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TECHNICAL ASSESSMENT DOCUMENT ON ETHANOL EMISSIONS AND CONTROL FROM CALIFORNIA WINERIES

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by

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CONTROL OF EMISSIONS FROM WINERIES

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TITLE: Technical Assessment Document on Ethanol Emissions and Control from California Wineries

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ABSTRACT

Technical Assessment Document on Ethanol Emissions and Control from California Wineries

by

Joan Allison Heredia

This document compiles the results of numerous studies on emissions from wineries and control of ethanol emissions during wine fermentation. A review of the mechanisms of emissions and methods used to estimate emissions from wineries during fermentation is presented. An emissions estimate for wineries in California indicated uncontrolled winery emissions of 584.6 tons of ethanol in the year 1991.

Five control methods were evaluated to determine cost effectiveness in terms of dollars per pound of ethanol reduced for numerous tank farm configurations. Carbon adsorption, incineration, condensation and scrubbing demonstrate a control efficiency greater than 90 percent at costs ranging from $0.93/lb to $26.80/lb. Fermentation temperature control achieves an efficiency of 30 percent and costs $6.74 and $7.56 per pound of ethanol reduced. In general, cost-effectiveness was better for tank farms with large capacitites due to economy of scale and red wine is more cost-effective to control than white wine. Carbon adsorption is the most favorable method to control emissions from wineries during fermentation, based on cost and operational considerations.

ACKNOWLEDGEMENTS

Nelson Chang, ARB, provided insight and background documentation which facilitated the development of this document. Gallo Winery and the Wine Institute has participated extensively in many of the studies which were performed to achieve a greater understanding of the emissions and methods of control for wine fermentation. Additional assistance was provided by Dr. Harold Cota, California Polytechnic State University, San Luis Obispo.

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SECTION 1

Introduction

This report is a technical assessment document that compiles the results of numerous winery fermentation studies which evaluate ethanol emissions and methods of control. The primary purpose of this work is to present emission control technologies for wineries. In addition, methods to estimate winery emissions are identified and an estimate of the quantity of winery emissions in California has been determined. This document has been prepared in conjunction with input by the California Air Resources Board (ARB). Many of the investigations for control of ethanol emissions have been supported by the ARB in their effort to identify and reduce air pollution in California.

The mission of the ARB is to define the health threat of air pollution and, in conjunction with county and regional air pollution control agencies, regulate its causes where necessary to achieve or maintain air which does not cause harmful effects. In California, the ARB:

- Sets air quality standards;
- Monitors air quality;
- Provides technical expertise to help county and regional air pollution control officials set emission limits for industrial sources of air pollution; and
- Operates one of largest air pollution research programs in the world.

Ambient air quality standards for ozone are frequently violated throughout the State. Ethanol is a reactive organic compound which combines with nitrogen oxides in the presence of sunlight to form ozone.[1] Emissions from wine fermentation tanks contribute to ozone formation by the release of ethanol vapor through vents in the tank roof.

A Suggested Control Measure (SCM) for control of ethanol emissions from winery fermentation tanks was considered by the ARB in 1986. The Board deferred action on the SCM pending outcome of a demonstration program to further evaluate the methods to reduce emissions from winery fermentation tanks. This report updates the technical support documentation that was prepared for the 1986 winery SCM and incorporates the results of subsequent demonstration projects which evaluated winery fermentation tank emission control methods.

A discussion of the wine making process and estimated emissions, available control technologies, potential emission reductions, estimated costs and potential adverse environmental and other impacts associated with control of winery emissions is presented.

SECTION 2

Background

Losses of ethanol during wine fermentation and methods of recovery have been of interest dating back to 1821 when Guy-Lussac considered this problem.[2] Numerous studies have been conducted since then to address the quantification and control of ethanol emissions. Theoretical models and actual source testing has been implemented to obtain a greater understanding of the mechanisms pertinent to releases of ethanol during wine fermentation. Control of ethanol emissions has been evaluated primarily through source testing with involvement by the ARB.

Initial ethanol emission studies indicated that emission from wineries could be predicted by utilizing a single emissions factor or an empirical regression equation. Recently developed batch fermentation computer modeling takes into consideration more complex chemical reaction stoichiometry and kinetics. A thorough discussion on quantification of emissions from wineries is presented in Section 4.

ARB interest in control of ethanol emissions from winery fermentation operations developed as a result of the identification of ethanol emissions as a source of oxidant precursors in the San Joaquin Air Basin in 1978.[3] Later that year, the ARB began investigation of winery ethanol emissions by conducting source tests on fermentation tank exhaust gases at E&J Gallo Winery in Fresno.[4] This test was conducted during a 24 hour period within the first three days of fermentation on a white blending wine with a total volume of 569,000 gallons. In 1980, the ARB performed further source testing at United Vintners (now Heublein Wines) in Reedly.[5] Ethanol emissions were measured continuously at United Vintners during one complete fermentation cycle for a total of 159 hours for a white blending with a total volume of 90,000 gallons. EAL Corporation, under contract with the ARB, performed source testing of fermentation tanks at several wineries in 1982.[6] A total of four complete fermentations were monitored by EAL, two were red and two were white wine. EAL also measured emissions from fugitive winery sources, such as wine bottling and the pomace press.

In 1980, the Fresno County Air Pollution Control District (FCAPCD) was identified as the lead agency for developing a winery SCM. The FCAPCD conducted a survey of the San Joaquin wineries to determine fermentation tank characteristics, fermentation temperatures and total throughput by tank size and type of wine produced.[7] A draft SCM was produced in 1982, which required a 90 percent reduction in ethanol emissions for all fermentation tanks with a capacity greater than 100,000 gallons.[8] The accompanying staff report recommended condensation as the most cost effective method for control.

In response to the SCM, the Wine Institute, an organization representing over 80 percent of the wineries in California, prepared an alternative proposal based on temperature control of the fermentation tanks.[9] The FCAPCD revised the SCM in December of 1985, the cost analysis indicated temperature control as the most cost effective method of control. ARB evaluated the cost analysis for various control methods and showed that temperature control was not the most cost effective. Due to a lack of resources at the FCAPCD, it was requested that ARB take over as the lead agency for further development of the SCM.

In April of 1986, the ARB presented a revised SCM for control of ethanol emissions from winery fermentation tanks.[10] At the conclusions of the meeting, the ARB was invited to tour several different San Joaquin Valley wineries to see plant layout and operations unique to each facility. Follow up meetings were conducted and the wine industry submitted comments on the material presented in April. As a result, the ARB deferred action on the SCM pending outcome of a demonstration program to further evaluate the methods to reduce emissions from winery fermentation tanks.

The first phase of the demonstration program was conducted during the 1987 fermentation season. An Ad Hoc Committee was formed composed of ARB technical staff and wine industry representatives. The Wine Institute and

Winegrowers of California jointly funded a pilot project utilizing the Viticulture and Enology Research Center at California State University, Fresno (CSUF). The pilot study objective was to determine the potential ethanol from wine fermentation tanks equipped with emission control devices. Four separate wine fermentations were performed at CSUF, two white and two red. The equipment configuration for each fermentation consisted of using four nearly identical 1400 gallon general wine fermentation tanks. One tank had no emissions control and the other three tanks were equipped with control devices to reduce the ethanol content of fermentation exhaust gases. Water scrubbing, carbon adsorption and catalytic oxidation were evaluated to determine the ethanol removal efficiency.

The study concluded that each of the control methods was capable of providing at least 90% efficiency in the control of ethanol emissions.[11]

However, the Ad Hoc Committee also determined that:

1. Water scrubbing was not feasible because most wineries could not dispose of the ethanol laden waters.
2. Catalytic incineration involved a prohibitively high initial capital cost.
3. Carbon Adsorption involved some operational problems.

It was recommended that further tests be carried out during the 1988 season.[12] These tests utilized carbon adsorption exclusively as the control device, as it appeared to be the most feasible method of control. The committee felt that another year of testing and equipment modification could resolve the operational problems documented in the 1987 evaluation of the carbon adsorption study.

The 1988 study focused on the efficiency of the collection hoods atop each fermentation tank vent in capturing ethanol emissions and operation efficiency of the carbon unit. The data obtained in 1988 indicated that better operation of the system was achieved. Based on observations and data collected during 1987 and 1988, it was decided that a demonstration study of a control system utilizing carbon adsorption for a commercial fermentation tank of 50,000 gallons capacity or larger was warranted.

The 1990 demonstration project was conceived and a portion of the E&J Gallo Winery's Fresno facility was made available as the test site. An emission capture and ethanol adsorption system was installed on a 207,000 gallon commercial tank. The demonstration project consisted of five red and three white fermentations. Information on all of the eight fermentations involved in the 1990 demonstration project is contained in "1990 Demonstration Program Ethanol Emissions Control from Wine Fermentation Utilizing Carbon Adsorption Technology," by Akton Associates.[13]

The last three fermentations, two reds and a white, were evaluated to determine the control efficiency of ethanol emissions using carbon adsorption. The ARB measured control device inlet and outlet ethanol concentrations to determine the efficiency. The results of the ARB ethanol measurements documented a 90 percent control efficiency.[14]

Although control of winery emissions during fermentation has been demonstrated technologically feasible, the need for mandated control is still under discussion. Primary concern evolves around the cost to achieve control. The cost of control is discussed in explicit detail in Section 5.

SECTION 3

Description of Process Operations

A. General Winery Operations[15]

Grapes for wine production in California are harvested from as early as mid-August in the interior valley to as late as December along the Central Coast. As grapes ripen, sugar content increases and acidity decreases. The most commonly used indicator of maturity is the degree Brix. The brix scale is a measure of the concentration of sugar in solution as grams of sucrose per 100 grams of liquid. For the best quality wines, grapes must be harvested at optimum maturity. For red wine production, 22 degree Brix (22 grams sucrose/100 grams liquid) is considered minimum. White wine grapes are usually harvested at a lower degree Brix, between 20 and 21 degrees. Grapes for dessert wine production are harvested at 23 to 26 degree Brix.

Grapes grown on site at wineries are harvested, transported by truck from the vineyard and conveyed to a crusher stemmer which separates the grapes from the stems and ruptures the skins. (Some wineries perform the crushing in the vineyard and transport the crushed fruit to the winery.) From 75 to 150 mg/L of liquified SO_2 is added to the crushed grape mass to control wild yeasts and spoilage bacteria. Dilution with water is permissible within certain limits to bring down the sugar content of overripe grapes, but the practice is avoided by most wine makers.

In red wine production, the entire mass of juice, skins, pulp and seeds (referred to as the must) is pumped into the fermentation tank and inoculated with yeast. Red wines are fermented for two to five days with the skins for maximum color and tannin extraction. After this period, the juice is drained from the mass of skins, pulp, and seeds (the pomace) and pumped into storage where fermentation is completed. Rose wines are fermented with the skins for 24 to 36 hours before the juice is separated. In white wine production, the pomace and juice are separated before inoculation with yeast and only the juice is fermented. A fermenting batch of juice is also called must by the wine industry. Hence, the term must can refer either to the mixture of juice, skins, pulp, and seeds in red and rose fermentation, or simply to the juice in white wine fermentation.

After the pomace cap is separated from the juice, it is conveyed to a press. The juice from the press is normally fermented for use as a blending wine since it is lower in quality than the free-run juice from the crusher stemmer. The remaining solids are either washed with water to extract any alcohol or grape sugar for distilling material or discarded. Some large wineries spread the pomace onto nearby land where it is dried and then sold as cattle feed.

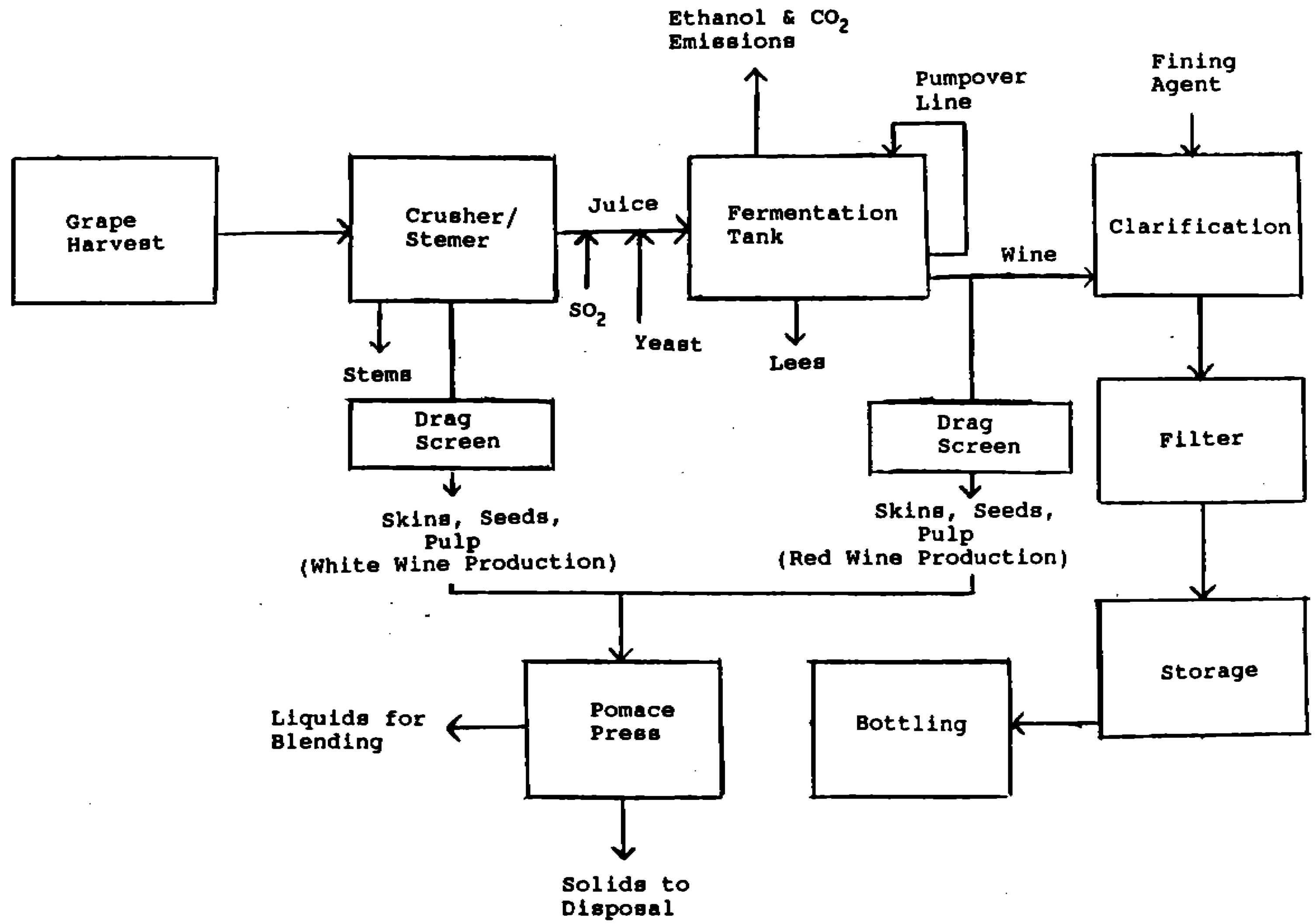
The amount of time required for complete fermentation is a function of fermentation temperature. At 55 to 60 degrees Fahrenheit, wines are fermented in seven to 10 days, while at 75 to 80 °F, wines take from three to six days to ferment. If fermentation is allowed to proceed uninterrupted, all of the sugar will be converted to ethanol. If sweeter wines are desired, fermentation is arrested by chilling and centrifugation or clarification and filtration to remove the yeast. This process allows some of the unconverted sugar (residual sugar) to remain in the wine.

After fermentation to the desired degree of Brix reduction, the wine is racked (drawn off) from the lees or sediment of yeast, pulp, tartrates, etc. at the bottom of the tank. The wine is then transferred to another tank and clarified with a fining agent such as bentonite or gelatin. After settling for a few weeks, the wine is racked again, filtered, and transferred to storage tanks filled to the top. Many wineries centrifuge the wine after the first racking. White wines are also often centrifuged before fermentation. The lees are used (either onsite or sold) as distilling material in the production of brandy. A simplified process flow diagram for wine production is shown in Figure 1.

Figure 1

Simplified Process Flow Diagram

for Wine Production



The above is a summary of table wine production. By law, table wine cannot contain more than 24 percent alcohol. The alcohol content of a finished wine is related to the initial sugar content of the grape juice. An estimate of the final alcohol can be obtained by multiplying the degree of Brix by 0.55. Thus grape juice of 21 degree brix will yield a wine with an alcohol content of 11.55 percent, assuming complete fermentation.

In addition to table wines, a number of other wine types are produced: sparkling wines, "special natural" wines, wine coolers, vermouth, dessert wines and brandy.

Sparkling wine (wine with a visible excess of CO_2) is made from blended table wine which is inoculated with yeast, sugared and fermented a second time under pressure. "Special natural" wines are table wines flavored with fruit juices, spices etc. They are classified according to alcohol content - either greater than 14 percent or equal to or less than 14 percent. Wine coolers are a category of special natural wines, usually diluted with fruit juice to approximately 6 percent alcohol.

Vermouth and dessert wines are fortified wines, that is, wines to which wine spirits (see below) are added to increase the alcohol content. Vermouth is made from dry table wine fortified to 15 to 21 percent alcohol and flavored with a mixture of spices and herbs. Dessert wines are commonly produced by arresting fermentation at about

12.5 to 14 degree brix to maintain sweetness and adding wine spirits to bring the alcohol content up to 18 to 21 percent. The partial fermentation only takes from 24 to 48 hours. Some wineries prefer to ferment the wine to dryness before fortification, sweetening with grape concentrate. Grape concentrate is produced by processing grape juice in a vacuum concentrator. California law forbids the use of sugar to sweeten dessert wines.

Sherries are also considered dessert wines, although dry sherry is typically consumed as an aperitif. The must is usually fermented to completion, after which the alcohol content is adjusted to 17 to 18 percent by the addition of wine spirit. The wine is then baked for nine to 20 weeks at temperatures of 130 to 140 °F. Sweeter types of sherry are produced by blending in appropriate amounts of angelica or white port, preferably after baking.

Brandy and wine spirits are both produced by distillation. Brandy is measured in terms of "proof gallons," one proof gallon being the equivalent of one gallon of liquid containing 50 percent alcohol. Brandy is made from wine distilled at 160 to 170 proof gallons (80 to 90 percent alcohol) and diluted with distilled water to 80 to 120 proof gallons before aging and bottling.

Wine spirits used in vermouth and dessert wines are distilled at 185 proof. Wine spirits may be from distilled wine, or fermented pomace washings, or fermented lees.

B. Fermentation Process

Fermentation is the process that makes wine from the juices of fruits such as grapes. Fermentation is the anaerobic (without free oxygen) breakdown of organic compounds by the action of microorganisms or their extracts, to products simpler than the starting substrate. With wine, this breakdown is caused by yeast. The yeast provides complicated enzymes that in the presence of sugar form alcohol, carbon dioxide gas, glycerin and other products.

The concentration of alcohol in wine is based upon sugar content, extent of fermentation, and losses or additions of alcohol. Wine grapes generally contain 15-25 percent sugar. One percent sugar yields about 0.55 percent alcohol by volume. In general, the theoretical chemical reaction for converting sugar to alcohol is:

$$C_6H_{12}O_6 = 2\ C_2H_5OH + 2\ CO_2$$

According to the above equation, sugar ($C_6H_{12}O_6$) should yield 51.1 percent alcohol by weight. Based on experimental data, sugar only yields about 47 percent retained alcohol by weight of the sugar fermented (glucose).[16] The reduced yield is attributed to the formation of other products such as glycerin, hydrogen sulfide, methyl and ethyl mercaptans and lost alcohol.

The fermentation is initiated by adding yeast inoculation to the grape juice. The juice is recirculated or "pumped over" one to ten times a day to promote uniform fermentation and extraction of color and tannins. The fermentation chemical reaction is exothermic (releases heat) and the temperature is controlled by refrigeration in the tank jacket. During fermentation, there is generally a 2.3 degree fahrenheit temperature rise per degree Brix reduced (reduction of 1 gram of sucrose/100 grams of liquid). If the temperature is not kept under control, the rate of fermentation can escalate to the point where a foamover can occur. Some wineries use anti-foaming agents to arrest formation the formation of foam.

Further at 95 °F, yeast is generally weakened and at 100 to 105 °F most of it dies or is inactive. Therefore, as the temperature approaches 85 °F, cooling should be initiated. Recommend fermentation for white wine is between 50 and 60 °F; temperatures above 80 °F yield a lesser quality wine. Red wines are fermented at higher temperatures partly to enhance color extraction from the skins. Red wine temperatures should not exceed 85 °F, for the best flavor and bouquet. Temperatures above the recommended maximums for both white and red wine will cause lower alcohol yield, reduced yeast efficiency and losses of aromatic constituents. Bacterial growth are also promoted at higher temperatures. Most winemakers record both degree Brix and temperature two to three times a daily in order to monitor fermentation and determine when to apply cooling.

Fermentation at large wineries is usually implemented in stainless steel, mild steel or concrete tanks. Many small wineries still use oak or redwood fermentors. A survey of fermentation tank characteristics by the Fresno County APCD showed various tank types used in the San Joaquin Valley to be as follows: stainless steel, 54%; concrete, 27%; mild steel, 12%; and redwood, 7%.[17]

During the fermentation, alcohol and carbon dioxide (CO_2) are released from a vent on the top of the tank. The alcohol losses can range from less than 0.1 percent to over 10 percent of the alcohol produced during fermentation. The alcohol loss is affected by alcohol concentration within the wine, agitation of the fermenting liquid, the presence of a pomace cap and fermentation temperature. Emissions during fermentation are discussed in detail in the following Section.

SECTION 4

Emissions from Wineries

A. Fermentation Emissions

The primary factors influencing the losses of ethanol during fermentation are the fermentation temperature and the sugar content of the grapes.[18] The mechanism for ethanol losses was previously believed to be caused by entrainment of ethanol liquid droplets in escaping CO_2 bubbles. Recent research indicates that evaporation is the major cause of ethanol loss.[19] Although droplets are formed and leave the surface of the fermenting must, they either fall back into the liquid within a second or less or impinge on the top and sides of the tank. The CO_2 upward velocity is insufficient to carry the droplets out of the fermentation tank. The partial pressure of the ethanol in the vapor phase is the only important mechanism for ethanol loss during fermentation.

The Environmental Protection Agency developed an emission factor formula which is a function of temperature and initial sugar content. The formula was developed based on empirical information. The following equation (1) is described in Supplement 10 of AP-42, Feb. 1980:

$$EF = (0.135T - 5.91) + [(B - 20.4)((T - 15.21)(0.00685) + C] \quad \text{(EQN. 1)}$$

where:

EF = emission factor, pounds of ethanol lost per thousand gallons of wine made

T = fermentation temperature, degrees F

B = initial sugar content, Brix

(Brix= grams sucrose/100 grams liquid)

C = Correction factor, 0 for white wine or 2.4 $lb/10^3 gal$ for red wine

More recently, a computer model by R. Boulton was developed to predict evaporative losses under any set of fermentation conditions.[20] The model is based on the kinetic and stoichiometric relationships during fermentation. The model can be expressed in general form, as follows:

$$\log_{10}\{E_{lost}/(S_o - S)^2\} = K_4 - \{K_5/(T+273) \quad \text{(EQN. 2)}$$

where:

E_{lost} = ethanol emitted (gr/l)

S_o = Initial sugar concentration (gr/l)

S = Final sugar concentration (gr/l)

T = Temperature (°C)

K_4, K_5 = Lumped Constants, 6.682 and 2552, respectively

Experimental data for pure ethanol-water phase equilibrium thermodynamics were fitted to the equations in the region of temperatures (0-40 degrees Celsius) and ethanol concentrations (0-14%) which pertain to wine fermentations. Actual data for fermenting musts and wines would be preferable, but were unavailable. Equation (2) calculates the evolution of ethanol during fermentation and integrates the rates to give the total amount lost as a function of temperature and the differential sugar content of the wine.

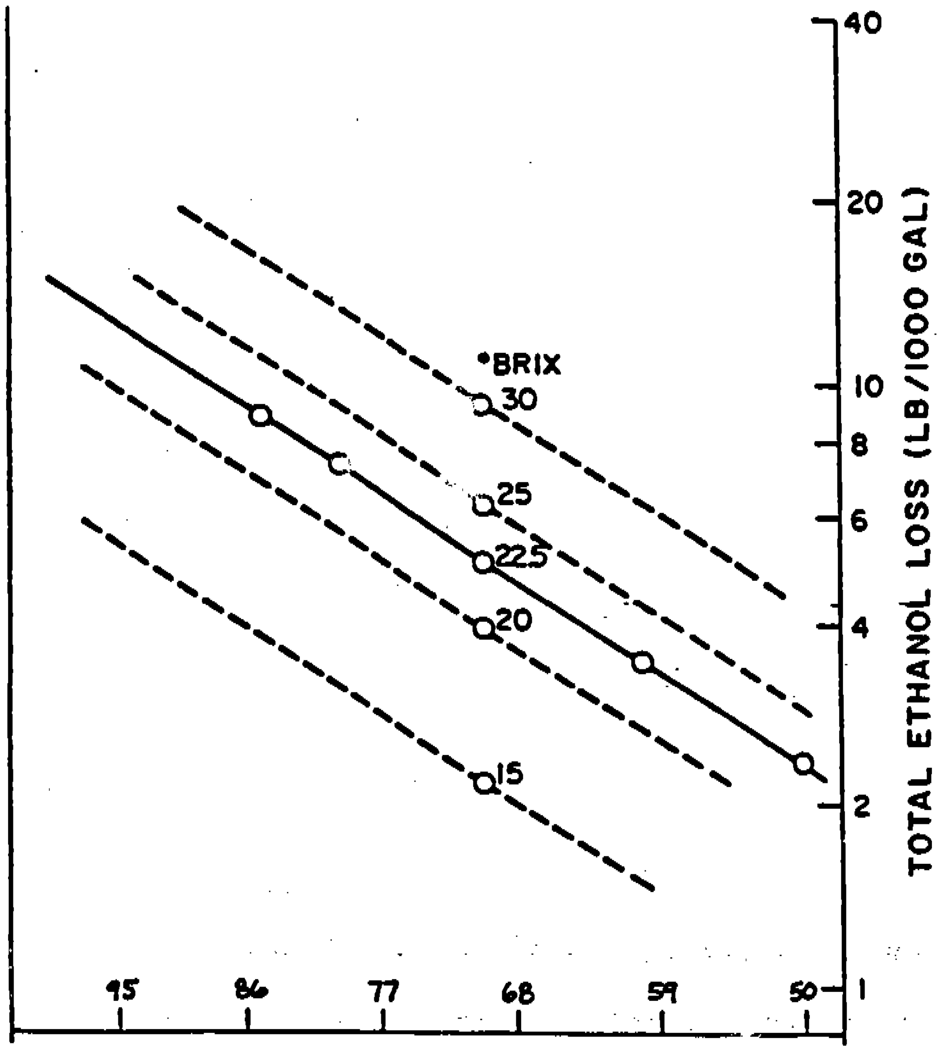
A graphical representation of the model, showing the relationship between ethanol emissions, fermentation temperature and degree Brix is shown in Figure 2. The graph indicates that ethanol losses increase exponentially as fermentation temperature increases. Further, ethanol losses are greater, the higher the initial degree Brix and the amount of sugar utilized.

