EPA-450/2-78-013

April 1978

COST AND ENGINEERING STUDY - CONTROL OF VOLATILE ORGANIC EMISSIONS FROM WHISKEY WAREHOUSING

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

EPA-450/2-78-013

COST AND ENGINEERING STUDY - CONTROL OF VOLATILE ORGANIC EMISSIONS FROM WHISKEY WAREHOUSING

Emission Standards and Engineering Division
Chemical and Petroleum Branch

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

April 1978

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - in limited quantities - from the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

Publication No. EPA-450/2-78-013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

UNITS AND CONVERSIONS

Listed below are abbreviations and conversion factors for the metric units in this report and definitions for non-standard units associated with whiskey production.

Metric Unit (Abbreviation)	Equivalent
1 meter (m)	= 39.37 inches = 3.28 feet
1 centimeter (cm)	= 10^{-2} meter = 2.54 inches
1 hectare (ha)	= 10^5 m^2 = 2.47 acres
1 kilogram (kg)	= 2.2 pounds
1 metric ton (MT)	= 1000 kilograms = 2200 pounds

Unit	Definition
proof gallon (pg)	one U.S. gallon of 231 cubic inches containing 50 percent by volume ethanol or any volume of liquid containing an equivalent amount of ethanol. A proof gallon thus contains 1.5 kilogram of ethanol.
proof	twice the volume percent ethanol in a liquid. The number of proof gallons in a gallon of liquid is the proof divided by 100.

1.0 INTRODUCTION

The Environmental Protection Agency is currently providing technical assistance to the States and local jurisdictions on industries that emit significant quantities of air pollutants in those areas of the country where National Ambient Air Quality Standards are not being attained. This document is related to one such industry, whiskey warehousing. It is a significant source of volatile organic chemicals (VOC) in the area where the industry is concentrated, Kentucky, Illinois, Indiana, and Tennessee.

1.1 EMISSION SOURCE DESCRIPTION

In producing whiskey, alcohol distilled from fermented grain is stored in charred oak barrels for periods of four to eight years or more. During this period, the alcohol absorbs, and reacts with, constituents in the barrel wood and gains the distinctive taste and aroma of whiskey. This process is known as aging or maturation. During the aging period, ethanol and water seep through the barrel and evaporate into the air. Also when the barrels are emptied to bottle the whiskey, ethanol and water remaining in the barrel wood evaporate into the air. These last two phenomena are the major sources of VOC emissions in whiskey production.

Based on changes in the proof and liquid volume of whiskey during aging, an emission factor of 3.2 ethanol? kg/barrel-yr. was computed. On the basis of production, the emission factor is .2kg ethanol/kg produced. Based on an estimated 10,260,000 barrels stored in Kentucky, Illinois, Indiana, and Tennessee, the total yearly emission of VOC from whiskey warehousing is 32,800 MT/yr for the four State areas.

1.2 CONTROL DEVICE DESCRIPTION

The method investigated for control of emissions both during aging and from barrel soakage after aging was carbon adsorption. Control of emissions during aging would involve closing the warehouse and ducting exhaust from the facility through a carbon adsorption unit. Control of barrel soakage losses would involve placing the empty barrels in a closed warehouse ducted to a carbon adsorption unit. These control methods are estimated to reduce emissions by 85 percent. The efficiency is limited by the need to design and operate the system in a manner that will not affect whiskey quality and by the physical difficulties in drying the saturated barrels.

The applicability of these control systems is determined by two factors:

1. the cost of systems and
2. the system's effect on whiskey quality.

The cost of the system for controlling losses during aging for three of the six cases studied is shown in Table 1-1. Also shown is the cost of controlling soakage losses by storing the empty barrels in a warehouse. As seen in the table, an important factor in the systems' cost is the credit for the recovered alcohol. The recovered alcohol can be redistilled to a product for which sufficient markets exist to use the amounts recovered; however, very few distillers have the equipment required for this redistillation. Thus, distillers would have to transport the recovered alcohol in crude form or install the necessary distillation equipment, options which significantly reduce the credit shown for the recovered alcohol.

Table 1-1

CONTROL SYSTEM COSTS

	Aging Loss Control			Soakage Loss Control
Warehouse Size, Barrels	20,000	50,000	100,000	50,000
Annual Capital Costs	$9,960	$15,410	$31,700	$71,000
Annual Operating Costs	$11,980	$17,280	$26,010	$58,710
Annual Credit, Recovered Alcohol	$13,610	$54,440	$68,050	$55,150
Net Cost (Return)/yr	$8,330	$(21,750)	$(8,340)	$74,560
Cost/Final Proof Gallon	3.0¢	-	-	2.8¢

Two other cost problems are present in installing and operating the control systems, providing steam for regeneration of the carbon beds and providing sufficient air flow to dry the empty barrels. Whiskey warehousing facilities, especially those in rural areas, are spread over large areas and would require long lines to carry regeneration steam from boilers to the warehouses. The cost of such a distribution system has not been estimated and thus was not included in the cost calculations. In controlling barrel soakage losses, large flows of air are used to dry the barrels. Since carbon adsorption unit costs rise directly with air flow capacity, the flow rate is a critical parameter in the system's cost. Since such a system has never been installed, the flow rate required is not known precisely and could have been underestimated in this report.

Whiskey quality could be affected if the carbon adsorption system altered such warehouse conditions as temperature, humidity, and ventilation. These changes would affect the various physical and chemical processes involved in whiskey aging and evaporation, such as the diffusion of water and ethanol through the wood, the transfer of wood constituents into the whiskey, and the chemical reactions occurring in the wood and the whiskey. In the one full scale test of the control system, whiskey quality was in fact lowered and the test was discontinued. However, analysis of the test indicates that certain design and operating changes may have eliminated the whiskey quality problems.

The cost problems discussed above and the failure of the full scale test show that control of emissions from whiskey warehousing has not been demonstrated at this time. However, the control systems show a potential for breaking even or producing a profit, an unusual characteristic for a control system. Even without credit for recovered alcohol, the control system costs 7-10¢/proof gallon, which compares favorably to a production cost of $2.10/proof gallon. In addition, engineering analysis indicates that problems with whiskey quality can potentially be solved with proper design and operation. Thus, it appears possible that further work could demonstrate the feasibility of control. This work would include the following:

1. investigation of alternate carbon regeneration techniques, for example electric heating/vacuum regeneration

2. additional economic analysis. A low sensitivity of liquor demand to price changes and the large percentage of liquor prices made up by taxes may allow the costs of the control to be passed on even without credit for recovered alcohol.

3. additional testing of the control systems

4. scheduled tests to demonstrate an alternate aging system. This system is discussed in section 4.5.

This further work was not able to be completed at the publication date of this document.

2.0 WHISKEY WAREHOUSING AND AGING

The manufacture of whiskey involves two distinct steps - the production of unaged whiskey from cereal grains and the maturation of this whiskey by storage in charred white oak barrels.

In the production of unaged whiskey, grain is first milled, then cooked in water to solubilize the starches. The solubilized starches are then mixed with partially germinated grain. This step results in the starches being hydrolyzed to sugars by the enzymes in the germinated grain. The sugars are then fermented with yeast and the resulting mixture is distilled to produce unaged whiskey. The production of unaged whiskey is a source of only a small percent of the volatile organic chemicals emitted in whiskey manufacture. The emissions from this first step are described in Appendix A.

The unaged whiskey, colorless and pungent tasting, must be aged by storage in charred oak barrels to produce an alcoholic beverage with the traditional characteristics of whiskey. This step, whiskey aging, is the major source of emissions in whiskey manufacture and will be the principal focus of the report. This chapter will describe whiskey warehousing operations and the physical and chemical processes that occur as whiskey ages. Chapter 3 will present emission factors for whiskey warehousing and the basis of these emission factors, and Chapter 4 will describe possible emission controls and their advantages and disadvantages.

2.1 BARRELING AND WAREHOUSING

To produce an alcoholic beverage with the traditional qualities of whiskey, the unaged whiskey is stored in new, white oak barrels, whose head and staves have been charred. The barrels are normally constructed of 25 staves from 2 to 3 cm in thickness and charred for 30 to 50 seconds. The barrels typically hold 190 liters and are approximately 89 cm tall and 54 cm diameter at the head.

During aging, the barrels are stored in large warehouses. There are three types of warehouse design: brick and masonry rack design; metal clad, wood-frame rack design; and palletized design. Rack designs consist of multi-level lattice structures made of wood or metal, on which the barrels are tightly packed on their sides in long parallel rows and supported by beams at the ends of the barrels. In rack design warehouses, there are commonly three to six levels of barrels per floor and five to ten floors per warehouse. Brick rack designs have concrete floors, roof, and brick exteriors, with windows normally on each floor for ventilation. Metal clad rack designs have corrogated or sheet metal exterior and roof which are attached to the interior wood lattice. The wood lattice supports the barrels and provides the structural support for the warehouse. In contrast to brick and masonry warehouses, where the concrete floors block internal air circulation, metal clad warehouses are open internally with ventilation provided by windows or ventilators at the top and bottom of the structure. Palletized design warehouses are single story structures with barrels stored upright on pallets, with 15 barrels a pallet. Palletized designs require more land than rack designs, but reduce the labor required to handle the barrels.

The barrel capacity range of warehouses varies as a function of design: 40,000 to 100,000 for brick rack designs, 20,000 barrels or less for metal clad rack designs, and up to 35,000 for palletized designs. The absence of water sprinklers for fire protection in metal clad rack warehouses limits their size for insurance reasons.

The total barrel capacity of a typical warehousing operation ranges from 200,000 to 600,000 barrels. Brick warehouses are generally used in urban areas because of fire and building codes, and metal clad warehouses are generally used in rural areas. Metal clad warehouses are placed 60 meters or more apart for fire protection and thus a large storage facility with 30 warehouses will cover up to 450 hectares. Other smaller rural facilities may be dispersed because of hilly terrain or to place the warehouses in the optimum location for aging. A listing of barrels stored in Kentucky distilleries is presented in Appendix B.

2.2 MECHANISMS OF AGING

The main components of whiskey, ethanol and water, are relatively insignificant factors in its flavor intensity and palatability. The distinctive qualities of whiskey are due for the most part to the trace constituents, called "cogeners," present in the beverage. These substances are generated in part during fermentation, but the majority are added in the course of aging.

During aging these trace constituents are added to the whiskey by three mechanisms:[1]

1. extraction of organic substances from the wood and their transfer to the whiskey,

2. oxidation of the original substances and of the extracted wood material, and

3. reaction between various organic substances present in the liquid to form new products.

The nature and changes in the concentration of these trace constituents are shown in a comprehensive study of whiskey during maturation by Liebmann and Scherl of Schenley Distillers.[2] Their study covered an 8 year period and included analysis of 469 barrels. Table 2-1 presents the statistical design of the major variables of the study and Table 2-2 lists the characteristics of whiskey at various maturation times. The main changes in physical and chemical characteristics of whiskey, occurring as a function of time are shown in Figure 2-1.

There are several points to note concerning changes in whiskey during aging as observed in the Liebmann and Scherl study. The fixed acids, furfural, solids, color, and tannins in whiskey are added entirely during aging. (The small amounts present initially in the whiskey sampled in the study were due to the fact that some of the whiskey had been treated with oak chips before barreling.) In contrast, there are significant quantities of esters and fusel oil and lesser quantities of total acids and aldehydes present prior to aging. The concentration changes for most constituents are essentially complete by three years of aging; however, esters and solids continue to show significant increases in concentration beyond that time. The increase in aldehydes, acids and esters, oxidation and reaction products of alcohols, show the importance of chemical reactions in aging. In examining the chemical changes it is important to note that there are only rough relations between chemical analysis and quality, i.e., taste and aroma of whiskey. It is necessary to rely on the human senses of taste and smell to detect fine variations and thus evaluate the quality of whiskey.

The precise sequence and interdependence of the mechanisms responsible for aging are quite complex and not completely understood. However, the following paragraphs describe in general the chemical and physical phenomena responsible for aging. The description is purposely qualitative since the

Table 2-1. STATISTICAL DATA OF WHISKEY MATURATION STUDY BY LIEBMANN AND SCHERL[2]

Grain formula			Distillation			Treatment			Warehouse			Storage		
Type	No.	%	Type	No.	%	Type	No.	%	Type	No.	%	Location	No.	%
Bourbon			Singled	82	17	Untreated	255	54	Rack (wood)	219	47	Louisville, Ky.	128	27
60% corn														
40% small grain	84	18	Doubled	387	83	Oak chip-treated	54	12	Concrete	250	53	Schenley, Pa.	114	24
75% corn												Lexington, Ky.	64	14
25% small grain	43	9		469	100	Nuchar-treated	160	34		469	100			
80% corn												Lawrenceburg, Ind.	91	19
20% small grain	151	32					469	100				Frankfort, Ky.	72	16
88% corn														
12% small grain	112	24											469	100
Rye														
51% rye														
49% other grains	79	17												
	469	100												

Table 2-2. CHARACTERISTICS OF AMERICAN WHISKIES AT VARIOUS AGES[2]

Age Yr.	Age Mon.	Proof	Total Acids	Fixed Acids	Esters	Alde-hydes	Fur-fural	Fusel Oil	Solids	Color (Density)	Tan-nins	pH
	0	101.8	5.9	0.8	16.7	1.4	0.2	111	8.7	0.032	0.7	4.92
	1	101.4	20.4	3.7	17.2	2.1	1.2	123	44.1	0.150	12	4.62
	3	101.3	32.2	5.3	18.5	2.8	1.5	131	66.6	0.205	21	4.46
	6	101.4	42.5	6.8	21.8	3.3	1.6	131	87.7	0.243	28	4.38
1	12	102.0	53.4	8.3	26.8	4.1	1.7	132	111.1	0.292	35	4.39
	18	102.5	58.1	9.0	31.1	4.8	1.8	132	127.6	0.308	39	4.29
2	24	103.1	61.8	9.2	35.5	5.5	1.8	134	137.5	0.328	42	4.29
	30	103.6	64.1	9.3	38.9	5.8	1.9	136	147.7	0.341	44	4.28
3	36	104.1	65.8	9.3	41.8	6.0	1.8	135	152.7	0.352	47	4.27
	42	104.7	67.8	9.4	44.7	6.0	1.9	137	157.7	0.360	48	4.26
4	48	105.2	69.2	9.4	47.6	6.1	1.8	138	165.9	0.365	49	4.26
	54	105.5	69.7	9.4	48.0	6.1	1.7	...	166.0	0.367	49	4.26
5	60	106.0	70.2	9.5	51.0	6.2	1.7	...	173.0	0.368	49	4.26
	66	106.7	72.0	9.5	55.6	6.3	1.8	...	174.2	0.369	49	4.26
6	72	107.4	71.6	9.5	57.6	6.5	1.8	...	181.5	0.380	49	4.24
	78	107.9	74.4	9.6	61.2	7.0	1.8	...	186.0	0.395	50	4.24
7	84	108.6	70.2	9.7	62.0	7.0	1.8	...	198.6	0.399	50	4.23
	90	108.9	70.4	9.7	64.4	7.0	2.0	...	198.9	0.413	50	4.22
8	96	109.3	81.9	9.7	64.8	7.0	2.0	...	209.6	0.449	53	4.20

* All figures represent average values and are expressed as grams per 100 liters at 100 proof, except proof (expressed as degrees proof), color (expressed as density), and pH.

