling at the rendering facility failed due to a pump malfunction).

In general more distinct compounds were detected at higher concentrations at both facilities during the summer sampling as compared to the winter studies. This result is as expected since the volatility of VOCs increases with ambient temperature.

Table 1. Winter sampling at the rendering facility and dead-stock facility.

	Winter					
Compound	Rendering			Dead-Stock		
	Up wind	In the Plant	Down wind	Up wind	In the Plant	Down wind
Sulfur	×	×	×	×	×	×
Ammonia	×	✓	×	×	✓	×
VFAs	×	✓	×	×	✓	×
VOCs	✓	✓	✓	✓	✓	×

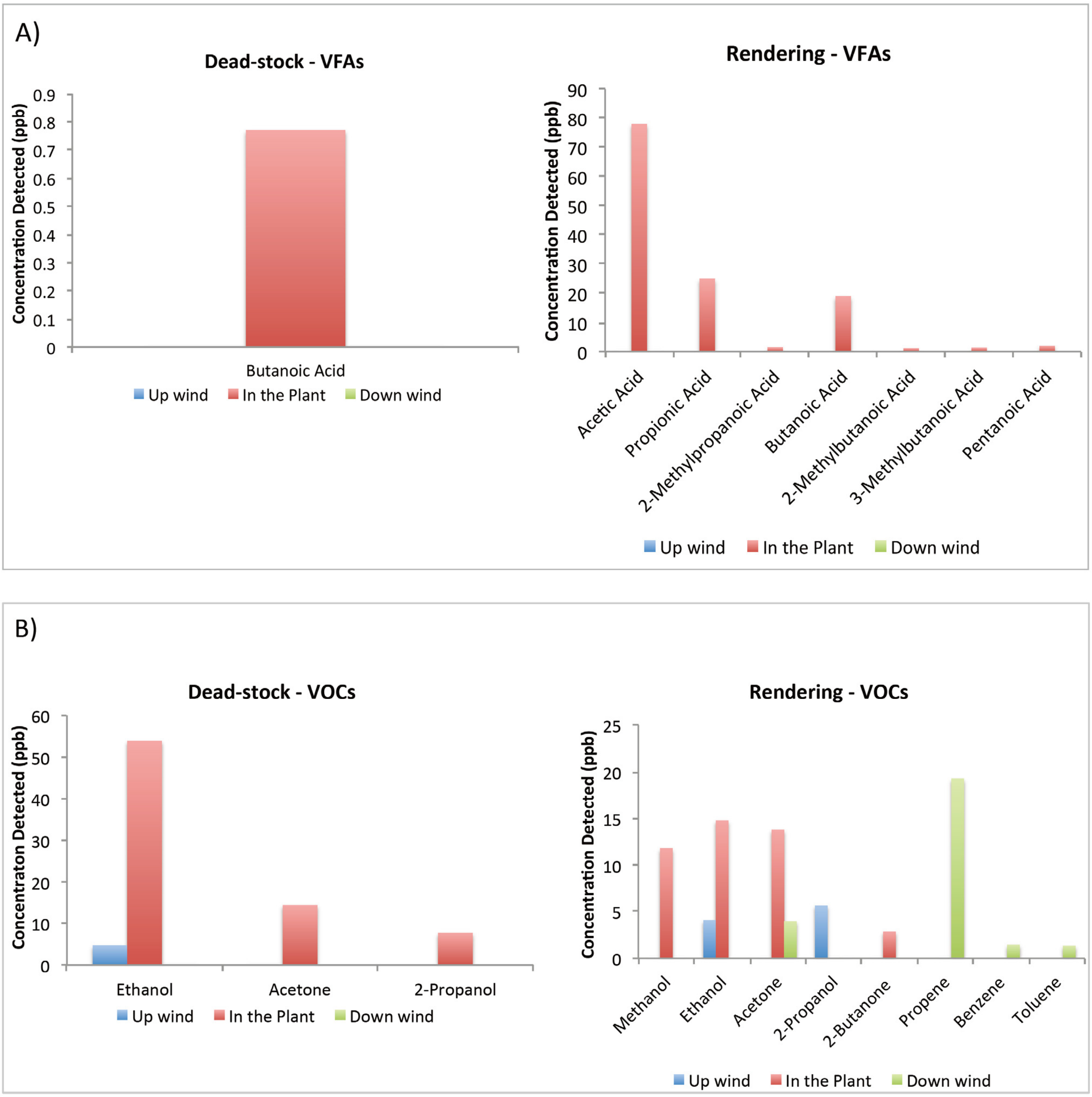


Fig. 2. Chemical compounds detected at the dead-stock and the rendering facilities during winter sampling. A) winter VFA air sampling results and B) winter VOC air sampling results.

