65 pp.

Coors

Coors Brewing Company
Golden, Colorado 80401-1295

Coors

Adolph Coors Company
Golden, Colorado 80401
(303) 277-3831
FAX: (303) 277-~~6670~~ 3080

March 11, 1993

Jere Zimmerman
Environmental ~~Engineer~~ Control Manager

David Reisdorph
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

AP-42 Section	9.12.1
Reference	3
Report Sect.	4
Reference	10

Re: Stack Test Reports from Coors Brewing Company

Dear Mr. Reisdorph,

Please find enclosed 11 Stack Test Reports and internal analysis of those reports from multiple source tests performed at the Coors Brewing Company facility in Golden. We hope that this information will be useful to you as you prepare the update of AP-42 for breweries. As we discussed we have provided general information about the process tested, information specific to the tests run at our facility to assist you in your analysis, and our estimate of how these results might be applied generally to other breweries. We would appreciate it if you could treat any information that is specific to our facilty as confidential. Any specific information is contained in the sections titled "Information Relating to Source Test" and in the calculations.

The material is divided into three main sections, Brewing, Packaging, and Byproducts operations. A summary table of emission factors is included at the beginning of each section. Please note that we have numbered and labeled the stack test reports because the tested source was not always readily apparent from the report title on the cover. We have included a summary table which should help you easily refer to the various tests.

Please note that where an emission factor is provided,expressed in pounds per 1000 barrels, the 1000 barrels refers to finished product volume, after the beer has been blended i.e. the total volume of beer produced at the facility.

I look foward to meeting with you as we arranged, on March 26, at Midwest Research Institute, to clarify any issues that may come up as you go through this material. If you have any questions please don't hesitate to call. I can be reached at 303/277-3831.

Sincerely,

Jere Zimmerman
Environmental Engineering

cc: John Schallenkamp
Jerry Fasso
File
Jon Goldman
Bob Brady
Document Control

files_ap42_let.doc

enclosures

FILE COPY

MRI

MIDWEST RESEARCH INSTITUTE
Suite 350
401 Harrison Oaks Boulevard
Cary, North Carolina 27513-2412
Telephone (919) 677-0249
FAX (919) 677-0065

June 8, 1994

Ms. Jere Zimmerman
Adolph Coors Company
Golden, Colorado 80401

Dear Jere:

Thank you for taking the time to discuss the Coors test data with me last Friday. I have put together a brief summary of our discussion for your review. I will begin to remove the confidential information from the summary report and test reports after I receive the replacement calculation pages from you. I am planning to send the pages containing confidential information back to you so that you can confirm that the confidentiality is not compromised. The pages that require white out will be copied, and I will send these originals to you also. I will take care of these matters as quickly as possible so that we can continue with the revision of the Malt Beverage AP-42 section. Thank you very much, and I look forward to hearing from you.

Sincerely,

Brian Shrager

Brian Shrager
Environmental Engineer

Enclosure

3061\460108

CONTACT REPORT--MRI Project No. 4601-08

From: Brian Shrager, Environmental Engineering Department

Date of Contact: June 3, 1994

Contacted by: Telephone

Company/Agency: Adolph Coors Company
Golden, Colorado 80401

Telephone Number: (303) 277-3831

Person(s) Contacted/Title(s)

Jere Zimmerman, Environmental Control Manager

CONTACT SUMMARY: Ms. Zimmerman was contacted to discuss the possibility of using the Adolph Coors Company (Coors) emission test data (currently held in confidential business information [CBI] files) for developing emission factors for inclusion in AP-42. Prior to the discussion of any specific CBI, Ms. Zimmerman was informed that our telephone lines are not secured. The data and information in question include emissions data from 11 test reports supplied by Coors to MRI and one summary document that provides process descriptions, process rates, and emission factor calculations for the emission tests documented in the test reports. Ms. Zimmerman stated that there was very little information in the actual test reports that Coors would consider to be CBI, and she will provide a list of any CBI pages contained in the reports. We then discussed the summary document, which contains several items that Coors considers to be CBI. These items, however, are details that MRI does not need to use to accurately characterize emissions from the processes tested and to develop emission factors. Table 1 presents the pages of the document that were discussed, indicates the pages that contain cleared information and the pages that contain CBI, and the steps that will be taken by MRI and Coors to eliminate the need to treat the material as CBI.

Another topic that was discussed was the basis for the filling operation emission factors. Ms. Zimmerman stated that Coors has data that suggest that the amount of beer spilled does not affect the magnitude of ethanol emission from filling operations. However, the data may suggest that the surface area of the beer spilled (not the depth) is the determining factor in the magnitude of these emissions. These data will be supplied to MRI for use in the background information for the revised AP-42 section.

TABLE 1. STATUS OF INFORMATION IN COORS SUMMARY DOCUMENT

Page (ID by process)	Status	Action
Brewhouse	Cleared	None
Two brewhouse calc. sheets and article	Cleared	None
Wort processing	CBI	MRI to remove the length of the batch cycle
Wort processing calculations	Cleared	None
Fermentation	Cleared	None
Fermentation calc. sheet	CBI	Coors will provide a new calc. page that does not contain CBI.
Aging	Cleared	None
Aging calc. sheet	CBI	Coors will provide a new calc. page that does not contain CBI.
Graph of aging data	Cleared	None
Blending/finishing	CBI	MRI to remove the last 2 sentences of the 4th paragraph as well as note (5) of the table titled "Brewing Table" on the 5th page of the document
Blending/finishing calc. sheet	CBI	Coors will provide a new calc. page that does not contain CBI.
Packaging--fillers	Cleared	None
Packaging--Tables 2,3,4,5,6	Cleared	None
Packaging--defill	Cleared	Coors will provide a new defilling section because an error was made in the process description and the calculations (only 3 tanks were operating rather than the 6 reported).
Bottle wash	Cleared	These data are based on a mass balance. However, Coors has performed some subsequent tests including a stack test on the bottle wash process. Coors will provide these data.
Byproducts	Cleared	None
Spent grain calc. sheets	CBI	MRI will remove the 5th note on page 1 of 8
Yeast	Cleared	None
Waste beer	Cleared	None

Coors Brewing Company
Golden, Colorado 80401-1295

June 28, 1994

Mr. Brian Shrager
Midwest Research Institute
401 Harrison Oak Boulevard, Suite 350
Cary, North Carolina 27513-2412

Re: Stack Test Reports from Coors Brewing Company Updates

Dear Mr. Shrager,

Enclosed you will find the information that I promised you during our telephone conversation:

- 3 stack test reports and summaries for (1) the can defill process with pneumatic conveying, (2) the bottle defill process with mechanical conveying, and (3) the bottlewash process.
- Emission rate engineering calculations for the aging and fermenting processes which do not contain confidential information.
- A Coors internal report labeled Filler Room Vent Emissions Reduction - - Results and Final Report (December 2, 1993) along with a summary sheet of the report.
- The fourth stack test report is a revised Fill on Vent report with a report date of December 9, 1992 by Clean Air Engineering (project no. 6265-4). The original report result was based on an incorrect number of tanks on vent during the test. This change is reflected in the revised report.

We hope this information is in format that can be useful to you, if you have any questions please do not hesitate to call. I can be reached at 303-277-3831.

Sincerely,

Jere Zimmerman
Air Quality Manager

cc: Bob Brady
Jon Goldman
Jerry Fasso
File/Document Control

Enclosures

MRI

MIDWEST RESEARCH INSTITUTE
Suite 350
401 Harrison Oaks Boulevard
Cary, North Carolina 27513-2412
Telephone (919) 677-0249
FAX (919) 677-0065

July 27, 1994

Jere Zimmerman
Adolph Coors Company
Golden, Colorado 80401

Dear Jere,

Thank you for your help in clearing up the Coors data confidentiality issue. As we discussed last Monday, attached are the pages that have been removed from the summary document. I have inserted replacements for all of the pages except for the "Brewing - Blending/Finishing Emission Factor Calculation" page, which you indicated that you will send me. Again, thank you very much for your time and effort.

Sincerely,

Brian Shrager

GRAIN HANDLING

All breweries produce beer from barley, rice, starch, hops, and water. The handling of some of these raw materials produces emissions of particulate matter (PM). At our facility emission factors were used to estimate these emissions. The factors most useful for this effort are as follows:

Receiving, cleaning, storage and transfer of barley or malt PM emissions	AP-42 Section 6.4, Grain Elevators, Table 6.4-1, Inland Terminal Elevator
Receiving, cleaning, storage and transfer of barley or malt PM10 emissions	AP-42 Appendix C, Tables C.2-2 and C.2-3
Malting of barley, Kilning Process	AIRS, p. 84, malt dryer
Starch receiving, transfer	AP-42 Section 6.11-1, starch manufacturing
Rice receiving, transfer	AP-42 Section 6.4 Table 6.4-6, rice precleaning and handling
Raw materials milling	AIRS, p. 81, barley milling

AP-42 SUBMITTAL STACK TEST REPORT INDEX

Stack Test Report #	Source	Testing Company	Report Date	Report Title or File Number
1	Multiple Sources	Clean Air Engineering	11/25/92	CAE Project No: 6265-1
2	Fill on Vent	Clean Air Engineering	12/9/92	CAE Project No: 6265-4
3	Cellar 13 - Yeast	Clean Air Engineering	11/25/92	CAE Project No: 6265-3
4	Cellar 9 - Waste handling	Clean Air Engineering	11/25/92	CAE Project No: 6265-2
5	Can and Bottle Filler Vent	Air Pollution Testing	10/14/92	Can and Bottle Filler Vent
6	Can and Bottle Filler Vent	Air Pollution Testing	12/2/92	Can and Bottle Filler Vent
7	Brewhouse	Western Environmental	Nov. 90	File Number 9010-204
8	Aging and Fermenting	Western Environmental	Nov. 90	File Number 9010-208
9	Spent Grain Dryers	Western Environmental	Feb. 91	File Number 9110-111
10	Spent Grain Dryers	Air Pollution Testing	11/9/92	Grain Dryer Diagnostic VOC Report
11	Spent Grain Dryers	Clean Air Engineering	11/25/92	CAE Project No: 6362-1

COORS BREWING COMPANY
12th and Ford Street
Golden, CO 80401
(303)277-3153
fax: (303)277-3080

fax transmittal

to:	Brian Shrager x5224 MRI
fax:	919-677-0065
from:	Jere Zimmerman 303/277-3831
date:	11/14/94
re:	Brewing AP42
pages:	2

NOTES:

Brewing

Operation	Emission Factor
Brewhouse - VOC	0.94 lb/1000 barrels (7)
Brewhouse - PM	0.52 lb/1000 barrels
Extract-Grain Separation (CARB report)	0.63 lb/1000 barrels
Wort Processing - Trub Settling Tank	0.075 lb/1000 barrels
Wort Processing - Open Wort Cooling/Aeration (1)	0.022 lb/1000 barrels
Fermenting - venting of CO_2 (2)	2.0 lb/1000 barrels
Aging - fill on vent	0.09 lb/1000 barrels
Aging - venting of CO_2 pressure (3)	0.43 lb/1000 barrels
Aging - tank purging of CO_2 (4)	3.1 lb/1000 barrels
Blending/Finishing - fill on vent (5)	0.29 lb/1000 barrels
Blending/Finishing - tank evacuation (6)	1.0 lb/1000 barrels

(1) Based on emission data from open wort cooler.
(2) Based on venting of CO_2 for the first 24 hours of fermentation cycle.
(3) Factor applies to facility which opens aging vessel to atmosphere for any reason after each batch.
(4) Factor applies to facilty which purges CO_2 from aging vessels after each batch.

(6) Factor will vary slightly depending on atmospheric conditions to which tank is evacuated.
(7) In all cases "1000 barrels" refers to finished product volume i.e. total volume of beer produced at the facility.

BREWHOUSE

General Process Description

In the brewhouse, the milled raw materials are mixed together with water and cooked in large kettles. The kettles have names such as mash tuns, cereal cookers, mash-in kettles, and brew kettles. In the course of cooking these materials, VOC and PM are emitted. The VOC consists of a complex mixture of at least 60 different compounds. No ethanol is present in the liquid at this point in the process.

Information Relating to Source Test

In November 1990 Western Environmental Services and Testing Inc performed a source test on the north brew kettle stack and the north combined cooker stack The results are reported in Stack Test Report No. 7. The north brew kettle stack vents the brew kettles from four brew lines. The north combined cooker stack vents all other vessels from the same four brew lines. During the source test, three of the four brew lines were operating.

The north brew kettle stack is equipped with a system to recover some of the energy lost when the water is converted to steam. The closed loop system is known as stack heat reclaim. The water in the closed loop system is sprayed into the kettle exhaust stack through a series of nozzles. This system also acts as a stack scrubber, as can be seen from the stack test data taken with stack heat reclaim on. In developing our emission factor we used data with the stack heat reclaim off, for maximum applicability to other facilities. Our emission factor for VOC from brewhouse operations is 0.94 lbs/1000 barrels beer produced (finished product volume). The emission factor for PM from brewhouse operations is 0.52 lb/1000 barrels (finished product volume).

The VOC is reported as propane, due to the complex nature of the stream. For more detail on components of brewhouse vapors see the enclosed paper entitled "Condensation and Thermal Treatment of Brewhouse Vapors" by K. Muller and R. Meyer-Pittroff.

Applicability

All breweries must have brewhouse operations as part of their brewing process. This factor should apply to virtually any brewery, except where the emissions from brew kettles or other brewhouse vessels are controlled.

ENGINEERING CALCULATION SHEET
CI—2343-D

SUBJECT		PROJECT NUMBER		DATE
Emission factor - brewhouse				2/4/93
PREPARED BY Jere Zimmerman	ENGINEERING TYPE Ch. E.		WORK PACKAGE NUMBER	PAGE 1 OF 2

(1) Emission rates taken from 11/90 source test. See Stack Test results, Book 7.

