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BACKGROUND INFORMATION ON HYDROCARBON EMISSIONS FROM MARINE TERMINAL OPERATIONS

VOLUME I: DISCUSSION

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Office of Air and Waste Management
Office of Air Quality Planning and Standards
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BACKGROUND INFORMATION ON HYDROCARBON EMISSIONS FROM MARINE TERMINAL OPERATIONS VOLUME I: DISCUSSION

by

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November 1976

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This report presents results of a study to develop background information necessary for the accurate assessment of hydrocarbon emissions from ship and barge loading and unloading of gasoline and crude oil. The report assesses marine terminal facilities, marine terminal operations, cruise history and product movement statistics, hydrocarbon emission rates and characteristics, control technology state of the art, safety considerations of marine terminal control technology and economics of controlling marine terminal emissions. The report also includes the results of a detailed cost analysis for a refrigeration and an absorption marine terminal vapor recovery system. Data gathering activities focused on the Houston-Galveston area; however, information was also assembled on hydrocarbon emissions from marine terminal operations in the metropolitan Los Angeles area generated by handling of gasoline and crude oils, including Alaskan north slope crude.

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ABSTRACT

The loading and unloading of volatile hydrocarbon liquids at marine terminals is known to be a source of hydrocarbon emissions. However, until recently very little data have been available on the sources, characteristics, and generation rate of these emissions. This report presents the results of an in depth study for EPA to report emission factors and to develop background information necessary for the accurate assessment of hydrocarbon emissions from ship and barge loading and unloading of gasoline and crude oil. Topics addressed in the final report include marine terminal facilities, marine terminal operations, cruise history and product movement statistics, hydrocarbon emission rates and characteristics, control technology state of the art, safety considerations of marine terminal control technology, and the economics of controlling marine terminal emissions. Although data gathering activities focussed on the Houston-Galveston Metropolitan area, information was also assembled on hydrocarbon emissions from marine terminal operations in the Metropolitan Los Angeles area generated by the handling of gasoline and crude oils, including Alaskan North Slope crude.

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1.0 INTRODUCTION

The loading and unloading of volatile hydrocarbon liquids at marine terminals is known to be a source of hydrocarbon emissions. However, until recently very little data have been available on the sources, characteristics, and generation rate of these emissions. This report presents the results of a detailed study for EPA on hydrocarbon emissions from marine terminal operations.

1.1 Objectives

The objectives of this program are to report emission factors and to develop background information necessary for the accurate assessment of hydrocarbon emissions from ship and barge loading and unloading of gasoline and crude oil. Data gathering focussed on the Metropolitan Houston-Galveston Intrastate AQCR. Also, sufficient information was assembled to project hydrocarbon emissions in the Metropolitan Los Angeles Intrastate AQCR generated by the handling of gasoline and crudes, including Alaskan North Slope crude.

1.2 Approach

The program objectives were accomplished through the completion of the following elements:

1) Identification and description of marine gasoline and crude oil loading and unloading terminals in the Houston-Galveston area, based upon industry data.

2) Collection of statistical data from the petroleum industry regarding daily and monthly loading of gasoline and crude oil in the Houston-Galveston area over a 12-month period.

3) Collection of cruise history statistics from the petroleum industry for ships and barges that have loaded gasoline or unloaded gasoline and crude oil in the Houston-Galveston area during the past 12 months.

4) Review and evaluation of both foreign and domestic information available which describes and/or quantifies hydrocarbon emissions from ship and barge loading, unloading, and transport.

5) Completion of limited Radian sampling studies of hydrocarbon emissions from ship and barge loading and unloading operations for the purpose of verifying reported emission factors.

6) Review of industry available data on control technology and associated costs applicable to the control of hydrocarbon vapors generated by the loading and unloading of petroleum products and crude oil into marine vessels.

7) Preparation of a test program based upon information gathered in the course of this study to statistically validate emission factors for the loading and unloading of gasoline and crude oil for ships and barges.

Radian received statistics and information on the marine terminal industry through contacting petroleum companies involved in major marine terminal operations in the Houston-Galveston and Los Angeles areas, and through review of petroleum industry files maintained by EPA. Marine terminal site visits were also conducted by Radian in the Houston-Galveston area and in the Los Angeles area.

The original scope of work for this project did not include addressing the safety problems associated with the application of vapor recovery systems to gasoline loading of ships and barges. However, during the course of the project it became apparent that safety considerations are a very important part of a complete discussion on emission control technology for marine terminals. Because of this importance, Radian included safety considerations in the marine terminal controls discussion. This discussion is not intended to be a comprehensive analysis of this subject, since the scope of the project limited the detail of the analysis. Instead, the discussions of safety include an analysis of the types of safety problems encountered in the different control systems.

1.3 Report Contents

The results, conclusions and recommendations developed from this study are presented in Section 2, the executive summary. Section 3 presents background information on marine terminal facilities and operations. Included in Section 3 are descriptions of marine terminals in the Houston-Galveston area, statistics on the movement of gasoline and crude oil in both the Houston-Galveston area and the Los Angeles area, and cruise history statistics for ships and barges. Section 4 characterizes hydrocarbon emissions from marine terminal operations and presents the results of emission testing conducted by the petroleum industry and Radian Corporation. Section 5 reviews hydrocarbon emission control technology available for marine terminal operations from the aspects of principle of operation, efficiency, safety, state of development, and cost. The economics associated with the implementation of marine terminal emission controls are presented in Section 6. Section 7 develops a test plan for establishing emission data in those areas where emission data is inadequate.

2.0 EXECUTIVE SUMMARY

This report is the first comprehensive examination of marine terminals transferring crude oil and gasoline in the Houston-Galveston AQCR. This section summarizes the results from the specific areas examined, presents conclusions which were drawn from these results, and provides a list of recommendations for further work.

2.1 Results

The results of this report are summarized below. They are organized according to the sections of the report which discuss that specific area:

- Background Information on Marine Terminals in the Houston-Galveston AQCR
- Background Information on Marine Terminals in the Los Angeles AQCR
- Emissions
- Emission Control Technology
- Economics of Emission Control

2.1.1 Background Information on Marine Terminals in the Houston-Galveston AQCR

The results included in this section are based on information obtained from the petroleum industry and from site visits made to marine terminals in the Houston-Galveston area.

Important facts included in this section are condensed below:

- Seven marine terminals, all of which are associated with refinery facilities, accounted for virtually all of the gasoline loaded onto ships and barges in 1975.

- Approximately 82.5 million barrels of gasoline (motor and aviation) were loaded at seven marine terminals in the Houston-Galveston area in 1975. The average RVP ranged from a high of 13-14 psi in the winter to a low of 9-10 psi in the summer.

- Projections show that approximately the same quantity of gasoline will be loaded annually in the Houston-Galveston area through 1985. Therefore, no significant growth in gasoline loading at marine terminals in the area is foreseen through 1985.

- Approximately 75 percent of the gasoline transferred at marine terminals in the area was loaded onto ships in 1975.

- Eight marine terminals, each associated with refinery complexes, accounted for virtually all of the crude oil unloaded from ships and barges in the Houston-Galveston area in 1975.

- Available information indicates that approximately 160 million barrels of crude oil were transported into seven of the marine terminals which imported crude oil in the area in 1975.

- Projections for the quantity of crude oil imported by tanker into the Houston-Galveston refinery terminals show a continuing increase through 1985. Should the proposed SEADOCK offshore terminal be completed in 1980 according to plan, the quantity of crude unloaded in the harbor will drop from approximately 360 million barrels in 1979 to 240 million barrels in 1980 and to 190 million barrels in 1985.

- Crude oil was loaded onto ships at one marine terminal in the area. A total of 7.5 million barrels were loaded there in 1975 most of which was shipped to East Coast refineries.

- Maximum gasoline loading rates at any one dock at marine terminals in the Houston-Galveston area ranged from 4,500 bbls/hr to around 50,000 bbls/hr. Typical rates were from 5,000-10,000 bbls/hr.

- All vessels loading gasoline in the area keep their ullage hatches open for visual inspection of the cargo liquid level. Also, P/V (pressure/vent) valves are manually opened during loading. Crude oil shops also follow this practice when they take on ballast after discharging their cargo.

- Crude oil ships may ballast from 20 to 40 percent of their cargo capacity before leaving the dock where they unloaded. This operation may be completed at dock or continue as the vessel leaves port, at the discretion of the ship's officers.

- Intercoastal barges do not take on ballast; however, the larger oceangoing barges do.

- For Grade A tankers the vapors displaced from the cargo tanks during loading and ballasting are vented from two places - the ullage hatch and the vent headers located 40 to 50 feet above dock level. For Grade B tankers, the vapors are vented from either the ullage hatch or the P/V valve, located a few feet above deck level.

- Ships arriving at marine terminals in the area may have average hydrocarbon concentrations in their cargo tanks varying from less than one percent to greater than twenty percent (less than 2 percent to greater than 40 percent of saturation). The ship's cruise history on the previous voyage is the reason for this difference.

- Barges arriving to load gasoline usually have not been cleaned during their prior trip. They typically have high arrival vapor concentrations in their tanks.

- The parameters affecting the arrival vapor concentrations for ship's tanks are: 1) previous prior cargo, 2) the type and extent of cleaning performed during the return voyage, and 3) the fraction of the tank ballasted.

- Investigations indicate that for those tankers loading gasoline 45 percent of ship's cargo tanks arrive cleaned, 10 percent arrive ballasted, and 45 percent arrive empty and undisturbed.

2.1.2 Background Information on Marine Terminals in the Los Angeles AQCR

The results presented in this section are based on information obtained from regulatory agency contacts, literature, and onsite visits of marine terminals in the Los Angeles AQCR. Results from the Southern California study are included in the following material:

- Eight marine terminals loaded approximately 9 million barrels of gasoline into ships in 1975.

- Nine marine terminals unloaded approximately 15.7 million barrels of gasoline from ships in 1975.

- Approximately 18 million barrels of crude oil were loaded into ships at ten terminals in 1975.

- Slightly over 177 million barrels of crude oil were unloaded from ships at twelve marine terminals in 1975.

- Virtually no crude oil or gasoline is transported by barge.

- Offshore as well as onshore marine terminals are used for loading and unloading crude oil.

- No cargo tank inerting is done in the LA AQCR, and currently, few, if any, ships service the area with the capability to inert.

- A proposed project by SOHIO could unload approximately 500,000 bpd of Alaskan crude oil from tankers at Long Beach in the LA AQCR by 1978.

- The proposed Long Beach terminal could handle tankers of up to 165,000 DWT.

- Half of the projected Alaskan crude oil tanker fleet of 26 ships will have inert gas systems onboard.

- A proposed project offshore of Santa Barbara County will produce up to 120,000 barrels per day of crude oil which will be loaded onto tankers at an offshore terminal there.

2.1.3 Emissions

The results included in this section are based on data from the petroleum industry and Radian verification and engineering analysis of this reported information. Some of the important results from this analysis are included here:

- Hydrocarbons are emitted from marine vessel cargo tanks during loading operations and during ballasting operations following cargo unloading operations.

- Test data indicate that if the arrival hydrocarbon concentration of a cargo tank to be loaded with gasoline is in the explosive range, it will remain in this range for about 80% of the loading time. Gasoline ship cargo tanks which have been ballasted or left uncleaned on the return voyage may have arrival hydrocarbon concentrations in the explosive range. Explosive arrival concentrations occur less often in those tanks which were cleaned on the return voyage. The above holds true for the loading of volatile crude oils into ship tanks also. However, loading gasoline and volatile crudes onto intercoastal barges displaces vapors that are usually above the explosive range.

- Industry data indicate that hydrocarbon emissions ($lb/10^3$ gal) from loading motor gasoline are approximately as follows:

	Ships		Ocean Barges		Barges	
	Range	Avg	Range	Avg	Range	Avg
Cleaned	0-2.3	1.0	0-3	1.3	UA*	1.2
Ballasted	0.4-3	1.6	0.5-3	2.1	NA**	
Uncleaned	0.4-4	2.4	0.5-5	3.3	1.4-9	4.0

The results of the Radian testing substantiated most of the above data.

* Unavailable
** Not Applicable

- Industry data indicate that hydrocarbon emissions ($lb/10^3$ gal) from loading aviation gasoline are approximately the following:

Cleaned Ships	0.5
Uncleaned Ships	2.4
Average Ships	1.3
Average Barge	4.3

- Radian preliminary test results indicate that hydrocarbon emissions from ballasting crude tankers are in the range of 1 to 2 pounds per thousand gallons ballasted.

- Parameters that lower emission factors include low initial fill rates, low vapor pressures for either the cargo being loaded or the previous cargo, and tank cleaning or ballasting prior to loading.

2.1.4 Emission Control Technology

Information provided by control equipment vendors and petroleum companies was used in the emission control section. Some of the results based on this information are included here:

- The principal vapor control systems being considered in the Houston-Galveston area are based on conveying hydrocarbon vapors generated onboard the vessels to shoreside vapor control units for recovery as liquid product or for disposal by incineration.

- Proposed vapor control systems are projected to have the capability of removing non-methane hydrocarbons from gasoline loading vapors to a concentration lower than 5 volume percent gasoline vapors. If high methane concentrations are present, as have been observed in some industry tests, controlled emissions may exceed 5 volume percent because conventional vapor recovery units are ineffective on methane vapors.

- Several potential safety problems exist with proposed marine terminal vapor control systems. Since the safety problems have not been completely resolved, the costs associated with installing the necessary safety controls may be inadequately defined.

2.1.5 Economics of Emission Control

The results presented below in this section were based upon information provided by the oil industry and control equipment vendors, and upon information developed in a detailed Radian cost study:

- The Radian cost study projects the initial capital cost of the shoreside portion of a vapor control system to be $80 per barrel per hour of marine terminal loading capacity.

- Projections from industry data are that the initial capital cost of vessel modifications will be $325,000 per ship and $68,000 per barge.

- Based on industry data, vapor control unit operating costs including maintenance and utilities are projected to be $15 per thousand barrels loaded.

- When amortized over a 15 year equipment life at 12% interest, the total annualized cost of an average vapor control system is projected to be $33 per bph of marine terminal capacity.

- Based on the annualized cost, the typical vapor control system proposed for the Houston-Galveston area is projected to exhibit a cost effectiveness of $2900 per ton of hydrocarbons recovered, and is projected to exhibit an economic impact of $0.07 per barrel of gasoline loaded.

- As a result of a Radian cost sensitivity analysis, the cost effectiveness of vapor control systems is reduced significantly when 1) the required control system size is proportionally reduced, 2) a marine terminal loads large quantities of gasoline onto barges, 3) the number of vessels requiring modification is small, 4) the cost of a given control system size can be reduced, or 5) the hydrocarbon concentration in the recovered vapors is high. These parameters can potentially reduce the cost effectiveness to $2000/ton of hydrocarbon recovered and reduce economic impact to $0.06 per barrel of gasoline loaded.

- The sensitivity analysis also indicates that the cost effectiveness and economic impact are significantly higher for small terminals requiring disproportionately larger and more expensive vapor recovery systems to handle infrequent but large tanker loadings. For such situations the cost effectiveness and economic impact could be twice as high as the typical vapor recovery system values. These parameters can potentially increase the cost effectiveness to $9500/ton of hydrocarbon recovered and increase economic impact to $0.22 per barrel of gasoline loaded.

2.2 Conclusions

1. In addition to loading operations, hydrocarbon emissions are also generated at marine terminals from ballasting operations subsequent to gasoline and crude oil unloading. In-transit hydrocarbon emissions occur at sea from diurnal tank breathing, from tank cleaning activities, and from inerting in the case of the ships in Alaskan Crude oil tanker fleet which have inert gas systems.

2. Cruise history, a very important parameter affecting marine terminal emission factors, has been demonstrated to vary significantly from one company to another company. Other parameters such as extent of ballasting, RVP, loading time, etc., create variations in emission rates and make the development of accurate emission factors difficult. Emission factors developed to date do not accurately account for the effect of all the loading variables. Also, accurate emission factors do not exist for crude oil loading or for the ballasting of gasoline or crude oil ships.

3. Emission control technology for marine loading of gasoline is a young technology which is faced with a unique set of problems, one of which is safety. The principles involved in marine vapor collection and control are well understood. Applicable control technologies have been developed in other fields and primarily need to be refined with respect to marine loading operations.

4. Based on Radian cost evaluation, the projected cost for installing marine terminal controls in the Houston-Galveston area averages $2900 per ton of hydrocarbons controlled. Wide variations from $2000 to $9500 per ton may exist in the cost of emission controls due to the cost of necessary safety equipment and to individual marine terminal characteristics.

5. Due to the emission control problems created by the presence of methane and to the possibility of regulations based on non-methane hydrocarbons, it is appropriate to use methane distinguishing analytical procedures in marine terminal emission testing programs.

2.3 Recommendations

As a result of this project, several areas have been identified as needing further work to more completely investigate the hydrocarbon emissions from gasoline ship and barge loading and crude oil ship ballasting. The following tasks are recommended to more completely characterize the emissions:

1. A study to obtain detailed information from ship's logs as to the actual breakdown of tank arrival conditions due to cruise history for ships servicing the

Houston-Galveston area and the Los Angeles area.

2. A sampling program designed to produce accurate emission factors for gasoline loading into dirty ship tanks, clean barge tanks, and unclean barge tanks. The program should also develop factors for crude oil loading onto ships and barges and crude oil and gasoline ship ballasting.

3. An investigation of the safety aspects involved in the application of control technology to gasoline marine loading emissions.

4. An investigation of the potential impact on hydrocarbon emissions from marine terminal operations due to cargo tank inerting and purging.

3.0 BACKGROUND INFORMATION ON MARINE TERMINALS

Many refineries are located on navigable waters and operate marine terminals for transferring crude oil, gasoline and other products by marine vessel. These facilities may vary from terminal to terminal, differing in size, material transferred, type of vessel handled, loading/unloading rate, and layout.

This section of the report presents information which identifies and describes marine terminals which transfer crude oil and gasoline in the Houston-Galveston area. Included in this presentation are descriptions of shoreside and shipside equipment and operating methods as well as cruise history statistics for the vessels which service these Houston-Galveston terminals. The majority of this information was obtained from the owners of the terminals and the rest from EPA Region VI.

A brief section showing the relationship of the marine terminal to the rest of the gasoline and crude oil transportation system is given first. It is intended to provide a perspective of the role that the marine terminal serves in the crude oil transportation and gasoline marketing systems.

3.1 Relative Quantities of Crude Oil and Gasoline Transported by Marine Terminals in the United States

A general flow diagram which shows the relative daily rates of the crude oil transported to U.S. refineries by pipeline, tanker/barge, and truck/tank car is presented in Figure 3.1-1. Based on 1974 data, Figure 3.1-1 shows that almost 28 percent of the crude oil transported to U.S. refineries is carried at one time by tankers or barges. Based on a total 1974 U.S. refinery

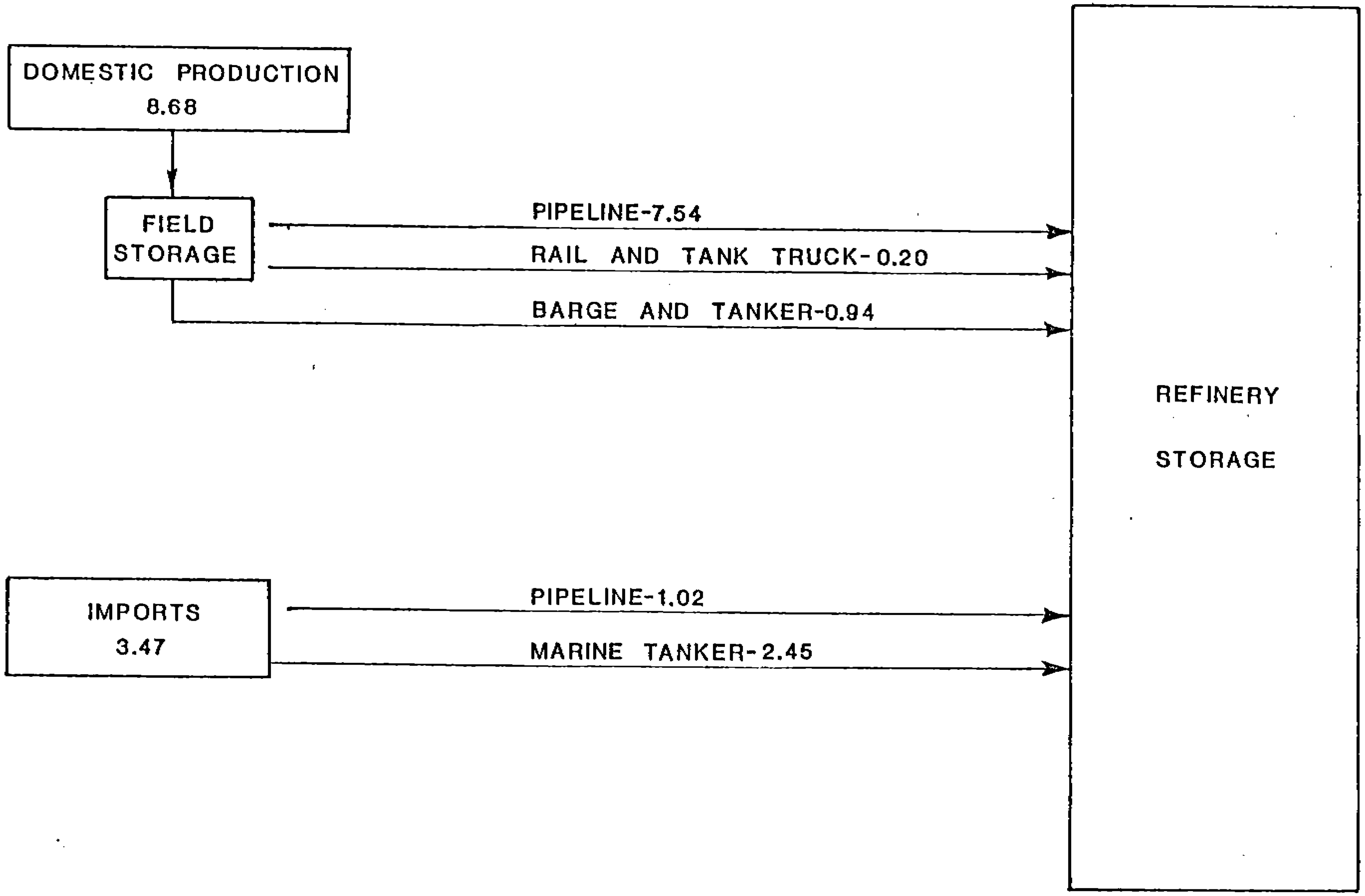


FIGURE 3.1-1
TRANSPORTATION OF CRUDE OIL, 1974
(RATES IN MILLIONS OF BARRELS PER DAY)
SOURCE: AM-166

demand of 12.15 million barrels per day, marine tankers and barges transported approximately 3.4 million barrels of petroleum daily (Ref. 1).

Figure 3.1-2 is a general flow diagram which shows the relative daily rates of the gasoline which is transported from U.S. refineries by pipeline, tanker/barge, and truck/tank car. The diagram indicates that about nine percent of the gasoline shipped from U.S. refineries leaves by tanker or barge. Based on 1974 data, this amounts to roughly 570,000 barrels per day of gasoline loaded into tankers and barges (Ref. 29).

3.2 Marine Terminals Transferring Crude Oil and Gasoline in the Houston-Galveston Intrastate AQCR

The objective of this section is to identify and describe those marine terminals in the Houston-Galveston Intrastate AQCR which transfer crude oil and gasoline to and from marine vessels. Table 3.2-1 lists those terminals for which sufficient information was obtained to identify them as terminals transferring crude oil and/or gasoline. Figure 3.2-1 shows the general location of the terminals in Table 3.2-1.

Although there are several other marine terminals in the area which transfer crude oil and/or gasoline, insufficient information was obtained on them for inclusion in this report. Their transfer operations are small enough, though, that their omission will not greatly effect the accuracy of the report. The owners of the terminals are Amerada Hess Corp., Pak Tank Co., and Adams Co.

A description of each of the marine terminals in Table 3.2-1 follows. This description includes the layout of the dockside facilities and the dockside operational methods

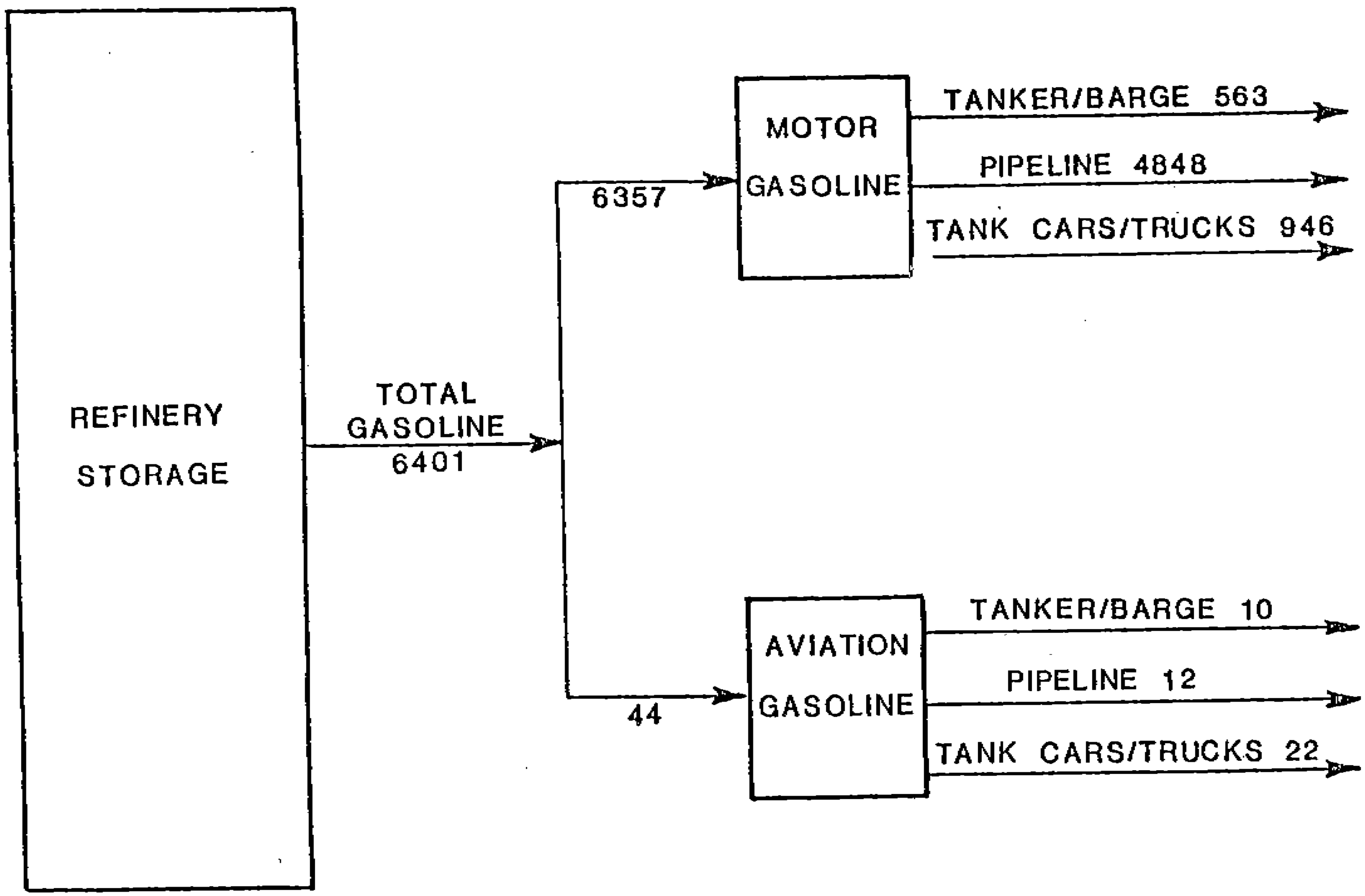


FIGURE 3.1-2 TRANSPORT OF GASOLINE
(RATES IN THOUSANDS OF BARRELS PER DAY, 1974)

TABLE 3.2-1

MARINE TERMINALS TRANSFERRING CRUDE OIL OR GASOLINE IN THE HOUSTON-GALVESTON AQCR

Terminal	Gasoline				Crude Oil			
	Ships		Barges		Ships		Barges	
	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded
Exxon-Baytown	✓		✓		✓	✓		✓
Shell-Deer Park	✓		✓			✓		✓
AMOCO-Texas City	✓		✓			✓		
Marathon-Texas City	✓		✓			✓		
ARCO-Pasadena	✓					✓		
Charter-Houston			✓			✓		
Texas City Refining-Texas City	✓					✓		
Crown-Deer Park						✓		

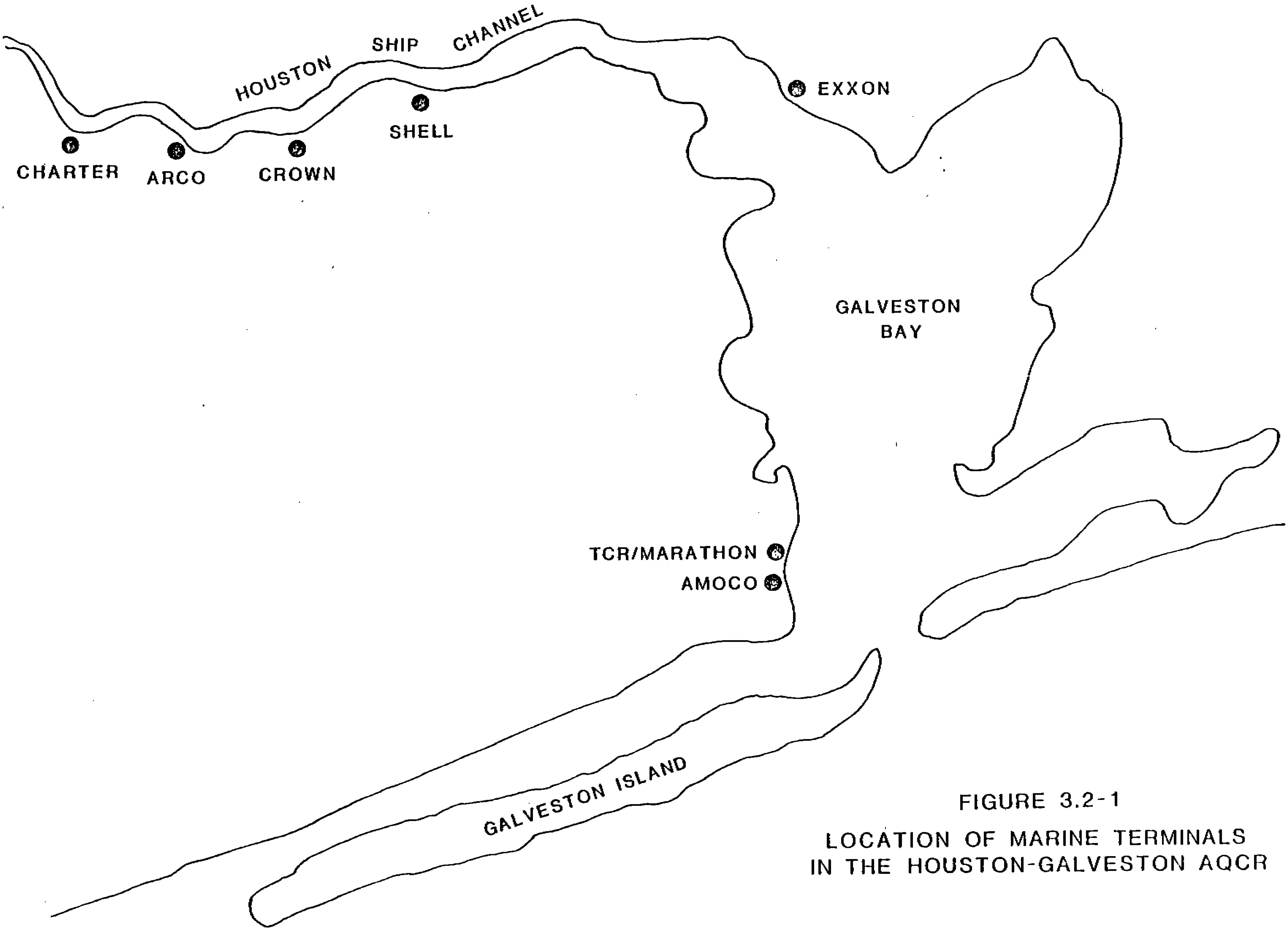


FIGURE 3.2-1

LOCATION OF MARINE TERMINALS
IN THE HOUSTON-GALVESTON AQCR

used for loading and unloading ships and barges with crude oil and gasoline. No gasoline unloading operations were identified in the area, and the Exxon terminal was the only one loading crude oil.

3.2.1. Exxon Baytown Refinery Marine Terminal

The Exxon marine dock facility is located on the east side of the Houston ship channel, the terminal consists of three separate docks as shown in Figure 3.2-2. Each dock has two berths, and each berth can handle one tanker or a minimum of two barges. The following information was obtained by correspondence between Radian and Exxon (Refs. 14,15).

3.2.1.1 Gasoline Loading System

Docks 1 and 2 handle all of the gasoline loading onto marine vessels. From storage the gasoline is pumped to the dock area through one or more of five loading lines by various combinations of seven pumps. The different types of lineups that can be made with the gasoline pumping system is shown in Table 3.2-2.

The gasoline storage tanks, located upstream of the pumps, are gauged manually to determine how much gasoline is loaded, and flow meters are also located on each of the five dock loading lines. The meters are part of a computer controlled blending operation.

The arrangement of the five gasoline loading lines to Dock 1 and Dock 2 is shown in Figure 3.2-3. Each loading line is capable of pumping gasoline to either dock. Figures 3.2-4 and 3.2-5 present the manifolding arrangement of the gasoline loading lines at Dock 1 and Dock 2, respectively. Each circled pipe intersection indicates that a valved interconnection exists between the pair of crossing pipes.

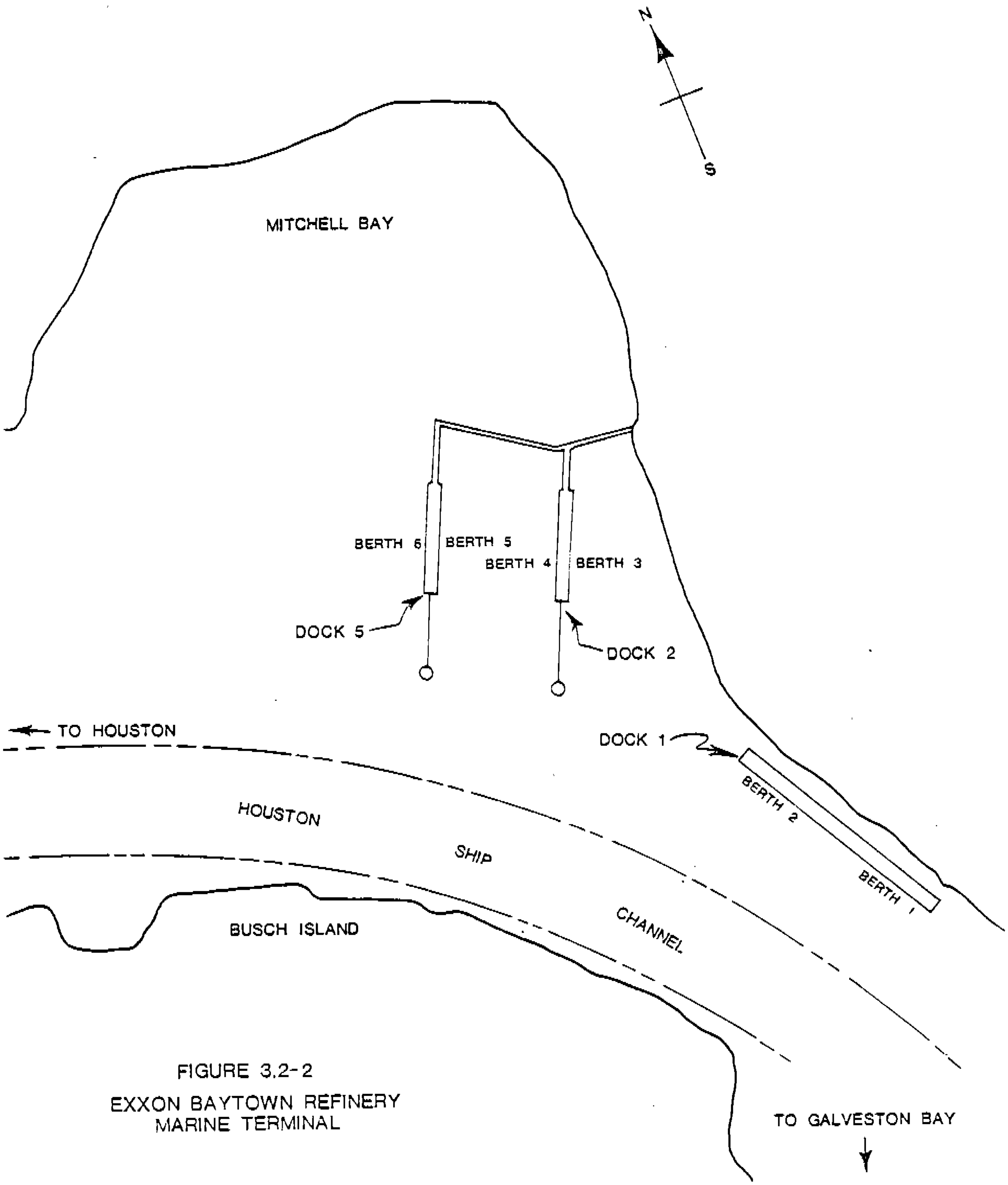


FIGURE 3.2-2

EXXON BAYTOWN REFINERY
MARINE TERMINAL

TABLE 3.2-2

GASOLINE PUMPING SYSTEM LINEUPS

Pump	Nominal Capacity, MB/Hour[a]	Pump Location	Products Handled[b]	Dock Lines Used
P-1	8	Pump Slab 137	Leaded Mogas, Avgas	7, 18, 53
P-2	5	Pump Slab 137	Leaded Mogas, Avgas	7, 18, 53
P-3	10	Pump Slab 137	Leaded Mogas, Avgas	7, 18, 53
P-16	10	Pump Slab 194	Leaded Mogas	7, 12, 53
P-17	10	Pump Slab 194	Leaded Mogas	7, 12, 53
P-18	10	Pump Slab 194	Leaded Mogas	7, 12, 53
P-19	10	Pump Slab 194	Unleaded Mogas	10