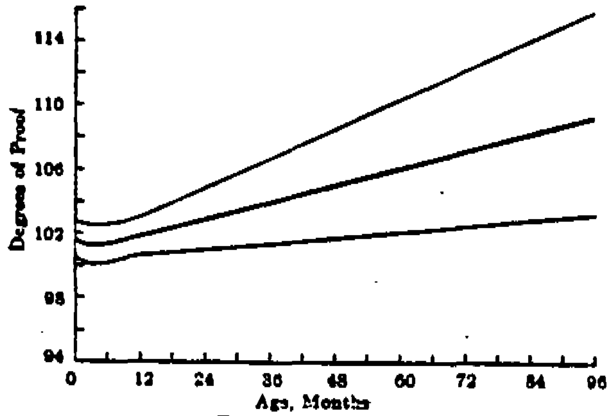

Figure 1. Proof

— Average; — dispersion limits

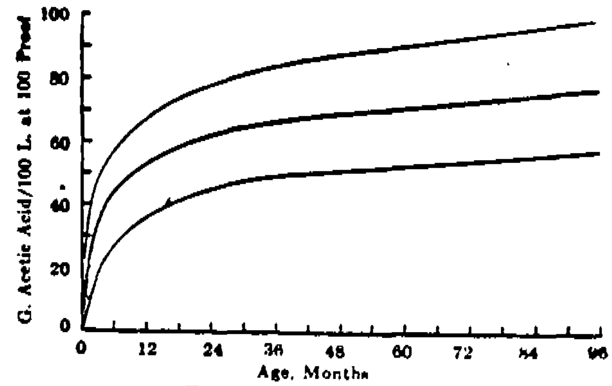

Figure 2. Total Acids

— Average; — dispersion limits

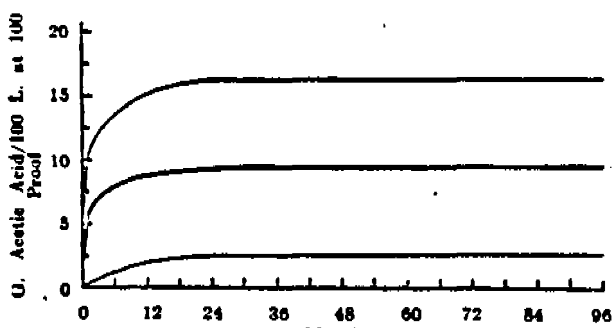

Figure 3. Fixed Acidity

— Average; — dispersion limits

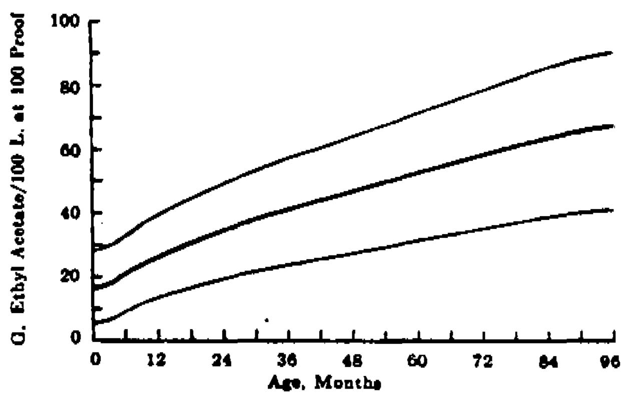

Figure 4. Esters

— Average; — dispersion limits

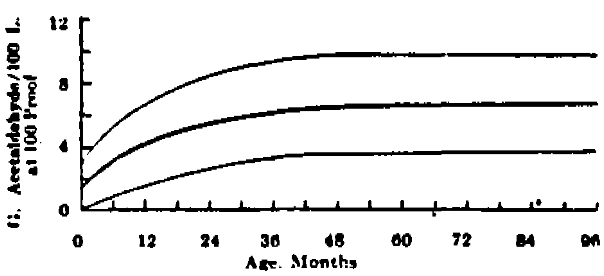

Figure 5. Aldehydes

— Average; — dispersion limits

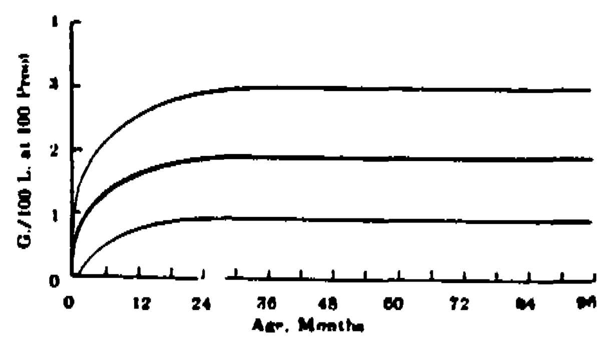

Figure 6. Furfural

— Average; — dispersion limits

Figure 2-1. Effect of maturation on the physical and chemical characteristics of whiskey, Liebmann and Scherl study [2]

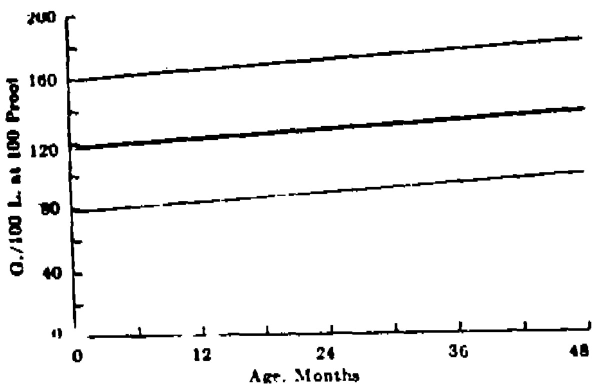

Figure 7. Fusel Oil
— Average; — dispersion limits

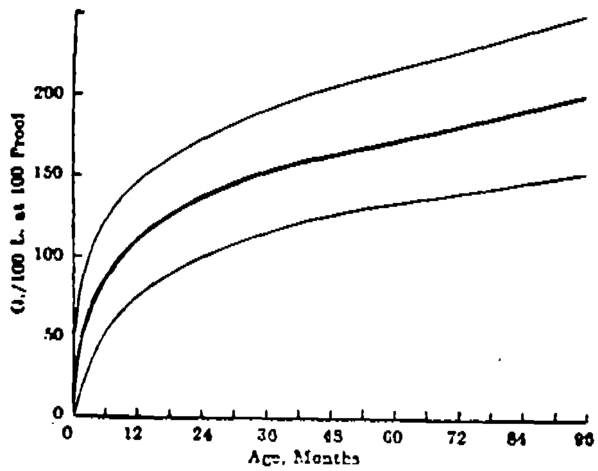

Figure 8. Solids
— Average; — dispersion limits

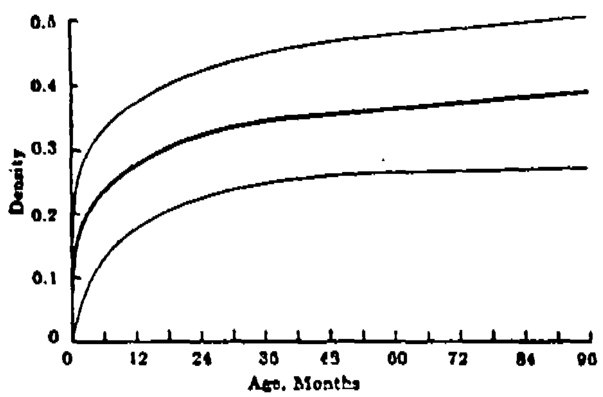

Figure 9. Color (Density)
— Average; — dispersion limits

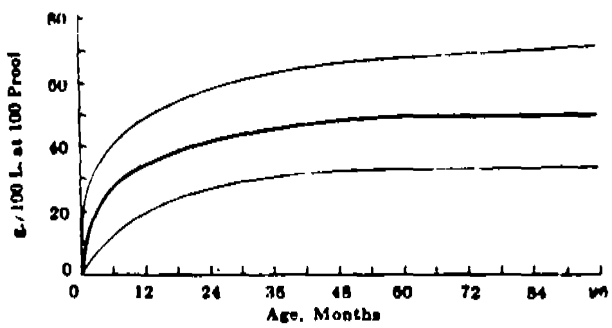

Figure 10. Tannins
— Average; — dispersion limits

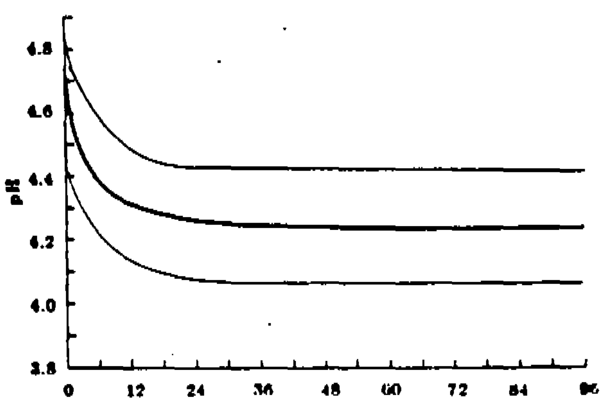

Figure 11. pH
— Average; — dispersion limits

Figure 2-1. (cont.) Effect of maturation on the physical and chemical characteristics of whiskey, Liebmann and Scherl study[2] exact rates of the phenomena and the sensitivity of these phenomena to changes in such variables as temperature and entry proof is not precisely known.

The aging process begins when the barrel is filled with whiskey and the charred wood becomes saturated with liquid. The liquid extracts from the charred wood partially oxidized organic substances in the char, the biologically formed organic substances in the uncharred wood, plus color and various solids. This material is transferred to the bulk liquid in the barrel by simple diffusion, by convection currents in the bulk liquid and by temperature cycling. Temperature cycling causes transfer of material in the following way. As the barrel heats up, the gas above the liquid increases in pressure and forces liquid into the barrel wood. When the barrel cools and the gas pressure drops, the liquid flows out of the wood into the bulk liquid, carrying wood constituents with it. The materials transferred and originally in the wood react to form new compounds. These reactions occur on the surface of the wood, with the char acting as a catalyst, and in the bulk liquid. In addition, oxidation of chemical substances occurs as a result of the slow diffusion of air into the barrel liquid.

The rates of extraction, transfer, and reaction depend on temperature and the concentrations of various whiskey constituents. The effect of temperature is straightforward - higher temperatures increase the rates of extraction, transfer by diffusion, and reaction. Also, temperature changes cause convection currents in the liquid and pressure changes in the gas affecting transfer. The effect of concentration is more complex. The rate of extraction of various char and wood constituents will depend on the relative concentration of ethanol and water in the wood, since the constituents will exhibit differing solubilities in water vs. ethanol. The rate of extraction will also depend on the overall concentration of liquid in the wood. The rate of diffusion will depend on the difference of concentrations of constituents in the wood, liquid, and air around the barrel. The rates of reaction will increase or decrease with the concentration of constituents.

The equilibrium concentrations of the various whiskey components depend heavily on the air flow around the barrel. A large air flow will lower the concentration of water, ethanol, and trace constituents in the air and increase the concentration gradient between the air and the barrel wood. This will have a number of effects. First, the larger concentration gradient will cause water and ethanol to evaporate faster and the ethanol/water content of the barrel wood to drop. An example of this phenomena is that a blotter strip whose end is stuck in water will be drier and water will evaporate faster with air blowing over it. The faster evaporating ethanol and water will draw more wood constituents out than normal, allowing less to travel inward to the bulk liquid. Also the lower liquid content of the wood will effect extraction. Finally, the larger concentration gradient for trace constiuents will cause these substances to evaporate to the air faster, again upsetting their inward transfer to the liquid. Figures 2-2 and 2-3 illustrate these various transfer mechanisms, and other aspects of aging.

2.3 WAREHOUSE OPERATION

The preceding discussion illustrates the importance of correctly controlling the barrel environment to produce a whiskey of a desired quality. Since each distiller desires to produce a whiskey with a quality distinctive to their brand, the various distillers control the barrel environment differently by operating their warehouses in different manners. However, it must be kept in mind that the effects on whiskey quality of such warehouse parameters as temperature, temperature cycling, humidity and ventilation are not precisely known.