The developers of the model indicate that the model is an accurate predictor of emissions from white wine fermentation, however it probably underestimates red wine emissions because of the presence of the pomace cap. Ethanol losses are also impacted by the presence of a pomace cap in red wine fermentation.[21]

Based on experiments by J. Guymon and E. Crowell, pomace cap-liquid temperature differentials can be as great as 15 to 20 °F in small tanks.[22] A simplified simulation

Figure 2

Relationship Between Initial Degree Brix, Fermentation Temperature, and Ethanol Loss



SOURCE: Williams and Boulton, 1983

model was developed by Boulton and Williams to predict the effect on ethanol emissions from the pomace cap-liquid temperature differentials. The simplified model indicated that losses almost double when the cap-liquid differential is 18 °F, assuming only a 70°F liquid temperature.[23] In order to reduce the potential for increased emissions caused by the pomace cap, it is recommended that cap management be implemented. This can be achieved by pumping over to minimize temperature differentials and separating the pomace from the juice earlier in the fermentation period.

Predicted ethanol emissions utilizing the EPA methodology and the Boulton computer model are compared to the results from various source tests in Table 1. It should be noted that the emissions associated with the computer model were estimated from Figure 2 and assume that the initial sugar content was totally depleted. The source test data was taken from pilot scale and full scale winery fermentation studies. It appears in general that both calculation techniques overpredict emissions. A statistical comparison of the actual source test results to the two predictive methods was performed utilizing the Pearson product moment correlation coefficient. The correlation coefficient for the source test data and the computer model was 0.751, in comparison the correlation coefficient for the EPA equation was 0.723.

Table 1

Comparison of Predicted Emissions

versus Source Test Results

Report Date	Source of Emissions	Fermentation Temperature (F)	Initial Brix (°)	Source Test Results (lb/1000gal)	AP-42 Eqn. (1) (lb/1000gal)	Computer Eqn. (2) (lb/1000gal)
1980	ARB, C-80-071, White Wine(a)	52	20.5	1.52	1.19	1.75
1982	EAL, UV Madera, White Wine (b)	57	23	2.6	2.59	2.69
1982	EAL, Mondavi Oakville, White Wine (b)	63	23.5	1.4	3.67	3.55
1982	EAL, UV Madera, Red Wine (b)	85	23	7.8	9.29	7.70
1982	EAL, UV Oakville, Red Wine (b)	72	22.4	10.5	7.06	4.54
1988	ARB/ML-88-027,White Wine I (c)	58.5	20.1	0.93	1.96	2.18
1988	ARB/ML-88-027,White Wine II (c)	57	22.3	3.55	2.39	2.52
1988	ARB/ML-88-027,Red Wine I (c)	77.5	24	6.13	8.57	6.39
1988	ARB/ML-88-027,Red Wine II (c)	78.75	25.2	5.67	9.29	7.38
1990	CATI 900705, Red Wine II, Tank1 (d)	80	21	4.5	7.64	5.36
1990	CATI 900705, White Wine I, Tank1 (d)	80	21	~~3.3~~	~~5.24~~	~~5.36~~
1990	CATI 900705, White Wine II, Tank1 (d)	55	21	1.415	1.73	2.07
1991	Akton, Gallo, Run 6, Red Wine (e)	73	22.8	3.17	7.37	4.88
1991	Akton, Gallo, Run 7, Red Wine (e)	74	22.6	3.98	7.44	4.98
1991	Akton, Gallo, Run 8, White Wine (e)	57	21.6	1.64	2.19	2.37
AVERAGE WHITE WINE		59.94	21.63	2.04	2.62	2.67
AVERAGE RED WINE		77.18	23.00	5.96	8.09	5.80

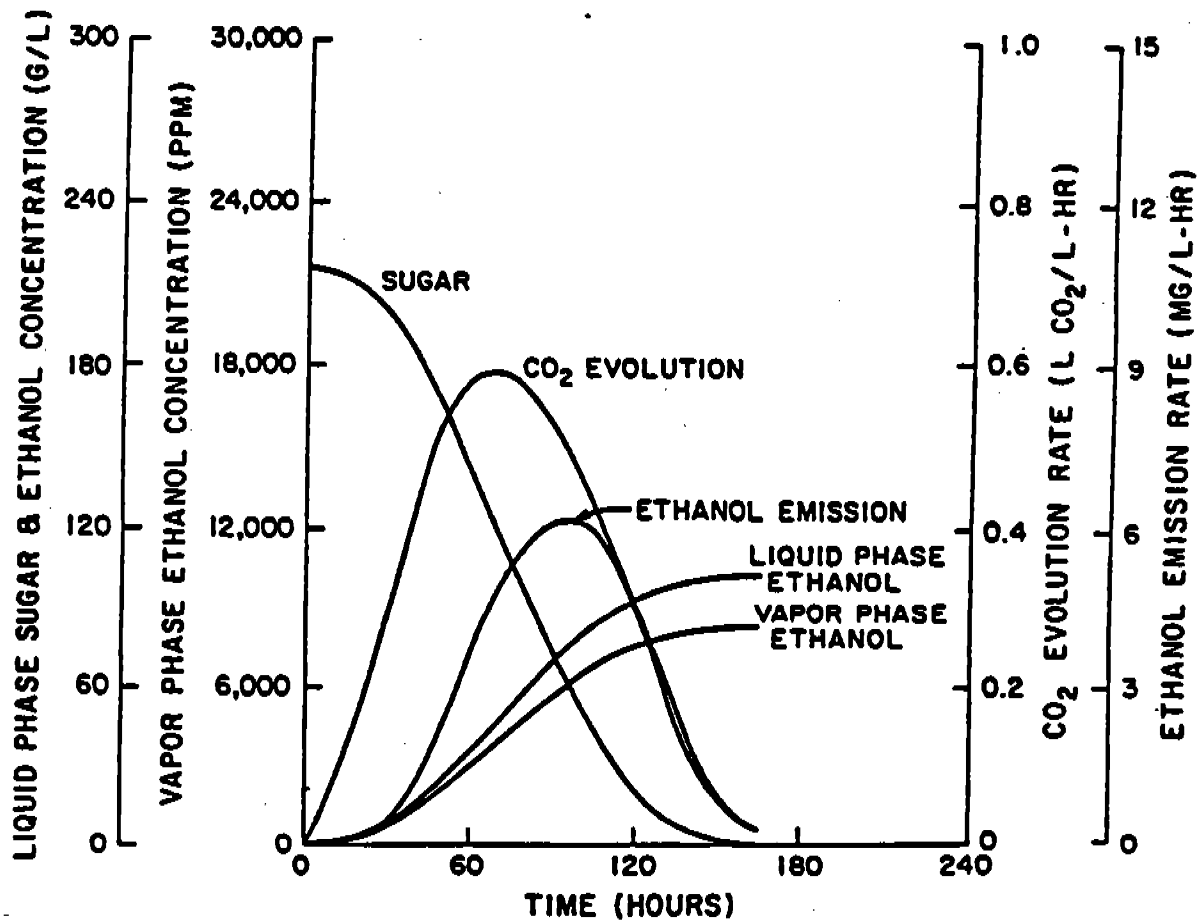
(a) ARB, C-80-071, op. cit., pg. 12.
(b) EAL Corporation, op. cit., pg. 7-42
(c) ARB/ML-88-027, op. cit., pg. 21-57
(d) CATI 900705, op. cit., pg. 14.
(e) Akton Associates, op. cit., pg. 22.

The exhaust gas composition from winery fermentation varies during the fermentation cycle. Predicted rate curves, using the Boulton model, of ethanol and CO_2 evolution for a complete fermentation cycle at 70 °F are shown in Figure 3. As depicted in the graph, sugar content of the must drops at a fairly constant rate as it is converted to CO_2 and ethanol by the yeast. Peak ethanol emission occurs slightly after peak CO_2 evolution; both are distributed as bell shape curves. The concentration of ethanol in both the liquid phase (must) and the vapor space (tank headspace) increases as the fermentation proceeds, until equilibrium is reached at the end of fermentation. Temperature increases cause an increase in the rate of fermentation; this would be graphically represented by a higher peaks and a more compressed curve.

Fermentation under non-isothermal conditions greatly increases ethanol losses. This occurs when the capacity of the cooling system is not sufficient to maintain a constant temperature. For example, temperature increases of only nine degrees Fahrenheit have been shown to increase ethanol emissions by 30 percent.[24]

Figure 3

Graphical Representation of Winery Fermentation Model



*Initial sugar content of 20° Brix, isothermal fermentation at 70°F.

SOURCE: Williams and Boulton, 1983.

B. Handling and Storage Emissions

Handling and storage of wine has the potential to result in ethanol fugitive emissions. Fugitive emissions occur whenever wine is exposed to air, such as transferring or racking, blending and storage. Factors affecting fugitive emissions include process equipment design, handling techniques and temperatures. There is limited data available on fugitive emissions, however emissions from fugitive emissions are significantly less in comparison to emissions during fermentation.[25] Table 2 contains emission factors for various wine handling processes.

Table 2

Emission Factors for Handling Processes[26]

Process	Emission Factor
Drag Screen	0.5 lbs ethanol/ 10E3 gal juice
Pomace Press	0.02 lbs ethanol/ ton pomace (red wine)
Wine Bottling	0.1 lbs ethanol/ 10E3 gal wine

C. Statewide Emissions from Wineries

The 1991 emissions from statewide winery fermentation has been determined based on the net wine production, estimates of the types of wines produced, average degree Brix of the grape harvest and fermentation temperatures. Emissions were calculated using equation (2). The estimated 1991 Statewide winery fermentation emissions is shown in Table 3.

Fermentation temperatures were compiled from a 1980 survey which sampled 40 percent of the wineries in the San Joaquin Valley[27]. The weighted average temperature based on throughput was 78°F for red wines and 58°F for white and rose wines. Because these data were the best available, they were assumed to apply statewide and used to estimate the emissions in Table 3.

The 1991 Statewide emissions from winery fermentation are 584.6 tons of ethanol. This is equivalent to 4.9 tons per day, assuming the fermentation season lasts from mid-August to mid-December (120 days). The timing and length of the fermentation season varies geographically. In the interior valley, the fermentation runs from mid-August to November (80 days).[28] In the north coast, the season runs from September to November (60 days). Seasonal variations by region need to be considered when calculating daily emissions for a specific area.

Table 3

Estimated 1991 Statewide

Winery Fermentation Emissions

Color Grape/ Type of Wine	Average Brix (a)	Gallons (b) (millions)	Ferment. Temperature (F)	Emission Factor (d) (lb/1000 gal	Ethanol Emissions (tons/yr)	Ethanol Emissions (tons/day)
Red	21					
Red Table		45.23 (a)	78	6.2	140.2	1.17
Rose Table		55.16 (a)	58	2.9	80.0	0.67
Dessert		7.9 (c)	78	6.2	24.5	0.20
"SN"<14%		4.66 (c)	78	6.2	14.4	0.12
"SN">14%		6.28 (c)	78	6.2	19.5	0.16
White	20.6					
White Table		154.88 (a)	58	2.5	193.6	1.61
Dessert		7.9 (c)	58	2.5	9.9	0.08
Vermouth		3.24	58	2.5	4.1	0.03
Sparkling		25.27	58	2.5	31.6	0.26
"SN"<14%		4.66 (c)	58	2.5	5.8	0.05
"SN">14%		6.28 (c)	58	2.5	7.9	0.07
Wine Cooler		42.56	58	2.5	53.2	0.44
TOTAL		363.134			584.6	4.9

(a) "Final Grape Crush Report 1991 Crop", California Dept. of Food and Agriculture, March 10, 1992.
(b) "1991 Wine Industry Statistical Report", Wine Institute, October 1992.
(c) Total production divided between red and white grapes
(d) Estimated using equation 2, assumed final sugar content =0

Emission estimates for the San Joaquin Valley were calculated from the proportion of grapes grown in the Valley. The 1991 Economic Research Report for the Wine Industry specifies that 75.8 percent of the grapes crushed by wineries and distilleries were grown in the San Joaquin Valley. It was assumed that 75.8 percent of the winery emissions occur in the area, resulting in emissions of 443.7 tons per year or 5.5 ton per day based on a 80 day fermentation season. This value is approximate since grapes are frequently purchased from a grower and transported several hundred miles to a winery. However, given the limited data this is the most accurate estimation methodology.

SECTION 5

Control of Emissions and Cost

A. Assessment of Control Technology

Five methods of control for ethanol emissions during winery fermentation are evaluated for cost-effectiveness in this Section. These emission control technologies consist of: carbon adsorption, catalytic incineration, wet (water) scrubbers, condensation and temperature control. General information on the operation of the control equipment is presented. Due to differences between wineries, the design and cost information was developed to cover a range of tank farm scenarios. Tank sizes in the layouts ranged from 50,000 (50K) to 600K gallons and tank farm sizes ranged from 5 to 15 tanks. Individual wineries will need to develop more specific analysis to determine actual emission control equipment design and costs. Design assumptions, simplified process flow diagrams, costs and emission reductions for the control of ethanol emissions from the tank farm scenarios are provided in Appendix A.

All of these control methods, excluding temperature control, require that exhaust vents on the fermentation tanks be ducted to a central control device(s). These technologies have been used in different industrial settings and are readily available on the market. Specific studies performed for control of emissions from wineries have demonstrated that ethanol emissions may be effectively reduced using the above mentioned control technologies. The effectiveness of temperature control varies with the temperature reduction. Condensation can achieve 90 percent control.[30] Based on an ARB study, carbon adsorption, catalytic incineration and wet (water) scrubbers have demonstrated average control efficiencies in excess of 90 percent.[29] Carbon adsorption has been subject to more operational evaluation as it has been considered the most viable method of control due to cost and operational considerations.[31]

It should be noted that reduced control efficiencies have been observed during the initial stages of fermentation. This is caused by the inherent difficulties in measuring and comparing low ppm ethanol concentrations. In addition, at low concentrations control equipment may exhibit reduced efficiencies due to the small quantity of inlet contaminant in contrast to outlet concentrations. Efficiency should be based on the level of control throughout the fermentation process.

Handling and storage emissions controls have not been pursued due to the perceived relatively low volume of emissions and the difficulty in controlling a non-point source.

1. Ducting Systems

The construction of a duct system is required to transport the exhaust from the fermentation tanks to a centralized control device(s). It is anticipated that ducting material will be stainless steel, due to sanitary requirements for products consumed by humans.

Winery fermentation exhaust flow rates ranges from 2.4 to 6.1 ACFM per 1000 gallons tank capacity (75% capacity) for red wine tanks and from 0.7 to 1.5 ACFM per 1000 gallons of white wine tank capacity (80% capacity), as shown in Table A-6, based on winery fermentation source testing discussed in Section 2. The peak observed flow rates from Table A-6 for white and red wine were selected as the basis for ducting design. The maximum flow rate was selected to ensure that the ducting system maximized the collection efficiency.

In order to prevent imposing pressure or vacuum on the tank, the hood design should allow dilution air to be drawn into the system in order to maintain a constant flow rate to the exhaust control system. Based on previously published preliminary designs by ARB and designs used during pilot testing at California State University Fresno, a hood design was developed which proved to be effective during a full scale demonstration project.[32] The hood was made moveable to provide ease of cleaning and sanitizing. A removable deflector cap was provided in the tank nozzle to prevent condensation droplets from entering the tank and to deflect foam formations from the vent ducting.

Pumpover or recycle piping is used to provide supplemental mixing of the tank contents which is a normal periodic operation during fermentation. Rearrangement of the recycle hoses on existing tanks may be necessary to accommodate the installation of the exhaust ducting.

The foam-over pot separates any liquids and/or foams that might be entrained with the vent gases.

The ducting system design is discussed further in Appendix A, page A-112.

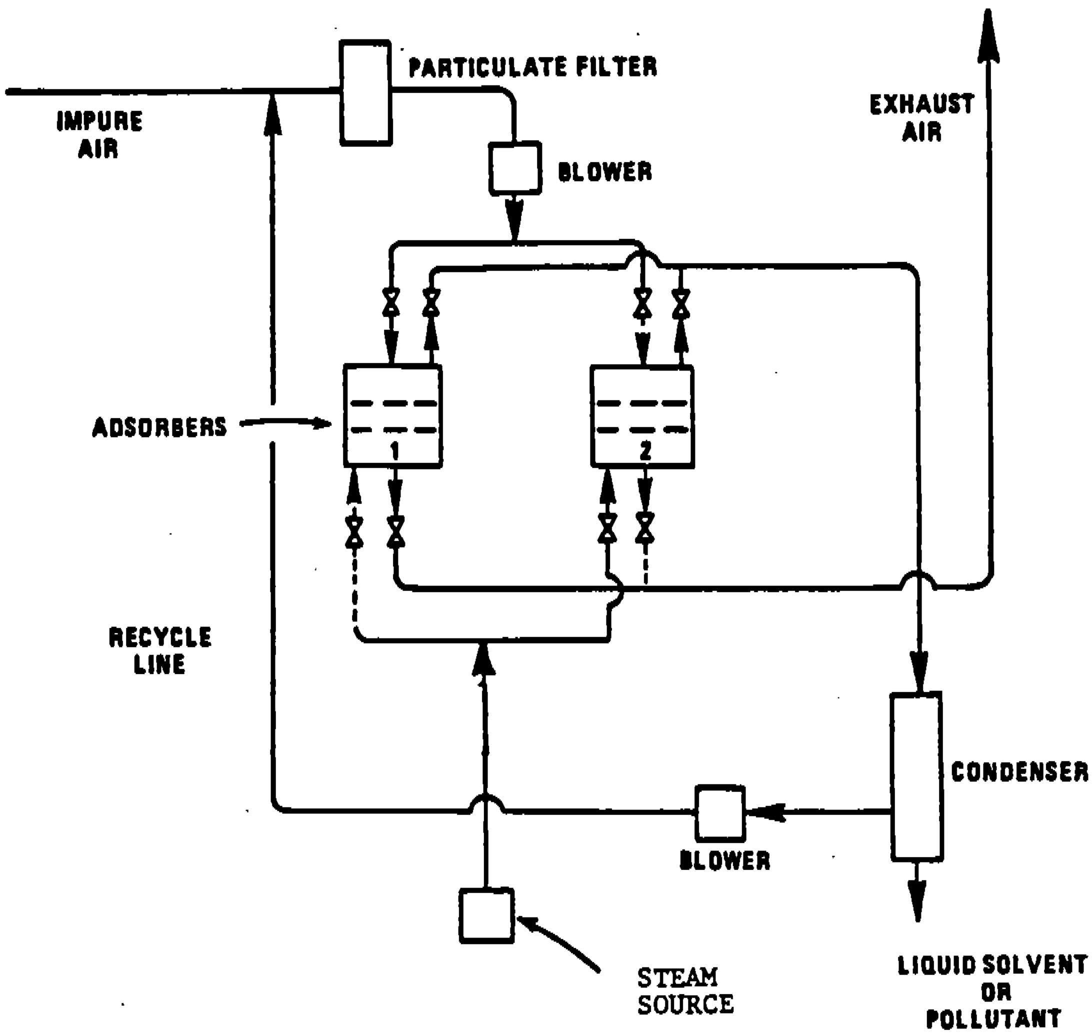
2. Carbon Adsorption

Carbon adsorption systems primarily consist of gas pretreatment and a granulated carbon bed with a steam boiler and accumulation tank to regenerate the carbon bed. A generic carbon adsorption system is shown in Figure 4.

Carbon adsorption is a physical separation process in which organic or inorganic materials are removed from an air stream by sorption or attraction and accumulation of materials onto the surface of the carbon. Activated carbon is considered to be a non-polar sorbent and tends to sorb the least polar and least soluble organic compounds; it will sorb most organic compounds.[33] Therefore, the carbon bed will preferentially absorb ethanol, but water and CO_2 will compete for adsorption sites.

Figure 4

Schematic of Carbon Adsorption System



SOURCE: ARB SCM, 1986

Pretreatment of the gases prior to entering the bed maximizes the ethanol adsorption capacity. The gas stream is typically filtered to remove droplets or particles in the gas stream. To minimize the competition of ethanol and water, relative humidity must be kept below 50%. This is achieved through the use of a heater or separate selective adsorbent (silica gel or alumina). Sizing of the carbon bed will alleviate the problem with CO_2.

Much of the surface area available to sorption by carbon is found in the pore space within the carbon particles created during the activated process. Activated carbon adsorbs organics from the process stream and exhausts clean air. The carbon pores eventually becomes saturated and break through occurs. The exhausted saturated carbon must be regenerated for use or replaced with fresh carbon. The adsorption capacity of the carbon can be restored by chemical or thermal regeneration.

Multi-stage carbon beds allow continuous treatment of organics in exhaust gases during regeneration. Two carbon beds may be placed in parallel, with the flow passing through one carbon bed at a time. Eventually the carbon bed cannot adsorb any more ethanol and breakthrough occurs. At that time, the gases are routed to a standby bed. The used bed is purged with steam to desorb the ethanol and carry it out of the bed. Outside the bed, the steam and ethanol are allowed to cool and condense. The water and ethanol are then either treated or disposed, and the carbon bed is put on standby until the other carbon bed begins breakthrough.

Thermal regeneration is most commonly used and involves heating the carbon at 820 to 980 degrees Celsius in the presence of steam. The organics are liberated from the carbon bed by the steam. The steam and organics are then condensed and may be further treated or disposed of. Non-condensed gases are recirculated through the carbon bed.

It is not cost effective to achieve 100% desorbtion, due to the cost of steam. Design of the system must optimize steam costs and increased bed size to compensate for the reduced working capacity. Further, during the regeneration process, some elemental carbon is lost to the process but this is usually limited to 10% by weight over the useful lifetime of the carbon bed. Eventually regenerated carbon will breakdown and need to be replaced by fresh carbon.

Commercially available carbon adsorption units may be utilized. Sizing of the carbon units is a function of the exhaust flowrates, chemical constituents and concentrations and the adsorptivity of the carbon for ethanol.

Calculations for the carbon adsorption system are shown in Appendix A, page A-23. The carbon adsorption system used in the cost analysis is designed for 95% efficiency. This efficiency may be readily achieved based on demonstration project source testing discussed in Section 2.

3. Incineration

Incineration oxidizes combustible organic emissions to carbon dioxide and water.[34] There are two types of incinerators (also known as afterburners): direct flame and catalytic. Direct flame depend on flame contact and relatively high temperatures to oxidize the organic materials. A typical catalytic incinerator operates by preheating the exhaust gas stream and then promoting further combustion by bringing the organic material into contact with a catalyst. The catalytic unit oxidizes the organic material at lower temperature than a direct flame unit (450 to 500 versus 1100 to 2000 °F), thus saving fuel costs. Because of the low operating temperatures, there are virtually no NO_x emission from catalytic units. For these reasons, catalytic rather than direct flame incineration was selected as a control technology for fermentation exhaust gases.

Common catalysts are platinum or other precious metals, often deposited in porous form on an inert substrate with a honeycomb configuration to maximize surface area, since the catalyst effectiveness depends on the accessibility of active sites. The incinerator used in this design calculations uses a pelletized metal oxide catalyst which is lower in cost and functions at lower temperatures than precious metal catalysts. Periodic replacement of the catalyst bed is required to maintain control efficiency.

A schematic diagram of a generic catalytic incinerator is shown in Figure 5. Fermentation exhaust gases first enter a heat exchanger where they are preheated to reaction temperature. They next enter a combustion chamber fired with a gas burner and finally pass through the reactor vessel containing the catalyst bed, where the remaining contaminant are combusted. Removal efficiency is rated at 95%.

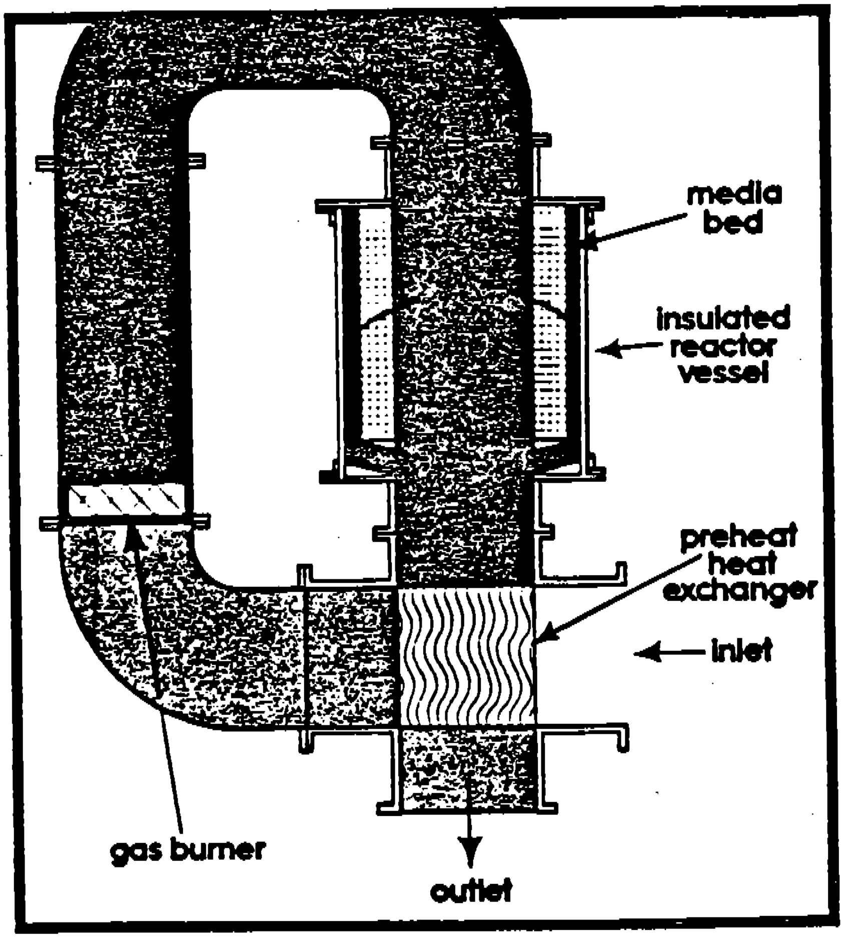
Natural gas is used to fuel the incinerator. Fuel requirements vary with the concentrations of ethanol and oxygen in the incoming stream. From 10 to 15 % oxygen is needed to sustain combustion, but make-up air drawn into the ducting system to maintain the exhaust flow rate should minimize the requirement for supplementary combustion air. A fan is provided for supplementary air when it is needed. Design calculations for fuel requirements and sizing of the catalyst unit are shown in Appendix A, page A-30.

4. Scrubbing

Scrubbing also known as absorption is the process of selective transfer of material from a gas to a contacting liquid.[35] Gas absorption involves the diffusion of material from a gas through a gas liquid interface and ultimate dispersion into the liquid. Effective scrubber design minimizes the pressure drop and maximizes liquid surface area for gas contact. Packed towers contain inert material which increases the liquid surface contact area. Liquid is introduced at the top of a vertical scrubber and flows down

Figure 5

Schematic of Catalytic Incinerator



SOURCE: ARB SCM, 1986

through the packing material. Contaminated gas enters at the bottom of the scrubber and contacts the liquid in a counter current direction. The contaminant becomes entrained in the liquid and flows out the bottom of the scrubber. Clean gas exits the top of the scrubber. A schematic drawing is shown in Figure 6.

The scrubber selected for this application is a fiberglass packed tower which uses water as the solvent. Based on pilot studies during the Demonstration Program, a packed scrubber with water as the solvent can achieve a 99% efficiency in the reduction of ethanol from the vapor stream.[36] The design is based on the anticipated maximum fermentation exhaust flow rate and ethanol concentrations. Design calculations are shown in Appendix A, page A-32.