[a] M = thousands
[b] Mogas = motor gasoline, Avgas = aviation gasoline

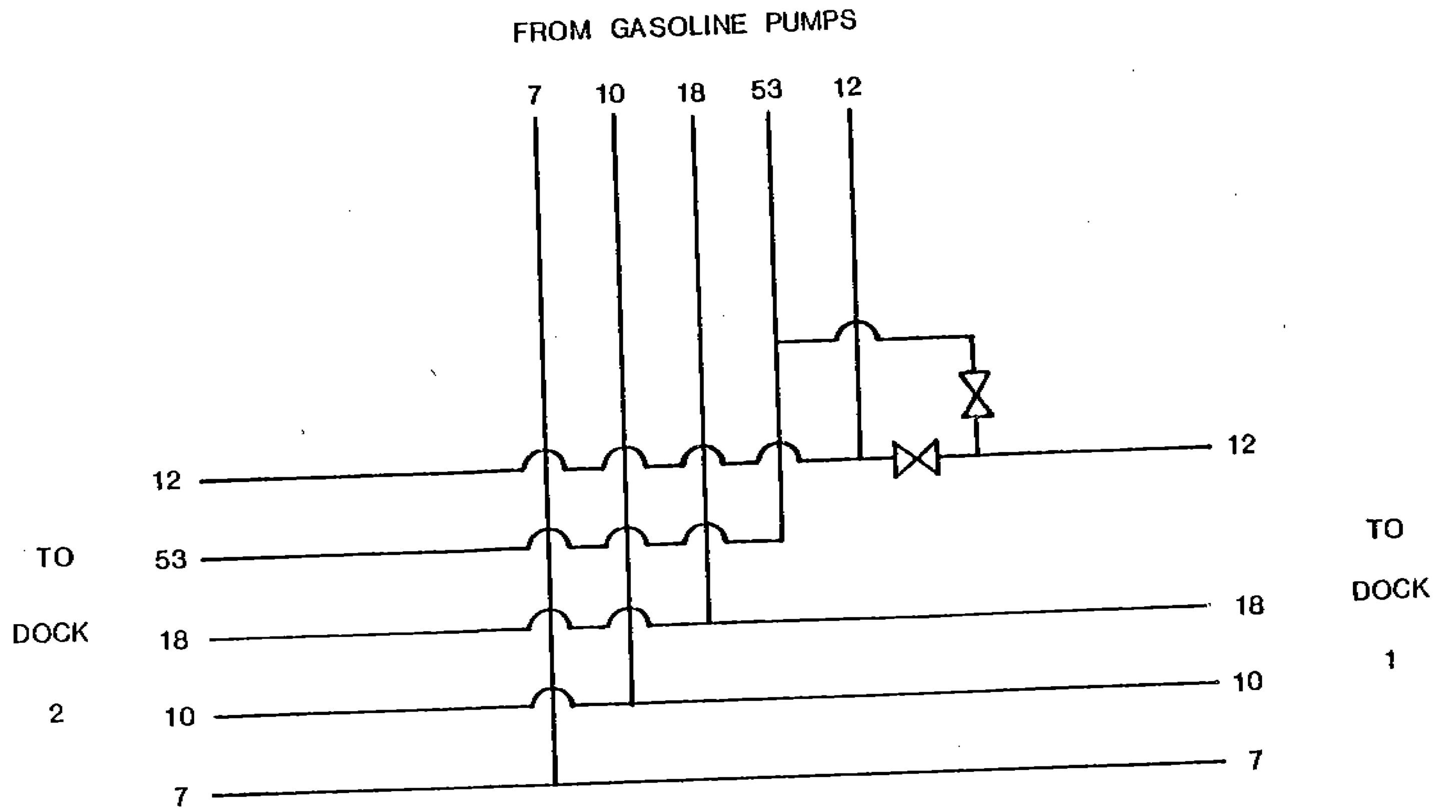


FIGURE 3.2-3 GASOLINE LOADING LINES TO DOCKS 1 AND 2

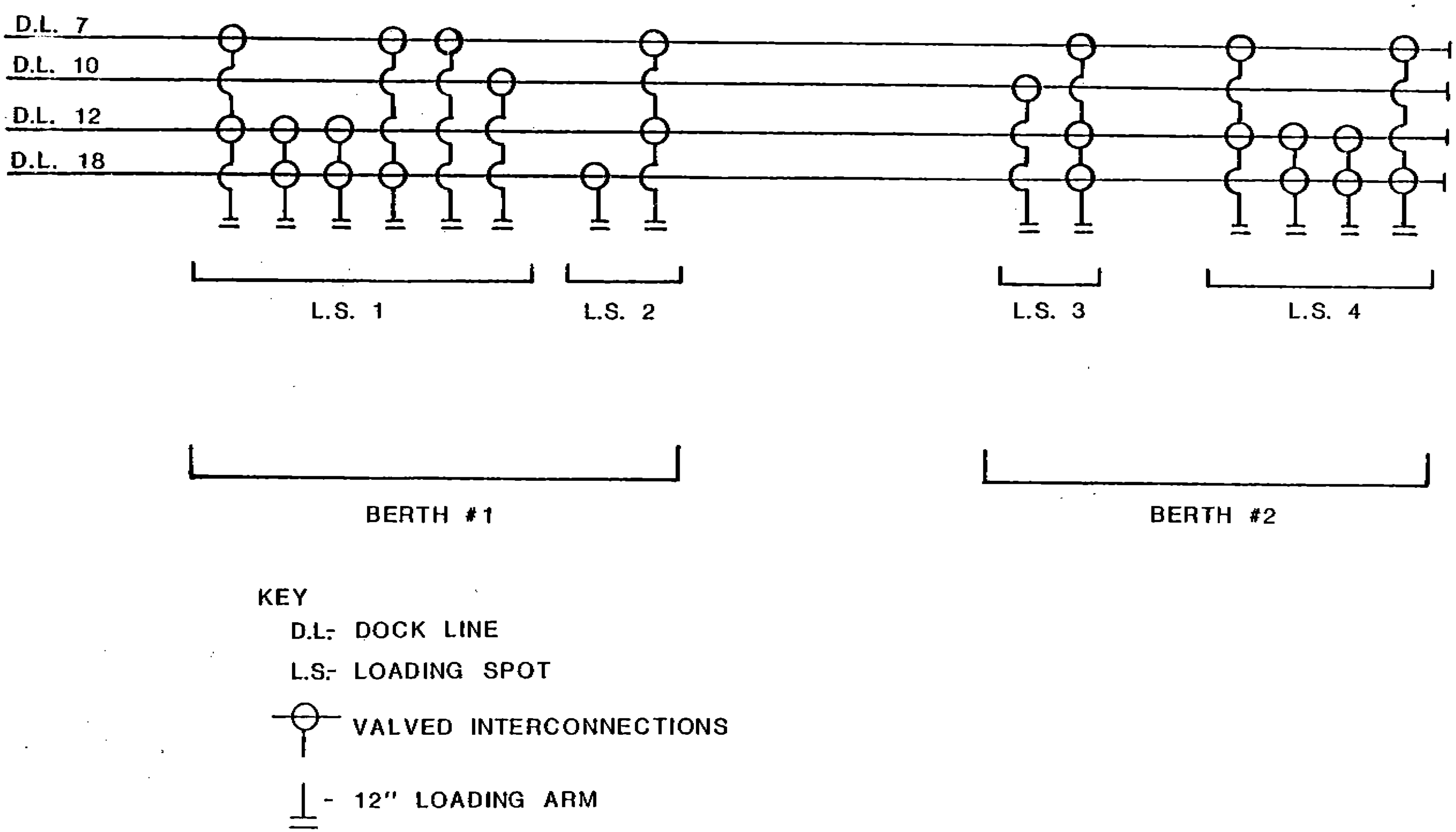


FIGURE 3.2-4 GASOLINE LINE MANIFOLDING AT DOCK 1

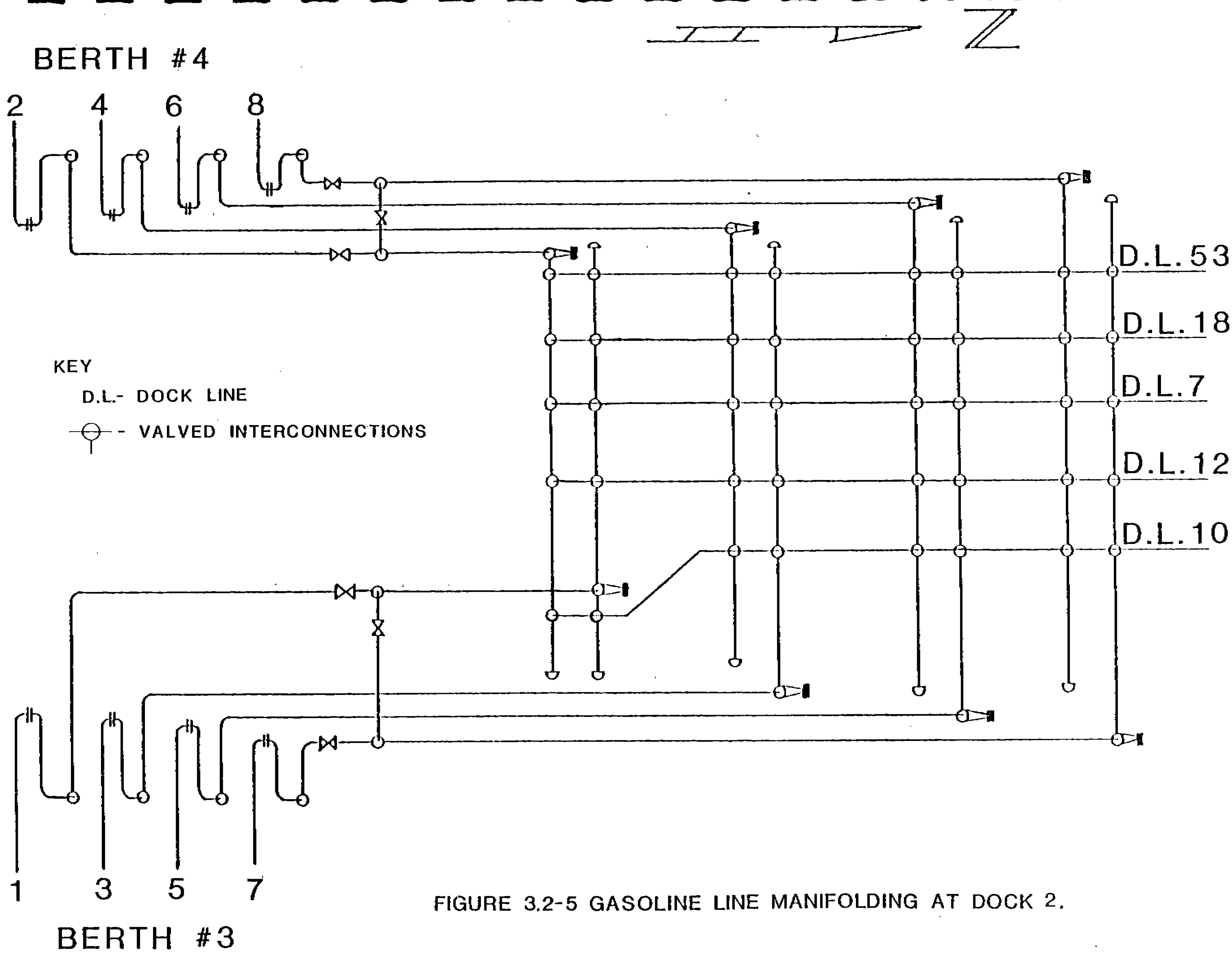


FIGURE 3.2-5 GASOLINE LINE MANIFOLDING AT DOCK 2.

At Dock 1 eight-inch diameter cargo loading hoses are used to transfer gasoline from the shoreside manifolds to the vessel's manifold. These hoses are bolted to the specified vessel and dock flanges for a particular cargo transfer. Booms are used to lift the heavy hoses into place for making the required connections and to position the hose so that the line does not twist during loading. Each hose can handle a maximum of 8,000 bph.

At Dock 2 metal hydraulic loading arms provide a permanent connection to the shoreside manifold. There are four 12-inch diameter loading arms and one 8-inch arm at each berth. Each of these arms has a special type of swivel joint that allows the arm to pivot as needed during the loading operation. Each loading arm is attached to the vessel manifold by a flange on the end of the arm. Adaptors are kept at each berth so that loading arms can be used with barges as well as tankers. Each 12-inch arm can handle transfer rates of over 13,000 bph.

The gasoline loading rate at Dock 1 can vary from 5,000 bph to 40,000 bph. The actual rate for a ship varies widely, depending upon such factors as the number of pumps and loading lines being used, the number and size of vessel tanks being filled, the types and sequence of materials loaded and the loading practices used by crew members on the vessel. The maximum loading rate for a single barge is not expected to exceed 8,000 bph.

For Dock 2 the gasoline loading rate can vary from 5,000 bph to 50,000 bph. The actual loading rate depends upon the factors mentioned above. Barges are not expected to be loaded at a rate higher than 8,000 bph.

3.2.1.2 Crude Oil Loading/Unloading System

Crude oil loading and unloading of marine vessels occurs at Dock 2 and Dock 5. For loading, crude oil is pumped to the docks through one or more of three lines by various combinations of three pumps. Figure 3.2-6 shows how these three lines, numbered 43, 44, and 67 run between the docks, the pumps, and the refinery storage area. Two of the three crude oil pumps which are located on Pump Slab 91 have capacities of 10,000 bph while the other has a capacity of 12,500 bph. As with gasoline, the quantity of crude loaded is determined by gauging shoreside tank levels.

The manifolding that exists at Dock 2 and Dock 5 for the crude oil lines is shown in Figure 3.2-7. The circled pipe intersections indicate that those lines are connected. Eight-inch cargo hoses are used to transfer the crude oil between the shore and the vessel at Dock 2. At Dock 5, both hoses and metal hydraulic loading arms are used. Both Dock 2 and Dock 5 have booms for positioning the cargo hoses.

Typical tanker crude oil loading rates at Docks 2 and 5 vary for the same reasons cited in the gasoline loading system discussion. The maximum and minimum rates are 32,500 bph and 10,000 bph, based on the capacity of the pumps at Pump Slab 91. An average rate of 14,000 bph is the maximum for single barges loading crude. Average rates for a tanker loading crude can be as high as 30,000 bph.

For crude oil unloading, tankers and barges use the same facilities at Dock 2 and Dock 5 as described for crude oil loading shown in Figure 3.2-7. The crude oil is pumped using the vessel's pumps through Line No. 105 (see Figure 3.2-6) to the primary refinery crude storage tanks or through some combination

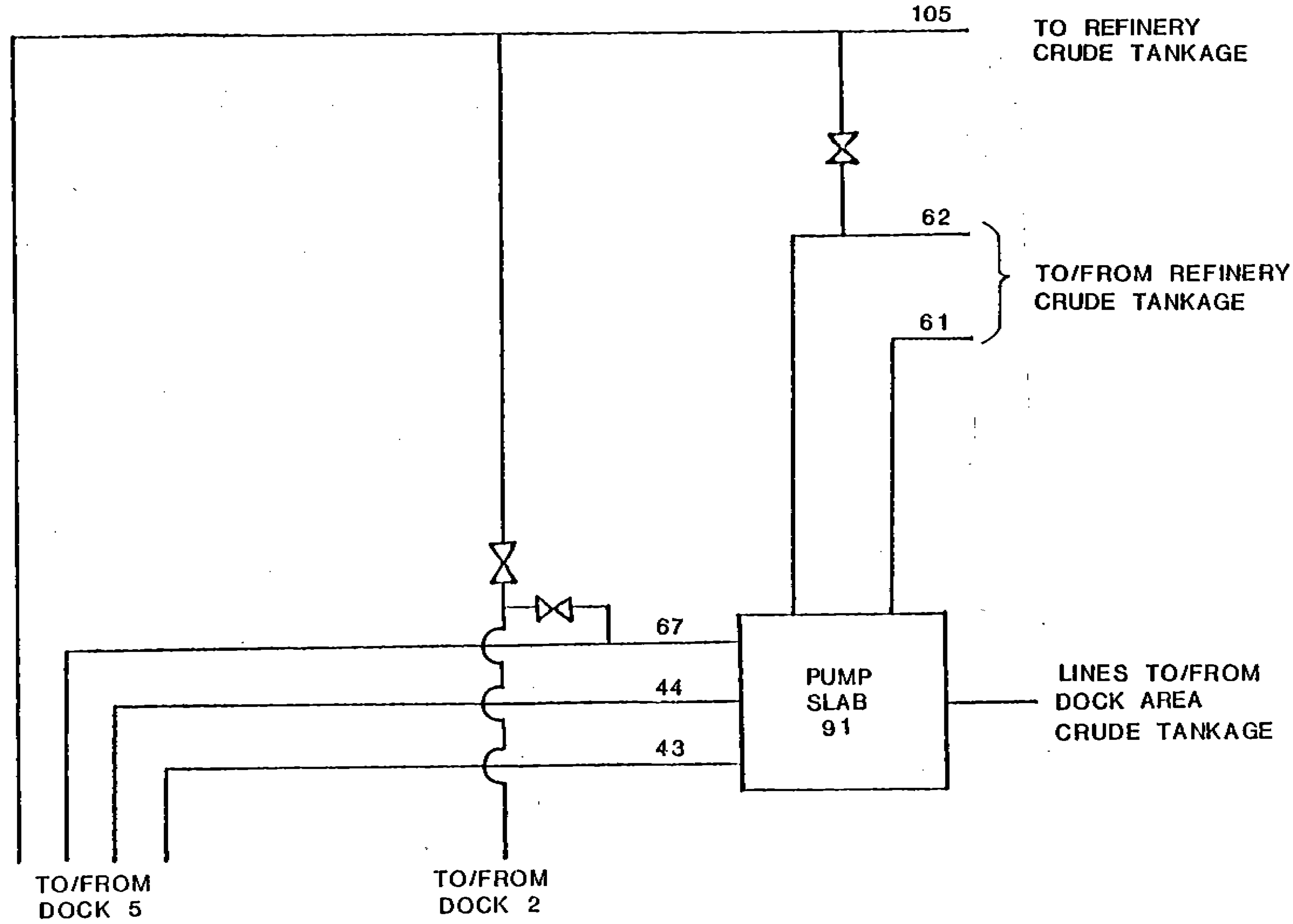


FIGURE 3.2-6 CRUDE OIL LINES TO/FROM DOCKS 2 AND 5

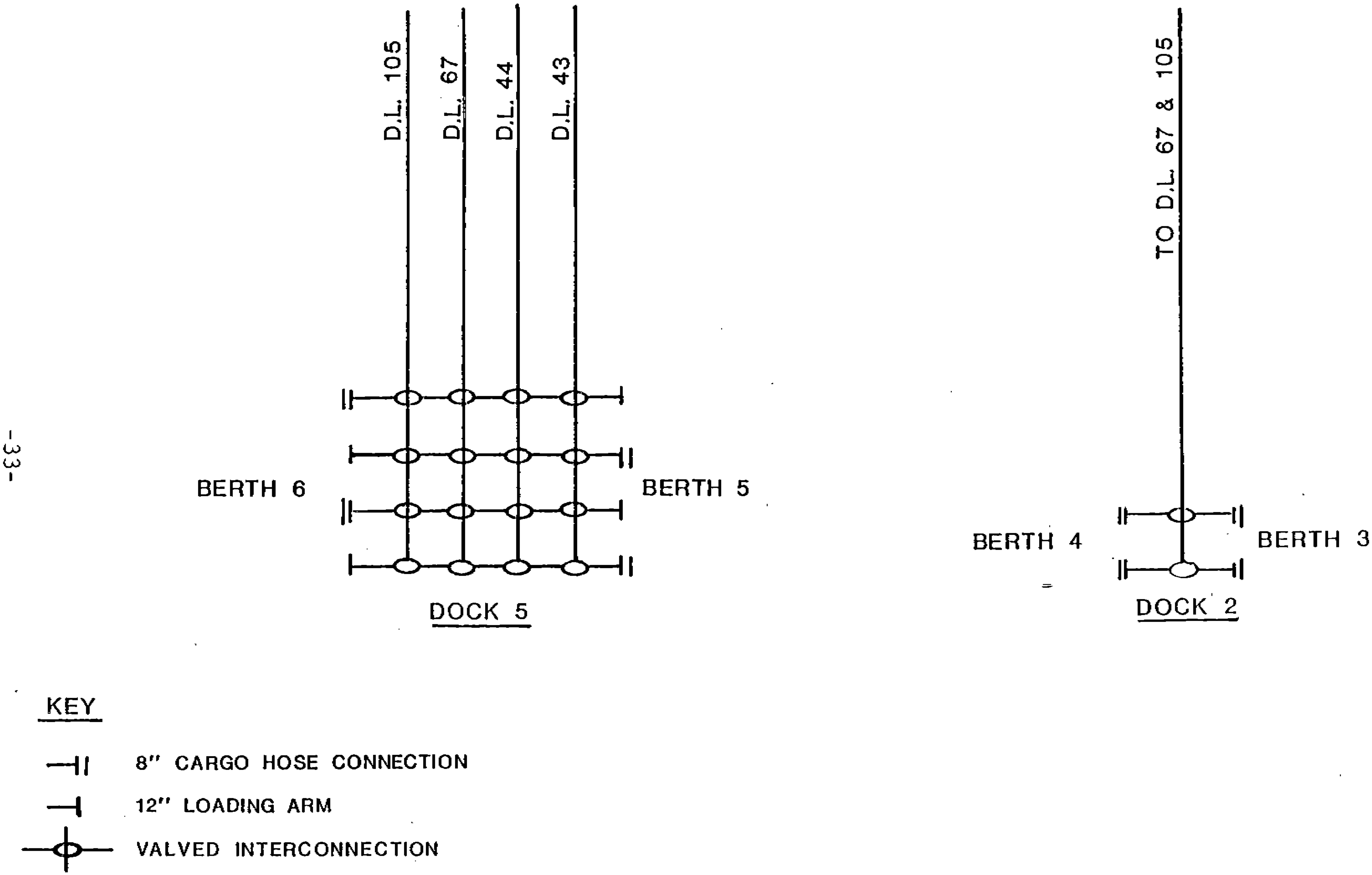


FIGURE 3.2-7 CRUDE LINE MANIFOLDING AT DOCKS 2 AND 5.

of Lines 43, 44, and 67 to a number of small crude storage tanks in the dock area. Should these smaller tanks have insufficient capacity for the quantity of unloaded crude, the three crude oil pumps at Pump Slab 91 can be used to transfer crude from the dock tanks to the primary crude storage tanks at the same time the vessel is unloading. The shoreside tank levels are manually gauged to determine the quantity of crude oil unloaded from the tanker or barge.

Crude oil unloading rates vary considerably from vessel to vessel, depending primarily upon the number and size of the vessel's pumps. Larger tankers with high capacity pumps unload at average rates up to 40,000 bph. Peak rates for these tankers can be as high as 60,000 bph early in the unloading cycle when the ship's pumps have relatively high suction pressure and low discharge pressure due to the high tank level on the ship and low tank level on shore. The average unloading rate for barges may be as high as 11,000 bph. Relatively little crude oil is shipped into the refinery by barge.

3.2.2 Shell Deer Park Refinery Marine Terminal

The Shell marine facility is located in a slip on the south side of the Houston Ship Channel. There are four docks at the terminal located as shown in Figure 3.2-8. Each dock can handle one tanker or two barges. The following information was obtained by correspondence with Shell.

3.2.2.1 Gasoline Loading System

Gasoline is loaded at any of the four docks onto marine tankers or barges. From storage the gasoline is pumped to the dock area through one of several systems. The piping system

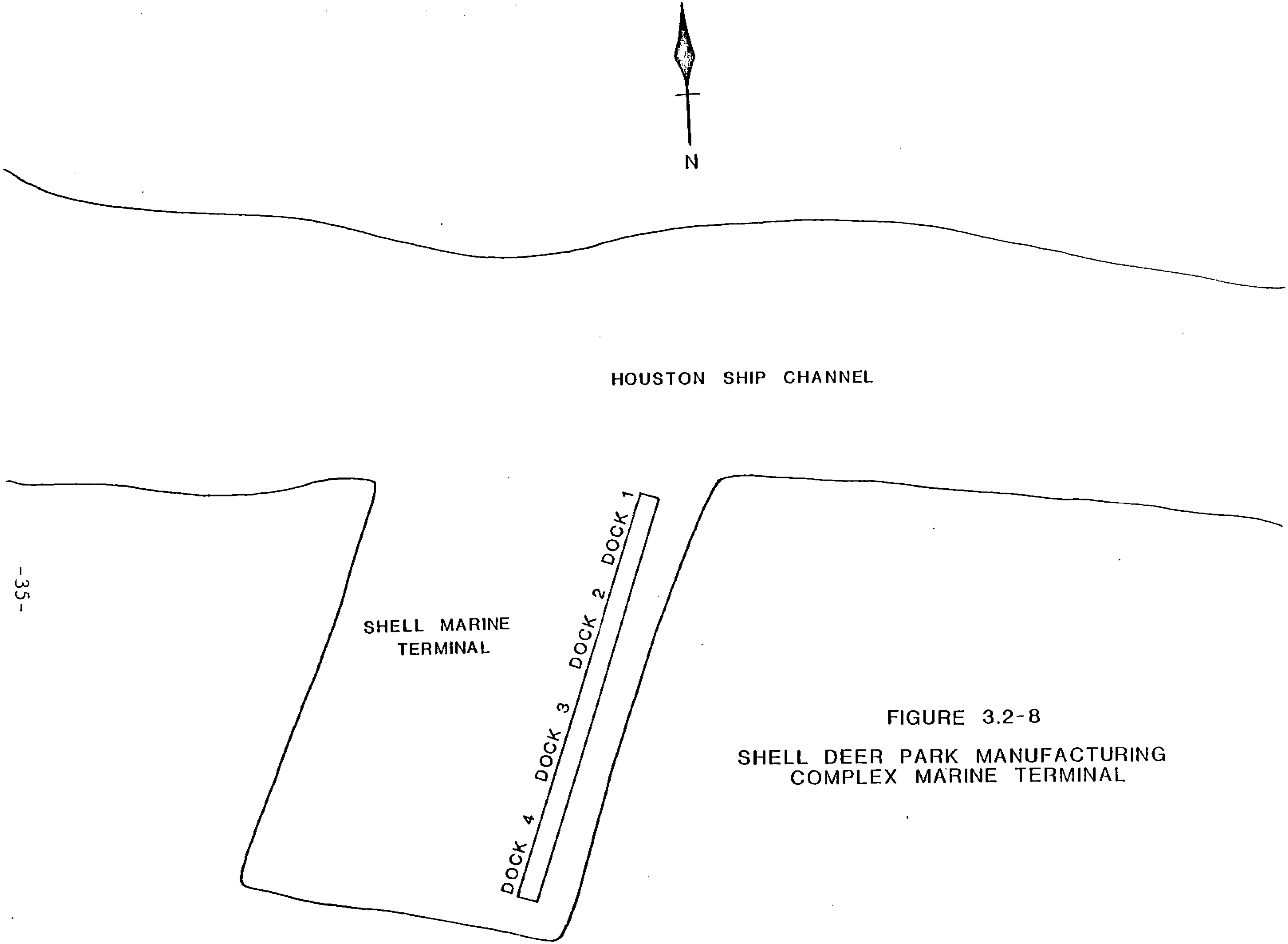


FIGURE 3.2-8

SHELL DEER PARK MANUFACTURING COMPLEX MARINE TERMINAL for the pumping of gasoline from storage to the four docks is shown in Figure 3.2-9. Each dock can handle Regular, Unleaded, and Premium Shell motor gasoline.

At each dock cargo loading hoses are used to transfer gasoline from the shoreside manifolds to the vessel's manifold. The hoses are bolted to the specified vessel and dock flanges for a particular cargo transfer operation. Booms are used to lift the heavy hoses into place for making the connections and to position the hose so that kinks do not develop during loading.

The loading pumps located in the refinery tank farm vary in capacity from 3500 to 5500 bph. The reported maximum rate at which gasoline can be loaded across any one dock is 25,000 bph. The maximum loading rate for all docks loading simultaneously is also 25,000 bph. The actual rate for a ship or barge varies widely, depending upon such factors as the number of pumps and lines being used, the number and size of vessel tanks being filled, the types and sequence of materials loaded and the loading practices of the vessel's crew.

3.2.2.2 Crude Oil Unloading System

Crude oil is received at the Shell refining complex at Dock 1 or Dock 4. The crude oil is pumped, using the vessel's pumps, through either of two available 24-inch lines. This arrangement allows two vessels to discharge crude simultaneously at the terminal. The two 24-inch lines are sized hydraulically for 40,000 bph maximum flow rate when used in parallel. Average flow rates generally run from 70 to 80% of the ship's maximum pump rate. Construction is currently underway at the terminal for the addition of a fifth dock which will be employed solely for receiving crude oil. Expected date of completion is 1977.

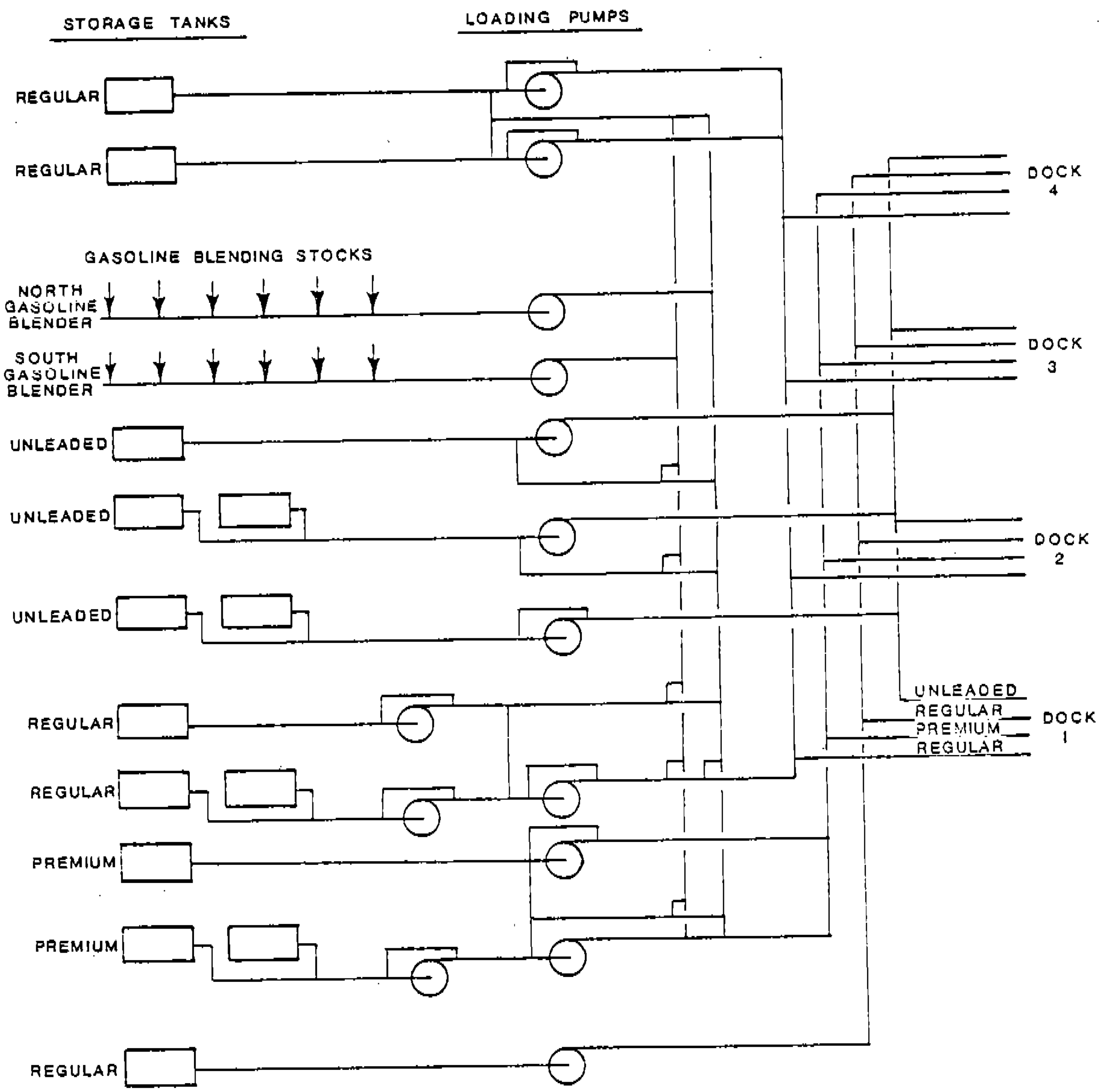


FIGURE 3.2-9

GASOLINE LOADING LINES TO SHELL'S MARINE DOCKS

3.2.3 AMOCO Texas City Refinery Marine Terminal

The AMOCO marine facility consists of 6 docks located on the west side of the Texas City Harbor as shown in Figure 3.2-10. Each dock has one berth. Dock No. 30 is used exclusively for handling barges, Nos. 31 and 32 are used for both ships and barges, No. 33 is for barges only, and Nos. 32A and 40 are used exclusively for handling crude oil from ships. Information for this section was supplied to Radian from AMOCO Oil Co. (Refs. 2,3).

3.2.3.1 Gasoline Loading System

Docks 30, 31, and 32 handle the loading of gasoline to ships and barges. From storage the gasoline is pumped to the docks using one of four available lines. Table 3.2-3 identifies the lines and pumps typically used for loading gasoline.

TABLE 3.2-3
LINES AND PUMPS FOR MARINE LOADING OF GASOLINE - AMOCO TEXAS CITY

Line Number	Pumps	Nominal Cap. (bph)
9	F-62A or F-62B	5,000
9A	F-62A or F-62B	5,000
9B	L-1, L-2, or L-3	4,500
804	L-1, L-2, or L-3	3,850

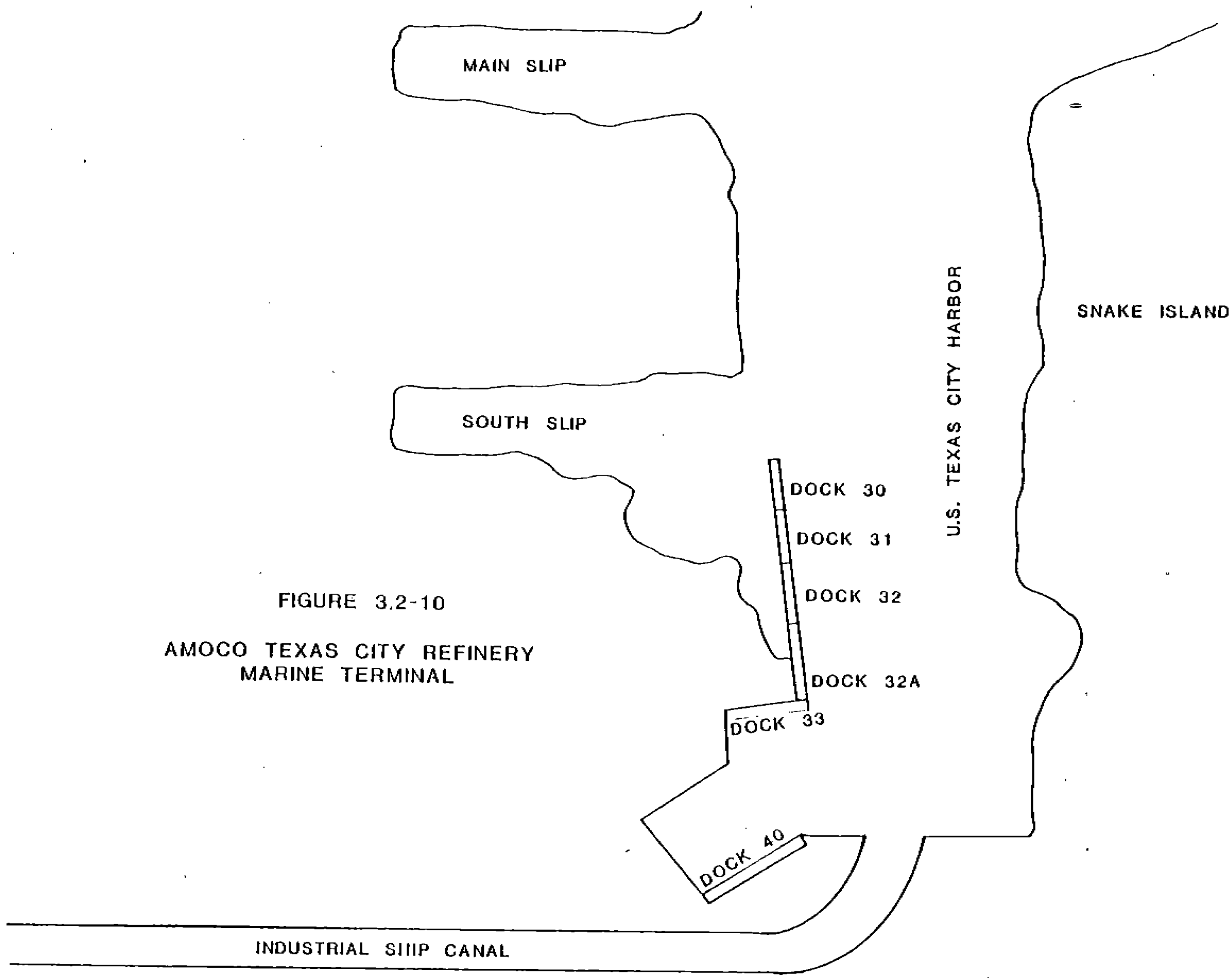


FIGURE 3.2-10

AMOCO TEXAS CITY REFINERY
MARINE TERMINAL

The arrangement of the gasoline lines to Docks 30, 31, and 32 is shown in Figure 3.2-11. At each dock, hoses are used for loading the gasoline cargo from the dock manifold to the ship manifold. These hoses are bolted to the specified vessel and dock flanges for a particular cargo transfer.

Figure 3.2-11 shows that the maximum rate gasoline can be loaded onto vessels at Docks 31 and 32 is 18,350 bph. The maximum rate barges at Dock 30 may be loaded is 4,500 bph. The actual loading rate at Docks 31 and 32 varies widely, depending upon the lines and pumps used, the number and size of the vessel tanks being filled, the types and sequence of materials loaded and the loading practices of the crew. The maximum loading rate for barges is usually less than that for ships. The amount of gasoline loaded is determined by measuring the ship tank ullages and/or gauging the onshore product storage tanks.

3.2.3.2 Crude Oil Unloading System

Crude oil can be unloaded at Docks 31, 32, 32A, 33, and 40. However, Dock 33 generally handles distillates. Nos. 32A and 40 are employed solely for receiving crude oil from tankers. The crude oil is pumped from the ship cargo tanks to onshore storage using lines 800, 801, and 805. Figure 3.2-12 shows the arrangement of these lines to the different docks. There are two booster pumps, one each for lines 800 and 801. There is no booster pump for line 805. The vessel pumps are used primarily for unloading the crude from the cargo tanks. Although actual unloading rates for each vessel vary considerably with the number and size of the vessel pumps, the maximum unloading rate for Docks 31, 32, and 33 is 10,000 bph. Docks 32A and 40 have individual maximum unloading rates of 28,000 bph.

