FINAL REPORT

CHARACTERIZATION OF ETHANOL EMISSIONS FROM WINERIES

Submitted to:

Research Division
California Air Resources Board

on

July 19, 1982

By:

EAL Corporation

Principal Investigators:

Mr. David R. Fielder (Technical Services Manager)
Mr. Philip A. Bumala (Air Program Manager)

Reference:

Mr. Joseph A. Pantalone (Contract Officer)
California Air Resources Board Agreement
No. AO-071-31

EAL Work Order No. 64-6003

ABSTRACT

Introduction

Wine industry ethanol emission factors have been determined with emphasis on the fermentation process and fugitive emissions. Information has been gained from winery surveys, an extensive literature search, and actual source testing of fermentation exhaust streams and suspected fugitive emission sources. Wine production in California may be characterized by methods and materials employed in two general regions. One is the warm Central Valley where the larger standard table and dessert wine producers typically harvest and ferment high sugar content grapes. In contrast, the northern coastal counties and Napa Valley are conducive to the production of premium wines, which are made from slower maturing grapes, grown in a unique microenvironment of moderate temperatures and sunshine.

Review of Problem

The California Air Resources Board has determined that ethanol emissions from winery production and storage processes may significantly contribute to the formation of ozone through photochemical smog reactions[1)]. The primary source of these emissions is ethanol entrainment by carbon dioxide during the fermentation process. However, emissions will occur from any other process or situation where wine is exposed to the air, such as in transferring or racking, blending, and storage utilizing porous materials. Factors affecting the degree of ethanol emissions include fermenting parameters, process equipment design, and handling techniques and temperatures.

Finally, since the ARB is concerned with control of organic emissions, particularly in areas of non-compliance with the national ambient air quality standards, appropriate control techniques must be determined to limit present and potential emissions of ethanol from the wine industry. Control strategies may well prove advantageous to the industry when abatement is non-destructive, effectively serving as a resource recovery system.

ACKNOWLEDGEMENTS

The following personnel and organizations were most helpful in providing information and/or allowing access to their facilities for surveys and testing:

Mr. Kazuo Sanbongi	Manager, Process Department	United Vintners Madera
Mr. Joe Rossi	Winemaker	United Vintners Madera
Mr. Al Del Bondio	Operations Manager	United Vintners Oakville
Mr. Timothy Mondavi	Executive Vice-President	Robert Mondavi Oakville
Ms. Kristi Koford	Production Enologist	Robert Mondavi Oakville
Dr. James Vahl	Technical Manager	Robert Mondavi Oakville
Mr. David Sicherman	Plant Manager	Paul Masson Madera

Additional personnel who assisted with this project include Farshid Salamati (EAL), Ben Stackler (EAL), John Lawton (EAL), Charles Parrish (EAL), Jayant Shringarpure (EAL), Elizabeth Minor (EAL), John Tan (EAL), and Jane Anderson (EAL).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION I

INTRODUCTION

STUDY APPROACH

The project objectives were:

- To perform an ethanol survey of selected wineries and blending and storage facilities.
- To determine the effect on ethanol emission rate and amount of the type of wine being produced, the type of yeast utilized, fermentation time and temperature, and the fermenting equipment design.
- To perform source and fugitive emission tests at selected wine industry facilities to obtain actual emission data per ton of fermentation feed stock and per unit of fermentation time.
- To determine the ethanol emissions from storage involving porous materials, and handling operations including transfer, blending and bottling.
- To review and discuss potentially applicable control technology for the reduction of ethanol emissions from industry processes.

In order to meet these objectives, a technical plan was followed beginning with consultation with experts in the wine industry. The exchange of information greatly assisted the subsequent literature search. The literature search formed the basis from which a winery survey was conducted. Detailed inspections of facilities and a continued dialogue with winemakers and plant managers eventually led to decisions on sampling locations.

METHODS

Sample Collection

An extraction method was employed in which a known volume of gas, withdrawn from the fermentation exhaust stream, was bubbled through a series of three large Greenburg-Smith impingers. The first two impinger collections were separated from the third in order to verify an acceptable collection efficiency.

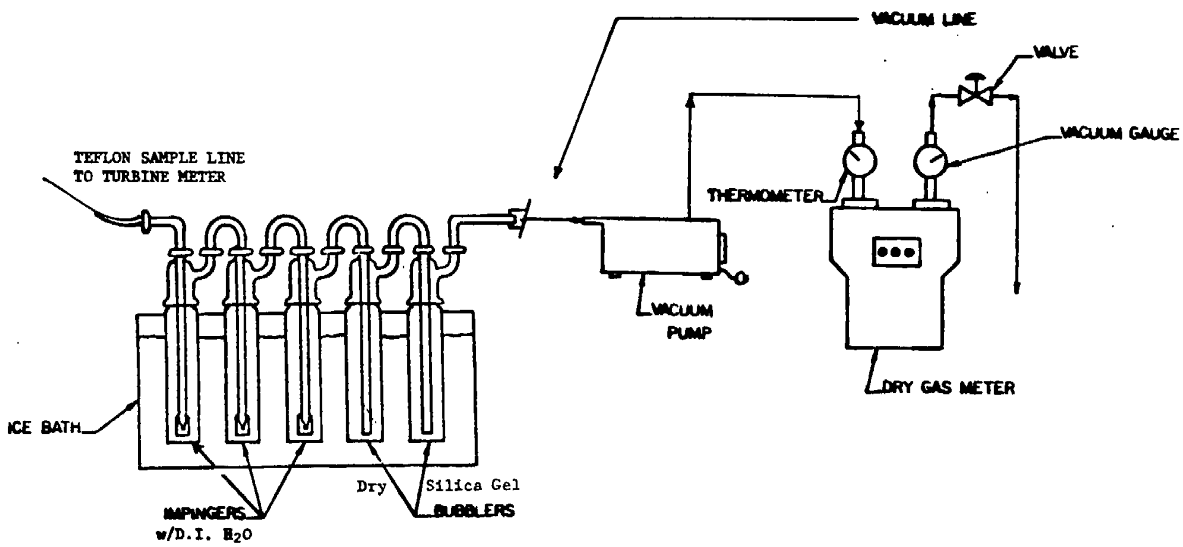
EAL personnel had previously conducted a large scale emission test of an acetator tank in Oakland, California. The process involves heating a solution of 6% acetic acid and 6% ethanol to 86°F while blowing air through it at a rate of 170 m^3 per hour over a 32 hour period. Oxidation of the ethanol occurs to produce an end product containing 12% acetic acid and 0.5% ethanol. These conditions closely approximate those of a wine fermentation tank.

Our sampling train for the acetator test consisted of a set of three impingers containing 100 mL each of a 0.1M NaOH solution (NaOH added to assist acetic acid absorption). Subsequently, the contents of the first two impingers were analyzed separately from that of the third to check absorption (capture) efficiency. The first four samples collected, during the initial high alcohol content portion of the cycle, had an average collection efficiency of 92% in the first two impingers. This information, coupled with the statistical evaluation of impinger collection efficiences contained in the JAPCA article "Estimating Overall Sample Train Efficiency" demonstrates that for the complete three impinger train, an overall collection efficiency of greater than 99% was achieved (1).

A sample interface and all connections were made of glass and teflon. A thorough leak-check of the collection train was performed prior to each test at a 10" Hg vacuum for sixty seconds with a maximum tolerance of 0.02 ft^3 of volume change. The sampling rate (cubic feet/min, cfm) test duration and dry gas meter conditions were carefully monitored (Ref. Figure 1). All the procedural items considered, the collection method had the advantage of simplicity, proximity to the source (minimizing ethanol wall losses and chances of leaks with a long sample line), and virtually no problem with entrained moisture.

FIGURE 1

ETHANOL GAS SAMPLING TRAIN



SAMPLE COLLECTION FIELD DATA

Date:________________ Analyte:________________

Client:________________ Collection Medium:________________

Location:________________ Ambient Temp.:________________

Process Operation:________________ Ambient Pressure:________________

Collected By:________________

Run Number	Time	Sample Volume	Temp. Met.	Pressure Met.	Sampling Rate	Duration (min.)	Comments

Fugitive Emissions

Samples were collected for fugitive ethanol emissions using the same impinger train illustrated in Figure 1, omitting the sample line and locating the train in selected sites for area sampling.

Analytical procedures were identical to those mentioned for source sampling.

A number of process handling procedures were evaluated and ethanol fugitive emissions estimated based on building ventilation and production activity during testing.

SECTION II
RESULTS

Introduction

Wine is the product of the partial or complete fermentation of the juice of grapes. The majority of ethanol emissions from wineries occurs during the fermentation process. That fact is supported by two factors. The first is that as the carbon dioxide produced during fermentation is allowed to escape from the tanks, it entrains ethanol in the form of suspended droplets[4]. There is a trend in California towards the use of closed tank fermentation. However, tanks that are capable of being closed frequently operate throughout the fermentation cycle with open hatches, and thus cannot truly be considered closed tanks. Open tank fermenters allow ambient air to contact the pomace cap present in red wine fermentation, and thus supplement ethanol entrainment emissions with evaporation emissions. At least one study shows negligible emissions due to evaporation from open tanks[4]. Aeration or pump recirculation of the fermenting must would accelerate emissions, particularly evaporation if aeration is employed. The pomace cap can also be expected to increase emissions by increasing the surface area. The second factor is fermentation temperature. The temperature at which fermentation occurs is the result of a number of interrelated parameters. Fermentation is an exothermic process. Thus, fermentation tanks must typically be cooled to control the process rate. Fermentation temperature is also critical in maintaining optimum conditions for the yeast. However, yeasts can be acclimated to lower temperature operations[5]. Finally, red wines are typically fermented at temperatures ranging from 70-80°F compared to the 50-60°F fermenting temperatures for white wines[5]. One reason for that disparity is the requirement for color extraction in red wine fermentation[5].

Fermentation tank design contributes to ethanol emissions. The ratio of surface area to total volume of the must would be a factor in determining emission rates. Also, larger tank volumes produce significantly higher fermentation temperatures due to decreased radiative cooling unless the tank is refrigerated. Higher temperatures would promote ethanol evaporation in open and aerated tanks. Tank materials also affect ethanol loss rate with porous concrete tanks losing up to 11.5 times more ethanol than stainless steel tanks [5]. Fermentation duration affects ethanol emissions because carbon dioxide emissions, the primary cause of ethanol emissions by entrainment, cease at the conclusion of fermentation. Thus, production of wines requiring longer fermentation times, specifically wines with the highest initial sugar content, the lowest final sugar content (higher final ethanol content), and wines where color extraction is essential, will result in increased ethanol emissions. Red wine fermentation typically proceeds for an average of one week or less, while whites are fermented for an average of two weeks.

Paul Masson, Madera

Mr. David R. Sicherman, Plant Manager, Paul Masson (Madera) personally conducted us through the Paul Masson (P.M.) facility on August 17, 1981. The P.M. facility is of recent construction. It typically produces 10.5 million gallons of wine from 12 million gallons of juice obtained from 60,000 tons of grapes. Approximately 50,000 tons of grapes are crushed for white and rose wines with the remainder used for reds. All fermentation tanks are stainless steel and range in capacity from 4,000 to 200,000 gallons. However, the majority are 50,000-gallon capacity. Twelve tanks for red wine fermentation are located outdoors and are exposed to both the weather and the sun. The white wine tanks, approximately 100 total, are located in a refrigerated building. There are no bottling facilities at this plant. The fermented wines are stored and blended prior to shipment by truck to P.M.'s bottling facility.

Mr. Sicherman stated that they typically crush fifteen varieties of grapes and utilize a single proprietary yeast in dry cake form for all their fermentations. Thus, there are no emissions from yeast starter tanks. Red wines are fermented during late September and October. The process takes 5 - 6 days at 85-90°F. During fermentation, the tank is pumped-over using a hose/sprinkler system inserted through the two foot diameter manhole on the tank top. The tanks are cooled by external chilled water jackets. White wines are fermented for 7 - 10 days at 50-55°F. Fermentation started August 13, 1981 and continued through September. The tank contents are cooled by external Freon spray chillers. These tanks do not require pumping over.

After fermentation, the juice is centrifuged and/or filtered to remove suspended solids including the dead yeast cells. Subsequently the wine is stored in stainless steel (whites) or redwood (reds) tanks for initial aging. In addition, fortified wines (port and sherry) are brought in from other facilities and stored in 48 gallon oak barrels for 6 months to 3 years. The ethanol content of those fortified wines is 18%. No brandy is produced or stored at this facility.

The P.M. facility has few other sources of ethanol emissions since no bottling is done there. After fermentation, every effort is made to minimize wine/air contact to decrease oxidation of ethanol to acetic acid.

United Vintners, Madera

Mr. Kazuo Sanbongi, Process Department Manager at United Vintners (U.V.) Madera facility, discussed their operations with us and conducted us through the plant on August 17, 1981. He stated that they crush approximately 100,000 tons of grapes per year of which 60,000 tons are Thompson Seedless. The 100,000 tons of grapes are expected to produce approximately 19.5 million gallons of juice and 17.2 million gallons of wine.

All the fermentation tanks are stainless steel with typical capacities of 350,000 gallons for whites and 130,000 gallons for reds. There are four 656,000 gallon fermentation tanks which utilize various winery residues to produce material for U.V.'s distillery operation. Those tanks produce a 2.5% alcohol product. In addition, there are champagne fermentation tanks which are sealed pressure vessels to preserve natural CO_2. A single variety of yeast (Montrachet) is utilized by starting it in a 305,000 gallon fermentation tank and withdrawing aliquots for innoculation of other tanks. The sugar level in the yeast tank is maintained between 5-15% by repeated additions of raw juice.

All fermentation tanks are refrigerated by external water or ammonia heat exchangers. The red tanks are kept at 80-85°F and the whites at 55°F. Fermentation for whites began August 10, and was expected to last into the middle of September. Red fermentation started in late September and continued through October.

After fermentation, the red wine is pumped over an open screen to remove the pomace. This practice would produce ethanol emissions from exposure of the wine to ambient air. Subsequently both reds and whites are filtered and/or centrifuged prior to storage.

The bottling facility has eleven bottling lines that operate at various times and shifts throughout the year. Immediately prior to bottling, the wines are filtered using plate-and-frame (PF) or membrane (Millipore) filters. The PF filters use a demand-type supply tank which is open to the room air (loosely covered) and is thus a source of ethanol emissions. The bottling lines utilize pressure or gravity feed filters which minimize exposure of the wine to room air. Nine of the lines use metal caps while 2 use corks for sealing the bottles. Measurements of the room air indicated 100-300 ppm ethanol.

This facility turned out to be the preferred Central Valley test location primarily because of the amenability of U.V. to minor modifications in their tank outlet systems to permit exhaust flow measurements and sampling. Also, the red wine tanks are pumped over internally and require no direct access during the fermentation cycle. The only perceived drawback was the potentially short white crushing season due to the early grape maturation and diminished U.V. purchases that year.

The United Vintners Madera facility was chosen for initial source testing. Mr. Kaz Sanbongi was extremely helpful in providing fermenter tank fitting adapters to facilitate connection of our test apparatus. In addition, both Mr. Sanbongi and Mr. Joe Rossi, winemaker, were able to arrange fermentation schedules and procedures which assisted our personnel with their tests.

The first tank tested was for white wine in number 576, a stainless steel tank with a capacity of 350,136 gallons. The major problem encountered with this test was that the record breaking prematurity of the crushing season throughout California, coupled with an unusually small harvest, meant that it was almost too late to get any white wine grapes to test [6]. Also, the daily amount of grapes crushed was so low that must was typically being added to fermentation tanks throughout the fermentation period to achieve a reasonable final fermentation volume. Adding fresh must during a test would have seriously jeopardized the usefulness of the data. This scheduling/production volume problem was a factor throughout the white wine testing phase. The testing team was faced with both an unexpected schedule and the necessity, through lack of choice, to test fermentation batches that were less than ideal due to accessibility and mechanical arrangement or because the batch subsequently did not follow ideal fermentation behavior. With the assistance of the U.V. personnel mentioned, we obtained a full tank of must by combining some cold unfermented must stored from the previous day's crush with ambient temperature must obtained that day. Testing commenced at 7 a.m. on September 9, 1981, and was completed at 12 noon on September 16, 1981. All samples were successfully shipped and analyzed.

