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EXECUTIVE SUMMARY

CHARACTERIZATION OF FERMENTATION EMISSIONS FROM CALIFORNIA BREWERIES

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1.0
INTRODUCTION

1.1 PURPOSE AND OBJECTIVES OF THE STUDY

The release of volatile organic compounds (VOC) into the atmosphere by the brewing industry has recently become a matter of concern to air pollution control officials. Although neither federal new source performance standards nor state and local regulations restrict VOC emissions from California breweries, these emissions are suspected of contributing to the atmospheric burden of VOC in ozone non-attainment areas of the South Coast and Bay Area Air Quality Management Districts. The four largest breweries in the state, which account for greater than 99 percent of the state's current annual beer production, are located in two ozone non-attainment areas (three in the South Coast Air Quality Management District; one in the Bay Area Air Quality Management District).

Previous studies have identified possible VOC emission sources within breweries. One study by the U.S. Environmental Protection Agency estimated VOC emissions of 10.9 pounds per thousand gallons of beer from spent grain drying operations (USEPA, 1977). The validity of this emission factor has been questioned due to the complete lack of substantiating field data. After a tour of a large brewery, representatives of the U.S. Environmental Protection Agency's (EPA) Region IX Surveillance and Analysis Division reported that generalized fugitive ethanol emissions within the brewery and yeast disposal areas totaled 23 and 40 tons per year, respectively (Lavignino and Henderson, 1979). The latter estimate was based largely on a literature review. EPA Region IX representatives have suggested that more comprehensive studies, incorporating field work, be performed.

The objectives of this study were to (1) characterize and inventory all VOC emissions from California breweries, (2) establish emission factors which are representative of each important emission source in a brewery, and (3) suggest potentially applicable control technologies which can be implemented to reduce VOC emissions from breweries. The results of this study should help air pollution agencies devise effective control strategies for ozone reduction in non-attainment areas.

1.2 OUTLINE OF RESEARCH

Research under this contract was conducted between September 1982 and June 1983. The major elements of the study were as follows.

1.2.1 Characterization of California Breweries

Since this project was geared towards developing representative emission factors based on source tests, it was necessary to design and distribute questionnaires to all California breweries. Information provided on these questionnaires enabled us to make brewery site selections based on the fulfillment of various selection criteria. Upon meeting the criteria, one large brewery ("large" is defined as a production rate greater than 60,000 bbls/year) and one small brewery were selected from the four large and five small breweries in California. Besides serving as a site selection tool, the questionnaire provided information on various throughput measures such as grain usage and beer production rates which, in conjunction with our experimentally derived process-specific emission factors, enabled us to develop a statewide inventory of brewery emissions.

1.2.2 Derivation of Emission Factors

To ensure that experimentally derived would be as accurate as possible, SAI conducted "pre-test" (Phase 1) monitoring, and detailed (Phase II) source testing, and then derived emission factors. The objectives of the pre-test monitoring were to sample all potential emission sites from one large and one small brewery and then, after sample analysis, rank them by expected emissions to identify the important species emitted from each source; and to provide input for developing an effective and reliable sampling and analysis plan to be implemented during Phase II. The objectives of the Phase II monitoring were to return to the same breweries to quantify the total VOC emissions from each major brewing process source and to identify the important species emitted therefrom. Stack velocity traverses were also performed so that emission rates could be calculated for various sources. Data obtained during Phase II monitoring were used to develop process-specific emission factors for large and small breweries based on the amount of grain used and beer produced. Throughput data supplied by all other California breweries together with experimentally derived emission factors enabled us to develop the first statewide inventory of brewery process emissions ever assembled.

After reviewing the relative importance of each emission site at the large and small brewery in terms of overall VOC emissions, we explored the applicability of various generic control technologies to brewery processes. Practical advantages and disadvantages for each technique are identified, and the costs roughly estimated for a "typical" large and small brewery.

2.0

FINDINGS AND CONCLUSIONS

2.1 SURVEY OF CALIFORNIA BREWERIES

2.1.1 Statewide Beer Production

(1) Our survey obtained detailed information from all four large breweries (capacities greater than 60,000 bbls/year) and all five small breweries.

(2) California beer production in 1982 is estimated to have been 20.7 million barrels/year (1 barrel = 31 gallons); breweries located in the South Coast Air Quality Management District contributed 81 percent of the total.

(3) The annual growth of the California industry between 1973 and 1982 was 7.6 percent; the nationwide rate was 3.6 percent over the same period.

(4) Large breweries accounted for 99.8 percent of the total production in the state in 1982.

2.1.2 Temporal Operating Cycles

(1) Three large breweries in the state brew 24 hours/day, 365 days/year; the fourth brews 260 days/year. Small breweries brew 8-10 hours/day, 3-5 days/week, 52 weeks/year.

(2) Percentage of production by season are: Summer, 26.7; Fall 25.6; Spring 24.5; and Winter, 23.2.

2.1.3 Existing Air Pollutant Controls

(1) Air pollutant emissions other than those from fuel combustion are not deliberately controlled in this industry.