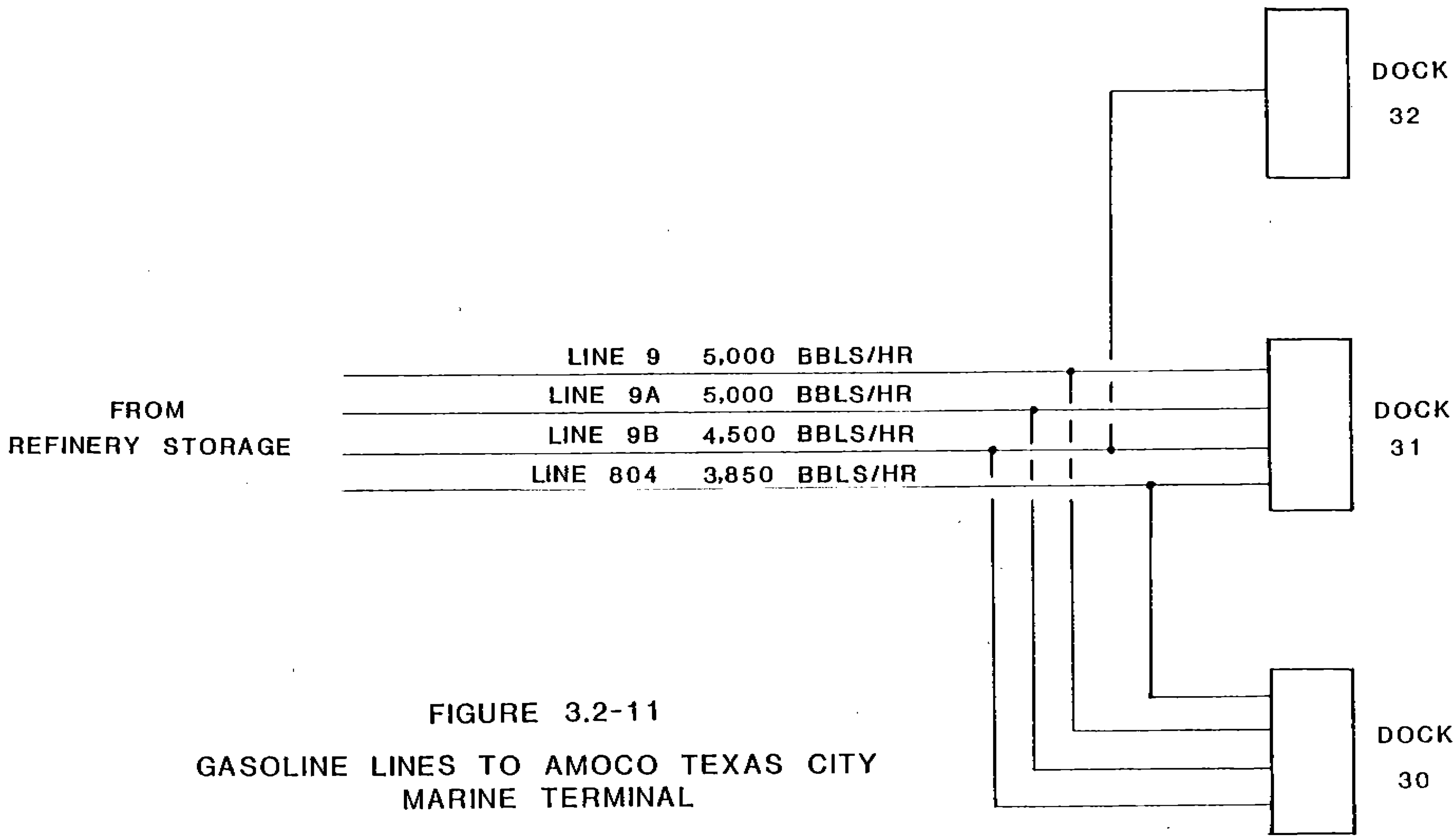


FIGURE 3.2-11

GASOLINE LINES TO AMOCO TEXAS CITY MARINE TERMINAL

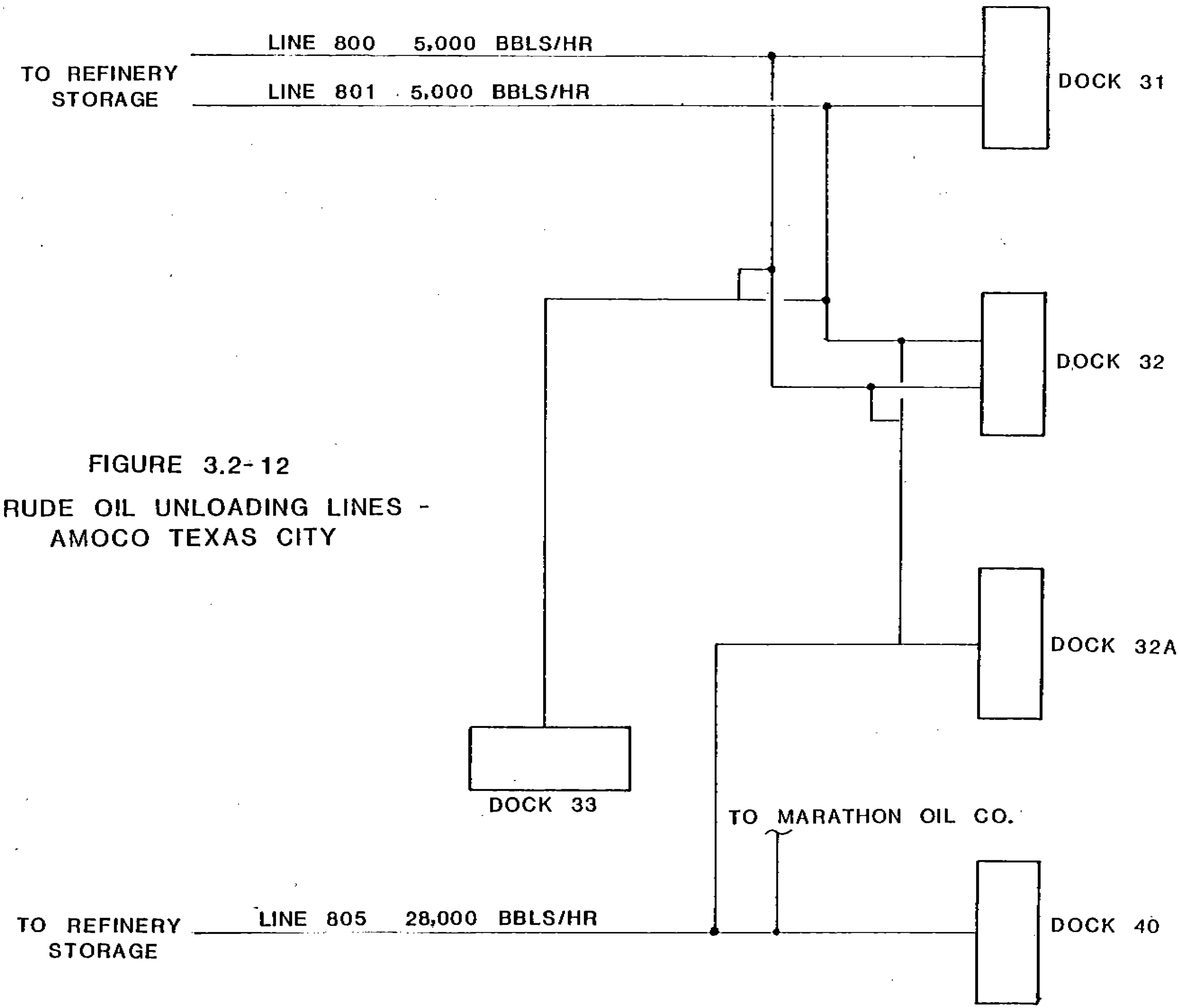


FIGURE 3.2-12

CRUDE OIL UNLOADING LINES - AMOCO TEXAS CITY

3.2.4 ARCO Houston Refinery Marine Terminal

The ARCO refinery marine facility is located on the south side of the Houston Ship Channel as presented in Figure 3.2-13. Dock A is used solely for barges and Dock 13 for ships. Information for this section was supplied to Radian by ARCO (Refs. 5,6).

3.2.4.1 Gasoline Loading System

Figure 3.2-14 is a diagram of the piping which transfers gasoline from ARCO's tank farm to the two docks. From the tank farm gasoline is pumped by one of three pumps to the dock area through one or more of three loading lines.

The gasoline loading rate at Dock A can vary from 1,050 bph to a maximum of 11,050 bph. The actual rate varies, depending upon the number of pumps and loading lines used, the number and size of the barge tanks being filled, and the loading practices of the barge tankmen.

The gasoline loading rate at Dock B can vary from 5,000 bph to a maximum of 20,000 bph. The actual loading rate varies with the same factors mentioned above.

3.2.4.2 Crude Oil Unloading System

Crude oil can be unloaded at all three of ARCO's docks. Dock A can handle only barges, while Dock B can handle both ships and barges and Dock C can handle light ships and barges.

An unloading facility may be built in the future at Bayport, Texas for crude oil destined for ARCO's Houston refinery. Use of this facility would substantially reduce the crude oil transfers at the existing docks.

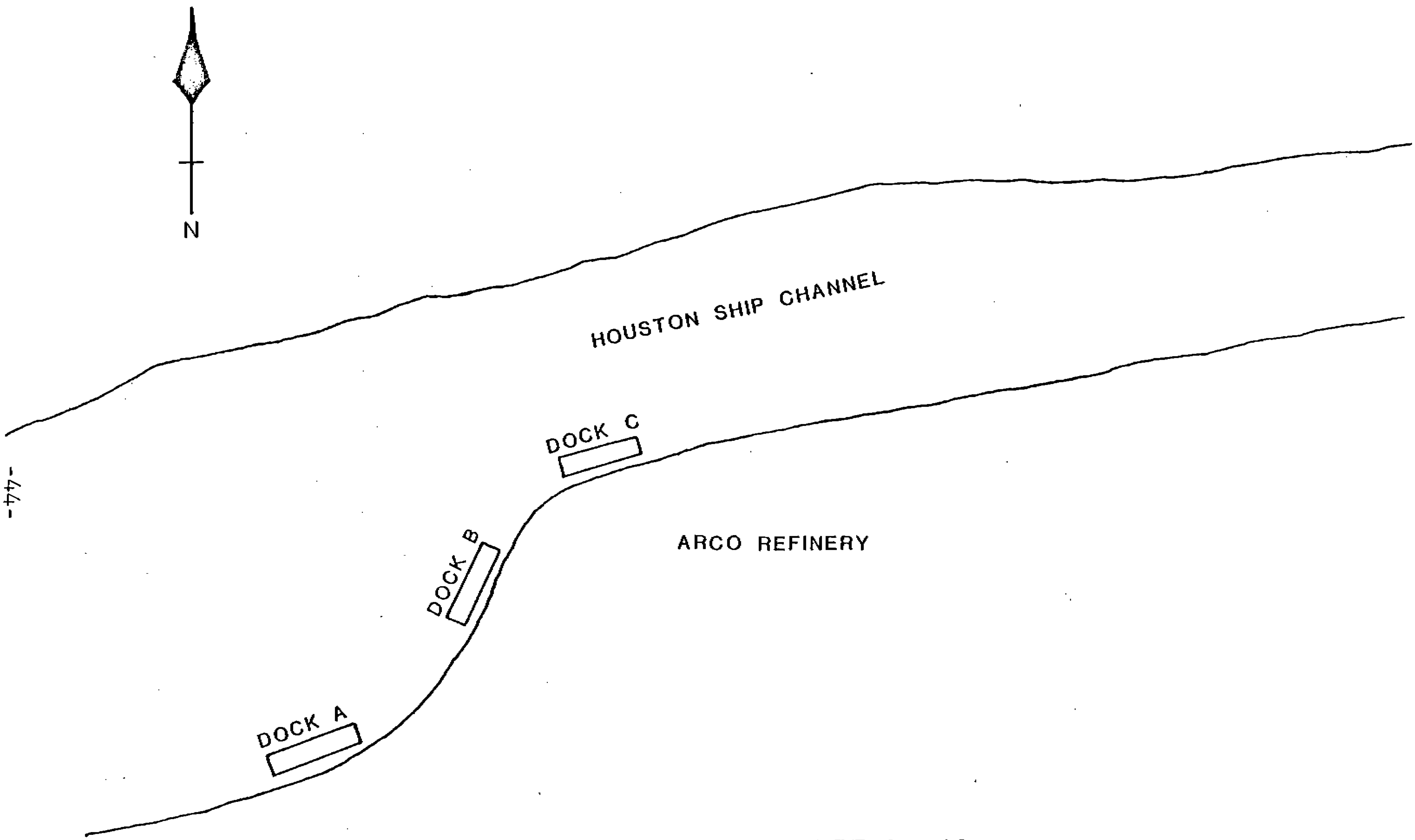


FIGURE 3.2-13
ARCO HOUSTON REFINERY MARINE TERMINAL

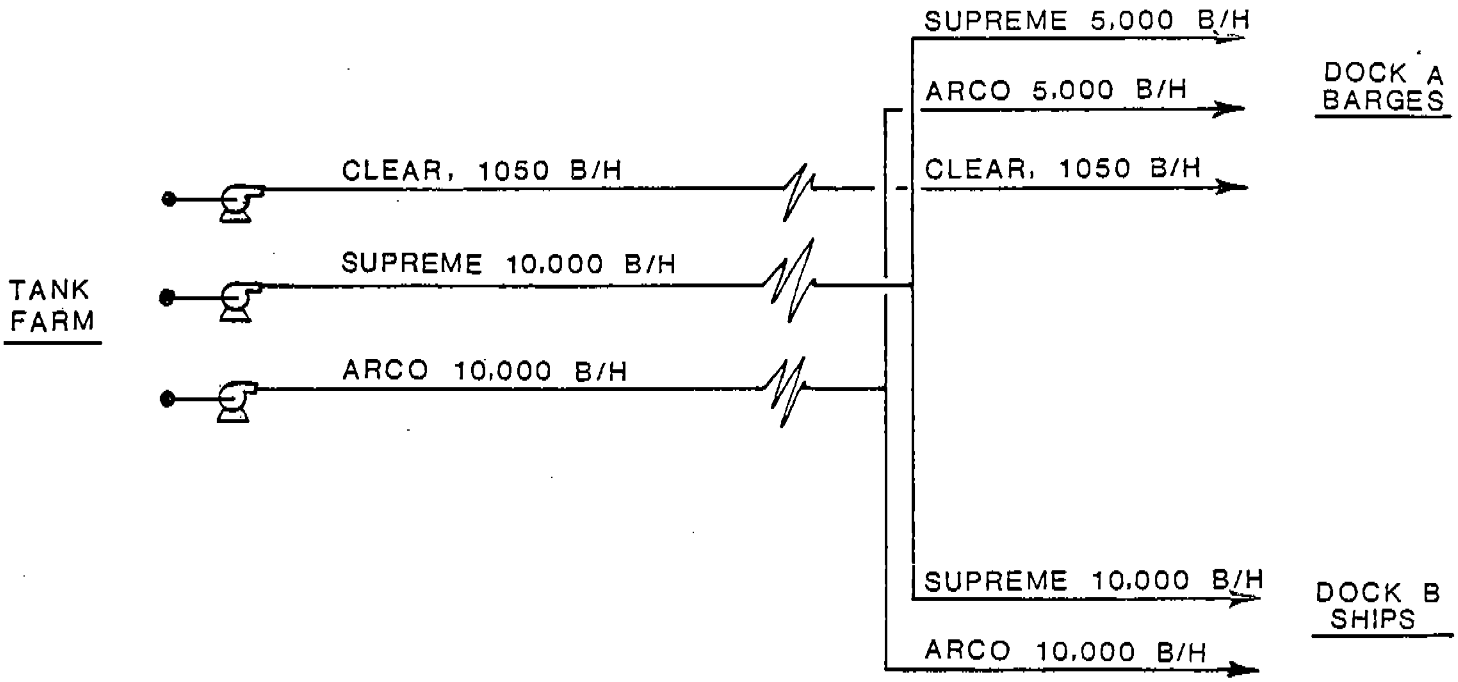


FIGURE 3.2-14
GASOLINE LOADING LINES
TO DOCKS A AND B
ARCO HOUSTON MARINE TERMINAL

Figure 3.2-15 is a diagram of the crude lines which transfer the crude oil from each dock to the refinery tank farm. Hydraulic arms and cargo hoses are used to connect ship to shore. Metering is done by gauging of onshore tanks.

3.2.5 Texas City Refining Texas City Refinery Marine Terminal

Texas City Refining shares its marine terminal docks with Marathon Oil Co. The facility consists of 5 docks located on the west side of the Texas City Harbor as shown in Figure 3.2-16. Each dock has one berth. Dock No. 3 handles barges only. The others can handle tankers or barges. Texas City Refining provided Radian with part of the information presented in this section (Ref. 25). The rest of the data came from EPA Region VI (Ref. 26).

3.2.5.1 Gasoline Loading System

The loading of gasoline onto barges and ships is accomplished at three docks, Nos. 2, 4, and 5. TCR has five pumps which transfer the gasoline to the docks. Their capacity ranges from 2,800 bph to 7,000 bph. Table 3.2-4 indicates the maximum gasoline loading rate at each dock. The gasoline loaded is metered by gauging of onshore tanks and/or ship tank ullage.

TABLE 3.2-4
MAXIMUM GASOLINE LOADING RATE AT TEXAS CITY REFINING'S MARINE DOCKS

Dock No.	Maximum Rate (bph)
2	12,000
4	12,000
5	20,000

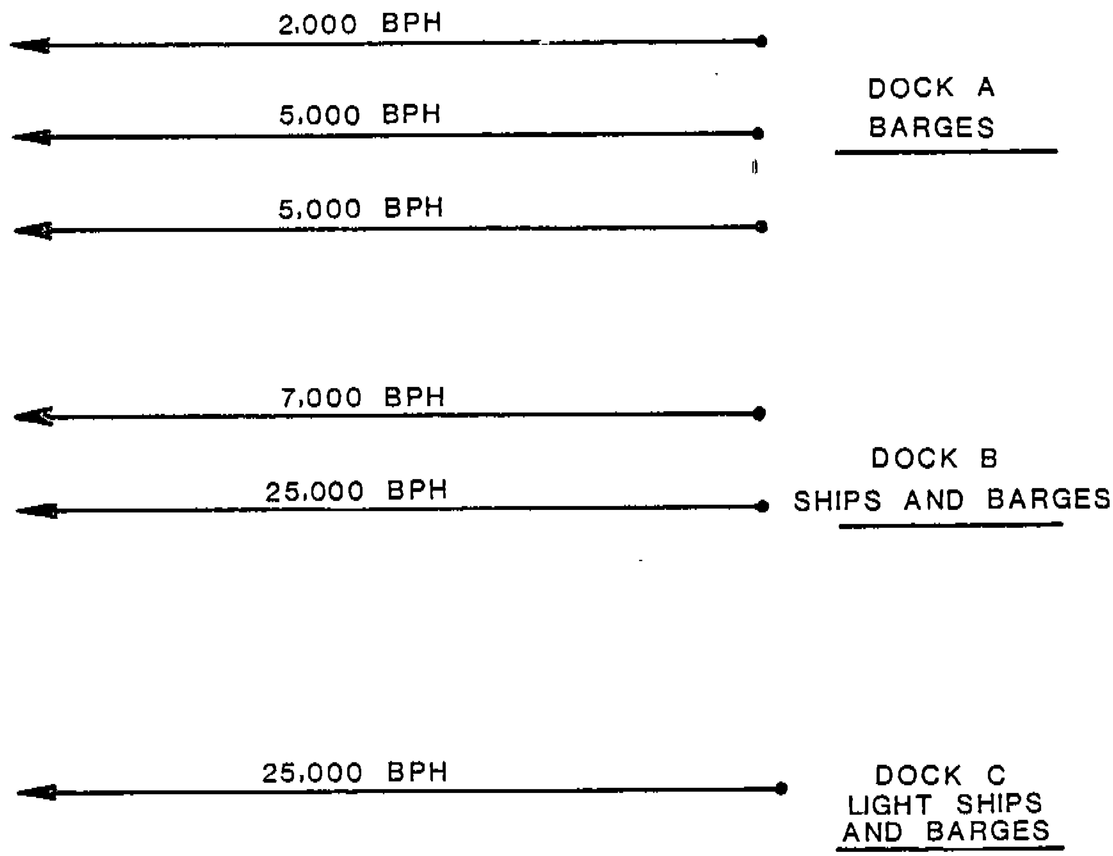


FIGURE 3.2-15 CRUDE OIL LOADING LINES FOR ARCO HOUSTON MARINE TERMINAL

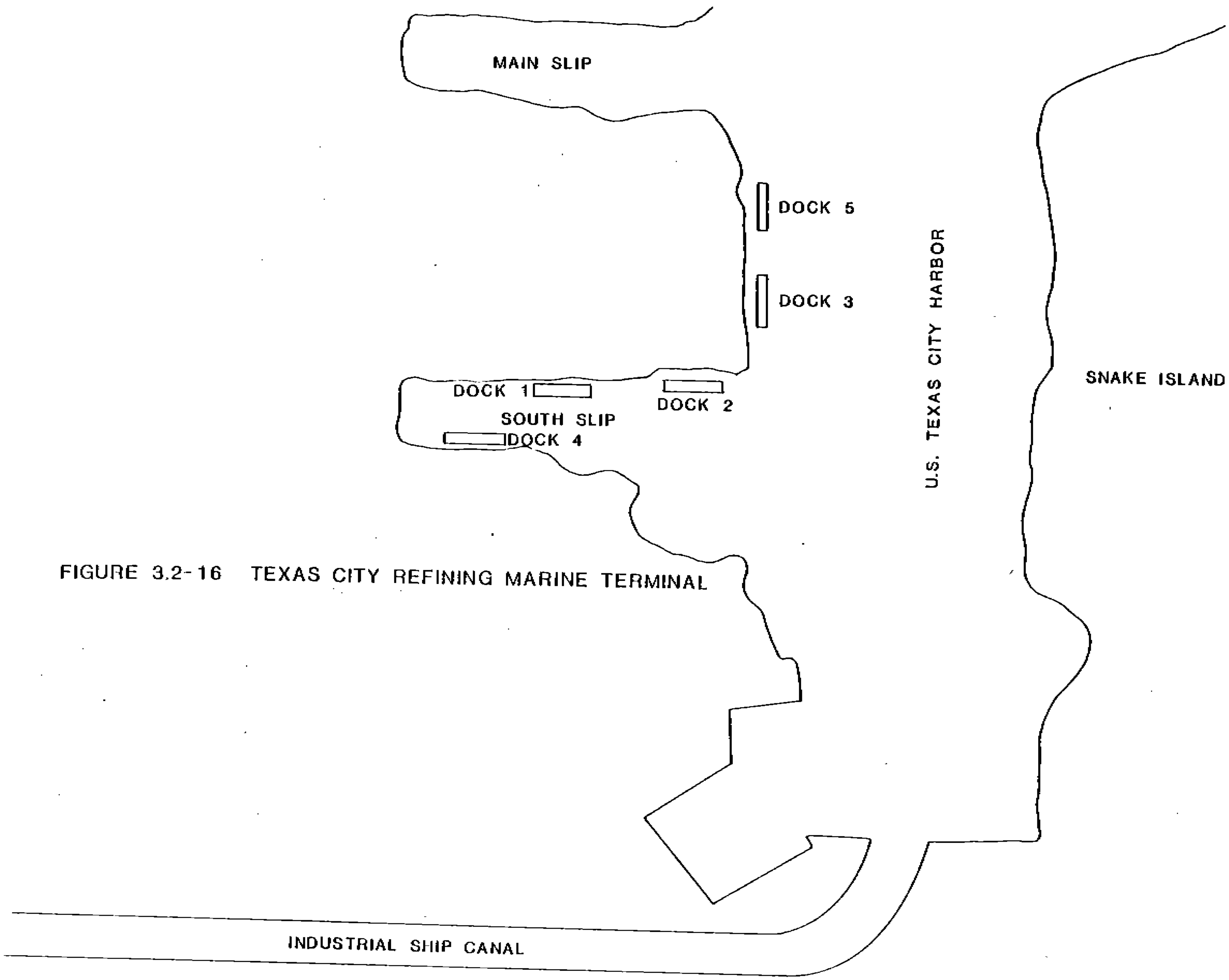


FIGURE 3.2-16 TEXAS CITY REFINING MARINE TERMINAL

At docks 2, 4, and 5, 8-inch loading hoses are used for connecting the dock manifolds to the ship manifolds.

3.2.5.2 Crude Oil Unloading System

Very little information was obtained on TCR's crude oil unloading system. However, it is assumed that all five of the docks shared with Marathon are capable of unloading crude oil. The maximum rate at which crude was unloaded from a ship in 1975 was 16,500 bph. The ship's pumps are used to pump the crude to TCR's storage tanks. Metering is done by tank gauging.

3.2.6 Crown Central Houston Refinery Marine Terminal

Crown Central Petroleum Company's marine facility is located on the south side of the Houston Ship Channel as shown in Figure 3.2-17. It consists of only one dock. No gasoline was loaded at this dock in 1975. It was used to receive crude oil and to periodically ship out various refinery products. Data in this section are based on correspondence between Crown and Radian (Ref. 11).

3.2.6.1 Crude Oil Unloading System

Both ships and barges unload crude oil at the dock. The crude is discharged using the vessel's pumps into three 8-inch cargo hoses which connect the ship manifold to the dock manifold. From the dock one 18-inch pipe and one 10-inch pipe transfer the oil to refinery storage. A normal range for the discharge rate is 9,000 to 15,000 bph. Metering is accomplished by onshore gauging.

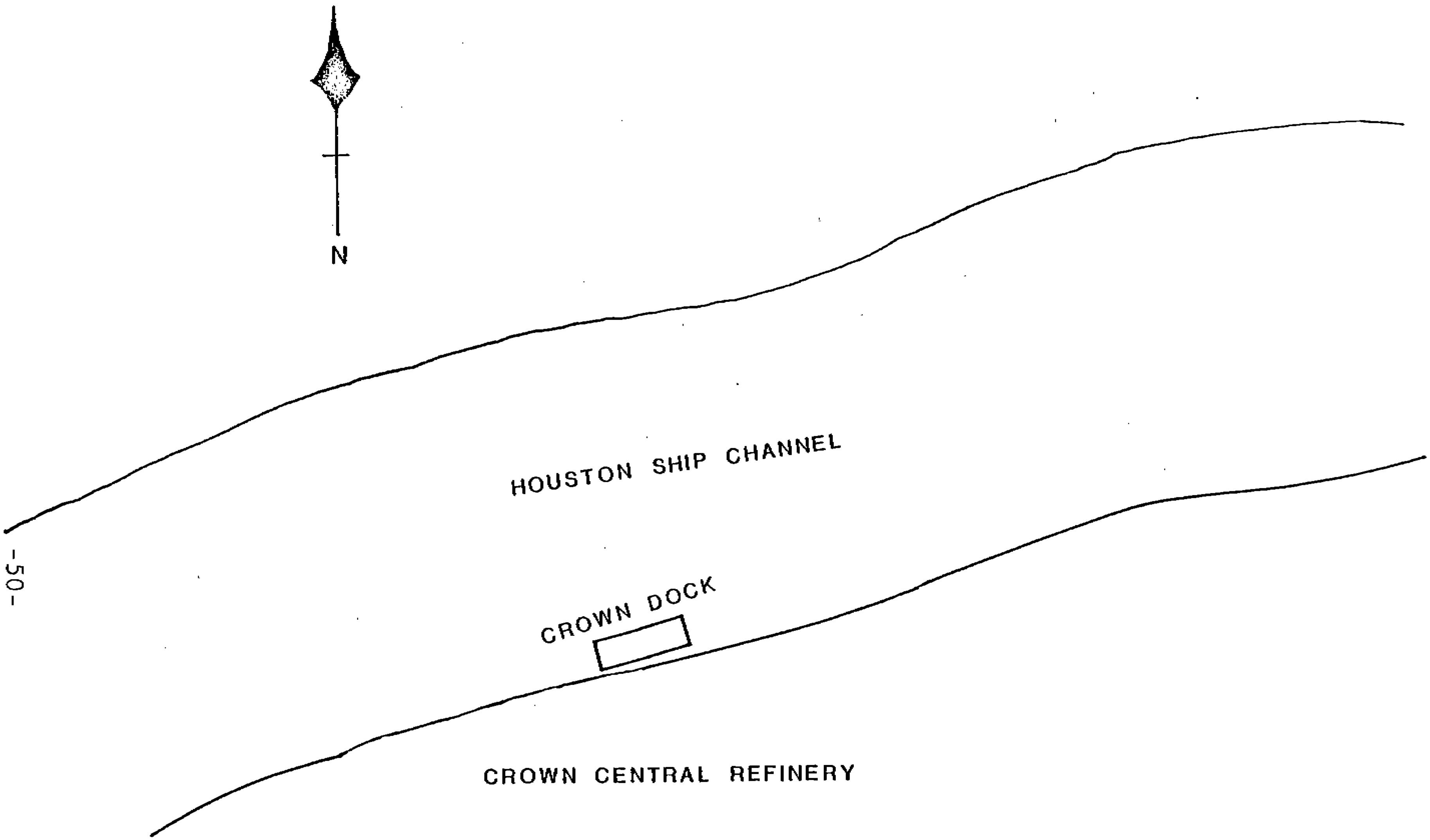


FIGURE 3.2-17
CROWN CENTRAL HOUSTON REFINERY MARINE TERMINAL

3.2.7 Charter Oil Houston Refinery Marine Terminal

Charter Oil Company's marine facility is located on the south side of the Houston Ship Channel as pictured in Figure 3.2-18. It consists of three docks only two of which transfer crude oil and gasoline. The Traweek Dock handles both ships and barges, while Dock No. 4 handles only barges. Dock No. 3 transfers chemicals. The information in this section was obtained from EPA Region VI files (Ref. 10).

3.2.7.1 Gasoline Loading System

No information was provided about the exact arrangement of lines and pumps from refinery storage to the docks at Charter's terminal. However, it is known that barges can load gasoline at #4 Dock at a rate of 4,500 bph and ships can load at 7,500 bph at the Traweek Dock. Eight-inch cargo hoses are used to transfer the liquid.

3.2.7.2 Crude Oil Unloading System

No information was provided concerning the crude oil unloading operations or the dock equipment. It is assumed, however, that the Traweek Dock would be used, and the discharge rate would depend upon the specific ship unloading.

3.2.8 Marathon Texas City Refinery Marine Terminal

The Marathon Oil Company Marine Terminal consists of five marine docks shared with Texas City Refining and one shared with AMOCO. Figure 3.2-12 shows Dock 40 which Marathon shares with AMOCO, and Figure 3.2-16 shows the five docks which Marathon shares with Texas City Refining. The following information was obtained partially from Marathon correspondence with Radian and partially from EPA Region VI (Ref. 19, 20).

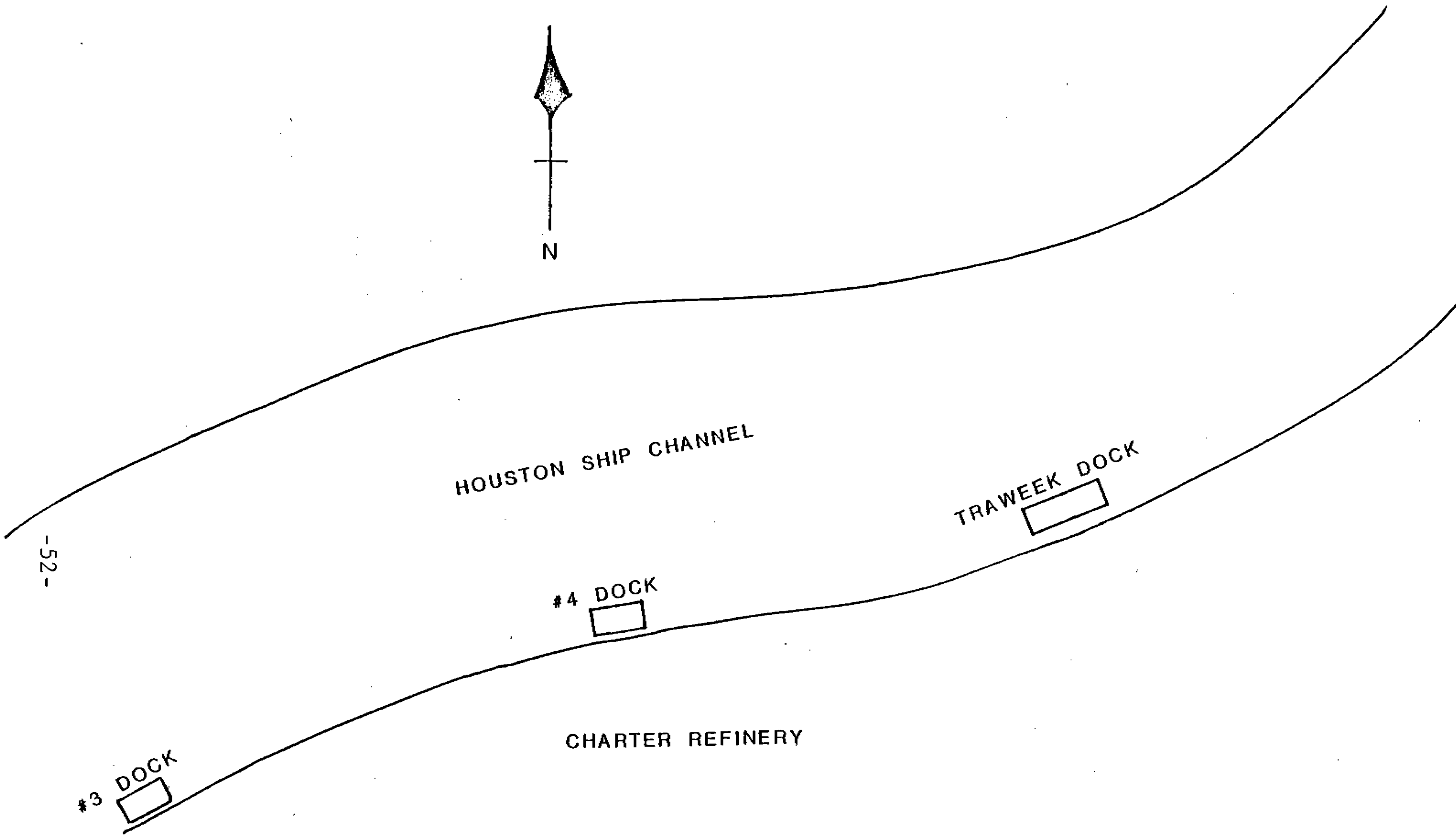


FIGURE 3.2-18
CHARTER OIL HOUSTON REFINERY MARINE TERMINAL

3.2.8.1 Gasoline Loading System

Relatively little information was obtained on the set-up of docks, pumps, and lines used for transferring gasoline from Marathon's refinery to ships and barges at its terminal. It is known, however, that three docks are used for loading gasoline onto marine vessels and that the typical loading rate is 5,500 bph. As mentioned before, all docks except No. 3 can handle both ships and barges. No. 3 handles only barges.

3.2.8.2 Crude Oil Unloading System

As with the gasoline loading system, relatively little information concerning the crude unloading system was obtained. The only information available pertains to Dock 40 which Marathon shares with AMOCO. This dock is dedicated to unloading crude from tankers. The actual unloading rate varies from tanker to tanker depending on the number and size of the vessel pumps.

3.3 Shipside Equipment and Transfer Procedures

This section describes ship and barge equipment used in transferring gasoline or crude oil in the Houston-Galveston area. Typical procedures used to load and unload gasoline and crude oil from marine vessels are also described.

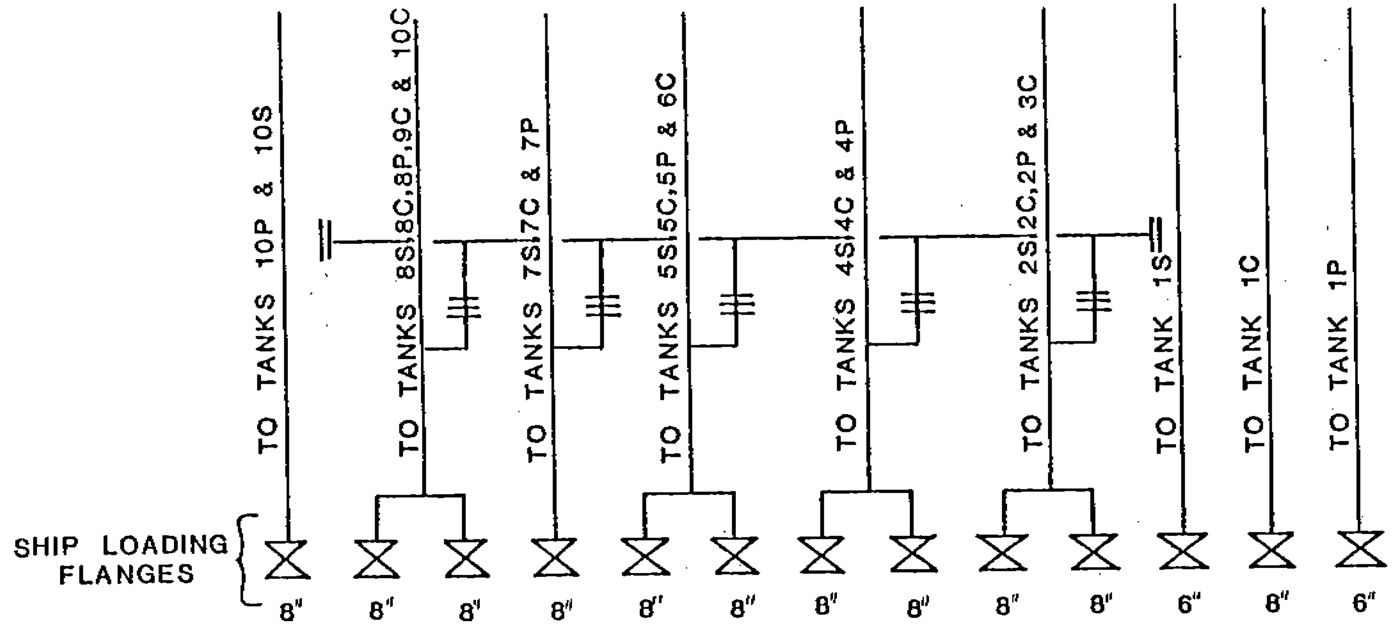
3.3.1 Crude Oil and Gasoline Loading of Ships

In the Houston-Galveston area the loading of crude oil and gasoline involves similar techniques and equipment since the same docks and similar size tankers are involved. The following material relates the typical sequence of steps involved in loading a tanker with gasoline.

This hypothetical case involves a Grade A tanker in dedicated gasoline service from a refinery terminal in the Houston-Galveston area to the East Coast. As the ship nears the refinery dock, it discharges into the Channel the clean ballast water it has onboard. With the help of several tugs it is piloted into position at the dock and made fast to the shore moorings with its heavy docking lines. Crew members and shore personnel next connect the ship's slop line to the shore slop line. Any oily ballast water onboard the ship is pumped through this line to the refinery for treatment before it can be discharged. Depending upon the amount of dirty ballast on board, this operation may take 10 or more hours to complete. Once the deballasting of the cargo tanks is complete, they are stripped, using small stripper lines located in the bottom of each tank. This operation removes the small amount of ballast the larger cargo pumping lines cannot remove.

After the deballasting is finished, cargo loading hoses are used to connect the ship with the shore in preparation for receiving product. A specific loading pattern and loading sequence for the tanks is determined by the ship's officers. Improper loading patterns can cause the vessel to be improperly trimmed or even rupture if the stresses are sufficiently high. A diagram of the ships cargo tanks and the product each will carry is shown in Figure 3.3-1. Flexible hoses will be attached to the proper shore and ship flanges. After each tank has been visually inspected and okayed, the deck officer advises the shoreside operators that the ship is ready to accept cargo. Before the shoreside loading pump is turned on, the product is usually allowed to drain from the shoreside tank through the loading line and into the vessel's tank (or tanks). This is done to insure that flow has been established and that the cargo lineup is correct.