The red wine fermentation tank chosen for testing had a capacity of 128,000 gallons. The tank was filled and innoculated on September 14, 1981, and testing commenced immediately. Due to our desire to measure the total emission volume from this tank, we attached the 6-inch ARB turbine meter to one of the 4-inch sampling ports, closed the 2-foot manhole cover, and relied on the remaining 4-inch pressure relief valve to protect the tank in case of over pressurization. Normally, the manhole is left open throughout the fermentation process. Our procedures and installation were observed by

U.V. personnel with no objections. We believed that in the event that the turbine meter flowrate capacity was exceeded, excess exhaust gas would escape through the pressure relief valve. However, instead of a relatively harmless release of vent gases, the fermenting must foamed over and shot out through both the turbine meter and pressure relief valve at approximately midnight Tuesday evening, September 15, 1981. An estimated 1,000 gallons of must were lost and U.V. personnel aborted the fermentation, and our test, the next morning. Subsequently, it became apparent that with the sudden release in pressure caused by the relief valve opening, the must acted like champagne and essentially "boiled over." This mishap placed a serious strain on our relations with U.V. personnel, although no one had forseen this occurrence.

Joe Rossi felt committed to our achieving a successful red wine test and agreed to arrange a second attempt. A similar tank was fitted with both ARB turbine meters, one on the sampling port and one on the pressure relief valve port (with the valve removed). The second turbine meter had just become available due to completion of the white wine test. In addition, the manhole cover was to be opened periodically for a few seconds throughout the test to guard against the initiation of foaming. Exhaust flow measurements were taken frequently to allow interpolation of exhaust volumes over the brief periods that the hatch was lifted. This test was completed successfully.

Detailed results of these tests are contained in the following figures and tables.

TABLE 2

PHYSICAL PARAMETERS
Tank #576
White Wine Fermentation

Tank Material: Stainless Steel

Fermentation Tank Dimensions

12 inch bottom cone

24 inch top cone

480 inch shell (height)

Gallons per inch = 711.4

Total tank capacity = 350,110 gallons
Actual capacity = 280,000 gallons

Temperature Control

Chiller temperature set point (°F) = 57 in/56 out

Fermentation Period

Beginning September 9, 1981 ... through September 16, 1981

Total Hours = 172

Total volumetric exhaust flow = 1,549,940 actual cubic feet @ turbine meter.

TABLE 3

White Wine Fermentation Exhaust Ethanol Emissions

Tank No. 576
Capacity (gals): 350,110
Actual (gals): 280,000
Location: United Vintners(Madera facility)

Run	Time (Day/hrs)	Exhaust Flow (acfm)	Ethanol ppm-vol	Ethanol Emissions (lbs/hr)	Cumulative (lbs)	Run	Time (Day/hrs)	Exhaust Flow (acfm)	Ethanol ppm-vol	Ethanol Emissions (lbs/hr)	Cumulative (lbs)
1	1/0800	0.0	-- (1)	--	0	26	4/2009	243.7	3625	6.2	183.6
2	1/1123	0.0	27	0.0	0	27	4/2304	233.9	3882	6.3	205.6
3	1/1500	0.0	12	0.0	0	28	5/0200	225.9	3632	5.8	234.4
4	1/1730	0.0	36	0.0	0	29	5/0909	210.0	3582	5.3	255.5
5	1/2010	0.0	70	0.0	0	30	5/1030	223.2	3409	5.3	266.2
6	2/0019	0.0	152	0.0	0	31	5/1306	218.5	3886	5.9	283.9
7	2/0213	6.3	37 (1)	0.0	0	32	5/1600	223.8	3891	5.8	307.2
8	2/0800	44.5	735	0.2	0.2	33	5/2052	209.8	3891	5.7	327.0
9	2/1000	61.2	563	0.2	0.8	34	5/2300	208.6	3775	5.5	338.0
10	2/1300	70.7	768	0.4	1.9	35	6/0200	182.6	3918	5.1	263.3
11	2/1600	82.5	745	0.4	3.4	36	6/0834	198.3	4256	4.8	394.6
12	2/2020	93.9	822	0.5	5.3	37	6/1214	186.0	3796	4.9	406.9
13	2/2300	118.7	1065	0.9	8.0	38	6/1341	209.2	5416	7.8	418.6
14	3/0200	138.1	1156	1.1	13.0	39	6/1600	216.0	5847	8.8	457.8
15	3/0800	156.6	1346	1.5	19.7	40	6/2000	247.0	5662	9.7	486.8
16	3/1123	176.3	1543	1.9	24.4	41	6/2300	198.2	6422	8.8	504.4
17	3/1300	192.5	2354	3.2	30.7	42	7/0200	218.9	6987	10.6	557.6
18	3/1621	177.3	1787	2.2	41.7	43	7/0830	188.1	5861	7.6	595.7
19	3/2048	190.8	2122	2.8	50.2	44	7/1100	175.7	6483	7.8	611.3
20	3/2300	198.6	2407	3.4	56.9	45	7/1304	169.3	5914	6.9	642.2
21	4/0220	222.8	2692	4.2	82.3	46	7/1945	153.2	6131	6.4	677.4
22	4/0913	232.2	3431	5.6	118.4	47	7/2300	141.4	6490	6.3	696.5
23	4/1050	242.2	3409	5.5	135.0	48	8/0300	55.8	6050	2.4	708.3
24	4/1300	248.7	600 (1)	5.5 (2)	151.6 (2)	49	8/0833	28.8	5015	1.0	712.3
25	4/1600	231.3	3397	5.5	168.2	50	8/1200	19.8	4273	0.6	713.5

(1) *Run is suspect.*

(2) *Although the sample run was suspect, the emissions rate (lbs/hr) and cumulative values were generated using the best estimate between runs 23 & 25.*

Figure 2

WHITE WINE FERMENTATION EXHAUST ETHANOL EMISSIONS

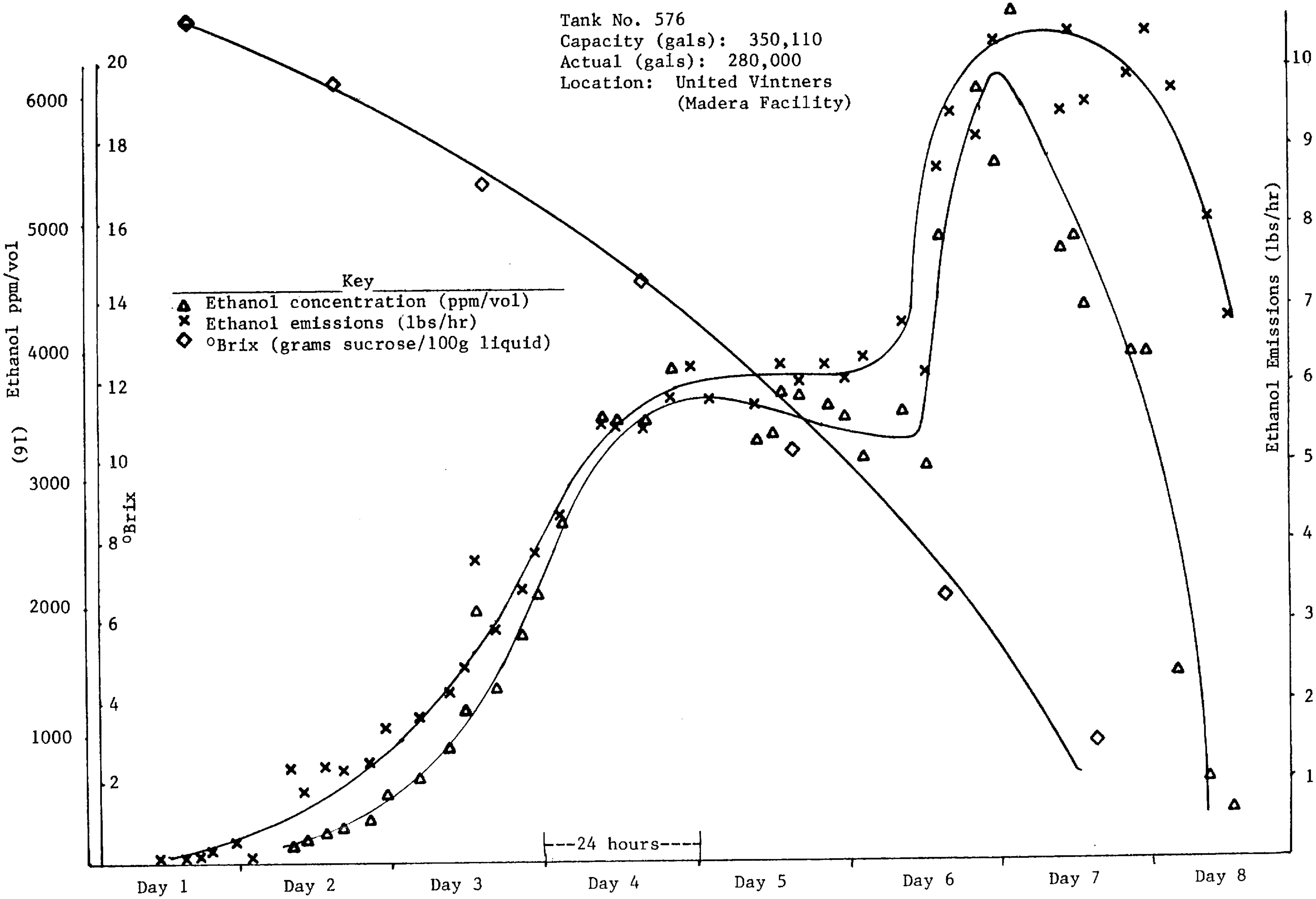


Figure 3

WHITE WINE FERMENTATION VOLUMETRIC EXHAUST FLOW

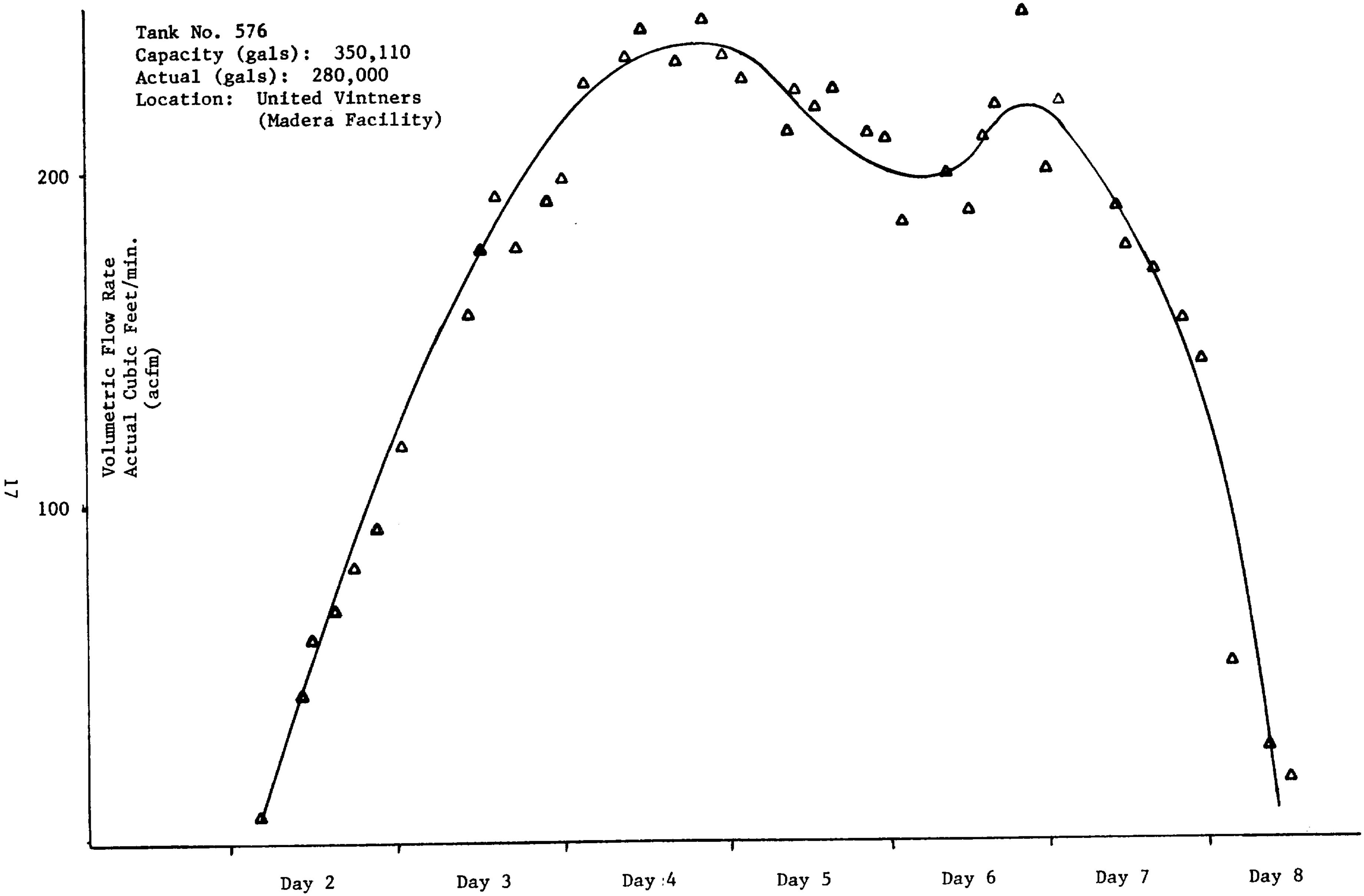


TABLE 4

PHYSICAL PARAMETERS
Tank No. 5
Red Wine Fermentation

Tank Material: Stainless Steel

Tank Dimensions: 24 inch bottom cone
12 inch top cone
480 inch shell (height)
gallons per inch = 288

Tank Capacity: 128,000 gallons

Actual Capacity: 44,000 gallons

Temperature Control: 1st 4 hrs @ 82°F
2nd 4 hrs @ 72°F
remaining 18 hrs 85°F

Fermentation Period:

Beginning September 17, 1981 through September 18, 1981

Total Hours = 26

Total Volumetric Exhaust Flow = 197380 actual cubic feet @ turbine meter

TABLE 5

Red Wine Fermentation Exhaust Ethanol Emissions

Tank No. 5
Capacity (gals): 128,000
Actual: 44,000
Location: United Vintners, Madera

Run	Time Day/Hours	Exhaust Flow (acfm)	Ethanol (ppm.vol)	Ethanol Emissions (lbs/hr)	Cumulative (lbs)
1	1/1400	0.0	579	0.0	0.0
2	1/1600	71.0	1271	0.6	0.6
3	1/1945	144.0	1098	1.1	4.4
4	1/2300	225.0	3186	4.9	19.2
5	2/0200	250.0	10,094	16.5	101.7
6	2/0900	270.0	17,932	31	256.7
7	2/1145	209.0	14,916	20.4	307.7
8	2/1418	155.0	13,177	13.4	334.5
9	2/1609	94.0	11,147	7.1	341.6

Figure 4

RED WINE FERMENTATION EXHAUST ETHANOL EMISSIONS

Tank No. 5
Capacity (gal): 128,000
Actual (gal): 44,000
Location: United Vintners (Madera Facility)