(2) Three brewlines were operating during the source test.

<u>VOC from brewkettles</u>

$0.98 \frac{lb}{hr} \times 8760 \frac{hr}{yr} = 8585 \frac{lb}{yr}$ for three brewlines

(Book 7, p. 4)

<u>VOC from other kettles (mash tun, etc.)</u>

$0.08 \frac{lb}{hr} \times 8760 \frac{hr}{yr} = 701 \frac{lb}{yr}$ for three brewlines

(Book 7, p. 2)

Total VOC for three brewlines = 8585 + 701 = $9286 \frac{lb}{yr}$

Each brewline can produce 3.3 million barrels of beer (on a finished product basis) per year.

$$\therefore \; 9286 \frac{lb}{yr} \times \frac{}{3 \text{ brewlines}} \times \frac{\text{brewline}}{3.3 \times 10^6 \text{ bbl}}$$

= 0.94 lb VOC/10^3 bbl finished product produced for brewhouse (includes brewkettles, mash tuns, etc.)

b

ENGINEERING CALCULATION SHEET

CI—2343-D

SUBJECT	PROJECT NUMBER	DATE
Emission factor - brewhouse		2/4/93

PREPARED BY	ENGINEERING TYPE	WORK PACKAGE NUMBER	PAGE
Jere Zimmerman	Ch. E.		2 OF 2

PM from brewkettles

$0.46 \frac{lb}{hr} \times 8760 \frac{hr}{yr} = 4030 \frac{lb}{yr}$ for three brewlines

(Book 7, p. 4)

PM from other kettles

$0.13 \frac{lb}{hr} \times 8760 \frac{hr}{yr} = 1139 \frac{lb}{yr}$ for three brewlines

(Book 7, p. 2)

Total PM for three brewlines $= 4030 + 1139 = 5169 \frac{lb}{yr}$

Each brewline can produce 3.3 million barrels of beer (on a finished product basis) per year.

$$5169 \frac{lb}{yr} \times \frac{}{3 \text{ brewlines}} \times \frac{\text{brewline}}{3.3 \times 10^6 \text{ bbl}}$$

$= 0.522$ lb PM/10^3 bbl finished product for brewhouse (includes brewkettles, mash tuns, etc.)

Condensation and Thermal Treatment of Brewhouse Vapors

By K. Müller and R. Meyer-Pittroff

ABSTRACT

Air protection is regulated in the Federal Republic of Germany by a federal Law and a series of by-laws. The emissions of organic substances and odors from brewhouses are limited by these same laws. Two different methods of decreasing brewhouse emissions were studied in a pilot plant.

Wort vapor is completely condensed in a plate heat exchanger and the odorous compounds were almost entirely removed with the condensate. The uncondensed gas quantity from a closed wort kettle is very small.

In the plate heat exchanger (of 40 m² surface area) the subcooled condensate was reduced in temperature to 40 °C by cooling water which was in turn raised to 92.5 °C. The flow rates were 7.5 hl water/hl of condensate. Alternatively, part of the wort vapor can be introduced into the combustion space of a steam boiler. If all the vapor is introduced, up to 90% of the organic substances can be combusted. The carbon monoxide concentration and the exit temperature of the flue gases both increase. Nitrous oxide and sulphur dioxide concentrations in the flue gas are not affected.

SINTÉSIS

Como las cervecerias han sido sujetas a multas debido a los olores emitidos por las salas de cocimiento, ha habido un aumento en interés sobre medidas para reducir estas emisiones. La última palabra del TA LUFT 1986/1/ trata, no solo sobre gases emitidos por los hornos, sino también la emisión de olores. Pero no fué solamente la presión ejercidad por las autoridades, sino también el deso de llegar a un arreglo con la creciente preocupación pública sobre el medio ambiente que indujo a las cervecerías a emplear medidas para manejar las emisiones de las salas de cocimiento.

Desde Julio de 1988 la firma A. Steinecker GmbH, Freising, ha estado llevando a cabo un proyecto de investigación en colaboración con la Facultad de Economías de Energía en la Industria Alimenticia de la Universidad Tecnica de Munich (Weihenstephan), con el proposito de remover las substancias ofensivas de vapores emitidos de la sala de cocimiento. El proceso—Combustion de Substancias Ofensivas a Traves del Sistema de Ignicion de la Caldera—es un método universal para remover materiales olorosos. Además de vapores emitidos por la sala de cocimiento, otros gases olorosos pueden ser también tratados.

SOURCE AND COMPOSITION OF BREWHOUSE EMISSIONS

The characteristic odor of a brewery comes from the brewhouse and originates from the boiling of mash and wort. The odor producing elements are organic compounds which, in the Federal Republic of Germany, are required by law to be held below limiting values, whether the odors are considered to be pleasant or objectionable.

In order to limit the emissions of odors and other organic substances from brewhouses the Department of Energy Management in the Food Industry at the Technical University of Munich, Weihenstephan, is carrying out a research program on the condensation and thermal treatment of brewhouse vapors in conjunction with the firm A. Steinecker GmbH, Freising.

In mashing, the emissions are generated principally during the boiling phase where lighter carbonyl based factions such as acetylaldehyde, propanaldehyde, isobutylaldehyde and acetone[1] as well as phenol[2] are driven off.

The organic substances driven off with the steam in the wort kettle consists in the main of hop oil derivatives, in particular esters, ketones, terpenes, alcohols, aldehydes, furans, and alkanes Table 1 shows the derivatives determined by Wächter et al.[3] Wächter et al. have determined [3] a range of substances which, from sniffing-tests and olefactory meter measurements, have been shown to correlate well with the appropriate odors (Table 2).

GERMAN REGULATIONS FOR ODOR EMISSIONS

Since 1974 the emission of odors from industrial plants in Germany has been subject to the Federal Republic Emission Protection Law (BImSchG-*B*undes *I*mission*ss*c*h*utzgesetz). In accordance with the fourth by-law (BImSchV-*B*undes *I*missions*sch*utzverordnung). Breweriés belong to that category of industrial plants for which official permission is required to operate existing and/or construct new plant. For air polluting emission the regulations and limiting values given in the first Federal Republic Air Pollution Regulations (BImSchVmV-*B*undes *I*mission*ssch*utzverwaltungvorschrift), normally referred to as "TA-Air" (Technical compulsary Advice-Air), are the legal requirements. The latest issue of "TA-Air" made these requirements significantly more rigorous.

Appendix E of TA-Air lists 149 organic compounds in three classifications and with respect to four characteristics viz:- ability to be broken down, propensity to accumulate, toxicity, and intensity of odor.

Brewhouse vapors contain substances from all three classifications. The total quantity of compounds in the individual classifications should not exceed the following values (taken from TA-Air, Section 3.1.7.):

- Classification I (for mass flow of 0.1 kg/h or greater)—20 mg/m³
- Classification II (for mass flow of 2.0 kg/h or greater)—100 mg/m³
- Classification II (for mass flow of 3.0 kg/h or greater)—150 mg/m³

Because of the large number of compounds contained in the brewhouse vapor (Table 1), the quantitative determination of the mass flow for individual compounds has not yet been accomplished, and will remain a very difficult problem. A general correlation of odor intensive groups of compounds with a classification of those compounds has not yet been carried out.[4]

POSSIBLE METHODS FOR REDUCING EMISSIONS

Table 3 gives an overview of the possible methods for handling brewhouse vapors. The best known of those methods is condensation. Brewhouse vapor compression plants, plants with absorption or organic-Rankine processes, and wort vapor condensers are included in this category.

Complete condensation of the brewhouse vapor in wort vapor condensers produces more warm water than the brew-

Professor Dr. R. Meyer-Pittroff holds the Chair of Energy Management in the Food Industry at the Technical University of Munich, Weihenstephan.

Dipl.-Ing. Klaus Müller is a Research Engineer in the same department and is employed under an "Industry-Campus Cooperative Research Program". The industry partner in this instance is the firm Anton Steinecker GmbH of Freising, Federal Republic of Germany.

Table 1
Derivatives in Wort Kettle Emissions

Ester	Acetic acid-2-metylbutylester, Propionic acid-2-metylpentylester, Butyric acid-3-hexenylester, Isobutyric acid-metylester, Isobutyric acid-2-metylbutylester, Isobutyric acid-pentylester, Isobutyric acid-hexylester, Isobutyric acid-heptylester, Isobutyric acid-metybutylester, 2-Metylheptan acid-metylester, Caprylic acidmetylester, 3-Metyl caprylic acidmetylester, 3,7-Dimetyl-26,6-octadien acid-metylester, Nonan acid-metylester, 4-Nonen acid-metylester, Caprinic acid-metylester, Thio-butyric acid-S-metylester
Ketons	3-Metyl-2-pentanon, 5-Metyl-hexanon, 2-Nonanon, 2-Decanon, 7-Decen-2-on, 2-Undecanon, 2-Dodecanon, 2-Tridecanon
Terpens	Camphen, Caryophyllen, p-Cymol, Humulen, Limonen, Myrcen, β-Pinen, -and-Terpinen, Terpinolen, and 2 Monoterpens, 12 Sesquiterpens, 1 Sesquterpenalcohol
Alcohols	1-Hexanol, 1-Octen-3-ol, 1-Nonanol
Aldehydes	Hexanal, tr-2-Hexenal, Heptanal, Octanal, Nonanal, tr-2-Decenal, Phenylacetaldehyde
Furans	2-Metylfuran, 2,5-Dimetylfuran, 2-Butyl,-tetrahydrofuran, 3-(4-Metyl-3-Pentenyl)-furan
Hydrocarbons	Octan, Undecan

Table 2
Correlation of Odor Strength with Emission Components

Emission Components	Correlation of Odor Strength
Myrcen	0,97
Caryophyllen	0,95
Humulen	0,95
2-Nonanon	0,93
2-Undecanon	0,93
Phenylacetaldehyd	0,94

Table 3
Possible Methods for Reducing Emissions

Condensation	Wort Vapor Condenser Wort Vapor Compressor Organic Rankine Cycle Plant High Temperature Wort Boiling
Absorption	Gas Scrubbing
Adsorption	Activated Carbon Filter
Biological Treatment	Bio Scrubber Bio Filter
Oxidation	Afterburning Catalytic Afterburning Chemical Oxidation
Dilution	Stack
Masking	Mixing with other Gases

Source for all three tables: Technische Universität München, Lehrstuhl für Energiewirtschaft der Lebensmittelindustrie.

ery can normally use and for that reason the existing wort vapor condensers have usually been so sized that condensation of all the vapors is not achieved.

Vapor compression plants normally feed to atmosphere for the first five minutes of boiling. This is precisely when a particularly high concentration of hydrocarbons exists in the vapor and for that reason vapor compression cannot completely prevent the emission of odors. Vapor compression is not economic for mash boiling since the boiling time is too short.

Plants with *organic-rankine processes* convert part of the thermal energy of the vapor into mechanical energy. One plant in the Bitburger Brewery uses the mechanical energy so generated to drive the refrigeration compressors. This type of plant is however, relatively expensive.

Absorption plants can be directly driven by the latent heat of condensation of the brewhouse vapor. They have, however, a low efficiency and are also very expensive.

High temperature wort boiling is a future possibility but the process will be difficult to master technologically.

Gas scrubbing (washing) processes are useful for treatment of only remaining gases in a condensation processes. Activated carbon or similar filters have not been used to date in such an application.

Biowashers and biofilters must first condense all the steam in the brewhouse vapor since the microorganisms in the washer/filter will be damaged by hot steam.

Combustion produces heating of the vapor up to 800 °C and the hydrocarbons are converted to carbon dioxide and water. This thermal treatment of odorous compounds is universally used and can be applied to all hydrocarbons. The energy required to raise the vapor temperature is however very high.

Catalytic afterburning allows the processes to proceed at temperatures around 400 °C, but the catalyst has only a limited life.

Chemical oxidation occurs with chlorine, permanganate, or ozone.

PILOT PLANT

The aim of the Weihenstephan research project is to develop, for brewhouse application, a process more suitable and more economic for the reduction of odor emissions. Condensation and combustion were the processes selected for the project and the schematic diagram showing those processes is given in Fig. 1.

In a wort kettle of 310 hl capacity, approximately 18.5 hl evaporates per hour, producing 3200 m^3 of vapor which can either be all condensed in a plate heat exchanger or all fed to the combustion space of a three pass boiler, or any combination of these two extremes. By combining both processes, the plate heat exchanger can be used to produce as much warm water as is required in the brewery and the remaining vapor can be fed to the boiler where its temperature is raised to ca. 1000 °C to convert the hydrocarbons. Since the boiler is used to supply energy for the boiling of the wort and the mash, it is normally in operation when wort vapor is being produced.