Once verification has been made that the lineup to a tank is correct, the crew advises the shoreside operators to turn on the loading pump. The displaced vapors are usually vented through the ullage cap located atop the cargo tank hatch. The term "ullage" refers to the distance between the cargo liquid level and the rim of the ullage cap. A sketch of a Grade A tanker cargo vent system is shown in Figure 3.3-2. The vapors may be vented out the P/V valve to the stack if the ullage cap is closed. Each cargo tank P/V valve is manually lifted off its seat during the loading operation to insure that a faulty valve does not cause overpressurization of the tank. Periodic checks of the ullage gauges of the tanks are made as they fill with gasoline. Typically, several tanks are being filled at once. Loading may be interrupted from time to time to correct trim on the vessel. For those situations in which three tanks across are being filled simultaneously with the same grade of gasoline, a special loading sequence is usually followed. The level of the center tank and the two wing tanks is allowed to reach an ullage of perhaps 15 to 20 feet. Then the flow to the center tank is shut off and the two wing tanks are brought up, one level slightly behind the other. Usually two to four members of the crew are responsible for bringing the product level up to the final ullage called "topping off". They do this with calibrated sticks about five to six feet long which resemble crosses. These sticks are inserted like a dipstick into the tank from the ullage cap and the ullage read directly from the stick. When the product reaches the desired final ullage the flow to that tank is shut off. Then the other wing tank is topped off soon after. Following this the flow is resumed into the center tank until it is topped off. This procedure is used for safety reasons. The wing tanks have a smaller volume than



10 PORT 4,833 BBLS	8P 11,601 BBLS		7P 5,991 BBLS	5P 11,997 BBLS		4P 5,791 BBLS	2P 11,841 BBLS		1P 6,024 BBLS
10 CENTER 11,026 BBLS	9C 11,047 BBLS	8C 11,075 BBLS	7C 11,103 BBLS	6C 11,131 BBLS	5C 11,158 BBLS	4C 11,131 BBLS	3C 11,103 BBLS	2C 11,047 BBLS	1C 13,736 BBLS
10 STARBOARD 4,833 BBLS	8S 11,601 BBLS		7S 5,991 BBLS	5S 11,997 BBLS		4S 5,971 BBLS	2S 11,841 BBLS		1S 6,024 BBLS

FIGURE 3.3-1

TANK CAPACITIES AND MANIFOLD ARRANGEMENT OF THE S.S. "PASADENA"

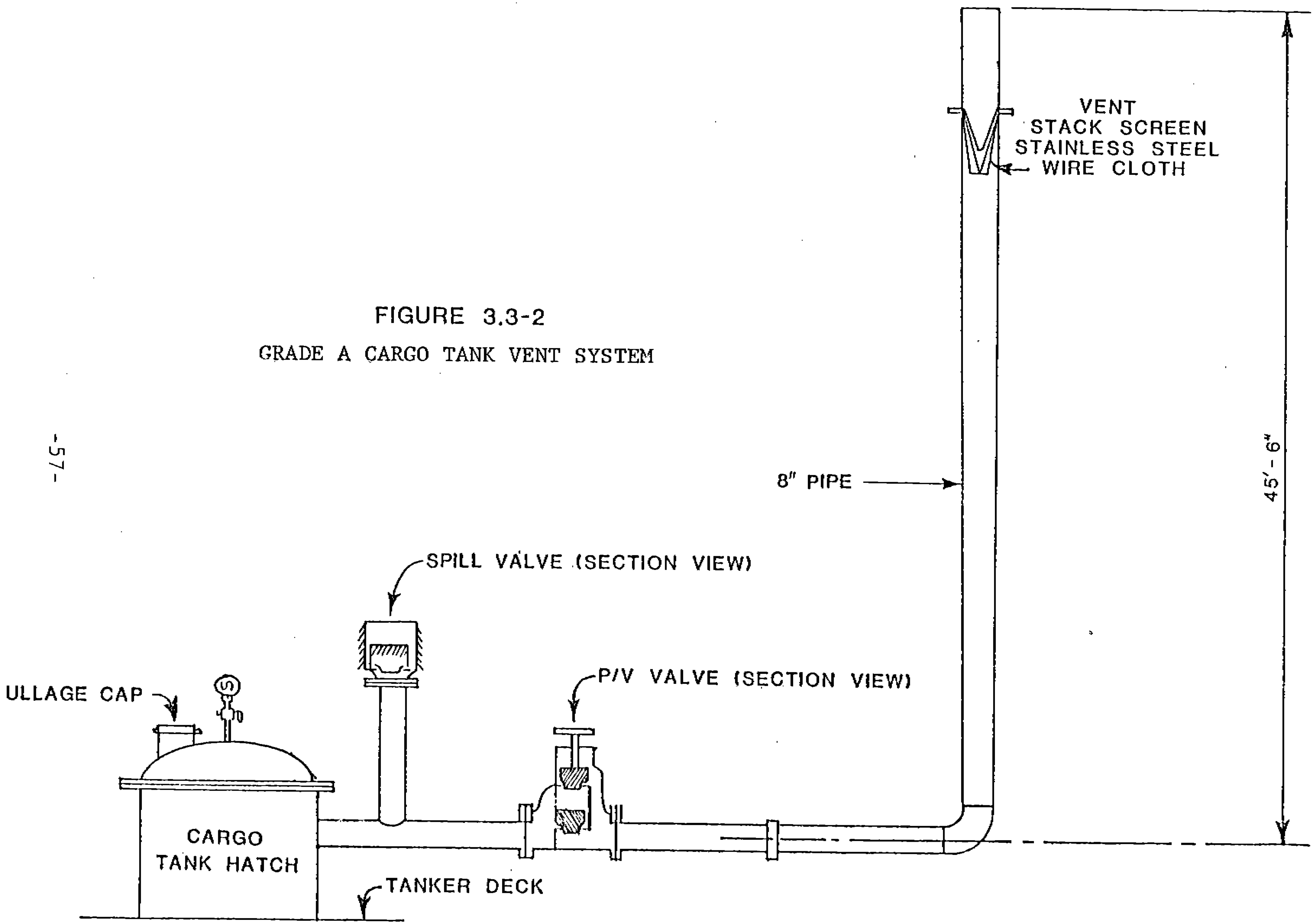


FIGURE 3.3-2

GRADE A CARGO TANK VENT SYSTEM

the center tank. Should any problem occur during the topping off of a wing tank, flow can be quickly and easily diverted into the center tank which has plenty of available space. Another reason for this sequence is that it is more difficult to top off three tanks in a short time than it is to first finish the two wing tanks and then the center.

For the topping off of the final cargo tank loaded with gasoline, the crew keeps in touch with the shoreside operators with walkie-talkies. A crew member notifies the operators the instant they should shut off the loading pumps of that grade of gasoline to complete the product transfer. Then the loading lines are disconnected; the ullage caps are sealed shut; the P/V valves are returned to their operating position; and the crew readies the ship for departure.

3.3.2 Crude Oil and Gasoline Loading Onto Barges

The loading of gasoline onto barges in the Houston-Galveston area is a common practice. However, very little crude oil is loaded onto barges in the area. The loading procedures are similar, however, for the same reasons that loading ships with gasoline and crude oil is similar.

Barges differ from ships in that they do not take on ballast after unloading. Empty barges are returned by tugboat to the terminal where they are to load their next product. Usually no cleaning is performed on the cargo tanks because barges lack cleaning facilities and convenient disposal methods for the cleanings, and for these reasons they remain in a single product service. This is true until it is sent to drydock for repairs.

In this case the barge tanks are cleaned by removing all hydrocarbon vapors so that regularly schedules maintenance on its equipment can be performed. Following this work, the barge would be free to switch cargo service.

For loading gasoline or crude oil the barge is moved into position at the marine dock by a tugboat and then tied up using its mooring ropes. Cargo hoses or hydraulic arms, if they are available, are attached to the barge's cargo loading header and to the shore manifold. A diagram of a barge's tanks and piping is shown on Figure 3.3-3.

The barge is filled in much the same manner as is a ship. Usually, only one person is available to monitor loading operations on the barge, though. Barge tanks require more frequent monitoring because the loading rate is generally higher relative to tank size on barges than on tankers. Topping off is completed in the same manner on barges as on ships. Observations on the product level are made by direct sighting through an ullage cap. The tank ventilation system on barges resembles Grade B cargo tank vent systems. Figure 3.3-4 shows a sketch of this type of ventilation system.

3.3.3 Crude Oil and Gasoline Unloading from Tankers

The unloading of gasoline from tankers rarely, if ever, occurs in the Houston-Galveston area. The unloading of gasoline would be similar to that of crude oil unloading since similar size tankers are involved. Large quantities of crude oil are imported into Houston-Galveston area refineries by tanker. The majority of these ships fly foreign flags. A description of the equipment and the procedure used for unloading crude from tankers follows.

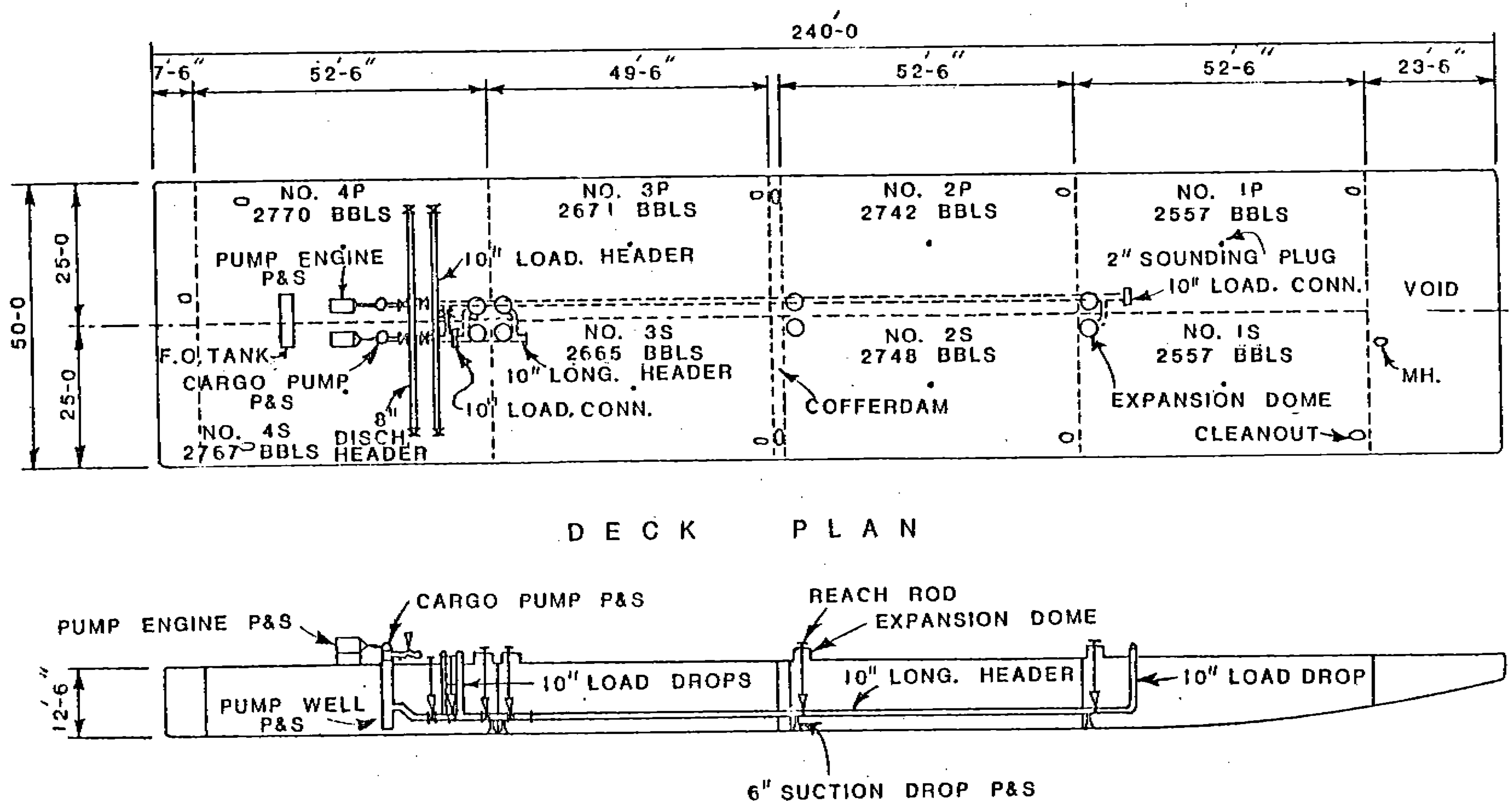


FIGURE 3.3-3 SINGLE SKIN TANK BARGE

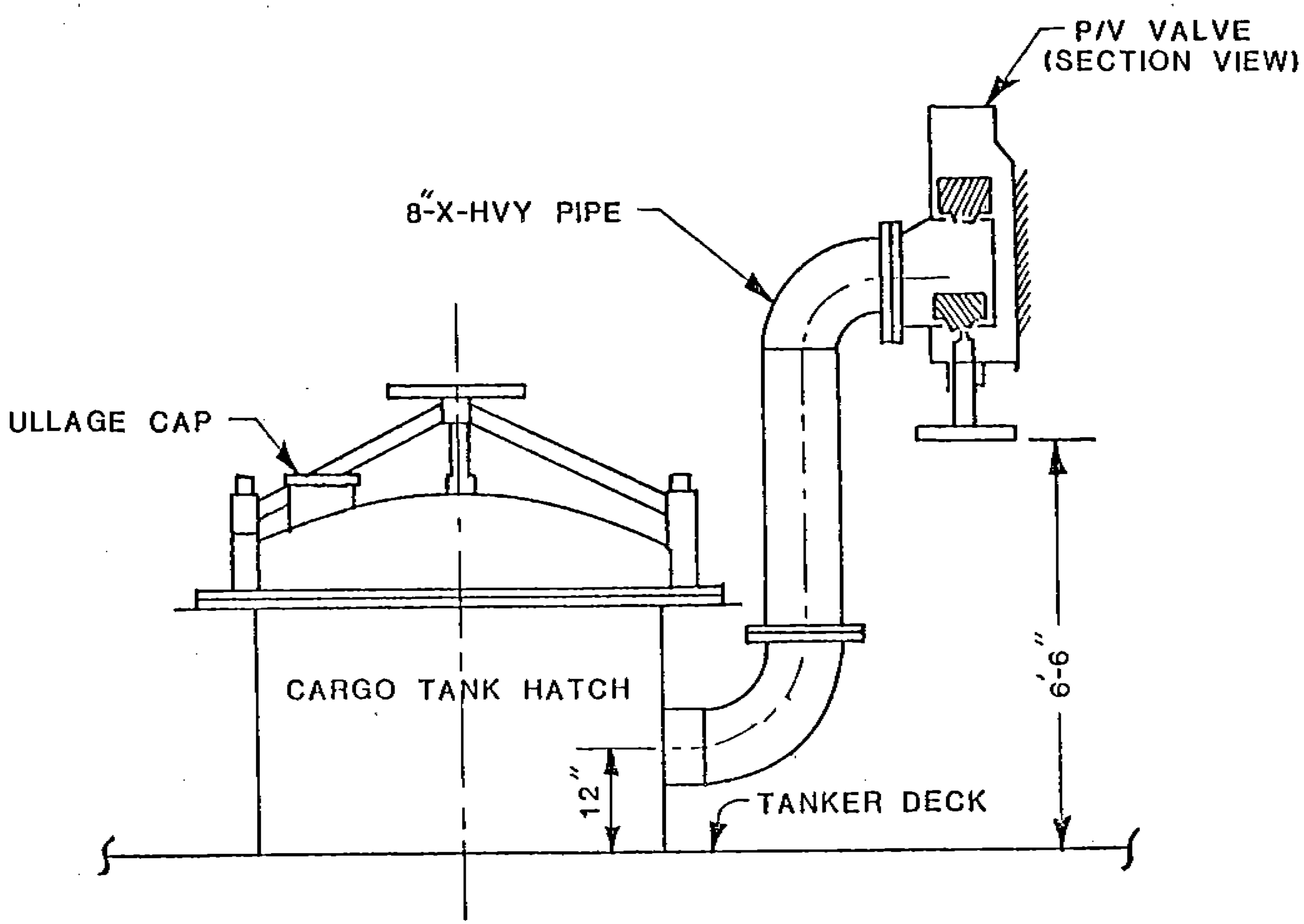


FIGURE 3.3-4 GRADE B CARGO TANK VENT SYSTEM

After the ship is docked at the terminal where it will discharge its load, dock and ship personnel connect the shore and ship manifolds using cargo hoses or hydraulic arms. Then the ship's main cargo pumps are used to discharge the crude. These pumps vary in number and capacity for different tankers. The tanks are unloaded from the bottom, just as they are loaded. During unloading the P/V valves are manually opened and the ullage caps are opened. There are two cargo tank vent systems for tankers. Figure 3.3-2 shows the system for a Grade A ship and Figure 3.3-4 shows the system for a Grade B ship.

Once the main cargo pumps have removed all the oil they can, they are switched off. The smaller stripper pumps and lines are used to remove the remaining crude oil from each tank. This procedure is called stripping. Each cargo tank's strippings are pumped to a designated cargo tank usually located aft. When all the tanks have been stripped, the main cargo pump for the tank holding the strippings is used to pump them ashore. This completes the unloading operation.

Before the tanker departs, however, it must take on some ballast to make it seaworthy. A ballast diagram drawn by one of the ship's officers determines which tanks will be ballasted. The sea valves to these tanks are opened allowing water to flow in. The displaced vapors are vented through the ullage cap and P/V valve which is still open.

Ships reportedly may ballast anywhere from 20 to 40 percent of their cargo capacity before leaving the dock, depending upon the ship officer's orders. Should weather conditions dictate it, more ballast may be taken on while the ship is at sea. The level of ballast in those tanks ballasted is usually brought up fairly high to minimize the danger of the ship's developing severe rolling in bad weather due to the sloshing of the ballast in its tanks.

Assuming all ballasting is done in port, after it is completed, the ullage caps are closed; the P/V valves are returned to their normal position; and the ship readies for departure.

3.4 Quantities of Crude Oil and Gasoline Transferred in the Houston-Galveston Area

This section provides monthly information concerning the quantities of crude oil and gasoline transferred at marine terminals in the Houston-Galveston area. In all but one case the information was obtained directly from those oil companies in the area transferring either crude oil or gasoline or both to marine vessels. Estimates from the Texas Air Control Board were used for the terminal owned by Amerada Hess. The list of companies is not complete since a few of the small terminal operators in the area did not provide data on their transfers. However, their totals are practicably insignificant compared to the larger terminals (Ref. 3,6,10,11,15,19,23,25).

A summary of the quantity of gasoline (motor and aviation) loaded at marine terminals in the Houston-Galveston area is presented in Table 3.4-1. Assuming that Charter Oil and Amerada Hess loaded approximately the same amount of gasoline in 1975 as in 1974, then the total amount loaded for the area is roughly 82.5 million barrels for 1975. Table 3.4-2 shows the variation of the Reid Vapor Pressure (RVP) of the gasoline loaded at the terminals by month for 1975.

Table 3.4-3 presents data on the amount of crude oil loaded in the Houston-Galveston area; Exxon in Baytown was the only terminal located which loaded crude oil. In 1975 Exxon loaded about 7.5 million barrels of crude.

TABLE 3.4-1

QUANTITY OF GASOLINE LOADED AT MARINE TERMINALS IN

THE HOUSTON - GALVESTON AREA

Marine Terminal	Year	Quantity Loaded (10^3 bbls)												
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Exxon	1975	2,739	1,737	2,777	2,445	2,815	2,946	3,583	3,274	2,910	3,129	2,456	2,721	33,534
Shell	1975	1,575	1,033	862	1,843	1,094	1,757	1,519	1,669	1,367	1,368	1,363	1,145	16,594
AMOCO	1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	19,560
Marathon	1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8,328
Texas City Ref.	1975	274	476	80	306	582	499	479	304	69	143	511	270	3,993
ARCO	1975	184	271	679	1,021	247	389	65	427	278	318	22	32	3,933
Charter	1974	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	410
Amerado Hess	1974	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2,595

NA - Not Available

TABLE 3.4-2

REID VAPOR PRESSURE OF GASOLINES LOADED AT MARINE TERMINALS IN THE HOUSTON-GALVESTON AREA

Marine Terminal	RVP (psi)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Exxon	14.1	12.4	11.6	11.0	10.5	10.0	10.1	10.3	11.0	12.3	13.2	13.2
AMOCO	13.1	13.1	13.1	10.1	10.1	10.1	10.1	10.1	10.1	13.1	13.1	13.1
Shell	12.9	13.1	12.6	10.8	10.4	10.0	9.8	9.7	10.1	11.4	12.9	13.0
Marathon	11.5	11.5	11.5	9.5	9.5	9.5	9.5	9.5	9.5	11.5	11.5	11.5
ARCO	10.8	11.1	10.4	9.9	9.4	9.5	9.5	9.3	9.4	10.1	11.2	11.7
Texas City Ref.	14.5	14.5	12.5	12.5	12.5	11.5	11.5	11.5	12.5	12.5	12.5	14.5
Amerada Hess	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Charter	11.0	11.0	11.0	9.0	9.0	9.0	9.0	9.0	9.0	11.0	11.0	11.0

NA - Not Available

TABLE 3.4-3

QUANTITY OF CRUDE OIL LOADED AT MARINE TERMINALS

IN THE HOUSTON-GALVESTON AREA

Marine Terminal	Year	Quantity Loaded (10^3bbls)												
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Exxon	1975	0	0	649	1,773	1,363	773	0	304	645	1,070	346	554	7,477

Table 3.4-4 lists the marine terminals which unloaded crude oil in 1975 along with the monthly and yearly quantities unloaded. Although this list down not include all of the marine importers of crude oil in the area, it accounts for over 90 percent of the crude oil imported by tanker/barge. The total crude oil unloaded as shown in Table 3.4-4 for 1975 is roughly 160 million barrels. The average RVP of this crude is listed by marine terminal in Table 3.4-5.

3.5 Projected Quantities of Crude Oil and Gasoline Transferred in the Houston-Galveston Area Through 1985

This section presents projections of the quantities of crude oil and gasoline to be loaded and unloaded at marine terminals in the Houston-Galveston area through the year 1985. Data was obtained from those refineries located in the area which transfer crude oil or gasoline (Rev. 3,6,15,19,23,25).

Projections presented in Table 3.5-1 of the quantities of gasoline to be loaded for each year through 1985 are those made by the owners of the marine terminals.

Table 3.5-2 presents projections of the amounts of crude oil to be loaded at marine terminals in the area through 1985.

Table 3.5-3 presents the projected quantities of crude oil to be unloaded at marine terminals through 1985.

TABLE 3.4-4

QUANTITY OF CRUDE OIL UNLOADED AT MARINE TERMINALS IN THE HOUSTON-GALVESTON AREA

Marine Terminal	Year	Quantity (10^3 bbls) Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Exxon	1975	3,997	4,286	1,942	2,749	1,980	2,767	3,445	4,791	3,347	4,196	5,380	5,012	42,892
AMOCO	1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	37,330
Shell	1975	3,195	2,040	1,690	1,310	871	347	1,751	2,465	2,763	2,890	2,497	2,516	24,335
ARCO	1975	1,289	666	1,003	1,576	1,990	1,289	1,758	1,492	1,475	1,134	1,353	1,277	16,302
Marathon	1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10,210
Texas City Ref.	1975	1,358	992	916	1,303	1,421	1,223	1,123	1,439	750	1,182	1,270	1,386	14,364
Charter		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Crown		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	15,000

NA - Not Available

ND - No Data

TABLE 3.4-5
AVERAGE RVP OF CRUDE OIL UNLOADED
AT MARINE TERMINALS IN THE
HOUSTON-GALVESTON AREA

Marine Terminal	Average RVP
Exxon	4.4
AMOCO	4.0
Shell	5.1
ARCO	3.8
Marathon	2.0
Texas City Ref.	ND
Charter	ND
Crown	3.7

ND - No Data

TABLE 3.5-1

PROJECTED QUANTITIES OF GASOLINE TO BE LOADED AT MARINE TERMINALS IN THE HOUSTON-GALVESTON AREA THROUGH 1985

	Quantity (10^3bbl)									
Terminal	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Exxon		45,625	31,025	32,850	36,500	ND	ND	ND	ND	36,500
AMOCO	19,560	19,560	19,560	19,560	19,560	19,560	19,560	19,560	19,560	19,560
Shell	16,590	16,590	16,590	16,590	16,590	16,590	16,590	16,590	16,590	16,590
Marathon	8,330	8,330	8,330	8,330	8,330	8,330	8,330	8,330	8,330	8,330
Texas City Ref.	3,600	3,850	4,300	4,650	4,950	5,250	5,550	5,875	5,875	5,875
ARCO	500	0	0	0	0	0	0	0	0	0

ND - No Data

TABLE 3.5-2

PROJECTED QUANTITIES OF CRUDE OIL LOADED

AT MARINE TERMINALS IN THE HOUSTON-GALVESTON AREA THROUGH 1985

	Quantity (10^3bbl)								
Terminal	1977	1978	1979	1980	1981	1982	1983	1984	1985
Exxon	1,825	0	0	9,125	ND	ND	ND	ND	0

ND - No Data

TABLE 3.5-3

PROJECTED QUANTITIES OF CRUDE OIL UNLOADED AT MARINE TERMINALS IN THE HOUSTON-GALVESTON AREA THROUGH 1985

Terminal	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Exxon		105,850	116,800	127,750	80,300[1]	ND	ND	ND	ND	18,250[1]
AMOCO	73,000	73,000	73,000	73,000	73,000	73,000	73,000	73,000	73,000	73,000
Shell	36,500	58,400	65,700	73,000	7,300[2]	10,950[2]	10,950[2]	10,950[2]	14,600[2]	14,600[2]
ARCO	25,000	53,000	47,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
Marathon	10,210	10,210	10,210	10,210	10,210	10,210	10,210	10,210	10,210	10,210
Texas City Ref.	20,100	20,300	27,000	31,600	33,000	33,200	35,600	37,000	37,000	37,000

[1] Assuming Seadock is built

[2] Assuming Seadock is built. However, if not, the quantities will be 76,650; 80,300; 80,300; 80,300; 83,950; and 83,950 for the years 1980, 1981, 1982, 1983, 1984, and 1985 respectively. Quantities in 10^3bbls.

3.6 Cruise History Information for Ships and Barges Which Transferred Crude Oil or Gasoline in the Houston-Galveston Area during 1975

The loading of gasoline or crude oil into cargo tank compartments of marine vessels displaces air which contains varying concentrations of hydrocarbons. Two factors contribute to the total emission of hydrocarbons from the vessel's tanks. One of these is termed the "arrival" component. This portion of the loss is attributed to the hydrocarbons which are present in the vessel's empty cargo compartments from its prior voyage. The other portion is termed the "generated" component, originating from the hydrocarbons which evaporate from the surface of the liquid being loaded.

The hydrocarbon concentration in the arrival component is a function of the prior cruise history of the vessel being loaded and, depending upon the vessel's prior cruise, this component may or may not contribute significantly to the overall loading emission.

This section presents information concerning cruise histories of the marine vessels which transported crude oil and gasoline to and from the Houston-Galveston area. The effects of a vessel's cruise history upon its arrival hydrocarbon concentration are investigated. Descriptions of the types of marine vessels used to transport crude oil and gasoline in the area are given. Also, vessels which service the various refineries in the area are identified. Finally, a breakdown of the emissions which occur during each portion of a vessel's journey in transporting gasoline, and a specific analysis of the tank arrival conditions and associated hydrocarbon concentrations as a function of cruise history are presented for the Houston-Galveston area.

3.6.1 Effects of Cruise History on Hydrocarbon Emissions from Marine Loading of Gasoline and Crude Oil

The results of Radian's sampling study verified the fact that a vessel's cruise history has a significant effect on its emissions from loading gasoline. The differences in average arrival hydrocarbon concentrations ranged from less than 1 percent for tanks which had been cleaned to over 20 percent for uncleaned tanks. Ballasted tanks generally showed arrival concentrations averaging less than 10 percent for a limited number of tests.

Industry data supports the trends observed during the Radian sampling study. A program was conducted in 1975 by Exxon at their Baytown refinery which provided the most comprehensive information to date on ship and barge cruise history (Ref.15). The primary objective of the Exxon study was to develop accurate emission factors for the loading of gasoline onto marine vessels. Data was collected on the arrival condition and prior cruise history of each tank sampled. From this data three categories based on the cruise history of the tank were established for cargo tank arrival hydrocarbon concentrations. Exxon discovered that defining hydrocarbon emission estimates on these categories improved the accoracy of the predictions. For tankers, the categories were defined as follows:

- Cleaned - Cargo tanks which had been cleaned in some manner during the previous trip or tanks which had previously carried nonvolatile products.

- Dirty ballasted - Tanks which arrived containing dirty ballast.

- Empty and undisturbed - Tanks which had contained gasoline on the previous voyage and arrived empty and undisturbed.

Table 3.6-1 shows the range of values Exxon measured within each category. The results shown in Table 3.6-1 are based on data taken on 70 ship tanks. These results reflect Exxon's test results and may vary from other company averages due to different ship operation characteristics. The reasons for the range of values within a category are differences in 1) the amount and volatility of the previous product left in the tank after unloading, 2) the type and extent of cleaning used during the return voyage, and 3) the fraction of the tank used for ballast.

TABLE 3.6-1

EFFECT OF SHIP CRUISE HISTORY ON ARRIVAL HYDROCARBON CONCENTRATION PRIOR TO GASOLINE LOADING

Tank Arrival Condition	Average Arrival HC Concentration (Vol %)	Typical Range of Arrival HC Concentration (Vol %)
Cleaned	2.5	0 - 5.0
Dirty Ballasted	5.0	2.0 - 8.0
Empty and Undisturbed	8.0	2.5 -13.5

Contacts made by Radian with marine industry personnel concerning the arrival condition of intercoastal barges indicated that the barges usually arrive with empty and undisturbed tanks. This is because barges do not take on ballast, and the lack of available manpower onboard prevents cleaning of the cargo tanks. Exxon's study confirmed this observation. They found that all barges sampled at their docks arrived with empty, uncleaned tanks.

3.6.2 Types of Marine Vessels Used in Transferring Crude Oil and Gasoline in the Houston-Galveston Area

There are three distinct classes of vessels used for transporting crude oil or gasoline into and out of the Houston-Galveston area. The most common is the marine tanker. The other two are the intercoastal barge, and the oceangoing integrated tug-barge.

3.6.2.1 Marine Tankers

Marine tankers transport over 90 percent of the gasoline and crude oil shipped in the Houston-Galveston area. They vary in capacity from around 20,000 Dead Weight Tons (DWT) to over 75,000 DWT. The Ship Channel's depth of 40 feet limits their size due to their draft requirements. No data was obtained on whether or not any tankers are lightered in the Houston-Galveston area. Lightering could effect emissions because cargo is transferred from a large tanker to a barge or smaller tanker outside of the port for transport into terminals in the area.

The number of cargo tanks and their capacities are dependent upon the individual ship design, size and service. The smaller tankers may have as many tanks as those ships with capacities 2 to 3 times greater. Clean product tankers generally have from 24 to 33 tanks on board, but crude oil tankers have about half that many, generally. The tank capacities may range from 5,000 to 10,000 barrels for the smaller tankers and from 5,000 to over 30,000 barrels for the larger tankers. Tank depths vary from about 40 feet for the smaller tankers to over 55 feet for the larger ones.

3.6.2.2 Intercoastal Barge

The intercoastal barge is a relatively small vessel used for transferring gasoline and crude oil over the inland waterways. Their capacity is usually around 20,000 barrels and they typically have 8 to 10 cargo compartments of approximately equal size. Barges are commonly transported in pairs by tug boats. Tank depths for barges generally vary from 10 to 12 feet.

3.6.2.3 Ocean Barge

The ocean barge is a large vessel designed to be integrated with a tug for power. The ocean barges are few in number. Their DWT capacity is in the range of that for average size tankers, but they typically have fewer cargo tanks. Tank depths are usually shallower than that for tankers, ranging from 30 to 40 feet.

3.6.3 Vessels Servicing Houston-Galveston Marine Terminals

Most of the marine terminals in the Houston-Galveston area utilize ships, intercoastal barges, and ocean barges for their marine shipments of gasoline. Crude oil is received primarily by ship with a small amount entering by barge. Very little, if any, gasoline is imported by marine vessel into the Houston-Galveston area. The crude oil which is loaded in the area is transported in tankers.

Appendix I contains information supplied by owners of the larger marine terminals in the Houston-Galveston area concerning the marine tankers which visited their docks to transfer crude oil or gasoline. The responses were not consistent with respect to the type of information presented. Data on vessel names, DWT, ownership, service, quantity loaded in 1975, number of cargo tanks, and number of visits in 1975 were obtained in different responses.

Very little information was obtained on the specific barges that transferred gasoline and crude oil in 1975 in the Houston-Galveston area.

The following discussions summarize by company the data presented in Appendix I.

Exxon Terminal

Almost all of the crude oil unloaded at the Exxon Baytown marine terminal was transported by marine tanker. Less than one percent of the crude was imported by barge. Forty-four of the fifty ships which transported crude oil into the terminal were foreign, four were Exxon ships, and two had unknown owership. Their capacities ranged from 20,000 DWT to 78,000 DWT. Average size was about 50,000 DWT (Ref. 15).

Of the ships loading gasoline at the Exxon terminal, ten were owned by Exxon, and twenty-two were owned by some other U.S. shipping company. The Exxon ships loaded about 74 percent of the gasoline, while the other tankers loaded about 7 percent. Barges loaded the remaining 19 percent. All Exxon ships were in mul tiple service.

Four Exxon-owned ships were used for transporting the crude oil that was loaded at the Baytown terminal.

No data was obtained on the specific barges that transferred crude oil and gasoline at the Baytown refinery.

Shell Terminal

The majority of the gasoline which was loaded onto ships in 1975 was transported by U.S. tankers under long-term charter to Shell Oil Company. Because Shell Oil is not a U.S. company, it cannot own the ships it uses for transporting products from its Deer Park facility. Under the Jones Act, vessels engaged in transporting goods between U.S. ports must be under U.S. registry. A vessel cannot be under U.W. registry unless it is owned by a U.S. citizen or company. All of the tankers transporting gasoline from the Deer Park terminal carry other products such as fuel oil and heating oil as well. The sizes of these tankers range from 20,000 DWT to about 45,000 DWT (Rev. 23).

Very little information was presented on the ships which unload crude oil at Shell's refinery in Deer Park.

AMOCO Terminal

In 1975 fifteen tankers loaded the gasoline transported from AMOCO's Texas City refinery. Three ships were owned by AMOCO, and twelve were owned by other U.S. corporations. The bulk of the gasoline transported by tanker was handled by the three AMOCO ships. Also, three ocean-going barges and sixteen intercoastal barges loaded gasoline at the AMOCO terminal in 1975. None of the barges were owned by AMOCO.

A total of thirty-one ships called at AMOCO's terminal to unload crude oil in 1975. Most of them made more than one trip to the terminal during the year. Twenty-seven tankers were foreign-owned, and the other four were U.S. company owned.

ARCO Terminal

Eight tankers were used to load gasoline at ARCO's terminal in 1975. Three of these ships were owned or company chartered by ARCO, two were time or trip chartered, and the remaining three were not controlled at all by ARCO. Also, nine intercoastal barges loaded gasoline at the terminal in 1975. Only one was owned by ARCO.

A total of twenty-four tankers were used to transport crude oil to the refinery terminal in 1975. Three of these were owned or company chartered by ARCO (Ref. 6).

3.6.4 Hydrocarbon Emissions From a Gasoline Tanker Cruise

This section presents estimates of the hydrocarbons emitted from a hypothetical cruise of a tanker transporting gasoline. Estimates for the loading, unloading, and transit losses are calculated. The selection of conditions for the cruise, material transferred, and size of the tanker is based upon operations observed by Radian to be typical of the marine transport industry in the Houston-Galveston area.

The length of time for a round trip cruise was chosen as twelve days: 1 day (24 hours) for loading, 5 days for a one way trip, 1 day for unloading, and 5 days for the return cruise. This length of time is typical for a tanker travelling to the East Coast from Houston, Texas. A 50,000 DWT capacity ship was chosen as typical. The ship is to be transporting 350,000 barrels of motor gasoline with an RVP of 10.0 as a typical cargo.

Loading Loss

For this case the emission factor used to calculate the loading loss is 1.2 pounds per 1000 gallons of gasoline loaded. The factor is taken from Table 4.2-2 in this report and its origin is discussed in Section 4.2. It represents the statistical average factor for a ship loading gasoline in the Houston-Galveston area. Based on the quantity loaded, the loading emission is 18,000 pounds.

Transit Loss

The ship is in transit with a full cargo load for a period of five days. Using the estimate in the EPA's Compilation of Air Pollution Emission Factors for marine vessel transit loss, the emission can be estimated. The factor is 3.6 pounds of hydrocarbon per week per 1000 gallons transported. Based on this factor the transit loss is 53,000 pounds. This factor originated from API Bulletin Number 2514 published in 1959 and it is based on a limited amount of data. API states that the transit loss is significant but more data is needed to verify this.

Unloading Loss

Following the discharge of its gasoline cargo, the ship must take on ballast to make it seaworthy. A typical quantity of ballast taken on for ships is 25 percent of its cargo capacity. The ballasting operation displaces the vapors which have evaporated into each tank during cargo unloading. Preliminary data reported in Section 4.2 on ballasting losses show the emission factor for crude oil ships to be in the range of 1 to 2 pounds per thousand gallons of ballast. Using a conservative factor of 1.0 pounds per thousand gallons of ballast for this gasoline ship's ballasting operation, the unloading loss is 4,000 pounds of hydrocarbon.

Return Transit Loss

On the return trip several operations may occur which could cause significant hydrocarbon emissions. These include: 1) leaving cargo tank hatches open to the atmosphere; 2) reballasting, which involves discharging the dirty ballast and taking on clean ballast; 3) tank "breathing losses"; and 4) tank cleaning operations such as gas-freeing. No data is available to allow the potential emissions to be calculated, but they could be significant.

Conclusion

Although limited information is available to confirm the emissions discussed above, a single gasoline ship cruise may emit over 75,000 pounds of hydrocarbons. The major contributor to this total is the transit loss with the return transit loss being potentially significant.

3.6.5 Analysis of Tank Arrival Conditions for Vessels Loading Gasoline and Crude Oil in the Houston-Galveston Area

In Section 3.6.1 an Exxon study was discussed concerning the effect of vessel cruise history upon arrival hydrocarbon concentration. The result of the study is presented in Table 3.6-2.

The results show that all of the intercoastal barges which load gasoline arrive with tanks that are empty and undisturbed. They also show that 45 percent of the tanker volume loading gasoline enters cleaned, 10 percent ballasted, and 45 percent empty and undisturbed. For ships loading crude oil, 25 percent of the tanker volume enters clean and 75 percent enters empty and undisturbed. The Exxon results for crude oil loading onto ships are not based on as much information as are the gasoline loading results.

While this breakdown should be a reasonable representation of Exxon loading conditions it is not necessarily the case for all the other refineries in the Houston-Galveston area which load gasoline. At least two exceptions are Shell Oil in Deer Park and ARCO in Houston. Not enough data is available on the other companies in the area to draw firm conclusions on arrival conditions. Shell Oil is different in that its ships often arrive with all tanks cleaned so that if a last minute product loading change is made, the ship will be ready to accept any cargo. ARCO on the other hand, usually loads gasoline into ship holds which are essentially vapor free because they previously carried a low-volatile product. ARCO loads only small quantities of gasoline by tanker, thus back-to-back gasoline service by a tanker is rare.

TABLE 3.6-2

EMISSION FACTORS FOR GASOLINE AND CRUDE OIL LOADING BY TANK ARRIVAL CONDITION

Vessel Type	Arrival Condition	Percent of Vessel Volumes Observed with Tank Arrival Condition
Intercoastal Barge-Gasoline TVP=6.0psia	Empty and Undisturbed	100%
Ship-Gasoline TVP=6.0psia	Cleaned	45
	Ballasted	10
	Empty and Undisturbed	45
Ship-Crude Oil TVP=4.5psia	Cleaned	25
	Ballasted	0
	Empty and Undisturbed	75

Therefore, it appears as though the results for the Exxon study when applied to the entire Houston-Galveston area may slightly overestimate the emissions from gasoline loading.

3.7 Marine Terminals Transferring Crude Oil and Gasoline In the Metropolitan Los Angeles Area

This section discusses the types of marine terminals located in the Metropolitan Los Angeles AQCR which transfer crude oil and/or gasoline. The objectives of the section are to present sufficient information on the marine terminals to assess their impact on hydrocarbon emissions in the Southern California area, and to compare the marine terminal operations in the Houston-Galveston area to the Southern California operations. The objectives were accomplished by gathering information on Southern California operations from refulatory agency contacts, literature, and on-site visits. The results of the Southern California study are presented in the following sections.

3.7.1 Background Information On Marine Terminals Transferring Crude Oil and Gasoline in the Southern California Area

There are eighteen identified marine terminals in the Metropolitan Los Angeles Intrastate AQCR which transferred crude oil and/or motor gasoline in 1975 (Rev. 7). Of the nine terminals which load or unload motor gasoline all but one of them are located near Los Angeles. Table 3.7-1 presents a breakdown of the marine terminals located in the three counties in the Los Angeles AQCR and the number of terminals transferring crude oil and/or gasoline. Table 3.7-1 shows that several of the terminals in the Los Angeles area load and unload both gasoline and crude oil. There are a total of 12 terminals in Los Angeles County, 4 in Santa Barbara County, and 2 in Ventura County which transfer crude oil and/or gasoline. The following sections discuss the similarities and differences in the shoreside equipment and transfer procedures

TABLE 3.7-1

MARINE TERMINALS TRANSFERRING CRUDE OIL OR GASOLINE IN THE METROPOLITAN LOS ANGELES AQCR

County	Number of Terminals Transferring Crude Oil and/or Gasoline	Gasoline		Crude Oil	
		No. of Terminals Loading Gasoline	No. of Terminals Unloading Gasoline	No. of Terminals Loading Crude Oil	Number of Terminals Unloading Crude Oil
Los Angeles	12	8	8	5	12
Santa Barbara	4	0	1	3	0
Ventura	2	0	0	2	0

Source: Ref. 7,17,22.

between Los Angeles AQCR terminals and Houston-Galveston AQCR terminals.