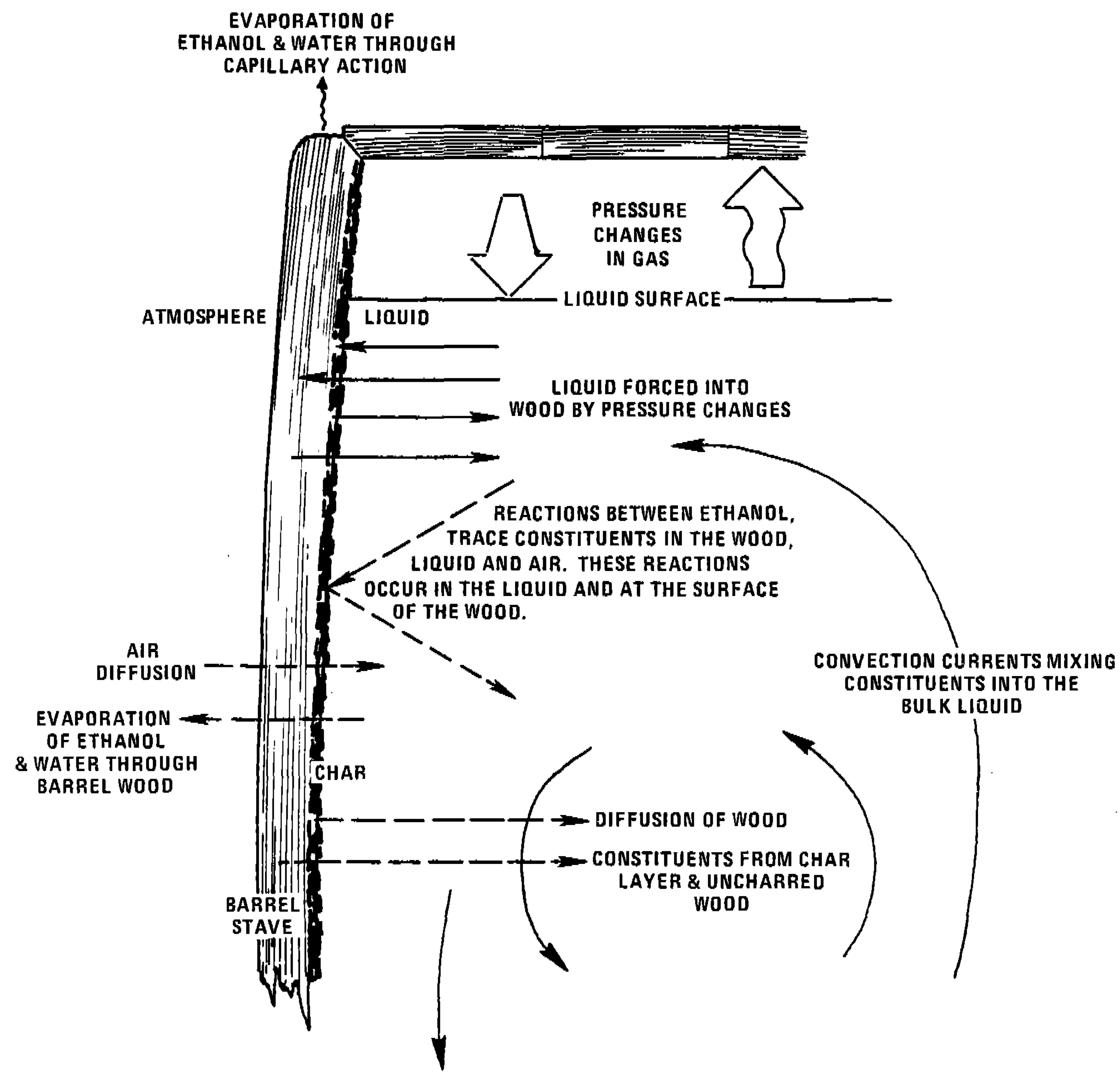

Figure 2-2. Mechanisms of whiskey aging.

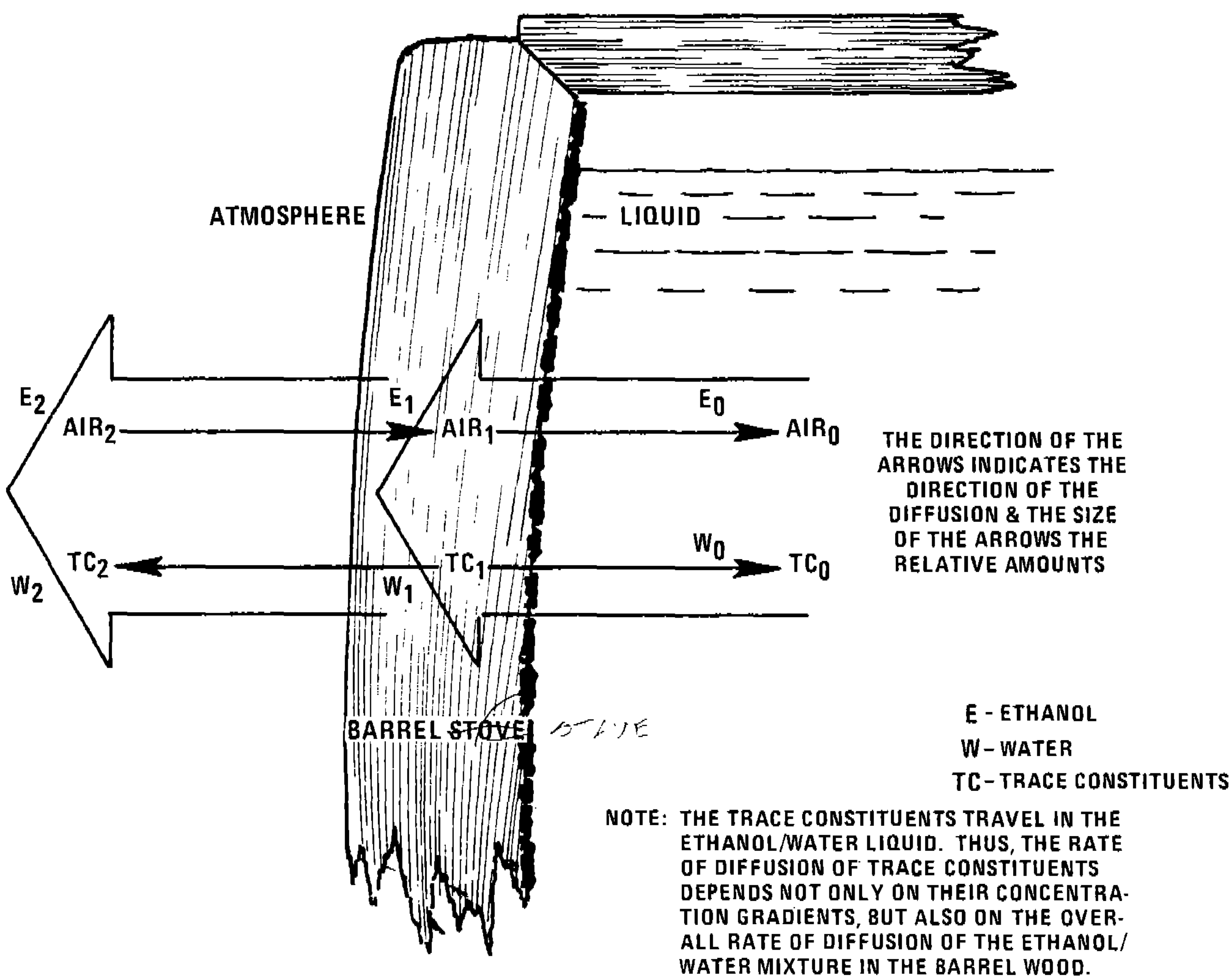

Figure 2-3. Diffusion through barrel staves in whiskey aging.

Thus, present methods of warehouse operation have not been developed by design and calculation; rather, each distiller's operation is for the most part the result of tradition and experience.

Other factors besides quality influence warehouse operation. These include the differing construction costs between metal clad and brick designs, the energy required if heating is used in the winter, the labor involved in moving barrels and opening and closing windows, the level of evaporative losses, and the savings in barrel costs if whiskey entry proof is increased.

The most important variation in warehouse operation is the type of warehouse: brick, metal clad or palletized. One aging/quality philosophy is that the best whiskey is produced when the barrel follows natural conditions during aging. Thus, metal clad warehouses are used since their exteriors are designed only to keep rain and snow from the barrels and provide no additional protection from the weather. However, the labor savings involved in palletized designs, construction costs and fire codes also influence the choice of warehouse type.

Another area where variations in practice occur is the type of ventilation provided for the solar heating effect. The large roof area of palletized designs and the poor insulation characteristics of metal clad designs allow relatively high rates of solar heat transfer through the roof and upper levels. If no natural or forced air circulation is provided, a hot, stagnant air mass develops in the upper area and a sizable temperature difference can develop between the top and bottom of the warehouse. This effect is commonly observed in metal clad warehouses during the summer, when temperatures of 120 to 140^{o}F can develop in the top floor while temperatures at the bottom are only 65 to 70^{o}F.

Various practices are followed with respect to this solar heating effect. Some distillers desire the elevated temperatures to achieve the type of aging they desire and thus close the bottom or top windows to create these high temperatures. Others provide for ventilation at the top and bottom of the warehouse to induce air flow and reduce the temperature difference. This is done not only to produce different temperatures for aging, but also to reduce the high evaporation losses at the elevated temperatures and to produce more uniform aging conditions in the warehouse. One distiller, in an effort to achieve complete uniformity of conditions and product, has sealed and insulated his metal clad houses and installed a central ventilation and heating system.

Variations in operating methods also exist among brick warehouses and between brick and metal clad houses. Brick houses have much better insulation characteristics, and thus do not experience the extreme temperature gradients in the warehouse during summer. Thus, whereas barrels stored in metal clad houses are rotated to average out the exposure temperature barrel rotation is not nearly as critical in brick warehouses. The insulating characteristics of brick warehouses also allow for heating in winter, whereas metal clads are allowed to follow the ambient temperature. In addition, among brick warehouses, different heating practices are used. Distillers not only maintain different temperatures in the winter, but also practice different cycling techniques. Some have only seasonal cycles, cooling in fall and warming in spring, while others intentionally increase and decrease the warehouse temperature several times in winter to produce the type of aging they desire. Variations between distillers also occur in the practice of summer ventilation. Some simply open the windows, while two locations have completely closed buildings and ventilate with fans.

Other more detailed variations undoubtedly exist. These include the time of the year windows are closed or heating starting, the length of temperature cycling, the frequency windows are open and shut, and the humidity characteristics of the spot selected for the warehouse. All of these variations illustrate the number of differing aging philosophies and traditions. The practices of several distillers are shown on Table 2-3.[3-11]

Table 2-3
Warehousing Operations

ick & Masonry Design

Company	Heating in Winter	Open Windows in Summer	Forced Air Ventilation in Summer	Temperature Cycles	Temperature Summer	Temperature Winter
A	Yes	Yes	No	seasonal	Ambient	$40^{o}F$
A, Bldg. E	Yes	No, no windows	Yes	seasonal	Ambient	$40^{o}F$
B	Yes	No	Yes	several times in winter	Ambient	$55^{o}F$
C	Yes	Yes	No	several times in winter	Ambient	$40^{o}F$
D	No	Yes	No	seasonal	Ambient	Ambient

:tal Clad

Company	Heating in Winter	Windows open in summer Bottom	Windows open in summer Top	Barrel Rotation	Temperature - summer Top	Temperature - summer Bottom
E	No	Yes	Yes	every 2 years	$95^{o}F$	$85^{o}F$
F	No	No	Yes	every 2 years	$120^{o}F$	-
; present	No	Yes	Yes	Not stated	Not Stated	
previously	No	No	Yes	Not stated	$120^{o}F$	$65^{o}F$
H	No	Yes	No	New barrels started at top and moved down	elevated	$70^{o}F$
I	The warehouses have been sealed and insulated and a central heating/ ventilation system installed				temperature cycling in winter; in summer forced air ventilation used to keep the ΔT to a minimum	

2.4 REFERENCES

1. Liebmann, A. J., and B. Scherl. Changes in Whiskey While Maturing. Industrial and Engineering Chemistry. 41:534-543, 1949.
2. Reference 1
3. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Jim Beam Distillery, Clermont County, Kentucky, April 7, 1977.
4. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Schenley Distillery, Louisville, Kentucky, April 7, 1977.
5. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Barton Distillery, Bardstown, Kentucky, April 7, 1977.
6. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Seagrams, Inc., Lawrenceburg, Indiana, March 30, 1977.
7. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Seagrams, Inc., Louisville, Kentucky, March 30, 1977.
8. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Brown-Foreman, Louisville, Kentucky, April 8, 1977.
9. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio, on a visit to Heaven Hill Distillery, Bardstown, Kentucky, April 7, 1977.
10. Telephone conversation between Mr. T. W. Samuels, Jr. President, Maker's Mark Distillery, Inc., Louisville, Kentucky and David C. Mascone, U. S. EPA, September 19, 1977.
11. Telephone conversation between Mr. David C. Mascone, U. S. EPA and Bill Padgett, Austin Nichols, Lawrenceburg, Kentucky, January 19, 1978.

3.0 VOLATILE ORGANIC EMISSIONS FROM WHISKEY WAREHOUSING

This chapter will describe the volatile organic emissions from whiskey warehousing, develop an emission factor for these emissions and present an estimated national emission inventory.

3.1 EMISSION SOURCE DESCRIPTION

The two sources of ethanol in whiskey warehousing are evaporation from the barrel wood during storage and evaporation from the saturated wood after the barrel is emptied. These emission sources are described below.

The first emission, evaporation during storage, occurs when liquid diffuses through the barrel staves and heads via the wood pores or travels by capillary action to the ends of the barrel staves. The liquid evaporated is both water and ethanol, with minor amounts of trace constituents. As discussed in Chapter 2.0, this ability of the barrel to "breath", i.e. allow liquid to evaporate and air to enter, is important to aging. Attempts made to age whiskey in sealed containers and thus prevent losses have proven unsuccessful since little aging occurred.

The rate of evaporation during aging is not constant. During the first six months to a year, the evaporation rate is low, since the wood starts dry and must become saturated before evaporation occurs. After saturation, the evaporation rate is greatest but decreases as the evaporation lowers the liquid level in the barrel. The lower liquid level decreases the surface area of the liquid in contact with the wood and thus the surface area subject to evaporation.

The second emission, evaporation after barrel emptying, occurs when the saturated barrels are stored after emptying. The amount and location of these emissions depend on the use that the distillers find for the barrels. A significant fraction are stored outside for lengthy periods during which much of the alcohol evaporates. Even if further use is found for the barrels, the bound alcohol will still evaporate if the barrels are stored long enough before reuse. Potential end uses for used barrels are aging Scotch, Canadian whiskies and American light whiskies, and as fuel or for decorative purposes. Federal law prohibits the use of used barrels in bourbon and American blended whiskey.