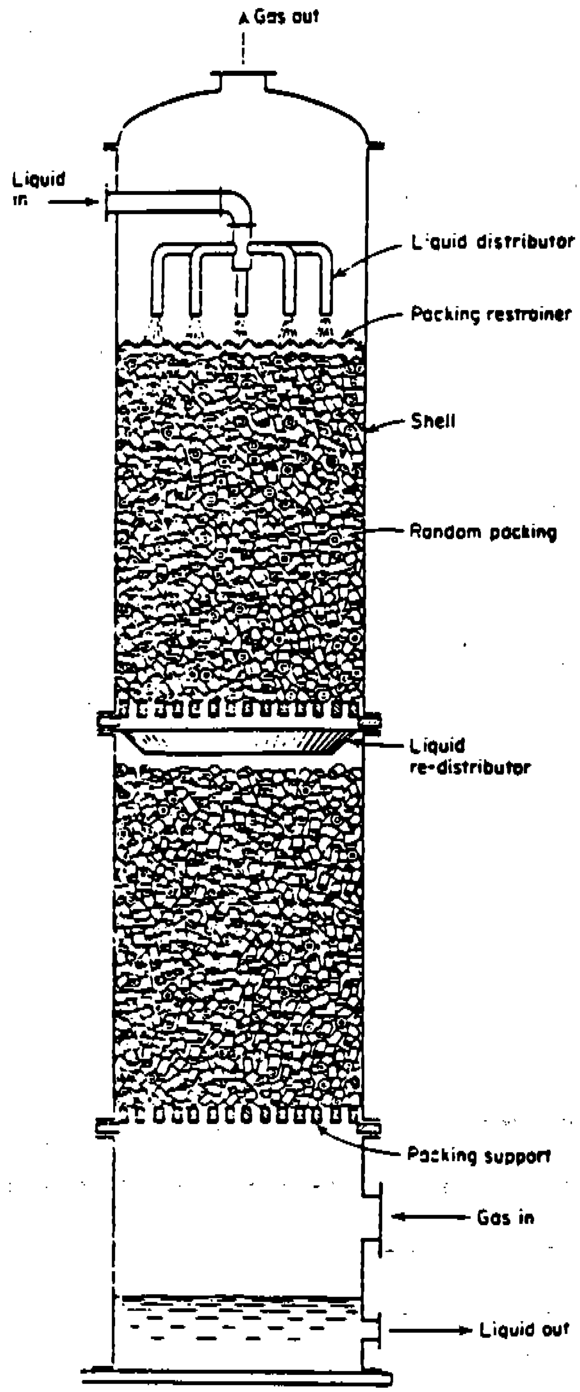
5. Condensation

Condensation is the process by which heat is removed from a vapor with a subsequent reduction in volume.[37] The reduction in temperature may also result in a reduction in the vapor pressure, subsequently the vapor forms into a liquid. Any component of a vapor mixture can be condensed, if brought to equilibrium at a low enough temperature. A refrigerant is usually used to achieve a sufficient reduction in temperature.

The design and cost estimates for the condenser used in this analysis were supplied to the wine industry by an equipment vendor.[38] The unit is an evaporative condenser

Figure 6

Schematic of Scrubber



SOURCE: ARB SCM, 1986

with fin tube coils to increase the heat transfer area and efficiency. Coolant circulating in the tubes removes heat from the fermentation exhaust gases as they flow through the unit. The gases condense on the cold surface of the tubes and the liquid drips into a collecting pan. The liquid (or condensate) is then stored for later distillation or disposal. Uncondensed gases (CO_2 and a portion of the ethanol) are vented to the atmosphere.

Both the water and the ethanol vapor in the fermentation exhaust gas stream condense as a function of their partial pressures. Virtually all the water and 90% of the ethanol are recovered in the condensate. Because water freezes at a higher temperature than ethanol, wine industry representatives have expressed concern that ice may form on the coils, resulting in maintenance and efficiency problems. ARB staff discussions with a vendor indicate that although the vendor would not guarantee it, the vendor believes that icing will not occur. Should icing occur, a hot gas defrost system could be installed to handle the problem.

Design of the system is based on the estimated refrigeration needs, using Freon R-22 and the equipment vendor specifications referenced above. Calculations are shown in Appendix A, page A-43.

6. Temperature Control

As discussed in Section 4, the rate of ethanol emissions is temperature dependent. One option for control of ethanol emissions suggested by the Wine Institute was reduction of the fermentation temperature. Most wineries generally cool the must to control the rate of fermentation. The three major systems employed in California are internal cooling coils in the fermentor, external shell and multi-tube coolers and jacketed tanks.[39] In the first two cases water or a coolant is used, often in conjunction with a cooling tower. In the jacketed tanks, ethylene glycol is the usual cooling medium. Cooling may be performed in one operation or it may be applied two or three times during fermentation so that the temperature can be lowered gradually. The fermentation process will stall at temperatures which are too high or too low. Section 3 discusses the optimum range of temperatures and the effect of temperature on the fermentation process.

Control of ethanol emissions may be achieved by further reduction of the fermentation temperature. This would require installation of additional refrigeration capacity at most wineries. Calculation for the refrigeration requirements are shown in Appendix A, page A-50. The design is based on a reduction in fermentation temperature for white wine from 65°F to 55°F; the red wine scenario is based a reduction in the fermentation temperature from 85°F to

80°F. These temperature reduction scenarios are consistent with the Wine Institute proposal for temperature control. Further, these temperature reductions were selected based on limited availability of data for refrigeration requirements and to avoid adversely impacting the fermentation process.

Efficiency of ethanol control depends on the amount the temperature is reduced, but there are complicating factors such as the presence of a pomace cap in red wine and non-isothermal fermentation. Based on the reductions of the temperature suggested by the Wine Institute, the control efficiency for red wine is will be 15% and 30% for white wine.

B. Emission Reductions

The ARB proposed that control of winery emissions would only be applicable to tanks of 50,000 gallons and over in California.[40] Because tanks under 50,000 gallons were proposed for exemption, accurate state-wide emission reductions cannot be estimated without a survey of all wineries to determine annual throughput by fermentation capacity. However, based on tankage assumptions and 1991 grape crush information statewide emission reductions may be estimated, as shown in Table 4.

There are over 650 wineries in the State, however the largest wineries are found in the San Joaquin Valley. Because the majority of the wineries outside of San Joaquin are relatively small, it is unlikely any of these wineries

Table 4

Estimated Emissions and Potential Emission Reductions for San Joaquin Valley, 1991

Control Technology	Emission Type	tons/yr	tons/dy
No Controls	Estimated Emissions	444	5.55
Carbon Adsorption, Condensation, Incineration, and Scrubbing	Potential Reductions	356	4.45
Temperature Control	Potential Reductions	62	0.78

would have tanks in excess of 50,000 gallons. Therefore most of the tanks outside of the San Joaquin basis would not be subject to emission control.

As stated in Section 4, the San Joaquin Valley had uncontrolled winery emissions of 444 tons. Within the San Joaquin Valley, data obtained by the Fresno County Air Pollution Control District indicates 89% of the tanks used for wine fermentation are greater than 50,000 gallons.[41] Therefore if an ethanol control Rule were in effect, 89% of these uncontrolled emissions would be subject to control.

Emission reductions for the five control methods are presented in Table 4. The reductions for the exhaust controls were based upon a 90 % control efficiency. This would result in an emission reduction of 356 tons per year (444 * 0.90 * 0.89 = 356).

The reduction in emission for temperature control assumes a 30 percent decrease in white wine emissions. The reduction in emissions from temperature control is based on the temperature control Rule proposed by the Fresno County APCD which had a maximum daily weighted average of 80°F for red and 55°F for white. However, based on a survey,[42] the 1980 San Joaquin Valley weighted average fermentation temperature for red wine is 78°F and 58°F for white wine. Therefore only white wine emissions would considered to be reduced. The associated emission reduction is based on the Statewide ratio of 0.52 (306.1/584.6=0.52) white wine to total emissions from Table 3. Therefore, the emission reductions are 62 tons per year (444 * 0.3 * 0.89 *.52 = 62)

C. Costs of Control Strategies

Due to the fact that no two wineries are identical, control technologies for individual wineries should be selected on a case-by-case basis. Further, cost effectiveness will vary for different tank configurations. The cost analyses are based on a variety of tank farm scenarios for white and red wine. For white wine, tank sizes of 50,000, 100,000, 300,000 and 600,000 gallons for tanks farms of 5, 10 and 15 tanks were used. For red wine, tank sizes of 50,000, 100,000 and 300,000 gallons for tank farms of five and ten tanks were used. Based on discussions with wine industry representatives, 35 % excess capacity is maintained by the wineries to facilitate moving the must or juice around during fermentation. Fifty percent more tank space to each of the tank farms has been added to accommodate the excess capacity.

Because each of the excess capacity tanks may be used for fermentation at some time, they need to be ducted to the control devices. However, this does not increase the exhaust flowrates from wine fermentation for each tank farm scenario.

Cost analyses for the control strategies are based on white wine tanks filled to 80% capacity and red wine tanks filled to 75% capacity. This filling capacity is representative of standard winery practices.

For the exhaust control systems, duct work and control equipment were sized assuming that all tanks within a tank farm reach their potential maximum exhaust flowrate and concentration at the same time. Cost estimates for the ducting and equipment was obtained from either vendors of the system or wine industry representatives.

Cost estimates for temperature control were obtained from wine industry representatives. Appendix A contains a detailed explanation of the sources of cost estimates.

D. Cost Effectiveness

Cost effectiveness is derived by dividing the present value after tax cost of control by the ethanol reduction associated with that control ($/lb) for a five year period. The cost is composed of fixed capital cost and operating and maintenance costs. Operating and maintenance costs include; maintenance, labor, property taxes, insurance, plant overhead and utilities. The present value after tax cost takes into consideration a six percent interest rate and State and federal tax benefits. These benefits include write-offs for operating and maintenance costs and a five year straight line depreciation for fixed capitol costs. The after-tax evaluation is representative of the costs that wineries will incur to implement the control strategies. The cost analysis methodology was performed consistent with the Air Resources Board Suggested Control Measure Technical Support Document.[43]

The cost-effectiveness values do not include treatment or disposal of any by-products of the control methods. The scrubber, carbon adsorption and condenser will have an ethanol water by-product. This product may potentially be distilled onsite or treated off site to recover the ethanol as a commercially viable product. Appendix B contains a general discussion on the estimated impacts of by-product waste handling.

The present value after-tax cost-effectiveness for the different control devices and tank scenarios is shown in Figures 7 through 11. Appendix A contains detailed calculations of the design parameters, cost assumptions and emission reductions that were used to derive the cost-effectiveness values. Table A-20, pg A-62, contains a summary of the Cost-Effectiveness values shown in Figures 7 through 11.

The selection of the appropriate control technology for specific wineries needs to be based on each facilities unique operating conditions and equipment configuration. The cost-effectiveness for different tank combinations can be interpreted from the cost-effective curves. However, costs will vary depending on site specific considerations.

The cost effectiveness values are conservative since emission reductions are based on average values and maximum emission control equipment costs. The design parameters for the control equipment are based on maximum exhaust flowrates and concentrations. This approach was selected to ensure that fermentation exhaust gases were controlled to the greatest extent possible throughout the fermentation process. As discussed in Section 4, exhaust flowrates and

Figure 7

Comparison of Cost Effectiveness for Control of Ethanol Emissions from White Wine Fermentation, Five Tanks

(Based on 1991 Cost Estimates)

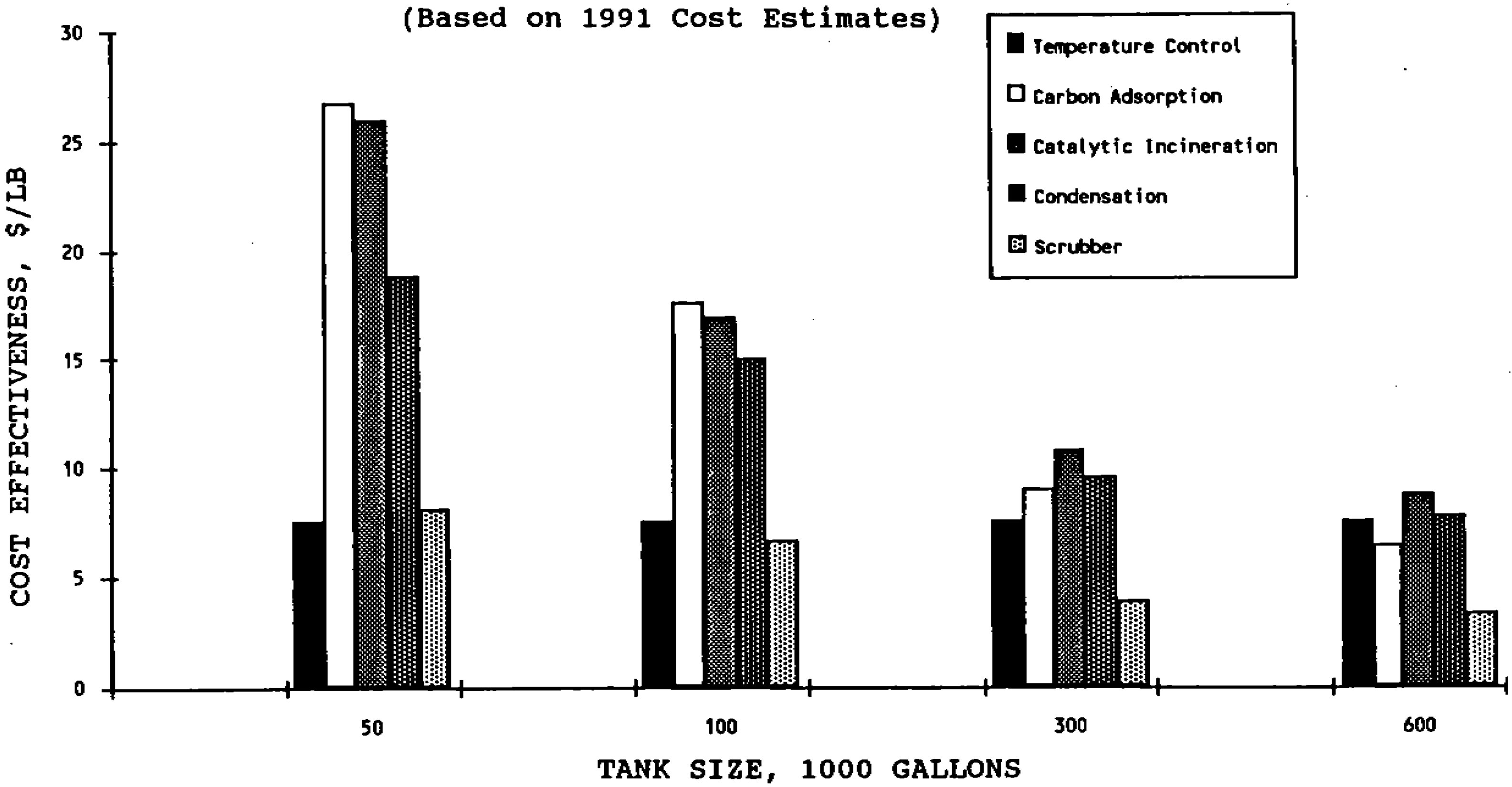


Figure 8

Comparison of Cost Effectiveness for
Control of Ethanol Emissions from White Wine
Fermentation, Ten Tanks
(Based on 1991 Cost Estimates)

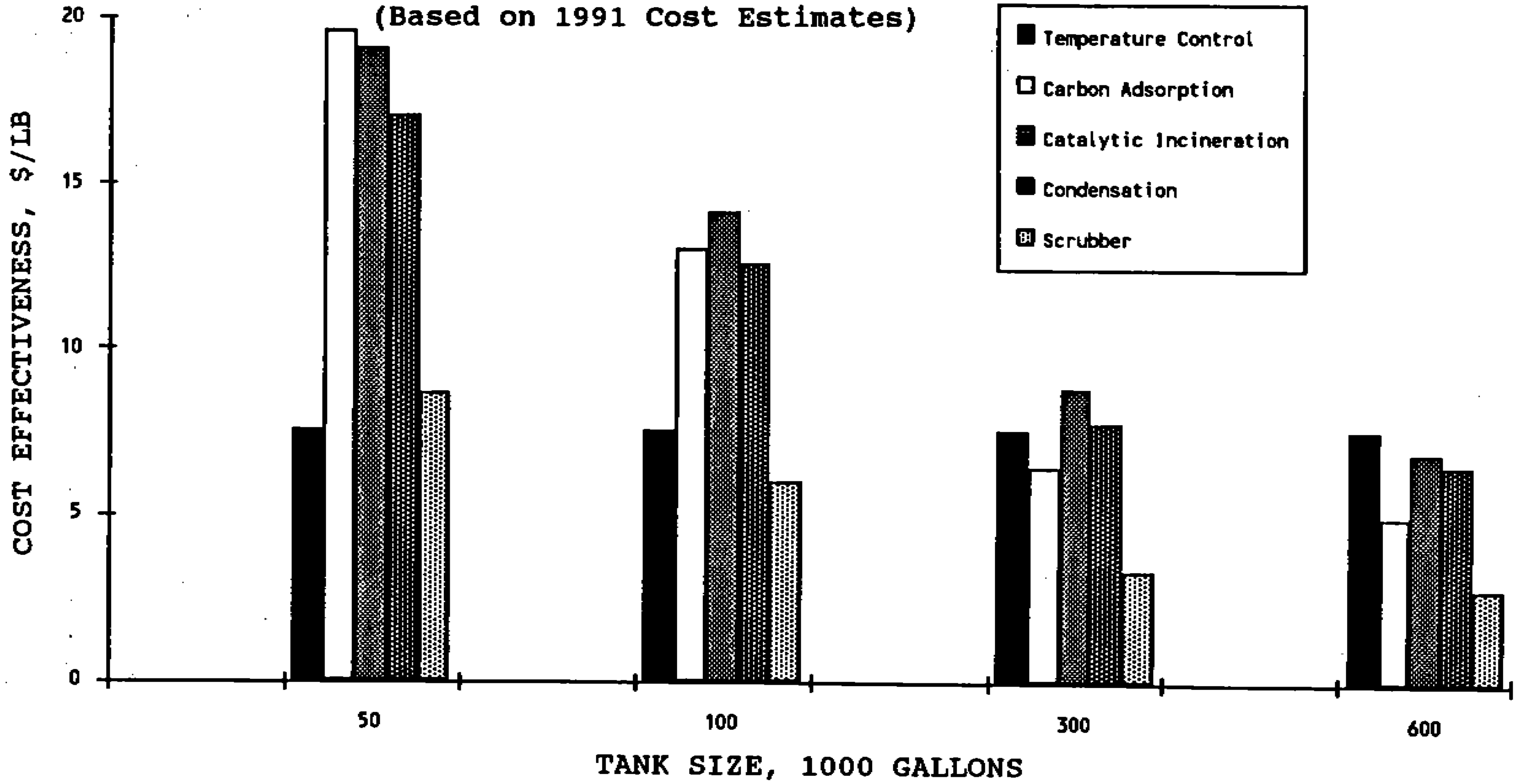


Figure 9

Comparison of Cost Effectiveness for
Control of Ethanol Emissions from White Wine
Fermentation, Fifteen Tanks

(Based on 1991 Cost Estimates)

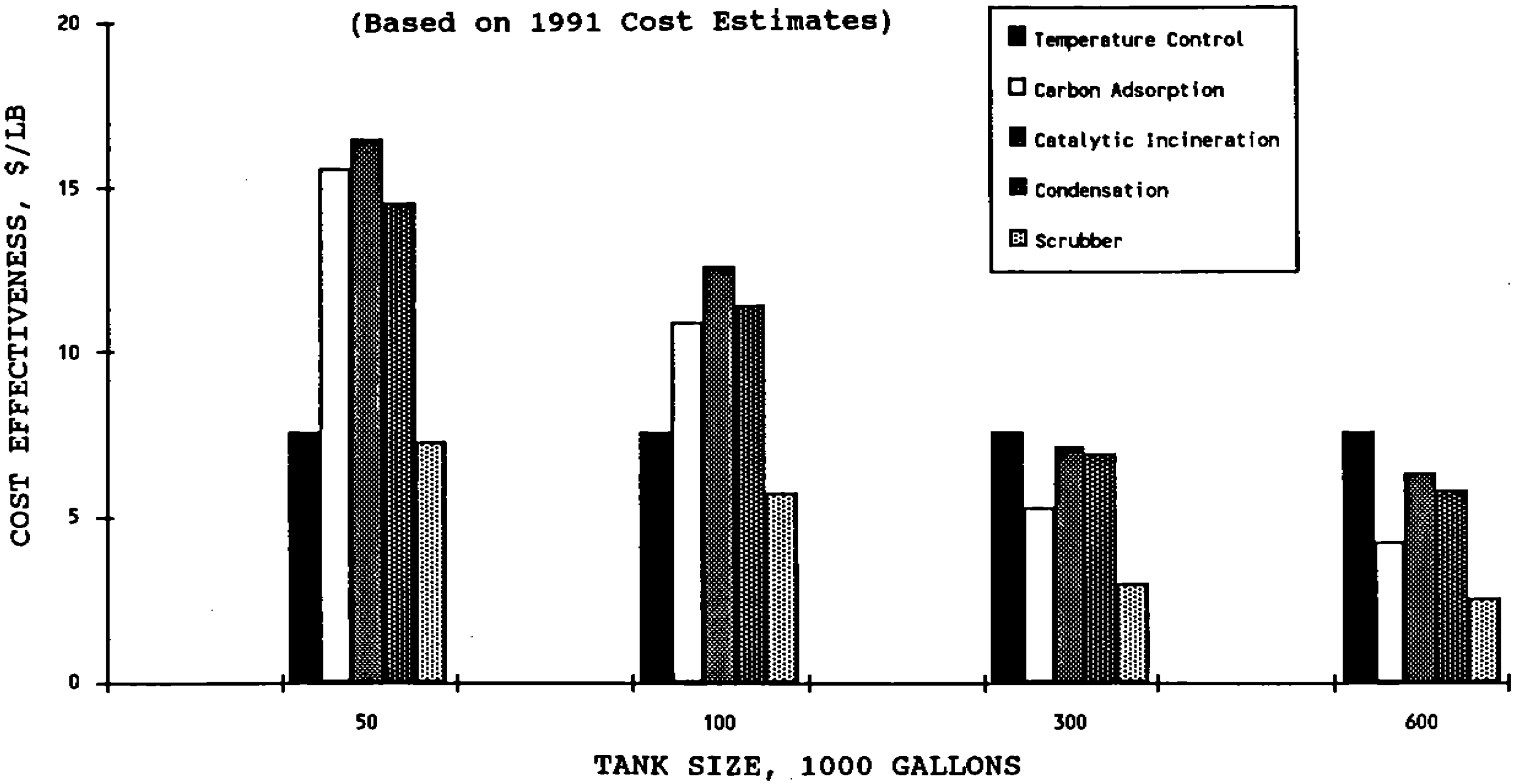


Figure 10

Comparison of Cost Effectiveness for
Control of Ethanol Emissions from Red Wine
Fermentation, Five tanks
(Based on 1991 Cost Estimates)

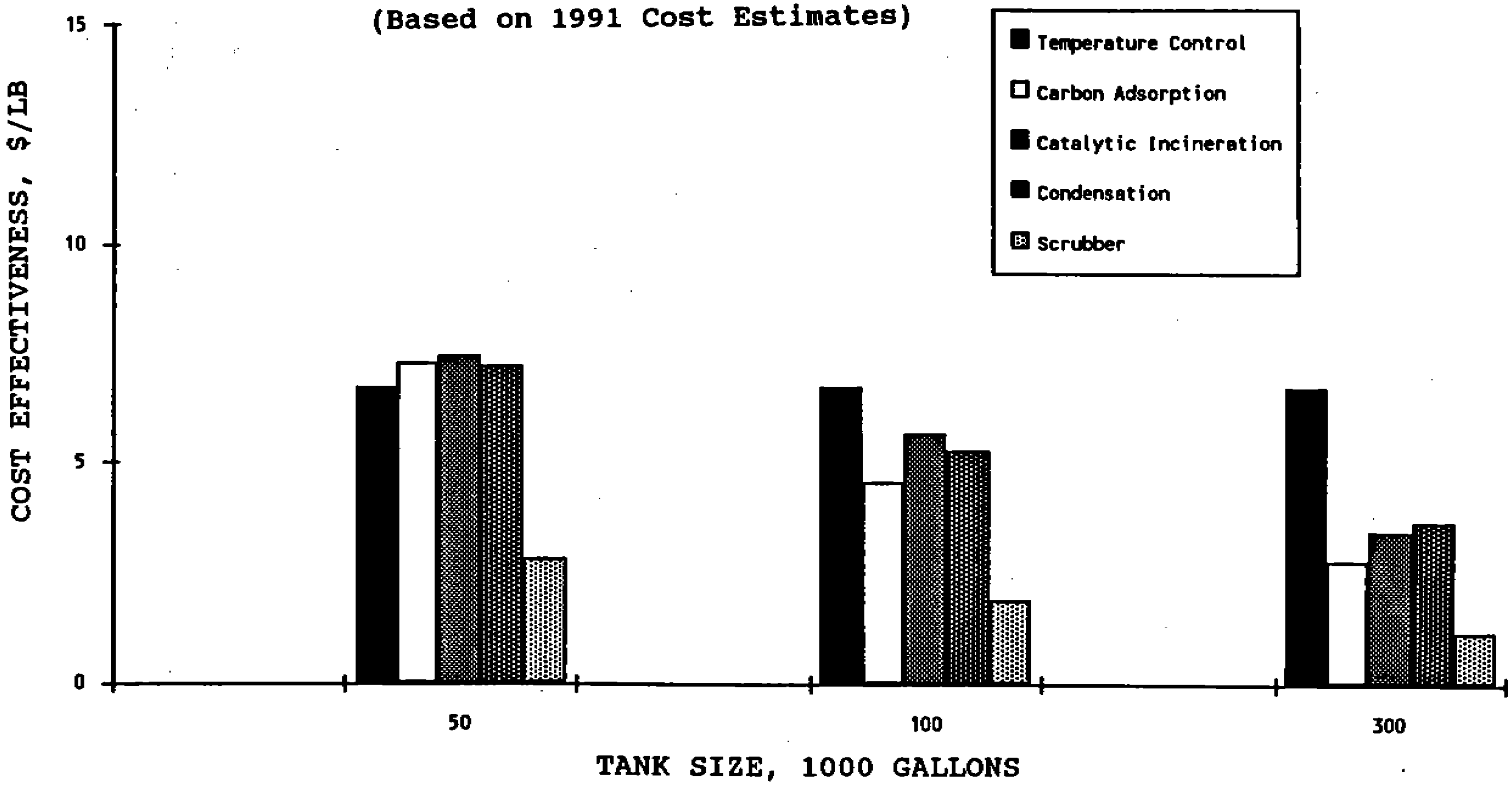
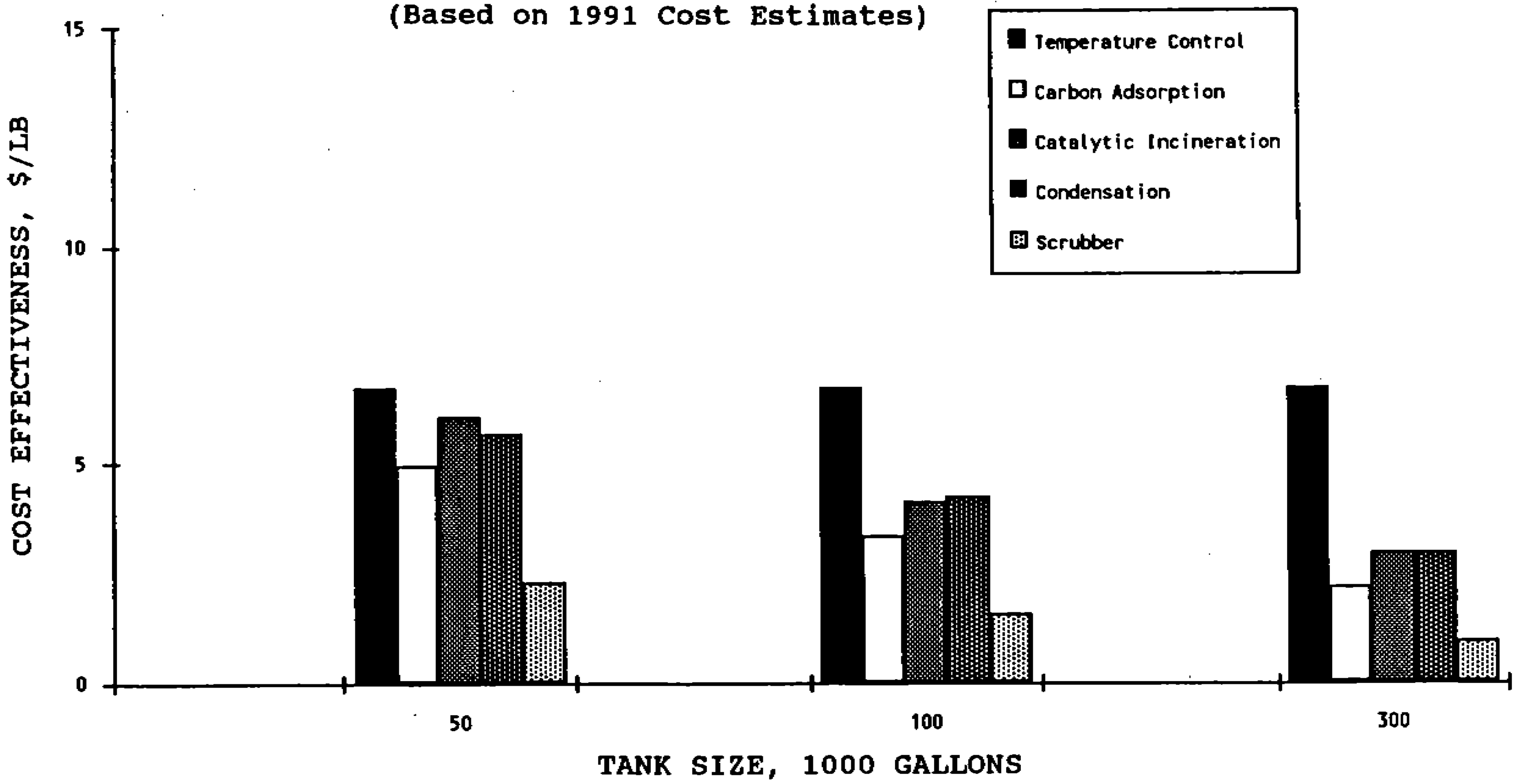


Figure 11

Comparison of Cost Effectiveness for
Control of Ethanol Emissions from Red Wine
Fermentation, Ten tanks
(Based on 1991 Cost Estimates)



concentrations reach a peak in the fermentation cycle. The peak observed flowrates and concentrations observed from source testing were used for design of the control systems (Refer to Appendix A) to ensure the desired control efficiency was obtained. In contrast, emission reductions are based on the average observed emissions from source testing throughout the fermentation cycle. Average emissions were used to represent emissions throughout a winery over the fermentation season.