3.7.1.1 Shoreside Equipment And Transfer Procedures-Gasoline

The equipment and transfer procedures used for gasoline loading and unloading at terminals in the LA AQCR are similar to those found in the Houston-Galveston AQCR. Inspection by Radian of three refinery associated terminals provided most of the information for this section. The facilities for transferring gasoline at the terminals inspected is similar to the equipment typically found at Houston terminals. The docks are constructed of concrete, and two of the three terminals inspected were equipped with metal hydraulic loading arms.

Gasoline loading rates at the LA terminals are approximately the same as for the Houston terminals. The average loading rate for gasoline at two of the terminals toured was about 10,000 bph. For the other terminal the average gasoline loading rate was 3,000 bph. No information was obtained for the unloading rate of gasoline. However, the unloading rate for gasoline from tankers is dependent primarily upon the ship cargo pump capacity, and the capacity of the ship to shore connector. Larger tankers with high capacity pumps are capable of unloading at average rates of up to 40,000 bph. Smaller tankers (20,000-30,000 DWT) may unload at average rates of only 10,000 to 15,000 bph. Specific information on individual ship to shore connector capacities for the LA terminals was not obtained.

3.7.1.2 Shoreside Equipment and Transfer Procedures - Crude Oil

Important differences exist between the Los Angeles AQCR and the Houston AQCR in relation to the loading and unloading of crude oil at marine terminals. There are basically two types of terminals transferring crude oil in the LA AQCR. The onshore terminal whose equipment and operational procedures are similar to those observed in the Houston AQCR. The other is the offshore terminal which is significantly different in terms of equipment, operational procedures, and emission control alternatives.

The onshore terminals which transfer crude oil are operated much the same as the ones in the Houston AQCR. Several of the terminals are dedicated solely to transferring crude oil. The terminals which are proposed to handle the Alaskan crude oil are discussed in a separate section, Section 3.7.4.

The offshore terminals in the LA AQCR evolved because of the deep waters which exist close to land. This affords ships easy access to much of the coast in the LA AQCR.

The terminals consist of four or five buoys firmly anchored to the ocean floor and an underwater pipeline from a shore storage facility to the buoy area. With the aid of a tugboat the tanker will move to the anchored bouys and then hoist the flexible free end of the transfer line up to the ship deck where it is connected to the cargo tank manifolding. Figure 3.7-1 illustrates a typical offshore terminal. After the transfer line is connected, the crude oil or gasoline is either loaded onto or unloaded from the ship.

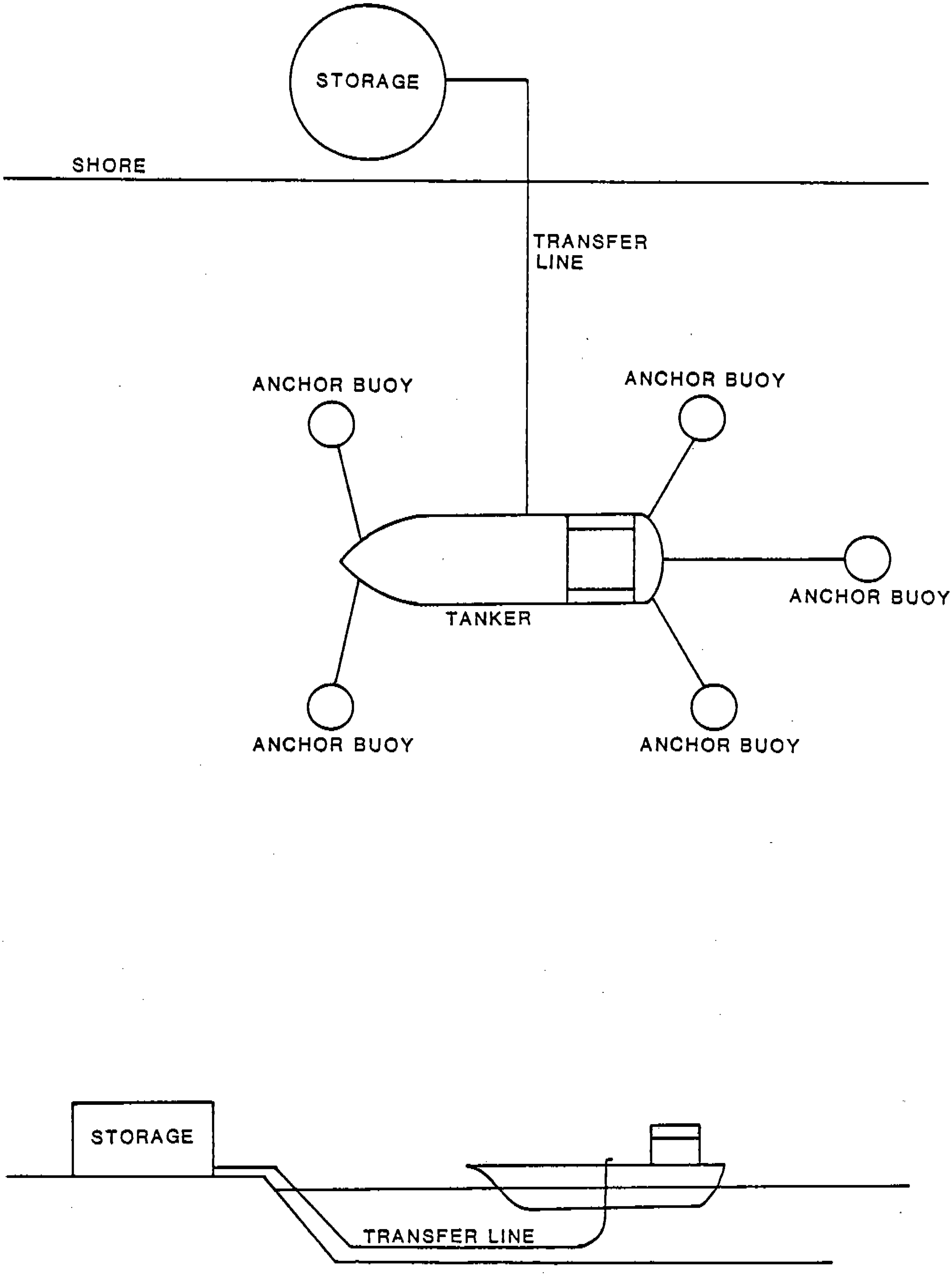


FIGURE 3.7-1. OFFSHORE TERMINAL

Because of the lack of a platform or support structure, the offshore terminal poses a problem in its potential for hydrocarbon emission control by vapor recovery systems. Insufficient space and safety considerations hamper installation of a system onboard the ship itself. Instead, emission control alternatives would be procedure or process modification types. For loading operations these may include prior tank cleaning, slow initial fill rate, and light loading of the cargo. For unloading and subsequent ballasting, an alternative for ships which must ballast would be requiring the vessel to take on minimum ballast at the terminal and finish ballasting when farther out at sea. Alternatives to the above options would be the construction of a platform to support control equipment or the construction of pipelines to markets, either of which would be very expensive.

3.7.2 Shipside Equipment and Transfer Procedures For The Los Angeles AQCR

General information was obtained on the shipside equipment and transfer procedures for vessels transferring crude oil and gasoline in the Los Angeles AQCR. The information indicated that, for the most part, the equipment and transfer procedures for the vessels servicing this area are similar to that seen in Houston-Galveston. There are two exceptions. First, the information suggests that very little gasoline and no crude oil are transported via barge. Presumably this is because of the lack of navigable intercoastal canals and rivers in California. The second exception noted was the closed loading technique used by all the ships owned by one oil company. Evidently, company policy prevents any vapors from being displaced at deck levels during loading of a liquid cargo. All tanks are close loaded with the displaced vapors being vented at a mast height roughly forty to fifty feet above deck level. Cargo tank level minitors are used during loading.

No visual inspection of the tank level occurs throughout loading unless there is a problem.

Some information on cruise history of tankers loading gasoline in the Los Angeles AQCR was obtained. It indicated that the tankers usually transport the gasoline to the Washington-Oregon region and occasionally to the San Francisco Bay Area. This is a shorter distance than that travelled by the tankers leaving the H-G AQCR with gasoline. Their destination is often the East Coast which may be two to three times further than the distance from LA to the Washington or Oregon ports. Also, the available information indicated that tankers load gasoline less frequently at LA terminals than at H-G terminals. This is a result of the larger quantity of gasoline (approximately 10 times larger) loaded in the H-G area than in the LA area. Thus, tankers in the LA AQCR loading gasoline are less likely to carry back-to-back gasoline loads, an occurence often seen in the H-G area at the more active terminals. This difference could effectively reduce hydrocarbon emissions from the loading of gasoline into tankers in the LA AQCR, assuming low volatility products such as fuel oil or heating oil are carried on the trips the tankers make between gasoline service. See Table 4.2-2 and the discussion in Section 4.1.4 on the effects of cruise history on emissions.

3.7.3 Quantities of Crude Oil and Gasoline Transferred In The Los Angeles AQCR

Data were obtained on the quantity of crude oil and gasoline transferred at marine terminals in the Los Angeles AQCR for the year 1975. The information was obtained from the Southern California APCD for Los Angeles County, from the Ventura County APCD for Ventura County, and from the Santa Barbara County APCD for Santa Barbara County (Ref. 7,17,22).

Tables 3.7-2 through 3.7-5 summarize estimates of the quantities of gasoline and crude oil loaded and unloaded in the Los Angeles AQCR. Table 3.7-2 presents the quantity of gasoline loaded by county. It shows that a total of 8,912,000 barrels of motor gasoline were loaded onto marine vessels in the LA AQCR in 1975. Table 3.7-3 shows that 15,650,000 barrels of motor gasoline were unloaded at marine terminals in the LA AQCR. Tables 3.7-4 shows that 17,950,000 barrels of crude oil were loaded onto ships in 1975 in the LA AQCR and Table 3.7-5 shows that 177,318,000 barrels of crude oil were unloaded from ships in 1975.

Information on the projections of the Alaskan crude oil unloaded from ships in the LA AQCR is discussed in the following section.

3.7.4 Projected Unloading of Alaskan Crude Oil In The Los Angeles AQCR

This section presents information on the variables affecting the hydrocarbon emissions from the potential unloading of Alaskan North Slope crude oil in the Metropolitan Los Angeles Intrastate AQCR in the future. Data were obtained on the port site, types and sizes of tankers, oil delivery quantities and frequencies, and the North slope oil characteristics. The primary source of this information was the report Air Quality Analysis of the Unloading of Alaskan Crude Oil At California Ports (Nov. 1976), by Pacific Environmental Services, Inc. (Ref. 9). This section addresses only the areas mentioned above and does not examine the emissions potential from the support facilities such as tug assistance, crude oil storage tanks, and the ship's boilers.

TABLE 3.7-2

QUANTITY OF GASOLINE LOADED AT
MARINE TERMINALS IN THE
LOS ANGELES AQCR

County	Year	Quantity (10^3 bbls)
Los Angeles	1975	8,916
Ventura	1975	0
Santa Barbara	1975	0
Total		8,916

Source: Ref. 7,17,22

TABLE 3.7-3

QUANTITY OF GASOLINE UNLOADED AT
MARINE TERMINALS IN THE
LOS ANGELES AQCR

County	Year	Quantity (10^3 bbls)
Los Angeles	1975	14,950
Ventura	1975	0
Santa Barbara	1975	700
Total		15,650

Source: Ref. 7,17,22

TABLE 3.7-4

QUANTITY OF CRUDE OIL LOADED AT
MARINE TERMINALS IN THE
LOS ANGELES AQCR

County	Year	Quantity (10^3 bbls)
Los Angeles	1975	7,211
Ventura	1975	6,804
Santa Barbara	1975	3,935
Total		17,950

Source: Ref. 7,17,22

TABLE 3.7-5

QUANTITY OF CRUDE OIL UNLOADED AT
MARINE TERMINALS IN THE
LOS ANGELES AQCR

County	Year	Quantity (10^3 bbls)
Los Angeles	1975	177,318
Ventura	1975	0
Santa Barbara	1975	0
Total		177,318

Source: Ref. 7,17,22

3.7.4.1 Port Site for Unloading Alaskan Crude Oil In The LA AQCR

The crude oil produced in North Slope fields in Alaska will probably be transported to the Continental U.S. via ocean-going oil tankers. Numerous projects have been proposed to handle the tankers and to pipeline the crude to the existing refining capacity in the U.S. West Coast refining demand for the Alaskan crude is estimated to account for 400,000 to 800,000 barrels per day (bpd). In 1978-1980 when Prudhoe Bay production reaches full capacity (1.2 million bpd) there is expected to be a surplus of 400,000 to 800,000 bpd of Alaskan crude (Ref. 16).

Standard Oil Company (Ohio) proposes to combine about 800 miles of existing natural-gas pipeline with newly constructed pipeline to move Alaskan crude from Long Beach, California to Midland, Texas. This project could deliver some 500,000 bpd of crude oil to Texas where it could be pipelined through existing networks with direct access to almost two-thirds of the nation's refining capacity (Ref. 16). The receiving port SOHIO plans to build in Long Beach will be a three-berth terminal. The terminal will handle tankers of up to 165,000 dwt and 55 ft. draft (Ref. 30).

Several oil refineries in the Los Angeles AQCR are planning to bring in Alaskan crude oil via tankers. These refineries are owned by ARCO, Shell, and Mobil. The crude oil will be used as refinery feedstock. No information on the size of these operations is known, but considerably lesser quantities of Alaskan oil will be received at the three refinery terminals combined than at the SOHIO terminal.

3.7.4.2 Types and Sizes of Tankers Delivering Alaskan Crude Oil from Valdez to The Los Angeles AQCR

Sufficient tanker tonnage exists to transport Alaskan oil from Valdez Alaska to the lower West Coast states. The total tonnage of the ships is in the range of 2,696,000 to 3,166,000 DWT according to the Pacific Environmental Services report. The final number depends on Exxon's plans to utilize its tanker fleet and the possible construction of two 165,000 DWT tankers for SOHIO. ARCO also is planning to build two 150,000 DWT tankers but is uncertain as to delivery date or usage (Ref. 9).

Table 3.7-6 summarizes information on the tankers which are projected to be used for transporting Alaskan crude. It shows that all tankers for which information was obtained have some amount of segregated ballast. Reportedly, a quantity of ballast of from 15 to 20 percent of tonnage capacity is generally sufficient to move a tanker out of port. Fully segregated ballast (approximately 35 percent of cargo tonnage) is planned for the ships currently under construction. The possibility exists that some ships without segregated ballast may be used to transport Alaskan crude to the Long Beach port facility. The quantity of crude that they transport is not expected to be significant (Ref. 9).

Most of the newer ships, as can be seen in Table 3.7-6, will have inert gas systems for deoxygenation of their cargo tanks. The inerting system is used to provide an inert gas blanket over the crude oil during transport from Valdez and to purge the empty cargo tank following discharge of the crude oil. Information available on the SOHIO tankers which are to be equipped with inerting systems indicates that it will require a minimum of approximately 8 hours to provide a volume of gas from the inerting system equivalent to the total volume of the cargo holds (Ref. 9).

Purging of empty cargo tanks results in a substantial emission of hydrocarbons. However, SOHIO indicates that there will be no purging of the cargo holds of their ships equipped with inerting systems within the Southern California Air Basin (Rev. 9).

TABLE 3.7-6

PROJECTED ALASKAN CRUDE OIL TANKER FLEET

Owner	Dead Weight Tonnage	Number of Ships	Anticipated Unloading Rate (bbls/hr)	Segregated Ballast (% of DWT)	Inert Gas System	Availability
ARCO	120,000	3	67,000	20	No	Now
	150,000	2	Unknown	Unknown	Yes	1977-79
CHEVRON	70,000	3	Unknown	Unknown	No	Now
EXXON	70,000	2	25,000	20	No	Now
	76,000	3	Unknown	Unknown	No	Now
MOBIL	130,000	1	70,000	20	Yes	Now
SHELL	188,000	2	106,000	35	Yes	1977-78
SOHIO	80,000	2	50,900	15-18	No	Now
	120,000	2	76,400	35	Yes	1976-77
	165,000	6	102,000	35.6	Yes	1977-78

Source: Ref. 9

3.7.4.3 Projected Quantities of Alaskan Crude Oil To Be Unloaded In The Los Angeles AQCR

The SOHIO project will be capable of unloading up to 700,000 barrels per day of Alaskan crude at the Long Beach terminal by mid-1978 if permit applications are approved by the second quarter of 1977. A pipeline from Los Angeles to Midland, Texas would be capable of handling 500,000 barrels per day of crude. The extra 200,000 barrels per day would allow for future deliveries in the Los Angeles area (Ref. 27).

The SOHIO project is presently the only proposal for unloading large quantities of Alaskan crude oil in the LA AQCR. Several refineries in the AQCR have tankers presently available or under construction for moving crude from Valdez to Los Angeles for processing. The refineries are ARCO, Shell, and Mobil. Information on the quantity of Alaskan crude to be unloaded at these refineries was not obtained, but the total quantity will probably be less than that for the SOHIO project.

SOHIO states that some 400 tanker visits are expected annually at the Long Beach terminal. Presumably this is at the maximum delivery rate of 700,000 barrels per day.

3.7.4.4 Characteristics of Alaskan Crude Oil

Information on the properties of the Alaskan crude oil to be transported to the LA AQCR was obtained from the Pacific Environmental Services report referenced earlier (Ref. 9). The properties are given below:

Sulfur Content: 1 percent by weight

Density: 312.7 lb/barrel at 60°F

Specific Gravity: 0.893

Vapor Pressure: Reported estimates of the vapor pressure of North Slope crude range between 7.4 psia as a winter minimum in Southern California to 9.6 as a summer maximum.

Temperature of Delivered Crude: It is reported that the temperature of the crude oil in the tankers after loading in Valdez during the first year of operation will be 45 to 60°F. Later, the temperature will rise to 80-97°F. For maximum flow through the pipeline the oil will be heated to reduce its viscosity, and the temperature of the crude will approach 140°F at Valdez.

Molecular Weight of Crude Oil Vapor: Based on data supplied by SOHIO the average molecular weight of the vapor in equilibrium with North Slope crude is 51. This assumes that the light ends are not lost during storage or transit. Table 3.7-8 presents the composition of the vapor in equilibrium with North Slope crude oil.

TABLE 3.7-8. COMPOSITION OF VAPOR IN EQUILIBRIUM WITH NORTH SLOPE CRUDE OIL

	MOL %	% HC	Molecular WT.	% x M.W./100
Carbon Dioxide	3.90	--	--	--
Water	5.30	--	--	--
Methane	9.90	10.9	16	1.74
Ethane	12.60	13.9	30	4.17
Propane	20.10	22.1	44	9.72
i-Butane	8.60	9.5	58	5.51
n-Butane	19.90	21.9	58	12.70
i-Pentane	6.60	7.3	72	5.26
n-Pentane	7.60	8.4	72	6.05
Hexane Plus (As C_6)	5.50	6.1	~90	5.49
	100.00	100.1		50.64 Avg. M.W.

Source: Ref. 9

3.7.5 Similarities And Differences In Marine Terminals Located In The Los Angeles AQCR And The Houston-Galveston AQCR

This section examines the similarities and differences in marine terminals which transfer or which are projected to transfer crude oil and/or gasoline in the Los Angeles AQCR and the Houston-Galveston AQCR. The comparisons are based upon data Radian obtained in the course of completing the Houston-Galveston phase and the Los Angeles phase of this project. A broad data base was established by Radian on the Houston-Galveston marine terminals. Because of time limitations, the Los Angeles study was not as detailed.

This section also points out those areas where additional information on the marine terminals in the Los Angeles AQCR would be valuable for assessing their impact on hydrocarbon emissions. Similarities and differences are discussed first for the marine terminals in Los Angeles County, then for Ventura County, and finally for Santa Barbara County. Areas requiring additional information are pointed out within each of the three discussions.

3.7.5.1 Los Angeles County

Los Angeles County marine terminal operations include loading and unloading of both crude oil and gasoline from tankers. There are several differences existing between Los Angeles County and the Houston-Galveston area with respect to marine terminals:

- little or no usage of barges to transport gasoline or crude oil at Los Angeles County terminals
- the unloading of gasoline at Los Angeles County terminals (15,650 x 10^3 barrels in 1975) versus no unloading of gasoline in the Houston-Galveston area

- a smaller quantity of gasoline loaded at Los Angeles County terminals ($8,916 \times 10^3$ barrels in 1975) versus the amount of gasoline loaded in the Houston-Galveston area ($82,500 \times 10^3$ barrels in 1975)
- the use of offshore marine terminals in Los Angeles County
- differences in the cruise histories between ships loading gasoline on the LA AQCR and ships loading gasoline on the H-G AQCR.

There are some similarities between marine terminals in the two areas:

- almost the same quantity of crude oil unloaded at Los Angeles County terminals ($177,320 \times 10^3$ barrels in 1975) as in the Houston-Galveston area ($160,000 \times 10^3$ barrels in 1975)
- similar equipment and techniques used for loading and unloading crude oil and gasoline except for the closed loading technique practiced by one company.
- no inerting of cargo tanks at either port, however, if Alaskan crude is unloaded at Long Beach, there will be tankers entering the LA AQCR with inerting capabilities.

Several areas were noted where additional information is needed to accurately determine the impact of gasoline and crude oil transfers on hydrocarbon emissions at marine terminals in Los Angeles County:

- analysis of the cruise history of those ships which load crude oil and gasoline in LA County
- analysis of the composition of the hydrocarbon vapors vented from cargo tanks during loading or ballasting operations.

3.7.5.2 <u>Ventura County</u>

There are two marine terminals in Ventura County. They both are used almost solely for loading crude oil, and both are located offshore. Combined they loaded at a total of 6,800 x 10^3 barrels of crude oil onto tankers in 1975.

There are very few similiarities between these two terminals and the terminal in the Houston-Galveston area which loads crude oil. The Ventura and Houston-Galveston terminals loaded roughly the same quantities of crude in 1975. However, the terminal in the Houston-Galveston area loads at a higher rate (10,000 bph minimum, 32,500 bph maximum) versus about 7,500 bph for the ventura terminals. As mentioned earlier, a unique hydrocarbon emission control problem exists in Ventura because of their location offshore.

Radian attended a hydrocarbon emission sampling run conducted by Chevron Research personnel onboard a tanker loading crude oil at the more active of the two Ventura terminals. It was learned that usually a tanker only picks up a partial load of crude oil at the terminal. Also, there are wide variations in vapor pressure of the crude loaded from one tanker visit to the next. This is because there are several crudes produced from different fields in the area having different vapor pressures.

Further information on the terminals and their hydrocarbon emissions will result when the Western Oil and Gas Association sponsored emission testing program conducted by Chevron Research is completed. This program is comprehensive and covers all aspects of the hydrocarbon emission problem occuring at Ventura.

3.7.5.3 Santa Barbara County

There are four marine terminals located in Santa Barbara County. Three of them load crude oil onto tankers, and one unloads gasoline from tankers. The ships which unload gasoline reportedly do not ballast following discharge of the cargo and, thus, do not vent hydrocarbons. The terminals loading crude oil are located offshore. In 1975 they combined to load a total of 700,000 barrels of crude oil.

Projects are proposed which could increase the production of crude oil in and near Santa Barbara waters. Information indicates that as much as 120,000 barrels per day or approximately 44 million barrels per year of crude oil may be produced and then loaded at offshore terminals near Santa Barbara County.

Very little information was available on the terminals or the crude oil being loaded in this area. To accurately determine the hydrocarbon emission impact on Santa Barbara County, more information is necessary on the existing and proposed marine terminals:

- location of each terminal and quantity of crude loaded or projected to be loaded there

- analysis of the cruise history of the ships being used to load the crude

- analysis of the composition of the vapors being vented from current loading operations

- analysis of the composition of the vapor in equilibrium with the crude oil to be loaded at the proposed terminals.

4.0 MARINE TERMINAL EMISSIONS

The source and mechanism of hydrocarbon emissions from marine terminal transfers of gasoline and crude oil are well understood. However, so many factors affect the magnitude of gasoline and crude oil transfer emissions that it becomes a very involved task to develop adequate emission factors or correlations for estimating the hydrocarbon emissions. Section 4.1 presents the general nature and characteristics of marine transfer emissions. Source testing data collected by Radian and by the petroleum industry concerning marine transfer emissions are presented in Section 4.2.

4.1 Emission Characteristics

4.1.1 Source and Mechanism

Hydrocarbon emissions are generated at marine terminals when volatile hydrocarbon products are either loaded onto or unloaded from ships and barges.

Loading Emissions

Loading emissions are attributable to the displacement to the atmosphere of hydrocarbon vapors residing in empty vessel tanks by volatile hydrocarbon liquids being loaded into the vessel tanks. Loading emissions can be separated into the arrival component and the generated component. The arrival component of loading emissions consists of hydrocarbon vapors left in the empty cargo tanks from previous cargoes. The generated component of loading emissions consists of hydrocarbon vapors generated in the cargo tanks as hydrocarbon liquids are being loaded.

The arrival component of loading emissions is directly dependent on the true vapor pressure of the previous cargo, the unloading rate of the previous cargo, and the cruise history of the cargo tank on the return voyage. The cruise history of a cargo tank may include heel washing, ballasting, butterworthing, vapor freeing, or no action at all. Temperature gradients, vessel motion, and long elapse times contribute to the well mixing of empty cargo tanks, resulting in almost uniform vapor concentrations in the arrival component. The arrival component for vessels loading gasoline characteristically range from 0 vol % to 20 vol % hydrocarbons, but can exceed 50 vol %.

The generated component of loading emissions is produced by the evaporation of hydrocarbon liquid being loaded into the vessel tank. The quantity of hydrocarbons evaporated is dependent on both the true vapor pressure of the hydrocarbons and the loading practices. The loading practice which has the greatest impact on the generated component is the loading rate.

An example profile of gasoline concentrations in a vessel tank during loading is presented in Figure 4.1-1. As indicated in the figure, the hydrocarbons present throughout most of the vessel tank vapor space are contributed by the arrival vapor component and the concentration is almost uniform. There is a sharp rise in hydrocarbon vapor concentration just above the liquid surface. This is the generated component. The generated component, also called a vapor blanket, is attributable to evaporation of the hydrocarbon liquid.

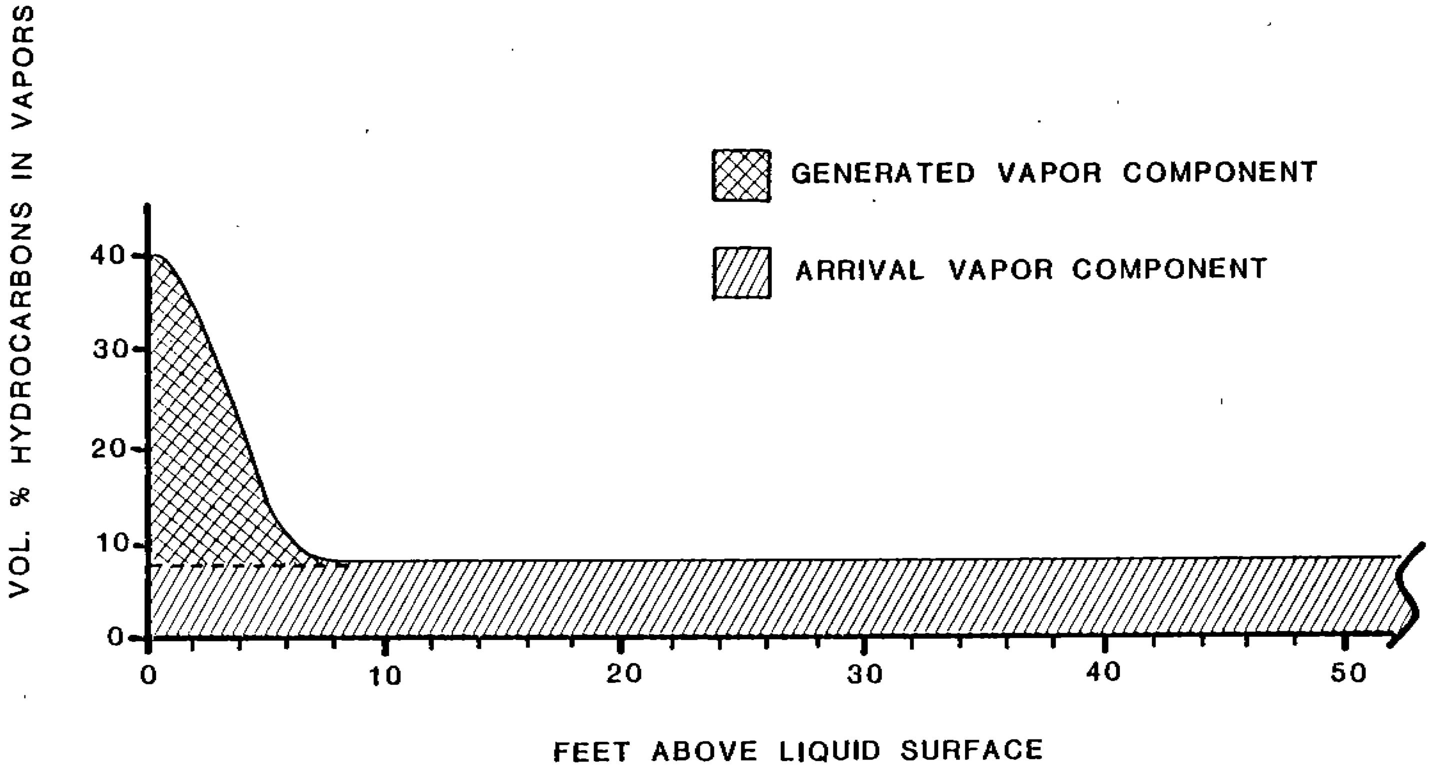


FIGURE 4.1-1 EXAMPLE PROFILE OF GASOLINE LOADING EMISSIONS

From Figure 4.1-1 it is apparent that for large vessels with 55 foot ullages, the average hydrocarbon concentration of vapors vented during loading operations is primarily dependent on the arrival component. For smaller vessels such as barges with 12 foot ullages the average hydrocarbon concentration in the vented loading vapors is dependent on both the generated component and the arrival component.

Unloading Emissions

Unloading emissions are hydrocarbon emissions displaced during ballasting operations at the unloading dock subsequent to unloading a volatile hydrocarbon liquid such as gasoline or crude oil. During the unloading of a volatile hydrocarbon liquid, air drawn into the emptying tank absorbs hydrocarbons evaporating from the liquid surface. The greater part of the hydrocarbon vapors normally lies along the liquid surface in a vapor blanket. However, throughout the unloading operation, hydrocarbon liquid clinging to the vessel walls will continue to evaporate and to contribute to the hydrocarbon concentration in the upper levels of the emptying vessel tank. Figure 4.1-2 presents a hypothetical profile of gasoline vapor concentrations in a vessel tank during ballasting. If significant temperature gradients are present, they will create convection currents which in time will disrupt the vapor blanket and promote a homogeneous hydrocarbon vapor concentration throughout the tank.

Before sailing, an empty marine vessel must take on ballast water to maintain trim and stability. Normally, on vessels that are not fitted with segregated ballast tanks, this water is pumped into the empty cargo tanks. As ballast water enters cargo tanks, it displaces the residual hydrocarbon vapors to the atmosphere generating the so termed, "unloading emissions".

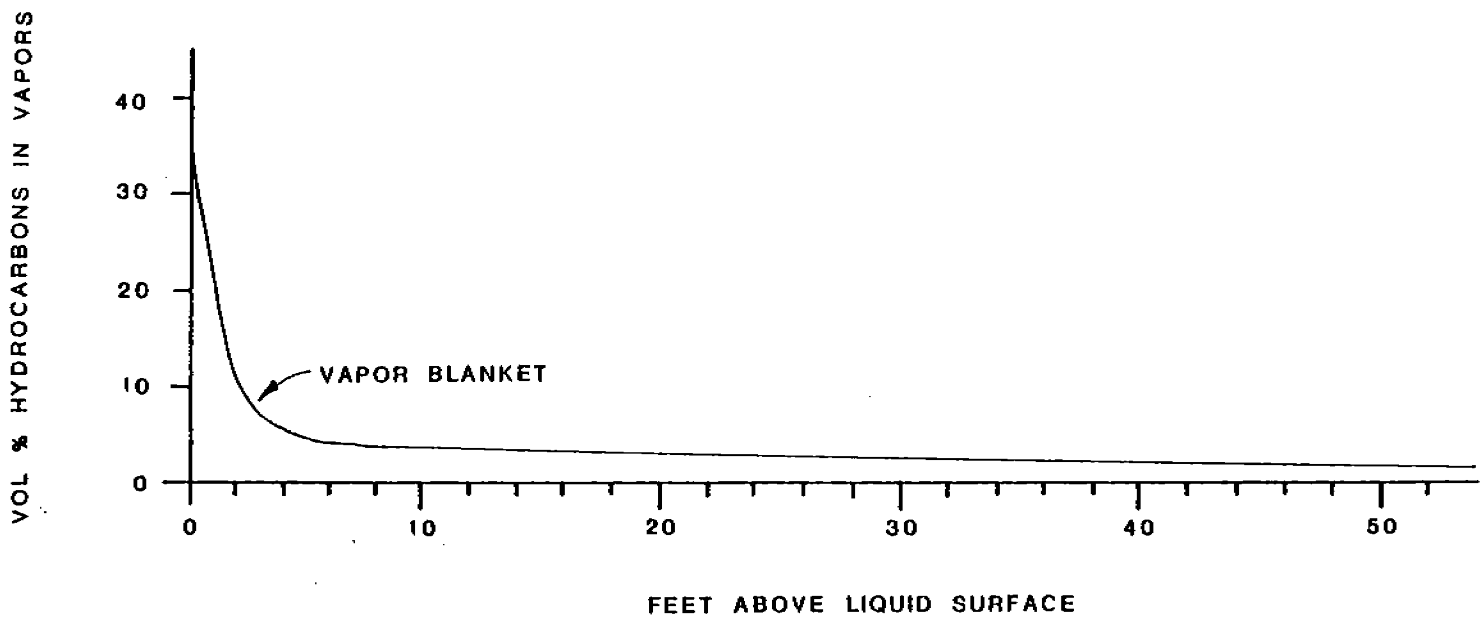


FIGURE 4.1-2 EXAMPLE PROFILE OF GASOLINE BALLASTING EMISSIONS

4.1.2 Effects of Loading Rate

The initial loading rate, bulk loading rate, and final loading rate all noticeably affect marine loading emissions. However, the influence of other parameters makes it difficult to quantify loading rate impacts. This section qualitatively presents the effects of loading rates on marine loading emissions.

Initial Fill Rate

There is a significant degree of splashing and liquid turbulence as cargoes are first pumped into empty vessel tanks. This splashing and turbulence results in rapid hydrocarbon evaporation and the formation of a vapor blanket. By reducing the initial velocity of cargoes entering empty tanks, it is possible to reduce the turbulence associated with initial tank filling and, consequently, to reduce the size and concentration of the vapor blanket. Figure 4.1-3 presents the results of AMOCO Oil Company tests on the effect of slow loading the first foot of gasoline cargo tanks. The curves in Figure 4.1-3 indicate a 50% to 60% reduction in vapor blanket size by using slow initial loading rates. For a clean gasoline cargo tank with a very small arrival vapor component, a reduction in the vapor blanket size is very significant.

Bulk Fill Rate

Normally, the vapor blanket profile is established by the initial filling rate and undergoes very little change throughout the loading sequence. The bulk loading rate normally has very little effect on the vapor blanket because of the relatively slow diffusion rate of hydrocarbon vapors in air. However, if the bulk loading rate is very slow, or is interrupted by ship personnel, the vapor blanket profile can change appreciably.

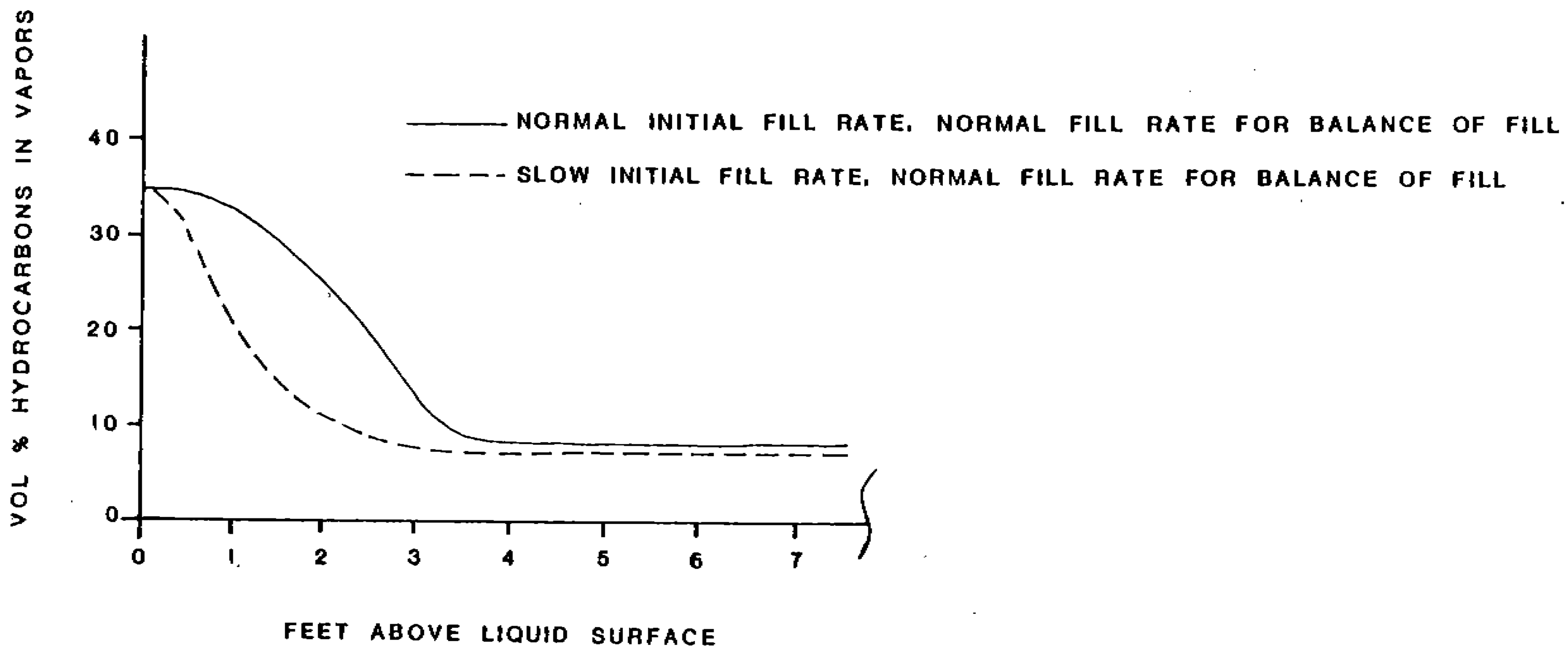


FIGURE 4.1-3 EFFECT OF INITIAL FILL RATE ON VAPOR BLANKET PROFILE

(AMOCO ILLINOIS - NOV. 6, 1974)

REFERENCE 2

Marine loading emission tests conducted by Atlantic Richfield indicated that lowering the bulk loading rate of a gasoline tanker from 3300 barrels per hour to 450 barrels per hour raised the average hydrocarbon emission rate from 2 vol % to 5.7 vol %. The emissions were almost tripled. (Ref. 6)

Final Fill Rate

As the hydrocarbon level in a marine vessel tank approaches the tank roof, the action of vapors flowing towards the ullage cap vent begins to disrupt the quiescent vapor blanket. Disruption of the vapor blanket results in noticeably higher hydrocarbon concentrations in the vented vapor. AMOCO test results from slow final loadings indicate that, although not as significant as slow initial loading, slow final loading can lower the quantity of hydrocarbon emissions from marine vessel loading of volatile hydrocarbon liquids. (Ref. 4)

Short Loading

Displacement of the high hydrocarbon concentration generated vapor blanket during the final stages of loading gasoline or volatile crudes into a cargo tank causes a significant part of the total hydrocarbon emissions from that tank. By stopping the loading of the cargo tank short the vapor blanket can be partially or totally kept within the tank. The depth of the blanket usually varies from 6 to 8 feet (see Figure 4.1-1). Therefore, to keep most of the blanket from being displaced, loading must be stopped about six feet from deck level.