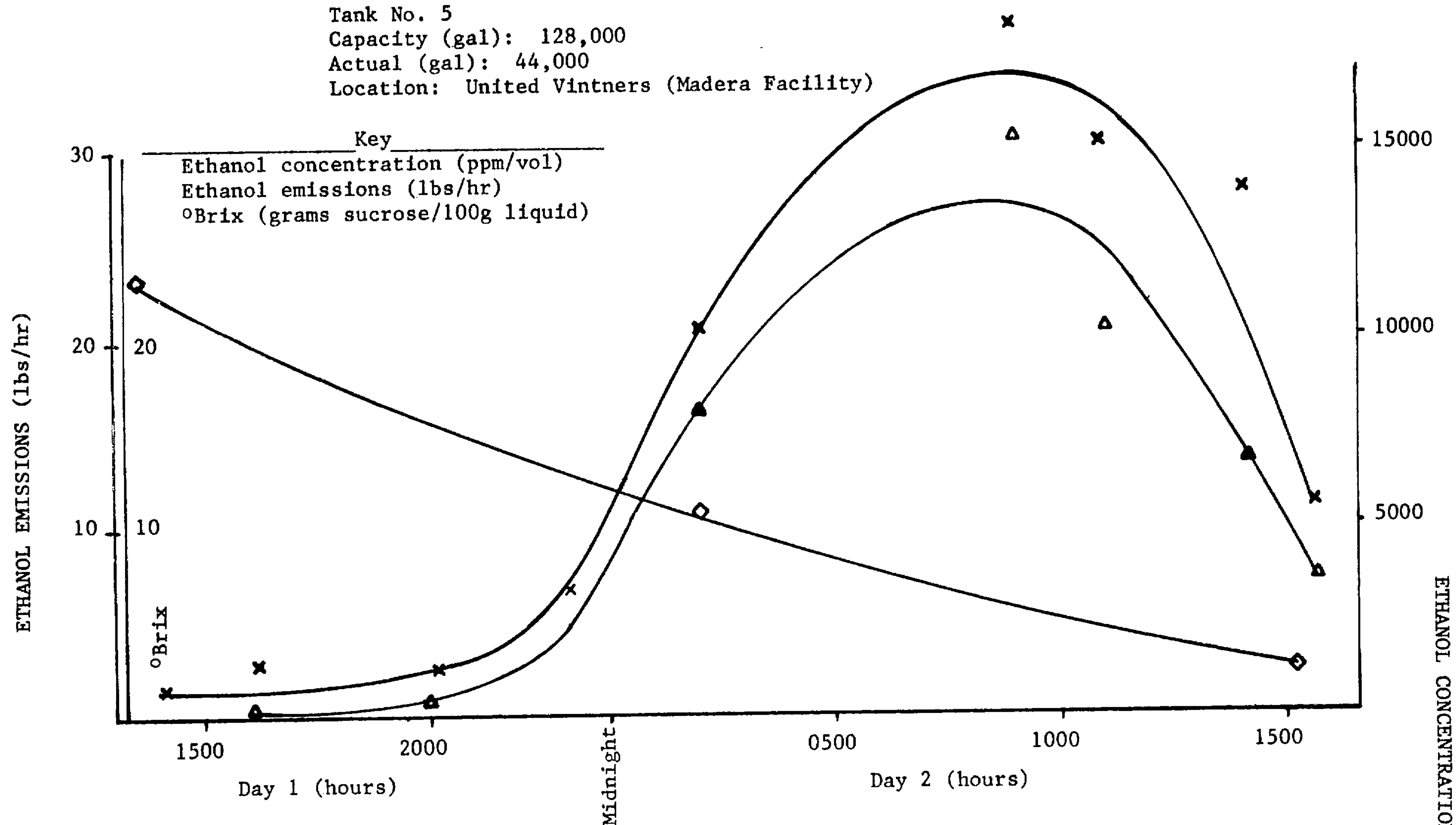
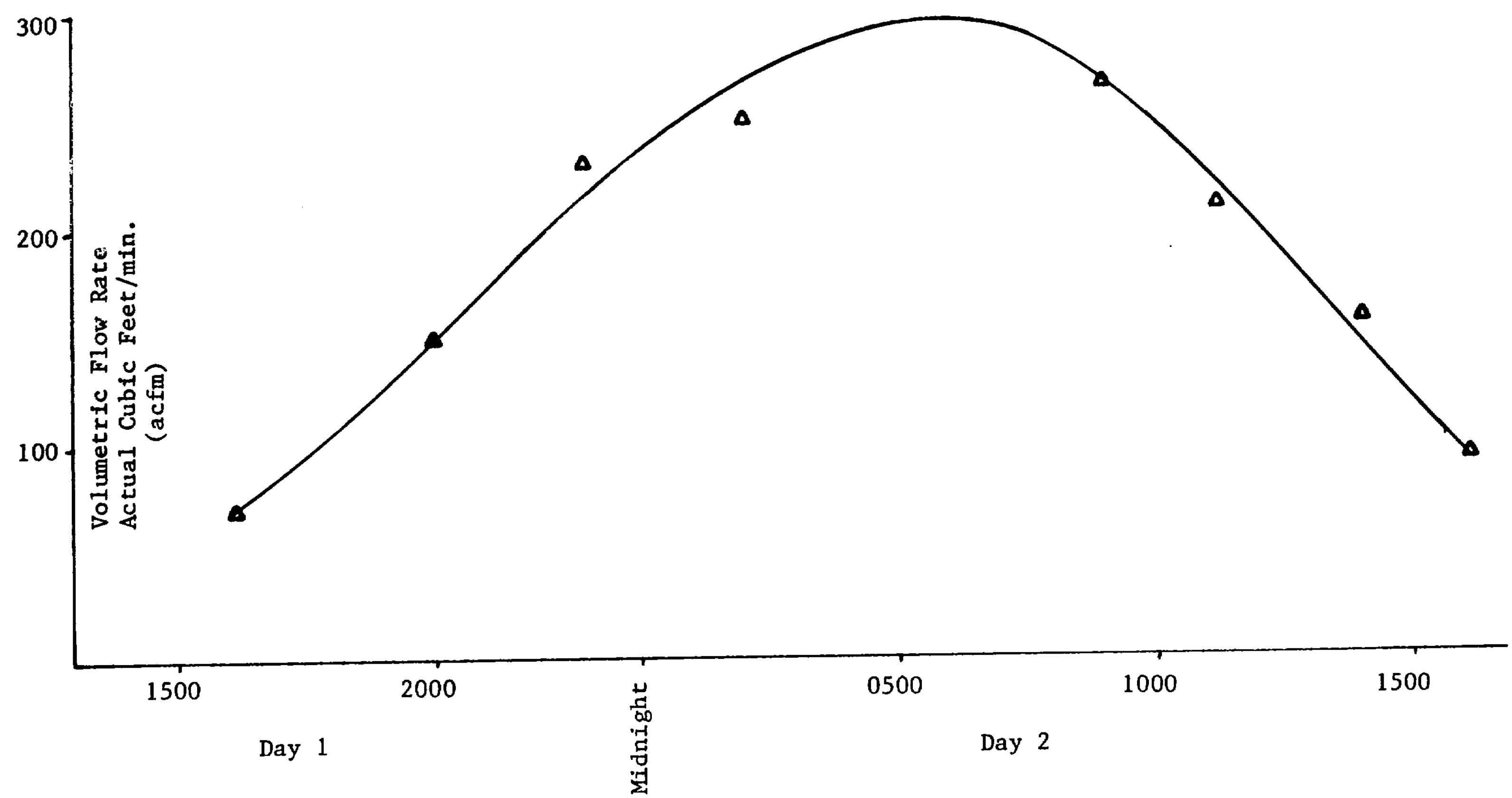


Figure 5

RED WINE FERMENTATION VOLUMETRIC EXHAUST FLOW

Tank No. 5
Capacity (gal): 128,000
Actual (gal): 44,000
Location: United Vintners (Madera Facility)



United Vintners, Oakville

The United Vintners Oakville facility was surveyed on August 25, 1981. It is managed by Mr. Al Del Bondio. They expected to crush approximately 8,000 tons of grapes in 1981 and to produce about 1.46 million gallons of juice from that crush (180-185 gal. per ton). Approximately two-thirds of the crush was for reds and one-third for whites. Whites were being crushed until early October while reds were crushed from mid-September through October. United Vintners uses Montrachet dry yeast for all its fermentations with a starting tank providing aliquots for subsequent innoculations. Reds are fermented for 4-6 days at 78-85°F. The red wines are pumped over manually with a hose through a manhole cover twice a day.

After fermentation, the wines are centrifuged and filtered (plate and frame) as necessary for clarification. There is no post-fermentation aeration of reds as at Robert Mondavi.

The fermentation tanks range from 6,000 to 30,000 gallon capacities. There are 36 epoxy lined outdoor concrete tanks used for white and rose wine production.

There are 6,000 gallon stainless steel and 20,000 gallon concrete tanks indoors for reds. The steel tanks have four foot manholes which are normally open during fermentation. The concrete tanks have 3 foot square wooden access covers with a rubber seal as well as a 3 inch pipe with threads.

The question of rotting fruit dumps and potential fugitive ethanol emissions has been settled with respect to the wineries. None of the four wineries surveyed permits rejected fruit to remain at their facility. The grapes received are immediately crushed and separated from the stems. For red wine, the de-stemmed must (grape skins and meat) is fermented directly, with the skins and other solids rising to the top of the mixture to form the pomace cap. Subsequently, the fermented free-run juice is pumped off and the lees (essentially the pomace cap and dead yeast cells) is taken through various extraction steps to remove any remaining liquids of value. Depending on the quality desired, the material extracted from the lees, and the extent of that extraction will vary, with the liquid product used for wine or crude distillation material. The resulting solids are dry and sugar free, eliminating any further significant fermentation. The dried lees/ pomace are sold for fertilizer or cattle feed. White wine must is extracted prior to fermentation to reduce skin contact. However, similar extraction procedures are employed and the final product is again dry and non-fermentable.

Because of the crushing season problems discussed earlier, it was vital to immediately commence fermentation tests at the Napa Valley winery. Mr. Al Del Bondio of United Vintner's Oakville facility had prepared suitable tank adapter fittings for our equipment. We arrived on site September 24, 1981. Mr. Del Bondio said that U.V. Oakville could not obtain sufficient white wine grapes to fill a tank prior to fermentation. Thus we would be required to use a tank being added to throughout the test. In addition, the expected fermentation period for white wines at this facility was 3-4 weeks and could not be significantly reduced. Those two factors prompted us, with the encouragement of our contract officer, to attempt to perform the white wine test at the Robert Mondavi winery located nearby.

The U.V. Oakville winery test program included two complete red wine fermentation tests. The first test failed to obtain measurable exhaust flow data, invalidating the test results. The second test was a Cabernet Sauvignon fermentation in a 9,000 gallons concrete tank. The tank was fitted with a gasketed hatch. During the two-day fermentation period, the hatch seal was supplemented by placing lead bricks on the hatch. The hatch was opened twice a day for pumping over the pomace cap. Testing was discontinued at those times until the hatch was replaced and pressurized conditions again obtained.

Fugitive emission testing was performed for various locations and processes at U.V. Oakville. Ambient ethanol levels in a barrel storage building were measured. In addition, a combined storage/fermentation building was monitored. Drag screen separation equipment, similar to that utilized at U.V. Madera, was monitored during operation as well as a conveyor assembly transporting fermented lees to the press. A bottling operation at the U.V. Inglenook Rutherford Winery was monitored for fugitive ethanol emissions. That facility was tested because U.V. Oakville does not have a bottling facility and R. Mondavi's was shut down for the season.

Detailed results of the United Vinters, Oakville source and fugitive emission tests are contained in the following figures and tables.

TABLE 6

PHYSICAL PARAMETERS
Tank No. 198
Red Wine Fermentation
United Vintners (Oakville)

Tank Material: Concrete

Tank Dimensions: 144 inch height
140 gallons per inch
Tank Capacity: 9000 gallons
Actual Capacity: 8100 gallons

Temperature Control: 72°F Average

Fermentation Period:

Beginning October 7, 1981 through October 9, 1981

Total Hours: 77

Total volumetric exhaust flow = 80490 actual cubic feet @ turbine meter

TABLE 7

Red Wine Fermentation Exhaust Ethanol Emissions

Tank Number 198
Capacity (gals) : 9000
Actual (gals) : 8100
Location: United Vintners (Oakville Facility)

Run	Time (Day/Hrs)	Exhaust Flow (adcfm)	Ethanol (ppm-vol)	Ethanol Emissions (lbs/hr)	Cumulative (lbs)
1	1/1000	53.5	5846	2.1	2.1
2	1/1400	65.5	5950	2.6	12.5
3	1/1800	57.5	12548	4.7	31.3
4	2/1020	21.0	13390	1.9	74.6
5	2/1210	19.0	13907	1.7	79.7
6	2/1610	14.5	14618	1.4	85.3
7	3/1100	0.0 (1)	10893	0.0	-- (1)
8	3/1600	0.0 (1)	10730	0.0	-- (1)

(1) volumetric flow undetectable.

Figure 6

RED WINE FERMENTATION EXHAUST ETHANOL EMISSIONS

Tank No. 198
Capacity (gals): 9000
Actual: 8100
Location: United Vintners (Oakville Facility)

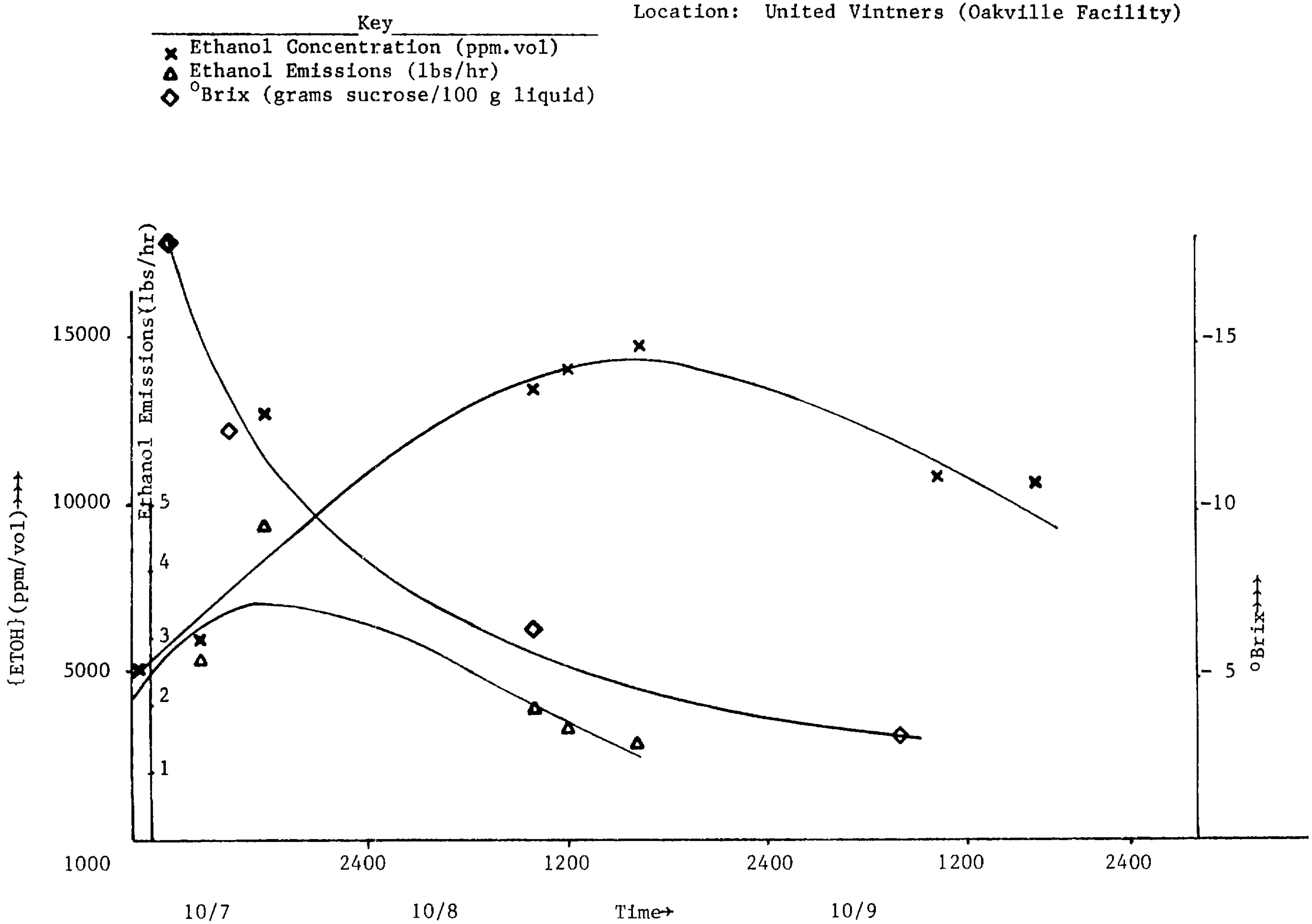


Figure 7

RED WINE FERMENTATION VOLUMETRIC EXHAUST FLOW

Tank No. 198
Capacity (gal): 9000
Actual (gal): 8100
Location: United Vintners (Oakville)