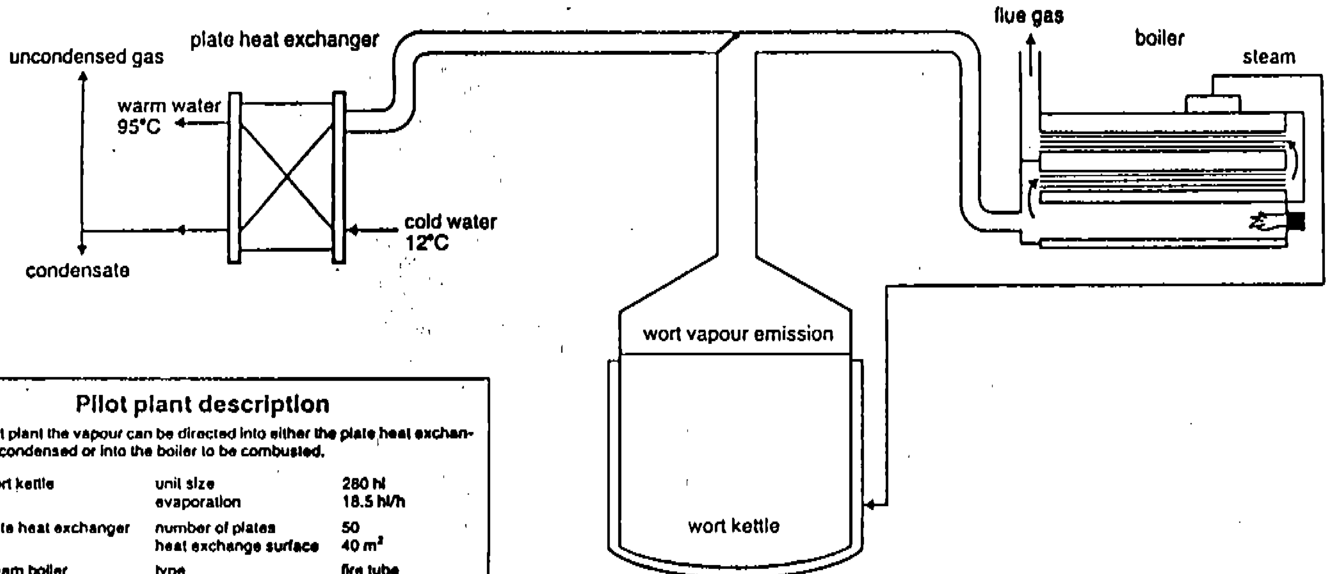
Plate Heat Exchangers as Wort Vapor Condensers

A plate heat exchanger was used as a condenser for the brewhouse vapors. The 50 plates (40 m^2 total area) condensed all the vapor and heated the condensing water to 90 °C (Fig. 2).

Temperatures in the Plate Heat Exchanger

The vapor passes at a temperature of 98.5 °C through two connections (nominal diameter 200) to the heat exchanger. Bellows on the vapor inlet flange cater for expansion stresses in the vapor inlet pipe. The vapor flows downwards through

9



Pilot plant description

In the pilot plant the vapour can be directed into either the plate heat exchanger to be condensed or into the boiler to be combusted.

Wort kettle	unit size	280 hl
	evaporation	18.5 hl/h
Plate heat exchanger	number of plates	50
	heat exchange surface	40 m²
Steam boiler	type	fire tube
	capacity	12 000 kg/h
	fuel	heavy fuel oil

Fig. 1. Pilot Plant.

25 paths each 12 mm wide and condenses. The counterflow passages containing cold water are 6 mm wide.

The warm water temperature is controlled by adjusting its mass flow rate. Cold water at 12.5 °C can be heated to e.g. 82.5 °C at 9.7 hl/hl or 92.5 °C at 7.5 hl/hl, the corresponding condensate temperatures being below 30 °C and approximately 40 °C respectively (Fig. 3). A condensate cooler is not necessary (Ref. 6)

Pressures in the Plate Heat Exchanger

The pressure drop on the water side of the plate heat exchanger is only marginally greater than for shell and tube heat exchangers. On the vapor side a slight overpressure is created between the wort kettle and the plate heat exchanger.

At 20 hl/h evaporation a pressure of 5 mbar was measured in the vapor pipe. At 33 hl/h this rose to 15 mbar. Pressures up to 29 mbar were recorded at the beginning of boiling and during the addition of hops. This arises from the fact that even in boiling where no air ingress exists a small quantity of air from the hops containers is admitted and carried over to the heat exchanger where it hinders the condensation of the vapor.

Uncondensed Gas and Chemical Oxygen Demand (COD)

In closed kettle boiling the gas remaining after condensation consists only of the air admitted to the wort kettle.

As a relative measure of the quantity of odoros matter-emitted, carbon concentration was measured continuously with a flame ionization detector. The carbon emission from the State Brewery Weihenstephan lay between 200 to 300 g/h for untreated, non-condensed vapor. The value with the vapor condenser in operation fell to 0–2 g/h which represented the emission of the non-condensed gases.

The remaining hydrocarbons went into the condensate and gave a value of COD of ca. 500 g/h.

Combustion of Organic Compounds in Brewhouse Vapor by Injection into a Boiler

The vapor not needed to meet the warm water demand of the brewery is fed to the combustion space of a boiler. Holes were drilled in the flame tube sealing plate of the boiler,

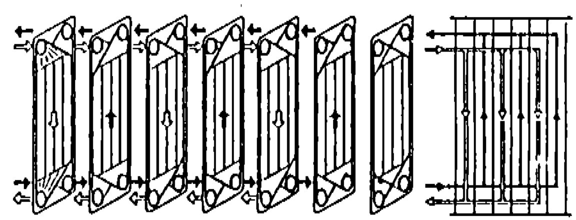
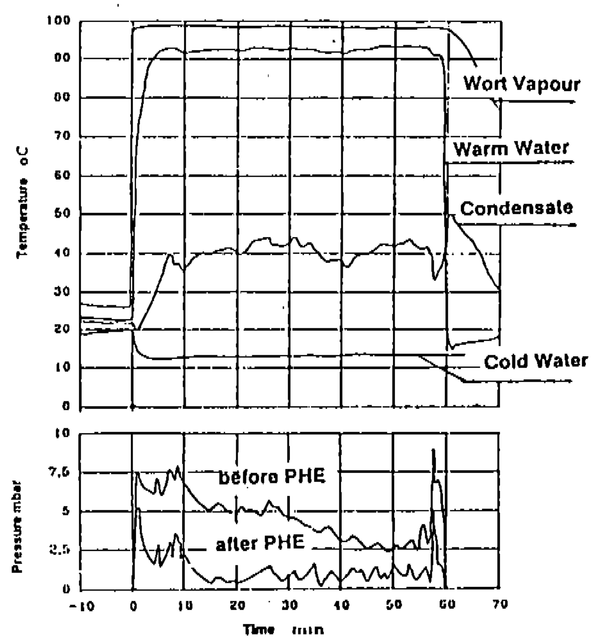


Fig. 2. Plate Heat Exchanger for Condensing Wort Kettle Emissions.



Water Side	Wort Vapour Side
Cold Water Temperature: 12,5 °C	Vapour Temperature: 98,5 °C
Warm Water Temperature: 92,5 °C	Condensate Temperature: ca. 40 °C
Volume Rate: 165,5 hl/h	Volume Rate: 22,1 hl/h
(Cooling Water)	(Condensate)

Fig. 3. Temperatures, Flow Rates and Pressures in the Plate Heat Exchanger at Warm Water Temperature of 92,5° C.

through which the vapor was fed into the ca. 1000 °C flue *gas* at the flame tube exit. The hydrocarbons are combusted there to form carbon dioxide and water. The flue gas then contains the brewhouse vapor which is reduced in temperature as it passes through the boiler and out of the brewery through the flue gas stack.

In closed wort kettles and at an evaporation of 18.5 hl/h a vapor flow and carbon emission of ca. 3200 m³/h and ca. 250 g/h respectively are produced. In the limiting case the entire vapor flow would be fed into the boiler where 90% of the hydrocarbons would be converted, leaving the remaining 10% unaffected in the flue gas. The carbon monoxide concentration of the flue gas increases to 50–100 mg/m³ but still lies well below the allowable TA-Air value of 170 mg/m³.

The flue gas temperature increases marginally. Nitrogen oxides and sulphur dioxide emissions are not effected.

References

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5. MEYER-PITTROFF, R., MÜLLER, K."Neues zur Beseitligung der Geruchsemissionen aus dem Sudhaus", Lecture presented at the 34th Brewing Seminar in Weihenstephan 24–27.4.1989.
6. MÜLLER, K."Breitspalt-Plattenwärmetauscher als Pfannendunstkondensator", Brauwelt 29, S. 1208–1210, 1989.

WORT PROCESSING

General Process Description

Once boiled, the wort must be processed to remove protein solids called trub. Small amounts of VOC can be emitted as the wort holding tanks are filled. Emissions might also come from the cooling and aeration of the wort, which is necessary before the fermentation process begins.

Information Relating to Source Test

At the facility studied, the trub is removed from the hot wort in a vessel called a whirlpool. A source test was performed on the whirlpool vent July 3, 1992 by Clean Air Engineering. The results are reported in Stack Test Report No. 1. The test data was analyzed on a per batch basis, but the emissions came primarily during the filling of the vessel, in the first 20 minutes of a batch cycle. The emission factor for filling a wort holding vessel is 0.075 lb/1000 barrels beer produced (finished product volume).

The open plate wort coolers were source tested on July 3, 1992 by Clean Air Engineering (see Stack Test Report No. 1). In this process hot wort flows over a stainless steel plate filled with cooling liquid. Air is pulled in, filtered and blown countercurrently over the wort. Once contacting the wort this air is released to atmosphere. The stack test was performed on one cooler with a capacity of 22 barrels per minute (36 barrels per minute on a finished product volume basis). The emission factor for open wort cooling is 0.022 lb/1000 barrels (finished product volume).

Applicability

If a brewery removes the trub from the hot wort, the factor for the wort holding vessel should apply. Many breweries cool their wort using closed plate heat exchangers, so the wort cooling factor would not apply to them. However, where the wort aeration step is done as an open process, the open wort cooling factor gives a good approximation of emissions from that process.

ENGINEERING CALCULATION SHEET

CI—2343-D

SUBJECT	PROJECT NUMBER	DATE
Emission Factor - Wort Processing		2/4/93

PREPARED BY	ENGINEERING TYPE	WORK PACKAGE NUMBER	PAGE
Jere Zimmerman	Ch. E.		1 OF 1

Emission rates taken from 7/92 stack test, see Book 1.

VOC emissions for filling trub settling tank:

$$0.0616\ \frac{lb}{batch} \times \frac{batch}{820\ bbl} \times \frac{1000\ bbl}{1000\ bbl} = 0.075\ \frac{lb}{1000\ bbl\ finished\ product}$$

(Book 1, p. 1-7) (Finished product volume)

VOC emissions for open wort cooling or aeration:

$$0.047\ \frac{lb}{hr} \times \frac{min}{36\ bbl} \times \frac{hr}{60\ min} \times \frac{1000\ bbl}{1000\ bbl} = 0.022\ \frac{lb}{1000\ bbl\ finished\ product}$$

(capacity, finished product basis)

12

FERMENTING

General Process Description

After the wort is cooled, yeast is introduced into the liquid, and the mixture is fermented at temperatures below 32 ^{o}F, producing ethanol and carbon dioxide as products of fermentation. The CO_2 which is evolved contains ethanol, a VOC. Most large breweries collect the CO_2 to be reused later in their process. However, emissions can come from the initial venting period, or from purging of CO_2 from the fermenters after they are emptied.

Information Relating to Source Test

At the facility studied, the fermenter gases are vented to atmosphere for the first 24 hours of the fermentation cycle. After 24 hours the CO_2 is collected. Once the fermentation cycle is complete the tank is emptied. At the facility studied the CO_2 must be purged from the tank with air to allow manual entry for removal of the yeast. The purging procedure is known here as CO_2 evacuation. A source test was performed in November 1990 by Western Environmental Services Testing Inc. (WEST) on two fermenting processes in Cellar 8 (see Stack Test Report No. 8). These are the venting of CO_2 for the first 24 hours, referred to in the source test report as CO_2 vent stack - Cellar 8, and the evacuation of CO_2 from the tanks, referred to as CO_2 exhaust stack - Cellar 8.

Cellar 8 is one of two similar fermenting cellars at the facility studied. All the fermenters in a cellar are vented to a common stack for venting, and a separate common stack/fan system for tank evacuation. The test was done at the outlet of these two stacks in Cellar 8. During the CO_2 vent test, 13 fermenters were venting to atmosphere. Unfortunately, no fermenters were evacuating during the CO_2 exhaust test so no emission factor is provided for that test. The emission factor for CO_2 venting, based on a 24 hour venting period, is 2.0 lb/1000 barrels (finished product volume).

Please note that the calculation of this emission rate uses a correction factor of 2.04. This correction factor is necessary to correct for the ability of the Flame Ionization Detector (FID) to detect ethanol as compared to propane, the calibration gas used in the test. For the other source tests where ethanol was the primary constituent measured, a correction factor was empirically determined for the specific FID used and that correction factor (2.36) was incorporated into the stack test reports. Because that was not done for the WEST source test, the correction factor of 2.04 was determined from data published in the "Journal of Gas Chromatography" (attached).

<u>Applicability</u>

Depending on how the brewery operates their fermentation process this factor may or may not apply. Typically gases are vented to atmosphere during the beginning of the fermentation cycle to purge the headspace gases from the fermenter until the CO2 is pure enough to collect. When this is the case the emission factor should apply, prorated to reflect the time period for venting.

No emissions occur during the CO2 collection period. However, the CO2 purification system should be examined to determine whether it is a source of emissions. Once the fermenting tank has been emptied of beer, the yeast must be removed and the tank cleaned. Under certain circumstances the CO2, containing some ethanol, must be purged from the tank with air, venting the gases to atmosphere. Conditions under which the tank would require purging include manual tank entry or automatic cleaning with a caustic solution. If these conditions exist, the CO2 purging will also be a source of VOC emissions.

Coors | **Coors Brewing Company** Golden, Colorado

ENGINEERING CALCULATION SHEET

CI—2343-D

SUBJECT		PROJECT NUMBER		DATE
FERMENTING				6/14/94
PREPARED BY	ENGINEERING TYPE	WORK PACKAGE NUMBER		PAGE
J. Zimmerman, M. Crespin	Env. Eng.			1 OF 2

Notes: (1) Emission rates taken from 11/90 source test. See Attached documentation.

(2) Test performed on Cellar 8 vent and evacuation stacks. Assume that same emission rates apply to cellar 13, which is identical.

(3) It is believed that no fermenters were evacuating during test, so emission rate from aging evacuation was used, less than 10% due to lower airflow in fermenting system.