During the summer visit, the ammonia sampling detected 2800 ppb (2.8 ppm) concentrations inside the rendering plant and 999 ppb (0.99 ppm) down-wind. Furthermore, VFAs were detected in the plant sites for both dead-stock and rendering facility, but were not detected at the up or down-wind sampling sites. The compounds were detected in a larger variety and at greater concentrations at the rendering facility: 320 ppb of acetic acid, 140 ppb of butanoic acid, 110 ppb of propionic acid, 9.50 ppb of pentanoic acid, 9.3 ppb of 2-methylpropanoic acid, 8.0 ppb of 2-methylbutanoic acid and 3-methylbutanoic acid, 5.90 ppb of 4-methylpentanoic acid, 5.50 ppb of hexanoic acid, 0.82 ppb of octanoic acid, 0.67 ppb of heptanoic acid and 0.47 ppb of nonanoic acid. Note also that the constituent compounds are present in significantly higher concentrations during the warmer summer months as compared to the concentrations that were detected during the winter sampling period. The sampling within the dead-stock facility did not detect pentanoic, hexanoic, heptanoic, octanoic or nonanoic acids. The detected amounts of the other compounds at that site were: 60 ppb of acetic acid, 21 ppb of butanoic acid, 15 ppb of propionic acid, 2.7 ppb of 2-methylpropanoic acid, 1.5 ppb of 2-methylbutanoic acid, 1.8 ppb of 3-methylbutanoic acid and 0.53 ppb of 4-methylpentanoic acid. Fig. 3 shows the quantitative results of the detected VFAs inside of each plant site during the summer sampling period.

Table 2. Summer sampling at the rendering facility and dead-stock facility.

	Summer					
Compound	Rendering			Dead-Stock		
	Up wind	In the Plant	Down wind	Up wind	In the Plant	Down wind
Sulfur	×	×	×	×	×	×
Amine	×	×	×	×	×	×
Ammonia	×	✓	✓	×	×	×
VFAs	×	✓	✓	×	✓	×
Carbonyls	✓	✓	-	✓	✓	✓
VOCs	✓	✓	✓	✓	✓	✓