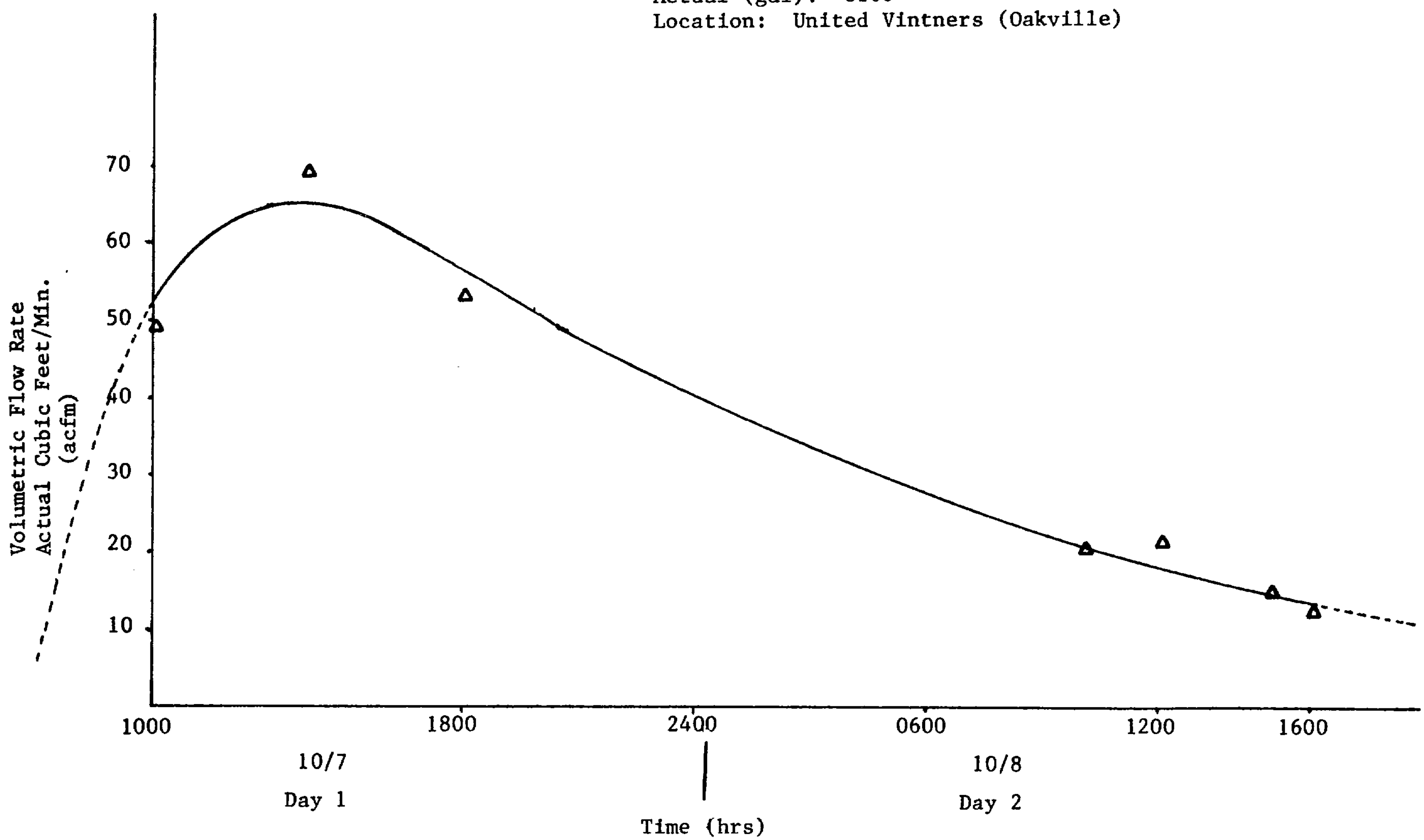


TABLE 8

FUGITIVE EMISSIONS

UNITED VINTNERS (Oakville)

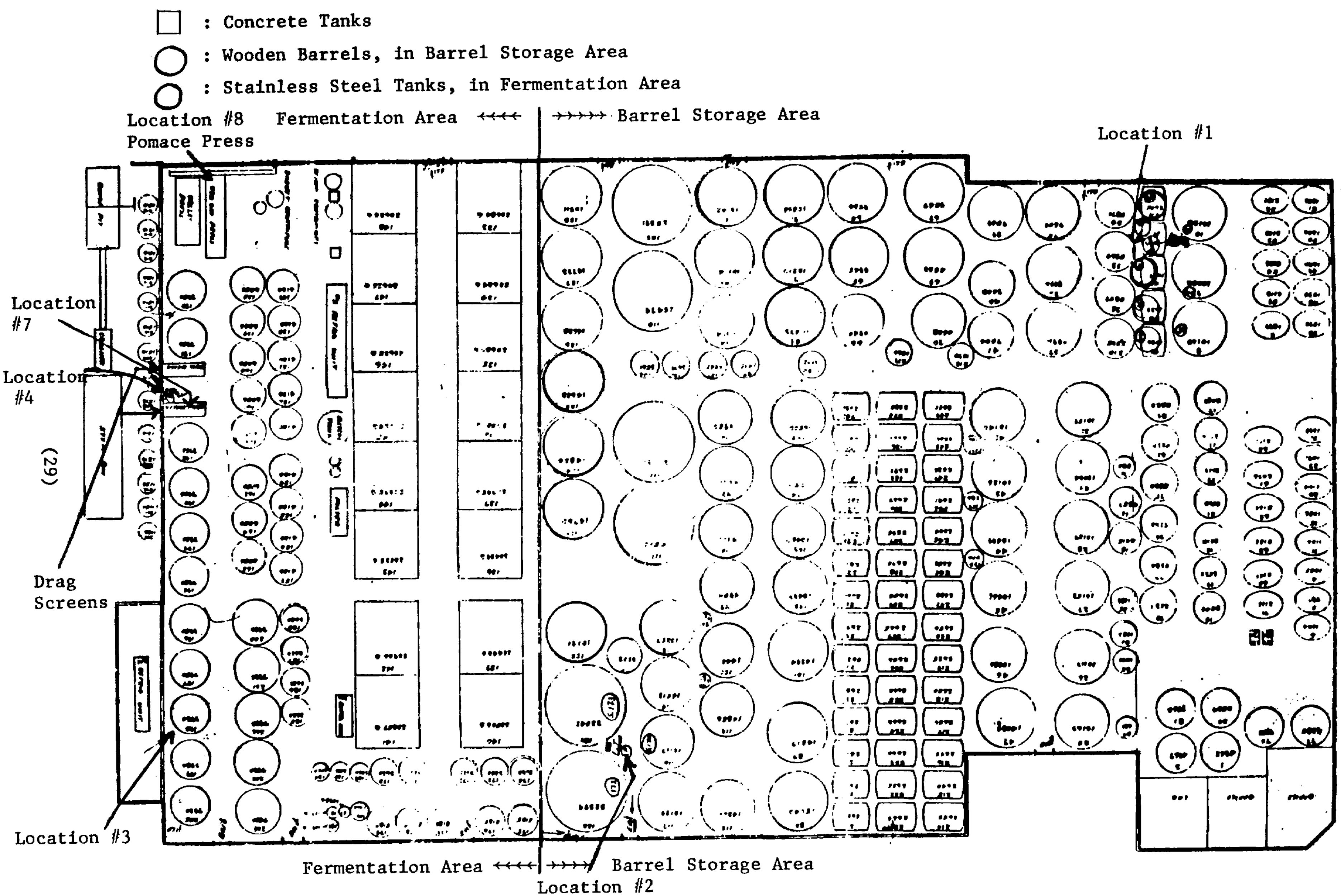
LOCATION	DATE, TIME (Hrs)	ETHANOL (mg/m³)	ETHANOL (grams/hr)	ETHANOL (ppm by vol)	COMMENTS
No. 1	9/25, 1000	0.04	0.003	0.02	Barrel Aging Area Samples (See Figure 8)
2	9/25, 1000	0.05	0.004	0.03	"
1	9/25, 1500	0.05	0.004	0.03	"
2	9/25, 1500	0.05	0.004	0.03	"
3	9/25, 1645	2.2	0.4	1.2	Fermentation area, Approx. 50,000 gals active, 20,000 being "racked out"
4	9/25, 1800	6.5 (1)	1	3.4	
5	9/26, 1300	0.04	0.003	0.02	Cold room storage (no fermentation)
6	9/26, 1430	0.08	0.007	0.04	
7	10/4, 1100	5429	923	2888	Drag Screen
8	10/6, 1000	1134	193	603	Pomace Press

(1) Area approximately 3 ft. away from lees drag screen.

Sample Calculation: $\text{Ethanol(grams/hr)} = \text{ETOHmg/m}^3 \times \frac{1\ g}{1000mg} \times \text{acfm} \times \frac{60\ min}{1\ hr} \times \frac{1\ m^3}{35.31\ cf}$

acfm = actual cubic feet per minute

Figure 8



NOTE: Locations 5 & 6 were in the Cold Storage Building (floor plan unavailable)

TABLE 9

FUGITIVE EMISSIONS

U. V. Inglenook (Rutherford)

LOCATION	DATE/TIME (hrs)	ETHANOL (ppm by vol)	ETHANOL (mg/m^3)	ETHANOL grams /Hr)
Filling Vent Outlet	10/13, 0900	1881	3536	27.2
Corking Vent Outlet	10/13, 1100	348	654	1.8
Room Air	10/3, 1230	17	32	---(1)

(1) no presence of significant turbulance or wind.

Sample calculations:

$$\text{Ethanol Emissions (grams/Hr)} = \frac{\text{ETOH mg}}{m^3} \times \frac{1 \text{ gram}}{1000 \text{ mg}} \times \text{SDC FM} \times \frac{1 \text{ m}^3}{35.31 \text{ cf}} \times \frac{60 \text{ min.}}{1 \text{ hr.}}$$

Robert Mondavi, Oakville

On August 25, 1981, the Robert Mondavi (R.M.) Oakville winery was surveyed. Dr. James Vahl was our contact at Robert Mondavi. Mr. Timothy Mondavi expressed interest in our project and hoped that the data might prove useful to them in the future. Yeast is propagated initially in test tubes ("slants") and continued in fermentation tanks with juice subsequently used for innoculation of other fermentation batches. Approximately six yeast strains are used for their individual characteristics. Two specific examples are Steinberg, used for cold, slow fermentations, and Ashman's, used for high temperature red fermentation.

We discussed the possibility of utilizing cold adapted yeasts for red fermentation and were told by Dr. Vahl that they had experimented and found that the quality of red wine was improved by higher temperatures during fermentation. Thus, their only temperature constraint was to control the speed of fermentation, with higher temperatures preferred up to the limit.

There are 140 stainless steel fermentation tanks ranging from 1,000 to 12,000 gallon capacity. Refrigeration for most tanks is by computer controlled glycol tank jackets. The last 1-2 percent sugar fermentation of some red wines is completed in oak tanks. Red tanks are pumped over 3 to 5 times per day for 20-40 minutes using a hand held hose inserted through the open manhole in the top of the tank. That procedure would have seriously interfered with accurate flow measurements of those tanks. Following fermentation, some red batches (~10%), are aerated to remove excess dissolved CO_2 and H_2S prior to storage. Aeration is accomplished by allowing the wine to splash into an open tank while continuously pumping it out again. Also, centrifuges, plate and frame filters, and racking are used to clarify the wine. The first two processes are similar to those described at the U.V./Madera facility. Racking involves allowing the solids in the wine to settle and pumping the clear wine off of the lees, which are then used as distillation material at another facility.

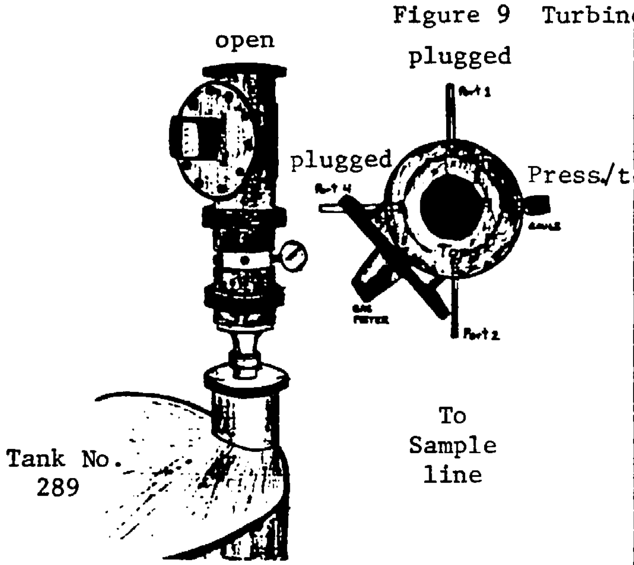
There is a single bottling line at R.M. which utilizes a pressure filling machine (similar to U.V./Madera) with minimal wine/air contact.

Dr. James Vahl assisted us in obtaining a tank with fittings suitable for the adapter Mr. Del Bondio had loaned to us. Also, a supply of Chardonnay grapes, requiring a shorter fermentation period, was available (the last of the season). Testing of a 6,000 gallon tank commenced on Saturday, September 26, 1981 and extended over a twenty-one day period. That test length resulted from the fermentation process "sticking" near the end, resulting in an unusually slow decrease in sugar content. In addition to the fermentation test, storage facility fugitive emissions were monitored as well as the process of aeration, used by quality vintners to remove undesired volatile flavor compounds such as excess H_2S or SO_2. The fermented juice is allowed to splash from a hose into an open trough prior to storage.

Exhaust volumetric flow was undetectable with the turbine meter during the first four days of the twenty-one day fermentation period as a result of the comparatively small volume of fermenting juice (5,800 gals). Consequently, a method was employed in which the top of the meter was sealed, restricting exhaust release to the existing turbine meter sample ports (Ref. Figure 9). Gas flow was measured with a more sensitive dry test meter. Two dry test meters were used in order to provide twice the pressure relief during greater flow activity (Day 5 through Day 10). The tank headspace was permitted to reach a stable temperature/pressure condition before measuring gas flow per unit time (dry cubic feet/min). This procedure permitted reliable measurements while avoiding the "foaming-over" problem encountered at U.V. Madera. At peak fermentation activity, the juice is saturated or super-saturated with carbon dioxide. Increased pressure placed on the system (tank) may cause foaming-over in the event of an abrupt agitation. Although flow was measured on an actual dry basis with the dry test meters, moisture percent was negligible due to the small volume of juice and comparable to typical white wine fermentation exhaust data.

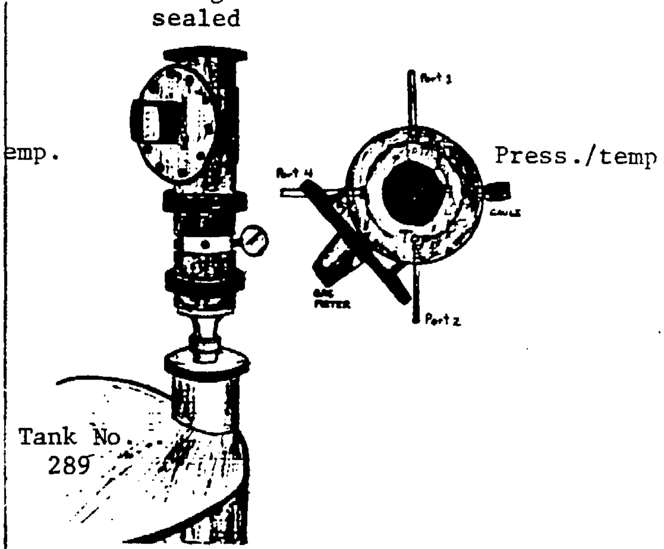
Detailed results of the Robert Mondavi source and fugitive emission tests are contained in the following figures and tables.