2.1.4 By-products Handling

(1) Spent grains from the brewing process are picked up, wet, by animal feed processors.

(2) Most breweries dispose of spent yeast in municipal sewers. One large brewery autolyzes spent yeast prior to removal by animal feed processors. Another large brewery maintains an on-site distillation system which recovers ethanol from spent yeasts and other ethanol-containing by-products.

2.1.5 Fermentation Gas Handling

(1) All large breweries carry out primary fermentation in systems closed to the ambient atmosphere; this enables fermentation CO_2 gas to be collected, purified and stored for later use.

(2) All small breweries carry out an open fermentation that results in emissions of CO_2, ethanol and other fermentation gases directly to the atmosphere.

2.2 DERIVATION OF EMISSION FACTORS

2.2.1 Definition

Because operations and processes can vary from brewery to brewery, the use of one composite emission factor to calculate brewery emissions would lead to inaccuracies. Therefore, we developed process-specific emission factors based on the mass of volatile organic compounds (VOC) emitted per 10^3 barrels of beer produced.

2.2.2 Previous Emission Factors

(1) A study by the U.S. Environmental Protection Agency (EPA) derived a hydrocarbon emission factor for spent grain drying based on a literature search only. California breweries do not dry spent grains.

(2) An EPA inspection team conducted a brief tour of a brewery and estimated VOC emissions from spent yeast disposal and "brewery operations;" the former was not based on field tests while the latter estimate was based on an average of instantaneous, readings throughout the brewery using a portable organic vapor analyzer.

2.2.3 Phase I Monitoring

The purpose of Phase I monitoring was to: (1) identify significant emission sources, (2) qualitatively characterize the VOCs emitted and (3) determine the most effective sampling and analytical technique for collecting these emissions. Tests were conducted using a variety of sampling techniques at one large and one small brewery (Anchor Brewing Co.). Samples were analyzed by gas chromatography (GC) using flame ionization detection (FID) and mass spectrometry (MS). Our results are as follows:

(1) The use of Tedlar bags, Tenax traps and a portable organic vapor analyzer (OVA) was ineffectual in collecting and/or analyzing emissions due to the high moisture content of the emission streams. Charcoal tubes and water filled impingers were effective in collecting VOC emissions at all brewery sites.

(2) After Phase I monitoring the following sites at Anchor Brewing were considered significant sources of VOCs: the mash tun, brew kettle and lauter tun stacks; hot wort tank vent; and fermentation room exhaust. Important large brewery sites included the mash cooker and brew kettle stacks, the activated carbon regeneration vent ofthe CO_2 purification system, beechwood chip washer vent; in addition to these sites, the strainmaster and rice cooker stacks and waste beer sump were considered important enough for Phase II sampling.

(3) The major species identified were ethanol, ethyl acetate, dimethyl sulfide, monoterpenes and other aldehydes and ketones.

2.2.4 Phase II Monitoring

The purpose of Phase II monitoring was to quantitatively characterize the VOCs emitted from sources identified during Phase I. Because many of the compounds identified were not readily soluble in water, XAD resin was added to the impinger sampling train; a charcoal tube sampling train was also used. Samples were analyzed using GC/FID and GC/MS techniques.

2.2.4.1 Source Tests at Anchor

Tests at this small brewery covered all sites listed in Section 2.2.3 (2) plus the spent grain tank. Uncontrolled brew kettle stack emissions were collected. Our results were as follows:

(1) The total emission rate for Anchor Brewing was estimated to be 7.2 kg/day (15.9 lb/day); the annual emission rate was 2.5 metric tons/yr (2.8 tons/yr).

(2) The most important site sampled was the fermentation room exhaust, which contributed 93.5 percent of Anchor's total daily emission rate. Ethanol accounted for over 99 percent of the emissions from this site.

(3) The brew kettle stack emissions accounted for 4.6 percent of the daily total. Dimethyl sulfide and a c_5-aldehyde account for about 33 and 26 percent of the total from this site, respectively.

(4) Hot wort tank emissions contributed almost one percent of the brewery's daily emission rate. Myrcene, a hop oil, contributed 34 percent of the emissions from the site while a c_5-aldehyde, ethanol and dimethyl sulfide contributed 14, 12 and 10 percent, respectively.

(5) The mash tun contributed only 0.5 percent of the total daily emissions. Dimethyl sulfide accounts for 53 percent of the daily total from this site.

(6) The lauter tun stack and spent grain tank contributed a combined total of 0.4 percent to the daily total. Ethanol and dimethyl sulfide were the major species in these emissions.

2.2.4.2 Source Tests at Facility A

Tests at this large brewery included all sites listed in Section 2.2.3 (2). Our results were as follows:

(1) The total daily emission rate was 19.4 kg/day (42.7 lb/day); the annual emission rate was 7.06 metric tons/year (7.8 tons/year).

(2) The brew kettle stack had the highest VOC emission rate, accounting for 45.9 percent of the total daily emissions. Myrcene and dimethyl sulfide contributed 47 and 28 percent of the total emissions from this site, respectively.