The effect of short loading on the emissions from gasoline loading onto a ship can be estimated from the numbers in Table 4.2-2. The contribution of the vapor blanket displacement to total tank emissions is approximately the same as the emissions from loading into a clean-vapor free tank. In this case only the vapor generated or evaporated from the liquid surface during loading (which forms the vapor blanket) contributes to the hydrocarbon emissions. Therefore, from 0.5 to 1.5 pounds of hydrocarbons per thousand gallons loaded represent the quantity of hydrocarbons emitted when the vapor blanket is displaced. From Table 4.2-2 it can be seen that emissions theoretically may be reduced from 100% to 20% for tankers loading gasoline, depending upon concentrations of hydrocarbons in arriving tanks.

There is a consequence of short loading which may adversely affect its ability to reduce emissions from loading gasoline on a tanker on successive trips. This problem becomes apparent when one loading/unloading cycle for a tank is examined. First, assume a tank is short loaded with a six foot space left from deck level to liquid level. During the time required for transport of the cargo to its destination the space left above the liquid will likely become saturated with gasoline vapors. As the cargo is unloaded the vapors become diluted with air to a lower concentration. When the ship returns for a new load, the vapor blanket which was not displaced during the previous loading now manifests itself as the arrival component of the emissions and will be displaced as the tank is refilled. Therefore, unless the vapors are vented from the tank during the return voyage the hydrocarbon emissions will not be effectively reduced.

4.1.3 Effects of TVP

The true vapor pressure (TVP) of a hydrocarbon liquid has a marked impact on the hydrocarbon content of its loading and unloading emissions. TVP is an indicator of a liquid's volatility and is a function of the liquid's Reid Vapor Pressure and of the liquid's temperature. Compounds with high TVP exhibit high evaporation rates and, consequently, contain high hydrocarbon concentrations in their loading and ballasting vapors. Section 4.1.6 on the Chemistry of Emissions presents information on the vapor pressures of gasolines and crude oils during loading operations. Marine loading tests conducted by Atlantic Richfield in the winter of 1974-1975 indicated that under the same loading conditions, a gasoline with a TVP of 6.6 psia generated emissions with a hydrocarbon content of 2.1 vol %, whereas a gasoline with a TVP of 8.0 psia generated emissions with a hydrocarbon content of 2.6 vol %. The TVP of gasoline can easily range from 6 psia to 10 psia, and the TVP of crude oils can range from 0 psia to greater than 15 psia. (Ref. 5)

4.1.4 Effects of Cruise History

The cruise history of a marine vessel includes all of the activities which a cargo tank experiences during the voyage prior to a loading or unloading operation. Examples of significant cruise history activities are ballasting, heel washing, butterworthing, gasfreeing, and split-deliveries. Cruise history impacts marine transfer emissions by directly affecting the arrival vapor component. Barges normally do not have significant cruise histories because they rarely take on ballast and do not have the manpower to clean cargo tanks.

Ballasting

Ballasting is the act of partially filling empty cargo tanks with water to maintain a ship's stability and trim. Figures 4.1-4, 4.1-5, and 4.1-6 present sample hydrocarbon vapor profiles for empty gasoline cargo tanks prior to ballasting, for ballasted gasoline cargo tanks, and for gasoline cargo tanks after ballast

FIGURE 4.1-4 HYDROCARBON PROFILE PRIOR TO BALLASTING AN EMPTY TANK

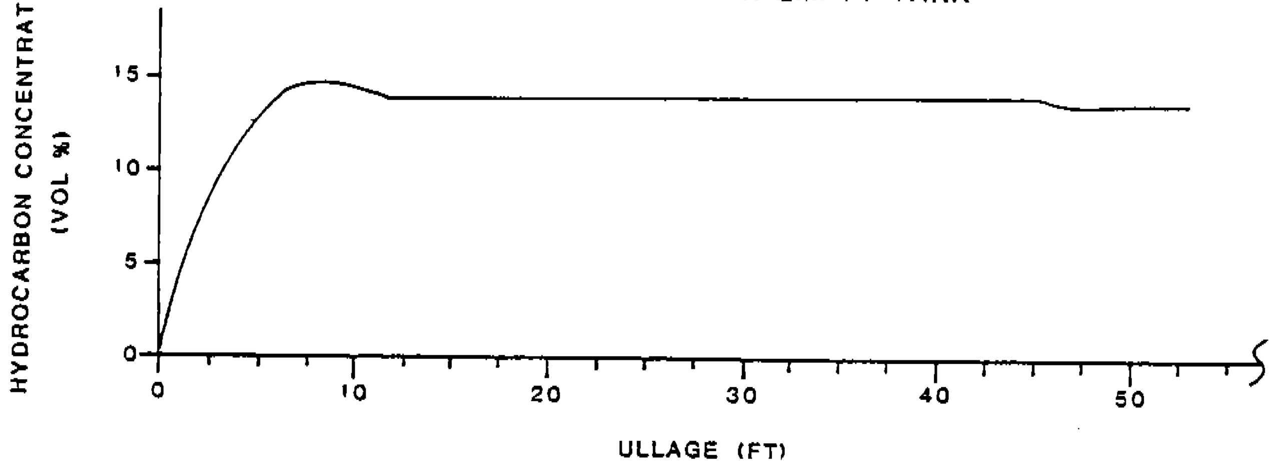


FIGURE 4.1-5 HYDROCARBON PROFILE OF A BALLASTED TANK

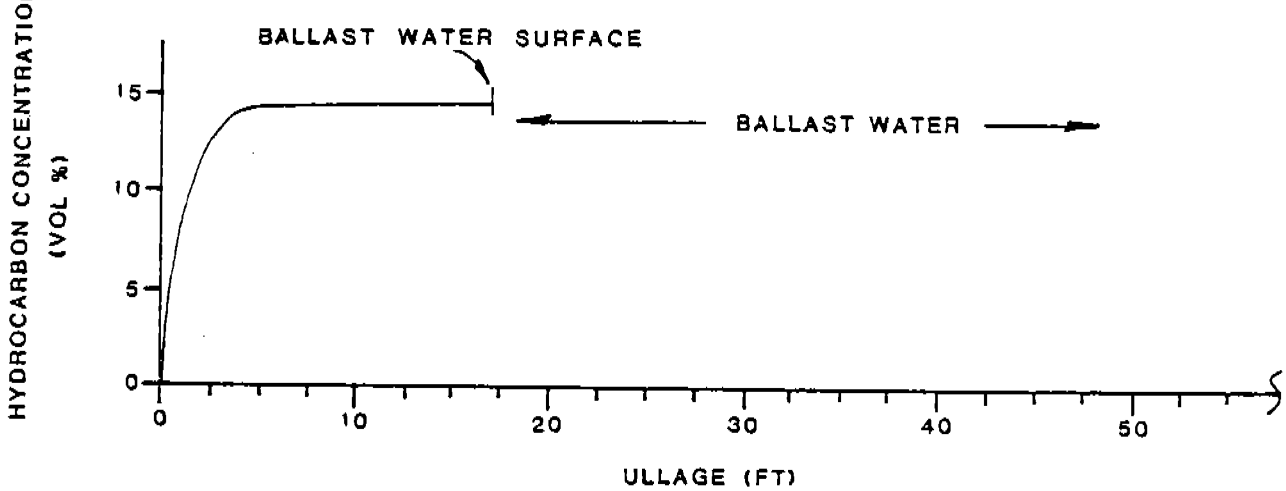
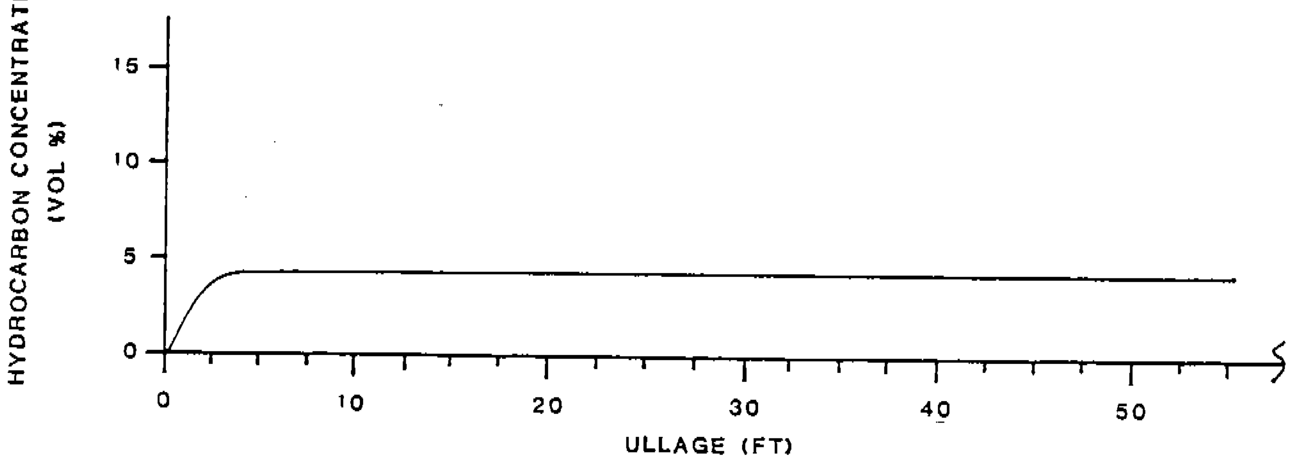


FIGURE 4.1-6 HYDROCARBON PROFILE OF AN EMPTY TANK AFTER BALLAST DISCHARGE



discharge. (Rev. 2) As Figure 4.1-4 indicates, prior to ballasting, empty cargo tanks normally contain an almost homogeneous concentration of residual hydrocarbon vapors. When ballast water is taken into the empty tank, Figure 4.105 indicates that hydrocarbon vapors are vented but that the remaining vapors not displaced retain their original hydrocarbon concentration. Upon arrival at a loading dock, a ship discharges its ballast water and draws fresh air into the tank. The fresh air dilutes the arrival vapor concentration and lowers the effective arrival vapor concentration by an amount proportional to the volume of ballast used (Figure 4.1-6). Although ballasting practices vary quite a bit, individual tanks are ballasted about 80% and the total vessel is ballasted approximately 40%. Consequently, ballasting potentially lowers individual tank arrival component by 80% and lowers the total ship arrival component by 40%.

Heel Washing and Butterworthing

The heel of a cargo tank is the residual puddles of hydrocarbon liquids remaining in cargo tanks after emptying. These residual liquids will eventually evaporate and contribute to the arrival component of subsequent vessel-filling vapors. By washing out this heel with water, AMOCO Oil Company found that they were able to reduce the hydrocarbon emissions from subsequent filling operations from 5.7 vol % to 2.7 vol % hydrocarbons. Butterworthing is the washing down of tank walls in addition to washing out tank heels. Butterworthing also reduces loading emissions by reducing the arrival component concentration. The hydrocarbon liquids washed from the tanks are stored in a slops tank for disposal onshore. (Ref. 2)

Gasfreeing

Heel washing and butterworthing lower arrival vapor components by removing residual hydrocarbon liquids from tank walls and bottoms before they evaporate. However, these two techniques do not affect hydrocarbon vapors which have already formed. Marine vessels can purge the hydrocarbon vapors from empty and ballasted tanks during the voyage by several gasfreeing techniques which include air blowing and removal of ullage dome covers. A combination of tank washing and gasfreeing will effectively remove the arrival component of loading emissions.

Split-Transfers

Sometimes a tanker will deliver its cargo to two different ports, or will pick up cargoes from two different ports. These split-transfers increase the quantity of hydrocarbons emitted from loading and unloading operations. After the partial delivery of a volatile hydrocarbon product, the partially filled cargo tanks contain large volumes of air into which hydrocarbons evaporate from the liquid surface during the balance of the ship's voyage. These hydrocarbons will be vented to the atmosphere during the ballasting operations following the discharge of the remaining cargo or when the tanker loads a new cargo. In a like manner, when tankers are engaged in multiple cargo pick-ups, the vapor space in partially filled cargo tanks increases in hydrocarbon concentration from evaporation of volatile vapors which are subsequently vented to the atmosphere when the balance of the cargo tank is filled.

Previous Cargo

The previous cargo conveyed by a tanker also has a direct impact on the arrival component of loading emissions. Cargo tanks which carried nonvolatile liquids on the previous voyage normally return with vapor spaces which are essentially vapor free. EXXON Oil Company tests conducted in Baytown indicated that the arrival component of empty uncleaned cargo tanks which had previously conveyed fuel oil ranged from 0 vol % to 1 vol % hydrocarbons. Cargo tanks with the same cruise history except for the fact that they had previously conveyed gasoline, exhibited hydrocarbon concentrations in the arrival vapors which ranged from 4 vol % to 30 vol % and averaged 7 vol %. (Ref. 12)

4.1.5 Composite Vapor Profiles

The hydrocarbon vapor profile experienced by vapor control equipment is a composite of the vapor profiles of each cargo tank venting into the vapor collection system. The composite vapor profile is of a different form than the individual profiles and is very dependent upon loading procedures. Figures 4.1-7 and 4.1-8 present two example composite vapor profiles. The profile in Figure 4.1-7 represents the composite vapor profile of a vessel which is loading each cargo tank separately. The profile in Figure 4.1-8 represents the composite vapor profile of a vessel which is loading several tanks simultaneously and tops-off all of the tanks near the end of the loading period. Most of the loading operations attended by Radian were more closely represented by Figure 4.1-8. However, a wide range of loading procedures are practiced on marine vessels depending on the ship loading officer and dock situations.

4.1.6 Chemical and Physical Properties

This section presents some of the chemical and physical properties of gasoline and crude oil vapors which are emitted to the atmosphere during loading and unloading operations.

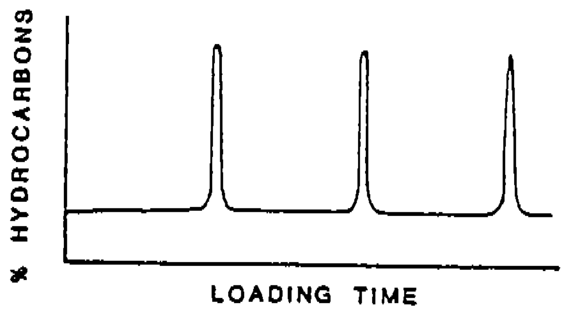


FIGURE 4.1-7 EXAMPLE COMPOSIT VAPOR PROFILE FOR LOADING SEQUENTIAL

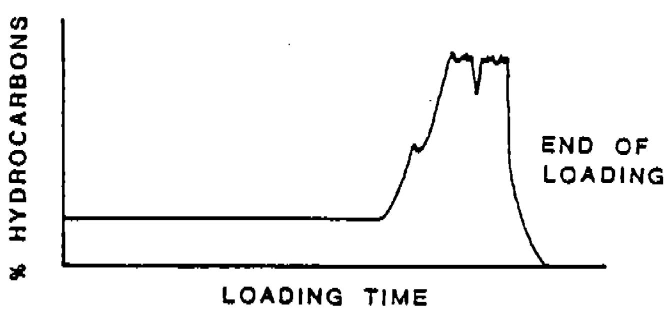


FIGURE 4.1-8 EXAMPLE COMPOSIT VAPOR PROFILE FOR SIMULTANEOUS LOADING

RVP

The Reid vapor pressures (RVP) of gasoline loaded in the Houston-Galveston area range from 9.5 psia in the summer to 13.6 psia in the winter, see Table 3.4-2. Section 3 of this report lists the RVP and quantities of gasolines loaded each month. The RVP of crude oils unloaded in the Houston-Galveston area normally range from 2 psia to 7 psia but may fall on either side of this range. Alaskan crudes which will be unloaded on the West Coast in the future are projected to have an RVP in the range of 14 psia to 15 psia.

The true vapor pressure of a liquid is a function of its RVP and its temperature. The nomographs presented in Figures 4.1-9 and 4.1-10 correlate the true vapor pressures of crude oils. However, since the TVP-RVP relationship for crude oil is very sensitive to the composition and amounts of light hydrocarbons in the crude oil, Figure 4.1-9 is not always accurate and actual crudes will vary widely from this nomograph.

Chemical Composition

Tables 4.1-1, 4.1-2, and 4.1-3 present the chemical compositions of hydrocarbon vapors emitted by motor gasoline, crude oil, and aviation gasoline marine loading operations. As indicated by Table 4.1-1, gasoline vapors can exhibit a wide range of compositions. ARCO has measured some high concentrations of methane in their gasoline loading vapors, while Shell measured only trace concentrations. The presence of methane in gasoline loading emissions presents a problem from the standpoint that most vapor control systems are ineffective on methane. Table 4.1-1 also indicates the wide range of molecular weights which gasoline vapors can be expected to exhibit.

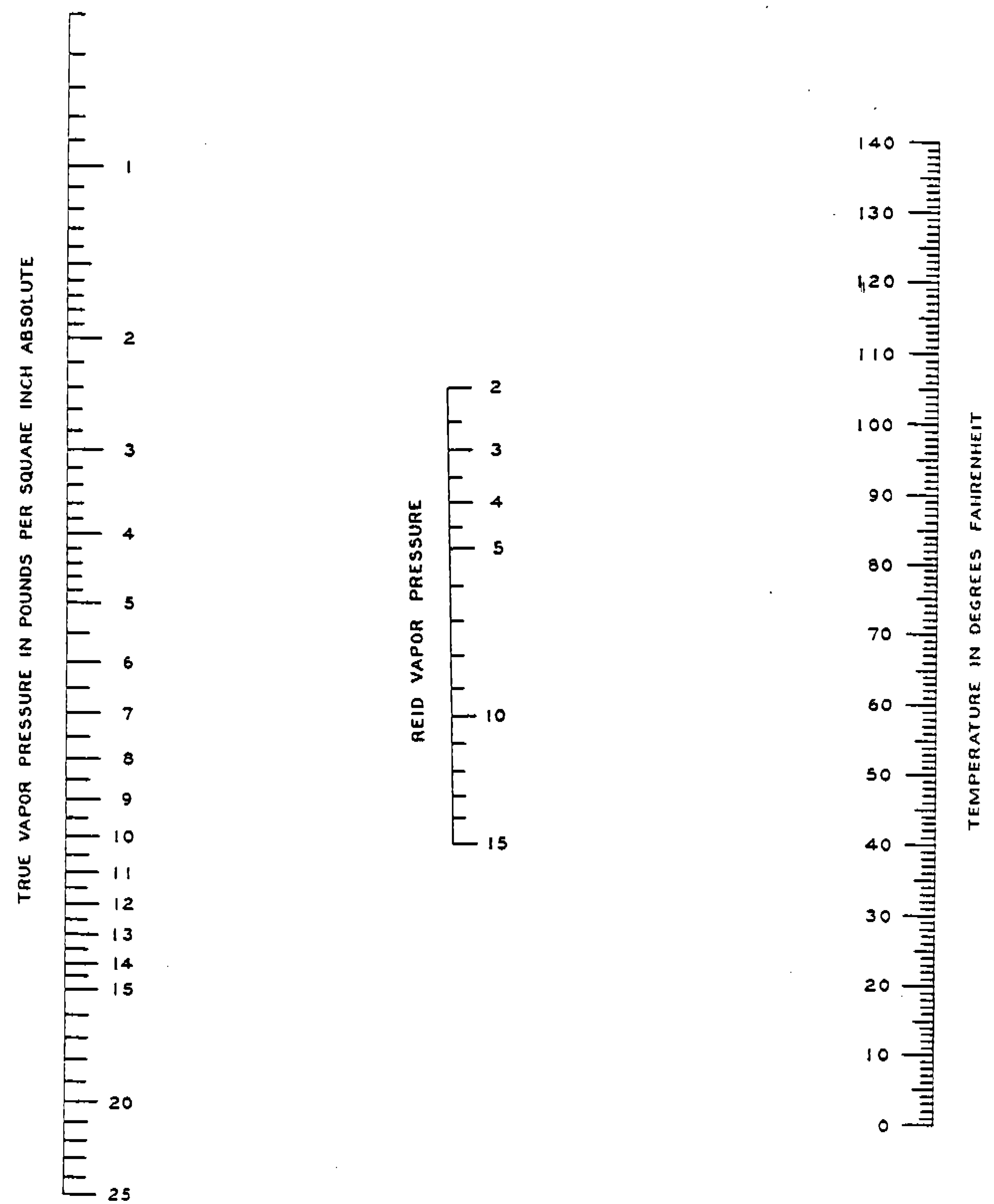


FIGURE 4.1-9 VAPOR PRESSURES OF CRUDE OIL.

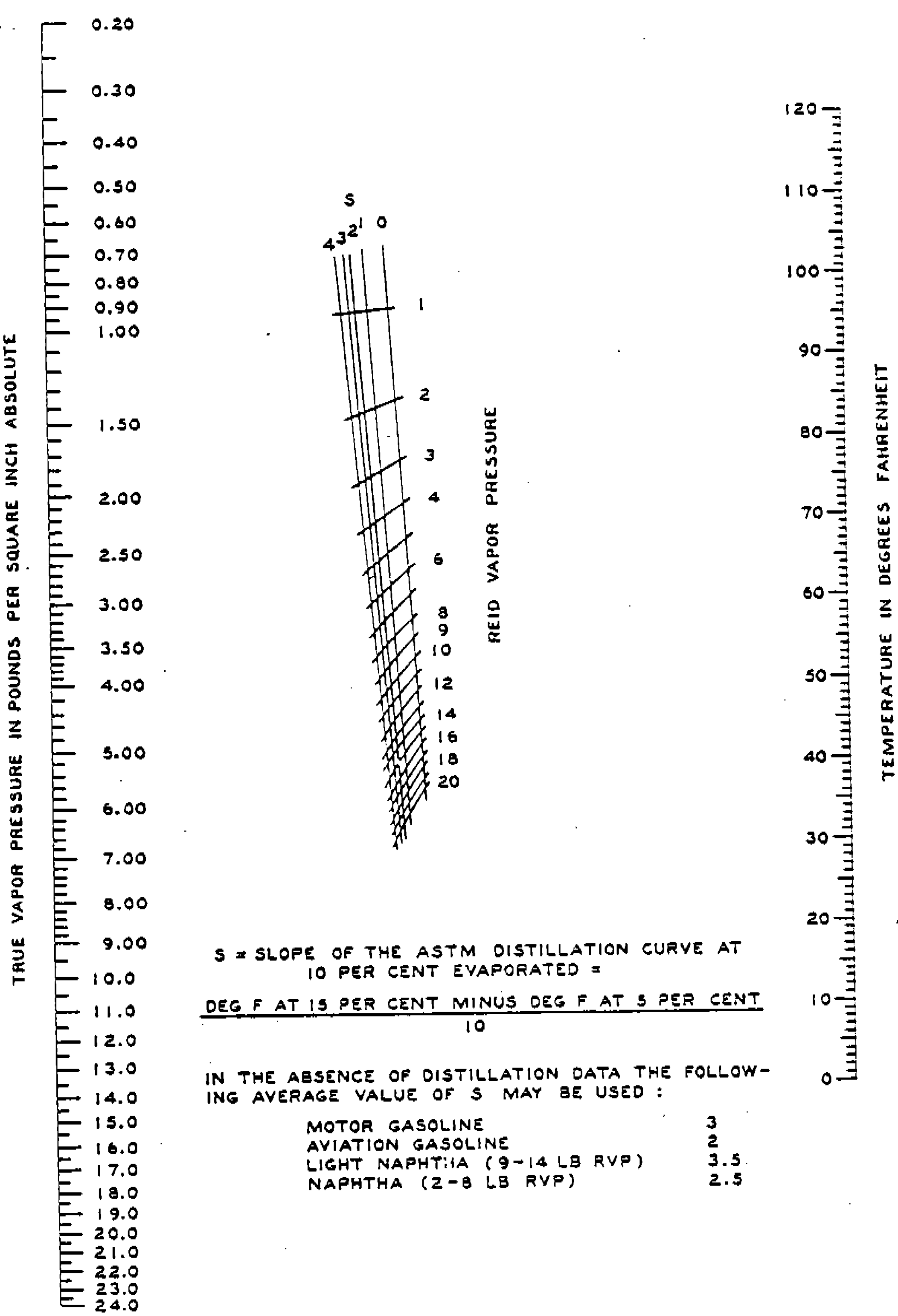


FIGURE 4.1-10 VAPOR PRESSURES OF GASOLINES AND FINISHED PETROLEUM PRODUCTS

TABLE 4.1-1

CHEMICAL COMPOSITION OF GASOLINE LOADING VAPORS

Shell Oil Company[a]
Ship-Valley Forge
10/19/1974

Compound	Vol. %
$C_1 + C_2$	0.02
C_3	0.02
C_4 paraffins	2.20
C_4 olefins	0.16
C_5 paraffins	1.01
C_5 olefins	0.06
C_6 paraffins	0.19
C_6 olefins	--
benzene	--
C_7 paraffins	0.04
C_7 olefins	--
toluene	0.15
C_8 paraffins	0.13
C_8 olefins	--
C_8 aromatics	0.02
Air	96.00
Molecular Weight of Hydrocarbons	66.9

Atlantic Richfield Oil Company[b]
Ship-ARCO Enterprise
11/13/1974

Compound	Vol. %
C^1	3.31
C_2	0.07
C_3 paraffin	0.20
C_3 olefin	0.00
iso-C_4	0.47
n-C_4	2.59
C_4-olefin	0.13
iso-C_5	2.63
n-C_5	1.27
C_5-olefin	0.24
n-C_6	0.08
C_6-paraffins	0.57
C_6+	0.23
Air	88.21
Molecular Weight of Hydrocarbons	52.99

[a] Reference 19

[b] Reference 5

TABLE 4.1-2

COMPOSITION OF VENTED VAPORS, VOL. %

CRUDE OIL LOADING TEST, 5-8-76,

AVILA TERMINAL, TANKER: LION OF CALIFORNIA

Hydrocarbon Fraction Only

Cargo Tank	3 Port	3 Center	3 Starboard
Final True Ullage, Ft	1.9	1.6	1.9
Tank Depth, Ft	39.3	40.2	39.4
Oil loaded, bbl	3911	8706	3911
True Ullage, Ft	29.1	9.0	16.4
C_1	24.17	2.23	16.76
C_2	3.72	0.39	3.20
C_3	14.38	3.25	13.85
iC_4	5.27	3.48	5.46
nC_4	22.08	25.10	21.21
iC_5	10.44	23.63	11.66
nC_5	8.58	20.35	9.84
C_6	7.50	13.60	10.19
C_7	4.59	6.88	6.52
C_8	0.84	0.67	0.75
C_9	0.32	0.37	0.51
C_{10}	0.08	0.05	0.05
C_{11}	0.03	--	--
Molecular Weight	53.5	70.1	57.6
Total Sample			
% Air	97.26	95.35	96.75
% CO_2	0.07	0.06	0.07
% Hydrocarbon	2.67	4.59	3.18
Temperature, °F			
Tank Vapor	66	77	68
Ambient	56	55	55
Dew Point	-13	4	-8

Reference 22

TABLE 4.1-3

CHEMICAL COMPOSITION OF AVIATION GASOLINE VAPOR

Component	Vapor Concentration (Weight Percent) at 80 F°[a]			
	(AvGas 80)	(AvGas 100)	(AvGas 115)	Average
n-Butane	3.170	2.517	4.071	3.253
Isopentane	62.711	62.118	62.366	62.398
n-Pentane	5.724	5.238	5.396	5.453
2-3 Dimethyl-Butane	3.261	3.168	2.687	3.039
2 Methyl Pentane	2.073	2.064	1.666	1.935
Cyclopentane	0.207	0.212	0.217	0.212
3 Methyl Pentane	0.824	0.865	0.644	0.778
Hexane	0.165	0.000	0.000	0.055
Cyclohexane	0.000	0.000	0.087	0.029
C_7 and Heavier	21.865	23.818	22.866	22.848
Total	100.000	100.000	100.000	100.000

[a] These compositions were calculated by Exxon Company using actual av-gas compositions and equilibrium flash calculations. Reference 12

The chemical compositions and molecular weights of crude oil vapors will vary over a much broader range than those of gasoline vapors. Crude oil vapors will range in molecular weight from 45 to 100 pounds per pound-mole.

Explosive Range

The explosive range of hydrocarbon product is defined as the range of hydrocarbon concentrations in air for which the gaseous mixture will support combustion. For gasoline vapors whose major components are n-butane, n-pentane, and iso-pentane, the explosive range in air is 1.4 vol % to 8.4 vol % hydrocarbons. If the concentration of hydrocarbons in gasoline vapors falls below 1.4%, there are insufficient hydrocarbons in the vapors to support combustion. If the concentration of hydrocarbons is above 8.4%, there is insufficient oxygen present in the vapors to support combustion. For those gasoline vapors which contain significant amounts of lighter components, especially methane and ethane, both the lower and upper explosive limits in air are increased.

From ballasted or uncleaned tanks, the vented vapors may be on the explosive range for up to 80% of the gasoline tanker loading operation. (Rev. 13).

4.2 Source Testing Results

4.2.1 Industry Testing

The petroleum industry has been very involved in test programs to quantify the hydrocarbon emissions from gasoline and crude oil transfer operations at marine terminals. Table 4.2-1 summarizes the test programs which have been conducted by the petroleum industry. The industry programs have included motor gasoline, aviation gasoline, and crude oil loading onto

Table 4.2-1

SUMMARY OF PETROLEUM INDUSTRY TESTING PROGRAMS ON MARINE LOADING EMISSIONS

Company	Types of Marine Testing	Location	Date	Extent of Testing	Emission Factors	Comments
WOGA	tanker loading and ballasting emissions for crude oil and natural gasoline	Ventura County Union Oil Terminal Getty Oil Terminal California	May 1976 - ? (tests are ongoing)	6 tests to-date	preliminary data indicates that emissions from loading a non-volatile crude into ballasted tanks which previously carried more volatile crude and not gasoline are 0.9 to 1.0 lbs/1000 gallons	Tests are just beginning but, it is apparent that they have developed a comprehensive testing program.
EXXON	primarily gasoline loading, but also avgas and crude loading	Exxon Terminal Baytown Texas Kharg Is., Iran	winter 1974-1975 summer 1975	100 ship tests 30 barge tests	Gasoline Loading tanker - gas free 3.24 vol % tanker - ballasted 6.96 vol % tanker - uncleaned 10.26 vol % average Exxon tanker 6.43 vol %(1.47 lb/mgal) ocean barge - gas free 5.69 vol % ocean barge - ballasted 9.08 vol % ocean barge - uncleaned 14.40 vol % avg. Exxon Ocean Barge 11.71 vol %(2.66 lb/mgal) barge 18.35 vol %(4.14 lb/mgal) Aviation Gasoline Loading tanker - gas free 1.63 vol % tanker - unclean(av-gas prev.) 6.65 vol % tanker - unclean(no gas prev.) 10.64 vol % average Exxon tanker 5.35 vol %(1.47 lb/mgal) average Military tanker 4.13 vol %(1.13 lb/mgal) barge 18.35 vol %(4.25 lb/mgal) Weighted Average Dock 1.8 lb/mgal Also have a TVP dependent correlation - see text	Exxon conducted extensive testing with well developed testing program, followed by indepth correlation generation.
American Petroleum Institute	motor gasoline loading	predominantly in Houston-Galveston area	1974-1976		clean tankers 1.3 lb/mgal clean barges 1.2 lb/mgal uncleaned tankers 2.5 lb/mgal uncleaned barges 3.8 lb/mgal	The API Evaporative Loss Committee consolidated all available marine loading loss data into these four factors. No testing was conducted on their part.
ARCO	motor gasoline loading of tankers	Houston Refinery	Nov. 1974, Feb. and April 1975	11 tests	Gasoline Loading on Tanker fast load, low TVP, clean 2.1 vol %(0.4 lb/mgal) fast load, med TVP, clean 2.6 vol %(0.5 lb/mgal) slow load, high TVP, clean 4.2 vol %(0.9 lb/mgal) slow load, high TVP, part clean 6.9 vol %(1.3 lb/mgal) avg ARCO tanker 3.9 vol %(0.84 lb/mgal)	
AMOCO	primarily motor gasoline loading crude barge unloading	Whiting, Ill Texas City, Texas	2/26/74 to 7/22/75 5/29/74 to 8/5/75	40-50 tests 9 tests	none developed none developed AMOCO did state that average emissions for AMOCO ship less than 10.2 vol %	No emission factors were developed by AMOCO on their test data. Summary tables of their test results are presented in the text.
Shell	gasoline loading on tanker	Deer Park, Tex	October 1974	5-10 tests	none developed	Summary table of test data presented in text. Too little data gathered for development of factors.
British Petroleum	crude oil loading on tanker	Middle East	1973	unknown	none developed	Although no specific emission factors were developed, British Petroleum did develop a family of curves presented in the text.

tankers, barges, and ocean barges. Well over 200 cargo tanks were sampled in these programs. Although not reported in this study, the petroleum and chemical industries have also conducted a limited number of tests on hydrocarbon emissions from petrochemical loading operations. The petroleum industry tests were primarily conducted between 1974 and 1975 in the Houston-Galveston area. Tests have also been conducted on the West Coast and in the Great Lakes area.

Tables 4.2-2 and 4.2-3 summarize the results of the petroleum industry emission testing programs. The individual industry results are presented in Appendix III and test data from the industry test programs are presented in Appendix IV.

The range of emissions presented in Tables 4.2-2 and 4.2-3 represent the range in values reported by the petroleum industry. The average value reported in the tables is the average of all values reported by the petroleum industry. The "average condition" reported in the tables represent the average emission factor reported by industry for their individual dock and cruise history situations.

Tables 4.2-2 and 4.2-3 indicate that the hydrocarbon emission rates from aviation gasoline transfers are very similar to those for motor gasoline transfers. The average tanker loaded in the Houston-Galveston area appears to have been cleaned or ballasted and has a hydrocarbon emission rate of approximately 1.2 pounds per thousand gallons transferred. The average ocean barge loaded in the Houston-Galveston area has a higher hydrocarbon emission rate of approximately 2.7 pounds per thousand gallons transferred. The average barge loaded in the Houston-Galveston area is neither cleaned nor ballasted and has a hydrocarbon emission rate of approximately 4 pounds per thousand gallons transferred.

TABLE 4.2-2
SUMMARY OF RESULTS
HYDROCARBON EMISSIONS FROM MARINE LOADING
MOTOR GASOLINE

	hydrocarbon emissions lb/mgal range	average
Tankers		
clean-vapor free	0.50 - 1.50	1.0
ballasted	1.62	1.6[a]
uncleaned	2.38 - 2.50	2.4
average condition	0.84 - 1.47	1.2
Ocean Barges		
clean-vapor free		1.3[a]
ballasted		2.1[a]
uncleaned		3.3[a]
average condition		2.7[a]
Standard Barges		
clean-vapor free		1.2[a]
uncleaned	3.80 - 4.14	4.0
average condition		4.1[a]

[a]Exxon Company was the only supplier of information in these categories.

TABLE 4.2-3
SUMMARY OF RESULTS
HYDROCARBON EMISSIONS FROM MARINE LOADING
AVIATION GASOLINE

	Emissions lb/mgal
Tankers	
clean-gas free	0.45[a]
uncleaned aviation previous cargo	1.83[a]
uncleaned motor gasoline previous cargo	2.92[a]
average tanker (Exxon)	1.47[a]
average tanker (Military)	1.13[a]
Barges	
average condition	4.25[a]

[a] Exxon Company was the only supplier of information in these categories. (Reference 13)

As the industry test data indicates, the cruise history of a marine vessel greatly impacts its loading emissions. Various company docks will exhibit variations in their loading emission rates due to variations which exist in each company's cruise history policies.

4.2.2 Radian Testing

Radian Corporation conducted a limited sampling program for the purpose of gathering data to use in the verification of industry reported emission factors. The test data gathered by Radian are contained in Appendix VI. Results of these tests are presented graphically in Appendix V.

The following observations were made based on the Radian test data.

- Hydrocarbon emissions from ballasting cargo tanks which were previously filled with a 3 RVP to 6 RVP crude oil will range from 5 to 10 vol % and average approximately 7 vol % (1.4 lbs/m gal).

- Hydrocarbon emissions from ballasting cargo tanks which were only partially filled with crude oil or which were used to collect strippings are generally much greater than emissions from ballasting tanks which were completely filled. This is due to evaporation into a larger vapor space.

- The vapor blanket above the surface of gasoline being loaded into cargo tanks is less than 5 ft. thick and normally ranges from 2 ft. to 3 ft. thick.

- The arrival components of ship and ocean barge cargo tanks were found to be the following:

cleaned tanks	0-2 vol %
ballasted tanks	2-10 vol %
uncleaned tanks	≈21 vol % (single sample).

- The total emissions from loading gasoline onto ships and ocean barges were found to be as follows:

cleaned tanks	3-5 vol % (≈0.6-1 lb/m gal)
ballasted tanks	9-13 vol %(≈1.8-2.7 lb/m gal)
uncleaned tanks	≈25 vol % (≈5.1 lb/m gal)

Note: The uncleaned tank value is a single test point.

- Limited barge data indicated barge emissions are in the range of 27 vol % hydrocarbons or approximately 5.5 lbs/m gal.

4.2.3 Conclusions

Radian test data indicate that the industry emission factors presented in Tables 4.2-2 and 4.2-3 accurately represent the hydrocarbon emissions from marine transfer operations. The Radian emission data deviated somewhat from industry data for loading uncleaned ships and loading barges; however, in each case, the Radian values were based on single data points. It may be necessary to conduct additional testing programs in these areas to verify industry emission factors.

Radian test results also indicate that hydrocarbon emissions from ballasting crude tankers are in the range of 1 to 2 pounds per thousand gallons ballasted.

5.0 EMISSION CONTROL TECHNOLOGY

Emission control technology for marine loading of gasoline is a young technology which is faced with a unique set of problems. Although vapor recovery has been used on marine loading operations in the petroleum and chemical industries for several years, the marine loading operations currently being controlled are closed systems with no air present, which have much slower loading rates, and involves products handled in relatively small quantities. The presence of air in vented hydrocarbon vapors presents a potential explosion hazard when in specific concentration ranges. The cumulative loading rates for a single gasoline tanker can be as high as 50,000 barrels per hour, which is equivalent to 4700 scfm of displaced vapors. Although gasoline vapor control technology has also been applied to tanktruck loading operations, truck terminal vapor control technology is not directly applicable to marine terminals because the flow rates are much smaller than those experienced in marine loading, and because the hydrocarbon vapor concentrations in tanktruck loading vapors are above the explosive range.

The safety and design problems associated with vapor control technology for marine loading of gasoline are not thought to be technically insurmountable. The principles involved in marine vapor collection and control are well understood.

The principle vapor control systems being considered in the Houston-Galveston area are based on conveying hydrocarbon vapors generated onboard the vessels to shoreside vapor control units for recovery as liquid product or for disposal by incineration. Shoreside vapor control systems can be divided into three components; the vapor control unit, the shoreside vapor collection system, and the shipside vapor collection system. These three components of shoreside vapor control systems are discussed in depth in Sections 5.1, 5.2 and 5.3, respectively. Alternative strategies for vapor emission control are presented in Section 5.4.