Further the cost-effectiveness values are conservative, based on a five year straight-line depreciation. The five year depreciation is based on tax considerations, however the equipment life is likely 10 to 15 years. The only costs after the five year period would be operating and maintenance costs. Therefore for example, the cost of operating the carbon adsorption system for ten 100,000 gallon tanks would be significantly decreased from \$13.11/lb-yr to \$1.35/lb-yr.

The cost effectiveness curves for temperature control are horizontal lines, as costs are proportional to load, based on wine industry estimates. Consequently the cost effectiveness is not dependent on tank size or the number of tanks. Red wine has a lower cost effectiveness at \$6.74/lb and white wine has a cost effectiveness of \$[illegible].56/lb.

Temperature control is the most cost-effective method of control for white wine tank scenarios of 5 and 10 tanks with 100K gallon capacity. However, as indicated in Table 4, the emission reductions achieved with exhaust control are much greater. Because of the minimal overall reductions associated with temperature control, its choice as a control method is not recommended.

The cost effectiveness for exhaust emission control varies with tank size and the number of tanks. In general, the cost is lower per pound of emission reduced for larger tank farms. This is the result of economy of scale, associated with ducting and equipment. The more tanks that are ducted together to a single control unit, the cheaper the per tank expense. However, from a practical sense it may be necessary to divide up the larger tanks farms due to the realistic size of available equipment. For example, for carbon adsorption 15-600K gallon white wine fermentation tanks would require a ten ton carbon bed.

Red wine generally has a lower cost-effectiveness than white wine. Red wine fermentation emits greater amounts of ethanol than white wine fermentation, thus requiring larger equipment; however the emission reductions are greater. Greater emission reductions together with economy of scale benefits produces better cost-effectiveness values.

Scrubbing is the most cost-effective method of exhaust control, for all tank scenarios. The cost-effectiveness ranges from $0.93/ lb to $8.69/ lb, which is significantly lower than the other exhaust control technologies. However, as indicated in Section 2, the wine industry does not favor this method due to the large volume of water which is produced as a byproduct.

Carbon adsorption is the next most cost-effective method for many of the tank scenarios. The costs for carbon adsorption range from $2.14/lb to $26.80/lb. Although at white wine tank farms with total tank capacities less than 10-100K gallon tanks, condensation is more cost effective. Cost effectiveness for condensation range from $2.96/lb to $18.89/lb.

Overall, catalytic incineration is the least cost-effective of the controls that were evaluated, the cost effectiveness values range from $2.96/lb to $26.01/lb.

SECTION 6

Conclusion

Based on the information presented in this report, the following conclusions have been derived:

1. Emissions from wineries during fermentation may be predicted using the Boulton kinetic and stoichiometric model for estimating emission as a function of fermentation temperature and initial and final Brix.

2. A Statewide total of 584.6 tons per year of ethanol was released from winery fermentation tanks in 1991. This is equivalent to 4.9 tons per day based on a 120 day fermentation season (mid-August through mid-December). Emissions from the San Joaquin Valley, where 75.8 percent of the wine is estimated to be produced, are approximately 443.7 tons per year or 5.5 tons per day during the 80 day fermentation season (mid-August through early November).

3. Four different exhaust control technologies have been evaluated for reduction of ethanol emission: carbon adsorption, water scrubbing, condensation and catalytic incineration. Winery fermentation emissions can be reduced by 95% using water scrubbing, catalytic incineration and carbon adsorption. Pilot and full scale testing during the demonstration program studies from 1988-1991 have demonstrated these commercially available emission control systems may be successfully implemented by the wine industry. Condensation may reduce emissions by 90%, based

on calculated efficiencies and vendor information. Due to difficulties with measuring low concentrations of ethanol at the beginning of the fermentation cycle, efficiency should be measured on a complete fermentation cycle.

4. Overall emission reductions from implementing exhaust control technology may result in a reduction of 355 tons per year, or 4.44 tons per day in the San Joaquin Valley.

5. Control of emissions were also evaluated using temperature control, however, this results in a San Joaquin emission reduction of 62 tons per year. Due to the low levels of emission reductions future consideration of this control method is unwarranted.

6. Ducting design at peak exhaust flow rates of 8.08 acfm/1000 gallon of red wine and 1.92 acfm/1000 gallon of white wine will maximize the capture rate of ethanol emissions. A hood design connecting the ducting to the fermentation tank has been demonstrated on a full scale fermentation tank to prevent imposing pressure on the tank from the ducting system. The hood is moveable to facilitate cleaning and contains a deflector cap to prevent foam from entering the ducting system.

7. The overall cost to the wine industry for implementing controls was not determined due to the variety of tank scenarios and operating conditions at individual wineries. However, fixed costs, operating costs and present value after tax cost-effectiveness was determined for tank farms

consisting of 5, 10 and 15 tanks with capacities of 50,000, 100,000, 300,000 and 600,000 gallons. Individual wineries may estimate their costs by grouping tanks on a case-by-case basis.

8. The capital cost for red wine emission control is higher than that of white wine due to higher flow rates and emissions. However, the present value after tax cost-effectiveness of red wine is considerably better because emission reductions are greater than for white wine.

9. For the exhaust control treatment technologies, the capital costs are lowest for scrubbing and are highest for catalytic incineration. Costs per 1000 gallons decreases with increasing capacity, due to economy of scale. The capitol costs for temperature control are lower than exhaust control. The temperature control cost is proportional to load and does vary per 1000 gallon capacity.

10. Scrubbing is the most cost-effective control for reducing emissions and catalytic incineration is the poorest. Cost-effectiveness varies with the number of tanks, tank size and the type of wine. The present value after tax cost-effectiveness varies from $0.93 per pound of ethanol reduced to $26.80 per pound based on 1991 estimates. Red wine exhibits a better cost-effectiveness than white wine. The present value after tax 1991 cost per bottle (750 ml) of wine ranges from $0.001/bottle to $0.01/bottle.

11. The handling, storage and treatment of an ethanol/water waste by-product from condensation and carbon adsorption may incur additional costs which were not included in the cost effectiveness. However, there is the potential that recovery of ethanol from the condensation waste may generate a slight profit if favorable ethanol fuel markets exist. The ethanol/water waste by-product from scrubbing is too dilute for recovery of ethanol to be cost effective. The scrubber waste may be routed to municipal systems, however this is dependent upon access and capacity of municipal systems. The wine industry has expressed that many wineries may not have access to a municipal system.

12. Based on operational and cost considerations carbon adsorption is the preferential method for emission control from wineries.

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APPENDIX A

Methods of Computing Costs for Control

APPENDIX A

Methods of Computing Costs for Control

1. Introduction

This appendix presents the methodology for computing the costs and cost effectiveness of the air pollution control equipment. Due to the variety of tank configurations which may exist at different wineries, the cost effectiveness was performed for a variety of tank farm scenarios. The intent of this cost analysis is to identify the potential range of cost for installation of ethanol emissions controls at wineries. Example calculations are presented throughout the Appendix based on random selection of tank farm scenarios.

Section I presents a brief overview of the cost analysis and summarizes the design parameters. Section 2 discusses tank farm layout for various cost scenarios. Sections 3 through 8 present the calculations for capital and utility costs. Section 9 discusses operating and maintenance costs. Section 10 presents the methods for estimating the emission reductions and cost-effectiveness for each control scenario.

The cost estimate methodology follows the assumptions developed in the ARB Suggested Control Measure (SCM) for Control of Ethanol Emissions from Winery Fermentation Tanks Technical Support Document (TSD).[1] This approach was selected so that a uniform basis for comparison was developed. The primary modifications to the ARB cost estimate is an adjustment for current market prices (1991) and calculations are based on a higher design exhaust flow rate. A higher flow rate was selected based on the maximum observed flow rates from the 1988-1990 Demonstration projects.[2] The maximum flow rate was selected to ensure collection of the exhaust gas throughout the entire fermentation cycle. The methods for calculating capital costs, operating maintenance costs, emission reductions, and the after-tax cost effectiveness are briefly outlined below.

First, costs are determined by calculating installed capital, fixed capital, and annual utility costs. Installed capital costs (ICCs) are the costs for purchasing and

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[1] ARB SCM., op. cit., pg. 42.

[2] EAL Corporation, op. cit., pg. 25.
ARB/ML 88-027, op. cit., pg. 57.

installing the hardware. Fixed-capital costs (FCCs) represent the capital necessary for the installed control equipment as well as all auxiliaries that are needed for operation. The FCC for each of the controls is made up of the same items. The breakdown of the FCC items are listed in Table A-1.

Table A-1

Breakdown of Fixed-Capital Costs[3]

Direct Costs	
1.	All purchased equipment and installed cost of equipment
2.	Electrical equipment, electrical labor, and services facilities (i.e. water, gas, and steam)
Indirect Costs	
1.	Engineering and Supervision; including process design and general engineering, drafting, consultant fees, engineering supervision and inspection.
2.	Construction operation and maintenance of temporary facilities.
3.	Contractor's fee
4.	Start-up expenses
5.	Contingency; to cover price change, small design changes, errors in estimation and other unforeseen expenses.
Fixed Capital Costs	
	Sum of direct and indirect costs

[3] Adapted from Peters M. and Timmerhaus, K., Plant Design and Economics for Chemical Engineers, Second Edition, McGraw-Hill, New York, 1968.

Due to the different methods used to obtain ICCs, on occasion some of the FCC items have been included in the ICCs. Such instances are noted in the following text. Those items are accounted for when the FCCs are calculated, so that the cost items will not be duplicated. The detailed calculations are covered in the appropriate sections.

Second, the annual operating and maintenance costs are determined. These consist of maintenance, operating labor, property taxes, insurance, overhead, and utility costs. The FCC's and operating and maintenance costs are then adjusted for present value after tax cost.

Third, the emissions and emissions reductions are calculated for use in the after-tax cost effectiveness estimates. The after-tax cost-effectiveness is calculated by dividing the total after-tax costs by the emission reductions.

Emission reductions and the cost estimates are a function of the assumed fermentation temperatures and exhaust flow rates. These parameters for ducted control systems are based upon the available information from winery studies discussed in Section 2. The fermentation temperature for white wine is 58°F and 78°F for red wine, based on a 1980 survey of the San Joaquin wineries.[4] Flow rates and gas composition were assumed based on maximum gas generation rates for red and white wine to maximize the exhaust gas collection and control efficiency throughout the fermentation season. Emission reductions were based on average emission factors as a conservative estimate.

The assumed parameters for temperature control are based on reducing the baseline temperature of 85 to 80°F for red and on reducing the baseline temperature of 65 to 55 degrees fahrenheit for white wine. These temperatures were chosen to parallel the proposed control rule by the Wine Institute and because of limited design data for temperature control systems.

Tables A-2 through A-4 summarize the design parameters for the cost estimates. Table A-2 shows the cycle and season lengths used in this analysis. Because the temperature control scenarios have fermentation temperatures different from the exhaust control scenarios, the fermentation cycle lengths are also different. To keep production levels the same, the number of cycles were kept constant, and the season lengths were adjusted. Also, by keeping production levels constant, the emissions will reflect changes due to

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[4] Fresno County Air Pollution Control District, op. cit., pg. 1.

temperature and not the cycles per season. This is discussed further in Section 10. Tables A-3 summarizes the data used for the exhaust control scenarios and cost-effectiveness.

Maximum exhaust flow rates and compositions were used for design of the control equipment and to calculate capital costs and annual utility costs. Average emissions of ethanol per 1000 gallons of capacity were used to calculate the emission reductions for the cost-effectiveness. Table A-4, contains the design exhaust flow rates for the various tank scenarios.

Table A-2

Fermentation Temperatures and Cycle Length

Control Type	Wine Type	Temp. F *	Cycle Length days	Season Length Days	No. Cycles
Exhaust Control	White	58	9	36	4
Exhaust Control	Red	78	3	30	10
Temp. Control	White	65	7	28	4
Temp. Control	White	55	10	40	4
Temp. Control	Red	85	2.5	25	10
Temp. Control	Red	80	3	30	10

(*) ARB SCM, op. cit., pg A-4.

Table A-3

Fermentation Exhaust Flow Data and Emissions Factors Used For Cost Estimates

Wine Type	Max. Exhaust Flow Rate acfm / 1000 gallons capacity*	Max. Exhaust Composition (%) Mole Percent**	% Tank Capacity Filled	Ave. lb ethanol /1000 gallons wine+	Ave. lb ethanol /1000 gallons capacity
White	1.54	Ethanol, 0.64% Water, 1.57% CO_2, 97.79% @ 57 degrees F	80	2.04	1.63
Red	6.06	Ethanol, 1.79% Water, 3.7% CO_2, 94.51% @ 85 degrees F	75	5.96	4.47

* Flow rate for white wine ARB/ML-88-027, op. cit., pg. 57. Flow rate for red wine EAL Corporation, op. cit., pg. 25.

** Composition data based on limited available data from ARB SCM TSD, op. cit., pg. A-4. At near maximum flow rate (representing 99 percent of the white wine emissions and 98 percent of the red wine emissions).

+ Average emissions from winery fermentation source tests, refer to Table 1.

Table A-4

Peak Observed Winery Exhaust Flow Rates
Used for Design of Ducting and Control Systems

Peak Flow Rate White Wine (acfm) [5]

No. of Tanks	Tank Capacity, 1000 gal. 50	100	300	600
5	385	770	2310	4620
10	770	1540	4620	9240
15	1155	2310	6930	13860

Peak Flow Rate Red Wine (acfm) [6]

No. of Tanks	Tank Capacity, 1000 gal. 50	100	300
5	1515	3030	9090
10	3030	6060	18180

[5] Based on; 1.54 acfm/1000 gal capacity, 80% capacity, ARB/ML 88-027, op. cit., pg. 57.

[6] Based on; 6.06 acfm/1000 gal capacity, 75% capacity, EAL Corporation, op. cit., pg. 25.

2. Tank Farm Scenarios

Various tank farm layouts were developed for red and white wine. Tank sizes in the layouts ranged from 50,000 (50K) to 600K gallons and tank farm sizes ranged from 5 to 15 tanks. Tanks were assumed to be 10 feet apart. The tank ducting for the exhaust controls extended to a height of 4 feet above the tank and dropped to a low of 10 feet above the ground to connect with the main duct routed to the control device. Tank dimensions and duct length are summarized in Table A-5. Tank farm layouts are shown in Figure A-1 and Figure A-2.

It should be noted that the simplified layout may not be representative of all wineries. Due to differences between wineries, it is not possible to make detailed estimates for particular wineries. In reality, some tanks may be closer together and others farther apart. The layouts are intended to develop a representative potential cost for piping configurations.

It was assumed that Aisle 1 was filled with overhead piping. Therefore the exhaust duct work was placed in Aisle 2. The scenarios represent typical tank farm clusters found in large wineries. The red wine scenarios consist of tank farms of 5 and 10 tanks of 50K, 100K and 300K gallon tanks. The white wine scenario consist of tank farms of 5, 10 and 15 tanks of 50K, 100K, 300k and 600K gallon tanks. The white wine scenarios were of a larger scale than the red wine scenarios because white wine production volume is much higher than red wine production and because white wine can be produced more cost-effectively in larger tanks than red wine. Duct work and control equipment were sized on the assumption that all tanks are fermenting at 75% capacity for red wine and 80 % capacity for white wine and that all tanks reach their maximum potential emissions at the same time.

A. Excess Tank Capacity (Working Tank Capacity)

During development of the ARB SCM, wine industry representatives met with the ARB on April 22, 1986 and pointed out that wineries needed to maintain excess tank capacity for moving the must or juice around during fermentation. Industry representatives stated that wineries normally maintain 35% excess tank capacity. The ARB staff recognized this need for excess tank capacity and added 50%[7] more tank space to each tank farm.

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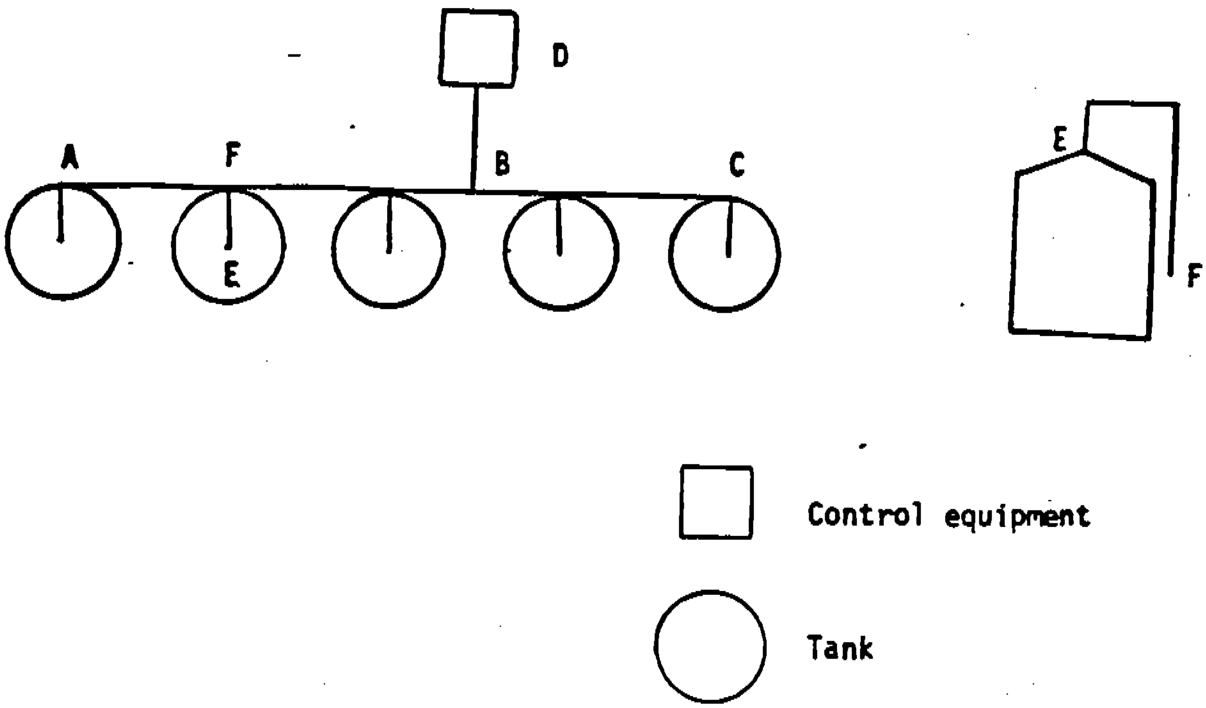
[7] $\frac{\text{Excess tank capacity}}{\text{Fermentation capacity}} = \frac{0.35}{0.75} = 0.5$

Table A-5

Tank Dimensions and Duct Length

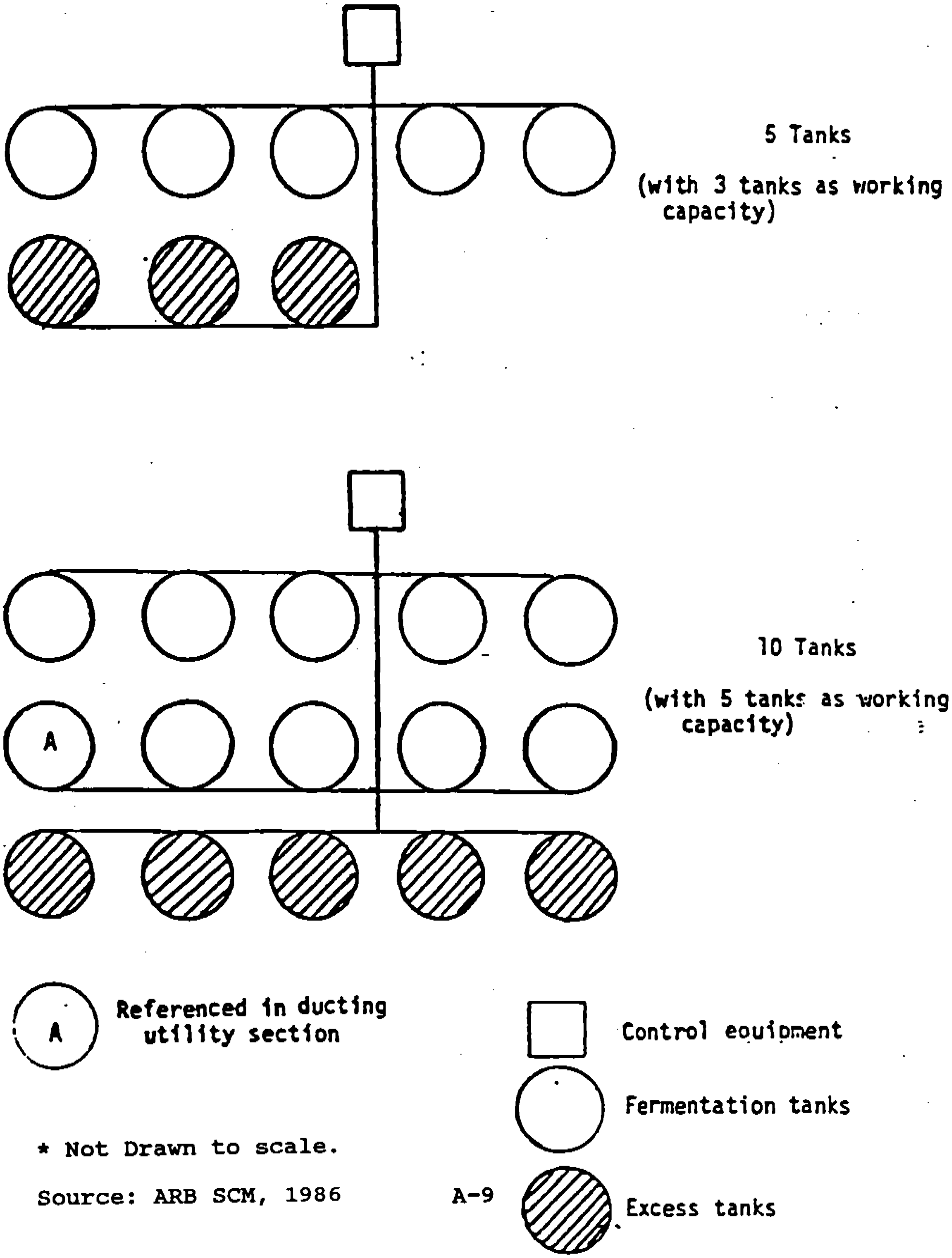
Tank Size 1000 gal.	Diameter ft.	Height ft.	Distance ft.			
			A-B	B-C	B-D	E-F
50	21	20	77.5	46.5	20	29
100	21	40	77.5	46.5	20	49
300	35	45	112	68	20	61
600	52	45	155	94	20	69



Source: ARB SCM, 1986

Figure A-1

Tank Farm Layouts

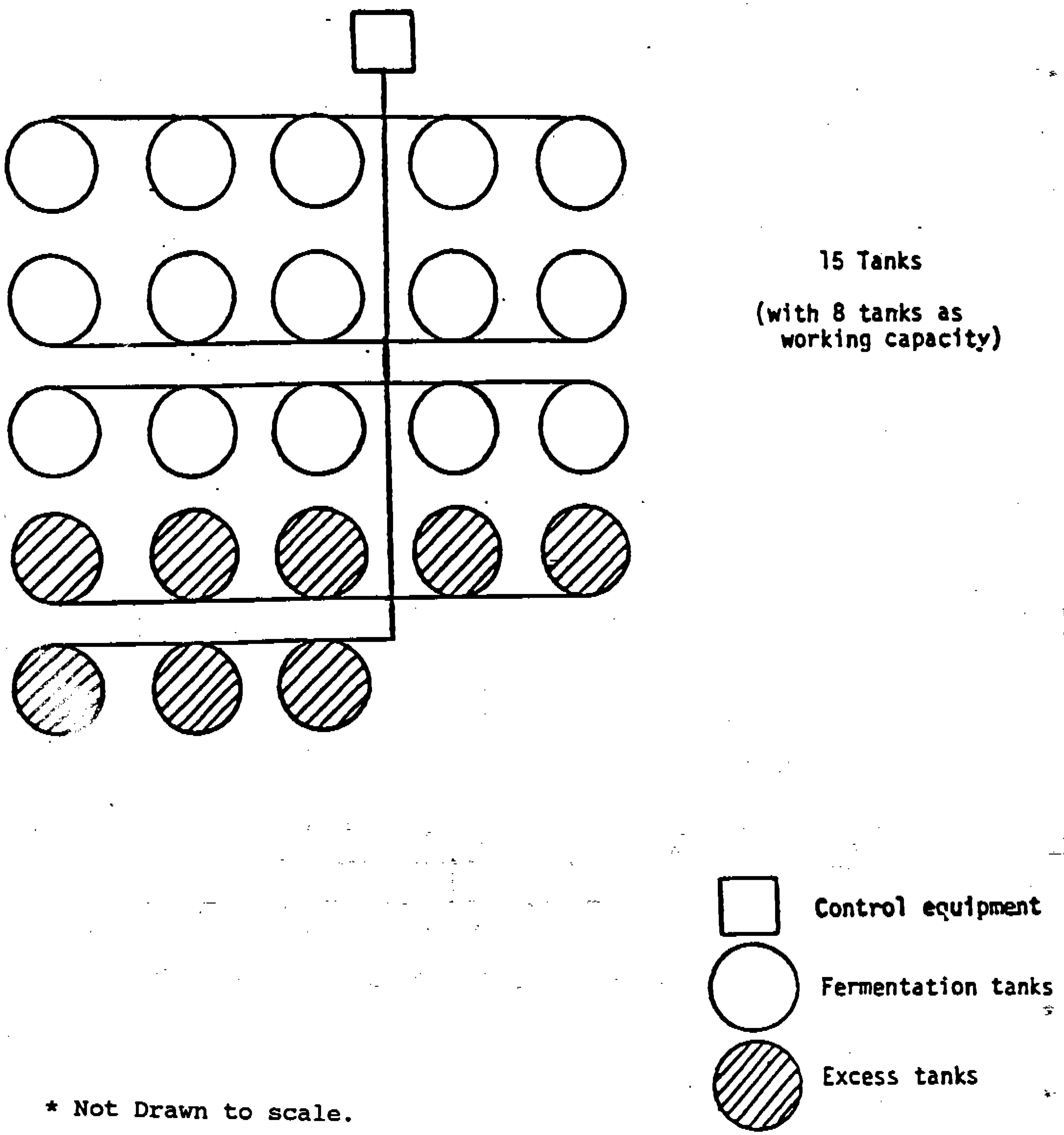


* Not Drawn to scale.