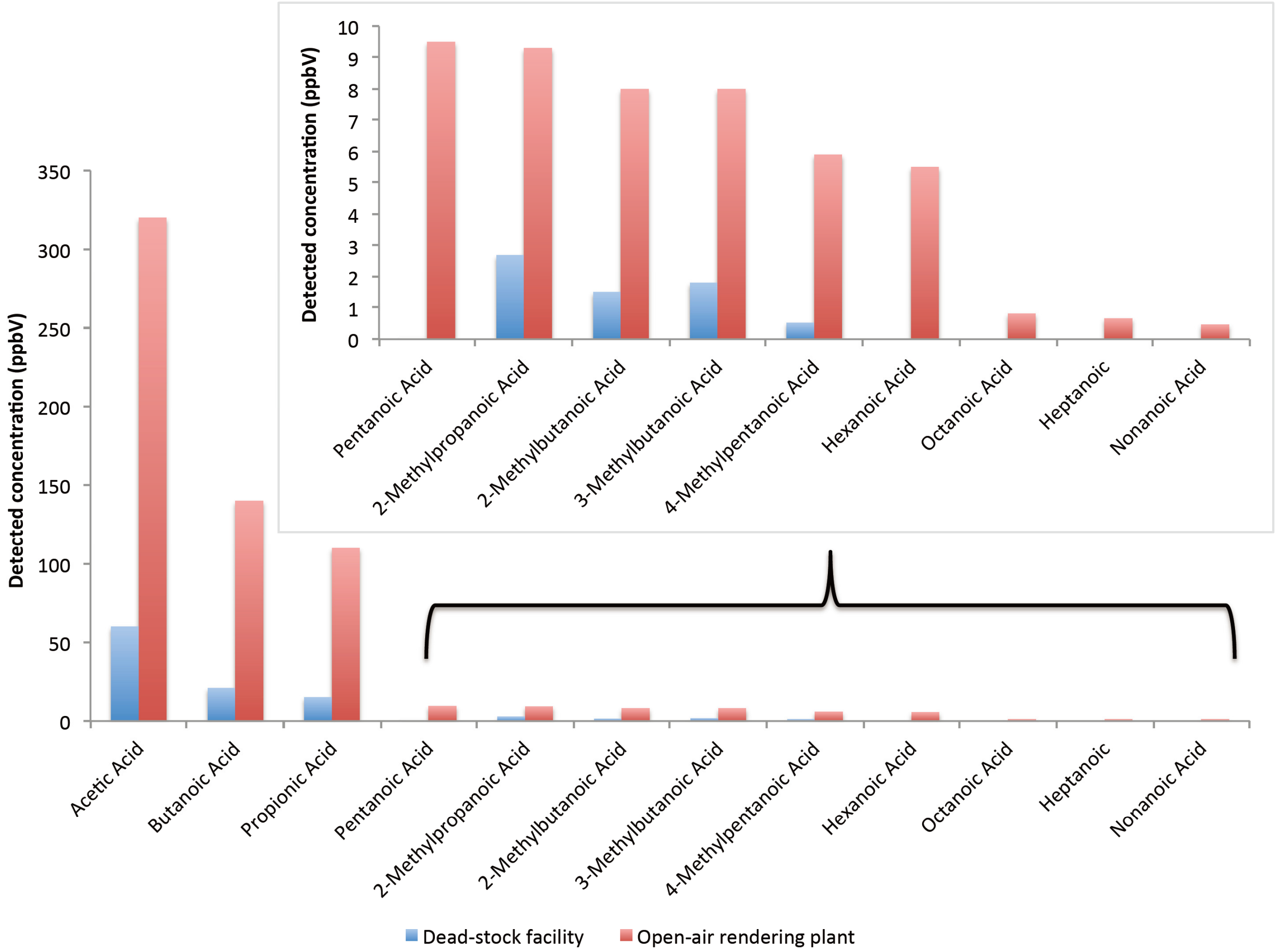
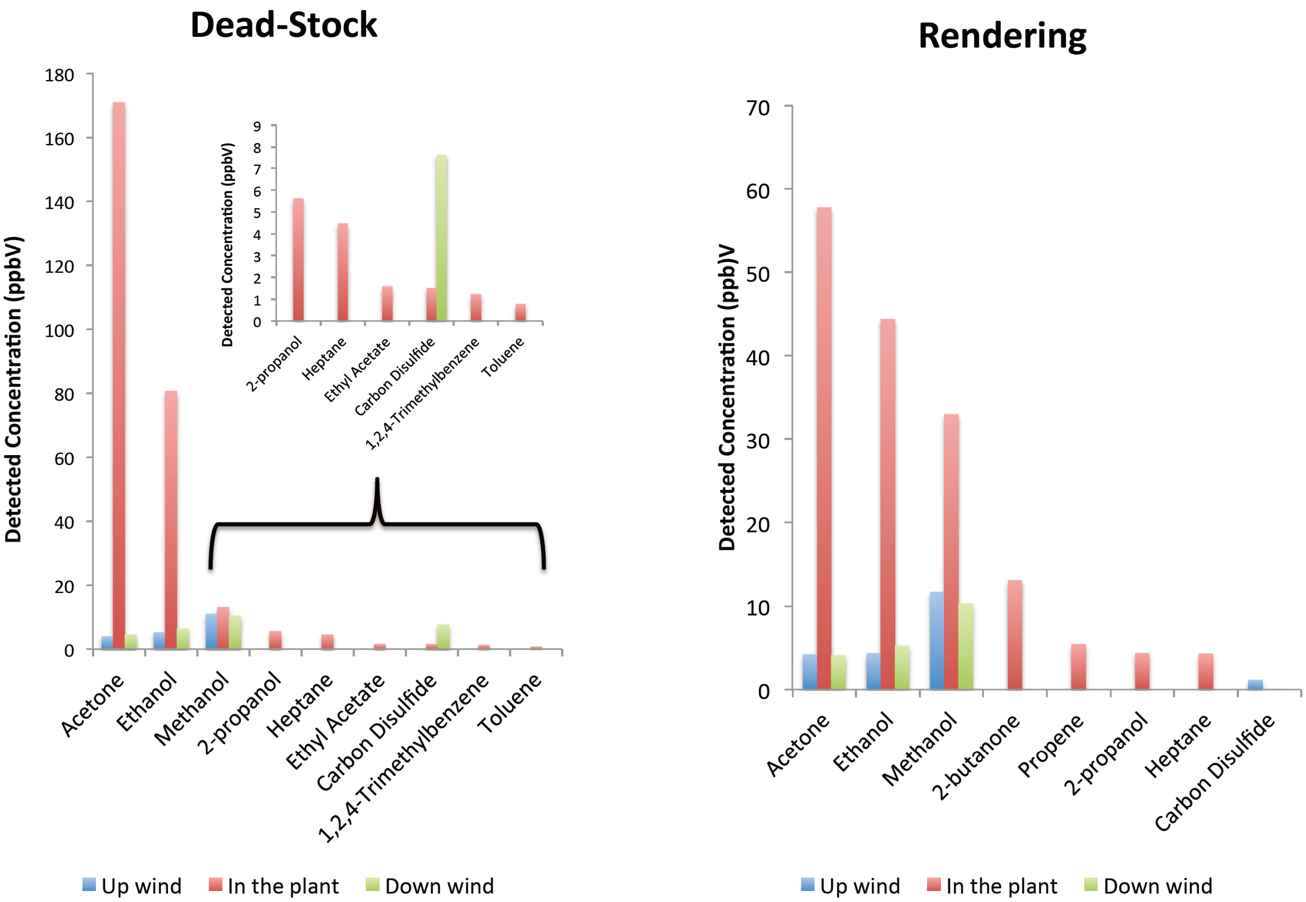