Figure 9 Turbine Meter Fittings

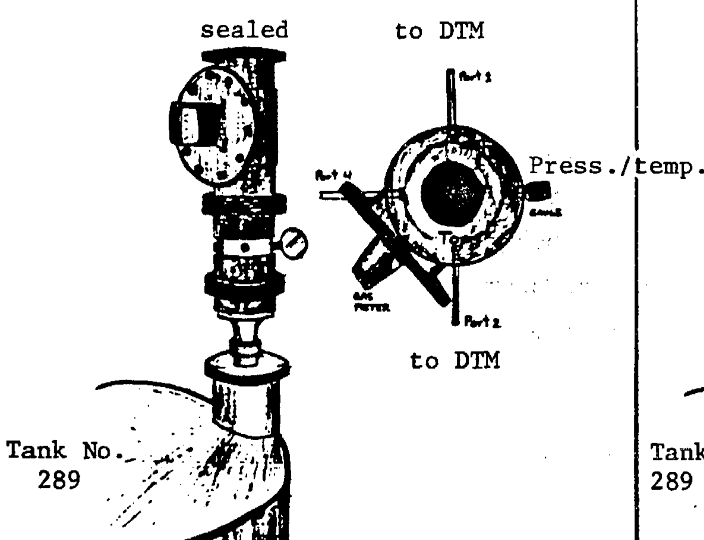


A. Original Operating Mode

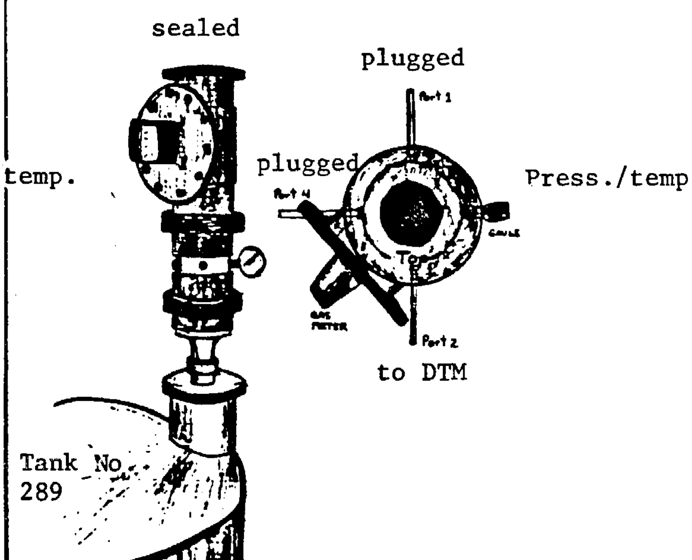
(Days 1-5, exhaust flow undetectable)



B. Modified Approach



C. Modified approach, peak fermentation activity



D. Modified approach, fermentation on downward slope, (i.e., 1 pressure relief sufficient)

TABLE 10

PHYSICAL PARAMETERS
Tank #289
White Wine Fermentation
Robert Mondavi (Oakville)

Tank Material: Stainless Steel

Fermentation Tank Capacity:

Total Tank Capacity = 5,955 gallons

Actual Tank Capacity = 5,800 gallons

Temperature "Control"

Ambient (i.e., tank located outdoors)

Fermentation Period:

Beginning September 26, 1981 through October 16, 1981

Total Hours = 512

Total Volumetric Exhaust Flow = 149 cubic feet

Table 11

White Wine Fermentation Exhaust Ethanol Emissions

Tank No. 289
Capacity (gal): 5,955
Actual (gal): 5,800
Location: Robert Mondavi (Oakville)
Test Start Date: 9/26/81

RUN	Time (Day/Hours)	Exhaust Flow (adcfm)(1)	Ethanol ppm-vol	Ethanol Emissions (lbs/hr)	Cumulative (lbs)
1	1/1027	0.0(2)	9	--	0.00
2	2/0200	0.0	4	--	0.00
3	2/0900	0.0	4	--	0.00
4	2/1214	0.0	6	--	0.00
5	2/1400	0.0	7	--	0.00
6	2/1624	0.0	31	--	0.00
7	2/2000	0.0	527	--	0.00
8	2/2200	0.0	650	--	0.00
9	3/0200	0.0	676	--	0.00
10	3/1000	0.0	663	--	0.00
11	3/1200	0.0	793	--	0.00
12	3/1600	0.0	765	--	0.00
13	3/1800	0.0	782	--	0.00
14	3/2200	0.0	833	--	0.00
15	4/0200	0.0	858	0.000(5)	0.00
16	4/0800	0.0	1696	0.001	0.00
17	4/1200	0.0	2882	0.002	0.01
18	4/1610	0.0	2110	0.004	0.03
19	4/2000	0.0	3511	0.005	0.05
20	4/2300	0.0	1780	0.006	0.06

(1) Actual dry cubic feet per minute
(2) Exhaust flow undetectable with turbine meter.
(5) Interpolated values from chart. (Runs 15-20).

Table 11 (continued)

RUN	Time (Day/Hours)	Exhaust Flow (adcfm)[1]	Ethanol ppm-vol	Ethanol Emissions (lbs/hr)	Cumulative (lbs)
21	5/0200	0.0	1817	0.008[5]	0.11
22	5/1042	0.0	2810[3]	0.011	0.17
23	5/1240	0.5	3416	0.012[6]	0.19
24	5/1450	0.5	4071	0.014	0.23
25	5/1726	0.5	3484	0.013	0.26
26	5/2000	0.5	2660	0.010	0.29
27	5/2400	0.6	2888	0.011	0.34
28	6/0400	0.8	3337	0.014	0.42
29	6/1218	0.8	3895	0.021	0.56
30	6/1637	0.8	3701	0.020	0.65
31	6/2203	0.8	8089	0.042	0.86
32	7/0220	0.8	3313	0.018	0.98
33	7/1123	0.8	8684	0.045	1.23
34	7/1336	0.8	8440	0.041	1.37
35	7/1758	0.8	8986	0.046	1.57
36	7/2207	0.7	5733	0.028	1.68
37	8/0200	0.7	4286	0.020	1.79
38	8/0923	0.7	7282	0.031	1.91
39	8/1330	0.7	9129	0.042	2.04
40	8/1530	0.7	14568[3]	0.063	2.39
41	8/2048	0.7	5631	0.026	2.50
42	8/2400	0.7	5717	0.026	2.58
43	9/0300	0.7	5762	0.025	2.74
44	9/1306	0.7	6984	0.031	2.94
45	9/1552	0.7	9046	0.040	3.09
46[4]	9/2050	0.7	6891	0.034	3.23
47	9/2350	0.7	6765	0.034	3.32
48	10/0200	0.8	4210	0.022	3.45
49	10/1106	0.8	8895	0.050	3.73
50	10/1330	0.8	8013	0.045	3.86

(1) Actual dry cubic feet per minute.
(2) Exhaust flow undetectable with turbine meter.
(3) Run is suspect.
(4) Average of two samples taken simultaneously for Quality Assurance.
(5) Interpolated values from graph, (Runs 21-22).
(6) Measured values, (Runs 23-75).

Table 11 (continued)

RUN	Time (Day/Hours)	Exhaust Flow (adcfm)[(1)]	Ethanol ppm-vol	Ethanol Emissions (lbs/hr)	Cumulative (lbs)
51	10/1650	0.8	8700	0.048	4.03
52	10/2030	0.8	6646	0.035	4.14
53	10/2308	0.8	6451	0.032	4.23
54	11/0200	0.8	6608	0.030	4.46
55	11/1447	0.4	8446	0.024	4.64
56	11/1646	0.4	8123	0.023	4.73
57	11/2232	0.4	6415	0.018	4.83
58	12/0338	0.4	6021	0.017	4.94
59	12/1200	0.4	9871	0.028	5.09
60	12/1400	0.4	8216	0.022	5.16
61	12/1900	0.3	7030	0.015	5.32
62	13/1130	0.2	9676	0.017	5.49
63	13/1413	0.3	9155	0.019	5.55
64	13/1749	0.3	8705	0.018	5.76
65	14/1407	0.2	6827	0.010	5.87
66	14/1540	0.2	8118	0.012	6.03
67	15/1648	0.3	6968	0.015	6.41
68	16/1729	0.3	8616	0.018	6.84
69	17/1721	0.2	8335	0.009	7.05
70	18/1545	0.2	7409	0.013	7.36
71	19/1625	0.3	9246	0.018	7.79
72	20/1530	0.2	9316	0.012	7.93
73	20/1700	0.2	5382	0.007	8.02
74	21/1500	0.2	8968	0.013	8.17
75	21/1637	0.2	9532	0.012	8.18

(1) Actual dry cubic feet per minute.

Figure 10

WHITE WINE FERMENTATION EXHAUST ETHANOL EMISSIONS

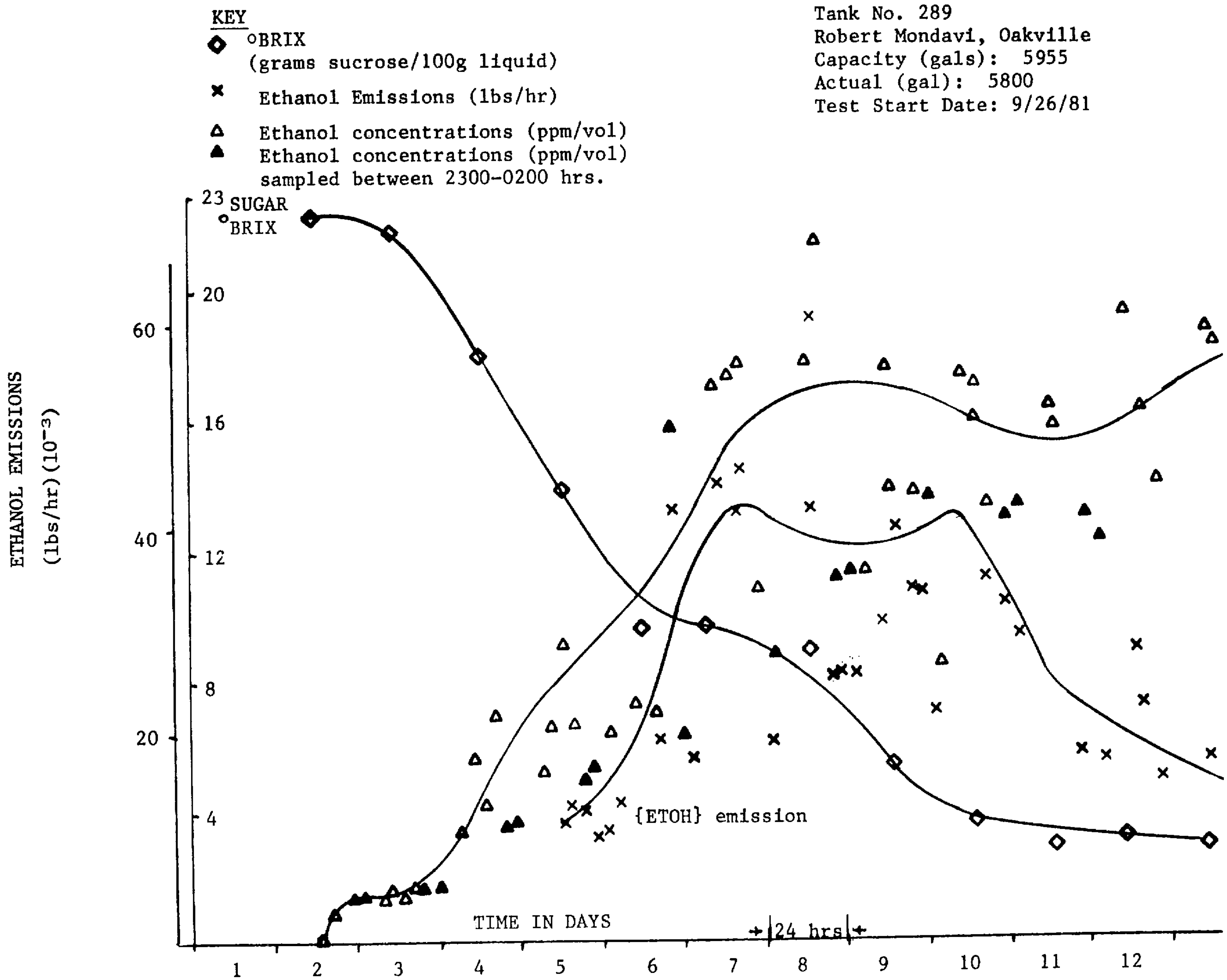


Figure 10 (continued)

WHITE WINE FERMENTATION EXHAUST ETHANOL EMISSIONS

Tank No. 289
Robert Mondavi, Oakville
Capacity (gal): 5955
Actual (gal): 5800
Test Start Date: 9/26/81

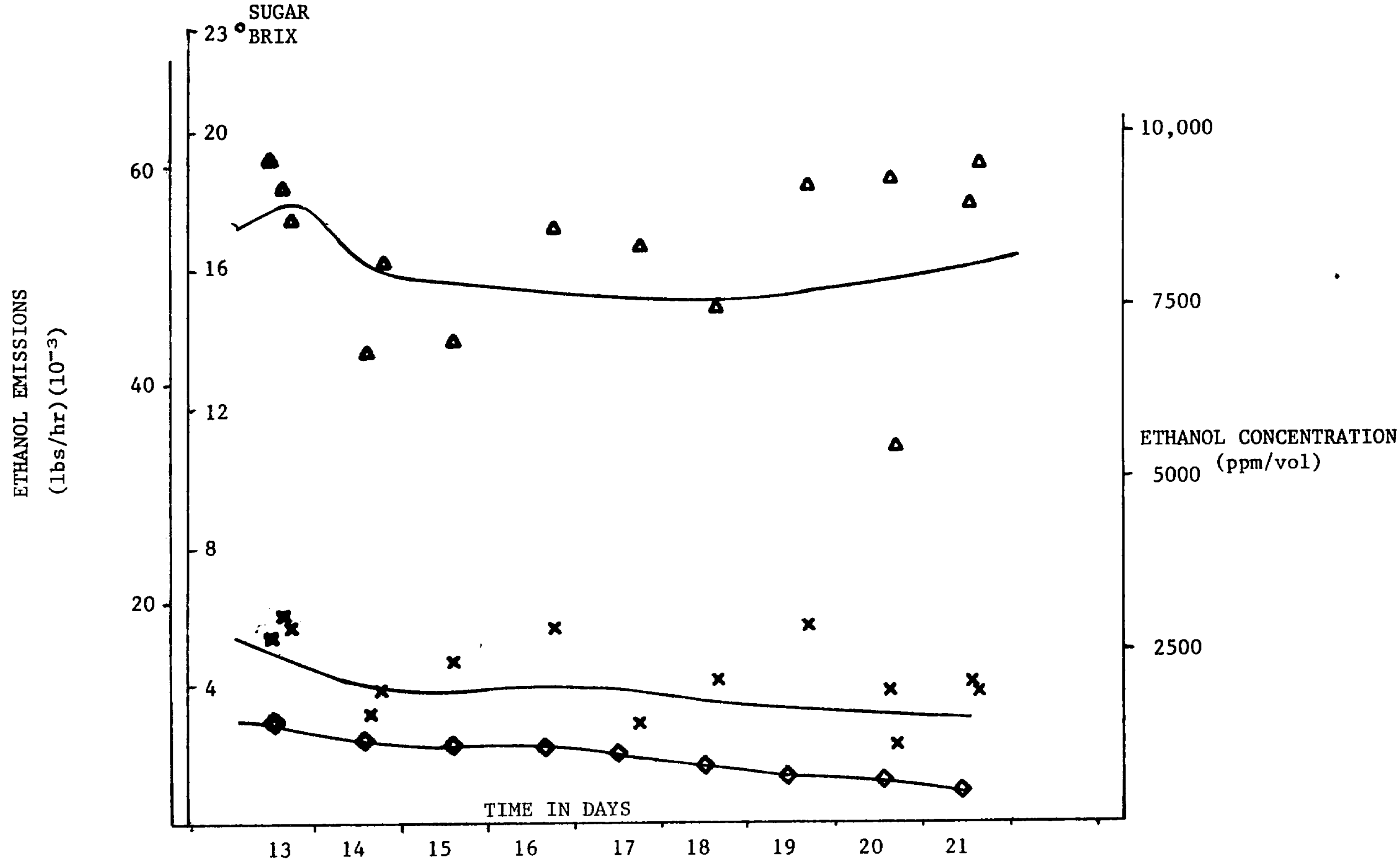


Figure 11

WHITE WINE VOLUMETRIC FLOW

Tank No. 289
Capacity (gal): 5955
Actual (gal): 5800
Location: Robert Mondavi (Oakville)