5.1 Vapor Control Unit

A key component in each vapor control system is the vapor control unit which serves the function of reducing the hydrocarbon content of marine loading vapors to an acceptable level. This section discusses the major vapor control units individually from the aspects of principle of operation, efficiency, safety, cost, and salient considerations.

5.1.1 Refrigeration

Principle of Operation

The refrigeration vapor recovery system recovers the hydrocarbon content of gasoline loading vapors by condensation at cryogenic temperatures and atmospheric pressure. The flow diagram of a refrigeration vapor recovery system is presented in Figure 5.1-1.

The vapors collected from gasoline loading operations are routed into one of two identical vapor processing trains. The gasoline vapors are first cooled in a dehydrator to a temperature of $25^{o}F$ to $35^{o}F$ by direct contact with finned tube cooling coils. A major portion of the moisture and a small portion of the heavier hydrocarbons in the vapors are condensed in the dehydrator. Vapors flow from the dehydrator to the condenser where they are cooled to a temperature of $-80^{o}F$ to

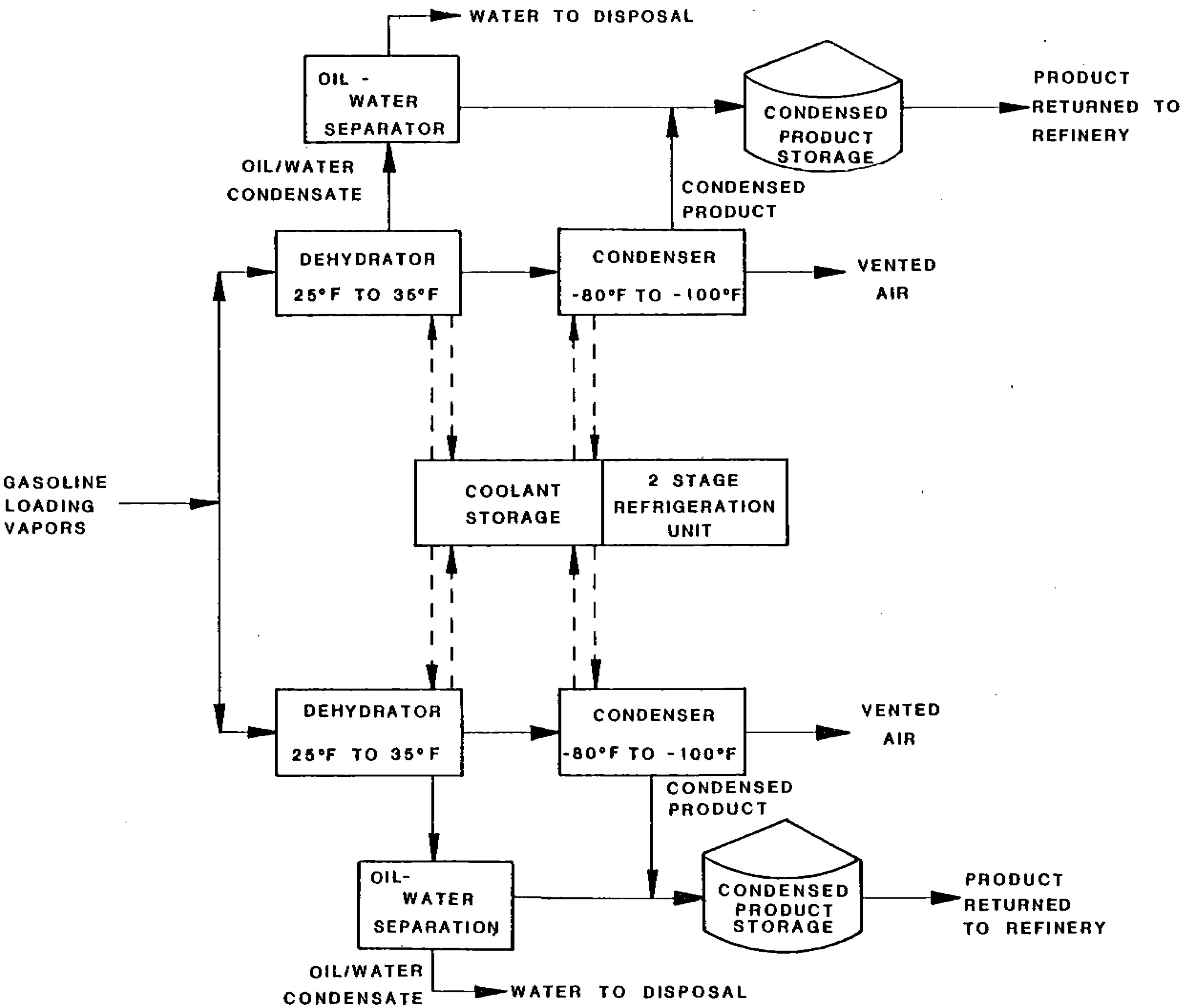


FIGURE 5.1-1 REFRIGERATION VAPOR RECOVERY UNIT

-100°F. Most of the remaining hydrocarbons in the gasoline vapors are condensed in the condenser unless methane is present in the vapors. Condenser temperatures of -100°F will not condense methane, and it will be vented from the condenser along with the treated air.

Water and oil condensates collected in the dehydrator are separated in a gravity oil-water separator. The recovered water is routed to waste water treatment, and the recovered product goes to product storage. Condensed product from the condenser also goes to product storage. The product recovered by the refrigeration vapor recovery unit is primarily composed of propane, butanes, and pentanes. Because of their high vapor pressures, these recovered products must be stored and handled in closed pressurized systems. Recovered product is pumped regularly from product storage back to the refinery.

Refrigeration for the dehydrator and condenser is supplied by a two-stage refrigeration unit. A large volume of cold coolant is stored in the system to supply instantaneous cooling capacity on demand.

Two vapor processing trains are used so that one train can be defrosted without interruption of vapor processing.

The cold air vented from the condenser will create a moisture plume in high humidity weather. To avoid the formation of plumes, some designs incorporate air reheat using waste heat from the refrigeration unit.

Efficiency

The vapor recovery efficiency of the refrigeration vapor recovery unit is directly dependent on the chemical composition of the hydrocarbon vapors, the concentration of the hydrocarbon vapors, and the operating temperature of the condenser. Some companies have identified methane in their marine loading vapors. Very little methane will condense at the condenser temperatures. Refrigeration vapor recovery units in service at tanktruck loading terminals are consistently reducing the hydrocarbon content of gasoline vapors to levels of 3% to 4% by volume. Information from the manufacturer indicates that, excluding methane, the hydrocarbon content of gasoline vapors can be reduced consistently to levels of less than 5% with condenser temperatures of -100°F.

Cost

Itemized costs estimates for the purchase and installation of proposed refrigeration vapor recovery units at existing terminals are presented in Appendix II. Estimates for the bare unit cost of a refrigeration unit range from $300,000 to $470,000 per 10,000 bbl/hr of gasoline loading capacity. Estimates for the installed cost of refrigeration vapor recovery units range from $350,000 to $1,300,000 per 10,000 bbl/hr of gasoline loading capacity. The average installed cost reported by the petroleum industry is $900,000 per 10,000 bbl/hr of gasoline loading capacity. In a separate cost analysis conducted by Radian (Appendix VII) the average installed cost for just the unit was estimated to be $600,000 per 10,000 bbl/hr capacity. Installed costs include such items as foundations, site work, utility hook-up, and instrumentation. Operating costs excluding taxes and depreciation range from $11 to $25 per thousand barrels of throughput.

Safety

The refrigeration vapor recovery unit is considered by many to be the safest among the three vapor control units being considered by industry. The low vapor velocities experienced in the dehydrator and condenser reduce the chance of static charge build-up. All moving and electrical parts are contained in the refrigeration unit and can be positioned well away from the dehydrator and condenser. The extremely cold vapor temperatures also make ignition more difficult. However, the lower explosive limit of a gas is reduced at cryogenic temperatures. This, in effect, widens the range of explosive limits for the gas.

The vapors both entering and exiting the refrigeration vapor recovery unit may be in the explosive range. The positioning of flame arrestors and/or water seal drums on the vapor feed line and vent line of the refrigeration vapor recovery unit may aid in preventing flame fronts from propagating to or from the unit. However, such flame control devices have not been tested for this type of service; therefore, data on their performance is not available. Careful engineering and design must be used in developing a safe and reliable refrigeration vapor recovery unit.

Refrigeration vapor recovery units have been operating very successfully at pipeline terminals for approximately two years. These units, though, have not dealt with the wide ranges of vapor compositions and concentrations to be handled by vapor recovery units in marine terminal application. Marine terminal application will require a ten- to fifteen-fold scale-up in size. No major problems are foreseen with the equipment scale-up, but initial systems will likely be oversized for insurance and will require considerable trial-and-error testing to achieve reliable operation. One of the initial operating problems requiring the testing will be the need for the unit to operate 15-20 hours continuously with minimal pressure drop.

5.1.2 Absorption

Principles of Operation

The absorption vapor recovery unit recovers hydrocarbon from gasoline vapors by absorption into a lean oil stream from the refinery. Figure 5.1-2 presents two lean oil absorption systems under consideration for use in the Houston-Galveston area.

One proposed lean oil absorption system operates at low pressure and ambient temperature. Gasoline loading vapors are compressed to 20 psig by a blower or liquid ring compressor. The compressed vapors then contact a lean oil stream in a packed bed absorber where hydrocarbons in the vapor are absorbed by the lean oil. Projected lean oil flow rates are 500 bbl/hr of lean oil per 1000 acfm of vapor. Purified air is vented from the absorber unless methane is present in the vapors. Lean oil will not absorb methane, and it will pass through the column and be vented with the treated air.

The lean oil source is cat-cracker feed from the refinery. A one-month supply of lean oil is stored on the vapor recovery site. Rich oil laden with light hydrocarbons absorbed in the absorber is recycled to the lean oil storage tanks until the vapor pressure of the lean oil is too high for effective absorption. At such a time, the enriched oil is returned to the refinery and the lean oil storage tanks are replenished with fresh cat-cracker feed.

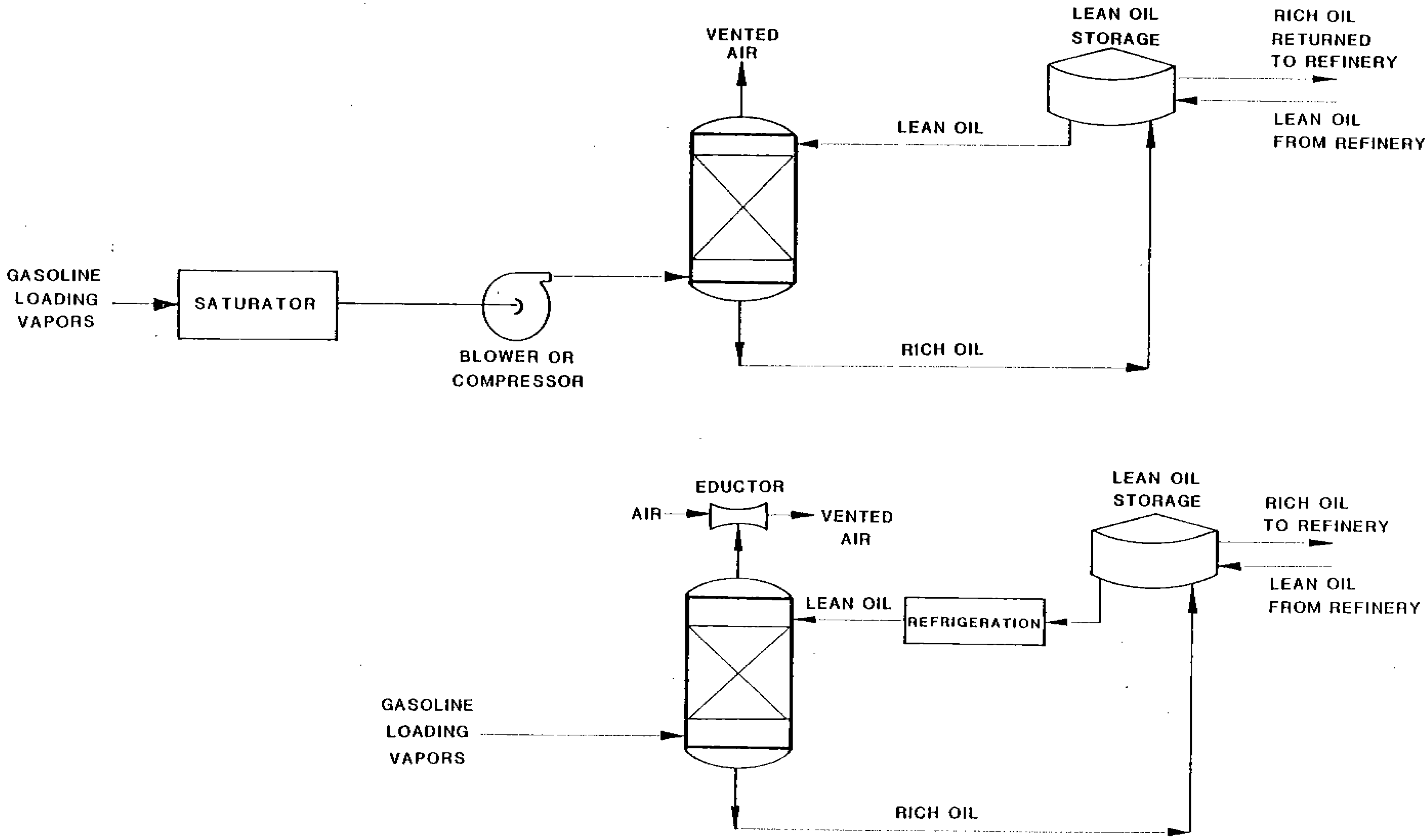


FIGURE 5.1-2 ABSORPTION VAPOR RECOVERY UNITS

In order to avoid some of the potential safety problems which have been associated with blowers and compressors, a second type of lean oil absorption system has been proposed which utilizes air eductors as the primary motive force. Because the use of air eductors results in a slight vacuum in the lean oil absorber, effective absorption requires the use of low temperatures. The lean oil is cooled to 40°F by refrigeration. Lean oil flow rates for the refrigerated absorption vapor recovery unit have been estimated at 200 bbl/hr per 1000 acfm.

Some absorber designs call for constant lean oil flow rates which are in excess of the flow rate required for effective hydrocarbon recovery at maximum loading rates. Other absorber designs include instrumentation and control systems for regulating lean oil flow rates with demand to conserve energy.

Efficiency

The hydrocarbon removal efficiency of absorption vapor recovery systems depends directly on the ratio of the lean oil flow rate to the vapor flow rate. Normally, the hydrocarbon content of gasoline loading vapors can be reduced to less than 5 volume percent with reasonable lean oil to vapor ratios. Some petroleum companies have identified methane in gasoline loading vapors. Lean oil absorbers have very little impact on methane, and methane is expected to pass unaffected through absorption units.

Cost

Itemized cost estimates supplied by industry for retrofitting absorption vapor recovery units are presented in Appendix II. Estimated installed costs for absorption systems range from

$200,000 per 10,000 bbl/hr to $1,000,000 per 10,000 bbl/hr and average $600,000 per 10,000 bbl/hr. A separate cost analysis conducted by Radian (Appendix VII) estimated the installed cost of absorption vapor recovery systems at approximately $600,000 per 10,000 bbl/hr capacity. Vapor collection systems are not included in this cost. The utilities component of the annual operating cost was estimated at approximately $12 per thousand barrels of gasoline loaded.

Safety

Some concern has been expressed for the safety of lean oil absorption systems as with all vapor recovery systems. In general, safety concerns center around the equipment used to force gasoline loading vapors through the absorber. Blowers and fans have been documented as the source of static electrical discharges leading to coal mine explosions. Misaligned bearings and impellor shafts can develop hot spots which serve as ignition sources. Safety problems have also been identified with eductors. Under certain conditions, eductors, like blowers, can also build up static charges.

Enrichment systems which raise the hydrocarbon content above the explosive range have been suggested in some designs, but these put an increased load on recovery systems and result in higher operating utility costs. It should also be noted that enrichment systems protect only the portion of the system which is between the enrichment system and the vapor control unit.

Safety is not an insurmountable problem with absorption systems, but it does require careful engineering and design.

State of Development

Several lean oil absorption systems are in service at pipeline terminals for the control of tank truck loading emissions. Although most of the units are working well, some units are experiencing problems in maintaining required removal efficiencies. The lean oil flow rate necessary for the required hydrocarbon removal is higher than the design flow rate.

Marine terminal absorption units will require a ten to fifteen fold scale-up from the largest pipeline terminal absorption unit now in operation. This large scale-up factor may produce minor problems in initial marine loading absorption units. The pipeline terminal units do not handle the wide variety of vapor concentrations and compositions as the marine terminal units will be subject to. This may add to scale-up problems.

5.1.3 Incineration

Principle of Operation

The incineration vapor control unit reduces the hydrocarbon content of gasoline loading vapors by combusting the hydrocarbons to carbon dioxide and water. The flow diagram of a typical incineration vapor control unit is shown in Figure 5.1-3.

Gasoline vapors from marine loading operations are drawn through a flame arrestor and a saturator. In the saturator gasoline vapors are saturated with hydrocarbons by contact with recirculating gasoline product. Some designs merely call for the enrichment of gasoline vapors beyond the upper explosive level. Some systems also call for propane to be used instead of gasoline as the enrichment source.

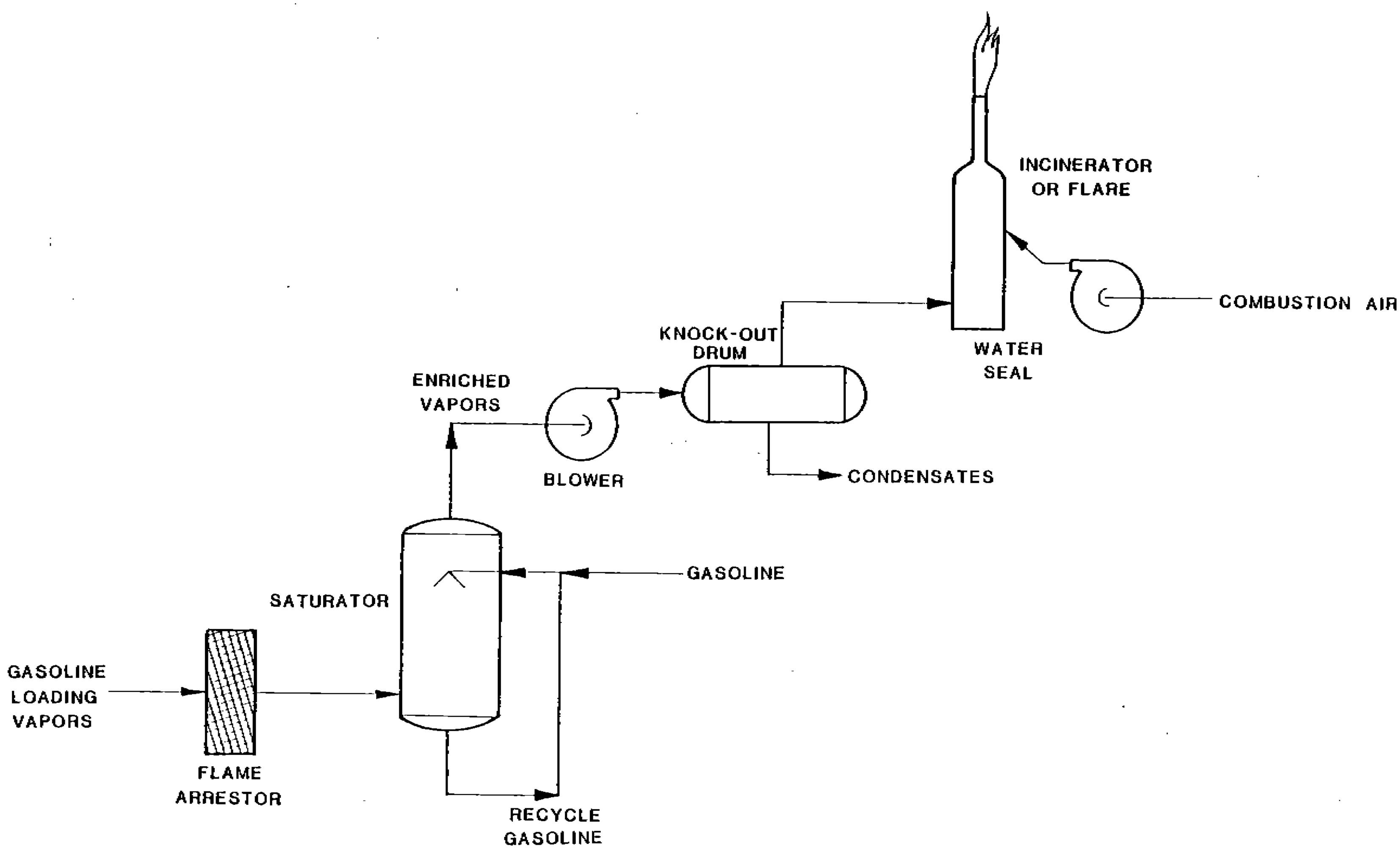


FIGURE 5.1-3 INCINERATION VAPOR CONTROL UNIT

The enriched or saturated vapor is conveyed by blower to a knockout drum where condensates are allowed to settle. From the knockout drum the gasoline vapors enter an incinerator or flare after passing through a water seal. In the incinerator or flare, combustion air is mixed with the gasoline vapors to bring them back into the combustion range. Subsequently, the vapors are combusted.

Incineration units require sophisticated instrumentation and control systems to maintain proper fuel to air ratios for all gasoline vapor flow rates and concentrations. Most incineration unit designs use oxygen analyzers, hydrocarbon analyzers and temperature sensors to control saturator operation and combustion air flow rates.

Efficiency

The efficiency of incineration units for control of gasoline loading vapors is well over 99% based on the hydrocarbon vapors vented from the ship. Hydrocarbon concentrations in the flue gas vented from incineration units are well below 1%.

Cost

Complete cost data is not available on incineration vapor control systems because, tentatively, none of the companies in the Houston-Galveston area have plans to install such systems. Rough cost estimates indicate, however, that the installed cost of an incineration system at an existing terminal range from $300,000 to $400,000 per 10,000 bbl/hr of gasoline loading capacity.

Safety

The presence of a flame in incineration vapor control units is viewed by some as a major safety problem. Although the saturator prevents the possibility of a flame propagating from the incinerator back through the system, a malfunctioning saturator could allow flame propagation back through the system to the ship or barge, causing a major explosion. Water seals at the incinerator or flare base are designed to protect against such occurrences, but their effectiveness has not been established.

The presence of a blower in the incineration system is not expected to present a safety problem because it is positioned downstream of the saturator. Safety problems associated with incineration requires careful engineering and design to develop a safe reliable unit.

State of Development

Incinerators and flares have been used in the petroleum and chemical industry for quite some time. The major components of these systems are generally considered well-developed technology. Incineration systems have also been used for the control of gasoline vapors from tanktruck loading at pipeline terminals.

However, marine terminal incineration systems present unique problems which require saturators and sophisticated instrumentation. The effectiveness of this equipment remains to be demonstrated.

5.1.4 Alternative Vapor Recovery Units

There are two other commonly used vapor recovery units which are not currently being considered for the Houston-Galveston area primarily because of safety reasons.

The first of these units is the compression-refrigeration-condensation (CRC) unit which recovers hydrocarbon vapors by condensation at low temperature and moderate pressure. The moderate pressures used in CRC systems are supplied by multi-stage compressors. Although a saturator is used in the system, the multi-stage compression of hydrocarbons in the presence of oxygen is considered by many to be a significant safety risk.

A second vapor recovery unit which is not currently being considered for use on marine loading emissions in the Houston-Galveston area is carbon adsorption. In a carbon adsorption unit gasoline loading vapors are passed through a carbon bed, and the hydrocarbon constituents in the vapors are removed by adsorption onto the carbon. Adsorption is an exothermic reaction which could possibly serve as an ignition source in marine loading vapor control systems.

As the carbon bed becomes saturated with hydrocarbons, its removal efficiency drops, and the bed must be reclaimed. Normally, carbon beds are reclaimed by using steam stripping and a vapor recovery unit. The need for a vapor recovery unit in addition to the carbon adsorption unit results in high capital costs for carbon adsorption systems.

5.1.5 Vapor Control Unit Installation

The installation of a vapor control unit is a quite involved process. The units must be placed on a firm foundation. Designs for the Houston-Galveston area generally include construction of pier supported concrete foundations for the vapor control unit.

Different vapor control units may require utilities including compressed air, water, electricity, lean oil, steam, enrichment gas, and wastewater sewers. These utilities must be run out to the unit site and hooked up.

Additional items which must be installed in conjunction with vapor control units include raods, control houses, sumps, and fire protection equipment. Operators and maintenance people must also be provided for the vapor control unit.

5.1.6 Inerting

Inerting systems replace the oxygen rich air residing in the vapor space of cargo tanks with inert, oxygen deficient flue gas. The flue gas is obtained from either the ship exhaust or from the exhaust of a special fuel burner. Prior to their use in the cargo tanks, the inert exhaust gases are passed through a water scrubber where they are cooled and cleaned. Currently the very large crude carriers (VLCC's) utilize inerting systems. Inerting their cargo tanks is considered by the marine industry to be the safest way of operating them.

Vapor inerting has been proposed by some as a possible means of solving the safety problems which potentially exist with the collection and processing of explosive vapor mixtures.

However, most petroleum companies have expressed strong doubts about the effectiveness of inerting systems.

If operating properly, inert gasoline vapors are collected and transferred to shore where they can be processed with a very minimal chance of an explosion or fire. Inerting systems are much less energy intensive than either vapor dilution systems or vapor saturation systems.

Some disadvantages of using inerting systems include (1) potential errosion problems due to sulfuric and sulfurous acids generated from combusting fuel oils containing sulfur, (2) added personnel and equipment expenses, (3) extreme hazard potential if operating problems introduce hot exhaust into cargo tanks, (4) the false sense of security created by inerting systems, (5) potential cargo contamination with CO_2 in the inert gas, and (6) increased hydrocarbon emissions.

Despite these disadvantages, inert gas systems on board the tanker or on the dock hold some potential to reduce the safety risks involved in marine terminal VRU.

5.1.7 Composite Vapor Profile

The composite vapor profile discussed in Section 4.1.5 has a significant impact on the efficiency of vapor recovery units. During portions of a clean vessel loading, the hydrocarbon concentration in the composite vapors is likely to be below 5 vol %. This phenomena is depicted in Figure 5.1-4. Vapor recovery units are designed primarily to reduce the hydrocarbon content of concentrated vapors to a concentration of less than 5 vol %. This situation complicates attempts to calculate the net reduction of hydrocarbons achieved by controlling marine facilities loading relatively clean vessels.

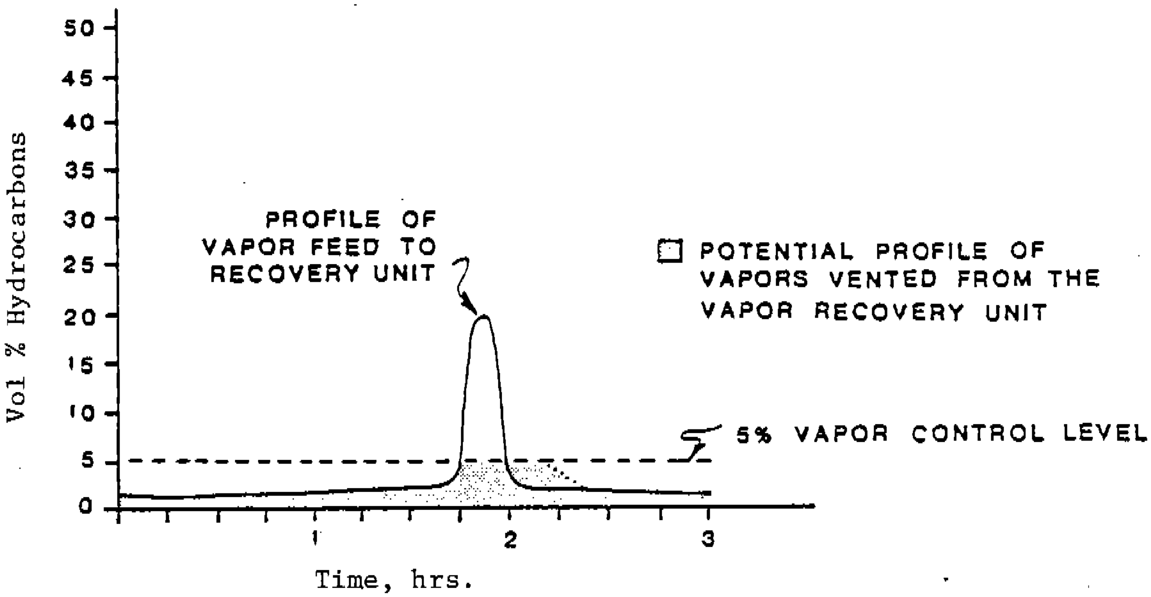


FIGURE 5.1-4 VAPOR PROFILES OF THE FEED AND PRODUCT OF A VAPOR RECOVERY UNIT

The principle of vapor recovery is further complicated with refrigeration systems which may retain small quantities of condensed hydrocarbons on its condensation coils. Subsequent loading of a clean cargo tank with an arrival hydrocarbon component of less than 5 vol % may result in re-evaporation of residual hydrocarbons on the condensation coils into the vented vapors. However, the re-evaporation cannot exceed the equilibrium concentration of the vapor recovery unit which is conservatively set at some point below 4 vol %.

It should also be noted that although re-evaporation may take place, with a properly operating vapor recovery unit, there will be a net recovery of hydrocarbons, and the hydrocarbon concentration in the vapors vented from the recovery unit will never exceed 5 vol %.

With respect to absorption control units a similar problem might exist. Clean vapors may be capable of stripping some hydrocarbons from the lean oil.

5.2 Shoreside Vapor Collection

Shoreside vapor control systems include a vapor collection system which conveys the gasoline loading vapors collected onboard the ship to the shoreside vapor control unit. This section presents the design, cost, and safety aspects of several shoreside vapor collection systems proposed for the Houston-Galveston area.

5.2.1 Design

The function of shoreside vapor collection systems is to safely and efficiently convey gasoline vapors collected onboard marine vessels to the shoreside vapor control unit. Figure 5.2-1 presents the flow diagram of a typical vapor collection system.

The ship to shore connection which conveys the collected gasoline vapors to shore can be made by either a flexible rubber hose or a hinged loading arm. Flexible hoses and loading arms are both currently used at marine loading terminals to load gasoline and will be compatible with current marine equipment. Projected hose and loading arm diameters range from 8 inches to 16 inches.

Following the ship to shore connection, most vapor collection system designs incorporate either flame arrestors or water seal drums which may inhibit the propagation of an explosion from either the vessel to the shore or from the shore to the vessel. Their effectiveness, as discussed earlier, is questionable.

After passing through a flame arrestor or water seal drum, the gasoline vapors are conveyed by large diameter piping to the vapor control unit. Several docks may be manifolded into a single vapor collection line, or each dock may use a separate vapor collection line to convey vapors to the central vapor control unit. Some vapor collection system designs also specify the use of separate vapor control units on each dock. If the vapor collection line traverses a long distance or is exposed to potential hazards, a second flame arrestor or water seal drum may be installed immediately before the vapor control unit. If shipside precautions have not been taken against possible tank overfills, an overflow sump may be needed on the dock for the purpose of catching overflows and keeping the vapor collection line free of liquid. In the case of a spill the sump could pose a substantial fire hazard.

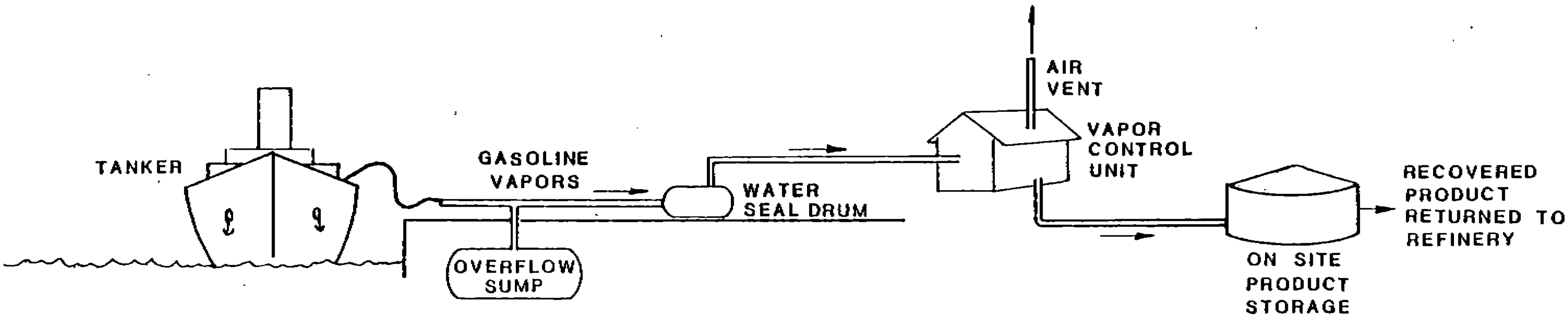


FIGURE 5.2-1 TYPICAL VAPOR COLLECTION SYSTEM

A major distinguishing characteristic of vapor collection systems is their means of inducing vapor flow. Vapor flow may be induced by displacement or by vacuum. In displacement systems, gasoline vapors are forced out of the ship or barge tank and through the collection system by the gasoline entering the tank. Displacement vapor collection systems require that there be very little pressure drop in the system to impede the flow of vapors. The displacement system also requires that vessels use closed gauging systems in that the opening of gauging hatches would release vapors from the tanks to the atmosphere and prevent their recovery. Liquid overfill of a cargo tank can cause structural damage to the ship and poses a potential for water pollution.

Vacuum collection systems utilize a blower or eductor to draw vapors from the vessel tanks and through the vapor collection system. Steam, air, and solvent eductors have been proposed. Vacuum systems allow the use of open-hatch gauging because the vessel tank will be at a negative pressure, preventing the possible escape of gasoline vapors. The chance of tank overfills and gasoline spills is considered more remote when open gauging is used. However, the presence of an eductor or a blower in the vacuum collection system presents the potential safety problem of static charge build-up. Both means of moving vapors have been associated with igniting explosions.

Different types of vapor recovery units have different magnitudes of pressure drop associated with them. For instance, refrigeration systems have relatively small pressure drops while the absorption and incineration units have relatively high drops. This makes vacuum collection systems necessary for absorption and incineration systems, and thus allows for open-hatch loading. However, closed-hatch loading with resulting cost and safety advantages is feasible with refrigeration systems.

5.2.2 Efficiency

In a properly functioning vapor collection system, no vapors will be lost from the system. All vapors will be conveyed from the marine vessel to the vapor control unit.

5.2.3 Cost

Itemized cost estimates provided by the petroleum industry for the installation of vapor collection systems at existing terminals are presented in Appendix II. Projected cost estimates range widely from $100,000 to $2,000,000 per 10,000 bbl/hr of gasoline loading capacity. The averaged projected cost was approximately $1,000,000 per 10,000 bbl/hr gasoline loading capacity. In an independent cost study Radian Corporation estimated the cost of the vapor collection system to be approximately $200,000 per 10,000 bbl/hr loading capacity.

5.2.4 Safety

The gasoline vapors conveyed through the vapor collection system will be in the explosive range during a significant portion of ship and barge loading operations. A fire or explosion on either the ship or the vapor control unit could be spread through the vapor collection system to other ships, barges, or vapor control units. A leak in the vapor collection piping would also present a safety problem.

It has been suggested that flame arrestors and water seal drums be positioned at the junctions between the vapor collection system and marine vessels and between the vapor collection system and vapor control units. These safety precautions would prevent the vapor collection system from becoming a mechanism for spreading fire. Water seal drums can also be equipped with internal chemical fire extinguishers. However, flame arrestors and water seal drums reportedly have not been tested for this magnitude of flow and variability of conditions.

Blowers and eductors have been cited as sources of static electrical discharges and present a potential safety problem. The positioning of blowers downstream from saturators greatly reduces these potential safety problems.

As an added safety precaution, some control system designs isolate each ship and barge by providing individual vapor control units for each vessel being loaded.

Although the presence of explosives and combustible vapors in vapor collection systems presents many potential safety problems, preliminary investigations indicate that such technology exists to construct safe vapor collection systems. However, the designs are preliminary and the costs may be subject to increases.

5.2.5 State of Development

The technology for designing a vapor collection system is well developed. Significant questions remain as to how much safety equipment is required to construct a safe system. It is anticipated that initial systems may be overdesigned until marine vapor control technology is refined.

5.3 Shipside Vapor Collection

The shipside vapor collection system is a network of vapor piping installed on ships and barges for the purpose of collecting and transporting to shore vapors generated by gasoline loading operations. This section presents the design, cost, safety, and state of development for ship-side vapor collection technology.

5.3.1 Design

The flow diagram for a typical ship-side vapor collection system is presented in Figure 5.3-1. Vapors generated by gasoline entering the tank are collected in the ullage dome and conveyed through vapor collection lines to a vapor collection header. All loading vapors are routed to the vapor collection header which then transports the vapors to the shoreside vapor control system. Block valves are provided on each vapor collection line such that individual tanks loading nonvolatile products can be isolated from the vapor control system. The loading of heavy oils in clean tanks produces insignificant emissions which need not be processed by the vapor control unit. Some collection systems also call for spill valves on each ullage hatch which will drain spills and prevent liquid from clogging the vapor collection header.

Vapor flow into the vapor collection system can be induced either by displacement forces or by vacuum forces. In displacement systems, vapors residing in the cargo tank are displaced into the vapor collection system by the gasoline entering the cargo tank. All tank openings other than the vapor collection line must remain closed throughout the tank loading. The ullage cap cannot be opened for tank gauging. In vacuum systems a compressor or blower onshore draws a vacuum in the vapor collection system, which in turn, pulls vapors from the vessel tanks and conveys them to the vapor control unit. Because the vacuum system creates a slight vacuum in the vessel tanks, ullage hatches can be opened for tank gauging without loss of vapor.