3.2 WHISKEY WAREHOUSING EMISSION FACTORS

Two sources of data are available to develop emissions factors for whiskey warehousing - aggregate loss data from IRS publications and individual loss data from specific distillers.

3.2.1 Emission Factors from IRS Data

The aggregate loss data from IRS publications are presented in Table 3-1.[1,2] Shown on this table are data on whiskey withdrawals, losses and stocks for 1974, 1975, and 1976, along with emission factors calculated from this data. Withdrawals represent whiskey removed from storage for comsumption. Losses represent the difference between the original and withdrawn amounts, i.e. that amount of whiskey lost due to evaporation and barrel soakage, plus theft, spills, etc. Average stocks represent an average of the amount of whiskey held in storage for that year and the previous five.

Three emission factors were developed from this data. Emission Factor I represents the fraction of whiskey production lost and equals .2 proof gallons lost for each proof gallon whiskey produced. This factor was computed by dividing

Table 3-1. LOSSES, WITHDRAWALS, AND STOCKS OF WHISKEY FOR THE U.S. From IRS Data

Column	1	2	3	4	5	6	7	8
	Year	Withdrawals	Losses	Withdrawals + Losses	Emission Factor I[1]	Average Stocks[2]	Emission Factor II[3]	Emission Factor III[4]
	1976	134.8	33.7	168.5	.200	870.6	.039 387	3.2
	1975	136.9	36.0	172.9	.208	910.0	.039 396	~~3.2~~ 3.3
	1974	138.1	33.9	172.0	.197	935.7	.036 362	3.0
					3/4			

[1]Computed by dividing column 3 by column 4, represents pg lost/pg whiskey produced.

[2]Represents the average of the stocks of whiskey in storage for the previous 6 years.

[3]Computed by dividing column 3 by column 6, represents (pg lost/year)/pg whiskey in storage.

[4]Computed by multiplying column 7 by 55 pg/barrel and 1.5 kg/pg lost, represents kg ethanol lost/barrel-yr.

Table 3-2. BARREL SOAKAGE LOSSES

Source	Barrel Soakage kg liquid	Barrel Soakage lbs liquid	Aging Time, years	Best Fit Equation	No. of years	kg lost-equation
Brown-Foreman	7.3 8.0	16	5		5	8.1
Boruff & Rittschof	10.3 10.0	22.6	8	kg liquid soakage	8	10.0
Gallagher, et. al.	8.6 8.0	19	5	(i.e. water + ethanol)	5	8.1
Schenley	5.5	12	1	=.67(aging time,yrs) +4.7	1	5.4
	11.4 11.4	25	10	for years 1 & greater	10	11.4

total losses by total production (losses plus withdrawals). Emission Factor II represents the loss rate based on stored whiskey and equals .038 proof gallons lost for each proof gallon in storage each year. This factor was computed by dividing total losses by average stocks. The number of proof gallons in stock was taken to be the average of the number of proof gallons in stock for that year and the previous five. The 6-year average stock was used since losses recorded for a given year represent losses on barrels emptied that year. These losses actually occurred not only during that year, but in previous years while the barrel was in storage. Six years is an approximation of the period of barrel storage - some of the losses for a given year come from barrels stored eight years and more, whereas some stored six years ago have already been emptied for four year old whiskey. Emission Factor III represents a weight loss rate per barrel per year and equals 3.2 kg ethanol/per barrel each year. This factor was computed by multiplying Emission Factor II by 55 proof gallons per barrel and 1.5 kg ethanol per proof gallon. It is important to note that the above figures include losses for both evaporation during storage and soaking into the barrel.

3.2.2 Emission Factors from Individual Distiller Data

The loss rate data from individual distillers and from experiments cover two areas, barrel soakage losses and evaporation losses during storage. These are discussed below.

The data available on barrel soakage losses are presented in Table 3-2.[3,4,5,6] The table shows the available data on total liquid soakage vs. aging time, plus a best fit equation for this data. The table indicates a rapid saturation of the barrel during the first year, followed by a constant, but slow, increase in weight during subsequent years. It should be noted that the data are for liquid soakage, i.e., both water and ethanol. Work by Boruff and Rittschof[7] indicates that the proof of the liquid in the barrel wood is approximately the same as the proof of the stored whiskey; this permits a conversion from kg liquid to kg ethanol. Thus, a typical barrel storing 120 proof whiskey emptied after four years contains 3.8 kg of ethanol in the saturated wood.

The data from experiments and individual distillers on evaporation during storage are shown on Table 3-3.[7-13] The cumulative loss represents the total ethanol loss due to evaporation during the aging time shown. The annualized loss rate expresses this total at a constant yearly loss rate and was computed by dividing the cumulative loss by the aging time. Table 3-3 also shows a best fit equation for annualized losses for aging times of four years or more.

Annualized loss rates vs. aging time, as computed from the data and equation in Table 3-3, are shown on Table 3-4. Also shown on Table 3-4 are computed cumulative loss and computed incremental loss. Cumulative loss was calculated by multiplying the aging time by the annualized loss rates from the best fit equation. Incremental loss was computed by subtracting the computed cumulative loss for two successive years. This later number represents the additional evaporative loss during the given year of aging.

Figure 3-1 shows graphically the data on annualized loss rate from Table 3-3 and the computed annualized and incremental loss rates from Table 3-4. The graph clearly shows the wide variation in evaporative loss between distillers. These variations can be explained qualitatively by variations between distillers in such warehouse parameters as temperature, ventilation patters and temperature cycling. However, because of the large number of conditions that affect evaporation and the limited knowledge on the precise effects of the conditions on the rate of evaporation, no attempt was made to statistically relate warehouse conditions to evaporative loss.

Figure 3-1 also shows the variation in the incremental loss rate during aging, with the rate increasing during the first two years and decreasing in

Table 3-3. EVAPORATIVE LOSSES DURING STORAGE

Source No.[a]	Aging Time Years	Cumulative Loss kg ethanol/barrel	Annualized loss[b] kg ethanol/barrel-yr	Best fit Equation-Annualized Loss
Gallagher, et. al.	1	2.35	2.35	
Gallagher, et. al.	2	6.59	3.30	
A	4	9.52	2.38	For years 4 & greater
C	4	15.60	3.90	Annualized Loss (kg ethanol/barrel-yr) = -.101(aging Time, yrs) +3.38
E	4	9.32	2.33	
F	5	14.45	2.89	
C	6	20.88	3.48	
Boruff & Rittschof	8	17.76	2.22	
F	9	18.81	2.09	
I	10	26.70	2.67	

[a]Letters indicate data from individual distillers; Letters refer back to same distillers as Table 2-3

[b]Annualized losses assuming equal loss each year.

Table 3-4. COMPUTED ANNUALIZED, CUMULATIVE & INCREMENTAL LOSSES

Aging Time Years	Annualized Loss kg/barrel-yr[a]	Cumulative Loss kg/barrel[b]	Incremental Loss kg/barrel-yr[c]
1	2.35	2.35	2.35
2	3.30	6.60	4.25
3	3.10	9.30	2.70
4	2.98	11.92	2.62
5	2.88	14.40	2.48
6	2.78	16.68	2.28
7	2.67	18.69	2.01
8	2.57	20.56	1.87
9	2.47	22.23	1.67
10	2.37	23.70	1.47

[a]Years 1 & 2 are taken from Gallagher, et. al.; years 3 & greater from the best fit equation, Table 3-3.

[b]Annualized loss times aging time.

[c]Difference between cumulative loss for successive years.

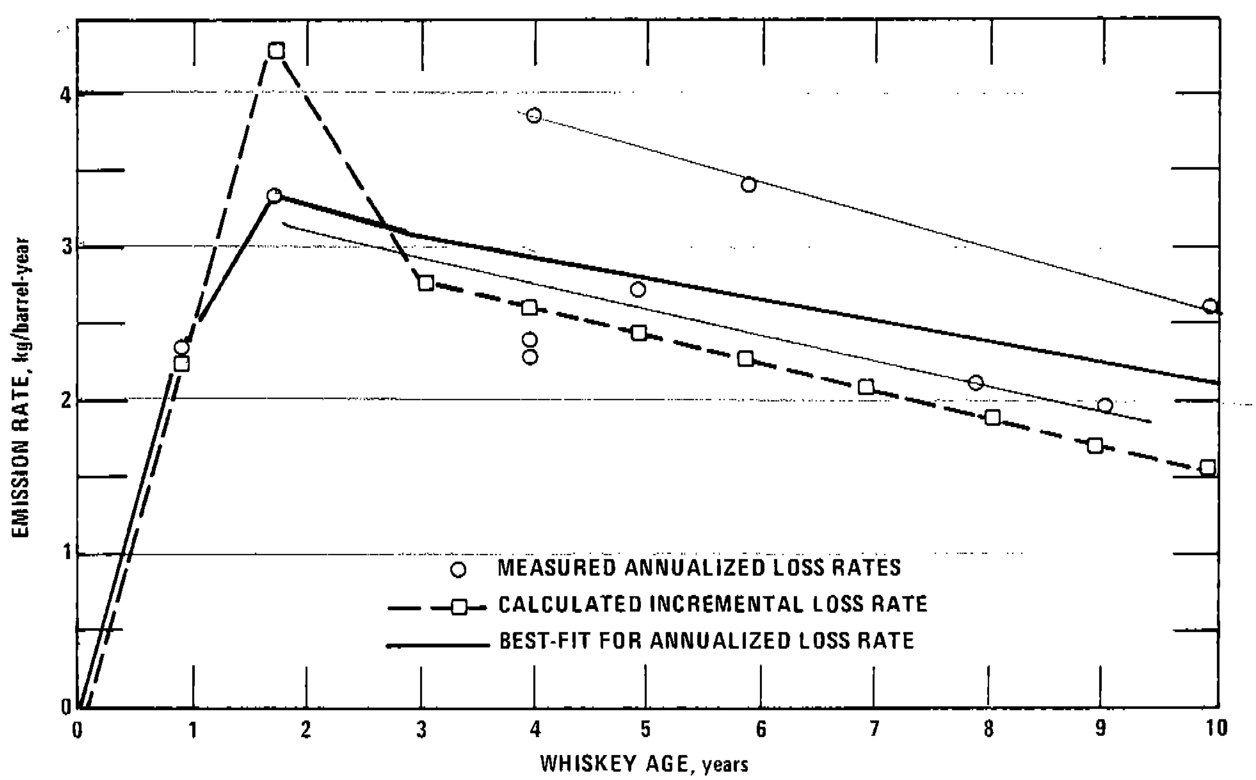

Figure 3-1. Emission rate relationships in the whiskey aging process.

subsequent years. This is in agreement with the theory discussed early. This variation in the incremental loss rate means that the age mix of the barrels in storage will affect the emission rate. Since barrels of different age have different evaporative loss rates, the total emissions will be determined by the fraction of barrels at each age.

Three different barrel age distributions were used to calculated emission factors: (1) the age distribution of bonded whiskey in Kentucky at the end of 1975;[14] (2) an age distribution based on fluctuating market from year to year; and (3) the age distribution based on distillers producing mainly four year old whiskey. Table 3-5 presents the barrel age distribution for the three cases and the respective emission factors of 2.55 kg/barrel-yr for case one, 2.74 kg/barrel-yr for case two, and 2.89 kg/barrel-yr for case three. These emission factors were calculated by multiplying the fraction of the barrels at a given age by the incremental loss for that age in Table 3-5. The four distillers producing primarily four and six year old whiskey used in case three are Jim Beam, Clermont, Kentucky; Jim Beam, Beam, Kentucky; Brown-Foreman, Louisville, Kentucky; and Fleischmann, Owensboro, Kentucky.[15]

The above emission factors represent evaporative losses during storage only. To determine overall emission factors, losses due to barrel soakage must be included. This loss is computed by assuming that the number of barrels emptied in a year equals the number of barrels one year old, and that the average barrel has a soakage equivalent to a five year old barrel. This figure is 4.2 kg ethanol/barrel. The overall emission factor is therefore:

Aging + Soakage = Total Emissions

case one) 2.55 + 4.2 (.112) = 3.02
case two) 2.74 + 4.2 (.172) = 3.46 kg/barrel-yr
case three) 2.89 + 4.2 (.181) = 3.65

In the preceding discussion, the variations in evaporative loss rate during aging were averaged together to develop a single emission factor.

Table 3-5. WAREHOUSE BARREL AGE DISTRIBUTION

(1) Whiskey by Various Periods of Production Remaining in Bonded Warehouses in Kentucky as of Dec. 31, 1975.

Age	Barrels in bond in Kentucky	Fraction by year	
0-1	685,600	0.112	0.2632
1-2	657,600	0.107	0.[illegible]
2-3	813,800	0.132	0.3564
3-4	943,400	0.153	0.4008 Average barrel loss
4-5	868,700	0.141	0.3140 2.55 kg/barrel-year
5-6	821,000	0.134	0.3055
6-7	761,900	0.124	0.2402
7-8	349,600	0.057	0.1062
9+	247,200	0.040	0.0664
	6,148,600	1.000	2.552[illegible]

(2) Barrel Age Distribution Assuming a Uniform Year-to-Year Consumption Rate (100 bbl/yr basis)

Age	% Used (end of year)	Total by year	Fraction in warehouse by year	
0-1		100	0.172	
1-2		100	0.172	
2-3		100	0.172	
3-4	35	100	0.172	Average barrel loss
4-5	20	65	0.112	2.74 kg/barrel-year
5-6	15	45	0.079	
6-7		30	0.052	
7-8	20	30	0.052	
9+	10	10	0.017	
		580	1.000	

(3) **4 to 6 yr Whiskey Production**

Age	Beam Beam, Ky.	Beam Clermont, Ky.	Brown-Forman Louisville, Ky.	Fleishmann Owensboro, Ky.	Overall age distribution
0-1	58948	60743	97000	30901	0.181
1-2	64014	74076	104437	38568	0.205
2-3	98247	78559	41840	35413	0.185
3-4	91239	84464	63371	36411	0.201
4-5	17572	24102	60514	30412	0.097
5-6	1110	31594	37320	35963	0.077
6-7	303	14981	4321	5412	0.018
7-8	2122	25207	2783	208	0.022
9+	5698	12069	858		0.014
					1.000

Average barrel loss = 2.74 kg/barrel-year

This single emission factor was then used together with data on barrel age distributions to compute several emission factors. A second method of developing emission factors from the loss data reported by individual distillers is to group the data into higher and lower measured annualized loss rates. As noted previously in Chapter 3, large variations in measured annualized loss rate result from differing warehouse operations. The analysis of the loss rates by dividing them into higher and lower values will provide two emission factors characterizing the spread of emissions caused by differences in warehouse operations. Examination of Figure 3-1 shows that the bottom four and top three data points for measured annualized loss fit into two convenient groups. Analysis of these groups results in emission factors of 2.3 and 3.6 kg/barrel-yr for evaporative loss during aging.