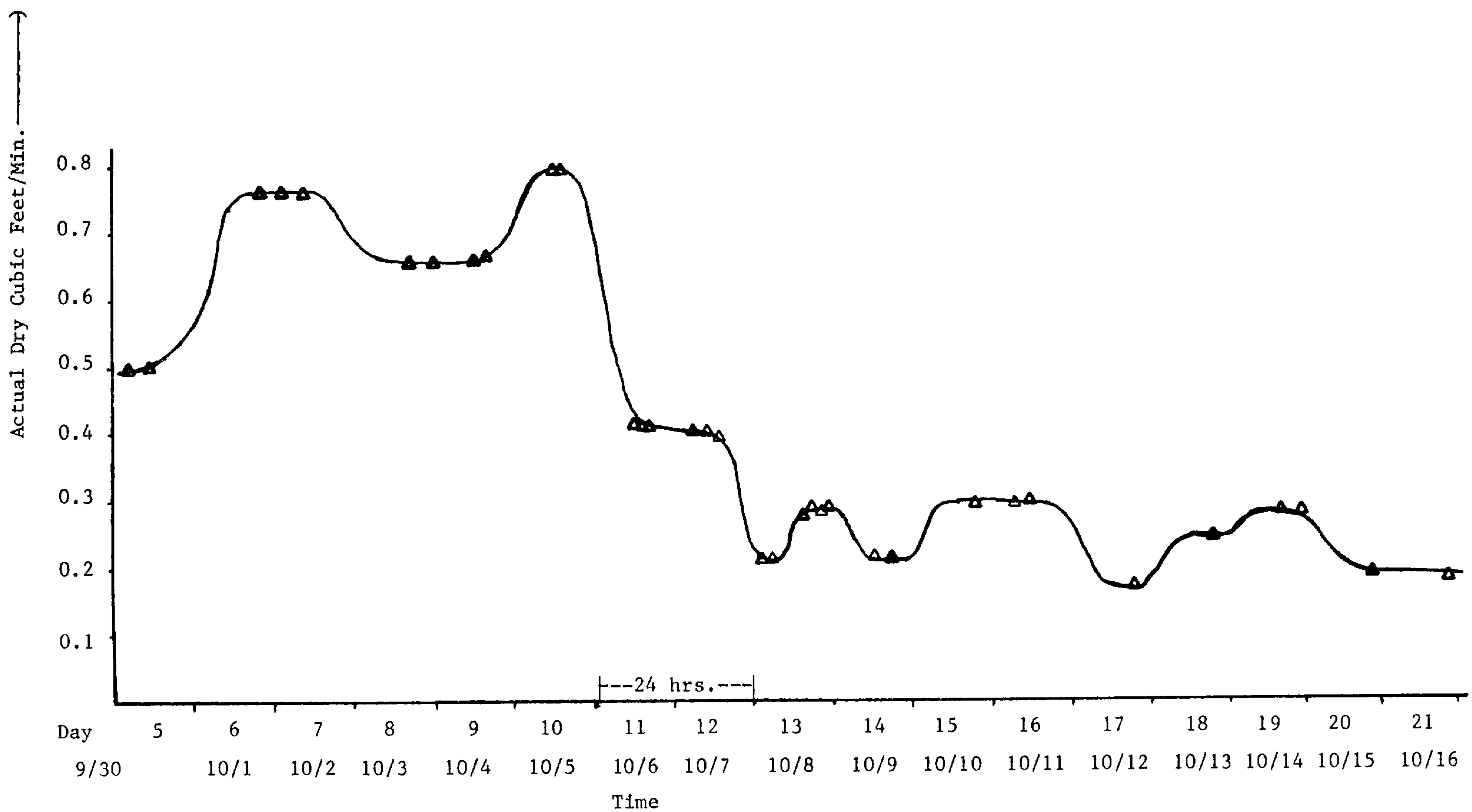


TABLE 12

FUGITIVE EMISSIONS
Robert Mondavi (Oakville)

Location (1)	Date, Time (hours)	ETHANOL mg/m^3	ETHANOL g/hr	ETHANOL ppm by volume
1	10/5, 0800	56	4.8	30
2	10/6, 1000	43	3.7	23
3	10/8, 1400	15	1.3	8

(1) Ref. Figure 12.

Sample Calculation: $\text{Ethanol (grams/hr)} = \text{ETOH } \frac{mg}{m^3} \times \text{acfm} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{1 \text{ m}^3}{35.31 \text{cf}}$

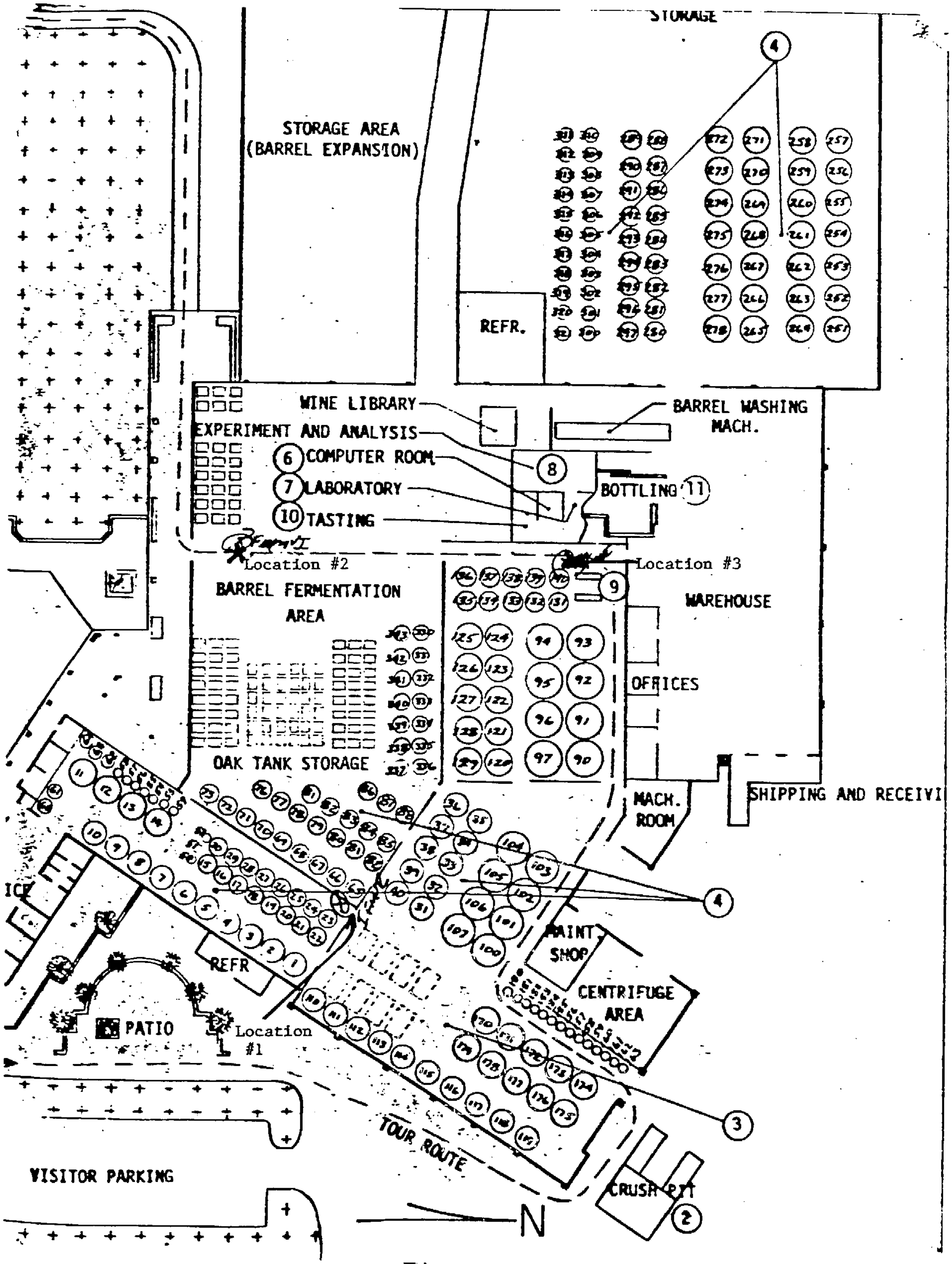


Figure 12
Robert Mondavi - Oakville Layout

SECTION III
SUMMARY AND CONCLUSIONS

Ethanol emission factors have been determined for the fermentation process. Additional measurements of ethanol fugitive emissions, generated from storage and handling during production, have been completed. Four fermentation tanks were monitored throughout their complete fermentation periods. The choice of tank location and type was made in an attempt to represent some of the variations in California wine production, given the time and budgetary limitations of the project. Final results listing ethanol fermentation emissions and emission factors are found in Table 13. Results for fugitive ethanol emissions and emission factors are detailed in Table 14.

The tabulated ethanol fermentation emissions (maximum lbs/hr and total lbs emitted) indicate a simple relationship between the volume of fermenting juice and wine type (i.e., red vs. white). Ethanol losses during red wine fermentation were higher than losses during white wine fermentation. The larger the volume of fermenting juice, the larger was the maximum quantity of ethanol emitted per unit time, or quantitatively, at the peak fermentation more CO_2 was produced and exhausted per unit time and thus more ethanol emitted through entrainment.

Ethanol emissions have been related to fermentation process conditions in order to generate emission factors, which in turn may be compared to historical data and theoretical attempts to characterize ethanol losses during fermentation.

Historical data representing ethanol emission factors as percent of total ethanol emitted versus fermentation temperature are graphed in Figure 13. Emission factors determined by EAL have been included in the graph and are in good agreement. In general, white wine fermentation emission factors are found at the lower end of the temperature range and red wine factors at the upper end. Comparison of EAL data to that of the California Air Resources Board (CARB) shows agreement for two separate white wine fermentations at approximately the same fermentation interval activity. Specifically, CARB reported an "ethanol concentration increase from 1,902 parts

TABLE 13

ETHANOL FERMENTATION EMISSIONS AND EMISSION FACTORS

		FERMENTATION PARAMETERS				EMISSIONS		EMISSION FACTORS		
Source	Location	Juice Volume (gal)	Average Temp. (°F)	Yeast Type	Duration (hours)	Maximum Ethanol Emission Rate (Lbs/Hr)	Total Ethanol Emitted (Lbs)	Ethanol Emitted (Lbs) / 10^3 Gal Juice	Ethanol[(1)] Emitted (Lbs) / Ton Grapes	% Ethanol Emitted Per Ethanol Produced
White Wine Fermentation Exhaust	United Vintners (Madera)	280,000	56	Montrachet	172	10.6	714	2.6	0.56	0.35
White Wine Fermentation Exhaust	Robert Mondavi (Oakville)	5,800	60	Montrachet	512	0.05	8.2	1.4	0.31	0.2
Red Wine Fermentation Exhaust	United Vintners (Madera)	44,000	83	Sacromices Servicia	26	31.0	342	7.8	1.7	1.3
Red Wine Fermentation Exhaust	United Vintners (Oakville)	8,100	72	Montrachet	77	4.7	85.3	10.5	2.3	0.82

(1) 220 Gallons Juice/Ton Grapes

TABLE 14

ETHANOL FUGITIVE EMISSIONS AND EMISSION FACTORS

Location: United Vintners, Oakville

Area	(mg/m^3)	(grams/hr)	(ppm by vol.)
Storage (Locations 1, 2, 5, 6) Ref. Figure	0.04-0.08	0.003-0.007	0.02-0.04
Handling (Location 3)	2.2	0.4	1.4
Handling (Location 4, adjacent to drag screen)	6.5	1.0	3.4
Handling (Location 7, immediately above drag screen)	5429	923	2888
Handling (Location 8, immediately above pomace press)	1134	193	603

Location: Robert Mondavi, Oakville*

Area			
Handling (Location 1)	56	4.8	30
Storage (Location 2)	43	3.7	23
Storage (Location 3)	15	1.3	8

*The storage and handling areas at Robert Mondavi (Oakville) were undergoing final clean up operations of the crush season, possibly explaining the relatively higher ethanol values compared to those at United Vintners(Oakville).

TABLE 14 (continued)

Location: Inglenook (Rutherford), bottling process (i.e., handling)

Area	(mg/m^3)	(grams/hr)	(ppm by vol.)
Room Air	32	-- *	17
Source, Corking Vent Outlet	654	1.8	348
Source, Filling Vent Outlet	3536	27.2	1881

ETHANOL FUGITIVE EMISSION FACTORS

HANDLING PROCESSES

Process	Ethanol
Drag Screen	0.5 lbs ethanol/10^{-3} gal juice
Pomace Press	0.02 lbs ethanol/ton of pomace
Wine Bottling	0.1 lbs ethanol/10^{-3} gal wine (white)

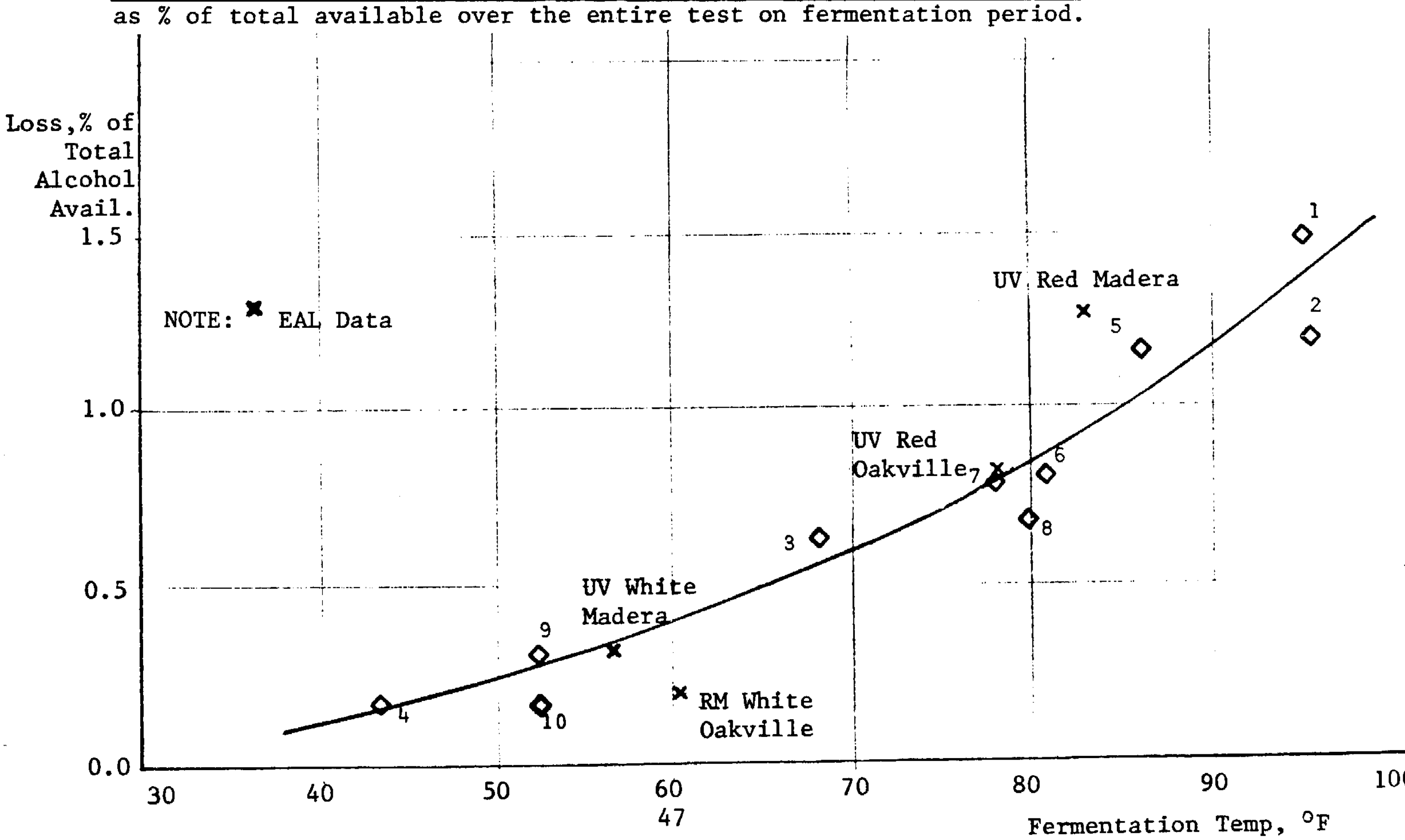
*No significant turbulence or air movement (i.e., ethanol dispersion).