Source: ARB SCM, 1986

Figure A-2

Tank Farm Layouts



* Not Drawn to scale.

Source: ARB SCM, 1986

Because each of the added tanks may be used for fermentation at some time, they need to be ducted into the control system. The additional ducting means that the cost of ducting increased by approximately 50 percent. Therefore, ARB ICC estimates for ducting were multiplied by 1.5. The fermentation capacity of the tank farm does not increase as a result of the excess tank capacity. Therefore, emission reductions continue to be based on fermentation capacity.

The capacity of the exhaust control equipment was based on the working capacity of the fermentation tanks (ie., did not include excess capacity).

3. Ducting

A ducting system was designed for the exhaust type controls- incineration, carbon adsorption, scrubbing and condensation- based on the tank farm scenarios. The duct system utilizes a vapor collection hood on each tank and manifolds the exhaust from a cluster of tanks through a foam separator and blower to a control device. The operation design is based on a constant near maximum flow rate maintained by the system blower. A simplified process flow diagram for the ducting system is shown in Figure A-3.

A vapor collection hood "china cap" design was developed during the 1990 Gallo demonstration project a photograph of the hood is shown in Figure A-4. The hood consists of a raised vent cap with an annular space that allows dilution air to be drawn into the system. Dilution air prevents imposing pressure or vacuum on the tank while maintaining a constant flow rate at the anticipated peak maximum fermentation exhaust rate. The hood was made moveable to provide ease of cleaning and sanitizing. A removable deflector cap was provided in the tank nozzle to prevent condensation droplets from entering the tank ant to deflect foam formations from the exhaust ducting.[8]

The calculation of the ICCs for the ducting system is based on the tank farm scenarios discussed in Section 2. The ICCs for the ducting system are based on the 1986 ARB SCM cost estimate and adjusted for increased design flow rate and the 1991 Chemical Engineering cost index [9].

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[8] Akton, Associates, op. cit., pg. 6.

[9] Chemical Engineering, February 1993.

Figure A-3

Simplified Process Flow Diagram of Ducting System

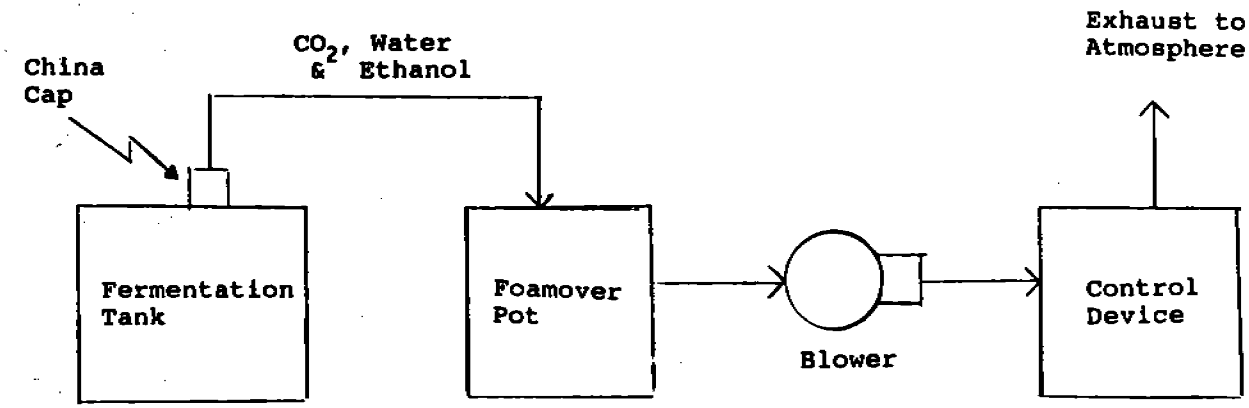
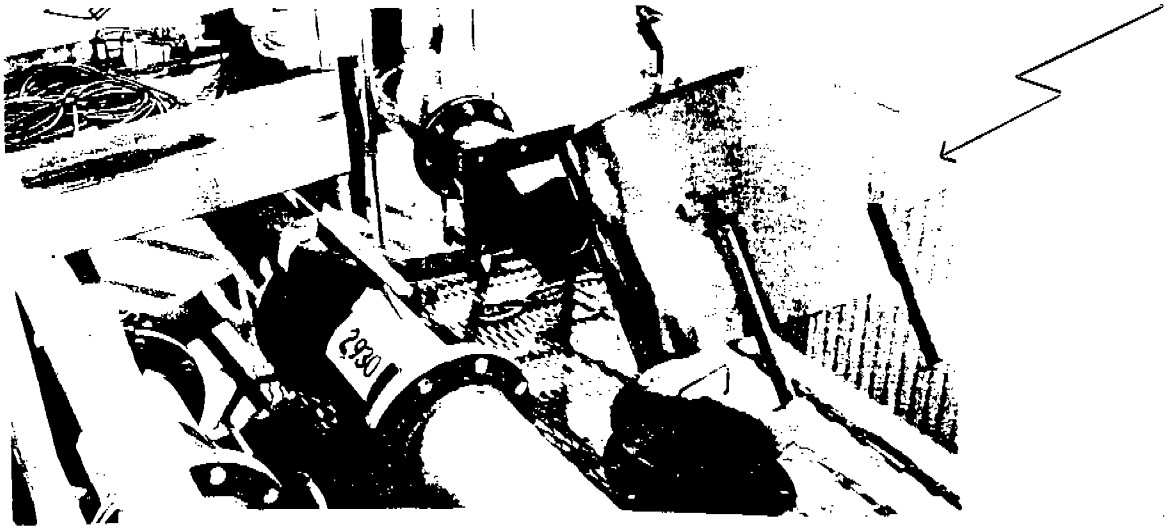


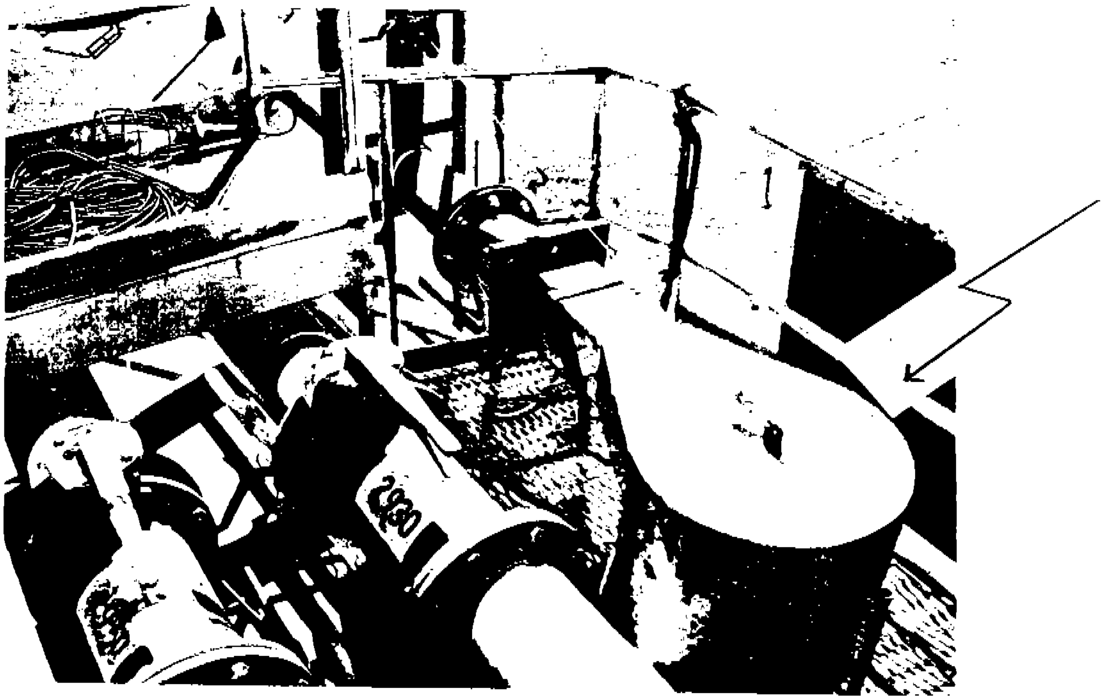
Figure A-4

Exhaust Vent Hood on

Winery Fermentation Tanks



Vent Hood in Partitally Raised Position



Vent Hood in Down Position

Appendix C, contains the ARB SCM ducting cost estimate methodology. The ARB cost estimate methodology and the calculation methodology used to adjust the ARB estimate is presented in the following Section 3.A.

As previously mentioned on page A-11, the estimate of the ARB ICCs for the ducting system were multiplied by 1.5 to cover the additional cost of ducting the extra working capacity tanks to the exhaust control equipment.

A. Installed Capital Costs

In determining installed capital costs the following were considered:

- duct size
- duct material cost
- installation costs
- cost of supports, foam separator, and clean in place system
- blower size and costs

The determination of each of these items is discussed in this section.

1) Duct Size and Flow rates

Duct size is based on the maximum peak exhaust flow rates observed during fermentation source testing. Table A-6 summarizes observed peak gas production rates from fermentation source testing studies. The maximum peak flow rate observed during these studies was selected as the design basis to obtain maximum exhaust gas collection efficiency for the ducting system throughout the fermentation season. The design gas rates for red and white wine are 6.06 and 1.54 acfm / per 1000 gallon capacity (equivalent to 8.08 and 1.92 acfm/ 1000 gallon juice fermented), respectively. The observed peak gas rates were measured in all cases, except the 1991 Gallo Demonstration project. The Gallo gas rates were calculated based on the maximum rate of change of ethanol concentration and stoichiometric calculations.

The design gas flow rates were then scaled to the tank capacities specified for each tank scenario. The flow rates for both white and red wine fermentation are summarized in Table A-4.

Table A-6

Peak Gas Flow Rates

Observed during Source Testing

Report Date	Source of Emissions	Ferment'n Temp. (F)	Initial Brix (%)	Peak Gas Rate (acfm)	Amount of Wine (gal)	Gas Rate (acfm 1000 gal cap.)(d)
1982	EAL, UV Madera, White Wine (a)	57	23	242.2	280000	0.69
1982	EAL, Mondavi Oakville, White Wine (a)	63	23.5	N/A	5800	N/A
1982	EAL, UV Madera, Red Wine (a)	85	23	270	44000	4.60
1982	EAL, UV Oakville, Red Wine (a)	72	22.4	65.5	8100	6.06
1988	ARB/ML-88-027,White Wine I (b)	58.5	20.1	1.18	1086	0.87
1988	ARB/ML-88-027,White Wine II (b)	57	22.3	2.08	1083	1.54
1988	ARB/ML-88-027,Red Wine I (b)	77.5	24	2.9	736	2.96
1988	ARB/ML-88-027,Red Wine II (b)	78.75	25.2	2.95	701	3.16
1991	Akton, Gallo, White Wine, Run 1 (c)	59	20	257.42	172000	1.20
1991	Akton, Gallo, White Wine, Run 2 (c)	56	20	318.75	170000	1.50
1991	Akton, Gallo, Red Wine, Run 3 (c)	72	23.2	1208	164000	5.52
1991	Akton, Gallo, Red Wine, Run 4 (c)	74	23	944.02	164000	4.32
1991	Akton, Gallo, Red Wine, Run 5 (c)	73	23	887.38	164000	4.05
1991	Akton, Gallo, Red Wine, Run 6 (c)	73	22.8	828.9	160000	3.88
1991	Akton, Gallo, Red Wine, Run 7 (c)	74	22.6	515.76	160000	2.42
1991	Akton, Gallo, White Wine, Run 8 (c)	57	21.6	274	170000	1.29
AVERAGE RED WINE						4.1
AVERAGE WHITE WINE						1.2

(a) EAL Corporation, op. cit., pg. 12.
(b) ARB/ML-88-027, op. cit., pg. 21-57
(c) Akton Associates, op. cit., field data, ACFM calculated based on peak ethanol formation rate
(d) Assumes 80 % capacity for white wine and 75% for red wine

Based on the flow rates in Table A-4, the ducting was sized for a stream velocity of 3000 fpm, consistent with ARB assumptions. This velocity is within the "Rule of Thumb" economic velocity range[10]. Note this velocity may appear to be higher than typical industrial ventilation rates, however, this velocity was selected to minimize the size of the ducting and the associated capital cost. In contrast, this will increase the utility cost for operation of the duct blower, but due to the short fermentation period utility costs do not impact the cost effectiveness as significantly as ducting capital costs. The actual sizing of ducting will depend on both economic and noise considerations. Calculated duct diameters for the tank scenarios are shown in Table A-7. To keep the pressure drop low, all calculated on were rounded up and 4 inch ducting was used for all calculated diameters less than 4 inches.

A sample calculation to determine duct size is illustrated using the white wine 10-100K gallon tanks scenario. Using the formula below, the flow rates from Table A-4, were substituted into Q to solve for d for the different duct branches.

$$d= ((Q*144*4)/(3000*pi))^{1/2}$$

where d = duct diameter, inches
Q = volumetric flow rate, acfm
pi= 3.1416

For "A" pipes Q= 154 acfm (770/5=154), d=3
Use minimum pipe diameter of 4 inches
For "B" pipes Q= 462 acfm (154*3=462), d=5.3
Use pipe diameter of 6 inches
For "C" pipes Q= 1540, d=9.7
Use pipe diameter of 10 inches
For "D" pipes Q= 770, d=6.8
Use pipe diameter of 8 inches

2) Adjustment for Design Flow Rates and 1991 Cost

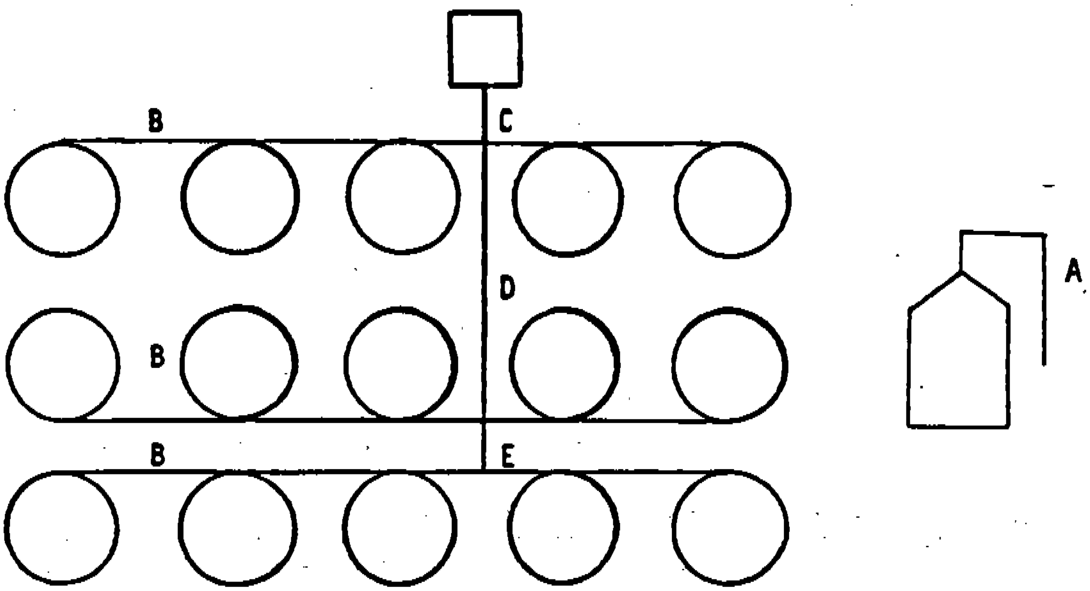
Installed capital costs were taken from the ARB SCM and adjusted to account for the increase in ducting design flow rate and current market cost of goods and services. Detailed cost calculations performed by the ARB are presented in Appendix C.

[10] M. Peters and K. Timmerhaus, op. cit., p.434.

Table A-7

Duct Diameters

Wine Type	Tank Farm Size	Duct Diameter - Inches A	B	C	D	E
White	5-50K	4	4	6	N/A	N/A
	10-50K	4	4	8	6	N/A
	15-50K	4	4	8	8	6
	5-100K	4	6	8	N/A	N/A
	10-100K	4	6	10	8	N/A
	15-100K	4	6	12	10	8
	5-300K	6	10	12	N/A	N/A
	10-300K	6	10	17	12	N/A
	15-300K	6	10	21	17	12
Red	5-50K	6	8	10	N/A	N/A
	10-50K	6	8	14	10	N/A
	5-100K	6	12	14	N/A	N/A
	10-100K	6	12	20	14	N/A
	5-300K	12	18	24	N/A	N/A
	10-300K	12	18	34	24	N/A



4-inch diameter was the minimum size used even though some flow rates were low enough to permit a smaller duct size.

Source: ARB SCM, 1986

In summary, the ARB estimated the size of the ducting for each tank scenario and used material cost based on price quotations from the Felker Brothers Corporation, Marshfield Wisconsin, for stainless steel 304L piping, elbows and tees. Installation costs were determined using Peters and Timmerhaus installation hours for straight piping elbows and tees and assuming a labor cost of 40 dollars per hour. Crane costs were added to the installation costs. Material costs for duct supports was based on 3 inch steel piping. This piping is capable of supporting a load which exceeds the anticipated weight of a 30 inch duct filled with water. Installation and painting of the supports are included in the fixed capital cost.

The ARB ICC cost estimate includes the cost for straight piping, elbows and tees, however it may be necessary for wineries to obtain custom made fittings and cross-connections. The ARB assumed a conservative contingency of 15 % to allow for additional costs which may be incurred.

Costs for a foam separator were scaled from the cost estimate done by Bob Calvin, an engineer for Heublein Wines, for a foam separator in a ducting system for carbon adsorption.[11] Costs for a ducting clean-in-place system were scaled by ducting footage from a price quotation given by Bob Calvin. Blower costs were based on a 3 psi turbo blower which should have adequate power to overcome pressure drop losses across the ducting and control equipment. The resulting installed capital cost estimated by ARB in 1986 is shown in Appendix C.

The ARB ICC cost was revised to reflect the increased design flow rate based on peak observed gas flow rates from source testing. This adjustment for capacity was achieved using the "six-tenths-factor rule". According to this rule, if the cost of given equipment is known, the cost of similar equipment with X times the capacity of the first is approximately $(X)^{.6}$ times the cost of the initial equipment[12].

$$\text{cost a} = \text{cost b} * (\text{capacity a}/\text{capacity b})^{0.6}$$

[11] ARB SCM, op. cit., pg. A-28.

[12] M. Peters, K. Timmerhaus, op. cit., pg. 107.

The application of the 0.6 rule is an oversimplification, however it can be used to estimate cost for equipment with similar materials of construction and temperature and pressure operating ranges.

After adjusting for the revised flowrate, the ICC was inflated from 1985 dollars to 1991 dollars using the Chemical Engineering Cost Index (CI). The following formula was used:

cost of equip 1991= (CI-1991$/CI-1985$) cost of equip 1985
where (CI-1991$/CI-1986$) = 361.3/324.8

The ICC adjusted for increased capacity and inflated 1991 dollars is shown in Table A-8.

B. Fixed Capital Cost

The following items are added to the ICC's to obtain the FCC's.

Installation and Painting of Supports	5% FCC
Electrical and Service Facilities	15% FCC
Engineering and Supervision	10% FCC
Construction Expense	7% FCC
Contractor's Fee	3% FCC
Startup Expenses	10% FCC
Contingency	15% FCC
Total	65% FCC

FCC's are calculated as follows:

FCC = ICC + 0.65 FCC

Solving for FCC

FCC = 2.86 ICC

FCC's are summarized in Table A-8.

Table A-8

Installed and Fixed Capitol Cost

and Utility Cost for Exhaust Ducting

(Based on 1991 Cost Estimates)

Wine Type	Tank Scenario	Installed Capital Cost ($)	Fixed Capital Cost ($)	Annual Utility Cost* ($)
White	5-50K	$74,311	$212,530	$47
	10-50K	$161,960	$463,205	$94
	15-50K	$201,974	$577,644	$140
	5-100K	$122,137	$349,311	$94
	10-100K	$223,124	$638,133	$187
	15-100K	$317,822	$908,972	$281
	5-300K	$211,119	$603,802	$281
	10-300K	$360,504	$1,031,041	$561
	15-300K	$476,162	$1,361,824	$842
	5-600K	$359,932	$1,029,406	$561
	10-600K	$609,007	$1,741,761	$1,122
	15-600K	$809,228	$2,314,392	$1,684
Red	5-50K	$174,555	$499,227	$153
	10-50K	$278,501	$796,512	$307
	5-100K	$226,659	$648,245	$307
	10-100K	$363,416	$1,039,369	$613
	5-300K	$422,869	$1,209,407	$920
	10-300K	$653,860	$1,870,039	$1,840

* Based on 36 days/year for white wine and 30 days/year for red wine

C. Annual Utility Cost

The annual utility costs consist of operating the system blower. The first step in calculating costs is to estimate pressure drops in the lines. The pressure drops for the large tank farms (15 tanks for white wine and 10 tanks for red wine) were estimated to ensure that the cost estimate would be conservative. An example calculation is shown below:

Red Wine 10-100K gallon tanks

Figure A-1 shows that Tank A experiences the highest pressure drop due to line losses. Therefore the blower must be able to handle the energy loss from Tank A. The pressure drop was estimated from the following formula:

$$v = Q_o * 144 * 4/(d^2 * pi)$$

$$p = 3.59*10^{-7} * f * L * \rho * v^2 /d$$ [13]

where
- d = diameter, inches
- v = velocity of gas, ft/min
- Q_o = volumetric flow rate, acfm
- pi = 3.1416
- p = pressure drop,psi
- f = friction factor, approx. 0.015
- L = pipe length, 100 ft
- ρ = Density, approx. 0.115 lb/ft^3

For simplification inserting the values above,

$3.59*10^{-7} * f * L * \rho = 6.193*10-8$

Thus $p = 6.193*10^{-8} * v^2 / d$

Starting with the duct work leaving the tank:

6 inch pipe, length 49 ft

$Q_o = 3030/5 = 606$ acfm

$v = 606 * 144 * 4/(6^2 *pi) = 3086.3$ ft/min

$p = 6.193*10^{-8} * 3086.3^2 / 6 = 0.098$ psi/100 ft

$\Delta p= 0.098 * 0.49 = 0.048$ psi

[13] Flow of Fluids Through Valves, Fittings and Pipe, Crane, Technical Paper No. 410, 1979, pg. 3-2.

12 inch pipe, length 77.5 ft

Q_o = 3030 *.6 = 1818 acfm (The flow rate 1818 is actually experienced downstream of the three tanks in row 2)

$v = 1818 * 144 * 4/(12^2 * pi) = 3333$ ft/min

$p = 6.193*10^{-8} * 3333^2 / 12 = 0.057$ psi/100 ft

$\Delta p = 0.057 * 0.775 = 0.044$ psi

14 inch pipe, length 52 ft

Q_o = 3030 acfm

$v = 3030 * 144 * 4/(14^2 * pi) = 2834$ ft/min

$p = 6.193*10^{-8} * 2834^2 / 14 = 0.035$ psi/100 ft

$\Delta p = 0.035 * 0.52 = 0.018$ psi

20 inch pipe, length 20 ft

Q_o = 6060 acfm

$v = 6060 * 144 * 4/(20^2 * pi) = 2777.7$ ft/min

$p = 6.193*10^{-8} * 2777^2 / 20 = 0.024$ psi/100 ft

$\Delta p = 0.024 * 0.2 = 0.0047$ psi

Total Δp = 0.048+0.044+0.018+0.0047 = 0.1147

The above calculated Δp was the maximum value for the tank scenarios. Since losses from the bends and merging streams were not considered, the blower load was based on 0.2 psi to cover these losses. Blower horsepower needs were approximated using the fan horsepower formula:[14]

Hp = 0.000157 * Q * P/ eff

where Hp = horsepower, hp

Q = volumetric flow rate, acfm

P = differential pressure, inches of water

eff= efficiency of the blower, 0.6

For the white wine 10-1000K gallon tanks,

Q = 1540 acfm

P = 5.54 inches (0.2 psi)

Hp = 0.000157*1540*5.54/.6 = 2.23 hp

[14] Perry and Chilton, op. cit., pg. 6-16.

The annual utility cost is calculated based on horsepower and electricity[15] cost, as follows:

Cost = Hp * 0.746 kw/hp * 24 *days/yr * 0.13 $/kw

Cost = 2.23 hp * 0.746 kw/hp * 24 * 36 days/yr
* 0.13 $/kw
= $187/yr

Table A-8 shows the estimated horsepower and utility cost for the tank scenarios. Utility costs are based on the length o the season. As indicated in Table A-2, the season length for white wine is 36 days/yr and 30 days/yr for red wine.

4. Carbon Adsorption

A. Installed Capital Costs

The capital costs are estimated from the following information supplied by VIC Manufacturing[16]:

Exhaust Flow Rate acfm	Uninstalled 1991 Capital Cost $
400	100,000
1000	130,000
3000	160,000
5000	180,000
16000	285,000

The costs include the initial charge of carbon, carbon housing, blower and regeneration system. The flow rates used to determine uninstalled costs are shown in Table A-4. Figure A-5 shows a simplified process flow diagram of the carbon adsorption system configuration.

Installation is estimated to be 75% of capital cost[17]. Installed capital costs are presented in Table A-9.

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[15] Personal Communication with Heidi DeSalvo, Gallo Winery, peak electricity cost, $0.13/kW.