(4) Operational data on duration of venting and evacuation procedures supplied by Harvey Stepanich.

(5) Emission rates as propane. Multiply by 2.04 correction factor for ethanol emission rates.

(6) Factor based on total number of tanks per year, number of fermenter tanks on vent during source test, and duration of venting, ~~or evacuating~~.

VENTING

$2.04 \times 1.13 \frac{lb}{hr} \times 9517 \frac{hrs}{yr} \times \frac{1\ ton}{2000\ lbs} =$ **11.0 ton/yr VOC from C8 venting**

(Note 5) (Note 1) (Note 6)

$2.04 \times 1.13 \frac{lb}{hr} \times 11{,}782 \frac{hrs}{yr} \times \frac{1\ ton}{2000\ lbs} =$ **13.6 ton/yr VOC from C13 venting**

(Notes 5) (Note 1) (Note 6)

FROM 2/20/96 Discussion with M. Crespin, emission factor should be based on 25 million bbls/yr

ENGINEERING CALCULATION SHEET

Coors

Coors Brewing Company
Golden, Colorado

CI—2343-D

SUBJECT	PROJECT NUMBER	DATE
FERMENTING		6/14/94

PREPARED BY	ENGINEERING TYPE	WORK PACKAGE NUMBER	PAGE
J. Zimmerman, M. Crespin	Ch.E.		2 OF 2

EVACUATION

$2.04 \times 2.679 \frac{lb}{hr} \times 0.9 \times 1,718 \frac{hr}{yr} \times \frac{1 \text{ ton}}{2000 \text{ lb}} =$ 4.2 tons VOC/yr from C8 Evacuation

(Note 5) (Note 1) (Note 3) (Note 6)

$2.04 \times 2.679 \frac{lb}{hr} \times 0.9 \times 2,111 \frac{hr}{yr} \times \frac{1 \text{ ton}}{2000 \text{ lb}} =$ 5.2 tons VOC/yr from Cellar 13 Evacuation

(Notes) (Note 1) (Note 3) (Note 6)

TOTAL

	VENT		EVAC		
C8 :	11.0 tpy	+	4.2 tpy	=	15.2 tpy
C13 :	13.6 tpy	+	5.2 tpy	=	18.8 tpy

Total = 34.0 tpy

REVISED 12/10/92

Correction factor = $\frac{\text{Sensitivity} \times \text{Mw of calibration gas}}{\text{Sensitivity} \times \text{Mw of ethanol}}$

$= \frac{0.98 \times 44.09 \text{ (Propane)}}{0.46 \times 46.07 \text{ (Ethanol)}} = 2.04$

where:

W_b = weight of component b

W_a = weight of standard a

A_a = measured area of standard a

A_b = measured area of component b

F_b = correction factor of compound "b" relative to compound "a" at equal weights.

The response of a FID is independent of temperature, carrier gas, and flow rate. This makes it well suited, possibly the best detector, for quantitative analysis. For weight percent calculations, Table VII-2 can be used. Divide the peak area by relative sensitivity, then normalize values to get weight percent.

An excellent reference for response factors for both flame ionization and thermal conductivity detectors is the article by Dietz [1].

TABLE VII-2—FID RELATIVE SENSITIVITIES [1]

COMPOUND	RELATIVE SENSITIVITY	COMPOUND	RELATIVE SENSITIVITY
Normal Paraffins		Aldehydes (cont.)	
Methane	0.97	Octaldehyde	0.78
Ethane	0.97	Capric aldehyde	0.80
⇒ Propane	0.98	Aromatics	
Butane	1.09	Benzene	1.12
Pentane	1.04	Toluene	1.07
Hexane	1.03	Ethylbenzene	1.03
Heptane	1.00	para-Xylene	1.00
Octane	0.97	meta-Xylene	1.04
Nonane	0.98	ortho-Xylene	1.02
Aldehydes		1M2-Ethylbenzene	1.02
Butyraldehyde	0.62	1M3-Ethylbenzene	1.01
Heptanoic aldehyde	0.77	1M4-Ethylbenzene	1.00
		1,2,3-Tri-methylbenzene	0.98

Dietz W.A.
Journal of Gas Chromatography
5, 68 (1967)

TABLE VII-2—FID RELATIVE SENSITIVITIES (cont.) [1]

COMPOUND	RELATIVE SENSITIVITY	COMPOUND	RELATIVE SENSITIVITY
Aromatics (cont.)		Acids	
1,2,4-Tri-methylbenzene	0.97	Formic	0.01
1,3,5-Tri-methylbenzene	0.98	Acetic	0.24
Isopropylbenzene	0.97	Propionic	0.40
n-Propylbenzene	1.01	Butyric	0.48
1M2-Isopropyl-benzene	0.99	Hexanoic	0.63
1M3-Isopropyl-benzene	1.01	Heptanoic	0.61
1M4-Isopropyl-benzene	0.99	Octanoic	0.65
sec.-Butylbenzene	1.00	Esters	
tert.-Butylbenzene	1.02	Methylacetate	0.20
n-Butylbenzene	0.98	Ethylacetate	0.38
Unsaturates		Isopropylacetate	0.49
Acetylene	1.07	sec.-Butylacetate	0.52
Ethylene	1.02	Isobutylacetate	0.54
Hexene-1	0.99	n-Butylacetate	0.55
Octene-1	1.03	Isoamylacetate	0.62
Decene-1	1.01	Methylamylacetate	0.63
Alcohols		Ethyl-(2)-ethylhexanoate	0.72
Methanol	0.23	Hexylcaproate	0.75
⇒ Ethanol	0.46	Cellosolve acetate	0.56
n-Propanol	0.60	Nitrogen Compounds	
Isopropanol	0.53	Acetonitrile	0.39
n-Butanol	0.66	Trimethylamine	0.46
Isobutanol	0.68	tert.-Butylamine	0.54
sec.-Butanol	0.63	Diethylamine	0.61
tert.-Butanol	0.74	Aniline	0.75
Amyl alcohol	0.71	di-n-Butylamine	0.75
Methylisobutyl-carbinol	0.74	Ketones	
Methylamyl alcohol	0.65	Acetone	0.49
Hexyl alcohol	0.74	Methylethylketone	0.61
Octyl alcohol	0.85	Methylisobutyl-ketone	0.71
Decyl alcohol	0.84	Ethylbutylketone	0.71
		Diisobutylketone	0.72
		Ethylamylketone	0.80
		Cyclohexanone	0.72

AGING

General Process Description

Aging is the continuation of fermentation, also known as secondary fermentation. This process occurs under CO_2 pressure, at temperatures below 32 ^oF. Emissions of VOC from this process would occur during tank filling or after the tank is empty, if the tank is opened to atmospheric pressure for any reason. Conditions under which the pressure would require venting, and the CO_2 purged, would be any time the tank must be opened, any time manual tank entry is required, or any time the tank is to be automatically cleaned with a caustic solution.

Information Relating to Source Test

At the facility studied, emissions from the aging emissions occur as the tank is filled, and after the tank is emptied. During filling the displacement gas vented to atmosphere is air, CO_2, and ethanol. This process is called fill-on-vent. A source test was performed on six aging tanks during the fill-on-vent process. The test was done by Clean Air Engineering on August 19, 1992, and is reported in Stack Test Report No. 2. The emission factor for this process is 0.09 lb/1000 barrels (finished product volume). This applies if the displacement gases are vented to atmosphere for every batch.

The actual aging process is conducted under CO_2 pressure. Once the tank is emptied of beer, the CO_2 pressure must be vented and the remaining CO_2 in the tank purged. A source test was conducted in November 1990 by Western Environmental Services Testing Inc. (WEST) on the venting of CO_2 pressure from the aging tank. The test is reported in Stack Test Report No. 8, and referred to as Aging Vent stack. Only one run was conducted because the pressure venting operation takes only 20 minutes. The test was conducted on a "set" of three tanks.

After the pressure is vented, the CO_2 must be purged to allow for manual tank entry for removal of the yeast. Valves are opened to allow fresh air in and the tank is hooked up to the building's tank evacuation system, which pulls the tank gases, CO_2 and ethanol, outside through a fan, allowing fresh air to enter. A source test was conducted in November 1990 by WEST on a set of three tanks undergoing CO_2 evacuation. The test is reported in Stack Test Report No. 8, and referred to as Aging Exhaust stack. Test data was taken during the first two hours of the six hour evacuation period, during which time the concentration of ethanol steadily declined. By the very nature of the operation, the emissions should continue to decrease over the rest of the six hour evacuation period. To account for this when calculating emissions the data was plotted and extrapolated to the end of the evacuation period. An average emission rate was used in calculating the emission factor for this operation.

The emission factor for venting of CO_2 pressure from an aging tank is 0.43 lb/1000 barrels and for purging of CO_2 from an aging tank is 3.1 lb/1000 barrels, both based on finished product volume. Please note that the calculation of this emission rate uses a correction factor of 2.04. This correction factor is necessary to correct for the ability of the Flame Ionization Detector (FID) to detect ethanol as compared to propane, the calibration gas used in the test. For the other source tests where ethanol was the primary constituent measured, a correction factor was empirically determined for the specific FID used and that correction factor (2.36) was incorporated into the stack test reports. Because that was not done for the WEST source test, the correction factor of 2.04 was determined from data published in the "Journal of Gas Chromatography" (attached to Fermenting emission factor calculation).

<u>Applicability</u>

While the aging process is universal to all breweries, these emission factors apply only to those which vent displacement gas to atmosphere, and those that open the aging tank to atmospheric pressure and/or purge the CO_2 from the tank after the aging cycle. The emission factor given assumes that the tank is opened and purged after each cycle. If this is not the case, the factor could be divided by the frequency of purging. For example a brewery might automatically remove the yeast and clean with water only for two cycles and caustic clean on the third cycle. In this case the emission factor could be applied by dividing it by three.

Coors

Coors Brewing Company
Golden, Colorado

ENGINEERING CALCULATION SHEET

CI—2343-D

SUBJECT	PROJECT NUMBER	DATE
AGING		6/14/94
PREPARED BY: J. Zimmerman / M. Crespin	ENGINEERING TYPE: Ch.E.'s	WORK PACKAGE NUMBER	PAGE 1 OF 3

Notes:

(1) Emission rates taken from 11/90 source test. See attached documentation.

(2) Test performed on cellar 20 vent and evacuation stacks. Assume that emission rates apply to other eight aging cellars, which are identical.

(3) Due to declining nature of evacuation emissions, data from test was extrapolated graphically.

(4) Operation data on duration of venting and evacuation supplied by Lawson Thomason.

(5) Emission rates are as propane. Multiply by correction factor 2.04 for ethanol emission rates.

(6) Factor based on total number of aging tanks per year, number of aging tanks on vent during source test, and duration of venting or evacuation.

VENTING

$$2.04 \times 3.476 \frac{lb}{hr} \times 152 \frac{hr}{yr} \times \frac{1\ ton}{2000\ lb} = 5.4 \frac{ton}{yr}$$

(Notes 5) (Note 1) (Note 6, 4)

5.4 ton/yr VOC total for 9 cellars

$$5.4 \frac{ton}{yr} \times \frac{1\ cellar}{9\ cellars} = 0.6 \frac{ton}{yr \cdot cellar}$$

Coors Coors Brewing Company
Golden, Colorado

ENGINEERING CALCULATION SHEET

CI—2343-D

SUBJECT	PROJECT NUMBER	DATE
AGING		6/14/94

PREPARED BY	ENGINEERING TYPE	WORK PACKAGE NUMBER	PAGE
J. Zimmerman / M. Crespin	Ch.E.		2 OF 3

EVACUATION

Note: Emissions decline steadily during the time of evacuation. Test run during the first 2 hrs, at the highest emission rates. Averaging concentration of THC over the vent time would be:

$$\frac{670 \text{ ppmV} + 110 \text{ ppmV}}{2} = 390 \text{ ppmV}$$

[Beginning concentration and projected concentration averaged, see attached graphical extrapolation].

at 501 ppmV, the mass flow rate of VOC = 2.679 lb/hr

$$\therefore \left(\frac{390}{501}\right) \times 2.679 \frac{\text{lb}}{\text{hr}} = 2.08 \text{ lb/hr}$$

$$2.04 \times 2.08 \frac{\text{lb}}{\text{hr}} \times 18{,}246 \frac{\text{hrs}}{\text{year}} \times \frac{1 \text{ ton}}{2000 \text{ lb}} = 38.7 \frac{\text{ton}}{\text{Yr}} \text{ VOC}$$

(2.04 ↑ Note 7; 2.08 ↑ (above); 18,246 ↑ (Note 6, 4))