Figure 13

Summary of Ethanol Loss Studies

	Study	Alcohol Content	Initial Sugar	Fermentation Temperature	Alcohol Lost*
1.	Mathieu and Mathieu		18.0%	95°F(35°C)	1.5 %
2.	Flanzey and Boudet		18.2	95 (35)	1.2
3.	"		18.2	68 (20)	0.65
4.	"		18.2	43 (5)	0.17
5.	Warkentin and Nury	4.6-10.6%range		86 (30)	1.17
6.	"	(7.6% avg.)		80.6 (27)	0.83
7.	Zimmerman, Rossi, and Wick		21	79.7 (26.5)	0.84
8.	"		16	79.7 (26.5)	0.70
9.	Air Resources Board (using Warkentin and Nury formula)	3-4% range		52 (11)	0.3
10.	Air Resources Board (based on measured alcohol loss)	(3.5% avg.)		52 (11)	0.2
	EAL/UV Red Wine Madera	entire range	23	84 (29)	1.3
	EAL/UV Red Wine Oakville	"	23.5	72 (22)	0.82
	EAL/UV White Wine Madera	"	23	57 (14)	0.35
	EAL/RM White Wine Oakville	"	22.4	63 (17)	0.2

*as % of total available over the entire test on fermentation period.



per million at the beginning of the test (approximately 60 hrs. after yeast inoculation) to 4,565 ppm at the end of the test"[8]. This compares well with EAL's data for a similar interval where ethanol concentrations ranged from 2,122 to 4,273 ppm (Ref. Table 3).

EAL's data may also be compared to the Environmental Protection Agency's (EPA) emission factor formula as described in Supplement 10 of AP.42, Feb. 1980, (ref. Table 15) where:

$$EF = (0.136T - 5.91) + [(B - 20.4)(T - 15 - 21)(0.00085) + C]$$

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

T = fermentation temperature, °F

B = initial sugar content, °Brix

C = correction term, 0 (zero) for white wine or 2.4 $lb/10^3$ gal for red wine

Final results of the fugitive emissions study indicate greater ethanol losses during handling stages of wine production than during storage. Table 14 summarizes the comparison between the final storage phase of wine production and three main handling processes during production. Table 14 also includes fugitive emission factors for the wine bottling process and the drag screen and pomace press or solids extraction process.

Fermentation ethanol losses measured during this study are consistent with results from past tests (Ref. Figure 13). A general review of the existing data indicate that ethanol losses are dependent upon fermentation temperature, duration of the fermentation period, and the volume of fermenting juice. Ethanol losses from all the parameters appear to be characteristic of predicted stoichiometric behavior. The fermentation process is stoichiometrically characterized in the following equation:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2\,CO_2$$

fructose	ethanol	carbon dioxide gas
180 g	92 g	88 g

TABLE 15

COMPARISON OF EAL AND EPA EMISSION FACTORS

Wine Type/ Location	Fermentation Temperature(°F)	Initial Sugar (°Brix)	EMISSION FACTOR (lbs ethanol/10^3 gals) Measured	EPA Formula
White Wine/U.V. Madera	57	23	2.6	2.6
White Wine/R.M. Oakville	63	22.4	1.4	1.7
Red Wine/U.V. Madera	84	23	7.8	9.1
Red Wine/U.V. Oakville	72	23.5	10.5	7.5

The determined ethanol emission factors can be used, together with Gay-Lussac stoichiometry, in order to perform an internal check on the complete ethanol emissions source test.

Example

Location: United Vintners (Madera)

Source: White wine fermentation tank No. 576

Questions: To what extent does the measured total cumulative/pounds of ethanol (ETOH) emitted agree with the value predicted by stoichiometry?

Given:
- o Volume of fermenting juice = 280,000 gallons
- o Initial sugar = 20°Brix where °Brix = grams sugar/100 mls juice
- o Final sugar = 3°Brix

- o Actual yield of alcohol (ethanol) = 47% by weight, (not theoretical 51.1%) due to conversion into other microbiological products and assimilation by yeast.[6]

Step 1: 17 grams of sugar are consumed per 100 mls. of juice from 20 to 3 °Brix.

thus: (17 g sugar) x 0.47 = 7.99 grams ETOH produced/100 mls. juice

Step 2: Grams ETOH produced per gallon of

$$\text{juice} = \frac{(7.99\text{ g ETOH})}{100\text{ mls. juice}} \times \frac{1000\text{ mls.}}{1\text{ liter}} \times \frac{3.79\text{ liters}}{1\text{ gallon}} = 302.8$$

Step 3: Total cumulative pounds of ETOH

$$\text{produced} = \frac{(302.8\text{ g ETOH})}{1\text{ gal.juice}} \times 280{,}000\text{ gals.} \times \frac{1\text{ lb.}}{454\text{ g}} = 186761.9\text{ lbs ETOH}$$

Step 4: Finally, 186761.9 lbs ETOH x 0.0035* = 654 total cumulative lbs ETOH emitted

Recall: 642 total cumulative lbs ETOH emitted (measured)

Conclusion: The theoretical value of total cumulative ETOH emitted (lost) agrees with the measured value to within 1.8%

---

*EAL calculated emission factor.

SECTION IV
RECOMMENDATIONS

Emission Inventories

Historical data and the results from this report contribute to the confidence with which ethanol emissions from wineries may be quantified. However, additional testing of the fermentation process would serve to further validate the data base. For example, independent monitoring of red and white wine fermentations at similar temperatures could narrow the variability of the temperature versus ethanol emission factor curve shown in Figure 13. Although present methods of monitoring sugar consumption/ethanol production are adequate, results describing carbon dioxide production and subsequent entrainment of ethanol would complete the mass balance picture.

Control Measures

Control of ethanol emissions may be economically justified through resource recovery. The reclamation of ethanol could produce distillation material. The remainder of this section is a discussion of possible control devices with comments on their applicability, efficiency, and costs.

Exhaust Vapor Refrigeration (condensation): The effluent is cooled to a temperature at which ethanol condenses. This method would require a certain energy cost outlay to maintain optimum refrigeration of the exhaust. Purchase, installation, maintainance and operation of the system may exceed the price of recovered ethanol, especially if the abatement unit were to be permanently mounted on a fermentation tank. Only limited information was obtained regarding refrigeration/condensation methods. The only document reviewed was a French paper, in which a conceptual schematic is presented[9].

Activated Carbon Adsorption: This process consists of an airstream conditioning system including dehumidification and particulate filtration stages. The exhaust stream would then pass through one of two vessels containing activated carbon specifically chosen for ethanol recovery. When the vessel which is on line becomes saturated, the airflow would automatically switch to the second vessel. The initial vessel will then be processed to strip the ethanol from the carbon (steam desorption). This ethanol will be returned to the plant in a water mixture which can then be purified to any required level by using existing distillation equipment. Purchase and installation would be approximately $35,000 based on the following parameters[10]:

270 cfm of exhaust at 80 - 90°F, Relative Humidity of 70 - 80%
18000 ppm of ethanol
24 hour/day operation

Maintenance and operational costs would vary depending on whether the system would be permanently installed or semi-mobile allowing abatement to take place as needed (Ref. Figure 14).

Wet Scrubber Exhaust System (Ref. Figure 15): The exhaust stream passes through a mist eliminator and into the "contact face area" where exhaust fumes are sprayed by a series of nozzels. The scrubber liquid would be water and recirculation could be employed. Periodic testing of the scrubber wafer would indicate a point at which the ethanol/water mixture should be transferred to distillation and scrubber water replenished. The scrubber system is relatively light-weight (plastic materials) with minimal energy demand.

The wet scrubber system appears to be the most attractive ethanol emissions control technology for the following reasons:

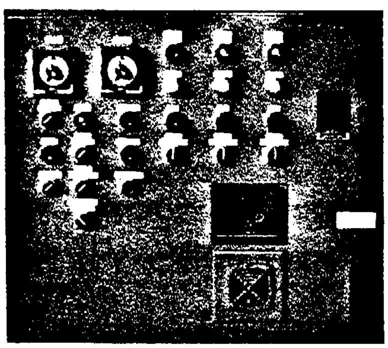
Item	Comments
Cost[11]	Approximately $4,000./unit
Adaptability	Could be moved from one fermentation tank to another as needed
Energy Use	Minimal, only need to operate low hp fans (approx. 2 hp) and pumps

Wet scrubbing would be the most cost effective control measure in terms of capital and energy expenditures. However, if separation or reconcentration of the dilute product solution were required for economically efficient recovery of the ethanol, the associated costs would be higher. Wet scrubbers have been used in the study of ethanol emissions from fermentation tanks and thus, indirectly, as control devices[12].

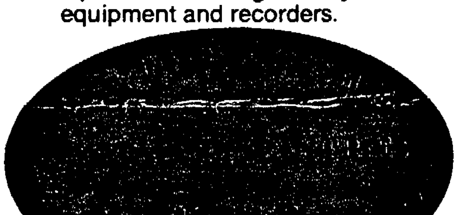
FIGURE 14
ACTIVATED CARBON ADSORPTION SYSTEM

VIC 500 Series System

- Modular concept
- Completely automatic operation
- Safety controls
- Explosion-proof motors, blowers and starters (as required)
- Low initial investment
- Low pressure steam desorption



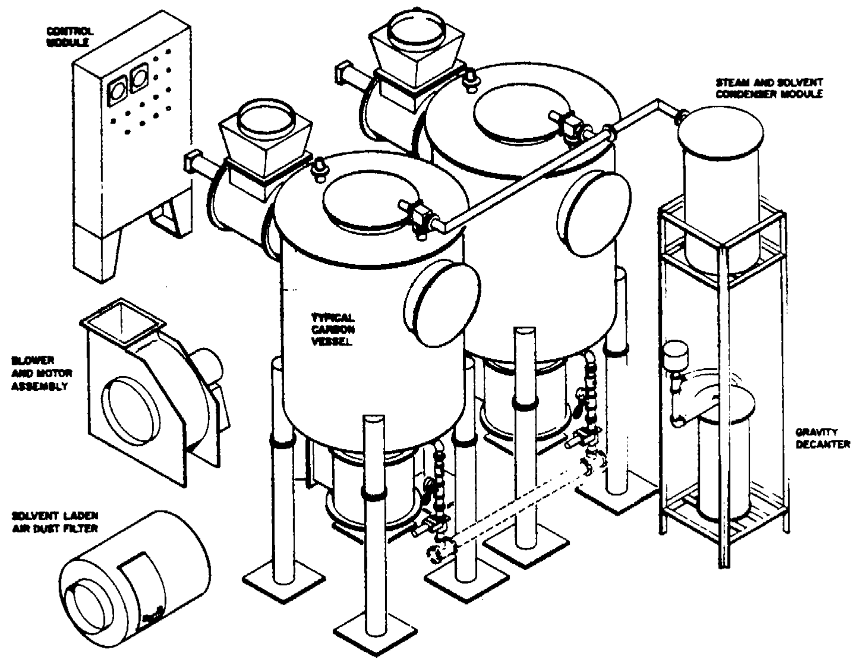
Automatic controls are available in various NEMA classifications for on-site or remote mounting, electromechanical or programmable. Optional exhaust gas analytical equipment and recorders.

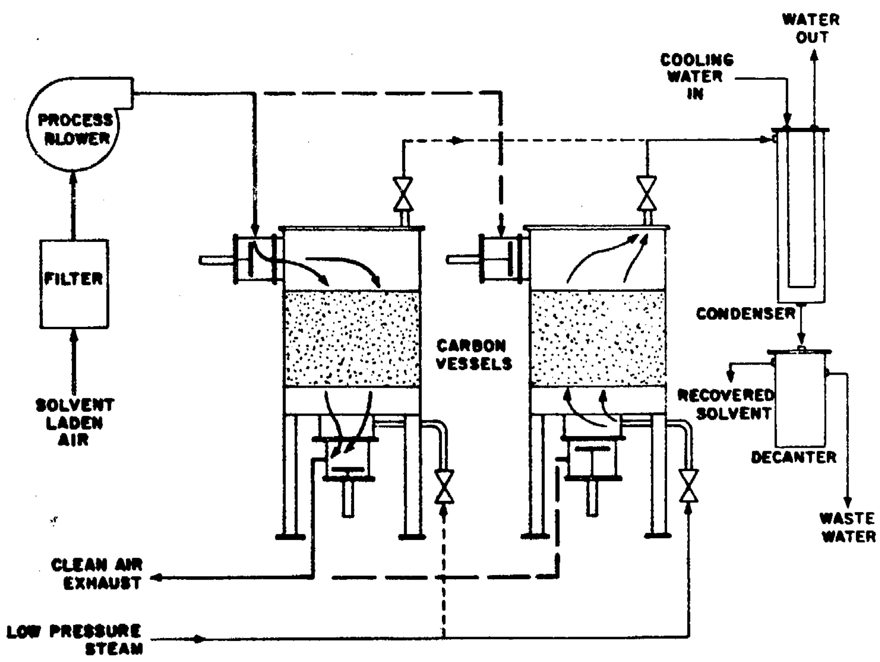


*Protected by one or more of the following patents: Patent No. 2,480,320; 2,910,137; 2,982,375; 2,893,925; 3,029,612; 3,089,250; 3,095,284; 3,728,074; Licensed Under U.S. Patents No. 2,772,747; 2,760,594; 2,702,433; 2,755,563; Canadian Patents No. 470,085; 612,477; 618,334; 660,220; 667,299; and other Patents applied for in U.S. and Foreign Countries.

All specifications shown are subject to change without notice. All Vic equipment is sold under our standard warranty. Copy available on request. Purchaser agrees to these terms when accepting delivery of equipment.