It should be noted that the above analysis was not performed rigorously. A rigorous analysis would require that the annualized loss data be converted to incremental losses, and then the incremental loss applied to barrel age distributions. This was not done because it was felt that three data points (four in the lower value case) were not sufficient for these conversions to remain statistically meaningful. Thus, the emission factors of 2.3 and 3.6 kg/barrel-yr were determined by drawing lines, lines through the bottom four and top three points for measured annualized losses (Figure 3-1) and the loss rate at year five were taken to be the appropriate emission factor.

All the emission factors for volatile organic chemicals from whiskey warehousing are summarized in Table 3-6. The emission factors based on the variations in warehouse operations are used in designing and costing the control system. The emission factors developed from the barrel age distributions, along with Emission Factor III from the IRS data, are used to develop emission inventories. Finally, Emission Factor I from the IRS data is used to relate

Table 3-6. SUMMARY OF EMISSION FACTORS
WHISKEY WAREHOUSING

Source	Figure	Description
IRS Publication	.20 proof gallons lost/proof gallons produced*	represents fraction of production lost
13-4	.038 proof gallons lost/proof gallons storage-yr*	represents fraction of storage lost per year
	3.2 kg ethanol/barrel-yr*	represents amount of ethanol lost per barrel in storage per year
Individual Distiller Data & Experiments	3.8 kg ethanol soakage/barrel	represents amount of ethanol lost per barrel due to soakage into wood. The figure is for a barrel stored 4 years.
	40 3.02,3.46,3.65 kg ethanol/barrel-year	represents amount of ethanol lost due to both evaporation during storage and soakage for various barrel age distributions
	2.3,3.6 kg ethanol/barrel-yr	represents the range of ethanol loss durir storage caused by differing methods of warehouse operation; does not include soakage loss

*These figures include all types of loss - evaporation during storage, soakage into the barrel, plus leakage, theft,etc.

whiskey sales to markets in the discussion of reuse of the recovered alcohol. The reason for using each emission factor for the uses described above is given with the calculations involving that emission factor.

3.3 EMISSION INVENTORY

Total emission estimates are developed for three areas: (1) typical size distilleries, (2) States; and (3) nationwide.

Two representative facilities were chosen to develop emission totals for typical size distilleries: (1) a large 400,000 barrel facility producing primarily four year whiskies and (2) a smaller 50,000 barrel facility producing whiskies up to eight years and older. To compute the emission total for the 400,000 barrel facility the emission factor used is that of case three in on page 3-9 This emission factor is used since the barrel age distribution for case three and for the 400,000 barrel facility are both based on producing four year old whiskies. For the 50,000 barrel facility, the emission factor used is that of case one on page 3-9. This emission factor is used since the Kentucky barrel age distribution approximates those of distillers producing eight year and older whiskies. The emission totals for the large distillery is 400,000 barrels x 3.65 kg/barrel-yr = 1460 MT/yr and for the large distillery 50,000 barrels x 3.02 kg/barrel-yr = 151 MT/yr.

Total emission estimates will be developed for five States - Kentucky, Indiana, Illinois, Tennessee, and Maryland. Table 3-7 shows the number of barrels stored in each State[16] and the total emission estimate. The emission factor used was 3.2 kg/barrel year, based on the aggregate loss data from IRS publications. This emission factor was used since, being based on the widest

Table 3-7. TOTAL EMISSION ESTIMATE BY STATE

State	No. of Barrels in Storage June, 1976, Thousands	Total Emissions (MT/yr)
Kentucky	6130	19,620
Illinois	1290	4,130
Indiana	2260	7,240
Maryland	640	2,050
Tennessee	580	1,780

data base, it was most likely to have correctly averaged the variation in barrel emission rates that occur between warehouses.

The national emission total estimate is 38,170 MT/yr, based on 11.9 million barrels stored in June, 1976. The five States above represent 91 percent of the estimated emissions.

3.4 REFERENCES

1. U. S. Department of the Treasury, Bureau of Alcohol, Tobacco and Firearms. Alcohol, Tobacco and Firearms - Summary Statistics, FY 1975. ATF P 1323.1 (4-76), U.S. Government Printing Office, Washington, D.C.
2. U. S. Department of the Treasury, Bureau of Alcohol, Tobacco and Firearms. Alcohol, Tobacco and Firearms - Summary Statistics, FY 1976 ATF P 1323.1 (4-77), U. S. Government Printing Office, Washington, D.C.
3. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Brown-Foreman, Louisville, Kentucky, April 8, 1977.
4. Gallagher, M., P. Kolachov, and H. F. Willkie. WHiskey Losses During Aging. Industry and Engineering Chemistry 34:992-995, 1942.
5. Boruff, C. S., and L. A. Rittschof. Effects of Barreling Proof on the Aging of American Whiskies. Agricultural and Food Chemistry. 7(9): 630-633, 1959.
6. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Schenley Distillery, Louisville, Kentucky, April 7, 1977.
7. Reference 4.
8. Reference 5.
9. Reference 6.
10. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Seagrams, Inc., Lawrenceburg, Indiana, March 30, 1977.
11. Letter from Dr. Alan T. Thomas, Brown-Forman Distillers, Louisville, Kentucky to Pedco, Cincinnati, Ohio, April 19, 1977.
12. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Jim Beam Distillery, Clermont County, Kentucky, April 7, 1977.
13. Trip Report by Terry Briggs, Pedco, Cincinnati, Ohio on a visit to Barton Distillery, Bardstown, Kentucky, April 7, 1977.

14. Liberty National Bank and Trust Co. of Louisville, Kentucky. Distilled Spirits in Bonded Warehouses in Kentucky on December 31, 1975. Bulletin 114, Louisville, Kentucky.

15. Reference 14.

16. Reference 2.

4.0 WAREHOUSE EMISSION CONTROL

Two methods for reduction of warehouse emissions were investigated: 1) carbon adsorption (CA) and 2) an alternate aging system. The second method of control is in early development and will require a number of years for testing. However, the system's potential for large reduction in aging costs makes it attractive as a control method, given successful testing.

4.1 CARBON ADSORPTION - SYSTEM DESCRIPTION

Controlling warehouse emissions by carbon adsorption would involve closing the warehouse and ducting the interior to a carbon adsorption unit. For brick warehouses, this would involve shutting most windows, doors, and ventilators, leaving some open for intake air, and running ductwork along the exterior of the building to the various floors. In some metal clad warehouses, extra work may be required to close gaps between metal sheets, and between the roof and the sides. However, most metal clad warehouses are tight enough in construction that closing windows, doors, and ventilators would be sufficient. The areas of sheet metal overlap would not need to be sealed since these areas would provide the infiltration required to balance the air removed by the CA unit.

The CA unit itself would be a skid-mounted package system containing two beds, fans, switching mechanisms and control, condenser/decanter, and internal piping for steam and air flow. The unit would run on a two cycle system with one bed adsorbing as the second was regenerated and cooled.

4.2 CARBON ADSORPTION - COST ANALYSIS

In determining the costs of the carbon adsorption system, a number of assumptions were made. These assumptions are listed in the sample calculation shown later. Several of the major assumptions are discussed below.

First, two warehouse ethanol concentrations, 750 and 1500 ppm, were chosen. The ethanol concentration must be stipulated since this parameter establishes the flow rate of the CA unit. The 750 ppm level complies with the OSHA exposure standard of 1000 ppm, 8 hour time-weighted average; the 1500 ppm level reflects the concentration believed to be required for proper whiskey aging. (A more complete discussion of the OSHA standard, whiskey quality and other impacts of the control system is presented later.) Second, a range of installed costs vs. adsorber size was chosen based on the evaluation of a number of sources.[1,2,3,4] The costs used ($20/scfm for units less than 4000 scfm, $14/scfm for units greater than 15,000 scfm, and $17 for those in between) represent figures in the middle of the range presented by the sources. Third, a value of $0.53/proof gallon of recovered alcohol was chosen. This was based on the current price of 190 proof alcohol of $1.12/gallon[5] (or $0.59/proof gallon) discounted $0.04/proof gallon for transportation and $0.02/proof gallon for the utilities required for redistillation of the recovered alcohol. Fourth, 85 percent recovery efficiency and an adsorber flow capacity of one and a half times that based on a warehouse mass balance were chosen. The 85 percent recovery allows for the maximum ethanol losses through openings in the warehouse, through design of CA unit to achieve proper aging and during redistillation. It is expected that greater efficiencies could be attained in many cases. The 1.5 times the mass balance design allows for variations in the adsorber air flow rate required for proper whiskey aging and for recovery of the higher emissions in summer caused by warmer temperatures. Finally, two barrel emission rates, 2.3 and 3.6 kg/barrel-year, were chosen to examine the effect the variations in emission rates caused by differing warehouse operations have on system design and cost. A sample calculation follows.

Sample Calculation

1) Assumptions

- barrel emission rate of either 2.3 or 3.6 kg/barrel-yr. (Approximately 5.0 or 8.0 lbs/barrel-yr) and warehouse ethanol concentration of either 750 or 1500 ppm.
- total installed costs (TIC)

  $20/scfm for units $\leq$ 4000 scfm
  $17/scfm 4000 scfm $\leq$ unit $\leq$ 15,000 scfm
  $14/scfm for units $\geq$ 15,000 scfm

- other costs

Annualized capital costs	= 15 percent TIC
Taxes, insurance, etc	= 4 percent TIC
Steam	= 17¢/100 lbs
Carbon	= $1.00/lb
Electricity	= 3¢/kw·hr
Maintenance	= .1 hr/hr operation at $10/hr

- design will be based on yearly operation, with an overall 85 percent recovery, with the actual unit at 1.5x the calculated flow rate

- bed design parameters - two foot bed depth, operating velocity at 75 fpm, 7 in. H_2O pressure drop, bed length 3 times bed width, 7 year bed life

- recovery parameters - bed capacity at 7lbs ethanol/100 lbs carbon, 3 lbs steam/lb ethanol recovered, $0.53/pg ethanol recovered

2) Calculations

Example - 50,000 barrel warehouse, 750 ppm, 3.64 kg/barrel-yr (8.0 lbs/barrel-yr)

- Mass Balance - the system must be designed so that the emission rate of ethanol matches the removal rate by the CA unit.

  emission rate = (No. of barrels)(lbs/barrel-year)
  removal rate = (scfm)ppm/10^6 (1/360)lb-mole/ft^3 X
  (46 lb/lb-mole)5.18$(10)^5$ min/yr

  or (No. of barrels)(lbs/barrel-yr) = scfm(ppm)6.62 $(10)^{-2}$
  thus (50,000)8 = scfm (750)6.62$(10)^{-2}$
  scfm = 8060

- Total Installed Costs

  Unit size = 1.5(8060) = 12,090 scfm
  $17/scfm (12,090) = $205,530
  Annualized .15($205,530) = $30,829

- Other Costs

the amount of ethanol recovered =
.85(50,000)8 =
340,000 lbs whiskey/yr

steam requirement =
340,000(3) = $1.02(10)^6$ lbs steam/yr
$1.02\ (10)^6$ \$.17/100 lbs steam =
\$1734/yr

taxes, insurance, etc. =
.04 (TIC) = .04 (\$205,530)
\$8221

electricity =
(7 in H_2O) 249 pascals/in H_2O = 1160 joules/m^3 Air
$5.18\ (10)^5$ min/yr (scfm) 1/35.3 (m^3/ft^3) = $1.47(10)^4$ (scfm) m^3

using a 60 percent efficiency factor and $3.6\ (10)^6$ joules/kw·hr
(7.06/.6) \$.03/kw·hr (8060) =
\$2850/yr

maintenance and labor
.1 hr/hr operation x \$10/hr =
8640 (.1) \$10 = \$8640

- Bed Design

scfm/linear velocity = surface area (SA)
SA = 12,090/75 = 161 ft^2

$L = 3W;\ SA = LW;\ SA = 3W^2;\ W = \sqrt{SA/3}$
$W = \sqrt{161/3} = 7.3$ ft
L = 3W = 22ft

Bed volume = 2 ft(SA) = 322
322 (30 lbs/ft^3) = 9660 lbs/carbon
9660/7 yr (\$1/lb) = \$1380/yr Replacement carbon

Cycle time (assume 50 percent of ethanol removed from bed each cycle)
340,000 lbs ethanol-yr/8640 = 39.4 lbs/hr
9660 lbs carbon (.07 lbs ethanol/lb carbon).5 removal efficiency =
338 lbs recovered/cycle
338/39.3 = 8.5 hours

- Value of Recovered Alcohol

3.31 lbs/pg
340,000/3.31 = 102,720 pg/yr
102,720 (.53) = \$54,400/yr

A comparison of six recovery system design cases is presented in Table 4-1. The cases cover three warehouse sizes and two emission rate/warehouse ethanol concentration combinations. The warehouse capacities chosen were 20,000, 50,000, and 100,000 barrels and represent typical sizes for existing metal clad and brick units. The emission rate/warehouse ethanol concentrations chosen were 8 lb/yr-barrel, 1500 ppm, and 5 lb/yr-barrel 750 ppm. These cases represent the highest and lowest net return rates, respectively.