38.7 ton/Yr VOC total for 9 cellars from Evacuation

FILL-ON-VENT

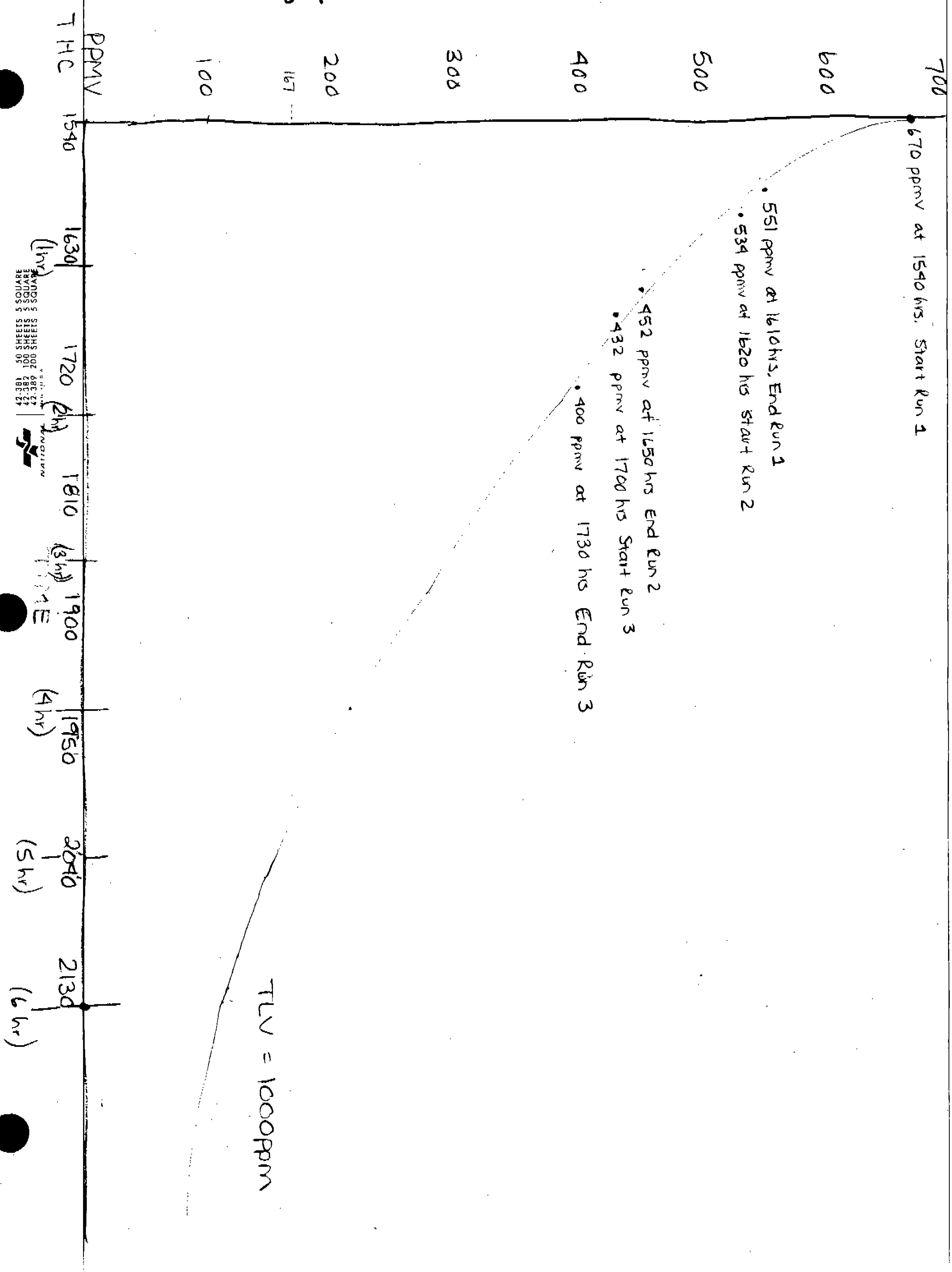
Note (7) Fill on vent emission rates from protocol source test performed by Clean Air Engineering on August 19, 1992.

$$3.077 \frac{\text{lb}}{\text{fill}} \times 1521 \frac{\text{fills}}{\text{Yr}} \times \frac{1 \text{ ton}}{2000 \text{ lb}} = 2.3 \frac{\text{ton}}{\text{Yr}} \text{ VOC for 9 cellars from fill on vent}$$

(1521 ↑ Note 6)

$$2.3 \frac{\text{ton}}{\text{Yr}} \times \frac{1 \text{ cellar}}{9 \text{ cellars}} = 0.26 \frac{\text{ton}}{\text{Yr} \cdot \text{cellar}}$$

AGING EMISSIONS - extrapolation graph | 12/7/92 Page 3 of 3 | Jere Zimmerman Ch. E. 145302



BLENDING/FINISHING

General Process Description

Blending/Finishing is the process in which aged beer is filtered and blended into the final product. The beer is then stored in tanks prior to being packaged. There are two processes that occur during finishing/blending that cause the emission of ethanol (VOC) to the atmosphere. First is fill-on-vent (FOV) which occurs each time a clean empty tank is filled with beer. As the tank is filled, a CO_2 blanket is provided so that the beer does not come in contact with oxygen. The air (CO_2, O_2, and ethanol) above the blanket is displaced as the tank is filled and vented to atmosphere. The second process, known as evacuation, occurs after a tank has been emptied to allow tank cleaning by production personnel. The evacuation process draws outside air through the tank to atmosphere to increase the oxygen content within the tank.

Information Relating to Source Test

Stack testing was performed during an FOV process on an Aging Cellar (the Aging FOV process is similar to Finishing/Blending). Results from the test are summarized in Table 1 and the VOC emission factor has been calculated on the calculation sheet.

For the evacuation process, the emission rate was based on the peak VOC concentration measured during an evacuation process at one of the Fermenting and Aging Cellars. The emission factor calculation for this process is presented on the attached calculation sheet.

For the above calculations, both the vent/evacuation frequency and total tank volume must be known. On average, the blending/finishing process takes aged beer through three steps, each in a different tank. [redacted]

Applicability

All breweries have the finishing/blending process. The application of these emission factors will depend on the average number of steps (tanks) the beer is processed through prior to packaging. It is important to note that the frequency of venting and evacuation depends on several factors such as throughput and cleaning schedule.

Brewing - Blending / Finishing Emission Factor Calculation

Fill On Vent

$$EF = \left(\frac{3.077\, lb\, VOC}{6\, Tanks}\right) X \frac{3\, Tanks}{2700\, bbl}$$

$$EF = 0.57 \frac{lbs}{10^3\, bbl}$$

Notes:

(1) Emission factor from source test (3.077 lb/6 tanks). [Revised Book 2, page 1-2]
(2) Approximate packaged beer throughput prior to tank cleaning.

CO_2 Evacuation

$$EF = \left(31.5\, \frac{gal}{bbl}\right)\left(0.13368 \frac{ft^3}{gal}\right)\left(\frac{30\, psia}{12\, psia}\right)\left(\frac{1002x10^{-6}\, ft^3\, EtOH}{ft^3\, gas}\right)\left(\frac{lbmol}{472\, ft^3}\right)\left(46.07 \frac{lb}{lbmol}\right)$$

$$EF = 1.0 \frac{lb\, VOC}{10^3\, bbl}$$

Notes:

(1) Conversion factor (30 psia/12 psia) for 18 psig system pressure reading.
(2) EtOH concentration ($1002x10^{-6}$) in air stream from source test. Scale factor of 2.04 for EtOH. [Book 8, page 6]
(3) Correction factor (472 ft^3/lbmol) for gas expansion at 68 F and 12 psia (see equation below):

$$\frac{V}{n} = \frac{R\, T}{P} = \frac{\left(10.73 \frac{psia\, ft^3}{lbmol\, R}\right)(528\, R)}{12\, psia}$$

Packaging

Operation	Emission Factor
Can Filling (1)	38 lb/ 1000 barrels filled
Bottle Filling (1)	37 lb/ 1000 barrels filled
Keg Filling	0.69 lb/ 1000 barrels filled
Defill (2)	3.0 lbs/ hour
Defill (3)	0.46 lbs/ hour
Bottlewash - VOC (4)	0.23 lb/ 1000 case

(1) Includes point and fugitive emissions, derived from sterile fill process.
(2) Defill system utilized a pneumatic crushed can transport system.
(3) Defill system utilized a mechanical system.
(4) Based on cases input into the system (case=24-12 oz. bottles)

FILLERS

General Process Description

After Blending/Finishing, the beer is packaged in cans, bottles, or kegs. The filling process is a high speed process similar for all container types. To keep the beer from foaming as it is introduced into the container and to prevent contact with oxygen, the container is first filled with CO_2. As the container fills with cold beer the CO_2 is displaced . Typically some mechanism is used to foam the beer and purge any oxygen from the headspace before the container is closed.

The filling process generates VOC emissions. The emissions are primarily ethanol from the beer. The process is a combination point and fugitive source. The point source emission rate is much smaller than the fugitive emission rate. The point source portion of the process is the filling machine. The CO_2 which is displaced as the container is filled is returned to the filling machine and vented. The CO_2 carries ethanol as a result of its contact with the beer. Fugitive emissions from the process result primarily from spilled beer. As spilled beer comes into contact with warm or hot process equipment some of the ethanol is evaporated into the room air.

Information Relating to Source Test

At the facility studied the filling systems for bottles and cans are located in enclosed rooms. Filtered air is forced into each filler room to provide ventilation for the filler machine operators. Approximately half of this ventilation air exits the filler rooms through the filler room vents. There is one filler room vent for the can filling machines, and one filler room vent for the bottle filling machines. The other half of the filler room ventilation air exits the filler rooms as fugitive into the building.

Source testing was conducted in June 1992 by Clean Air Engineering to determine emission rates from the filler machine bowls, the keg fillers, and the can and bottle filler rooms (see Stack Test Report #1). Because the emission rates for the filler rooms were higher than expected, two additional source testing exercises were conducted. Both were performed by Air Pollution Testing, the first in October 1992, the second in December 1992. The results reported in Stack Test Reports #5 and #6 verify the VOC emissions from the filler rooms.

Beer filling rate data was collected during the source tests and have been used to develop emission factors. The tested emission rates from the filler rooms was multiplied by the ratio of the inlet air over the collected outlet air, to account for fugitive emissions from the filler rooms. The emission rate was then divided by the fill rate during that test run. Then the emission rate for the filler machine vent on a pounds per barrel basis was added to determine the overall emission factor. The average emission factors from all the tests are: 38 lbs/1000 barrels filled for can filling, 37 lbs/1000 barrels filled for bottle filling, and 0.69 lbs/1000 barrels filled for keg filling.

Applicability

All breweries have packaging operations. VOC emissions would be expected from the filling machines themselves due to the displacement of the gas in the container by the beer, and evaporative emissions from spilled beer. Since not all breweries have enclosed filling machines, the evaporative emissions may be fugitive. Several factors affect the rate of VOC emissions and will vary based on the filling operation used. In addition to the rate of filling, three of the most important factors are the HVAC air flowrate, the quantity of beer spilled, and the temperature of the beer after spilling. It is expected that the greater the quantity of spilled beer the greater the emission rate, as more ethanol would be available for vaporization and for stripping. A greater air flowrate would also be expected to increase the emission rate, as the larger airflow would strip more ethanol from the available spilled beer. Finally, if the temperature of the spilled beer is increased by exposure to heat sources, such as hot gearboxes, higher emissions would be expected.

These emission factors were derived specifically from a sterile fill operation (beer not pastuerized after filling, also referred to as "draft" beer), and would apply most directly to other sterile fill operations. Non-sterile fill processes at breweries which utilize pastuerization as an alternative to sterile filling may have different emissions rates from filling.

VERSION 3/11/1993 | TABLE 1.

NOTES FOR TABLES 2,3,4,5

NOTE NO.	
1	Actual barrels of beer packaged in cans, bottles, and kegs during the run period. (data from the packaging line sheets for the run period.)
2	F.I.D. average PPM (as propane) measured during the run period.
3	Dry Standard Cubic Feet Per Minute volume of gas measured during the run period.
4	FORMULA = PPM (AS PROPANE) X SCALE FACTOR X MW PROPANE /(385.3) X 1/1,000,000 X DSCFM X60 WHERE: SCALE FACTOR = 2.36 — ETOH/ PROPANE MW PROPANE = 44 — (ETOH = ethanol) 385.3 = LB-MOLE/DSCFM LBS/HR ETOH = PPM X DSCFM X 0.00001617
5	LBS/BBL = (LBS/HR)/(BBLS/HR)
6	All tests were performed as protocol compliance tests by Clean Air Engineering, Inc. (June, 1992) see Book 1, pages 1-2 through 1-5
7	.000378 lbs of ethanol per barrel of beer packaged must be added to each filler calculated emission rate to account for the emissions from each machine bowl vent. See Table 3 for test result.

version 2/4/1993

TABLE 2.

CAN LINE ROOM VENT TEST DATA - (Book 1, p. 1-2)

COMPLIANCE TEST RUN JUNE 23,1992

RUN NO.	TIME OF RUN	BBL/RUN (note 1)	MEASURED (PPM PROPANE) (note 2)	DSCFM (note 3)	LBS/HR (note 4)	LBS/BBL (note 5)
1	14:00-15:00	1429.83	61	25410	24.9	0.0174
2	15:30-16:30	1528.17	61	26780	26.6	0.0174
3	17:00-18:00	1480.63	51	26460	22.0	0.0149
	Average	1479.54	58	26217	24.500	0.017

CAN ROOM EMISSIONS = .017 X (61242/26217) X .000378 = .0401 LBS/BBL

WHERE:
- 61242 = ROOM INLET CFM
- 26217 = ROOM OUTLET CFM
- .000378 = CO2 BOWL VENT LBS/BBL (SEE TABLE 3)

notes are explained on table 1.

VERSION 2/4/1993

TABLE 3.

CAN AND BOTTLE FILLER MACHINE BOWL VENT TEST DATA (Book 1, p. 1-3)

COMPLIANCE TEST RUN JUNE 24,1992

RUN NO.	TIME OF RUN	BBL/RUN (note 1)	MEASURED (PPM PROPANE) (note 2)	DSCFM (note 3)	LBS/HR (note 4)	LBS/BBL (note 5)
1	10:05-11:05	1902.14	38	1331	0.848	0.000446
2	12:00-13:00	1882.12	30	1311	0.725	0.000385
3	14:00-15:00	1918.24	18	1268	0.579	0.000302
	Average	1900.83	29	1303	0.717333	0.000378

see table 1 for explanation of notes

version 2/4/1993

TABLE 4.