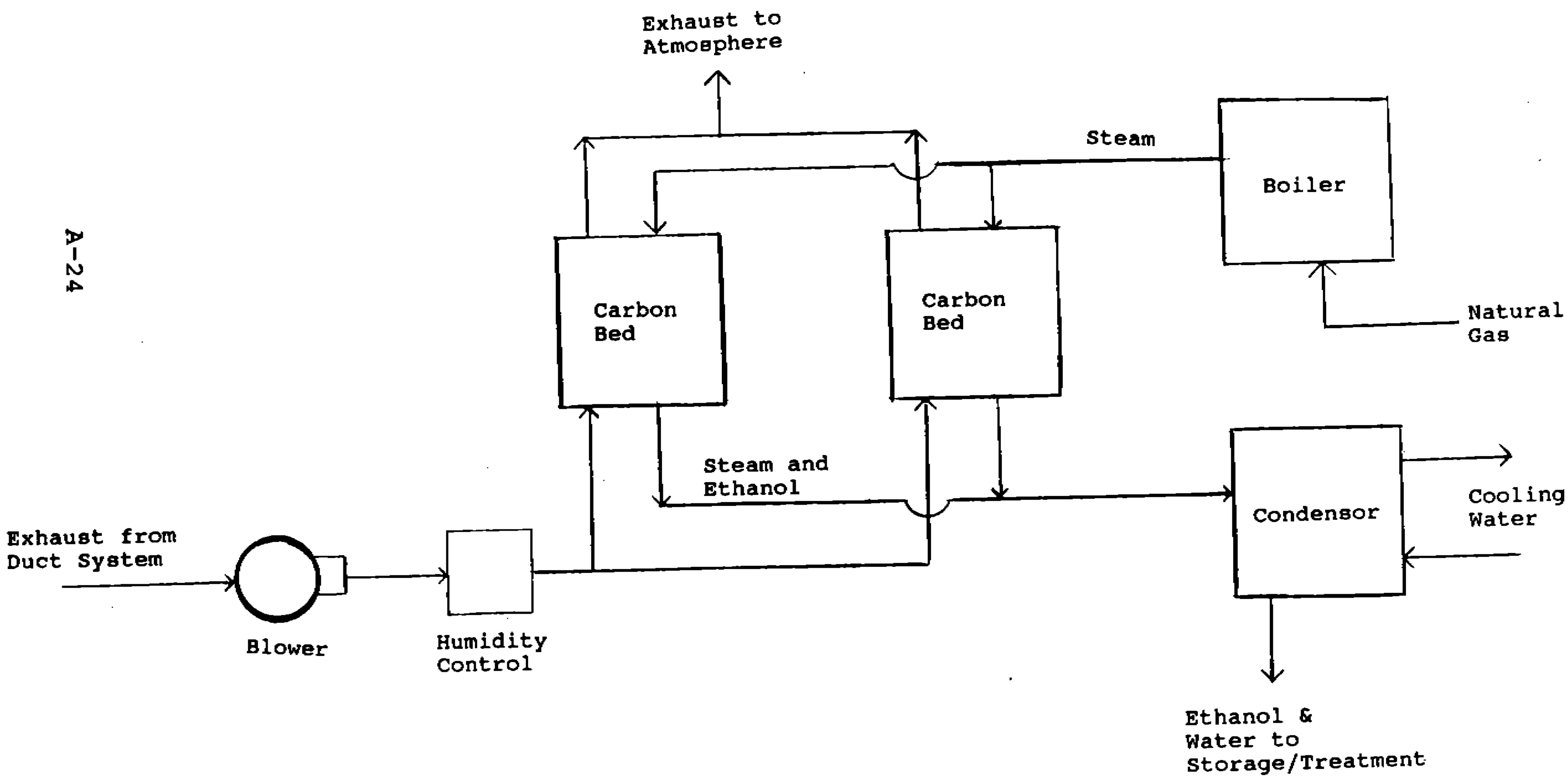
[16] Personal Communication with Tom Cannon, Vic Environmental Systems.

[17] Personnel Communication with Jack Preston, Pullman Ind. 714-973-1533

Figure A-5

Simplified Process Flow Diagram

of Carbon Adsorption System



B. Fixed Capital Costs (FCC'S)

The installation cost of 75% of the capital cost quoted by the Pullman Ind. includes the following FCC items:

1. Installation of control equipment
2. Electrical installation
3. Engineering estimates
4. Site preparation
5. Contractor's fee
6. Installation of a cooling tower
7. Contingency

The installation cost includes all the FCC items listed in Table A-9. Therefore, the ICC is equal to the FCC for all control scenarios utilizing carbon adsorption. The FCC's are summarized in Table A-9.

C. Annual Utility Cost

Annual utility cost are estimated based on the following conditions.

White Wine: 6,400 ppm ethanol in CO_2
Red Wine: 17,900 ppm ethanol in CO_2

Both the ethanol volume and mass flow rates can be calculated from the design conditions. All of the following calculations will be demonstrated with the white wine parameters. The ethanol volume and mass flow rates are calculated as follows:

volumetric 1000 acfm * 0.0064% volume
= 6.4 acfm ethanol

mass 6.4 acfm * 1 mole/359 ft^3 * 60 min/hr
46 lbs/mole * 492/ (460 + 57)
= 46.8 lb/hr ethanol

The remaining calculations are all based on the ethanol mass flow rate[18].

1) Carbon Requirements

For continuous operation, two carbon beds are required. The beds cycle between an adsorption mode and regeneration mode. The carbon beds saturation capacity is 18% of their weight in ethanol. One third of the total saturation

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[18] Calculation methodologies for carbon, steam, boiler and blower requirements are from the ARB SCM., op. cit., pg. A-49 through 51.

capacity of each bed will consist of the "heel" of residual ethanol which will remain on the bed after regeneration. Therefore, the working capacity is 18 % reduced by one third.[19]

Size of one carbon bed, based on an example flow rate of 1000 acfm:

lbs/1000 acfm = 46.8 lbs/(.18 *.33) 1000 acfm = 788 lbs/1000 acfm

The carbon bed sizes are scaled according to the tank farm scenario flow rates.

Carbon requirements for 5 tanks - 100K gallons each:

788 lbs/1000 acfm * 770 acfm = 607 lbs/bed

and the amount of ethanol captured is:

770 acfm * 46.8 lb/hr /1000 acfm = 36.04 lbs ethanol

For two beds the total carbon required is 1214 lbs.

2) Steam Requirements

Steam is used to regenerate the bed. The ratio of steam to carbon is 0.35:1. Therefore, for 607 lbs of carbon, the steam required is:

212.44 lbs/hr = 607 * 0.35

3) Boiler Requirements

Boiler requirements in boiler hp are calculated by the following relationship:[20]

Boiler hp = lbs of steam * 1 boiler hp/34.5 lbs steam*1.6

The factor 1.6 represents the additional heating required to heat water from ambient to 212 ° F under low pressure and to account for heat losses to the environment. The boiler requirements for 212.44 lbs of steam per hour:

Boiler hp = 212.44 lbs/hr * 1hp/34.5 lb * 1.6
= 9.85 boiler hp

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[19] ARB SCM, op. cit., pg. A-45.

[20] ARB SCM, op. cit., pg. A-50.

To convert to Btu/hr multiply by 33475 Btu/hr. Thus, $3.30 * 10^5$ btu/hr of natural gas is required.

For one season of operation, the cost of natural gas[21] is as follows:

$$\$/yr = 3.30*10^5 \text{ Btu/hr} * 24\text{hr/day} * 36 \text{ day/yr} * \$6.9 \text{ MMbtu/hr} = \$1966/yr$$

4) Blower Requirements

For simplification the following equation for air[22] was used:

$$Hp = 0.0154 * Q_1 * P_1 * [(P_2/P_1)^{(K-1)/K} - 1]$$

where
Q_1 = volumetric flow rate, acfm
P_1 = pressure in, psia
P_2 = pressure out, psia

The carbon bed has a pressure drop of 30 inches of water. Thus, P_1 = 14.696 psia and P_2 = 15.779. Since K_{air} = 1.395, (K-1)/K = 0.283

Substituting these values into the hp equation:

$$Hp = 0.0154 * 770 \text{ acfm} * 14.696 * [(15.779/14.696)^{0.283} - 1] = 3.54 \text{ hp}$$

Assuming 60 % efficiency, the hp required is 3.54 hp/ 0.6 = 5.9 hp and the cost of electricity is:

$$\$/yr = 5.9 \text{ hp} * 24\text{hr/day} * 36 \text{ day/yr} * 0.13 \$/\text{kwh} * 0.746 \text{ kw/hp} = \$495/yr$$

5) Condenser Requirements

To condense 212.4 lbs of steam and 36.04 lbs of ethanol per hour from 212° F to 90°F, the cooling requirements are based on the following formulas.

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[21] Personal Communication, Pacific Gas and Electric, Fresno, Gas Rate $0.69/therm.

[22] Perry and Chilton, op. cit., pg. 6-16.

For conversion of saturated steam to saturated water:

$btu/hr = m_{H2O} * (H_{s\,212} - H_{w90})$

where

mH2O = mass water

$H_{s\,212}$ = enthalpy of saturated steam at 212°F

H_{w90} = enthalpy of saturated water at 90°F

Therefore

= 212.37 lb/hr * (1150Btu/lb - 58 Btu/lb)

= 231,908 btu/hr

For conversion of ethanol vapor to liquid ethanol:

$btu/hr = m_e * [H_{ve} + C_{pe}\ (212-90)]$

where

m_e = mass of ethanol

H_{ve} = enthalpy of vaporization for ethanol

C_{pe} = heat capacity of ethanol

Therefore

= 36.04lb/hr * [362 btu/lb + 0.58 Btu/lb°F * (212-90)

= 15,595 btu/hr

Total cooling requirements:

231,908 + 15,595 = 247,503 Btu/hr

It is anticipated a winery would probably buy a cooling tower to supply cooling water. However, for simplification in this analysis, cooling water at a temperature of 70°F is assumed to be purchased.

Cooling water flow rate:

$Q = \Delta H / C_{pH2O} * 1/\Delta T * 1/\rho$

where

H_{ve} = total change in enthalpy

C_{pH2O} = heat capacity of water

ΔT = change in temperature

ρ = density of water

= 247,503 Btu/hr / 1 btu/lb°F * 1/20°F * 1/8.33lb/gal

= 1486 gal/hr

For one year of operation, based on water rates for the City of Stockton:

1486 gal/hr * 24 hrs/day * 36 day/yr * $.35/748 gal

= $600/yr

6) Carbon Replacement

The manufacturer suggested replacement every 5-7 years for continuous operation. Since the unit will be operated a maximum of 36 days per year, the carbon bed should last 10 years. The replacement cost is $2/lb of carbon, based on costs from Vic Manufacturing. For two 607 lb beds the replacement cost is $2428/10 yrs = $243/year.

7) Summary

The annual utility cost is the sum of the operating costs for operating the boiler, blower, condenser and the annual cost for carbon replacement. The total utility cost for 5-100K gallon tanks is $3,316. Annual utility costs are summarized in Table A-9.

Table A-9

Installed and Fixed Capitol Cost

and Utility Cost for Carbon Adsorption

(Based on 1991 Cost Estimates)

Wine Type	Tank Scenario	Installed/ Fixed Capital Cost ($)	Total Utility Cost * ($/yr)
White	5-50K	$175,000	$1,652
	10-50K	$201,250	$3,303
	15-50K	$227,500	$4,955
	5-100K	$201,250	$3,316
	10-100K	$253,750	$6,607
	15-100K	$271,250	$9,910
	5-300K	$271,250	$9,910
	10-300K	$315,000	$19,820
	15-300K	$332,500	$29,731
	5-600K	$315,000	$19,820
	10-600K	$402,500	$39,641
	15-600K	$437,500	$59,453
Red	5-50K	$253,750	$13,244
	10-50K	$280,000	$26,489
	5-100K	$280,000	$26,489
	10-100K	$332,500	$52,978
	5-300K	$402,500	$79,467
	10-300K	$498,750	$158,933

* Based on 36 days/year for white wine and 30 days/year for red wine

5. Catalytic Incineration

The design of the catalytic incinerator is based on a combustion temperature of 500°F with 15 % excess air. The system consists of a preheater, fan for supplementary fuel combustion air, combustion chamber and catalytic converter. A simplified process flow diagram for the system is shown in Figure A-6. The capital cost is based on the total flow of all the gases passing through the converter during start-up, which is worst case. The utility rate is based upon fuel consumption at steady-state conditions. All equations for determining heat loads and temperature rise were obtained from Pillar Corporation[23].

A. Installed Capital Costs (ICCs)

The design concentrations are the maximum concentrations:

White Wine: 6,400 ppm ethanol in CO_2
Red Wine: 17,900 ppm ethanol in CO_2

With the assumption that the fermentation exhaust gas does not contain air the design should be very conservative. The exhaust gas would probably contain an average of 30 to 50 percent air because not all the tanks will be at maximum fermentation at the same time. The design capacity of the furnace is therefore greater than required.

Combustion requires at least ten percent oxygen present. To ensure combustion, the design is based on 15 percent.

For white wine, using a basis of 13860 acfm [24] exhaust gas (15-600K gallon tanks) from Table A-4, one can determine the quantity of air required, indicated as the variable y, to satisfy 15% oxygen (O_2):

$$\frac{0.15 \text{ acfm } O_2}{\text{acfm total}} = \frac{(0.2\% \ O_2)*(y \text{ acfm air})}{(y \text{ acfm air} + 13860 \text{ acfm fermentation exhaust})}$$

y = 41,580 acfm air

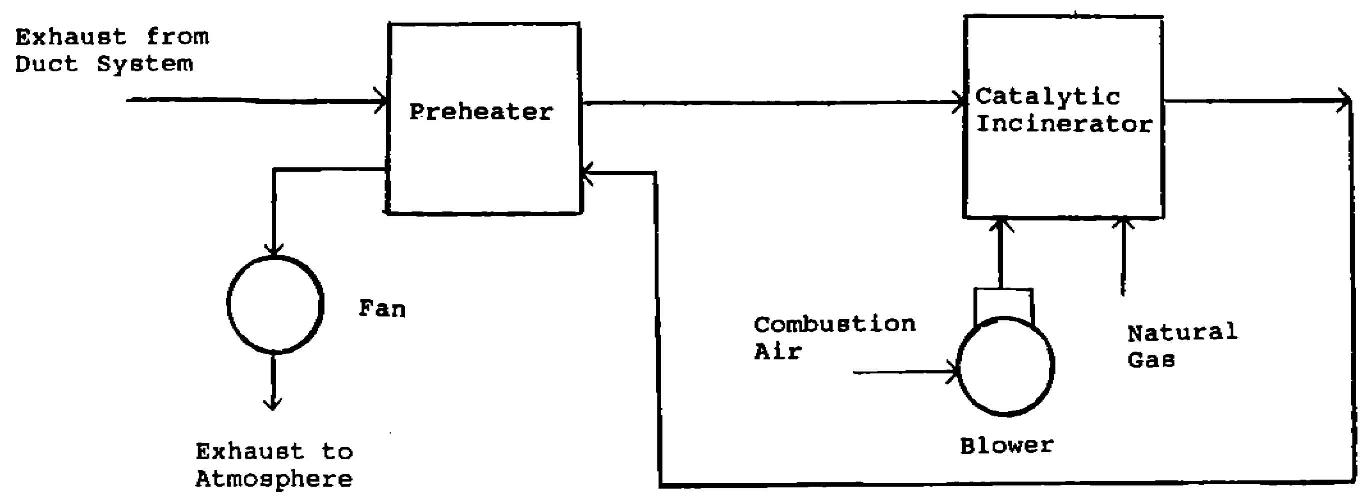
[23] Personal Communication, Rob Hablewitz, Pillar Corporation., 414-367-3060.

[24] Assumed the temperature is 70 °F which is chosen to be standard temperature for incineration. Thus acfm would equal scfm.

Figure A-6

Simplified Process Flow Diagram

of Catalytic Incineration System



The incoming stream now has a total of 55,440 acfm (41580 air + 13860 exhaust = 55440) which needs to be heated to 500°F to maintain combustion. For purposes of sizing the incinerator we take the worst case which is start-up. During start-up the heat required (Btu/hr) is:[25]

Btu/hr = 1.08 * (incoming stream, acfm)* (500-70)

= 1.08 * 55440 * (500-70)
= 25.75 MMBtu/hr

The additional volume of air required at 70° F to combust the natural gas is calculated by first determining the moles of natural gas required which is:

moles gas/hr = 25.75 MM Btu/hr/(21,495 Btu/lb * 16 lb/lbmol)
= 74.86 moles/hr

The mole ratio of oxygen to natural gas assuming 15 % excess oxygen is 2.3 (2/1.15). Therefore the moles/hr of oxygen required is 172.2, which corresponds to 860.9 moles air (172.2/.2). Moles of air is converted to volume of air using the ideal gas law, as follows:

acfm = 860.9 moles/hr * 359 ft^3/mole * ((460+70)/492) * 1 hr/60 min
= 5,548.96 acfm

The total flow rate of gas for sizing the incinerator, ignoring the small flow rate for natural gas, is 61,000 acfm (55,500 + 5,600). The design volumes for the remaining white and red wine scenarios were calculated using these equations. Uninstalled costs as a function of design air flow rates were provided by Catalytic Product International.[26]

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[25] Personal Communication, Rob Hablewitz, Pillar Corporation., 414-367-3060.

[26] Personal Communication, Scott Shaver, 708-438-0334.

Uninstalled Capital Costs for Catalytic Incineration

Exhaust Flow Rate (acfm)	Uninstalled Capital Cost 1991 ($)
2000	110,000
3000	125,000
5000	166,000
8000	209,000
10,000	245,000
15,000	315,000
20,000	385,000
30,000	425,000
35,000	470,000
60,000[27]	770,094

The uninstalled costs were scaled based on the design incinerators gas and air volumes. Installation cost is assumed to be 25 percent of the uninstalled cost. The installed capital costs are indicated in Table A-10.

B. Fixed Capital Cost

The ICC's include all of the FCC items, with the exception of costs for electrical installation and contingency. The cost for electrical installation is assumed to be 3 % of the FCC. A contingency of 15 percent of the FCC is also added to cover miscellaneous costs.

The FCC is calculated as follows:

$$FCC = ICC + 0.03\ FCC + 0.15\ FCC$$
$$= 1.22\ ICC$$

FCCs are shown in Table A-10.

C. Annual Utility Costs

The utility costs consist of costs for natural gas for the incinerator, electricity for the fan and blower and catalyst replenishment.

[27] Personal Communication, Scott Shaver, Typically, the maximum size unit is 35,000 acfm.

1) Natural Gas Requirements

The natural gas requirements were determined for steady state operation. In this mode the incoming air and exhaust gas are preheated by the converter exhaust. However, the additional air to combust the natural gas is not preheated. The first step is to determine the temperature rise in the converter from combustion of ethanol:

$t = H_{c,eth} * m / (f_i * 1.08)$
where

$H_{c,eth}$ = Heat of Combustion of ethanol, 11,1954 Btu/hr
m = $f_e * C * 10^{-6}$ * 60 min/hr* 46 lb/lbmole * lbmole/359ft^3 * 492/(460+70)
f_i = incoming volumetric flow rate, acfm
f_e = fermentation exhaust flow rate, acfm
C = ethanol concentration, ppm

For white wine 15-600K gallon tanks, substituting the values m= 632.86 lb/hr, f_i = 55,440 acfm, yields a temperature rise of 126.35°F. Thus the downstream temperature from the converter will be 626.35°F.

The second step is to calculate the temperature of the incoming preheated stream. Assuming the heat exchanger is 60 percent efficiency, this temperature is estimated as follows:

(626.35°-70°) * 0.06 +70° = 403.8°F

Finally, the heat loads of the incoming stream are calculated. The heat load for the preheated stream is:

1.08 * 55,440 acfm * (500-403.8°F) = 5.76 MM Btu/hr

The moles of natural gas required to achieve this heat loads is:

moles/hr = 5.76 MM Btu/hr / 21,495 Btu/lb
* 1/16 lbs/mole
= 16.75 moles/hr

The oxygen requirement using the mole ratio of oxygen to natural gas assuming 15 % excess oxygen is 2.3 (2/1.15). Therefore the moles/hr of oxygen required is 38.52 (16.75*2.3), which corresponds to 192.6 moles air (38.52/.2).

Moles of air is converted to volume of air using the ideal gas law, as follows:

$$acfm = 192.58 \text{ moles/hr} * 359 \text{ ft}^3\text{/mole} * ((460+70)/492) * 1 \text{ hr/60 min} = 1241.21 \text{ acfm}$$

The heat load for this stream is:

$$1.08 * 1241 \text{ acfm} * (500-70°F) = 0.576 \text{ MM Btu/hr}$$

The total heat load for both streams is 6.34 MM Btu/hr, which costs $37,772/yr (6.34 MMbtu/hr*24 hr/day *36 day/yr * $6.9 MMBtu = $37,772/yr).

The annual utility costs for the red wine scenarios is based on the average concentration in the incoming stream because the utility costs will not only be more representative of actual operating conditions, but the requirements will be higher. Thus the design requirements are as follows:

For 10-300K gallon tanks

f_i, = incoming duct volumetric flow rate, 18180 acfm
f_a = incoming air from dampers, 5400 acfm(=0.3*18180)
f_e = fermentation exhaust flow rate, 12780 acfm(=0.7*18180)
C = ethanol concentration, 9000 ppm

The additional air required to achieve 15 percent oxygen is calculated as follows:

$$\frac{0.15 \text{ acfm } O_2}{\text{acfm total}} = \frac{(0.2\% \ O_2)*(y + 5400)\text{acfm air}}{(y \text{ acfm air} + 18180 \text{ acfm fermentation exhaust})}$$

y = 32,735 acfm

Thus the total incoming stream f_i contains 50,905 acfm (18180+32735= 50905 acfm). The remaining calculations are the same as the white wine case.

2) Blower and Fan Requirements

The fan requirements for the incoming streams were calculated as follows, using the fan horsepower formula:[28]

Hp = 0.000157 * V * P/ eff
where Hp = horsepower, hp
V = volumetric flow rate, acfm
P = differential pressure, inches of water
eff= efficiency of the blower, 0.6

For this system, there are two incoming streams. The stream passing through the heat exchanger, combustor, converter and back through the heat exchanger experiences a 14 inch (water) pressure drop while the burner air stream experiences an 8 inch pressure drop. The total horsepower requirements for these two streams can be calculated by expanding the formula to the following form:

$Hp = 0.000157 * (V_1 * 14 \text{ inch} + V_2 * 8 \text{ inch})/0.6$
where
V_1 and V_2 = flow rate of the two streams,acfm

Based on this formula the 15-600K gallon white wine tank farm would require 205.69 hp of electricity (0.000157 * (55440 * 14 + 1241 * 8)/0.6 = 205.69).

The yearly cost is calculated as follows:

Cost = 205.69 hp * 0.746 kw/hp * 24 * 36 days/yr
* 0.13 $/kw
= $17,235/yr

3) Catalyst Requirements

Catalyst requirements were scaled from the following information[29]:

- 28.3 acfm flow rate requires 1 lb of catalyst
- A full year of operation requires a replacement of 3-5 percent of the bed due to attrition
- Catalyst cost $57/lb

[28] Perry and Chilton, op. cit., pg. 6-16.

[29] Personal Communication, Scott Shaver, Catalytic Product Int'l, 708-438-0334

A one percent a year attrition is used for wineries because although the operating time is approximately one month a year, a conservative estimate is desired. The catalyst requirement for the 15-600K gallon tank farm is calculated as follows:

60988 acfm * 1 lb/28.3 acfm * 0.01 =21.55 lbs/yr

The cost is then $1228/yr (21.55 lbs/yr * $57/lb= $1228/yr)

4) Summary

The annual utility cost is the sum of the operating costs for the catalyst heater, combustion air blower and the catalyst cost. For the example of 15-600K gallon white wine the utility cost is $56,235 per year. Annual utility costs are summarized in Table A-10.

Table A-10

Installed and Fixed Capitol Cost

and Utility Cost for Catalytic Incineration

(Based on 1991 Cost Estimates)

Wine Type	Tank Scenario	Installed Capital Cost ($)	Fixed Capital Cost ($)	Total Utility Cost * ($/yr)
White	5-50K	$137,500	$167,750	$1,562
	10-50K	$156,250	$190,625	$3,124
	15-50K	$207,500	$253,150	$4,686
	5-100K	$156,250	$190,625	$3,124
	10-100K	$243,750	$297,375	$6,248
	15-100K	$306,250	$373,625	$9,373
	5-300K	$306,250	$373,625	$9,373
	10-300K	$481,250	$587,125	$18,745
	15-300K	$531,250	$648,125	$28,118
	5-600K	$481,250	$587,125	$18,745
	10-600K	$687,500	$838,750	$37,490
	15-600K	$962,500	$1,174,250	$56,235
Red	5-50K	$243,750	$297,375	$3,412
	10-50K	$393,750	$480,375	$6,825
	5-100K	$393,750	$480,375	$6,825
	10-100K	$531,250	$648,125	$13,650
	5-300K	$687,500	$838,750	$20,475
	10-300K	$1,231,250	$1,502,125	$40,950

* Based on 36 days/year for white wine and 30 days/year for red wine

6. Scrubber

The scrubber design is a packed bed fiberglass absorption tower. A simplified process flow diagram for the scrubber system is shown in Figure A-7. The absorbent water is assumed to be available at municipal pipeline pressure, eliminating the need to purchase a pump. The capital and utility cost methodologies were all supplied by Croll-Reynolds.[30]

A. Installed Capital Costs

The installed capital costs are based on fermentation exhaust flow rates for the tank scenarios in Table A-4. The following uninstalled cost as a function of exhaust flow rates were used to estimate the installed capital costs. The costs include the scrubber housing, packing bed fiberglass material, and a blower. These uninstalled costs were provided by Croll-Reynolds:

Uninstalled Capital Cost 1991 $/acfm	Exhaust Flow rate acfm
$10-15	less than 500
$7-10	500-1500
$5-7	1500-5000
$3.5-5	5000-10000
$2.5-3.5	10000-50000

Because the cost guidelines are rough estimates, some adjustments were made to keep the increase in costs consistent with the increase in flow rate. Installation was assumed to be 60 percent of the capital costs[31]. Installed capital costs are summarized in Table A-11.

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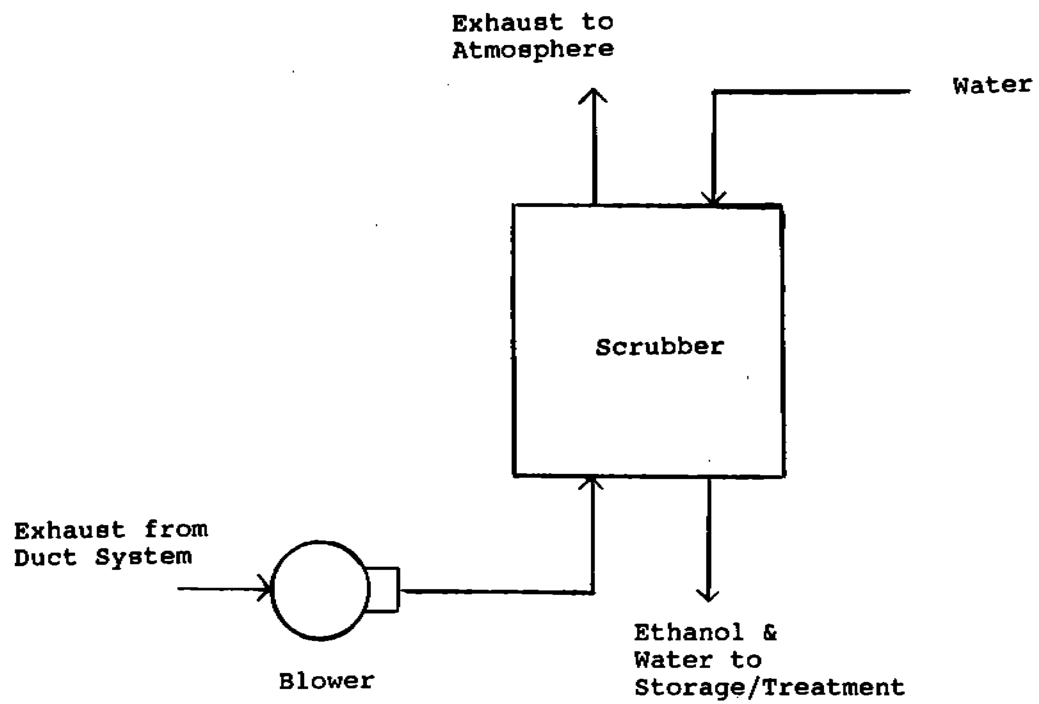
[30] Personal Communication, Bob Shirinna, Croll-Reynolds, 201-232-4200

[31] Peters and Timmerhaus, op. cit., pg. 109.