Fig. 3. Summer VFA sampling results obtained in the dead-stock facility and in the open-air rendering plant.

The summer VOC sampling experiments using summa cans (Fig. 4) detected acetone, ethanol, and methanol in all three regions of both the dead-stock and rendering facilities. Acetone concentrations detected in the dead-stock facility upwind, in the plant, and down wind were 3.97, 171, and 4.55 ppb, respectively. The acetone concentrations detected in the rendering facility for the same three regions were 4.22, 57.8, and 4.1 ppb. Ethanol concentrations detected at the dead-stock facility upwind, in the plant, and down wind were 5.2, 80.6, and 6.43 ppb, respectively. The concentrations detected at the rendering facility plant site for the same three regions were 4.34, 44.4, and 5.24 ppb. Methanol concentrations detected at the dead-stock facility upwind, in the plant, and down wind were 11.0, 13.1, and 10.4 ppb, respectively. The methanol concentrations detected at the rendering facility for the same three regions were 11.7, 33, and 10.3 ppb.

During the summer sampling campaign, carbon disulfide was detected at the dead-stock facility inside the plant and downwind at concentrations of 0.77 and 7.62 ppb, respectively. At the rendering facility, carbon disulfide was only detected upwind of the plant, with a concentration of 1.17 ppb. The other compounds detected during the summer sampling period at the dead-stock facility inside



(a) (b)