BOTTLE LINE ROOM VENT TEST DATA (Book 1, p. 1-4)

COMPLIANCE TEST RUN JUNE 25,1992

RUN NO.	TIME OF RUN	BBL/RUN (note 1)	MEASURED (PPM PROPANE) (note 2.)	DSCFM (note 3.)	LBS/HR (note 4.)	LBS/BBL (note 5)
1	9:04-10:04	522.57	40	20290	13.1	0.025
2	10:33-11:33	495.96	47	19960	15.2	0.031
3	11:57-12:57	533.09	41	20450	14.5	0.027
	Average	517.21	43	20233	14.267	0.028

BOTTLE ROOM EMISSIONS = .028 X (28056/20233) + .000378 .039204 LBS/BBL

WHERE:
28056 = ROOM INLET CFM
20233 = ROOM OUTLET CFM
.000378 = CO2 BOWL VENT LBS/BBL (SEE TABLE 3)
notes are explained on table 1.

30

VERSION 2/4/1993

TABLE 5.

KEG LINE FILLER (CO2) VENT TEST DATA (Book 1, p. 1-5)

COMPLIANCE TEST RUN JUNE 25,1992

RUN NO.	TIME OF RUN	BBL/RUN (note 1.)	MEASURED (PPM PROPANE) (note 2.)	DSCFM (note 3.)	LBS/HR (note 4.)	LBS/BBL (note 5)
1	19:00-20:00	0.01	140	37	0.084	8.4
2	20:30-21:30	218	277	38	0.170	0.00078
3	22:00-23:00	192.5	209	34	0.115	0.000597
	Average	136.84	209	36	0.1425	0.000689

notes are explained on table 1.

On this table the averages were computed from runs 2 and 3 only.

Run 1 was performed while keg filling was not being accomplished.

VERSION 3/11/1993				
		TABLE 6.		
CALCULATIONS FOR APT EMISSION TESTS				
TEST NO.	test area	calculation, lbs/ bbl.	plus	emission rate
(date)		(or value direct	bowl vent	lbs of ethanol
		from stack report #5 and 6)	emission	per barrel of
			rate, lbs/bbl.	beer packaged
1 (10/14/92)	total bottle	.014 x 28056/12224 = .0321	0.000378	0.033
2 (10/14/92)	total can	.012 x 61242/25696 = .0286	0.000378	0.029
3(12/2/92)	#3 bottle	0.0376	0.000378	0.038
4(1216/92)	#5 can	0.0359	0.000378	0.036
5(12/16/92)	#6 can	0.0368	0.000378	0.037
6(12/3-12/5)	#9 can	0.0416	0.000378	0.042
1992				
Average of all CAE and APT stack tests				
	APT	average can emission	rate	**0.036**
	APT	average bottle emission	rate	**0.035**
	CAE	average can emission	rate	**0.040**
		(from table 2)		
	CAE	average bottle emission	rate	**0.039**
		(from table 4)		
		average of all tests (can)	rate	**0.038**
		average of all tests (bottle)	rate	**0.037**
NOTES:	CAE tests were performed June, 1992			
	APT tests were performed Oct. and Dec. , 1992.			

PACKAGING - DEFILL

General Process Description

The defill operation is utilized to remove beer from containers (cans and bottles) for a variety of reasons, including rejects from beer filling operations. A defiller is typically comprised of a conveyor system which leads the containers to a grinder. Full cans and bottles are then crushed by the system's grinder to evacuate the contained beer. From this point the waste beer is pumped into a holding tank and the container material, which may still contain residual beer, is sent to recycling or the landfill for disposal.

Emission Factor

a) Can Defill (Pneumatic Conveying):

At the tested facility the can defiller was configured with an open system crusher and pneumatic conveyor which transported the crushed cans to a cyclone for collection. Emissions from the can defilling operation are generated when full cans are shredded and emptied.

An initial protocol stack test was performed on the open system crusher just prior to the cyclone which collects the crushed cans. Ethanol emission rates remained fairly steady independent of throughput in barrels per hour. This is believed to be due to the air stream being saturated with ethanol. The calculated emission factor resulting from this testing was 6.6 lbs/hour operation.

The can defilling system was studied and attempts were made to minimize emissions. The crusher roller speeds were changed as well as being modified, and watersprays were introduced to more thoroughly remove beer before the airveyor. In addition, control changes were made in order to deliver cans in batches to the system. A protocol source test was again conducted on the open system crusher. Results from this testing show a calculated emission factor from the upgraded defilling system of 3.0 lbs/hour of operation. The test uncovered that an erroneous assumption was made when determining the initial emission factor, that in fact the initial factor of 6.6 lbs/hour was double what the true factor should have been. After recalculating this emission factor, the test indicated that the adjustments made to the process had little effect on emissions.

b) Bottle Defill (Mechanical Conveying):

Filled bottles are dumped into the bottle crusher unit for crushing by the system's grinder to evacuate the contained beer. The crusher is a source of fugitive VOC emissions. Dumping into the crusher occurs in batches. After crushing, the waste beer and broken glass are passed over a screen for separation. Mechanical conveying is used to transport the broken glass to a truck trailer dump.

A protocol stack sampling test was performed at the bottle crusher unit by placing a temporary enclosure around the unit. Air was provided to the temporary room by a fan and the air was vented to the outside. The testing was conducted at the exhaust duct outside the room. The initial testing indicated a VOC factor of 1.4 lbs/hr of operation.

The bottle crusher unit was upgraded to include a larger dump bin in addition to installing water sprays at the bottle crusher. The water spay unit operates during the beginning of each batch dump. Another protocol stack test was conducted at the bottle crusher following original procedures. Results from this testing indicated a reduction in emission to a VOC factor of 0.46 lbs/hr of operation.

<u>Applicability</u>

Many breweries have defill operations for destruction of packaged beer. The purpose of this operation is to recover the alcohol taxes paid on the product. Typically, defilling is a fugitive VOC source. Additional sources of VOCs from defilling might include breathing and working losses from the waste beer storage tank. The emission factor will vary depending on the method of defilling and the conditions in the defill operation. Testing at the can defill facility and the bottle defill facility indicate that the use of pneumatic conveying promotes emissions from volatile organic compound, i.e., the airveyor acts as an airstripper.

PACKAGING - BOTTLEWASH

General Process Description

Bottlewash systems are used to clean returned long neck bottles prior to refilling with beer. The "as received" bottles are removed from their cases and loaded onto a conveyor system. As the bottles move through the system, they are tilted to allow residual liquid to pour out. The bottles are then given an interior and exterior warm-water prerinse. Residual liquid and rinse water are collected and filtered before disposal.

The bottlewash system is a source of VOC (ethanol and glycol ethers) and sodium hydroxide. Bottlewash systems also have several fugitive emission locations. For ethanol, the first is the trough where the residual liquid and prerinse spray are collected and the second is at the filtering system. For glycol ethers, the soaker (bottle label removal system) is the fugitive emission source due to the use of surfactants.

Emission Factor

A protocol source test was conducted on the bottle washing system. Testing was conducted to determine combined ethanol emissions from the trough and the filtering system. Results from testing indicate an emission factor of 0.00023 lb of VOC per case input. This emission factor was determined by dividing the cumulative quantity of ethanol released from the bottlewash unit over a specific period of time by the number of bottles processed over the same time frame. A mass balance approach was used to determine glycol ether emissions. They are a component of the surfactant used in the label removal process in the bottle soaker. Due to the low vapor pressure of the glycol ethers and the high temperature within the soaker, it was assumed that they completely volatilized out of solution. Glycol ether emission will greatly depend on the surfactant type. Consultation of the surfactant's MSDS for percent volatiles will provide the information required to perform the mass balance.

An emission factor for sodium hydroxide is available through the EPA's AIR CHIEF CD-ROM, version 2.0, Record number 21,858, May 1992. The factor is 9.0 lb/hour of operation.

Applicability

The emission factor for bottle washing should be applicable to any facility which utilizes a beer bottle return system. This would include most breweries. The factor is based on VOC emissions from the initial high temperature pre-rinse prior to entering the bottle washer.

PACKAGING - BOTTLE WASHER

General Process Description

Bottle wash systems are used to clean returned long neck bottles prior to refilling with beer. The "as received" bottles are removed from their cases and loaded onto a conveyor system. As the bottles move through the system, they are tilted to allow residual liquid to pour out. The bottles are then given an interior and exterior warm-water prerinse. Residual liquid and rinse water are collected and filtered before disposal.

The bottle wash system is a source of VOC (ethanol), glycolethers and sodium hydroxide. Bottle wash systems also have several fugitive emission locations. For ethanol, the first is the trough where the residual liquid and prerinse spray are collected and the second is at the filtering system. For glycolethers, the soaker (bottle label removal system) is the fugitive emission source due to the use of surfactants.

Information Relating to Source Test

A mass balance approach was utilized to calculate the bottle washer VOC emission factor. The calculation is based on bottle case input to the system. System output is not utilized due to bottle breakage at various steps within the bottle washer. VOC emissions are fugitive due to the prerinse process prior to the bottles entering the caustic wash. The high temperature water from the spray rinse (55-57 ^{o}C) is assumed to volatilize 100 percent of the ethanol out of solution.

Residual liquid volume was quantified by pulling random cases off the load-in conveyor and pouring the bottle contents into a container. Two separate tests were run with a resultant volumetric average of 3.2 ± 1.8 quarts of liquid per 40 cases of return bottles. A liquid sample was then analyzed for percent alcohol with a result of 1.82 percent by weight. The reduced alcohol content as compared to packaged beer is believed to be due to warehousing of the open bottles at ambient temperatures prior to being brought on-site for cleaning. The attached calculation sheet provides the emission factor calculation for VOC emissions.

A mass balance approach could also be used to determine glycolether emissions. They are a component of the surfactant used in the label removal process in the bottle soaker. Due to the low vapor pressure of the glycolethers and the high temperature within the soaker, it was assumed that they completely volatilized out of solution. Glycolether emission will greatly depend on the surfactant type. Consultation of the surfactant's MSDS for percent volatiles will provide the information required to perform the mass balance.

An emission factor for sodium hydroxide is available through the EPA's AIR CHIEF CD-ROM, Version 2.0, Record number 21,858, May 1992. The factor is 9.0 lb/hour of operation.

<u>Applicability</u>

The emission factor for bottle washing should be applicable to any facility which utilizes a beer bottle return system. This would include most breweries. The factor is based on fugitive VOC emissions from the initial high temperature pre-rinse prior to entering the bottle washer.

Packaging - Bottle Washer Emission Factor Calculation

$$EF = \left(\frac{3.2\ quarts}{40\ cases}\right)\left(\frac{gal}{4\ quarts}\right)\left(8.35\ \frac{lb}{gal}\right)(0.0182\ EtOH)$$

$$EF = 3.0\ \frac{lb\ VOC}{10^3\ cases}$$

Notes:

(1) Volume of residual liquid (3.2 quarts) measured by randomly pulling 40 cases off the input conveyor system over a 10 hour period. Two tests performed, average volume was 3.2 ± 1.8 quarts.
(2) Density of residual liquid collected (8.35 lb/gal).
(3) Alcohol content of residual liquid measured at 1.82 percent by weight with a SCABA Automated Beer Analyzer.

PACKAGING - MISCELLANEOUS SOURCES

Other common packaging sources which have potential fugitive VOC emissions include:

- Bottle line conveyor lubricants/cleaners;
- Inkjet printers; and
- Box and label gluing operations.

Bottle line conveyor lubricants are typically a soap solution which is sprayed onto the conveyor system to allow the bottles to move along. The use of the lubricant reduces bottle breakage. Inkjet printers are used to code and date bottles, cans, and cases after filling.

Emissions from these processes depend on the chemicals utilized (e.g., solvent, glue, ink, etc. VOC content), therefore, an emission factor could not be developed. However, by tracking the chemical's consumption rate and percent volatility (check chemical MSDS) an emission rate can be calculated.

Byproducts

Operation	Emission Factor
Yeast Lysing - VOC (1)	4.8 lb/1000 barrels (4)
Yeast Storage - VOC	7.7 lb/1000 barrels
Waste Beer - VOC	1.1 lb/1000 barrels
Spent Grain Drying - VOC (2)	2.6 lb/1000 barrels
Spent Grain Drying - PM (2)(3)	0.94 lb/1000 barrels
Spent Grain Drying - PM10 (2)(3)	0.29 lb/1000 barrels
Spent Grain Drying - CO (2)	0.91 lb/1000 barrels

(1) Based on heat lysing operation.
(2) Based on steam heated dryers.
(3) Controlled emission rates. Control device is a wet scrubber.
(4) In all cases "1000 barrels" refers to finished product volume i.e. the total volume of beer produced at the facility.

WASTE YEAST HANDLING AND STORAGE

General Process Description

At the completion of the fermentation process, beer is decanted from the fermenting vessel and a beer/yeast slurry remains in the bottom. Once removed, this slurry must either be returned to the production process or handled as a waste or byproduct. This is also true of the aging process except that aging yeast is not suitable for return to the production process and must be handled as a waste product. Yeast handling and storage is a potential source of VOC emissions because both the beer in the beer/yeast slurry and the yeast cell itself contain ethanol.

Information Relating to Source Test

At the facility studied , waste yeast from fermenting goes through one of two high pressure chamber filter presses to recover the beer. The yeast cake drops into one of two hoppers, where it is heated. Heating the yeast serves two purposes. First, it returns the yeast to a pumpable consistency. Second, the yeast is lysed. Lysing is the process of killing the yeast by rupturing the cell wall. This is most commonly done using heat or chemicals. Lysing also stops yeast action, such as foaming, and releases CO_2 entrained in the cell. The lysing actually occurs as the yeast is circulated between the hopper and a mixed, heated storage tank. The lysed yeast is transferred to a holding tank, then sent to a drying plant and subsequently sold as a byproduct. Heat lysing of yeast releases large amounts of ethanol because the yeast cell is broken, thereby releasing the ethanol in the cell. The heat tends to vaporize the ethanol and drive off any entrained CO_2 from both the beer and the yeast. The CO_2 which is given off also tends to carry ethanol with it.