The cost analysis as presented in Table 4-1 indicates that the control system is financially feasible. Four of the six design cases offer net returns, the remaining cases small net costs. When these net costs are calculated on a per original proof gallon basis, aged 4 years, the cost is 0.52¢/proof gallon for Case A and 3.0¢/proof gallon for Case C. An average total cost for the six cases (costs without credit for recovered product) is 7¢/original proof gallon, aged 4 years. These figures compare to a $2.10/original proof gallon production cost for aged whiskey.[6]

The cost analysis in Table 4-1 does not include expenditures for steam production facilities or steam lines. Facilities without steam heating of warehouses (this includes most facilities with metal clad warehouses) would require lines, in some cases up to 750 meters, to transfer steam from the production plant to the warehouses. In addition, one or two smaller facilities would be require steam boilers in addition to steam lines. No calculations were made of these extra costs, but they would be significant.

4.3 CARBON ADSORPTION - FEASIBILITY

In addition to cost, several other considerations affect the applicability of carbon adsorption to control of VOC emissions from whiskey warehouses. These considerations are the system's effect on whiskey quality, the ability to reuse the recovered alcohol and OSHA standards.

Table 4-1

Recovery System Costs

Case	A	B	C	D	E	F
No. of Barrels	50,000	50,000	20,000	20,000	100,000	100,000
Warehouse ethanol conc.,	750	1,500	750	1,500	750	1,500
Emission rate, lbs/yr-barrel	5	8	5	8	5	8
Actual SCFM	5,040	4,030	2,010	1,610	10,070	8,060
Design, 1.5 Actual	7,560	6,045	3,020	2,420	15,100	12,080
Total Installed Costs (TIC)	$128,520	$102,760	$60,420	$48,340	$211,400	$205,360
Annualized TIC	$ 19,280	$ 15,410	$ 9,960	$ 7,250	$ 31,700	$ 30,800
Whiskey recovered, lbs/yr	212,500	340,000	85,000	136,000	425,000	680,000
Steam, 10^6 lbs/yr	.637	1.02	.255	.408	1.27	2.04
Steam, $/yr	$ 1,080	$ 1,730	$ 430	$ 690	$ 2,160	$ 3,470
Electricity, $/yr	$ 1,780	$ 1,420	$ 710	$ 570	$ 5,330	$ 2,850
Tax, etc., $/yr	$ 5,140	$ 4,110	$ 2,420	$ 1,930	$ 8,460	$ 8,210
Maintenance, $/yr	$ 8,640	$ 8,640	$ 8,640	$ 8,640	$ 8,640	$ 8,640
SA, $ft.^2$	100	80	40	32	200	160
Length, ft.	17	16	4	10	25	22
Width, ft.	5.8	5.2	3.7	3.3	8.2	7.3
Cycle Time, hrs.	8.5	4.3	8.5	4.3	8.5	4.3
Carbon, lbs.	12,000	9,600	4,800	3,840	23,000	19,200
Carbin, $/yr	$ 1,720	$ 1,380	$ 680	$ 540	$ 3,420	$ 2,740
Proof gallon whiskey/yr	64,200	102,720	25,680	41,090	128,400	205,540
Whiskey value, $/yr	$ 34,030	$ 54,440	$13,610	$21,780	$ 68,050	$108,940
Total Annual Costs, $	$ 37,640	$ 32,690	$21,940	$19,620	$ 59,710	$ 56,710
New Cost (Return)	$ 3,610	$(21,750)	$ 8,330	$(2,160)	$ (8,340)	$(52,230)
Cost/4 yr. Proof gal.	.52¢	--	3.0¢	--	--	--

4.3.1 Effect on Whiskey Quality

Whiskey quality is a critical factor in the marketability of whiskey and in the distinction between the various brands. Alterations in whiskey quality, i.e., taste and aroma, are a serious concern to distillers since such alterations could affect consumer acceptance of the product and thus reduce sales.

As discussed in Chapter 2, the taste and aroma qualities of whiskey are largely a product of whiskey aging. Whiskey aging, in turn, is a complex process composed of a number of interrelated chemical and physical mechanisms. A CA system, with the potential for changing such warehouse conditions as temperature, ventilation patterns, and humidity, could affect these aging mechanisms and thus alter quality.

The installation and operation of a CA system could affect whiskey quality in a number of ways. First, the increased ventilation provided by a carbon adsorber could lower the concentration of ethanol, water and trace constituents in the air around the barrel. This would increase the rates of evaporation of these constituents and alter the liquid content of the wood, upsetting the equilibrium concentrations in the wood, liquid and air and potentially affecting quality.

Proper design of the CA system could eliminate this effect. If the flow rate of the CA unit was adjusted so that the removal rate of air matched that provided by natural ventilation, the ethanol, humidity and trace constituent levels in the warehouse would remain unchanged. Since the CA unit is removing air, and thus the components in the air, at the same rate as natural ventilation, both natural ventilation and the CA system would provide for the same build up of these components in the warehouse.

However, other effects could occur. A CA unit provides a continuous flow of air across the barrels; natural ventilation would be intermittent. Thus, a CA unit would provide constant concentrations around the barrels, whereas natural ventilation would allow the buildup of stagnant layers. These stagnant layers would be removed occasionally by the natural ventilation, producing a stop-start effect in which evaporation occurs quickly after a draft and slows as the stagnant layer builds up. Another effect would be the lowering of the temperature differentials between the top and bottom of the warehouse. A CA would take air from several floors within the warehouse and either recirculate this air or draw in new air This mixing and ventilation would remove the hot, stagnant air at the top of the warehouse, reducing the temperature on these floors.

It appears that proper design could also eliminate these effects. The proper stagnation periods and concentration levels could be maintained around the barrel by adjusting the air flow rate and sequencing the ventilation. In such a system, only two or three of the warehouse floors would be ducted to the carbon adsorber at one time. Time-controlled dampers in the air exhaust lines would sequence which floors received ventilation. During the period a floor was off ventilation, the stagnation layers could build up. Elevated temperatures at the top of the warehouse could be achieved by using very low or no ventilation on the lower floors. Alternately, the system could be designed to draw air upward through the warehouse. The air drawn in at the bottom would be heated by the sun during the period it rose upward. Thus it appears that the proper combination of air flow rates, ventilation patterns, air recirculation, and other design parameters could reproduce most warehouse conditions. In addition, it appears that this could be achieved in most cases with straightforward engineering and at moderate cost.

However, proper design is not the only criterion; it is important to know what conditions to reproduce. Given the complex nature of whiskey aging, it is difficult to state precisely what are the conditions for proper aging and thus how to design the CA system. This is especially true considering the number of different brands of whiskey. Development of the system through experimentation is also difficult. A minimum of 2 years is required to notice quality changes in aging whiskey and 4 to 8 years to make a complete assessment. Potentially, 2 or 3 four to eight year aging cycles could be required to adjust the CA system to eliminate whiskey quality problems. Thus, the CA system's affect on whiskey quality is indeterminate. It would appear possible to design a system to reproduce the desired conditions but not possible to state with precision what these conditions are.

4.3.2 Re-use of Recovered Alcohol

Important to the costs of the CA system is the ability to re-use the recovered ethanol. This ability depends on two factors, the feasibility and costs of converting the recovered ethanol to a product suitable for use and the availability of markets for this converted product.

There are no market barriers to the re-use of the recovered alcohol, once it has been converted to grain neutral spirits. Though tax regulations prohibit its use in whiskies, the grain neutral spirits could be used in vodka and gin, or denatured for chemical use. Consumption figures[7,8] for both these indicate that sufficient markets exist to absorb the recovered product. If ethanol losses amount to 25 percent of the sales of American blended and straight whiskies,* this would provide 28 x 10^6 wine gallons/year or (assuming 100 proof

*Emission Factor II from the IRS data is .2 pg lost/pg produced. To calculate an emission factor based on consumption, the losses must be subtracted from production to arrive at a consumption figure. The loss rate on consumption is thus .2/(1-.2) = .25

whiskey) 15 x 10^6 190 proof gallons/year. The use of ethanol for gin and vodka (assuming 100 proof for these products) is 53 x 10^6 190 proof gallons/year. Thus, the available market, gin, vodka, and industrial use, is 253 x 10^6 190 proof gallons/year (See Table 4-2). The recovered ethanol represents 11 percent of this market.

The conversion of the recovered ethanol to grain neutral spirits presents no technical problems. The recovered alcohol is of sufficient quality for distillation to grain spirits and the equipment and procedures to perform this distillation are known to the industry. However, few distillers actually have the installed capacity to produce grain neutral spirits; only one in Kentucky has such a capacity.[9] Thus, most distillers would be required to ship the recovered alcohol to a location with distillation capacity or install the capacity themselves. Both options present additional costs. The recovered alcohol would be at approximately 50 proof before redistillation, and in such a dilute form, would cost 19 cents/proof gallon to transport by tank truck.[10,11] The costs of installing and operating distillation equipment to produce grain neutral spirits were not calculated but would be considerable.

4.3.3 OSHA Standards, Insurance, Energy, and Secondary Environmental Impact

An important consideration in applying carbon adsorption to whiskey warehouses is the effect the control device will have on safety and worker health. Closing the warehouse to install a CA unit could increase the concentration of ethanol inside the warehouse, potentially violating OSHA standards and increasing insurance risks.

The OSHA standard for ethanol is 1000 ppm, time-weighted-average for 8 hours. Several of the proposed design cases are based on 1500 ppm ethanol in the warehouse, an apparent violation of the OSHA standard. However, several factors should be considered. First, the OSHA standard is a time-weighted

TABLE 4-2

Distilled Liquor Sales

$(10)^6$ wine gallons/yr

	1975	1973
Vodka	65.0	54.0
Gin	36.2	35.3
	101.2	89.3
Cordials	23.8	20.6
Rum	14.4	13.4
Bottled Cocktails	7.0	5.0
Imp. Whiskey	95.3	91.9
Other	19.4	17.3
	159.9	148.2
Blended Am. Whiskey	46.6	53.5
Straight & Bonded Whiskey	64.1	66.2
	110.7	119.7
TOTAL	371.8	357.2

Industrial Ethanol Use

$(10)^6$ gallons 190 proof/yr

1975	210
1976	200
1980	220

Ethanol Market Pattern

Percent

Chemical Manufacture	44
Solvent	46
Export	10

average with no short term maximum exposure limit. Thus, the OSHA standard would not be violated if a worker spent only part of his time in the warehouse and the remaining time outside or in other parts of the distilling complex. Thus, a 1500 ppm ethanol concentration would not restrict entry. The OSHA standard may affect labor practices since workers could not remain in the warehouse all day.

Secondly, as the discussion of whiskey quality indicates, the CA system would of necessity have to be operated to reproduce existing conditions and practices. The 1500 ppm design case was chosen to represent ethanol concentration presently used in aging. Thus, the installation of a CA system would present no additional problems for worker health compared to present methods of operation.

Contacts with an insurance company indicated that no additional insurance on the warehouse is required.[12] In addition, as discussed above, the operation of a CA system should not increase ethanol levels in the warehouse over existing levels.

Another important consideration in control device evaluation is energy and secondary environmental impact. In recovering ethanol and converting it to a usable product, the main areas of energy consumption are the steam used in regeneration of the carbon and in redistilling. Assuming that a one still system can adequately purify the recovered alcohol, the energy usage for regeneration is calculated to be 6.6×10^6 joules/kg ethanol recovered and for redistillation 7.9×10^6 joules/kg ethanol recovered. The energy for redistillation would be required even without the control system since the recovered alcohol would be replacing alcohol presently produced. By comparison, a distiller in his normal production operations (cooking grain, heating warehouses, operating other stills) uses an estimated 80×10^6 joules/kg ethanol recovered. In addition, the energy value of the ethylene required in production of synthetic ethanol is calculated to be 33×10^6 joules/kg ethanol. Thus, the proposed control system could potentially save energy.

The main secondary environmental impact of the control system is the disposal of the waste water from distilling the recovered alcohol to grain neutral spirits. The amount of waste water produced in this manner would be 4 liters/kg ethanol recovered. By comparison, using a figure of 143 liters water/bushel grain in producing whiskey and assuming 95 of these liters become waste water, an estimated 61 liters waste water/kg ethanol recovered is produced by the normal operation of a distiller. Existing methods of waste water disposal at distillers should be able to handle this extra load.

4.4 CARBON ADSORPTION - WAREHOUSE TESTS

Between 1960 and 1968, a major distiller operated a carbon adsorption system on a whiskey warehouse at one of their facilities. A second distiller, National Distillers and Chemical Corporation, also installed a carbon adsorption system in the early 1950's to develop background data for a patent. However, the National test was conducted on only one warehouse floor, for one year, diverting a very small fraction of the exhaust air through a laboratory size carbon adsorber. Thus, the only full-scale test of the proposed control system is the one run from 1960 to 1968.

Table 4-3 lists the important data from the full scale test. Several points should be noted. First, the recovery efficiency and the proof of the recovered alcohol are both lower than the values used in the design calculations. Second, the carbon adsorber increased the rates of evaporation from the barrel and adversely affected quality. This last effect, the alteration of whiskey quality, was one of the principal reasons the test was stopped.

The full scale test, as run, does not demonstrate that a carbon absorption unit can be successfully applied to whiskey warehousing. At a recovery proof of 30, the transportation cost for the recovered alcohol is

Table 4-3. CARBON ADSORPTION SYSTEM DATA FULL SCALE TEST, 1960-1968

Adsorber Design & Operating Parameters

Warehouse Size/Type:	97,500 Barrels/Brick & Concrete
Barrel Emission Rate:	5.25 lb/barrel-yr
Recovery Efficiency:	74 percent (5 yr. average)
Recovery Proof:	30.5

Operating Procedures & Conditions

Experiment One (1960-1964)	Year 1 & 2	Year 3	Year 4 & 5
Ventilation Rate	Normal	Reduced	Normal
Recirculation	Yes	Yes	No
Humidity	Elevated	Elevated	Normal
Proof	Decreased	Decreased	Stabilized
Whiskey Quality	-	Sour, wet wood characted	Improved to satisfactory

Experiment Two (1965-1968) All years

Ventilation Rate:	Normal	Proof:	Normal
Recirculation:	No	Quality:	Poor all years
Humidity:	Normal		

Chronology: The changes in year 3 of experiment one were made to reduce the elevated humidity and temperature in the experimental warehouse. This proved unsuccessful and due to this and continued problems with whiskey quality, changes were made in year 4. The second experiment was run since the number of changes that were made in the first experiment made it unreliable as a data source.