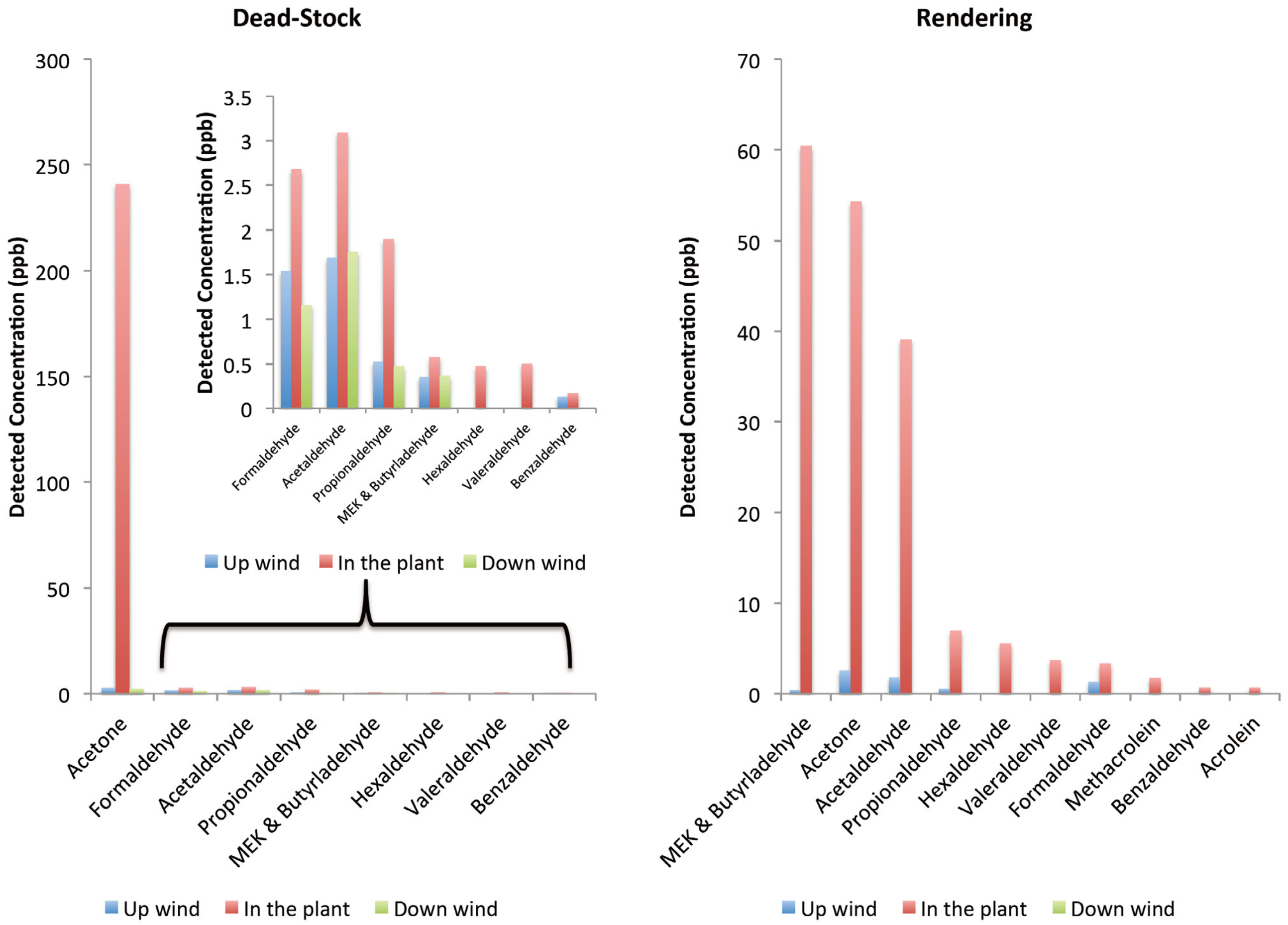
Fig. 4. Summer VOC sampling. Detected VOCs at a) rendering facility and b) dead-stock facility.

the plant were: 2-propanol, heptane, ethyl acetate, 1,2,4-trimethylbenzene and toluene, at concentrations of 5.62, 4.47, 1.58, 1.5, 1.23, and 0.77 ppb respectively. Other compounds detected inside the rendering plant were: 2-butanone, propene, 2-propanol and heptane with concentrations of 13.1, 5.44, 4.35, and 4.3 ppb, respectively.

Additionally, when we returned to the plant sites in the summer, we elected to also more carefully explore the presence of carbonyl-containing VOC constituents by collecting 100 min carbonyl samples using sampling pumps and 2,4-dinitrophenylhydrazine-impregnated sample cartridges (Fig. 5). Thus, the summer carbonyl sampling at the dead-stock facility detected several carbonyl containing VOCs including (in plant values in parentheses): formaldehyde (2.68 ppb), acetaldehyde (3.09 ppb), acetone (241 ppb), propionaldehyde (1.9 ppb), and a combination of methyl ethyl ketone (MEK) and/or butyraldehyde (indistinguishable in the assay, 0.58 ppb). These same analytes were also present in the up and downwind samples as well, albeit at lower concentrations Further, benzaldehyde was detected in the plant (0.175 ppb) and up wind (0.133 ppb) but not down wind. Finally, valeraldehyde (0.505 ppb) and hexaldehyde (0.476 ppb) were detected only inside the plant.

The results for the analysis conducted at the rendering facility detected the following molecules in the plant: formaldehyde (3.31 ppb), acetaldehyde (39.1 ppb), acetone (54.3 ppb), propionaldehyde (6.97 ppb), MEK/butyraldehyde (60.4 ppb), benzaldehyde (0.682 ppb), valeraldehyde (3.66 ppb), methacrolein (1.73 ppb), acrolein (0.661 ppb), and hexaldehyde (5.58 ppb). The following compounds were detected up-wind of the rendering facility, albeit at lower concentrations: formaldehyde (1.31 ppb), acetaldehyde (1.8 ppb), acetone (2.56 ppb), propionaldehyde (0.561 ppb), and MEK/butyraldehyde (0.389 ppb). (Note: No results were obtained for down-wind carbonyl sampling at the rendering facility since on-site sample collection failed due to a pump malfunction).