In June of 1992 VOC source testing was conducted by Clean Air Engineering on the yeast lysing process. During the process, ethanol is released from the yeast receiving hopper, and the yeast holding tank. The yeast receiving hoppers are fugitive to the production area which is vented through two roof fans to the atmosphere. The yeast holding tank is equipped with a stack. During the lysing process emissions were monitored on the tank vent and on one of the production area roof vents. The other roof vent was closed during the testing. The results of this testing are reported in stack test report #3. The emission rate was continuously monitored from June 10 through June 15. Runs #7 and #8 were chosen to highlight in the report because the highest emissions and the greatest production activity occurred during those two runs. To calculate an annual emission rate the highest six hour average emission rate, representing a period of production at 100% design capacity, was extrapolated to 8760 hours per year. The operation logs for the period during the testing were consulted to obtain a process production rate, and an emission factor has been calculated. A factor of 4.8 lbs/1000 barrels beer produced (finished product volume) was calculated.

This factor is believed to underestimate the emission rate from the yeast lysing operation. This value is based in part on the VOC emissions measured from the building roof fan. This fan would not be expected to capture 100% of the air in the building , and therefore, the measured emission rate is believed to underestimate the emissions. Because the source test did not take into account the capture efficiency of the roof fan, an emission rate was estimated using a mass balance approach and production data . This method of estimation produces an emission factor of 7.12 lbs/1000 barrels beer produced (finished product volume).

The storage of the yeast also generates emissions. To prevent settling of the yeast in the storage tanks, air is constantly sparged through the tanks. A source test was conducted on the yeast storage tank vents in June 1992 by Clean Air Engineering. The results are reported in stack test report #4. Each yeast tank has its own vent. There are three types of yeast stored. Live yeast refers to yeast from fermentation that has not been lysed. HPF yeast refers to yeast from fermenting that has been lysed. Aging yeast refers to yeast from the aging process, none of which is lysed. The emissions were monitored for a minimum of 24 hours from each type of yeast storage tank. An emission factor of 7.7 lbs/1000 barrels for VOC emissions from the yeast storage tanks has been calculated.

Applicability

All breweries produce waste yeast in a slurry of beer, which must be handled in some way. Handling , storing, and processing waste yeast can result in significant ethanol emissions. The method of waste yeast handling is expected to vary from brewery to brewery. These emission factors would best apply to heat or chemical yeast lysing processes, and to storage of waste yeast, especially at ambient or higher temperatures.

Waste Yeast Handling and Storage Emission Factor Calculations

Calculated from Stack Tests

Notes:

1) Emission rates were taken from engineering stack tests performed June 10th through June 15th, 1992.
2) Data on the yeast recovered was taken from operation logs of the Reclaim Area on June 10th through June 15th, 1992.
3) 11.373 lbs/hr is the highest six hour average emission rate recored during the source testing. Emission rate occurred during run #7, performed 6/13/92.

11.373 lbs VOC/hr x 8760 hr/year = 99,627 lbs/year

Emission Factor = 99,627 lbs ethanol/year/20.8 million barrels of beer
= 4.8 lbs VOC/1000 bbls

Handling and Storage Emission Factor

Tested VOC emissions from storage of live yeast (Tank 9C-2*)	6.8 tpy x 2 tanks
Tested VOC emissions from storage of aging yeast (Tank 9C-6*)	2.75 tpy x 4 tanks
Tested VOC emissions from storage of HPF yeast (Tank 9C-12*)	27.8 tpy x 2 tanks
(*All from book 4, p. 1-2)	
	80.2 tpy

Emission Factor = 80.2 tpy x 2000 lbs/ton/20.8 million barrels of beer
= 7.7 lbs VOC/1000 bbls

WASTE BEER HANDLING AND STORAGE

General Process Description

A brewery generates waste beer from various processes and operations. Off-specification beer, spillage, defilling, and liquids recovered from byproduct and waste streams contribute to the waste beer volume. Waste beer is usually collected in a separate collection system apart from the normal sewage system, due to its high TOC (total organic carbon) content. Waste beer storage, processing, and disposal produce VOC emissions in the form of ethanol.

Information Relating to Source Test

The facility studied collects waste liquids in a building referred to as Cellar 9. Cellar 9 consists of tanks for storage of waste liquids. The tanks are located on the B and C floors of Cellar 9. Eight tanks hold waste beer. A waste beer condensing system is used to recover alcohol from waste beer and concentrate the waste liquid. Condensate from this system is stored in eight tanks in Cellar 9. Breathing and working losses from these tanks result in ethanol emissions. Cellar 9 also has a truck loadout system for loading of liquids into trucks for transport.

Stack tests were conducted on the waste beer storage tanks and the alcohol condensate storage tanks in June 1992 by Clean Air Engineering. Emissions from each type of vent were monitored for 12-24 hours. The alcohol condensate tanks on the B level are vented through a common stack. The waste beer tanks on the C level are each equipped with a separate vent. Results can be found in stack test report #4.

The emission rate for the truck loadout system was estimated using the calculation method found in AP-42, Section 4.3 "Storage of Organic Liquids". Overall brewery production data has been used to convert the measured tank emission rates and the calculated truck loadout emission rate to an emission factor. The calculated emission factor for waste beer handling is 1.1 lbs/1000 barrels beer produced (finished product volume).

Applicability

All breweries produce waste beer and other ethanol containing liquid waste streams. Although emissions will vary from brewery to brewery, it is important to note that high emissions of VOCs can result from byproducts operations, especially where heat processing is used and where storage occurs at ambient temperatures. Several factors will determine the emission rate for a particular brewery. These include: the amount of waste beer generated per barrel of beer produced, the manner in which waste products are processed prior to disposal or sale as byproducts, the degree to which waste products are handled onsite, and the collection, storage, processing, and disposal methods used for waste liquids.

Waste Beer Storage and Handling Emission Factor Calculations

Emissions from storage of waste beer (Tanks C9-8 and C9-9) 0.497 tpy (book 4, p. 1-2) x 8 (typical of eight tanks) =	3.98 tpy
Emissions from storage of alcohol condensate (book 4, p. 1-2, C9-B) (test inclusive of all alcohol condensate tanks)	7.01 tpy
Emissions from truck loadout (AP-42) see attached sheet	0.73 tpy
	11.72 tpy

11.72 tpy x 2000 lbs/ton = 23,440 lbs per year

23,440 lbs/yr/ 20.8 mm barrels = 1.1 lbs/1000 barrels beer produced
(finished product volume)

43

CELLAR 9.
TRUCK LOADOUT
Annual Emission Rate Estimate
Stack Number:C09-057

Parameter (1)	Abbrev.	Value	Units	Notes
Molecular Weight of Vapor (2)	Mv	20.59	lb/lbmole	Table 4.3-2
Avg. Atmospheric Pressure	Pa	12.0	psia	See attached altitude correction chart.
True Vapor Pressure of Liquid	P	3.05	psia	Table 4.3-2
Tank Diameter	D	16.3	ft	See attached calculation sheet.
Avg. Vapor Space Height	H	3	ft	See attached calculation sheet.
Avg. Diurnal Temp. Change	T	1	F	
Paint Factor	Fp	1.33	n/a	Based on light grey paint.
Adjustment Factor for Tank Dia.	C	0.3	n/a	Figure 4.3-4
Product Factor	Kc	1	n/a	Note 4, Section 4.3-8
Tank Capacity	V	6510	gal	
Total Throughput Per Year (3)		18,600,000	gal/yr	See attached
Turnovers Per Year	N	2857	n/a	Annual throughput/tank capacity
Turnover Factor	Kn	0.25	n/a	Figure 4.3-7
		ER (lb/yr)	ER (TPY)	
Breathing Loss - Fixed Roof	Lb	19.55	9.78E-03	
Working Loss - Fixed Roof	Lw	7008.42	3.50E+00	
Total Solution loss	Lt	7028.0	3.5140	Note : total alcohol loss = total solution loss X .207
Total Alcohol loss	La	1454.79	0.73	.207 = the mole fraction of vapor that is alcohol.

(1) Parameters taken from Section 4.3, Storage of Organic Liquids, AP-42, Fourth Edition.
(2) The liquid stored is condensate (water and ethanol) from the waste beer condensor and the YDP.
(3) Based on the estimated annual 1992 production.

SUBJECT TRUCK LOADING AP42	PROJECT NUMBER 425201		DATE 9/23/92
PREPARED BY F. Varani	ENGINEERING TYPE Environ.	WORK PACKAGE NUMBER	PAGE 1 OF 5

Calculation of TANK TRUCK LOSSES USING AP42.

Chemical data

wt. of Mixture	MW	Mole % of Mixture
10% ETOH	46 g/mole	4.159 %
90% H_2O	18 g/mole	95.941 %

To calculate the above mole %, the following steps were taken:

Basis 1gm ⇒ .1 g ETOH ⇒ .00217 moles ETOH
.9 g H_2O — .05 moles H_2O
.05217

Mole % ETOH .00217/.05217 = 4.159 %

Antoine Equation for estimating vapor pressure (1)

$$\log_{10} P^*_{ETOH} = 8.04494 - \frac{1554.3}{T + 222.65}$$ Units - T in °C, P^* in mm-Hg

$$\log_{10} P^*_{H_2O} = 8.10765 - \frac{1750.286}{T + 235}$$ Units same as above.

⟶ $P^*_{ETOH}(T=60°C) = 351.489$ mm-Hg $P^*_{H_2O}(T=60°C) = 149.444$

(1) Filder & Roosiess, Elementary Principles of Chemical Process

45

SUBJECT	PROJECT NUMBER	DATE
TRUCK LOADING, AP42	425201	9/23/92
PREPARED BY: F. Varani / ENGINEERING TYPE: Envirou.	WORK PACKAGE NUMBER	PAGE 2 OF 5

* Determine Partial Pressure of Species in Solution. (P partial)

$EtOH = .0416 (351.489) = 14.62$

$H_2O = .9584 (149.444) = 143.22$

Vapor P. of mixture 157.85 mm-Hg

* Fixed Roof Tank breathing loss and Working Loss

AP-42 Tank emission rates are based upon the properties of the mixture.(2) Therefore the true vapor of the mixture is used in the calculations. Thus, based on this analysis, the following steps are taken:

Step(1) Determine Mole fraction in the Vapor (based on solution)

$y_{ETOH} = 14.62/157.85 = 0.0926$

$y_{H_2O} = 143.22/157.85 = 0.9074$

Step(2) Determine Molecular wt of Solution Vapor

$MW_v = 0.0926(46) + 0.9074(18) = 20.59$ g/mole

Step (3) - Determine the Mass Fraction of the Vapor

Basis 1 mole

(2) "Estimating Air Toxic Emissions for Organic Liquid Storage Tanks"

SUBJECT TRUCK LOADING AP42		PROJECT NUMBER 425201	DATE 9/23/92
PREPARED BY F. Vavani	ENGINEERING TYPE Environ.	WORK PACKAGE NUMBER	PAGE 3 OF 5

Etoh 0.0926 (46) = 4.26 g

H20 0.9074 (18) = 16.33 g

20.59 g

$\Rightarrow$ $y_{Etoh} = \frac{4.26}{20.59} = .207$ g/g total

$y_{H_2O} = \frac{16.33}{20.59} = .793$ g/g total

Step (4) Breathing loss (lbs of Solution/year)

$$L_{(B)} = 2.26\times10^{-2} MW_v \left(\frac{P}{P_a - P}\right)^{.68} D^{1.93} H^{.53} \Delta T^{.5} F_p K_c C$$

where: $D = 16.3$ ft } (APPARENT DIAMETER) Dimensions of Tank Truck Tank.

$H = 3.0$ ft } (Average gas space height)

$\Delta T = 20$

$P_a = 12.0$ psia, $P = 3.05$ psia ← Vapor pressure of mixture

(157.85 mm-Hg = 3.05 psia)

F_p = assumed as 1.33 (light Grey Color)

$C = .0771(6) - .0013(6)^2 - .1334 = .2824$

(C = .3 from table in AP42)

$K_c = 1$ for organic liquid

47

SUBJECT: TRUCK LOADING AP42	PROJECT NUMBER: 425201	DATE: 9/23/92
PREPARED BY: F. Varani	ENGINEERING TYPE: Environ. / WORK PACKAGE NUMBER:	PAGE 4 OF 5

$$L_{(B)} = 2.26\times10^{-2}(20.59)\left(\frac{3.05}{12.0-3.05}\right)^{.68}(16.3)^{1.73}(3.0)^{.51}$$

$$\rightarrow ((20)^{.5}(1.33)(.2824)(1)$$

$$L_B = 2.26\times10^{-2}(20.59)(.34078)^{.68}(125.05)(1.751)(4.47)(1.33)(.2824)(1)$$

$$L_B = (2.26\times10^{-2})(20.59)(.48093)(125.05)(1.751)(4.47)(1.33)(.2824)(1)$$

L_B = 82.276 lbs solution/year (breathing Loss)

* to determine individual species loss, multiply above breathing loss estimation by the mole fraction calculated in step (3).