Other Effects:

Evaporation: During both experiments, the rate of evaporation from the barrels increased. During the first experiment, the increase was .3 percent/yr (3.2 percent/yr. vs. 2.9 percent/yr normal) and during the second experiment, the increase was .4 percent/yr higher (3.3 percent/yr vs. 2.9 percent/yr normal).

Recovery: During the first two years of experiment one, when the adsorber exhaust was recirculated to the warehouse, the recovery rates were 83.3 and 93.3 percent compared to the 74 percent overall recovery for all five years.

32¢/proof gallon; this amount must be subtracted from the value of the recovered alcohol since the distiller would be required to absorb this cost. The recovery rate is 10 percent lower, and the steam usage higher (at 30 proof, the steam rate is 7 kg/kg) than the figures used in the design calculations, again adding costs. Finally, the whiskey lost due to the excess evaporation would need to be reproduced at $2.10/proof gallon aged. Though some of this is recovered by the carbon adsorption system (75 percent in the full scale test study), the recovery value is much lower. The effect of these factors on the recovery system cost is shown in Table 4-4. Thus, the factors in the test result in a net loss for the system. However, the net loss is 4.8¢/proof gallon aged, compared to $2.10 production costs. Therefore, the increased costs shown in the test, though significant, do not by themselves make the system infeasible.

The more critical problem was the system's demonstrated adverse effect on whiskey quality. In the full scale test, 360 barrels (180 in the second experiment) were filled with a quality approved lot of whiskey and split equally between the experimental warehouse (the warehouse with the CA unit) and a control warehouse (a warehouse operated normally). Whiskey quality tests were run yearly on samples from both sets of barrels; the samples were evaluated by taste test panel in a procedure similar to the method by which the actual product is tested. The results are shown in Table 4-3. The quality was poor into year three of experiment one; subsequent changes in the recovery system corrected this poor quality in year four and five. A second experiment was conducted to verify these results; however, the quality was poor in all years. The acceptable quality of years four and five in experiment one seems to have occurred because the poor quality of the previous years was being "undone." Normally, aging would not start with whiskey which had an inferior quality that needed to be corrected.

Table 4-4. COST CALCULATIONS
FULL SCALE TEST

Design Parameters:	No. of barrels: 100,000 Emission Rate: 5.25 lbs/barrel-yr Ethanol Concentration: 1500 ppm (assumed) Excess loss: .35 percent yr (average of two experiments) or .35/2.9 = .12, fractional increase in emission rate Recovery: 75 percent Steam Rate: 7 lbs steam/lb ethanol recovered	
System Parameters:	Adsorber size calculated: 5290 scfm Adsorber size, 1.5 x calculated: 7930 scfm Ethanol lost: $5.88(10)^5$ lbs/yr Ethanol recovered: $4.41(10)^5$ lbs/yr, $1.33(10)^5$ proof gallons/yr Steam: $3.09(10)^6$ lbs/yr Carbon: 12,720 lbs	
Costs:	Annual Capital Cost	$20,220
	Taxes, Ins., etc.	5,390
	Electricity	2,800
	Steam	5,250
	Maintenance	8,640
	Carbon	1,820
		44,120
	Credit for recovered ethanol, $.21/pg (includes transportation)	-27,930
	Net cost	$16,190/yr $64,760 for 4 years
	Excess Evaporation	.12(100,000)(5.25)4 = 252,000 lbs, 76,130 proof gallons at $2.10/proof gallon $159,980
	Total Cost	$224,720 for four years
Cost per Proof Gallon	55 proof gallons/ barrel orignally	
	100,000 barrels	5,500,000 proof gallons
	minus evaporation	- 532,000
	minus soakage	- 250,000
		4,718,000 final proof gallons
Cost/final proof gallon	$\$225(10)^3/4.72(10)^6 =$	4.8¢/proof gallon

It appears that certain changes in the design and operation of the CA system during the test could have eliminated problems encountered. First, the low recovery rate experienced was apparently due to the inadequate size of the adsorber unit. During each cycle, it is hypothesized that the bed became saturated and breakthrough occurred. Alcohol laden air thus passed through the adsorber to the atmosphere with no recovery occurring. The higher recoveries experienced during the first two years were apparently due to the recycling of the adsorber exhaust stream to the warehouse. Thus, when breakthrough occurred, the unrecovered alcohol was recirculated back into the warehouse and no loss to the atmosphere occurred. This unrecovered alcohol was eventually captured because, as it was recirculated back to the warehouse, the ethanol concentration in the warehouse increased. This increased concentration would increase the capacity of the adsorber unit, resulting in the eventual recovery of the alcohol. Confirmation of this hypothesis would require, among other things knowledge, of the adsorber bed capacity at the concentration, temperature and humidity of the warehouse air. This information is not available.

The deterioration of whiskey quality in the test study was apparently caused by three factors: higher humidity, lower ethanol concentrations, and continuous ventilation. The elevated humidity existed in the first three years during the time the adsorber exhaust was recirculated. Since the CA unit did not remove water, the recirculation of the adsorber exhaust resulted in the accumulation in the warehouse of the water evaporating from the barrels. The lower ethanol levels resulted from the continuous removal of organics from the warehouse by the CA unit. Though natural ventilation would also remove ethanol, the CA unit provided continuous air removal. In contrast, natural ventilation would be intermittent, removing ethanol only occasionally. In fact, during nights, weekends and winter, there may be no ventilation in warehouses since during those periods the windows and doors are sometimes closed. In addition to continuous ventilation lowering the ethanol concentration, continuous ventilation also upset the stagnant air layers that develop around the barrel in natural ventilation. As discussed in Chapter 2.0, the removal of these stagnant layers replaces the stop-start diffusion pattern that normally occurs with natural ventilation.

The manner in which these factors affected quality is not clear. However, the altered concentrations of ethanol and water around the barrel and the continuous ventilation probably altered the concentrations, and cycles in concentrations, of substances in the barrel wood and bulk whiskey. The rates at which the mechanisms responsible for aging - extraction and solubilizing of wood constituents, diffusion of these constituents into the bulk liquid, chemical reactions between the various substances and transport of air into the bulk liquid - occur depend on these concentrations. Thus altering these concentrations alters the rate at which the aging mechanisms proceed, altering whiskey quality.

Various modifications in the test may have alleviated the whiskey quality problems. These modifications would have been to operate the system intermittently and to recirculate the adsorber exhaust part of the time. Intermittent operation could have been accomplished by sequencing the floors that receive ventilation, as described in section 4.3.1. Another option would have been to shut off the CA system during periods when the warehouse windows and doors would have been closed under normal operation. Such a method of operation would have allowed for stagnation periods, permitted the accumulation of ethanol to the proper levels required for aging, and reduced or eliminated excess ethanol evaporation. Partial recirculation could have eliminated the problem of both low and excessive humidity. This could have been accomplished by occassionally routing the adsorber exhaust to the warehouse. The amount of partial recirculation would be determined by the humidity level in the warehouse; the adsorber would be exhausted outside when the humidity became too high. Another variation of partial recirculation could occur in winter, when high air circulation rates may have been required for forced air heating. During this period, the adsorber could have been partially bypassed, with this by-pass stream being recirculated. This would allow for sufficient air movement for heating, without exhausting ethanol laden air to outside and without upsetting aging by removing the ethanol from the larger air streams required for heating.

4.5 ALTERNATE SYSTEM OF AGING

A novel system of whiskey aging is under development in which maturation takes place not in charred oak barrels but in closed stainless steel vessels lined with straight charred staves.[13] This system is of interest due to its potential for large savings in aging costs and for almost complete elimination of aging losses. Its applicability to whiskey aging and control of warehousing emissions will depend on the system's ability to produce whiskey of acceptable quality.

The central component of the system is a cylindrical stainless steel vessel approximately 5 meters in diameter and 7 meters high, holding approximately 100,000 liters of liquid. Inside the vessel, straight charred oak staves are held in the whiskey by arms extending radially from a shaft at the center of the vessel. The staves are arranged so that air spaces created between them are manifolded together to the central shaft holding the arms, and from there to vacuum, pressure and condensing equipment. The central shaft can be designed to rotate to move the staves through the whiskey. The vacuum equipment pulls vapors through the staves to duplicate aging and the condenser recovers this vapor as liquid and returns it to the vessel. The pressure equipment provides for further controls over the aging process potentially useful in producing whiskey of a desired quality. Finally, internal heating coils provide for temperature control of the aging whiskey.

The large cost savings in the system occur in three areas. First, the labor and wood cost of the barrels is reduced by using straight wood staves and using less wood per volume of whiskey stored. Second, the loss of whiskey through evaporation is eliminated since the system captures the vapors and returns them after condensation. Third, the warehouse area is reduced since the system requires only 1/10th the volume. The cost savings that result can be substantial, up to 50 percent of present aging costs.

The system's most important feature of the system from an emission standpoint is the complete elimination of whiskey loss. Loss during aging is eliminated since ethanol evaporating through the staves is captured in the air spaces manifolded to the condensers, which return the vapor as liquid to the vessel. Soakage losses are reduced since the alcohol remaining in the used staves is partially recovered by continuing to draw a vacuum after the whiskey is emptied. The vacuum evaporates the ethanol in the staves and draws it to the condensers where the ethanol is recovered. Finally, any losses due to spillage and barrel leaks are eliminated since the whiskey is piped into and out of the aging vessels. Thus, the system has the capacity to be almost loss free.

The key factor determining the system's applicability to whiskey aging and emission reduction is the quality of the whiskey produced. Since testing of the system has not been completed, it is not known if the system will properly age whiskey. Testing of the system is scheduled for 1978.

4.6 CONTROL OF BARREL SOAKAGE LOSSES

The major control device discussed to this point, carbon adsorption, is applicable only to the control of evaporation during barrel storage; control of losses due to soakage in the barrel staves would require additional measures. These measures, along with present uncontrolled practices, are described below.

Present practice is to rinse used barrels with one gallon of water before selling or storing the barrels. The amount of whiskey recovered in this manner appears to be low since such a rinse removes only the surface film of whiskey on the barrel staves. One distiller practices a more complete rinse using 3 gallons of water and rolling and shaking the barrel to improve recovery. This practice removes approximately one half gallon from the barrel wood, or about .7 kg ethanol.[14] This is less than 20 percent of the estimated 3.8 kg of ethanol in the barrel wood. Thus, present practices recover only a small percent of the liquid soakage in whiskey barrels. No other systems to further recover barrel soakage are in practice.

Three types of systems have potential applicability: more complete rinsing, vacuum evaporation, and steaming. More complete rinsing could be accomplished using a greater amount of water, greater agitation of the barrel, more than one rinse and heating the water. Vacuum evaporation would involve connecting the used barrel to a vacuum source to draw out the vapors. Vacuum is available at most distillers since vacuum evaporation is used to dry spent grain for animal feed. Steaming would involve passing steam through the barrel, using the heat to evaporate the ethanol in the wood. The steam would then be condensed to recover the ethanol. The dilute whiskey produced in these methods could be used in adjusting the proof of bottled whiskey. Whiskey is typically diluted before bottling, since it is aged at higher proofs than those at which it is marketed.

Two factors appear to limit the effectiveness of all three recovery methods, the inherent slowness of diffusion in wood and the barrel configuration. The physical mechanisms, extraction, heat, and vacuum evaporation, on which the recovery methods are based all attempt to increase the rate of diffusion of ethanol through the wood. However, the small pore structure of the wood and the great width of the stave (2 cm is a considerable distance in terms of molecular diffusion) results in extremely slow diffusion; 3 to 6 months are required to saturate the wood after filling the barrels. Even if a hundred fold increase in the diffusion rate could be achieved, more than a day would be required to recover all ethanol in the barrel staves. In addition, the barrel configuration does not allow optimum contacting in rinsing and steaming. Water touches only a small percentage of the wood at any one time in rinsing, and unless extra holes or special spargers are provided, steam distribution inside a barrel would be uneven and steam contact with the walls poor.

It would appear that other methods of recovery of barrel soakage losses might be necessary. These methods would require methods of operation both unfamiliar to the whiskey industry and complex. They would involve splintering the barrels into small slivers of wood, passing the slivers through water extraction and vacuum filtration and evaporation. The slivers would then be available as fuel. Alternately, the saturated wood slivers or the saturated staves themselves could be fed to a boiler. Adjustments in the boiler operation would be required to assure proper firing with saturated wood as a partial fuel. As noted, these operations would be complex, but could be technically possible and, with credit for the wood fuel and recovered ethanol, financially feasible. However, no analysis of this option was made.

One final method may be feasible, storage of the empty barrels in enclosed warehouses vented to a carbon adsorber. An economic analysis of this option is shown on Table 4-5. The analysis assumes that nine months of storage would be required to remove 85 percent of the liquid in the barrel wood and that the first 20 percent of the liquid would have been removed by water rinsing. Thus, assuming 3.8 kilograms of ethanol in the wood, the system would recover .65(3.8) or 2.5 kg from each barrel. A warehouse ethanol concentration of 250 ppm was chosen since a low concentration would be required to evaporate the liquid from the wood. Finally the recovery efficiency was set at 95 percent or better since no special features would be required to protect whiskey quality. The final cost of the system is 2.8¢/proof gallon whiskey.

Since many of the design parameters used in the analysis were based only on engineering judgement, the final cost figure for this control system could change significantly in actual practice. The nine month time period, the 85 percent removal and the 250 ppm ethanol level need to be verified before the system can be finally judged. However, the analysis does give a preliminary indication of the system's feasibility and shows that further study is warranted.