500 SERIES—TWO VESSEL SOLVENT VAPOR RECOVERY SYSTEM PICTURED, ONE OF MANY VERSATILE COMBINATIONS.



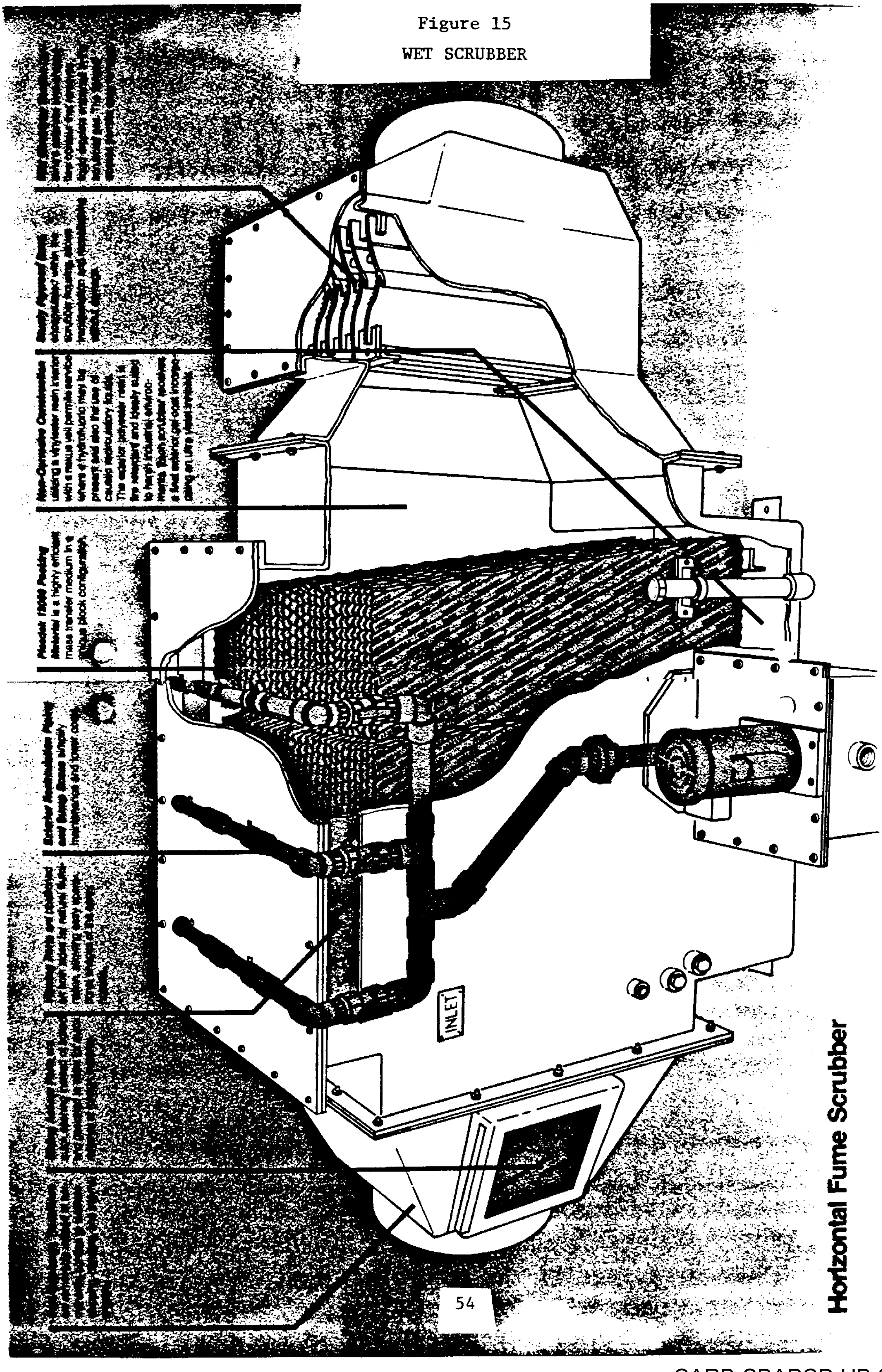


VIC MANUFACTURING COMPANY
1620 Central Ave. N.E., Minneapolis, MN 55413 (612) 781-6601

APC6005—12/81

Figure 15

WET SCRUBBER



Control of fugitive emissions from handling, bottling, and storage operations would be most efficiently performed by prevention of emissions through use of enclosed transfer and handling systems and enclosure of process and storage areas so that emissions from those areas could be ducted to the fermentation tank scrubbers.

Section V

REFERENCES

Citations:

1. Draft Report No. C8-050, *Gallo Wine Fermentation Tank,* California Air Resources Board, (obtained from David Craft of CARB, September 18, 1980).

2. Smith, J.R., *Estimating Overall Sample Train Efficiency,* J. Air Poll. Control Assoc. 29, 969 (1979).

3. Personal Communication, Gary Murchison (CARB).

4. *Quality Assurance Handbook for Air Pollution Measurement Systems; Stationary Source Specific Methods,* Vol. III, USEPA, EPA-600/4-77-027b (1977).

5. Zimmerman, H.W., E.A. Rossi, Jr., and E. Wick, *Alcohol Losses From Entrainment in Carbon Dioxide Evolved During Fermentation,* Amer. J. Enol. Vitic., 15, 63 (1964).

6. Amerine, M.A., H.W. Berg, and W.V. Cruess, *The Technology of Wine Making,* 3rd ed., The Avi Publishing Co., Inc., 1972.

7. *Wine Grape Crush Down,* San Francisco Chronicle, February 12, 1982, Page 34.

8. CARB report titled, *Evaluation Test to Measure Ethanol Emissions From A 106,000 Gallon Fermentation Tank,* Report No. C-80-071, October 1980.

9. *Recovery of Alcohol Entrained With Carbon Dioxide Gas During Production Fermentation and Refrigeration,* Le Progres Agricole et Viticole, 133, (1950). (French).

10. Personal Communication, Stephen J. Lutz, P.E., Emission Controls Division, Pullman Industries, July 15, 1982.

11. Personal Communication, Roger D. Flippen, Harrington Industrial Plastics, Inc., July 16, 1982.

12. Warkentin, H. and M.S. Nury, *Alcohol Losses During Fermentation of Grape Juice in Closed Fermenters,* Amer. J. Enol. Vitic., 14, 68 (1963).

13. Personal Communication, Joe Rossi, United Vintners.

Further References:

The computer data bases searched and reported on covered information from the following:

- Compendex - Engineering Index - 7/71-Present
- CRIS - U.S.D.A. Cooperative State Research Service - 7/74-Present
- Energyline - Environmental Information Center - 1971-Present
- Food Adlibra - K and M Publications - 1974-Present
- Environmental Bibliography - Environmental Studies Institute - 1974-Present
- Pollution Abstracts - Cambridge Scientific Abstracts - 1971-Present
- Enviroline - Environmental Information Center - 1971-Present
- Food Science & Technology Abstracts -International Food Information Service - 1969-Present
- APTIC - Manpower & Technical Information Branch, U.S. EPA - 1966-9/78
- NTIS - National Technical Information Service - 1964-Present
- Agricola - National Agricultural Library - 1970-Present
- Scisearch - Institute for Scientific Information - 1/74-Present
- CA Search - Chem Abstracts Service - 1967-Present

The following references were obtained primarily through those data bases but were not cited due to lack of relevant content or lack of funds to translate. Quoted professional translation costs were discussed with the Contract Officer and EAL was directed to refrain from obtaining those services. The data bases utilized are cited after most references along with the language, if non-English.

References Reviewed But Not Cited:

1. Flanzy, M. and Boudet, V., *The Fate of Ethanol During Transformation of Grape Juice to Wine,* Viticulture Arboriculture, 95, 104 (1949). (French).

2. Dietrick, K.R., *The Control of Alcohol Loss During Fermentation,* Deutsche Wein - Zeitung, 90, (August, 1954). (German).

3. Tararykov, G.M., *Losses of Ethyl Alcohol With Carbon Dioxide Escaping During The Periodic Fermentation of Starch-Containing Mashes,* Fermentn. Spirt. Prom-st., 2, 33 (1978). CA Search. (Russian).

4. Nosko, S., *Alcohol Yield from Fermented Cherry Material. I. Effect of Sugar Content, Amount of Bottom Substances, and Fermentation Losses,* Branntweinwirtschaft, 115, 233 (1975). CA Search (German).

5. Kadlec, K. and Labik, V., *Concentration and Losses of Ethanol in Aeration Processes,* Kvasny Prum., 19, 247 (1973). CA Search. (Czech).

6. Bal'shin, M.S. et al., *Losses of Alcohol With Uncondensed Gases on Fermented Malt-Fractionation and Fractionation Apparatus,* Ferment. Spirt. Prom., 3, 18 (1973). CA Search (Russian).

7. Venkataramer, K. et al., *Wine Yeasts and Their Fermentation Products,* Journal of Food Science and Tech., 14, 227 (1977). CA Search.

8. Stokes, J.L., *Interference of Temperature on the Growth and Metabolism of Yeasts; The Yeasts,* by Rose and Harrison, Vol. 2, Chpt 4 (1969).

9. Wet, P. et al., *Evaluation of a Synthetic Stopper as a possible Substitute for Cork in the Wine Industry,* 566, 60 (1978). Food Science and Technology (183316:80-04-H0550).

10. Gleizes, C., *Pollution Generated by Vinification and Distillation of Wine Products,* Forests and Waterways, 1973. APTIC (French).

11. Grossland, J., *Ferment in Technology,* Environment, 16, 17 (1974). Enviroline.

12. Carter, R.V. and Linsky, B., *Gaseous Emissions from Whiskey Fermentation Units,* Atmospheric Environment, 8, 57 (1974). Enviroline.

13. Wang, J.Y., *Effects of Agrochemicals on Weather and Climate,* Water Air and Soil Pollution, 12, 83 (1979). Enviroline

14. Iions, S. et al., *Studies on the Use of Sulfur Dioxide in Wine Making. Part 7. Effect of the Press Rate of Grape Juice on the Formation of Sulfur Dioxide-Combining Compounds During Fermentation,* Yamanaski-ken (Journal), 10, 5 (1978). CA Search (Japanese).

15. Cabezudo, M.D., *Analysis of Alcohols by Gas Chromatography,* Sem. Vitivinic., 28, 5.417 and 5.419, (1973). CA Search (Spanish).

The computer data bases cited were vital to EAL's efforts on this contract for the following reasons:

- Valuable references were obtained from obscure sources that would otherwise have been overlooked.
- Confidence was increased that most relevant information regarding recent technical efforts in this area had been reviewed.
- Literature search effort efficiency was maximized at minimal cost.

It must be emphasized that a serious gap exists in those bases due to their relatively narrow scope in time. However, careful use was made of bibliographies contained in the references reviewed to alleviate that concern.

The following two references were brought to our attention by the Wine Institute. They contain data regarding the relative photochemical reactivity of ethanol and were submitted to support the Wine Institute's concern about the basis for this project rather than its goals or conclusions.

1. *Air Quality Criteria for Ozone and Other Photochemical Oxidents,* EPA Assessment Office, Research and Development, April, 1978.

2. Laity, J.L. et al., *Photochemical Smog and the Atmospheric Reactions of Solvents,* presented at the ACS Division of Organic Coatings and Plastics Chemistry meeting, Washington, D.C., 31, 419 (9/71).

Section VI

GLOSSARY

Item	Description
acfm	actual cubic feet per minute
cfm	cubic feet per minute
D.I.	de-ionized (water)
ETOH	ethanol
FFAP	free fatty acid packing
ft^3	cubic feet
I.D.	inside diameter
O.D.	outside diameter
P.F.	plate and frame filter
P.M.	Paul Masson
R.M.	Robert Mondavi
U.V.	United Vintners

Section VII

APPENDIX

Appendix

SAMPLE CALCULATIONS

GENERAL

A known volume of gas was extracted from the fermentation exhaust stream and passed through three 500 mL Greenburg-Smith impingers (Ref. Methods, Sample Collection). The impinger collections were analyzed employing gas chromatographic techniques and data reduction proceeded in the following step-wise manner.

STEP	*EXAMPLE*
1) An aliquot was withdrawn from the impinger collections and directly injected onto the FFAP column (Ref. Methods, Analysis).* An Ethanol concentration was determined in units of ppm-v/v based on the response factors of a number of working ethanol standards and a least squares evaluation of the data, generating a regression line and correlation coefficient.	Run #36 (White Wine, Tank 576) Impinger #1 & 2: 24833 ppm v/v Impinger #3: 2030 ppm v/v
Impinger collections were separated in order to monitor the possibility of sample breakthrough.	Impinger #1 & 2: 24833 ppm(v/v) = 24833 μL EtOH/L solution. $\frac{24833\ \mu L\ EtOH}{L\ solution}\left(\frac{1\ mL}{1000\ \mu L}\right)\left(\frac{0.7893\ g\ (EtOH\ dens)}{1\ mL}\right) = \frac{19.60\ g\ EtOH}{L\ solution}$ $\frac{19.60\ mg\ EtOH}{L\ solution}\left(0.340\ L\ solution\right) = 6.664\ g\ EtOH\ Total$
In this case, impingers 1 and 2 had a total combined solution volume of 340 mL with an ethanol concentration of 24833 ppm (v/v). Impinger 3 had a solution volume of 145 mL and an ethanol concentration of 2030 ppm(v/v). The following calculations are used to determine the collection efficiency:	Impinger #3: 2030 ppm(v/v) = 0.232 g EtOH Total Collection Efficiency: $\frac{6.664\ g\ (Imp.1\ \&\ 2)}{6.896\ g\ (Imp.1 - 3)} \times 100 = 96.6\%$
Impinger collections were combined for a total ethanol concentration from which the total milligrams of ethanol captured was calculated.	Total Collection Run #36 = 6.896 g Ethanol in 485 mL solution.
2) Total milligrams ethanol, when compared to the standard dry gas volume sampled, yields a mgs ethanol per cubic meter value which translates to both a gaseous concentration of ethanol (ppm.vol) and an emission value (Lbs/Hr Ethanol).	$\Rightarrow \frac{6897\ mg\ ethanol}{0.86\ m^3} = \frac{8020\ mg}{m^3}$ $\Rightarrow \frac{8020\ mg}{1\ m^3} \times \frac{24.45\ Liters/mole}{46.07\ grams/mole}$ = 4256 ppm vol
Note: Lbs/Hr ethanol have been based on an actual cubic feet per minute volumetric flow rate, hence, the gas volume sampled was expressed as actual cubic feet.	$8020\ mg \div 0.86\ m^3 + \left(\begin{matrix} mLs\ H_2O \\ entrained \end{matrix} + \begin{matrix} grams \\ silica\ gel\ gained \end{matrix}\right)$ $\times 0.0474\ \frac{cu.\ ft.}{mL} \times \frac{0.02832\ m^3}{1\ cu.\ ft.}$ $= \frac{8020\ mg\ Ethanol}{1.24\ m^3\ (actual)}$
*The lowest analytical detection limit for ethanol was 5 μg/mL, thus with collection and analysis of the first impinger, (i.e., no ETOH expected in 2nd or 3rd):	$\frac{5\ \mu g\ ETOH}{mL} = \frac{0.005\ mg}{mL} \times \frac{0.7893\ mg\ ETOH}{mL}$ $= \frac{0.0039\ mg\ ETOH}{mL} \times 160 = 0.63\ Total\ mg\ ETOH$ $\Rightarrow \frac{0.63\ mg\ ETOH}{0.86\ m^3} \times \frac{24.45\ Liters/mole}{46.07\ grams/mole} = 0.4\ ppm(by\ vol.)$

STEP	*EXAMPLE*
2) (continued)	$\frac{8020 \text{ mg ethanol}}{1.24 \text{ m}^3} \times 198.3 \text{ acfm} \times \frac{1 \text{ Lb.}}{454000 \text{ mg}}$
	$\times \frac{60 \text{ minutes}}{1 \text{ hour}} \times \frac{1 \text{ m}^3}{35.31 \text{ cubic foot}}$
	$= \frac{4.8 \text{ Lbs. ethanol}}{1 \text{ Hour}}$ at this point in the fermentation period.
3) Finally, ethanol losses during fermentation can also be expressed in the following terms.	
• Total Lbs ethanol emitted per 1000 gallons of fermenting juice	697 Lbs. total ethanol emitted ÷ 280 Kgal juice
	= 2.5 Lbs ethanol/10^3 gallons of juice
• Total Lbs. ethanol emitted per ton of crushed grapes given: (13) $\frac{220 \text{ gallons juice}}{\text{Ton grapes}}$	$\frac{697 \text{ Lbs total ethanol}}{280{,}000 \text{ gallons} / 220 \text{ gallons/Ton of grapes}}$
	$= 0.55 \text{ Lbs ethanol emitted / Ton of grapes}$

• Theoretical ethanol production based on volumetric flow:

measured:

1549940 total cubic feet @ turbine meter in 172 hours

given:

CO_2 density = 0.1236 Lbs/cubic foot

0.1236 Lbs/cf x 1549940 cf = 191573 Lbs CO_2 produced

$\frac{46 \text{ mol wt. ethanol}}{44 \text{ mol wt. } CO_2} \times 191573 \text{ Lbs } CO_2 = 200280$ Lbs alcohol produced

$\frac{200280 \text{ Lbs. alcohol} \times 0.15 \text{ gal/lb}}{280{,}000 \text{ gallons of fermented juice}} = 0.11$ or 11% ethanol @ end of fermentation

• Percent ethanol lost of percent produced:

$\frac{697 \text{ Lbs. Total ethanol emitted}}{200280 \text{ Lbs alcohol produced}} = 0.35\%$ (Ref. CARB report, March 19, 1981, Warkentin & Nury Equations)