Step (5) Working loss (lbs of solution/year)

$$L_W = 2.4\times10^{-5} \times MW_v \times P\,V\,N\,K_N\,K_C$$

where: $MW_V = 20.59$ $K_C = 1$ (from AP42)

$P = 3.05$ psia

$V = 210$ barrels = 6510 gallons

N = throughput / tank capacity

throughput = 600,000 barrels / year

capacity = 210 barrels

$V = 600,000/210 = 2857$ Tanks/year

48

ENGINEERING CALCULATION SHEET

CI—2343-D

SUBJECT	PROJECT NUMBER	DATE
TRUCK LOADING AP42	425201	9/23/92

PREPARED BY	ENGINEERING TYPE	WORK PACKAGE NUMBER	PAGE
F. Varani	Environ.		5 OF 5

K_N = Turnover Factor = .25 {from figure 4.3-7 AP42}

$L_w = 2.4 \times 10^{-5} (20.59)(3.05)(6510)(2857)(1)(.25)$

L_w = 7008.073 lbs solution loss/year

Total yearly loss of solution = 7008.073 + 82.276

= 7090.35 lbs soln/yR

Yearly loss of alcohol = 7090.35 lbs soln/yR × $\frac{0.207 \text{ lb EtOH}}{1 \text{ lb soln}}$

= 1467.70 lbs alcohol lost/year

= .7338 Tons/year

Total Alcohol Lost/TRUCK Fill = 7090.35/2857 TRUCKS/yR

= 2.481 lbs solution/TRUCK FILL. (LOST)

= .5137 lbs alcohol/TRUCK FILL. (LOST)

SPENT GRAIN DRYING SYSTEM

General Process Description

The spent grain drying system is used to dry spent grain and spent hops The grain that is filtered out of the liquid in the kettles is called spent grain. Spent hops are removed from the wort. Drying of the grain and hops produces VOCs, particulate matter, and carbon monoxide emissions. The composition of VOCs emitted during the drying process is similar to the composition of the VOCs emitted from the brew kettles. Ethanol is not emitted from the dryers, as the spent grain is removed from the brewing process prior to fermentation.

Information Relating to Source Test

At the facility studied, the spent grains are dried in nine, counterflow rotary steam-heated dryers equipped with wet scrubbers. The wet scrubbers are designed to remove particulate matter. The scrubbing water is recirculated making the scrubbers ineffective for VOC control.

The dryers operate continually and are operated near capacity. The feedrate of materials to the dryers is directly linked to the volume of beer produced, however, because beer is produced in batches, the feedrate to the drying system is not constant.

Exhaust from dryers 1 through 4 goes through a scrubber and stack unique to that dryer. Exhaust from dryers 5 through 8 is routed to three wet scrubbers and then vented through two stacks. Exhaust from dryer 9 goes through a separate scrubber and then is mixed with the exhaust from dryers 5 though 8.

Three separate source testing exercises have been conducted on the drying system. In February of 1991, Western Environmental Services and Testing, Inc. (WEST) performed a series of tests to determine VOC, particulate, and carbon monoxide emission rates for several of the dryers and to establish a particulate matter control efficiency for the wet scrubbers. In August of 1992, Clean Air Engineering (CAE) performed testing on Dryer 9 for total hydrocarbon emissions and to determine the particulate removal efficiency for the scrubber. Testing to determine the effect of overdrying on VOC emissions was conducted by Air Pollution Testing, Inc. (APT) on Dryer 4, in November of 1992. Copies of the source test reports are provided (Stack Test Report Nos. 9, 10, and 11).

WEST performed testing at four locations. Tests were run on the North NB4 stack ,the South NB4 stack, and at two locations in the exhaust system for Dryer 4. Measurements were taken at the inlet and outlet of the Dryer 4 wet scrubber. The NB4 North stack vents exhaust from dryers 5, 7, and 8. The South NB4 stack vents dryers 6 and 7. Dryer 9 was not installed at the time of this test, but vents through the south stack. During the testing on the North NB4 stack, two dryers were operating,. One dryer operated during the testing of the NB4 South stack.

CAE conducted testing on Dryer 9. This testing was necessary because Dryer 9 is equipped with a Roto-Clone, type W, size 20 wet scrubber rather than a custom built scrubber, and it was necessary to determine the particulate matter control efficiency of the Roto-Clone scrubber. Testing for VOC emissions was also conducted. The testing was conducted at a point in the ducting which conveys exhaust only from Dryer 9.

APT conducted testing as part of a program designed to determine if the degree to which the grain is dried affects VOC emissions. The tests were conducted on Dryer 4, at a point prior to the wet scrubber. Results from the test program indicate that the VOC emissions cannot be controlled by controlling the moisture content or temperature in the discharged grain.

The emission factor provided below is an average of all available test data. Because feed rate data was not included in the test reports, the factors were developed by correlating the tested emission rates with average feedrate data provided by plant engineering personnel. The emission factors are as follows: 2.6 lbs per 1000 barrels VOC (as propane), 0.94 lbs per 1000 barrels PM (controlled using wet scrubbers), 0.29 lbs per 1000 barrels PM10 (controlled using wet scrubbers), and 0.91 lbs per 1000 barrels CO. These emission factors are on a finished product volume basis.

Applicability

All breweries generate spent grain as a waste stream. Most breweries do not dry the spent grain on site. It is more typically transported wet and used as cattle feed. In some cases, especially at large facilities, more wet spent grain is generated than can be consumed by the local market. In those cases grains may be dried on-site. These factors apply to steam heated dryers. Gas fired dryers would also have emissions from combustion.

EMISSION FACTOR SUMMARY FOR SPENT GRAIN DRYING SYSTEM

Pollutant	Emission Factor (lbs/1000 barrels)
Volatile Organic Compounds	2.64
Particulate Matter	0.94 (controlled using wet scrubbers)
PM10	0.29 (controlled using wet scrubbers)
Carbon Monoxide	0.91

RADIAN CORPORATION

CALCULATION SHEET

CALC. NO. ______

SIGNATURE K. McDonnell DATE 2/9/93 CHECKED ______ DATE ______

PROJECT Air Quality Mgmt Support JOB NO. 238-094

SUBJECT Spent Grain Dryer Emissions SHEET 1 OF 8 SHEETS

Convert the emission rates from the Spent Grain Dryer Source tests to an emission factor in lbs of pollutant per 1000 barrels of finished beer produced

Feedrates to the dryers during the periods when source testing was conducted are not available. Information on the average feedrates to the dryers has been provided by Plant Engineering personnel.

The average feedrate to the spent grain drying system is the grain from one brew per brewline every 2 hours.

There are now 8 brewlines. There were 7 brewlines when the WEST, Inc testing was done.

There are 820 finished barrels of beer per brew. (on a finished product volume basis)

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PROJECT Air Quality Mgmt Services JOB NO. 238-094

SUBJECT Spent Grain Dryer Emissions SHEET 2 OF 8 SHEETS

The feedrate to the spent grain drying system during the WEST, Inc. test can be calculated:

$$\frac{1 \text{ brew}/2 \text{ hours}}{\text{brewline}} \times 7 \text{ brewlines} = 3.5 \frac{\text{brews}}{\text{hour}}$$

On a per dryer basis (8 dryers were in place at that time):

$$3.5 \frac{\text{brews}}{\text{hour}} \times \frac{1}{8 \text{ dryers}} = 0.44 \frac{\text{brews/hour}}{\text{dryer}}$$

The feedrate after the 8th brewline and 9th dryer were installed is estimated as:

$$\frac{1 \text{ brew}/2 \text{ hours}}{\text{brewline}} \times 8 \text{ brewlines} = 4.0 \frac{\text{brews}}{\text{hour}}$$

On a per dryer basis:

$$4.0 \frac{\text{brews}}{\text{hour}} \times \frac{1}{9 \text{ dryers}} = 0.44 \frac{\text{brews/hour}}{\text{dryer}}$$

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CALCULATION SHEET

CALC. NO. ____

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PROJECT Air Quality Mgmt Services JOB NO. 238-094

SUBJECT Spent Grain Dryer Emissions SHEET 3 OF 8 SHEETS

Convert WEST, Inc. test results from lbs/hour to lbs/10^3 barrel

$$\frac{0.44 \frac{\text{brews}}{\text{hour}}}{\text{dryer}} \times \#\ \text{dryers} = \frac{\text{brews}}{\text{hour}}$$

$$\frac{\text{lbs}}{\text{hour}} \times \frac{\text{hours}}{\text{brew}} \times \frac{\text{brew}}{0.820 \times 10^3 \text{ barrels}}$$

$$= \frac{\text{lbs}}{10^3 \text{ barrels}}$$

K-1[1] (Dryers 1-4)

Pollutant	Average Emission Rate[3] (lbs/hour)	Emission Factor[2] (lbs/10^3 barrels)
Particulate Matter[(4)]	0.184	0.51
PM 10[(4)]	0.044	0.12
Total Hydrocarbons (as propane)	0.62	1.72
Carbon Monoxide	0.12	0.33

1 The test on the K-1 dryer outlet stack was conducted on dryer #4

2 $$\frac{\text{lbs}}{\text{hour}} \times \frac{\text{hours}}{0.44 \text{ brews}} \times \frac{\text{brew}}{0.820 \times 10^3 \text{ barrels}}$$

3 From Page 5 of WEST, Inc Source test report (Report No. 9)

4 Emission rates reflect use of wet scrubbers for control of particulate matter emissions.

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CALCULATION SHEET

CALC. NO. ____

SIGNATURE K. McDonnell DATE 2/9/93 CHECKED ____ DATE ____

PROJECT Air Quality Mgmt Services JOB NO. 238-094

SUBJECT Spent Grain Dryer Emissions SHEET 4 OF 8 SHEETS

NB4 North Dryer Stack (Dryers 5, 8, 7)[1]

Pollutant	Average Emission Rate (lbs/hour)[2]	Emission Factor (lbs/10^3 barrels)[3]
Particulate Matter[(4)]	0.912	1.26
PM10[(4)]	0.394	0.55
Total Hydrocarbons (as propane)	2.23	3.09
Carbon Monoxide	1.23	1.70

1 Two dryers were operating during the source testing

2 From WEST, Inc. Source Test Report P. 2 (Report No. 9)

3 $\frac{\text{lbs}}{\text{hour}} \times \frac{\text{hours}}{0.88 \text{ brews}} \times \frac{\text{brew}}{0.820 \times 10^3 \text{ barrels}}$

4 Emission rates reflect the use of wet scrubbers for control of particulate matter emissions

50

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CALCULATION SHEET

CALC. NO.

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PROJECT Air Quality Mgmt Services JOB NO. 238-094

SUBJECT Spent Grain Dryer Emissions SHEET 5 OF 8 SHEETS

NB4 South Dryer Stack (Dryers 6 and 7)[1]

Pollutant	Average Emission Rate[2] (lbs/hour)	Emission Factor[3] (lbs/10^3 barrels)
Particulate Matter[(4)]	0.438	1.21
PM10[(4)]	0.070	0.19
Total Hydrocarbons (as propane)	0.54	1.50
Carbon Monoxide	0.25	0.69

1 One dryer was operating during the testing

2 From WEST, Inc. Source Test Report P. 3 (Report No. 9)

3 $\frac{\text{lbs}}{\text{hour}} \times \frac{\text{hours}}{0.44 \text{ brews}} \times \frac{\text{brew}}{0.820 \times 10^3 \text{ barrels}}$

4 Emission rates reflect the use of wet scrubbers for control of particulate matter emissions

9/13
CO EF
is 0.76
not 0.69.

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CALCULATION SHEET

CALC. NO.

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PROJECT Air Quality Mgmt Services JOB NO. 238-094

SUBJECT Spent Grain Dryer Emissions SHEET 6 OF 8 SHEETS

Convert CAE test results from lb/hour to lbs/10^3 barrels

Dryer #9

Pollutant	Average Emission Rate (lbs/hour)[1]	Emission Factor (lbs/10^3 barrels)[2]
Particulate Matter[(3)]	0.28	0.78
VOC (as propane)	1.79	4.96

1 From CAE Test Report (Report No. 10) P. 1-2

2 $\frac{lbs}{hour} \times \frac{hours}{0.44\ brews} \times \frac{brews}{0.820 \times 10^3\ barrels}$

3 Emission rate reflects the use of a wet scrubber for control of particulate matter emissions

Convert APT Test Results from lb/hour to lbs/10^3 barrels

Dryer #4

Pollutant	Average Emission Rate (lbs/hour)[1]	Emission Factor (lbs/10^3 barrels)[2]
VOC (as propane)	0.70	1.94

1 From APT source test report P. 6+7 (Report No. 11)

2 $\frac{lbs}{hour} \times \frac{hours}{0.44\ brews} \times \frac{brew}{0.820 \times 10^3\ barrels}$

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CALCULATION SHEET

CALC. NO. ____________

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PROJECT Air Quality Mgmt Services JOB NO. 238-094

SUBJECT Spent Grain Dryer Emissions SHEET 7 OF 8 SHEETS

Average the Calculated Emission Factors

Particulate Matter

	lbs/10^3 barrels
K-1	0.51
NB4 North Stack	1.26
NB4 South Stack	1.21
Dryer 9	0.78
	3.76

$$\frac{3.76 \text{ lb}/10^3 \text{ barrels}}{4} = 0.94 \frac{\text{lbs}}{10^3 \text{ barrels}}$$

PM10

	lbs/10^3 barrels
K-1	0.12
NB4 North Stack	0.55
NB4 South Stack	0.19
	0.86

$$\frac{0.86 \text{ lbs}/10^3 \text{ barrels}}{3} = 0.29 \frac{\text{lbs}}{10^3 \text{ barrels}}$$

VOC (as propane)

	lbs/10^3 barrels
K-1	1.72
NB4 North Stack	3.09
NB4 South Stack	1.50
Dryer 9	4.96
Dryer 4	1.94
	13.21

$$\frac{13.21}{5} = 2.64 \frac{\text{lbs}}{10^3 \text{ barrels}}$$

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CALCULATION SHEET

CALC. NO. ____

SIGNATURE K. McDonnell DATE 2/9/93 CHECKED ____ DATE ____

PROJECT Air Quality Mgmt Services JOB NO. 238-097

SUBJECT Spent Grain Dryer Emissions SHEET 8 OF 8 SHEETS

Carbon Monoxide

	$lbs/10^3$ barrels
K-1	0.33
NB4 North Stack	1.70
NB4 South Stack	0.69
	2.72

$$\frac{2.72 \frac{lbs}{10^3 \text{ barrels}}}{3} = \boxed{0.91 \ lbs/10^3 \text{ barrels}}$$