Typically, occupational exposure to VOCs are regulated through different exposure limit values, such as time-weighted average (up to 10-hour workday) (TWA), short-term exposure limit (STEL) and ceiling value (C). State and federal agencies (e.g., the California Division of Occupational Safety and Health Administration (Cal/OSHA), The United States Labor Department Occupational Safety and Health Administration (OSHA), and the National Institute for Occupational Health and Safety (NIOSH)) establish recommended exposure limits for a variety of VOCs (Centers for Disease Control and Prevention, 2016; State of California, 2016; United States Department of Labor, 2016). For example, the short-term Exposure Limit (STEL) for ammonia is 35 ppm, according to the California Division of Occupational Safety and Health (Cal/OSHA, 2016). The



(a) (b)

Fig. 5. Summer carbonyl sampling. Detected carbonyls at a) rendering plant and b) dead-stock facility.

STEL value is a 15-minute TWA exposure that should not be exceeded at any time during a workday. Ammonia experiments were conducted during a 100 min time period and the results show that the detected concentration was 0.73 ppm at the rendering facility and 1.6 ppm at the dead-stock facility during the winter sampling. Similarly, 2.8 ppm concentrations of ammonia were detected at the rendering facility during summer sampling. Since these results were obtained for a 100 min sampling period, a comparison between experimental and regulated value can best be made using the STEL values, since they are obtained over a much shorter period of time when compared to TWA. By comparing these values, the observed ammonia concentrations for the 100-minute experiment fall squarely within safe regulated levels. We made similar comparisons with all of the detected compounds that have recommended exposure limits and found that all of the compounds detected in this study were well below the recommended exposure limit, using the typically more stringent Cal/OSHA standards (Cal/OSHA, 2016). Nonetheless, all of these compounds are highly volatile with very low odor thresholds (Leonardos *et al.*, 1969; Van Langenhove *et al.*, 1982; Rappert and Müller, 2005), and could therefore contribute to unsavory nuisance odors at rendering operations.

Many of the aforementioned VOCs detected at the dead-stock and rendering plants arise from microbe-mediated decomposition of the animals and raw material, respectively. Specifically, microbial decomposition of carbohydrates, fats, and proteins under anaerobic conditions results in the production of organic compounds, such as VFAs and carbonyls. Generally VFAs are produced as metabolic intermediates or end products from different bacteria. Small fatty acids and aldehydes also arise from the decomposition of fats (Rappert and Müller, 2005). Furthermore, ammonia is produced from urea hydrolysis and during the deamination of amino acids. Similarly, amino acids containing sulfur in their structure can generate sulfur compounds via metabolic processes and sulfate reduction. It is important to emphasize that all of the compounds that were detected fell within acceptable regulated exposure limits.

CONCLUSIONS

The sampled sites analyzed contained a variety of volatile organic compounds, although all detected compounds were present in concentrations well below regulated values. Interestingly, unlike other sources of VOCs the concentration of the detected analytes differed dramatically depending on seasonal temperatures. Despite being present at environmentally benign concentration, these VOCs do likely contribute to nuisance odor problems at rendering facilities (Leonardos *et al.*, 1969; Van Langenhove *et al.*, 1982; Rappert and Müller, 2005). We plan to parlay the information gleaned from this study to explore the utilization of functional nanomaterials (Campbell *et al.*, 2015) as a mitigation strategy for the removal of VOC constituents that contribute to nuisance odors at rendering and related facilities. The results of the present study indicate that a broad range of VOCs, mostly associated with normal decomposition processes, are present at safe but detectable levels at rendering facilities. For the first time, we have assessed seasonal changes in the VOC load emitted from rendering operations in an open-air rendering plant. Additionally, we have provided insight into the VOC contribution arising from a dead-stock processing plant that provides raw materials for rendering operations. Nevertheless, this study, coupled with previous assessments of rendering operations (Van Langenhove *et al.*, 1982, 1983; Defour *et al.*, 2002; Bhatti *et al.*, 2014), beckons for a assessment of the contribution of worldwide rendering operations to global VOC emissions. Indeed, the logistics of such an undertaking are daunting, but a clear understanding of the global VOC emission load resulting from this vital industry would contribute to the overall sustainability of rendering operations and, more broadly, global agriculture and food sustainability.

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