Figure A-7

Simplified Process Flow Diagram

of the Packed Tower Scrubber System



B. Fixed Capital Costs

The ICCs include only the cost of equipment and installation. The following items are added to the ICCs to obtain the FCC's.

Electrical and Service Facilities	15% FCC
Engineering and Supervision	10% FCC
Contractor's Fee	3% FCC
Startup Expenses	10% FCC
Contingency	15% FCC
Total	53% FCC

FCC's are calculated as follows:

FCC = ICC + 0.53 FCC

Solving for FCC

FCC = 2.13 ICC

FCC's are summarized in Table A-11.

C. ANNUAL UTILITY COST

1) Water Requirements

Water requirements were estimated according to the following guidelines: 10 gpm per 1000 acfm of exhaust gas. The cost of water was assumed to be $ 0.35 per 748 gallons[32].

An exhaust flow rate of 770 acfm (white wine 5-100K gallon tanks) would require 77 gpm of water costing $1868/yr.

Calculations are as follows:

gpm = 770 acfm * 10 gpm/1000 acfm = 7.7 gpm

$/yr = 7.7 gpm * $.35/748 gal * 60 min/hr * 24 hr/dy * 36 dy/yr

= $187/yr

[32] Water rates for the City of Stockton.

2) Blower Requirements

Blower requirements were estimated based on the following guideline: 1.5 hp/ 1000 acfm[33]. Blower hp and electricity costs for 770 acfm would be 1.16 hp costing $97/yr.

Calculations are as follows:

hp = 770 acfm * 1.5 hp/100 acfm = 1.16 hp

$/yr = 1.16 hp * 0.746 kw/hp * $.13/ kw * 24 hr/dy * 36 dy/yr
= $97/yr

The system blower would be sized to handle this load.

3) Summary

Total annual utility costs for the white wine 5-100K gallon tanks is $284/yr. The red wine utility costs were calculated in the same manner. Total annual utility costs are summarized in Table A-11.

[33] Based on a centrifugal blower rated at 10-20 in of water operating at 50 percent efficiency.

Table A-11

Installed and Fixed Capitol Cost

and Utility Cost for Scrubber

(Based on 1991 Cost Estimates)

Wine Type	Tank Scenario	Installed Capital Cost ($)	Fixed Capital Cost ($)	Total Utility Cost * ($/yr)
White	5-50K	$2,772	$5,904	$142
	10-50K	$4,158	$8,857	$284
	15-50K	$5,544	$11,809	$425
	5-100K	$4,158	$8,857	$284
	10-100K	$6,468	$13,777	$567
	15-100K	$8,316	$17,713	$851
	5-300K	$8,316	$17,713	$851
	10-300K	$13,860	$29,522	$1,701
	15-300K	$18,711	$39,854	$2,552
	5-600K	$13,860	$29,522	$1,701
	10-600K	$19,404	$41,331	$3,403
	15-600K	$29,106	$61,996	$5,104
Red	5-50K	$6,363	$13,553	$465
	10-50K	$10,908	$23,234	$930
	5-100K	$10,908	$23,234	$930
	10-100K	$18,180	$38,723	$1,860
	5-300K	$19,089	$40,660	$2,790
	10-300K	$32,724	$69,702	$5,579

* Based on 36 days/year for white wine and 30 days/year for red wine

7. Condensation

A. Installed Capital Cost

The calculation for design requirements are based on a procedure developed by the late Professor Lynn Williams[34]. A simplified process flow diagram for the condensation system is shown in Figure A-8. The design parameters for condensation are:

Red Wine	White Wine
Exhaust temp 85 °F	Exhaust Temp 57°F
17,900 ppm(w) EtOH	6400 ppm(w) EtOH
3.7 % H_2O	1.57 % H_2O
Gas Flow 8.08 acfm /1000 gal wine	Gas Flow 1.92 acfm /1000 gal wine

The basis for calculation is 100,000 gallon of red wine. The partial pressure of ethanol is:

$P_e = y_e * P$

where

P_e = partial pressure of ethanol
y_e = mole fraction of ethanol, 1.79 %
P = total pressure, 760 mm Hg

$P_e = .0179 * 760 = 13.6$ mm Hg

Similarly, water partial pressure is 28.12 mm Hg.

The gas flow of 808 acfm adjusted for temperature is 729.2 scfm. The mass flow rate of ethanol based on the ideal gas law is 100.3 lb/hr (729.2 scfm * 46 lb/lb mol * 0.0179% ethanol * 60 min/hr * 1 lbmol/359 cf = 100.3 lb/hr). The mass flow rate of water is 88.7 lb/hr. Therefore, the total potential liquid condensate is 189 lb/hr.

To achieve the specified 90 % removal of ethanol, it is necessary to reduce the partial vapor pressure to 1/10 of it's original value (i.e. 1.36 mm Hg). This calculation depends on the ethanol and water compositions of the final condensate as well as the temperature.

The condensate composition may be estimated by assuming it contains 90 % of the ethanol originally in the vapor and virtually all the water. The condensate composition is:

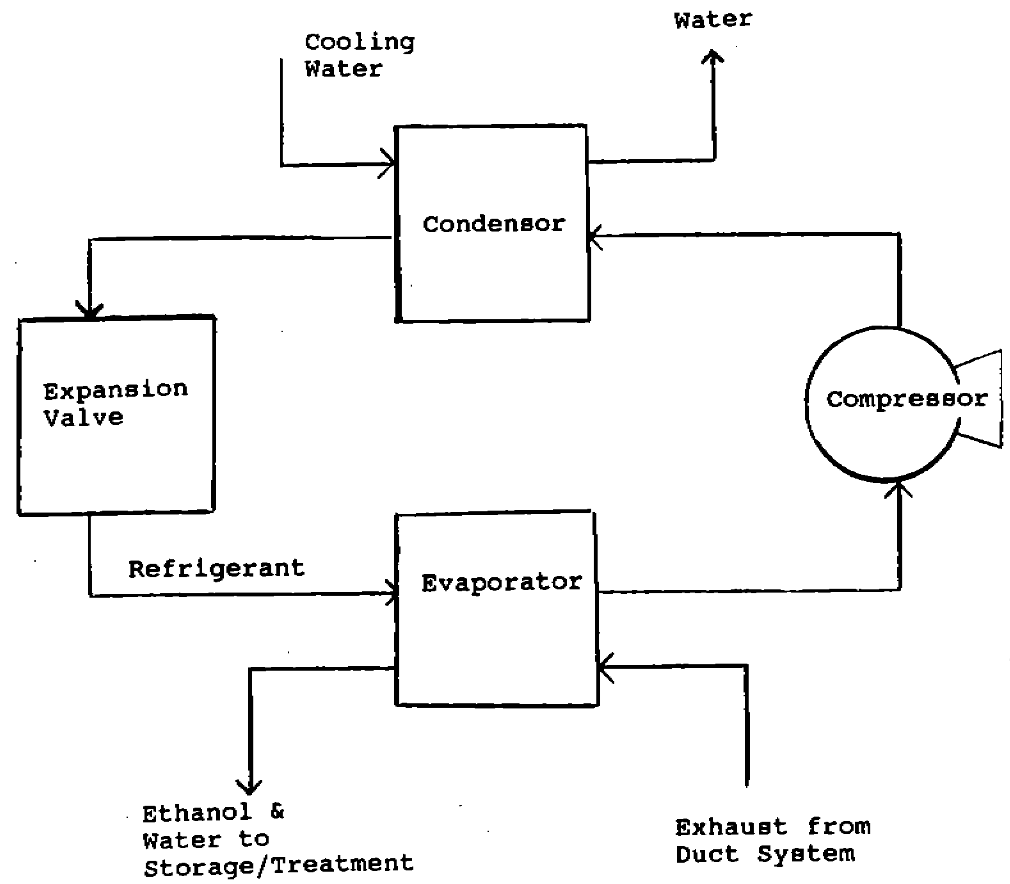
Ethanol	90.3 lb/hr	50.4 % w/w = 28.4 mol %
Water	88.7 lb/hr	49.6 % w/w = 71.6 mol %
Total	179 lb/hr	

[34] ARB SCM, op. cit., pg. A-80.

Figure A-8

Simplified Process Flow Diagram

of the Condensation System



The temperature at which this composition will exert a partial vapor pressure of 1.36 mmHg is governed by the following equation:[35]

$$P_e = x_e * P_e^{\circ} * \delta_e$$

where

x_e = liquid phase mole fraction ethanol

P_e° = pure ethanol vapor pressure (temperature dependent)

δ_e = activity coefficient (composition and mildly temperature dependent)

The activity coefficient is nearly independent of temperature at these conditions. At 30°C and 0.284 mol fraction the activity coefficient is 1.83[36]. The required value of P_e° may be calculated:

$$P_e^{\circ} = \delta_e / (P_e * x_e)$$
$$= 1.36/(1.83 * 0.284) = 2.62 \text{ mm Hg}$$

From vapor pressure for pure ethanol[37], it can be determined that a temperature of -19°C = -2.2°F is needed to achieve a value of 2.62 mm Hg.

The vapor condenser must operate at -2.2°F. The actual coolant temperature must be 10 degrees lower to provide a driving gradient for heat transfer. Therefore, the required coolant temperature is -12.2°F.

Note, that the final condensate would have a freezing point of -37°F, but intermediate condensate would have a much higher freezing points and ice formation in the condenser may be a serious problem.

The cooling load can now be calculated to determine the design capacity of the condenser. First stage cooling includes only gas cooling from 85°F to -2.2°F.

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35 Ibid.

36 J. Chem. Thermodynamics 10:867-888, 1987.

37 Perry and Chilton, op. cit., pg. 3-54.

The gas cooling load can be calculated, using the following equation:

$$btu/hr = m_g * C_{pg} * (\Delta T)$$

where

m_g = mass of gas (CO_2)
= 729.2 SCFM = 5364.19 lb/hr

C_{pg} = heat capacity of CO_2 at 0 °C
= 0.205 Btu/lb°F

ΔT = 85 - (-2.2) = 87.2 °F

Therefore,

= 5364 lb/hr * 0.205 Btu/lb°F *(87.2°F)
= 95,887 btu/hr

Second stage cooling consists of condensation of 179 lb/hr of condensate at a composition of 50.4 % w/w ethanol. The heat of vaporization (condensation) for this condensate is: delta H = 681.1 Btu/lb. Therefore the second stage cooling load is 121,917 Btu/hr (179 lb/hr * 681.1 Btu/lb= 121,917 btu/hr).

The design total cooling load and condenser duties required for a system condensing 100,000 gallons of red wine is 217,804 btu/hr. This corresponds to the need for 18.15 tons refrigeration (217,804 Btu/hr * 1 ton refrigeration / 12,000 btu/hr = 18.15 tons) at the temperature of -12 °F.

A similar calculation was performed based on a 100,000 gallons of white wine, and the parameters, above. The calculations resulted in an estimate of 3.14 tons of refrigeration at a temperature of -36°F.

Uninstalled costs for the red wine system were scaled from an estimate given by L and A Engineering & Equipment[38], using the sixth tenths rule:

$$\text{cost a} = \text{cost b} * (\text{capacity a}/\text{capacity b})^{0.6}$$

where

cost of b = $39,400 (1982$)
capacity of b = 13.75 ton refrigeration

The vendor quote is based on a Freon R-22 system with a 50 hp compressor, a surface condenser, low pressure drop fin tube coil and a drip pan.

[38] ARB SCM, op. cit., pg. A-83.

Based on a design of 18.15 tons of refrigeration for 100K gallons of red wine, the capacities were scaled according to the tank farm size and assuming the tanks were 75% full. For example 5-50K gallon tanks require 34 tons of refrigeration (18.15 * 0.75 * 250K/100K = 34.03). The cost of equipment for 34 tons of refrigeration is $67,864 ($\$39,400 * (34/13.75)^{0.6} = \$67,864$).

Installation hours were estimated from Figure D-7 (p. 768) in Peters and Timmerhaus, as a function of refrigeration capacity. Installation hours were then calculated assuming $40 dollars per hour.

Installed capital costs for white wine were estimated in the same manner. Installed capital costs are summarized in Table A-12.

B. Fixed Capital Costs

The ICCs only include of equipment and installation. The following items are added to the ICCs to obtain the FCCs:

Electrical and Service Facilities	20% FCC
Engineering and Supervision	10% FCC
Construction Expense	7% FCC
Contractor's Fee	3% FCC
Startup Expenses	10% FCC
Contingency	15% FCC
Total	65% FCC

FCC's are calculated as follows:

$$FCC = ICC + 0.65\ FCC$$

Solving for FCC

$$FCC = 2.86\ ICC$$

FCC's are summarized in Table A-12.

C. Annual Utility Cost

Utility requirements were based on the following conditions:

1. Water is available for condensing at an inlet temperature of 85°F and an outlet temperature of 95°F.

2. R-22 is the refrigerant.

3. The heat transfer is designed for a 10°F driving differential between the mediums.

4. Evaporator temperature for white wine is -36°F and for red wine is -12°F.

1) Compressor Horsepower Requirements

The required horsepower was calculated using the following equation for refrigeration processes[39]:

$$Hp = R * 200 \text{ Btu/min-ton} * [(h_d - h_g)/(h_g - h_f)] / 42.4 \text{ Btu/min}$$

where
R = refrigerant, tons
h_d = enthalpy of vapor leaving compressor, 127 Btu/lb
h_g = enthalpy of gas leaving the evaporator, 103.6 Btu/lb
h_f = enthalpy of liquid leaving the condenser, 40.9 Btu/lb

Enthalpy values from pressure-enthalpy diagram for R-22[40]. For red wine:

$$Hp = R * 200 * (127-103.6)/103.6-40.9) / 42.4$$
$$= R_r * 1.76$$

Factoring in a 60 percent efficiency: $Hp = R * 2.93$

Following a similar procedure for white wine results in the relationship: $Hp = 3.6 * R_w$

[39] Perry and Chilton, op. cit., pg. 12-33.

[40] Perry and Chilton, op. cit., pg. 3-195.

Utility costs for the compressor hp based on red wine 5-50K gallon tanks:

Cost = 2.93 * 34.03 ton * 0.13 $/kwh * 0.746kw/hp
* 24 hr/day * 30 day/yr
Cost = $ 6962/yr

2) Condenser Cooling Water

The amount of water used in the condenser is based on the following equation[41]:

gpm ={[R + Hp * (2545 Btu/hr/hp / 12000 Btu/hr/ton)]
* 200 btu/min ton} / (1 Btu/lb°F * 10°F
* 8.33 lb/gal)

For red wine 5-50K gallon tanks, 130.5 gpm of condenser water is required. ([34.03 + 99.6 * 2454/12000] * 200 / 10 * 8.33 = 132.4 gpm)
The utility cost for water based on 0.34 $/ 748 gallons:

cost = 132.4 gpm * $.35/748 gpm * 60 min/hr * 24 hp/day
* 30 day/yr

cost = $ 2677/yr

3) Summary

Total annual utility costs for the red wine 5-50K gallon tanks is $9639/yr. Annual utility costs for both red and white wine are summarized in Table A-12.

[41] Perry and Chilton, op. cit., pg. 12-40.

Table A-12

Installed and Fixed Capitol Cost

and Utility Cost for Condensation

Wine Type	Tank Scenario	Installed Capital Cost ($)	Fixed Capital Cost ($)	Total Utility Cost * ($/yr)
White	5-50K	$33,929	$97,036	$2,539
	10-50K	$51,338	$146,828	$5,078
	15-50K	$65,965	$188,659	$7,617
	5-100K	$51,338	$146,828	$5,078
	10-100K	$78,683	$225,032	$10,156
	15-100K	$99,408	$284,307	$15,234
	5-300K	$99,408	$284,307	$15,234
	10-300K	$151,816	$434,195	$30,468
	15-300K	$196,469	$561,902	$45,701
	5-600K	$151,816	$434,195	$30,468
	10-600K	$242,702	$694,128	$60,935
	15-600K	$311,226	$890,107	$91,403
Red	5-50K	$92,087	$263,369	$9,639
	10-50K	$138,358	$395,704	$19,278
	5-100K	$138,358	$395,704	$19,278
	10-100K	$210,997	$603,452	$38,556
	5-300K	$280,808	$803,110	$57,833
	10-300K	$442,807	$1,266,429	$115,667

* Based on 36 days/year for white wine and 30 days/year for red wine

8. Temperature Control

A. Installed Capital Cost

The refrigeration required was based on the assumption that the present fermentation temperatures are 65°F for white wine and 85°F for red wine and that the new limits would be 55°F for white wine and 80°F for red wine. The values representing the additional refrigeration required, 5000 Btu/hr per 1000 gallon for red and 2,479 btu/hr per 1000 gallon for white wine were provided by Hueblein wine[42]. These values represent the extra refrigeration required per 1000 gallons of incoming must. These values must be converted to tank capacity in order to determine costs per tank farm size. The values were converted as follows:

R = r * 1/t * tank capacity
where
r = refrigeration required, Btu/hr per 1000 gallon/day
t = length of the fermentation cycle, days; for red wine t= 2.5, for white wine t = 7
tank capacity = for red wine, 0.75; for white wine, 0.8
R = refrigeration required, Btu/hr per 1000 gallon capacity

The 1985 installed cost of $2000/ton[43], was scaled up to 1991 dollars using the cost index, resulting in a cost of $2225/ton (2000 * 361.3/324.8).

The cost of refrigeration was calculated as follows:

D = R * 1/12000 Btu/hr-ton * 2225 $/ton
where
D= $/1000 gal capacity

A 5-100K gallon white wine tank would require 11.80 tons of refrigeration (2,479 * 1/7 * .80/12000 * 500K = 11.80) costing $26,266. A 5-50K gallon red wine tank farm would require 31.25 tons of refrigeration costing $69,531. The costs for other scenarios were scaled up proportionately form these two cases.

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[42] Personal Communication, Borge Landgren, Hueblein Wines, Madera, CA 209-673-7071

[43] Personal Communication, Borge Landgren, Heublein Wines, Madera, CA 209-673-7071

Additional fermentation capacity would be required to maintain present production levels. Costs for additional fermentation capacity were determined assuming that present storage tanks would be converted to fermentation tanks. The cost would be approximately 10 percent of the cost of a new tank, about $0.15/gal for white wine and $0.40/gal red wine[44] tanks. Fermentation capacity for white wine must be increased by 43 percent (10/7 =1.43) because of the increase in fermentation tome from 7 to 10 days. For red wine the increase is 20 percent (3/2.5=1.2). The cost for the additional capacity is calculated by multiplying cost per gallon by the additional tankage. For a 5-100K gallon white wine tank farm the cost would be $32,250 (500,000 * 0.43 * 0.15 = 32,250). For a 5-50K gallon red wine tank farm the cost would be $20,000. Installed capital costs are summarized in Table A-13.

B. Fixed Capital Costs

The cost of $2225 per ton of refrigeration quoted by the wine making industry is a complete cost. It is assumed that all the FCC costs equal the ICCs, these costs are shown in Table A-13.

C. Annual Utility Costs

1) Compressor Electricity Cost

The electricity required is determined by first calculating the power of the compressor. The following assumptions were made to determine the power required:

a. Water is available for condensing at an inlet temperature of 85°F and an outlet of 95°F.

b. Ammonia is the refrigerant.

c. Heat transfer is designed for a 10°F driving differential between mediums.

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44 ARB scm, op. cit., pg. A-13.

The required horsepower was calculated in the same manner as shown in Section 7.C.1 for the condenser compressor horsepower. For ammonia as the refrigerant and white wine:

$$Hp = R * 200 \text{ Btu/min-ton} * [(h_d - h_g)/(h_g - h_f)] / 42.4 \text{ Btu/min}$$

where

R = refrigerant, tons

h_d = enthalpy of vapor leaving compressor, 683 Btu/lb

h_g = enthalpy of gas leaving the evaporator, 624 Btu/lb

h_f = enthalpy of liquid leaving the condenser, 161 Btu/lb

Enthalpy values from saturated ammonia tables[45]. For white wine:

$$Hp = R * 200 * (683-624)/624-161) / 42.4$$
$$= R_w * 0.60$$

Factoring in a 60 percent efficiency: $Hp = R_w * 1$

Following a similar procedure for red wine results in:

$Hp = 0.554 * R_r$

Utility costs for the compressor hp based on white wine 5-100K gallon tanks:

$$\text{Cost} = 1 * 11.80 \text{ ton} * 0.13 \text{ \$/kwh} * 0.746\text{kw/hp} * 24 \text{ hr/day} * 28 \text{ day/yr}$$
$$\text{Cost} = \$\ 769/\text{yr}$$

2) Condenser Cooling Water

The amount of water used in the condenser is based on the following equation[46]:

$$gpm = \{[R + Hp * (2545 \text{ Btu/hr/hp} / 12000 \text{ Btu/hr/ton})] * 200 \text{ btu/min ton}\} / (1 \text{ Btu/lb°F} * 10°F * 8.33 \text{ lb/gal})$$

For white wine 5-100K gallon tanks, 130.5 gpm of condenser water is required. ([11.80 + 11.80 * 2454/12000] * 200 / 10 * 8.33 = 34.13)

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[45] Perry and Chilton, op. cit., pg. 3-155.

[46] Perry and Chilton, op. cit., pg. 12-40.

The utility cost for water based on 0.34 $/ 748 gallons:

cost = 29.84 gpm * $.35/748 gpm * 60 min/hr * 24 hr/day

* 28 day/yr
cost = $ 644/yr

3) Summary

The total utility cost for the 5-100K gallon tanks is $1413/yr. Annual utility costs for both red and white wine are summarized in Table A-13.

9. Operating and Maintenance Costs

In addition to the one-time fixed-capital costs, there will be annual operating and maintenance costs (O&M) for each control device. Those items consist of maintenance and labor, insurance and property taxes, plant overhead, and utilities. Those costs are determined as follows:

Maintenance and labor	3% of FCC
Insurance and local taxes	2% of FCC
Plant Overhead	0.75% of FCC
Utilities	From appropriate table

Total O & M = sum of the above four items.

Table A-13

Installed and Fixed Capitol Cost

and Utility Cost for Temperature Control

(Based on 1991 Cost Estimates)

Wine Type	Tank Scenario	Installed/ Fixed Capitol Cost ($)	Total Utility Cost * ($/yr)
White	5-50K	$29,258	$707
	10-50K	$58,516	$1,413
	15-50K	$87,773	$2,120
	5-100K	$58,516	$1,413
	10-100K	$117,031	$2,826
	15-100K	$175,547	$4,239
	5-300K	$175,547	$4,239
	10-300K	$351,094	$8,479
	15-300K	$526,640	$12,718
	5-600K	$351,094	$8,479
	10-600K	$702,187	$16,958
	15-600K	$1,053,281	$25,437
Red	5-50K	$89,531	$2,414
	10-50K	$179,063	$4,828
	5-100K	$179,063	$4,828
	10-100K	$358,125	$9,656
	5-300K	$537,188	$14,483
	10-300K	$1,074,375	$28,967

* Based on 28 days/year for white wine and 25 days/year for red wine

10. After-Tax Cost-Effectiveness

In order to calculate cost-effectiveness, emissions and reductions and after-tax costs must first be calculated.

A. Emissions and Reductions

The uncontrolled emissions for the exhaust controls are based on the average measured values from source tests performed between 1980 to 1991. From Appendix A, Section 4, Table A-3, the average emission factors are 2.04 lb/ 1000 gallons white wine and 5.96 lb/ 1000 gallons red wine. The emission factors are converted from 1000 gallon of wine to 1000 gallons of tank capacity, assuming white wine tanks have a capacity of 80 % and red wine tanks have a capacity of 75 %. Expressed in terms of capacity the emission factors are, 1.63 lb/ 1000 gallons of capacity for white wine and 4.47 lb/ 1000 gallons red wine.

Uncontrolled emissions per cycle were calculated for each tank farm scenario by scaling up the capacity based emission factors. The yearly emission are calculated by multiplying the emission factors by the tank capacity and by the number of cycles shown in Table A-2 which are 4 for white and 10 for red. The yearly uncontrolled emission from the exhaust control scenario are shown in Table A-14.

The uncontrolled emissions for temperature control are based on 65°F and 21.5 ° Brix for white wine and 85°F and 23° Brix for red wine. These values were selected as average operating parameters for fermentation. The emission factors were estimated using the graph in "Modeling and Prediction of Evaporative Ethanol Loss During Wine Fermentation", shown in Section 4, Figure 1. The emission factors read off the graph are 2.8 lb/1000 gallons (2.24 lb/1000 gallon capacity) and 8.3 lb/1000 gallons (6.2 lb/1000 gallon capacity). Yearly emission are then calculated the same way as the exhaust control scenarios. Uncontrolled emission are shown in Table A-14.

Emission reductions are found by multiplying the uncontrolled emissions by the control efficiencies shown in Table A-15.

Table A-14

Uncontrolled Emissions for Wine Fermentation

Wine Type	Tank Scenario	Tank Capacity (1[illegible] gal)	Exhaust Control Scenario (lb/yr)	Temp. Control Scenario (lb/yr)
White	5-50K	250	1630	2240
	10-50K	500	3260	4480
	15-50K	750	4890	6720
	5-100K	500	3260	4480
	10-100K	1000	6520	8960
	15-100K	1500	9780	13440
	5-300K	1500	9780	13440
	10-300K	3000	19560	26880
	15-300K	4500	29340	40320
	5-600K	3000	19560	26880
	10-600K	6000	39120	53760
	15-600K	9000	58680	80640
Red	5-50K	250	11175	15500
	10-50K	500	22350	31000
	5-100K	500	22350	31000
	10-100K	1000	44700	62000
	5-300K	1500	67050	93000
	10-300K	3000	134100	186000

Table A-15

Control Efficiencies Used in Emission Reduction Cost Estimates

Temperature Control	Red Wine 85°F to 80°F	15%
Temperature Control	White Wine 65° to 55°F	30%
Exhaust Gas Ducting	Red Wine	98%
Exhaust Gas Ducting	White Wine	99%
Incineration	Red and White Wine	95%
Carbon Adsorption	Red and White Wine	95%
Condensation	Red and White Wine	90%
Scrubbing	Red and White Wine	99%

B. Cost-Effectiveness

Each point on the cost-effectiveness curves presented in Section 5 (Figures 6-10) represents the cost effectiveness of one control scenario. There are five control systems and eighteen tank farm configurations. Therefore, there are 90 cost effectiveness calculations. However, the method of calculation is the same for each control scenario. The method used to calculate the after-tax cost effectiveness is based on a present value cost analysis.

A present value method was selected instead of the more traditional annualized cost analysis based on Wine Institute recommendations. Both methods will give results within 5% of either method. The calculations include State and Federal write-offs. Straight line depreciation is used for fixed capitol costs. The write-offs include depreciation and operating and maintenance costs. A five year present value period was selected for analysis, based on depreciation tax law.

A complete list of the assumptions used in the analysis are shown in Table A-16. Sample calculation for the present value after tax cost effectiveness of ten 300,000 gallon tanks is shown in Tables A-17 through Table A-19.

The first step in determining the cost-effectiveness consisted of calculating the fixed capitol costs and the operating and maintenance costs as summarized in Table A-17.