(3) The strainmaster stack accounted for 17.8 percent of the total emissions from the brewery. Dimethyl sulfide was the most significant component, contributing 80 percent of the total, followed by a c_5-aldehyde at 10 percent.

(4) The beechwood chip washer vent contributed 10.8 percent of the total daily emissions. Emissions consisted almost entirely of ethanol.

(5) The activated carbon regeneration vent accounted for 8.7 percent of the total emissions. Ethanol and ethyl acetate contributed 77 and 13 percent of the emissions from this site, respectively.

(6) Waste beer sump emissions contributed 8.8 percent of the total emissions; ethanol was the only compound identified.

(7) The mash cooker and rice cooker stacks accounted for 7.8 and 0.2 percent of the total daily emissions, respectively. Ethanol and dimethyl sulfide were the major species identified in mash cooker emissions, contributing 53 and 44 percent of the total from this site.

2.2.4.3 Comments on Sampling Techniques

(1) Charcoal tubes collected the greatest mass of VOCs per site of all the sampling train components, followed by XAD resin and distilled water impingers.

2.2.5 Recommended Emission Factors

All emission factors were based on the amount of beer produced; the units are expressed as kg of VOC emitted per 10^3 barrels of beer produced andlb of VOC emitted per 10^3 barrels (in parentheses).

2.2.5.1 Small Breweries

(1) Mash tun stack -	0.183	(0.403)
(2) Lauter tun stack -	0.088	(0.194)
(3) Brew kettle stack -	1.711	(3.771)
(4) Hot wort tank vent -	0.361	(0.797)
(5) Fermentation room exhaust vent -	23.395	(51.578)
(6) Spent grain holding tank -	0.027	(0.060)

2.2.5.2 Large Brewery

(1) Mash cooker stack -	0.125	(0.275)
(2) Rice cooker stack -	0.002	(0.005)
(3) Strainmaster/Lauter tun stack -	0.286	(0.631)
(4) Brew kettle stack -	0.741	(1.634)
(5) Activated carbon regeneration vent -	0.300	(0.660)
(6) Beechwood chip washer vent -	0.437	(0.963)

2.3 ESTIMATION OF ORGANIC COMPOUND EMISSIONS IN CALIFORNIA

2.3.1 Emissions By Geographic Unit

(1) Annual statewide emissions of VOCs from breweries was estimated to be 38.7 metric tons/year (42.6 tons/year); on a daily basis the total was 109.5 kg/day (241.3 lb/day).

(2) Emissions from Los Angeles County accounted for 75 percent of the total annual emissions, followed by Solano - 18 percent, and San Francisco - 6 percent.

2.3.2 Emissions By State Air Basin

(1) The South Coast air basin accounted for 75 percent of the total annual emissions from breweries.

(2) San Francisco Bay Area air basin contributed 25 percent of the total; the Sacramento Valley air basin contributed less than 1 percent.

2.3.3 Emissions By Firm Size

(1) Large breweries account for 93 percent of the total annual emissions.

2.3.4 Perspectives

(1) Estimated emissions from beer production in California constitute 0.001 percent of the statewide total organic gas (TOG) emissions, and 0.002 percent of stationary source TOG emissions as reported in the 1979 Statewide Emission Inventory.

(2) Emissions from the three large breweries in Los Angeles County (where the industry is concentrated) were estimated to account for only 0.019 percent of the total county-wide stationary source reactive organic gas (ROG) emissions based on 1979 inventory data.

(3) Currently, emissions inventory data include only fuel combustion emissions from boilers at breweries. Inclusion of brewing process emissions in the emissions inventory for Los Angeles County would result in a 10-fold increase in total ROG emissions from breweries in the county.

2.4 CONTROL TECHNOLOGY

Since estimated emissions from individual breweries are rather low, we focussed our attention upon the most important processes at small and large breweries: the fermentation room and the brew kettle, respectively.

(1) Fermentation room emissions can be controlled by activated carbon adsorption. With credit for sale or re-use recovered ethanol, the control cost would be on the order of $5/lb pollutant removed.

(2) Ethanol concentrations in the exhaust stream are too low for absorption to be practical.

(3) Since the majority (by weight) of the pollutants in the brew kettle stack are slightly soluble or insoluble in water, an organic solvent would be needed were absorption to be used. Annualized capital costs for an absorption and stripping system would be from $22 to $84/lb pollutant removed.

(4) Activated carbon systems would be practical for removal of brew kettle emissions, although recovery of exhaust constituents would probably not be economical. The estimated total annualized capital cost and operating cost for such a system would be about $24 per pound pollutant removed.

3.0

RECOMMENDATIONS

On the basis of our findings, we recommend:

(1) The information obtained through our survey of the California brewing industry (provided to the Air Resources Board as a separate document) and the applicable results of our source testing program should be incorporated into local emission inventories and the statewide Emission Data System. Furthermore, the ARB should establish Source Classification Codes (SCCs) for each device and major species combination at large and small breweries.

(2) Emission factors for this industry should be process-specific and be based on the amount of beer produced.