Table 4-5

Control System for Barrel Soakage
Losses - Warehousing

Assumptions	Storage period: Ethanol level: Total Barrel soakage: Warehouse capacity:	9 months 250 ppm 3.8 kg ethanol 50,000 barrels
Recovery on Adsorber	Removal from barrel	85 percent 20 percent from rinsing 65 percent from storage
	95 percent	
Design	Emission rate: Adsorber size: Surface Area: Carbon: Recovery: Steam:	3.3 kg ethanol/yr-barrel slot 21,900 scfm 292 ft^2 35,040 lbs 104050 pg 1.03 $(10)^6$ lbs/yr
Costs	Annualized Capital Cost: Taxes, Insurance, etc: Electricity: Steam: Carbon: Maintenance:	\$46,000 \$12,260 \$ 7,730 \$ 1,750 \$ 5,000 \$ 8,640
	Warehouse-Depreciation[15] Handling (50¢/barrel)[15]	\$15,000 \$33,330
		\$129,710/yr
	Recovery Credit	\$55,150
	Net Cost	\$74,560/yr
	Cost/proof gallon	2.8¢

4.7 REFERENCES

1. U. S. Environmental Protection Agency. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume I: Control Methods for Surface Coating Operations. EPA 450/2-76-028, November, 1976.
2. U. S. Environmental Protection Agency. Capital and Operating Costs of Selected Air Pollution Control Systems. EPA 450/3-76-014, GARD, Inc. May, 1976.
3. Memo from Ted Jackson, Chemical Manufacturing Section, U. S. EPA, to David R. Patrick, Chemical Manufacturing Section, U.S. EPA, Research Triangle Park, N.C. Cost Estimates of Carbon Adsorption. December 19, 1977.
4. Telephone conversation between Mr. Larry Euchre, Union Carbide Corporation, Cleveland, Ohio and Mr. David Augenstein, PEDCo, Cincinnati, Ohio, April 27, 1977.
5. Chemical Marketing Reporter, January 16, 1978, pg. 7.
6. Letter and comments from Mr. Murray Sobolov, Chairman, DISCUS Technical Committee, to EPA. October 26, 1977.
7. Liquor Handbook. Clark Gavin, editor, Gavin-Jobson, Inc., New York. 1974, 1975, 1976.
8. Chemical Marketing Reporter. Chemical Profile-Ethanol. September 13, 1976.
9. Trip Report from David C. Mascone, U.S. EPA to David R. Patrick, Chemical Manufacturing Section, U.S. EPA, Research Triangle Park, N.C. on a meeting with the DISCUS Technical Subcommittee. January 20, 1978.
10. Telephone conversation between Mr. Ted Jackson, U.S. EPA and Mr. Larry Thompson, Liquid Transporters, Inc., Louisville, Kentucky. November 7, 1977.
11. Telephone conversation between Mr. Ted Jackson, U.S. EPA and Roger Fredrick, Southern Tank Lines, Langstown, Pennsylvania, November 7, 1977.

12. Telephone conversation between Mr. Fred Hoit, Factory Mutual Corporation Norword, Massachusetts, and Mr. Terry Briggs, PEDCo, Cincinnati, Ohio. May 4, 1977.

13. Murray, Robert G. Preliminary Evaluation of New Method for Aging Spirits. Standford Research Institute, Menlo Park, California.

14. Trip Report by Terry Briggs, PEDCo, Cincinnati, Ohio, on a visit to Jim Beam Distillery, Clermont County, Kentucky. April 7, 1977.

15. Reference 13.

APPENDIX A. EMISSIONS FROM THE PRODUCTION OF UNAGED WHISKEY

The production of unaged whiskey involves preparation and fermentation of grain and distillation of the resulting liquid to produce unaged whiskey. The three largest sources of volatile organic emissions in this operation are the fermentor vent, the distillation column vents and the drying of the used grain.

The fermentation of grain in whiskey manufacture produces large amounts of carbon dioxide. This carbon dioxide exits from the fermentor by vents on the top and carries with it minor amounts of ethanol. A measured value for this emission is 183 g ethanol/m^3 grain.[1] Using 146 proof gallons whiskey/m^3 grain, and a production of whiskey of 79.2×10^6 proof gallons in 1976, the total nationwide emissions from this source are 99 MT/yr. A typical large distillery producing 4×10^6 proof gallons whiskey/year would emit 5.0 MT/yr.

In the operation of the various distillation columns in a distillery, ethanol is emitted from the inert vents on the column condensers. However, with the double condenser system commonly used and condenser temperatures of 70 to 90°F, these emissions are low. One emission estimate is 0.0022 kg ethanol/proof gallon-column.[2] Using the whiskey production above, and assuming 1.5 columns/distillery as an average, the total nationwide emissions from this source are 260 MT/yr. A typical large distillery with a 3 distillation column system producing 4×10^6 proof gallons/year would emit 26.4 MT/yr.

The grain remaining after fermentation and distillation is typically dried and sold as animal feed. During drying some of the residual ethanol in the grain is evaporated to the air. The ethanol content of the grain slurry remaining after distillation is 0.1 to 0.01 percent by weight;[3] however, a large portion of this ethanol would be mixed with the wastewater removed from grain slurry. Assuming 0.05 percent ethanol in the grain and that 30 percent is evaporated to the air, the nationwide emissions are 206 MT/yr. A large distillery producing 4 x 10^6 proof gallons/yr would emit 10.1 MT/yr.

The typical large distillery described in this appendix is analagous to the typical distillery in Chapter 3.0. That distillery had emissions of 1460 MT/yr from aging; the total emissions from the emission points described in this appendix is 41.3 MT/yr, less than 3 percent of the aging emissions.

REFERENCES APPENDIX A

1. Telephone conversation between Mr. Lew Heckman, EPA Region II, New York, New York, and David C. Mascone, U.S. EPA, February 9, 1977.
2. Carter, R. V., and B. Limisky. Gaseous Emissions from Whiskey Fermentation Units. Atmospheric Environment. 8:57-62. 1974.
3. Telephone conversation between Dr. Allen Thomas, Brownforeman Distillery, Louisville, Kentucky and David C. Mascone, U.S. EPA, Research Triangle Park, N.C., December 22, 1976.
4. Trip Report by Terry Briggs, PEDCo, Cincinnati, Ohio, on a meeting with the DISCUS technical committee, March 30, 1977.

APPENDIX B.

WHISKEY BY VARIOUS PERIODS OF PRODUCTION REMAINING IN BONDED WAREHOUSES IN KENTUCKY AS OF DECEMBER 31, 1975

Prepared from information obtained at the Office of the Department of Revenue of the Commonwealth of Kentucky

DISTILLERY	REMAINING WHISKEY PRODUCED OR RECEIVED									TOTAL	
	BOTTLED IN BOND – AGE										
	CALENDAR YEAR ENDING DECEMBER 31										
	Over 8 Years	1968 No. Barrels	1969 No. Barrels	1970 No. Barrels	1971 No. Barrels	1972 No. Barrels	1973 No. Barrels	1974 No. Barrels	1975 No. Barrels	No. Barrels	Per Cent
Barton Brands, Inc. Bardstown, D.S.P. Ky. 12	25,829	10,596	34,533	53,657	34,464	1,544	64,279	16,831	20,248	261,981	4.26
Jas. B. Beam Distilling Co. Bardstown, Kentucky								41,233	13,320	54,553	799,601
Beam, Ky.	5,698	2,122	303	1,110	17,572	91,239	98,247	64,014	58,948	339,253	13.01
Clermont, Ky.	12,069	25,207	14,981	31,594	24,102	84,464	78,559	74,076	60,743	405,795	
Blair Distilling Co. St. Francis, Ky.			4,523	4,336	328		531			9,718	.16
J.T.S. Brown's Son Co. Lawrenceburg, Ky.	4,450	24,761	28,391	10,582	13,816					82,000	1.33
Brown-Forman Distillers Corp. (3 Units) Louisville, Ky.	858	2,783	4,321	37,320	60,514	63,371	41,840	104,437	97,000	412,444	6.70
Commonwealth Distillers, Inc. (Formerly T.W. Samuels) Deatsville, Ky.	11,299	5,625	7,071	4,266						28,261	.46
Double Springs Distilling Co. Bardstown, Ky.	2,470	8,214	4,538	7,190	6,540	3,928	5,644			38,524	94,833
Frankfort, Ky.	1,399	1,642	5,928		10,753	16,731	15,380	1,800		53,633	1.54
Louisville, Ky.	1,243	1,019	389	25						2,676	
Fleischmann Distilling Corp. Owensboro, Ky.		208	5,412	35,963	30,412	36,411	35,413	38,568	30,901	213,288	3.47
Glenmore Distilleries Co. Owensboro, Ky.	6,621	24,968	8,988	25,111	45,418	40,017	29,884			181,007	2.94
Yellowstone, Inc. Louisville, Ky.		3,311	10,577	23,637	20,891	18,236	13,076	10,816	1,117	101,661	1.65
Heaven Hill Distilleries, Inc. Bardstown, Ky.	13,207	24,058	35,726	49,775	66,816	62,141	64,771	53,868	47,429	417,791	6.80
Hoffman Distilling Co. Lawrenceburg, Ky.	6,768	1,423	869	824	2,099					11,933	.20
Medley Distilling Co. Owensboro, Ky.	844	1,275	6,759	3,137	31,098	28,745	29,721	17,928	9,713	129,220	2.10
Ben F. Medley Distillery Stanley, Ky.	75		35		119					229	.01
National Distillers & Chem. Corp. (3 Units) Louisville, Ky.	1,493	12,258	96,993	133,920	126,436	99,304				470,404	1,081,752
(3 Units) Frankfort, Ky.	1,411	7,740	124,302	152,553	151,814	106,923			66,605	611,348	17.59
Austin Nichols Distilling Lawrenceburg, Ky.	3,413	16,083	23,202	20,050	14,685	22,763	23,552	30,226	17,446	171,420	188,152
Jessamine County, Ky.									16,732	16,732	3.06

WHISKEY BY VARIOUS PERIODS OF PRODUCTION REMAINING IN BONDED WAREHOUSES IN KENTUCKY AS OF DECEMBER 31, 1975

Prepared from information obtained at the Office of the Department of Revenue of the Commonwealth of Kentucky

DISTILLERY	REMAINING WHISKEY PRODUCED OR RECEIVED — BOTTLED IN BOND → AGE — CALENDAR YEAR ENDING DECEMBER 31									TOTAL	
	Over 8 Years	1968 No. Barrels	1969 No. Barrels	1970 No. Barrels	1971 No. Barrels	1972 No. Barrels	1973 No. Barrels	1974 No. Barrels	1975 No. Barrels	No. Barrels	Per Cent
Old Boone Distillery Co. Meadowlawn, Ky.	14,254	4,783	3,726	1,483	269	2,142	9,812	3,314	3,997	43,780	.71
Old Fitzgerald Distillery, Inc. Louisville, Ky.	6,107	36,252	61,382	51,119	50,417	38,420	10,969	9,962	9,287	273,915	4.45
Schenley Industries, Inc. Bernheim Distilling Co. Louisville, Ky.	6,209	27,569	38,212	22,478	21,692	53,988	108,108	44,987	47,436	370,679	1,102,515
Park & Tilford Dist. of Ky. Louisville, Ky.	6,062	2,679	3,922	14,727		5,543	9,767	16,185		58,885	17.93
The Geo. T. Stagg Co. Bardstown, Ky.	32,634	510	9,614	1,284	2,991	10,428	18,222	10,309	19,719	105,711	
Frankfort, Ky.	49,972	23,492	31,842	19,593	43,242	92,417	114,147	58,934	133,601	567,240	
Joseph E. Seagram & Sons, Inc. Louisville, Ky.	12,459	23,900	39,558	16,459	26,330	17,598	5,308	11,089	21,825	174,576	641,003
Cynthiana, Ky.	1,762	3,616	8,351	4,898	2,143	661	1,389			22,820	10.43
Lawrenceburg, Ky.		2,575	1,145	369	75					4,164	
Huntington Creek Corp. Coxs Creek, Ky.	12,733	48,447	139,235	84,539	53,969	40,305	25,791	34,424		439,443	
Star Hill Distilling Co. Loretto, Ky.	462	1,188	2,789	3,648	4,934	6,001	6,491	5,637	4,975	36,125	.59
Willett Distilling Co. Bardstown, Ky.	5,349	1,271	4,210	5,343	4,711	75	2,875	3,942	4,522	37,328	.61
Totals Each Year Dec. 31, 1975	247,150	349,575	761,557	820,990	868,700	943,395	813,766	657,580	685,564		
Totals All Years Dec. 31, 1975										6,148,587	
Totals December 31, 1974	235,498	608,963	995,317	960,854	1,018,144	943,578	846,142	748,722		6,683,654	
Totals December 31, 1973	230,085	886,818	1,159,606	1,100,151	1,014,776	1,024,001	1,004,877			7,285,998	
Totals December 31, 1972	177,515	1,149,734	1,335,124	1,114,402	1,070,059	1,081,542				7,514,642	
Totals December 31, 1971	214,333	1,306,734	1,354,324	1,170,710	1,171,358					7,877,969	
Totals December 31, 1970	331,462	1,428,095	1,462,894	1,391,300						8,491,893	
Totals December 31, 1969	413,702	1,496,524	1,653,901							8,609,815	
Totals December 31,1968	504,299	1,731,446								8,706,688	

Note — Fractional barrels reduced to one full barrel. Storage does not necessarily represent ownership.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/2-78-013	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Cost and Engineering Study - Control of Volatile Organic Emissions from Whiskey Warehousing		5. REPORT DATE April 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) David C. Mascone, ESED		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE 200/04
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This document provides cost and engineering information on control of volatile organic emissions from whiskey warehousing. Included are a description of whiskey aging, warehousing, and of volatile organic emissions from warehousing; a development of emission factors and inventories for these emissions; a cost and engineering analysis of available control techniques for these emissions; and a discussion of volatile organic emissions from other whiskey manufacturing operations. The major control technique discussed is carbon adsorption.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Whiskey Warehousing Whiskey Aging Ethanol Carbon Adsorption	Air Pollution Control Stationary Sources Organic Vapors	

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
Leave blank.

7. **AUTHOR(S)**
Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
Insert appropriate code.

15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
(a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

(b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

(c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.

ENVIRONMENTAL PROTECTION AGENCY
General Services Division (MD-28)
Office of Administration
Research Triangle Park, North Carolina 27711

OFFICIAL BUSINESS
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
ENVIRONMENTAL PROTECTION AGENCY
EPA-335

U.S.MAIL

Return this sheet if you do NOT wish to receive this material ☐ or if change of address is needed ☐. (Indicate change, including ZIP code.)

PUBLICATION NO. EPA-450/2-78-013