Second, depreciation and tax benefits were determined. Straight line depreciation of the FCC was assumed for a five year period. State and federal annual tax benefits were calculated using write-offs for depreciation and operating and maintenance with the appropriate tax rate. The annual tax benefits were adjusted to present value. Depreciation and tax benefit calculations are contained in Table A-18.

Finally, the cost-effectiveness was evaluated by summing the present value of the FCC and the operating and maintenance costs for the five year period. Tax benefits were subtracted from this value to derive the total after-tax cost present value. This value was divided by the total anticipated five years of emissions reductions.

The results of the cost effectiveness calculations in 1991 $/lb of emissions reduced are summarized in Table A-20.

Table A-16

Assumption for Cost Effectiveness Calculations

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1. Maintenance and Labor Cost is 3 % of FCC
2. Property Taxes and Insurance are 2% of FCC.
3. Plant Overhead is 0.75% of FCC.
4. Maintenance, labor, property tax, insurance, overhead, utilities and depreciation are federal and State tax deductions.
5. Five year straight line depreciation is used for State and federal write-offs.
6. Federal corporate tax rate is 34%.
7. State Corporate tax rate is 9.3%.
8. Interest Rate is 12 % before tax and 6 % after-tax.

Table A-17

Cost Basis for 10-300K Gallon White Wine Tank Farm
Using Carbon Adsorption
1991 Dollars

FCC		
Ducting FCC (Table A-8)	$360,504	
Equipment FCC (Table A-9)	$315,000	
Total FCC		$675,504
Operating and Maintenance (O&M)		
Maintenance & Labor (3% FCC)	$20,265	
Property Taxes & Ins.(2% FCC)	$13,510	
Plant Overhead (0.75% FCC)	$5,066	
Utilities (Ducting Table A-8 and Equipment Table A-9)	$20,381	
Total O&M		$59,222

Table A-18

Calculation of Depreciation and Tax Benefits
for 10-300K Gallon White Wine Tank Farm
Using Carbon Adsorption
1991 Dollars

Year	1	2	3	4	5
Depreciation (St. Line)	135,101	135,101	135,101	135,101	135,101
O&M	59,223	59,223	59,223	59,223	59,223
California* Tax Benefit	18,072	18,072	18,072	18,072	18,072
Federal** Tax Benefit	59,926	59,926	59,926	59,926	59,926

Total Tax Benefits per year $ 77,998

Present Value of Tax Benefit for 5 years*** $ 328,557

* California Tax Benefit = (Depreciation + O&M) * 9.6/100

** Federal Tax Benefit = (Depreciation + O&M - Calif. Tax Benefit) * 34/100

*** Present Value = 77,997 * (Σ 1/(1+.06)^n), for n = 1 through 5

Table A-19

Calculation of Cost Effectiveness
for 10-300K Gallon White Wine Tank Farm
Using Carbon Adsorption
1991 Dollars

FCC	$ 675,504
Present Value Tax Benefit	$ - 328,557
After-Tax Capital Cost Present Value	$ 346,946
Present Value O&M for 5 years	$ 249,471
Total After-Tax Cost Present Value	$ 596,417
Annual Emission Reductions (Table X-1)	18,396 lbs
Emission Reductions for 5 years	91,980 lbs
After Tax Cost Effectiveness	$6.48/lbs

Table A-20

Summary of Cost-Effectiveness

(Based on 1991 Cost Estimates)

Wine Type	Tank Scenario	Temp. Control ($/lb)	Carbon Adsorption ($/lb)	Catalytic Incineration ($/lb)	Scrubber ($/lb)	Condensation ($/lb)
White	5-50K	$7.56	$26.80	$26.01	$8.16	$18.89
	10-50K	$7.56	$19.67	$19.09	$8.69	$17.10
	15-50K	$7.56	$15.63	$16.50	$7.26	$14.56
	5-100K	$7.56	$17.58	$16.99	$6.68	$15.01
	10-100K	$7.56	$13.11	$14.23	$6.04	$12.64
	15-100K	$7.56	$10.89	$12.66	$5.71	$11.41
	5-300K	$7.56	$9.02	$10.79	$3.91	$9.54
	10-300K	$7.56	$6.48	$8.84	$3.34	$7.82
	15-300K	$7.56	$5.29	$7.10	$2.96	$6.92
	5-600K	$7.56	$6.48	$8.84	$3.34	$7.82
	10-600K	$7.56	$5.00	$6.88	$2.80	$6.57
	15-600K	$7.56	$4.20	$6.33	$2.50	$5.82
Red	5-50K	$6.74	$7.29	$7.49	$2.83	$7.27
	10-50K	$6.74	$4.98	$6.06	$2.27	$5.70
	5-100K	$6.74	$4.58	$5.66	$1.89	$5.30
	10-100K	$6.74	$3.35	$4.10	$1.53	$4.22
	5-300K	$6.74	$2.78	$3.43	$1.18	$3.64
	10-300K	$6.74	$2.14	$2.96	$0.93	$2.96

APPENDIX B

Generation of Waste Products

APPENDIX B

Generation of Waste Products

Carbon adsorption and catalytic incineration will generate a solid waste by-product. The solid waste will be generated as the result of periodic replacement of the catalyst, and therefore will be a part of maintenance operations. It is anticipated the solid waste would be removed offsite for disposal. Condensation, scrubbing and carbon adsorption will generate a ethanol/water liquid waste by-product. The liquid waste which is generated will be on a continuous basis during operation of the control equipment. Therefore, wineries will need to develop operating procedures for handling the by-product. Since the water/ethanol waste has the potential to impact daily operating procedures it is more of an issue. This Appendix focuses on the handling of the liquid waste product.

As shown on pages B4-B10, the ARB performed calculations in the 1986 SCM estimating the quantity of liquid waste generated. The flowrates and concentrations which were used in the calculations represent average values. The quantity of waste generated will not be significantly increased as the result of higher peak exhaust flow rates which have been observed through the 1988-1990 demonstration projects.

Scrubbing produces large quantities of extremely dilute (0.1 to 0.04 percent ethanol) solution. Carbon adsorption produces much lower quantities of a 77 to 10 percent solution. Condensation produces the lowest quantity of a highly concentrated (40 to 44 percent ethanol) waste product. It is anticipated that wineries in most cases will have sufficient onsite storage capacity for temporary handling of the waste water. No additional costs have been evaluated for storage of waste products.

Distillation to recover the ethanol is feasible for the carbon adsorption and condensation wastes. Consideration has been given to using the distilled ethanol as fortification for brandy or other higher alcohol products. However, this has met with limited success due to product quality.[1]

Waste ethanol product may also be transferred offsite for
recovery. Based on discussions with Parallel Products[2], they would be interested in recovering the ethanol as feed stock for ethanol fuel. Currently, they have a plant in Rancho Cucamonga and are working on developing a facility in Bakersfield. The purchase price for the ethanol/water product would be based on the concentration of ethanol and cost indexed to the current market price of fuel alcohol which is roughly $0.30/gallon pure ethanol. For example a solution of ethanol/water with a 40% concentration would be purchased for $0.12/gallon.

As shown in Table B-2, condensation yields a waste product of 37 volume percent (white wine) and 41 volume percent (red wine), with a subsequent purchase price of $0.11/gal and $0.12/gal. Carbon adsorption yields a product of 8.1 volume percent (white wine) and 18 volume percent (red wine), with a subsequent purchase price of $0.02/gal and $0.05/gal. The shipping cost is approximately $0.05/gal to $0.09/gal[3], based on a flat fee of $55/hr for a truck with 3500 gallon capacity. The waste water from condensation and carbon adsorption may result in a slight profit or breakeven. Although, in the case of emission control of white wine with carbon adsorption there may be costs associated with handling the waste.

The large quantity of dilute ethanol/water solution generated by scrubbing are too dilute for cost-effective distillation or recovery. The application of the wastewater to land as irrigation was considered and determined unfeasible due to the potential rerelease of ethanol to the atmosphere. A study was performed at CSUF during the pilot

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[1] Personnel communication, David Todd, ARB.

[2] Personal discussion, Rick Eastman, Parallel Products, 916-756-1027

[3] Personal communication, Bento Bros Trucking, 805-772-7577

scale testing[4] of the exhaust emission controls[5], which measured approximately 60-70% percent of the ethanol applied to the land evaporates into the atmosphere.

Disposal of the scrubber water to municipal water facilities is expected to result in lower quantities of ethanol returning to the atmosphere due to microbial action. Concern has been expressed by the wine industry that most wineries are not connected to municipal systems or would generate quantities of waste in excess of available capacities at municipal waste treatment facilities. Due to the large volumes of wastewater generated and the difficulty in disposal, scrubber technology is not feasible for control of winery fermentation emissions.

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[4] ARB/ML 88-027, 1988

[5] Personal Communication, Art Caputi, Chair, Ethanol Emissions Subcommittee.

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[4] ARB/ML 88-027, 1988

[5] Personal Communication, Art Caputi, Chair, Ethanol Emissions Subcommittee.

The following pages in this Appendix are excerpts from the Air Resources Board, Suggested Control Measure, op. cit., B-1 through B-7.

STORAGE REQUIREMENTS FOR THE ETHANOL/WATER PRODUCT

I. MATERIAL BALANCE

Three out of the four exhaust controls generate an ethanol/water by-product. The three exhaust controls are scrubbing, carbon adsorption and condensation. In order to determine the storage requirement for the by-product, the amount of by-product from each type of control has to be calculated. The concentration of ethanol in the by-product is also needed to determine the method of disposal.

To calculate the concentration and amount of the by-product, a material balance is made around the control unit. Flow charts representing the process of the exhaust control systems are shown in Figure B-1.

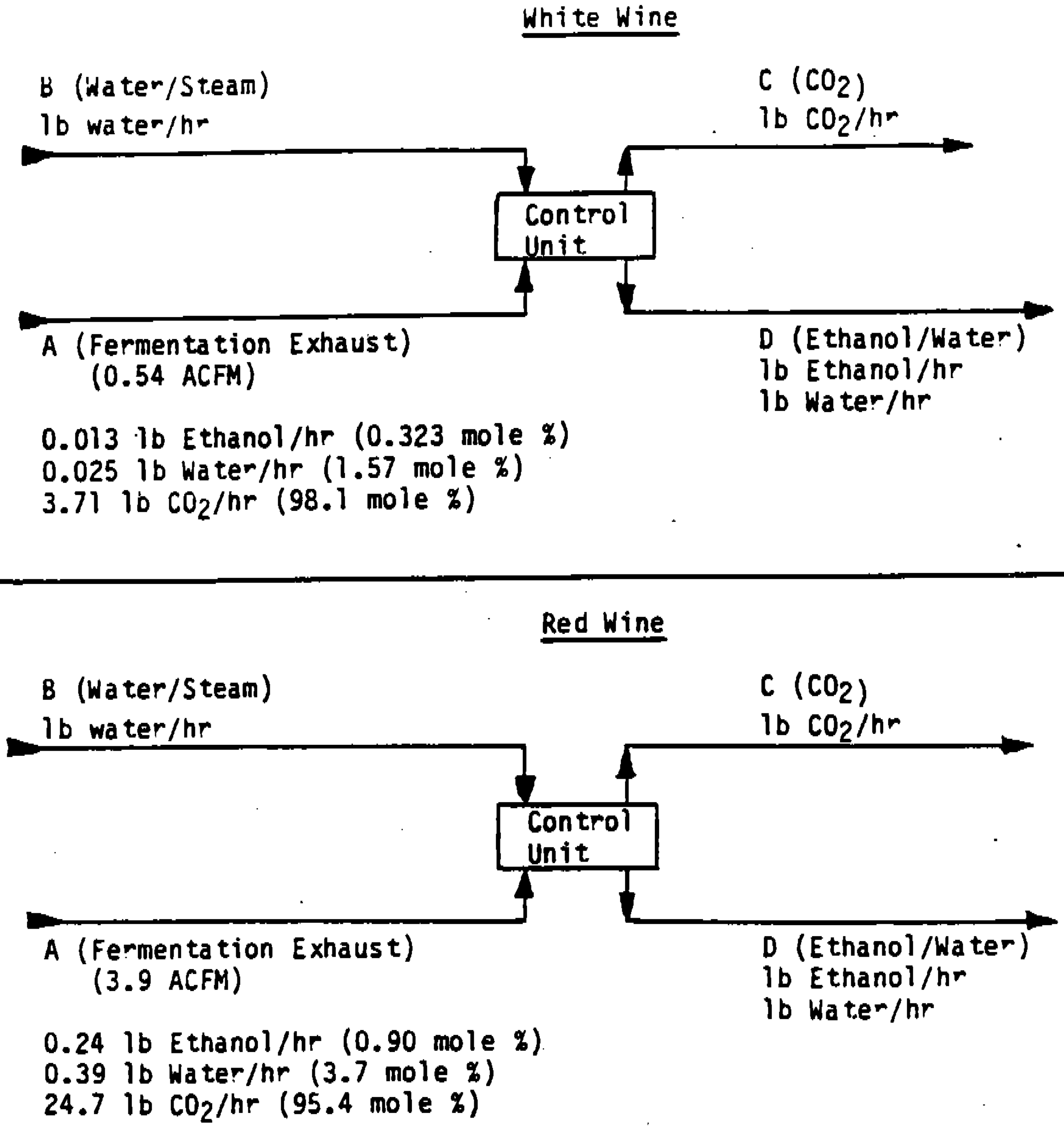
The material balance is the same for each type of control. The bases for the material balance are 1,000 gallons of juice, and one fermentation cycle.* The fermentation cycle is treated as a continuous process. Assuming that the exhaust control system operates at steady state, then the "input" into the control unit would equal the "output." "Input" is all of the material entering the control unit and "output" is all of the material leaving the control unit.

Stream A is the fermentation exhaust. The flow rate of Stream A represents the average exhaust flow rate over one fermentation cycle. The average flow rates and the composition of Stream A are based on source tests performed by EAL Corporation. Stream B is the water/steam entering the

*The actual fermentation time of the fermentation cycle.

Figure B-1

PROCESS SCHEMATIC OF EXHAUST CONTROLS*



*Based on 1,000 gallons of juice, over one fermentation cycle.

Source: ARB/SSD

control unit. The scrubbing unit uses water to absorb ethanol, and the carbon adsorption unit uses steam to remove ethanol from the carbon beds. The condensation unit does not use water. Therefore, Stream B for condensation is zero. The flow rates for Stream B can be found in Appendix A. CO_2, being an inert gas, enters and leaves the control units unchanged. CO_2 enters the control unit as part of Stream A and leaves as part of Stream C. The other components in Stream C are the uncaptured ethanol and water. The amount of ethanol and water in Stream C is very small compared to the CO_2 in the stream. Therefore, the amount of ethanol and water in Stream C has been neglected. Stream D is the ethanol/water product of the control unit. The amount of ethanol in this stream depends on the control efficiency of the control unit. All of the ethanol removed by the control unit leaves as part of this stream. All of the water entering the control unit is also assumed to be part of this stream. Theoretically, the water/ethanol product absorbs some CO_2, but the amount of CO_2 is very small compared to the other components in the stream. Therefore, the amount of CO_2 in Stream D is neglected.

Table B-1 shows the result of the material balance for both white and red wine. The mass rates and the composition of the ethanol/water product from the control units (Stream D) calculated from the material balance are used to calculate the storage requirement. Storage requirements for the ethanol/water product from a 300,000 gallon white wine tank farm of 10 tanks using condensation as the method of control are listed in Table B-2. Sample calculations are shown in the next section.

II. SAMPLE CALCULATIONS

1. Conversion of mole percent to lb/hr

The equation used for converting mole percent of a component in the fermentation exhaust is

$$M = (Q)\ [492/(460 + T)]\ (X/100)\ (1 \text{ lb-mole}/359 \text{ ft}^3)\ (M.W.)\ (60 \text{ min/hr})$$

Where M = mass flow rate of component, lb/hr

Q = Fermentation exhaust flow rate, ACFM

T = Fermentation temperature, ^oF

X = Mole percent of component

M.W. = Molecular weight of component, lb/lb-mole

For the ethanol in the fermentation exhaust of 1,000 gallons of white wine, $M = (0.54)\ [492/(460 + 57)]\ (0.323/100)\ (1/359)\ (46)\ (60) = 0.013$ lb/hr

The mass flow rates of the components in the fermentation exhaust (Stream A) shown in Figure 1 were calculated as shown above.

2. Calculation of volume percent of ethanol in the ethanol/water product.

The equation for calculating volume percent of ethanol in the product (Stream D) is:

$$V\% = (Me/\rho e)/\ [Me/\rho e) + Mw/\ w]$$

Where V% = Volume percent of ethanol

Me* = Mass rate of ethanol, lb/hr

ρe^{**} = Density of ethanol, lb/gal

Mw^* = Mass rate of water, lb/hr

ρw^{**} = density of water, lb/gal

For white wine condensation the volume percent of ethanol in the ethanol/water product is

$$V\% = (0.0116/6.6)/[(0.0116/6.6) + (0.025/8.3)] = 37\%$$

3. Volume of product from one fermentation cycle. The volume of product is found by the following:

$$V = [(Me/\rho e) + (Mw/\rho w)]\ G\ (24\ hr/day)\ (no.\ of\ days/cycle)$$

Where V = Volume of Product, gal

$G = 10^3$ gal of wine

For a 300,000 gallon white wine tank farm of 10 tanks using condensation as the method of control,

$$V = [(0.0116/6.6) + (0.025/8.3)]\ (2,400)\ (24)\ (7) = 1,923\ gal$$

---

*Mass rates are listed in Figure B-1.

**The density of ethanol is 6.6 lb/gal, and the density of water is 8.3 lb/gal.

Table B-1

MASS RATE OF STREAM IN EXHAUST
CONTROL PROCESS
(lbs/hr)

White Wine, based on 1,000 gallons of wine

Control Type	A Ethanol	A Water	A CO_2	B Water	C CO_2	D Ethanol	D Water	Total
Scrubbing	0.013	0.025	3.71	26	3.71	0.0127	26.023	26.04
Carbon Adsorption	0.013	0.025	3.71	0.149	3.71	0.0122	0.174	0.18
Condensation	0.013	0.025	3.71	0	3.71	0.0116	0.025	0.0366

Red Wine, based on 1,000 gallons of wine

Control Type	A Ethanol	A Water	A CO_2	B Water	C CO_2	D Ethanol	D Water	Total
Scrubbing	0.24	0.39	24.7	195	24.7	0.233	195.39	195.69
Carbon Adsorption	0.24	0.39	24.7	0.88	24.7	0.223	1.27	1.49
Condensation	0.24	0.39	24.7	0	24.7	0.212	0.39	0.602

Source: ARB/SSD

Table B-2

VOLUME OF ETHANOL/WATER PRODUCT

10 Tanks - 300,000 Gallons Each

Control Type	White White		Red Wine	
	Gallons/ Cycle*	Concentration of Ethanol (Avg. Vol %)	Gallons/ Cycle*	Concentration of Ethanol (Avg. Vol %)
Carbon Adsorption	9,198	8.1	10,100	18.1
Scrubbing	1.26×10^6	0.061	1.27×10^6	0.15
Condensation	1,923	37	4,275	40.6

*Fermentation time of one cycle.

Source: ARB/SSD

APPENDIX C

Air Resources Board
Suggested Control Measure
Calculation of Ducting Costs

The information presented in this Appendix is an excerpt from the California Air Resources Board, Suggested Control Measure, op. cit., pg. A-18 through A-30.

APPENDIX C

Air Resources Board
Suggested Control Measure
Calculation of Ducting Costs

2. Duct Material Costs

Duct material costs are based on stainless steel 304L price quotations from Felker Brothers Corporation, Marshfield, Wisconsin. Duct gauge was based on the ability to withstand a full vacuum for the ducting under 14 inches in diameter; 12 gauge duct was selected for diameters of 14 inches and over because estimates of gauge requirements for partial vacuums could not be obtained. However, the ducting would not experience a vacuum more than 5 inches of water below atmospheric pressure. Thus, 12 gauge duct would probably be adequate for ducting with diameters over 14 inches. If necessary, stiffening rings could be installed for added strength. The price quotations for the straight pipe, elbows, and tees are listed in Table IV-3. If a tee connected pipes of different diameters, then the tee price for the larger diameter was used. Felker Brothers does not carry cross connections off-the-shelf. These specialized pieces are custom made. Therefore, prices could not be obtained without a drawing. Instead, the cost of these pieces

Table IV-3: Uninstalled Capital Costs for Ducting

Diameter Inches	Gauge	Costs Straight $/ft.	Elbow $/ell	Tee $/Tee
4	14	5.00	20.40	48.70
6	14	6.50	40.00	70.80
8	14	10.00	75.00	82.70
10	12	14.00	100.00	132.20
12	12	20.00	175.00	220.35
14	12	29.27	-	-
16	12	32.49	-	250.10
17	12	37.32	-	-
19	12	39.29	-	-
20	12	41.25	-	-
21	12	48.58	-	525.10
30	12	58.69	-	-

Source: ARB/SSD

as well as for valves and dampers is accounted for in the contingency factor. Material costs were estimated using Tables II-1, IV-2, and IV-3 as follows:

For 5-100k gallon white wine tanks

4 in.	369 ft @ $5/ft		[124 ft + (5 x 49 ft) = 369 ft]
	10 ells @ $20.40/ell		
	5 tees @ $48.70/tee		
Subtotal:	$2,292		
6 in	20 ft @ $6.50/ft		
	1 tee @ $70.80/tee		
	Subtotal $200		

Grand Total: 2,292 + 200 = $2,492

3. Installation Costs

Installation costs were estimated using Figures 13-10 through 13-13 (pp. 532-4) in Peters and Timmerhaus. The figures give installation hours for straight piping, ells, and tees. A labor cost of 40 dollars per hour was also used.

Crane costs of 800 dollars per 400 feet of ducting ($800 minimum cost) were added to the installation costs.* Installation costs were estimated as follows:

* Personal Communication with Ron Hill, Department of Water Resources

For 5-100k white wine tanks

4 in. [369 ft X .28 hrs/ft + 10 ells X 6.4 hrs/ell + 5 tees X 10 hrs/tee] X $40/hr = $8,693

6 in. [20 ft X .36 hrs/ft + 16 hrs/tee X 1 tee] X $40/hr = $928

Crane $800

Total Costs: 8693 + 928 + 800 = $10,421

4. Supports

In determining the cost for supports, a deflection limit was first chosen. A limit of 0.125 inches under a full load of water was suggested by Bob Calvin, an engineer for Heublein Wines. Felker Brothers supplied information on distances between supports for various deflection limits.* The distances for a 0.125 inch deflection are listed in Table IV-4.

The number of supports was estimated by dividing the total length of ducting for each diameter by the distance between supports.

The support material used for cost estimates is 3 inch steel piping. A 10 foot steel pipe can support a 36,000 pound load which greatly exceeds the maximum load of roughly 8,000 lbs between supports for a 30 inch diameter duct filled with water (10-300k gallon red wine tanks). Furthermore, the total length, including that of vertical ducting, was included in the

* Pipe Support Data Span - Deflection Relationship and Stress-Span & Deflection Relationship for Felkerweld Stainless Tubing (Pipe), Felker Brothers Corp., Corrosion Resistant Products, Marshfield, Wis.

Table IV-4: Distance Between Supports

Diameter Inches	Gauge	Distance Feet
4	14	12
6	14	14
8	14	16
10	12	19
12	12	21
14	12	22
16	12	23
17	12	23
19	12	24
20	12	24
21	12	25
30	12	27

calculation for number of supports. Vertical piping constitutes 30-40 percent of the total piping. These factors would make the estimates conservative enough to cover part of the contingency costs for the supports such as collars and labor for assembling supports.

The mass of steel piping required per support (75.8 pounds) was calculated from Table 6-4 of Simplified Engineering for Architects and Builders.* Costs of steel are approximately $2/lb.** The cost of the supports was calculated from these data and Tables II-1 and IV-4 as follows:

For 5-100k gallon white wine tanks

Length of 4 inch duct: 369 ft

Length of 6 inch duct: 20 ft

Number of supports: 32.2 (369/12 + 20/14 = 32.2)

* H. Parker, Simplified Engineering for Architects and Builders, Fifth Edition, John Wiley and Sons, New York, 1975, p. 167.

** Personal Communication with Ron Hill, Department of Water Resources

Cost of supports: \$4,880 (32.2 X 75.8 lbs/support X \$2/lb = 4880)

Installation and painting of the supports are assumed to be completed by subcontractors. The costs for installing and painting the supports are estimated to be 5 percent* of the fixed capital costs.

5. Foam Separator Costs

Costs for the foam separator were scaled from the cost estimate done by Bob Calvin, for a foam separator in a ducting system for carbon adsorption, which was \$42,400 for a 4,220 cfm flow rate. The costs were scaled according to flow rate and inflated from 1983 dollars to 1985 dollars using the Chemical Engineering (CE) cost index**. The following formula was used:

$$\text{Cost of equipment} = \frac{1985\$}{1983\$} \times \$42{,}400 \times (\text{flow rate}/4{,}220)^{.49} \text{ where}$$

1985\$/1983\$ = 324.9/316.9

The factor .49 is used for centrifugal separators.***

A sample calculation is shown below to demonstrate the use of this formula.

* Estimated by using subcontractor conversion factors, K.M. Guthrie, Process Plant Estimating Evaluation and Control.

** Chemical Engineering, September 30, 1985, p.7.

*** M. Peters and K. Timmerhaus, op. cit., p. 167.

For 5-100k gallon white wine tanks

Flow rate - 314 cfm

Cost of equipment - $12,170

$$1.025 \times \$42,400 \times (314/4220)^{.49} = \$12,170$$

6. Clean-In-Place Costs

Costs for clean-in-place were scaled by ducting footage from the price quotation given by Bob Calvin in 1983. The price quote is $83,375 for 800 feet of main ducting plus an unspecified amount of branch ducting for the 20 tanks. From the schematic attached to Mr. Calvin's letter, the length of ducting branching to each tank appeared to be about 30 feet. Thus, the total length of ducting is about 1400 feet. The clean-in-place costs for each scenario were based on the total footage of all duct work 8 inches and over. Eight inches was chosen as a cut-off because wineries are presently not using clean-in-place on fermentation tank pipelines, all of which are under 8 inches. Finally, the costs were inflated to 1985$ using the CE cost index.

The formula used to scale costs is based on the six-tenths rule-of-thumb.

$$\text{Cost} = 1985\$ / 1983\$ \times \$83,375 \times (\text{ft. of ducting} / 1,400 \text{ ft.})^{.6}$$

For the scenario of 10-100k gallon white wine tanks the cost would be calculated as follows:

ducting length 8 inches and over: 20 ft

cost = 1.0252 X 83,375 X $(20 / 1{,}400)^{.6}$

cost = $6,700

7. Blower Costs

Blower costs were estimated using Figure 13-52 (p. 562) from Peters and Timmerhaus. Figure 13-52 gives costs for a 3 psi turboblower which should have adequate power to overcome pressure drop losses across the ducting and control equipment. After obtaining the purchase costs (in 1979$), the values were inflated to 1985$ using the CE cost index. Installation was assumed to be 60% of the purchase price.* The following formula was used to estimate 1985 costs:

1985 installed cost = 1.6 X 1985$ / 1979$ X (1979 purchase cost)

For the 5-100k gallon white wine scenario, the 1985 installed cost is $5,400 (1.6 X 324.9 / 238.7 X 2,500 = 5400).

8. Summary

The ICC is 1.5 times the sum of the costs from items 2 through 7 (the factor 1.5 is discussed in Section I-A). The ICCs do not include the cost for installing and painting the supports. The cost for installing and painting the supports is added during the calculation of the FCC. ICCs are summarized in Table IV-5.

* M. Peters and K. Timmerhaus, op. cit., p. 169.