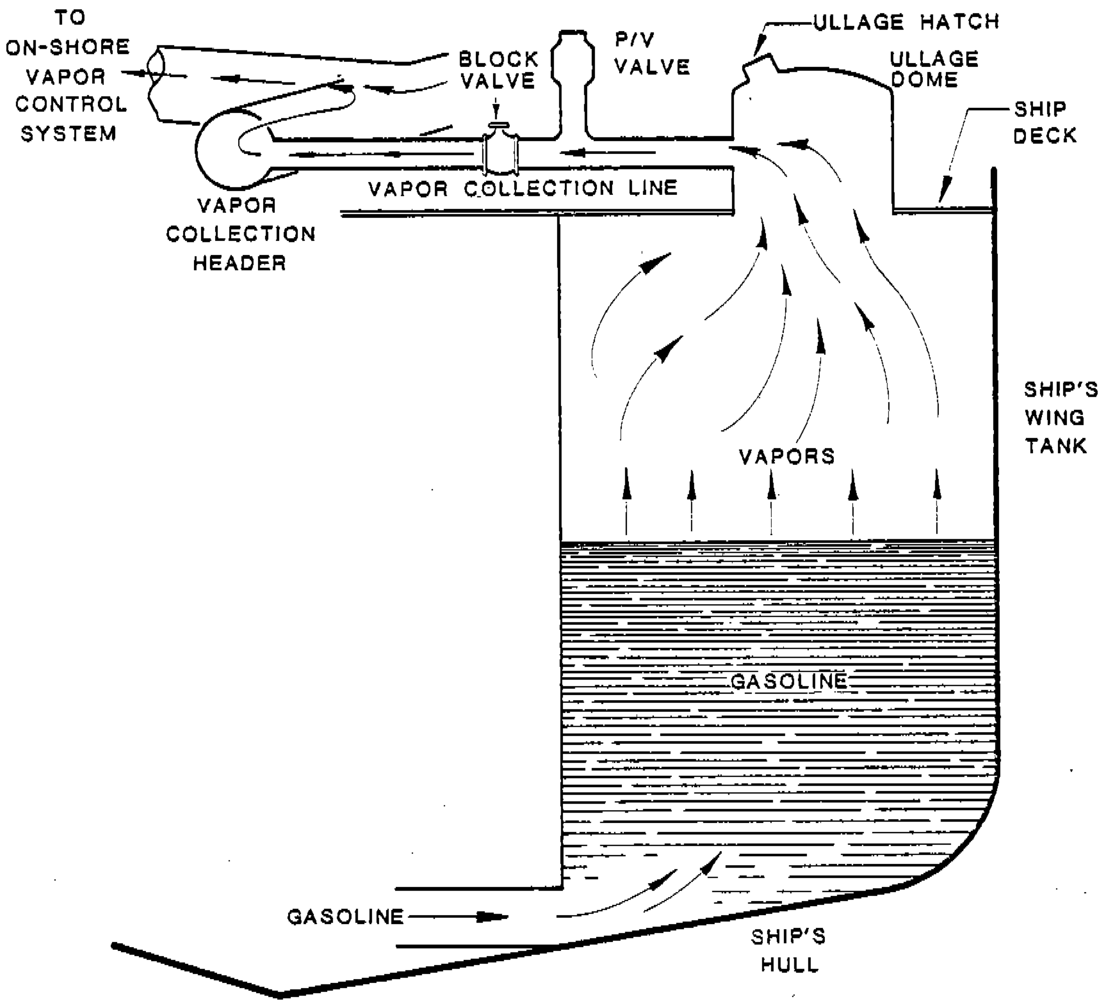


FIGURE 5.3-1 SHIP-SIDE VAPOR COLLECTION SYSTEM

Regardless of size and construction materials, ship and barge tanks are not capable of withstanding large pressures or vacuums without warping. Normally, ships and barges are rated for a -0.5 psig vacuum. Most ships are rated for a pressure of 2.0 to 2.5 psig and most barges are rated for a pressure of 1.5 psig. To insure against over pressuring or drawing excess vacuums, a pressure/vacuum valve is positioned in each vapor collection line. The pressure/vacuum valve is designed to release excessive pressures or vacuums which may occur in malfunctioning vapor collection systems before ship or barge damage occurs.

5.3.2 Efficiency

The vapor collection efficiency of the ship-side vapor collection system is expected to be 100%. All hydrocarbon vapors generated during gasoline loading will be conveyed to the onshore vapor control system.

5.3.3 Cost

Projected costs for the installation and operation of vapor collection equipment onboard ships are presented in Appendix II. The estimated installation costs for ships generally ranged from $300,000 to $350,000 per vessel. The estimated installation costs for shallow barges ranged from $50,000 to $85,000 per vessel. The single projected installation cost for deep-draft ocean barges was $150,000 per vessel. In addition to the installation costs, operating costs have also been projected for maintaining onboard collection equipment and accounting for the extra labor and time required to load controlled ships. The projected operating costs for ships is $110,000 per ship-year and for barges is $36,000 per barge-year.

5.3.4 Safety

The potential for loading accidents onboard ships is increased by the use of vapor collection systems. However, there are safety devices which can be installed to greatly reduce the potential of accidents. A system of pressure/vacuum valves can be installed to guard against the formation of excessive pressures or vacuums in the cargo tanks. Routine maintenance of pressure/vacuum valves will insure their proper performance. The risk of contaminating other cargoes by tank overflows into the vapor piping is minimized by the use of overflow valves. Equipping each tank with two level gauges and a high level alarm gives added protection against tank overfills. Ships can be isolated from shore-side fires and explosions by positioning water seal drums in the vapor collection piping between the ship and shore-side vapor control equipment.

5.3.5 Salient Considerations

The installation of vapor collection systems on all ships loading gasoline will require a significant effort to insure that all ships and shore-side facilities install compatible systems. Ship-to-shore connections must be compatible with each other. Problems may also arise if ships designed for vacuum vapor collection attempt to load at terminals designed for the displacement system, and vice-versa.

The time required to retrofit a ship or barge with vapor collection equipment is approximately two weeks. Most vessels are scheduled for dry docking and repairs on a two-year cycle. Therefore, it is estimated that two years will be required for the complete retrofitting of all ships with vapor collection equipment within a ship's normal maintenance schedule.

5.4 Alternative Control Strategies

Several alternative control strategies have been proposed for controlling gasoline loading vapors. At this time, however, none of these control strategies look favorable.

5.4.1 Ullage Hatch Condensers

Ullage hatch condensers are a set of refrigeration coils located under the ullage dome and designed to condense hydrocarbon compounds from gasoline vapors vented through the ullage hatch. The refrigeration coils would be maintained at a temperature of -100°F by a refrigeration unit located either onboard the ship or on the dock. The need for conveying explosive mixtures onto shore for recovery is eliminated by the use of ullage hatch condensers. Drawbacks to the use of ullage hatch condensers include (1) the high cost of retrofitting each ullage hatch of each barge and ship with condensing units, (2) the restricted access of ship personnel to the vessel tanks caused by ullage hatch condensers, (3) the questionable efficiency of ullage hatch condensers because of the short contact time between fast flowing gasoline vapors and condenser coils, and (4) difficulty in defrosting the coils while loading the tanks.

5.4.2 Ship Boiler Incineration

Ship boiler incineration systems would incinerate gasoline loading vapors in much the same manner as shoreside incineration units described in Section 5.1.3. Explosive vapors would not need to be transported to shore for processing with the ship boiler incineration system. However, the risk of combusting explosive vapors in the ship's boiler is considered very high. Loading rates would also have to be greatly reduced because of the limited capacity of ship boiler systems.

5.4.3 Foam

Foam systems have been developed which cover liquid surfaces and effectively reduce hydrocarbon evaporation. In the proposed foam system, a shallow layer of foam would be placed in each tank before filling. As the gasoline cargo is pumped into the tanks, the foam floats on its surface, preventing the evaporation of hydrocarbons into the vented vapors. Although foam systems were effective in reducing hydrocarbon vapors, the foam left an intolerable scum in the gasoline product.

5.4.4 Product Cooling

Systems based on the reduction of hydrocarbon vapors by cooling the product prior to loading have also been investigated. Gasoline would have to be cooled to $0^{\circ}F$ in order to reduce the hydrocarbon concentration in loading vapors to 5%. The cooling load required to lower the temperature of gasoline to $0^{\circ}F$ is cost-prohibitive.

5.4.5 Controlled Loading

One proposed control technique involves the combination of ship cleaning and loading rate control. While at sea, the ship or barge would thoroughly clean and devapor each cargo tank to be loaded with gasoline. Effective tank cleaning can be accomplished by double ballasting or by butterworthing. When loading gasoline, the first three feet would be loaded slowly so as to minimize gasoline vapor generation. The balance of the tank would be rapidly loaded and loading would be terminated three feet from the tank roof, thus, preventing the venting of the vapor blanket which forms above the gasoline surface. Baffles can be placed in the tank to prevent sloshing, thus maintaining ship stability.

The efficiency of the controlled loading system has not been determined, but the system is potentially capable of lowering the hydrocarbon content of gasoline loading vapors to a maximum of 4-7 vol %.

6.0 ECONOMICS OF EMISSION CONTROLS

The economics of installing hydrocarbon emission controls on existing marine terminals in the Houston-Galveston area are very difficult to establish. Each marine terminal involved is confronted with unique problems. There are also wide variations in the estimated costs associated with marine terminal controls because currently there are no marine terminals equipped with gasoline loading controls. The unique arrangements required to control gasoline vapors from marine loading prohibit the direct translation of cost data from truck loading control technology to marine loading control technology.

Section 6.1 presents the cost evaluation techniques used by Radian to evaluate the cost effectiveness of marine terminal vapor control systems and to assess the sensitivity of control costs to unique situations in the Houston-Galveston area. Section 6.2 discusses the results of Radian's cost effectiveness and sensitivity study.

6.1 Establishment of Cases

The wide variety of marine terminal operations in the Houston-Galveston area combined with the wide range of projected control system costs greatly complicate the task of evaluating the cost effectiveness and economic impact of installing marine terminal controls. In an attempt to simplify this task, it was decided to develop cost evaluations for several typical situations which might occur in the Houston-Galveston area.

Table 6.1-1 presents statistics on the vapor recovery systems proposed by the six major shippers of motor gasoline in the Houston-Galveston area. Marathon Oil Company and Texas City Refining Inc. share dock facilities and propose to construct a

TABLE 6.1-1

STATISTICS ON THE PROPOSED HOUSTON-GALVESTON VAPOR RECOVERY SYSTEMS

Petroleum Company	1975 Marine Facility Throughput 10^6 bbl/yr	Projected Recovery Unit Size 10^3 bph	No. of Vessels to be Modified by Company		Volume of Gasoline Transported 10^6 bbl/yr		Refinery Crude Capacity 1975 10^3 bbl/cd
			Ships	Barges	Ships	Barges	
Exxon	33.5	50	9	6	27.3	6.2	390
AMOCO	20	18	3	0	12	8	333
Shell	16.6	25	7	0	16.6	0	294
Marathon/TCR	12.3	30	0	0	4.5	7.8	150
ARCO	3.9	16	2	0	3.5	0.4	213

Note: 1. AMOCO has 35 barges on charter which will pass modification costs on to AMOCO as a charter price increase.

jointly owned vapor recovery system. Projected recovery unit sizes range from 16 to 50 thousand barrels-per-hour vessel loading rate. The ratio of vapor recovery unit size to marine terminal throughput ranges from 1 to 4 bph per 10^3bbl/yr. The number of company owned vessels which must be modified varies greatly in the H-G area. Many companies charter or contract shipping vessels and will not be required to put forth the initial capital outlay to modify marine vessels. There is also a wide variation in the split between the volume of gasoline transported by tanker and the volume of gasoline transported by barge among the H-G marine terminals. From 0% to 60% of a company's marine transported gasoline may be transported by barges.

In addition to variations in the statistics on proposed vapor control systems, there are also wide variations in the estimated costs for marine loading vapor control systems. Table 6.1-2 summarizes projected cost data for the installation and operation of marine loading vapor control systems. Installed capital costs for all shoreside portions of marine loading vapor control systems ranged from 0.5 to 3.5 million dollars per 10,000 bph capacity on comparable units. The average of the shoreside system capital costs supplied by industry appeared to be 2 million dollars per 10,000 bph capacity. An independent Radian cost study estimated the total shore side system capital costs to be $800,000 per 10,000 bph capacity. The variations in projected ship modification costs ranged from 0.15 to 1.0 million dollars per ship, and averaged approximately 0.35 million dollars per ship. Estimates of barge modification costs more closely centered around $67,000 per barge. Annual operating costs reported in Table 6.1-2 comprise maintenance and utility costs. The annual operating costs for the shoreside portion of vapor recovery systems are projected to range from $11 to $25 per thousand barrels transferred. The average projected cost was $15 per thousand barrels. Only one source projected operating costs for the onboard portion of the vapor collection system, and they were $110,000 per ship and $36,000 per barge.

TABLE 6.1-2

SUMMARY OF COST DATA FOR MARINE TERMINAL CONTROLS

	Range	Average	Radian Study
Installed Capital Costs			
Vapor Recovery Units (10^3\$/10^4 bph)	300 - 1300	800	600
Vapor Collection System (10^3\$/10^4 bph)	100 - 2000	1000	200
Ship Modifications (10^3\$/ship)	150 - 1000	325	-
Barge Modifications (10^3\$/barge)	50 - 85	67.5	-
Ocean Barge Modifications (10^3\$/barge)	-	150*	-
Annual Operating Costs			
Vapor Recovery Systems (\$/10^3 bbl)	11 - 25	15	-
Vapor Collection Systems	neg	neg	-
Ship Collection Systems (\$/ship)		110,000*	-
Barge Collection Systems (\$/barge)		36,000*	-

* Only one value was given in these cost categories

Based upon the information presented in Table 6.1-1 and Table 6.1-2, Radian selected ten unique cases for which to develop cost information. Table 6.1-3 presents these ten cost cases. These ten cases incorporate the variations expected among the vapor control systems proposed for marine terminals in the Houston-Galveston area. Case 1 represents the median among the marine terminals and proposed control systems and, therefore, should also represent the aggregate of the Houston-Galveston marine terminals.

Six parameters are varied among the ten cost cases. The ratio of recovery unit size to terminal throughput is varied from 1 to $4x10^3$bph/10^6bpy. The projected capital costs of the shoreside systems range from \$0.80 to \$$3.0x10^6$/$10^4$bpd. Ship and barge modification costs range from \$325,000 and \$68,000 per vessel, respectively, to \$650,000 and \$136,000 per vessel, respectively. Annual operating costs range from \$15 to \$25 per barrel transferred. The operating costs projected by one company for onboard control equipment were omitted because of their uncertainty. The volume ratio of gasoline transported by ships/barges ranges from equal volumes transported by ships and barges to all gasoline transported by ships.

The vessel modification optimization efficiency reported in Table 6.1-3 is an attempt to account for all of the ships and barges which will require modification. Although most barges and many ships loading gasoline in the Houston-Galveston area are not owned by the petroleum companies, the costs for their modification will be passed on to the refineries either directly or indirectly. The task of determining how many vessels will require modification per company is complicated by the fact that many vessels call at more than one Houston-Galveston terminal during the year. Data from Exxon and Shell indicate that a typical ship transports $5x10^6$bbl/yr, and a typical barge transports $0.4x10^6$bbl/yr.

TABLE 6.1-3

SUMMARY OF CASE PARAMETERS

Case	Ratio of Recovery Unit Size to Terminal Throughput (10^3bph/10^6bpy)	Capital Cost of Shoreside System (10^6\$/10,000 bph)	Capital Cost of Vessel Modification (10^3\$/ship:10^3\$/barge)	Annual Operating Cost of Recovery Unit (\$/10^3bbl)	Volume Ratio of Product Transported by Ships/Barges	Efficiency in Vessel Modification Optimization (%)
1	2	0.8	325:68	15	3	50
2	2	2.0	325:68	15	3	50
3	2	3.0	325:68	15	3	50
4	1	0.8	325:68	15	3	50
5	4	3.0	325:68	15	3	50
6	2	0.8	325:68	15	1	50
7	2	0.8	325:68	15	all ships	50
8	2	0.8	325:68	15	3	75
9	2	0.8	325:68	25	3	50
10	2	0.8	650:136	15	3	50

These estimates were combined with the total volumes of gasoline transported by ship and by barge and the vessel modification optimization efficiency to provide a projected number of ships and barges which must be modified.

6.2 Methodology

The methodology used to calculate the cost and effectiveness of each case is discussed in this section. Table 6.2-1 presents the results of these calculations.

The cost and effectiveness calculations used to evaluate each cost case are based upon a terminal throughput of 10×10^6 bbl/yr of gasoline. Standardizing marine terminal throughput will not impact the relative cost effectiveness of the cost cases; yet it will put all results on a common basis.

All annualized capital costs developed for the vapor control systems are based upon a service life of 15 years and an annual interest rate of 12%. Although various portions of the vapor control systems have shorter service lives, it is believed that the major capital components of vapor recovery systems do have a service life of 15 years. It is also true that prime interest rates are lower than 12%; however, the before tax investment potential of petroleum industry capital is likely to be in the range of 12% or better. The annualized cost factor was calculated to be 0.147.

The quantity of gasoline recovered by application of vapor controls on marine loading of gasoline is assumed to be 0.5 lb/10^3gal transferred for ships and assumed to be 3.0 lb/10^3 gal transferred for barges. These two values were based on the following information. Uncontrolled hydrocarbon emissions from

TABLE 6.2-1

RESULTS OF STUDY ON VAPOR RECOVERY ECONOMICS

Cost Case	Marine Terminal Throughput (10^6 bbl/yr)	Capacity of Vapor Recovery Unit (10^3 bbl/hr)	Shore-side Capital Cost (10^6 \$)	Annualized Shore-side Cost (10^3 \$)	Annual Operating Cost of Recovery Unit (10^3 \$)	Volume Loaded Ship/Barge (10^6 bpy/10^6 bpy)	Quantity of Gasoline Recovered (10^3 lbs/yr)	No. of Ships/Barges Modified	Vessel Capital Cost (10^6 \$)	Annualized Vessel Capital Cost (10^3 \$)	Total Capital Costs (10^6 \$)	Total Annual Costs (10^6 \$)	Initial Capital Investment (\$/bbl loaded)	Cost Effectiveness (\$/ton recovered)	Economic Impact (\$/bbl loaded)
1	10	20	1.6	235	150	7.5/2.5	462	3/13	1.9	279	3.5	0.66	0.35	2900	0.07
2	10	20	4	588	150	7.5/2.5	462	3/13	1.9	279	5.9	1.02	0.59	4400	0.10
3	10	20	6	882	150	7.5/2.5	462	3/13	1.9	279	7.9	1.31	0.79	5700	0.13
4	10	10	0.8	118	150	7.5/2.5	462	3/13	1.9	279	2.7	0.55	0.27	2400	0.06
5	10	40	12	1764	150	7.5/2.5	462	3/13	1.9	279	13.9	2.19	1.39	9500	0.22
6	10	20	1.6	235	150	5/5	756	2/25	2.3	338	3.9	0.72	0.39	1900	0.07
7	10	20	1.6	235	150	10/0	210	4/10	1.3	191	2.9	0.58	0.29	5500	0.06
8	10	20	1.6	235	150	7.5/2.5	462	2/9	1.3	191	2.9	0.58	0.29	2500	0.06
9	10	20	1.6	235	250	7.5/2.5	462	3/13	1.9	279	3.5	0.76	0.35	3300	0.08
10	10	20	1.6	235	150	7.5/2.5	462	3/13	3.8	558	5.4	0.94	0.54	4100	0.09

vessel loading in the Houston-Galveston area may average 1.3 $lbs/10^3 gal$ transferred for ships and 4 $lbs/10^3$ gal transferred for barges. Controlled hydrocarbon emissions for ships will be below the 1 $lb/10^3$ gal proposed by regulation because the arrival vapors of many clean ships contain less than 0.1 $lb/10^3 gal$. Therefore, the controlled hydrocarbon concentration for ships was assumed to be 0.8 $lb/10^3 gal$. This phenomena is discussed further in Section 4.1.5. The controlled hydrocarbon emissions from barge loading were assumed to be the maximum allowed by the proposed regulation, or 1.0 $lb/10^3 gal$ throughput.

The number of ships and barges which require modification was calculated from the volumes of gasoline transported by ship and by barge assuming that a typical tanker transports $5x10^6$ bbl per year, and a typical barge transports $0.4x10^6$ bbl per year. These two factors were derived from data supplied by Exxon and Shell on their marine vessel movements. The number of ships and barges calculated from the factors was divided by a scheduling efficiency factor which accounts for extra vessels requiring modification because of scheduling inefficiencies.

6.3 Results

The cost effectiveness and economic impact of applying marine terminal vapor controls can be evaluated by studying the results of the ten cost cases which are summarized in Table 6.2-1.

6.3.1 Base Case

Cost case 1 is the base case and represents what appears to be both the typical vapor recovery system and the aggregate vapor recovery technology which will be applied in the Houston-Galveston area. Input data for the 10 million barrel per year gasoline terminal in case 1 include the following:

- 20,000 barrel per hour gasoline loading rate.
- 1.6 million dollar capital cost for shore side equipment (based on results of a Radian cost study).
- 7.5 million barrels per year of gasoline is transported on 3 ships.
- 2.5 million barrels per year of gasoline is transported on 13 barges.
- 462 thousand pounds of gasoline per year is recovered by the recovery unit.
- Vessel modification costs (based on industry data) are 325 thousand dollars per ship and 68 thousand dollars per barge.

Based on construction cost estimates developed in the Radian cost study (Appendix VII), the total capital investment of the base case vapor recovery system is approximately 3.5 million dollars or 0.35 dollars per yearly barrel of marine terminal capacity. The annual capital cost of the vapor recovery system amortized over the expected equipment life is 514 thousand dollars; the annual operating cost is approximately 150 thousand dollars. These data yield a total annual cost for the case 1 vapor recovery system of approximately 0.7 million dollars. The net cost effectiveness of the case 1 vapor recovery unit is estimated to be 2900 per ton of hydrocarbon recovered. The net economic impact of the case 1 vapor recovery unit is estimated to be 0.07 per barrel of gasoline loaded at the terminal.

6.3.2 Sensitivity to Cost Inputs

A wide range was observed in the capital cost estimates provided by industry for marine terminal vapor recovery systems. Industry cost estimates for total shoreside capital costs ranged from a low of approximately $500,000 per 10,000 bbl/yr loading capacity to a high of approximately $3,500,000 per 10,000 bbl/yr loading capacity. The Radian vapor recovery system cost study estimated the total shoreside capital costs to be approximately $800,000 per 10,000 bbl/yr. The predominantly higher petroleum industry cost estimates are assumed to incorporate high contingency factors to account for possible scale-up problems associated with the construction of the first marine vapor recovery systems. Cost Case 1 utilizing the Radian capital cost estimate also represents the lower range of industry cost estimates. Case 2 and Case 3 were designed to investigate the sensitivity of the cost effectiveness and economic impacts projected in Case 1 to the higher capital costs reported by the petroleum industry. In Case 2 the shoreside vapor recovery system capital costs were estimated to be 2 million dollars per 10,000 bph of capacity or 4 million dollars. This figure represents the median range of industry-reported capital costs for vapor recovery systems in the Houston-Galveston area. Table 6.2-1 indicates that the cost effectiveness of Case 2 would be $4,400 per ton of hydrocarbons recovered, and the economic impact of Case 2 would be $0.10 per barrel of gasoline loaded.

In Case 3 the shoreside vapor recovery system capital costs were estimated to be 3 million dollars per 10,000 bph of gasoline loading capaicty, or 6 million dollars. This case represents the upper range of capital costs reported for the proposed vapor recovery systems in the Houston-Galveston area.

The cost effectiveness of case 3 is estimated to be \$5700 per ton of hydrocarbons recovered and the economic impact is estimated to be \$0.13 per barrel of gasoline loaded.

Case 10 investigated the effect of doubling the cost of vessel modifications. Ship modification costs were inputted as 650 thousand dollars per vessel and barge modification costs were inputted as 136 thousand dollars per vessel. Table 6.2-1 indicates that the cost effectiveness of Case 10 is \$4100 per ton of hydrocarbons recovered and the economic impact is \$0.09 per barrel of gasoline loaded. Although most cost data indicate that vessel modification costs will probably be much closer to the base case cost than the case 10 cost, it is apparent that changes in vessel modification costs have as large an impact on cost effectiveness and economic impact as changes in shoreside capital cost.

Case 9 investigates the impact of a vapor recovery system operating cost at \$25 per thousand barrels instead of \$15 per thousand barrels. This case represents the upper range of projected operating costs reported by the petroleum industry. The results of Case 9 indicate that higher operating costs would raise the cost effectiveness of the base case to \$3300 per ton of hydrocarbons recovered and would raise the economic impact of the base case to \$0.08 per barrel of gasoline loaded.

From the results of the cost cases investigating sensitivity to cost parameters it can be concluded that higher shoreside capital costs or higher ship modification costs as estimated by the petroleum industry could potentially raise the base case cost effectiveness by \$1500 to \$2800 per ton of hydrocarbons recovered and could potentially raise the base case economic impact by \$0.03 to \$0.06 per barrel of gasoline loaded. Unlike the impact of changes in modification and capital costs, higher operating costs only raise the cost effectiveness of the base case by $400 per ton of hydrocarbons recovered and raise the economic impact of the base case by $0.01 per barrel of gasoline loaded. The cost effectiveness and economic impact of vapor recovery systems are much less sensitive to operating cost than they are to capital cost and vessel modification costs.

6.3.3 Sensitivity to Unit Size

The size of the vapor recovery system relative to the marine terminal throughput is a very important factor. The normal rate at which a single ship is loaded represents a minimum capacity for vapor recovery units. This minimum capacity would be required even if no more than one ship were loaded per month. Under these conditions a vapor recovery unit size to terminal size ratio of $4x10^3$bph/10^6bpy could occur in the Houston-Galveston area. The cost to capacity ratio is also likely to be higher for smaller vapor recovery systems. Case 5 investigates the impact of a unit to terminal size ratio of $4x10^3$bpy/10^6bpy and a shoreside capital cost of $3x10^6/10,000 bph. The cost effectiveness of Case 5 is $9500 per ton of hydrocarbons recovered, and the economic impact is $0.22 per barrel of gasoline loaded. The dramatic increases in cost effectiveness and economic impact are in part attributable to the fact that the increased annualized cost of Case 5 is not offset by any increase in hydrocarbon recovery.

In a similar manner, larger dock facilities may be able to install a smaller vapor recovery unit relative to their yearly gasoline throughput. Case 4 investigates the cost effectivenes and economic impact of installing a vapor recovery system with a recovery unit size to terminal throughput ratio of $1x10^3$bph/10^6 bpy. The resulting cost effectiveness of Case 4 is $2400/ton of hydrocarbons recovered and the economic impact of Case 4 is $0.06/barrel of gasoline loaded.

From the results of Case 4 and Case 5 it can be concluded that a high volume marine terminal installing vapor recovery systems may experience a cost effectiveness and economic impact lower than the base case for the Houston-Galveston area. It is also apparent that a low volume marine terminal installing a vapor recovery system may experience a cost effectiveness and economic impact much higher than the base case for the Houston-Galveston area.

6.3.4 Sensitivity to Vessel Mix

Three cases were established to investigate the sensitivity of cost effectiveness and economic impact to the relative volumes of gasoline loaded onto barges and ships and to the number of ships and barges requiring modification. Because fewer hydrocarbon vapors are generated and, consequently, recovered during ship loading than during barge loading, it is felt that cost effectiveness is highly dependent on the mix of ships and barges loading at the terminal. Case 6 investigates the impact of loading equal volumes of gasoline onto ships and barges. Case 7 investigates the impact of loading all gasoline onto ships only. For Case 6 loading equal volumes of gasoline onto ships and barges reduces the cost effectiveness of marine terminal controls of the base case to $1900 per ton of hydrocarbons recovered while the economic impact of controls remains relatively the same at $0.07 per barrel of gasoline loaded. For Case 7 loading all gasoline onto ships raises the cost effectiveness of marine terminal controls for the base case to $5500 per ton of hydrocarbons recovered, while the economic impact of controls remains relatively the same at $0.06 per barrel of gasoline loaded.

The base case conservatively assumed that petroleum companies and shipping companies would find it necessary to modify twice the optimum number of ships and barges required to transport their yearly gasoline shipments. Case 8 investigates the cost effectiveness and economic impact of more efficient shipping operations which require that only 1.5 times the optimum number of vessels be modified. In Case 8 two ships and nine barges are modified as opposed to three ships and thirteen barges as required in the base case. The cost effectiveness of Case 8 is $2500 per ton of hydrocarbons recovered and the economic impact of Case 8 is $0.06.

The results from Cases 6, 7, and 8 indicate that the ratio of gasoline loaded onto ships to gasoline loaded onto barges has a much greater impact on vapor control economics than does a change in the number of ships and barges requiring modification. The primary impact of loading ratios between ships and barges is attributable to their impact on the volume of hydrocarbons recovered and, consequently, to the cost effectiveness. The effect of loading ratio to the economic impact of vapor controls is minor. The effect of reducing the number of vessels requiring modification is small and applies equally to the cost effectiveness and to the economic impact.

7.0 TEST PLAN DEVELOPMENT

The results of this program to develop background information on marine terminal emissions and emission control technology indicate several areas where further emission testing is warranted. Section 7 develops a test plan for establishing emission data in those areas where emission data is inadequate.

7.1 Objective

As part of this program, Radian conducted a series of emission tests to verify emission data which have been reported by the petroleum industry. The results of the emission tests indicate that industry reported values for the hydrocarbon emissions from loading gasoline onto clean ship tanks and ballasted ship tanks adequately represent marine loading emissions in the Houston-Galveston area. The accuracy of petroleum industry values for these emissions is within the range of sampling accuracy and within the range of variations introduced by fluctuations in undefined parameters.

Insufficient data was collected in the emission tests to verify reported emission data for gasoline loading into uncleaned ship tanks, uncleaned barge tanks, and cleaned barge tanks. Although large quantities of industry data are available for these emission categories, a program of spot testing is required to establish their accuracy independently. A second area of extensive industry data requiring verification is the chemical composition of vented vapors. Wide ranges have been reported for the volume of methane present in the vented vapors. Methane is very difficult to control with conventional vapor recovery units and may present a major problem to some terminal facilities.

Studies on available emission data have also identified the following areas where practically no data is available on marine terminal emissions:

- crude loading - ships and barges
- crude ballasting - ships
- gasoline ballasting - ships
- chemical and fuel loading - ships and barges
- chemical and fuel ballasting - ships

It has been apparent that a composite vapor profile for ships loading gasoline and crude oil is important in assessing the hydrocarbon reduction potential of vapor recovery systems primarily treating ship loading vapors. Average emission factors per cargo tank do not present as complete a picture of loading emissions as does a plot of the composite vented vapor profile.

The major geographical areas of concern in this study are the Houston-Galveston area and the West Coast. Gasoline ballasting and chemical and fuel loading and unloading operations are not primary sources of hydrocarbon emissions in these areas.

Based on this information, Radian developed the following test plan to (1) quantify and characterize hydrocarbon emissions from crude loading and crude ballasting operations, (2) verify reported emissions from gasoline loading onto uncleaned ships and barges, and (3) characterize the composite vapor profile from operations loading gasoline onto ships.

An emission factor is calculated from the volumetric average hydrocarbon concentration using equation (1).

$$F = \left(\frac{10Y_1}{7.48}\right)\left(\frac{MW}{359}\right)\left(\frac{492}{T}\right)\left[1 + \left(\frac{Y_1 - Y_0}{100 - Y_1}\right)\right] \qquad (1)$$

when F = emission factor (lbs/1000 gallons transferred)

Y_0 = avg arrival vapor concentration (%)

Y_1 = volumetric average vented hydrocarbon concentration (%)

MW = molecular weight (lb/lb-mole)

T = temperature of vented vapor (°R)

The term $\left[1 + \left(\frac{Y_1 - Y_0}{100 - Y_1}\right)\right]$ corrects for the expansion in vented vapor due to evaporation of the product during loading operations. When calculating ballasting emissions this term should be set equal to 1.

The proposed method for obtaining an emission factor is based upon ullage measurements instead of direct vapor volume measurements. Although direct vapor volume measurements are potentially more accurate, gas meters and flow instruments large enough to directly measure vapor flow are too bulky to be conveniently moved from ullage hatch to ullage hatch and from ship to ship.

The parameters required to generate composite vented vapor profiles are ullage levels-vs-real time, tank volume, and cruise history for each cargo tank on the vessel. Real time is meant to be actual clock time recorded, so that the relative stage of fill for each cargo tank will be known with respect to the stage of fill for each of the other cargo tanks. Combining this information with information on tank volumes, cruise histories for each tank, and standard vapor concentration profiles for the cruise histories represented, it is possible to develop a graph of hydrocarbon concentration in the composite vented vapors-vs-time for the entire vessel loading or ballasting operation.

7.2.3 Required Level of Sampling

The level of sampling required to produce meaningful results is very difficult to predetermine. Decisions on how many tests should be conducted should be re-evaluated as the test program develops based upon the consistency of data collected. When conducting tests to verify existing emission factors it will suffice to test the vapors vented from three or more cargo tanks on two or three vessels for each emission factor. When testing for the purpose of establishing emission factors it is necessary to collect more emission data than that is required to verify existing emission factors. It will be advisable to test three or more cargo tanks on a minimum of six vessels for each emission factor.

When collecting vapor samples from gasoline loading for determining chemical composition operations, it is important to collect several vapor samples from cargo tanks in various stages of the loading sequence. A set of gasoline vapor samples should be collected for each company loading gasoline because of the wide variations in vapor composition which have been observed among companies. In sampling crude oil vessels several vapor samples should again be collected from cargo tanks in various stages of loading or ballasting. Sets of crude oil vapors should be collected for each major category of crude transferred.

7.2 Approach

This section outlines the basic approach to a concise point source testing program to effectively achieve the stated test program objectives.

7.2.1 Results Format

The proposed test plan is designed to develop emission data in the form of emission factors. Evaluation of emission testing results indicate that emission correlations and equations for marine terminal operations are difficult to develop and generally do not predict emissions with significantly greater accuracy. This is in part due to the inability of correlations to account for the large number of parameters affecting the emission rate.

The emission factors will be in units of pounds of hydrocarbons per thousand gallons of gasoline and categorized by arrival condition. Radian proposes the following arrival condition categories:

Loading Operations

Clean Tanks - Cargo tanks with very low arrival components attributable to either the previous cargo being non-volatile or to tank cleaning on the return voyage.

Ballasted Tanks - Cargo tanks which carried ballast water on the return voyage and which did not undergo any form of cleaning.

Uncleaned Tanks - Cargo tanks which were neither cleaned nor ballasted on the return trip.

Ballasting Operations

Full Tanks - Cargo tanks arriving completely filled

Partially Filled - Cargo tanks arriving partially filled.

Stripping Tanks - Cargo tanks used to collect strippings from other tanks prior to pumping them to shore.

The results of the tests to characterize the composite vented vapor profile will be presented in the form of composite vapor concentration-vs-time for the duration of the vessel loading operation. This would be equivalent to a concentration-vs-time profile for the vapor vent of a ship having all tank vents manifolded into a single vent.

7.2.2 Parameters

Emission factors for each tank will be obtained by measuring the hydrocarbon concentration in the vented vapor when the liquid level is at given ullages. From a plot of hydrocarbon concentration-vs-ullage it is possible to obtain a volumetric average hydrocarbon concentration for the tank filling operation by integration of the plot.

The level of sampling required to establish meaningful composite vented vapor profiles is unknown because the extent to which these profiles vary among ships is undetermined. However, at this time it is estimated that three or four composite vapor profile tests will provide an accurate indication of composite vapor characteristics.

7.2.4 Test Program - Instrumentation

Gasoline vapors are composed principally of saturated hydrocarbons. The components may typically range from C_1 to C_{10} or even higher. Straight chain hydrocarbons as well as their isomers tend to make the mixture even more complex. These compounds are similar chemically, making component analysis of the vapors difficult. Also, it has been proposed that methane be excluded from current hydrocarbon regulations. Such regulations would require not only the determination of the total hydrocarbon present but also the methane content. This section presents information on the instrumentation available for measuring total hydrocarbon concentration and for analyzing hydrocarbon components.

In choosing the proper or best suited instrument for obtaining hydrocarbon emission information from gasoline loading of marine vessels, certain test parameters should be met by the equipment. Some of these parameters are listed below:

- The equipment should not impair the time required to sample. The data should be obtainable fairly rapidly.

- With the result of the program being dependent to a large part on the accuracy of the instrument, a minimum accuracy of ± 10 percent should be achievable.

- The results should be highly reproducible by following tests.

- The costs which are dependent on several factors, should be kept to a minimum by considering the following:

1) Initial equipment cost
2) Equipment reliability
3) Maintenance costs
4) Skill level required of operators
5) Data reduction time
6) Data interpretation

7.2.5 Hydrocarbon Analysis

The characterization of saturated hydrocarbons relies on tests which measure physical properties such as boiling point, thermal conductivity, infra-red absorption, etc. For this reason, analysis of pure compounds is accomplished by a variety of test methods. The analysis of mixtures of hydrocarbons in terms of total hydrocarbon content also can be done without great difficulty. However, the quantitative analysis of a sample (by individual component) requires much more complicated testing.

The type of analysis required in sampling gasoline loading emissions is directly associated with the degree of sophistication necessary in both equipment and operator skills. Should regulations for marine gasoline loading be revised to exclude methane, complicated test procedures would be needed.

The following discussions present information on the current state-of-the-art of methods which are applicable to direct hydrocarbon analysis.

Combustible Gas Indicator

The combustible gas indicator is designed to measure the total concentration of hydrocarbons up to a maximum detectable concentration which corresponds to the Lower Explosive Limit (LEL) of the hydrocarbon mixture. This limitation is due to insufficient oxygen being present at higher hydrocarbon levels to insure that complete combustion will take place. For this reason direct application of this type of instrument is limited to vapors whose concentrations are below the LEL. Therefore, if the stream being analyzed has a greater concentration of hydrocarbon, the sample must be diluted to the proper concentration range prior to analysis. This dilution step, though, tends to lower the accuracy of this method due to the errors associated with this additional handling step.

The hydrocarbon concentration is measured in this analyzer by monitoring the output voltage of a balanced Wheatstone bridge circuit. Part of the bridge circuit is a heated wire filament which burns any combustible gas which enters as a sample. As the temperature of the filament rises, its resistance also increases, causing a change in the output voltage of the bridge. The magnitude of the output voltage is proportional to the concentration of hydrocarbon(s) in the sample.

Thermal Conductivity Meter

A thermal conductivity meter measures thermal conductivity of a sample relative to air by means of a heated filament. The filament is part of a balanced Wheatstone bridge. It is cooled by the hydrocarbons in the sample and causes a change in the conductivity of the filament. This, in turn, changes the electrical output of the circuit an amount proportional to the concentration of the hydrocarbon(s) in the sample.

The meter must be calibrated with a known hydrocarbon over the range of 0 to 100 percent. For best results the calibration gas mixture should approximate the composition of the stream to be sampled.

Infra-Red Analyzer

Infra-red analysis of saturated aliphatic hydrocarbons shows a characteristic absorption peak in the infra-red region at 3.4 microns. The particular stretching frequency of the carbon-hydrogen bonds in the hydrocarbon molecules account for this. However, the spectra of the homologous series C_1 to C_8 are so similar that there is no practical way to distinquish these compounds on the basis of infra-red absorption. Nonetheless, infra-red spectrometers are very accurate instruments for analyzing total hydrocarbon concentration in a stream.

There are two techniques available to quantitatively determine the hydrocarbon concentration in a mixture by infra-red analysis. For one method the spectrometer is set to detect the percent absorption at 3.4 microns. Since the hydrocarbons absorb energy in proportion to their concentration, the total hydrocarbon concentration can be determined. This method can be used to measure concentrations on a continuous basis by feeding the instrument cell with a constant sample flow. The second method is based on a direct comparison between the sample and a known standard. The standard (sealed in a cell) and the sample are both exposed to the same infra-red source. Each cell will generate an electrical signal whenever the gas in it absorbs a quantum of energy which causes it to heat up and expand. The instrument is standardized by placing identical gases in each cell, and the output is nulled to zero. During testing a sample is drawn into the sample cell. Then, both cells are irradiated; and any electrical output is an indication of a compositional difference between the sample and the standard. By using known mixtures the instrument may be calibrated to give a direct readout of the total hydrocarbon concentration.

Gas Chromatography

With proper calibration the gas chromatograph is capable of determining total hydrocarbon concentration and of quantitatively measuring multi-component mixtures of hydrocarbons. This sampling method requires expensive equipment and skilled personnel to assure reliable results. The time required to process a sample is roughly 20 minutes but could be shorter in a routine situation. For this reason it is not suitable for continuous stream analysis. It would best serve in testing for the component analysis of the vapors vented from a particular cargo tank.

Mass Spectrometry

A mass spectrometer can analyze a hydrocarbon sample in terms of the individual components present as well as in terms of the total hydrocarbon concentration. It operates by converting molecules into ions and by separating these ions on the basis of their mass/charge ratios. This instrument is probably the most accurate hydrocarbon analyzer available. However, as with the gas chromatograph, it does not lend itself to continuous applications; the equipment is quite expensive; and a very high operator skill level is required for reliable results.

Oxygen Analyzers

Measuring the oxygen concentration in a hydrocarbon sample from a tank vent stream is an indirect method of determining total hydrocarbon content. The principle is simple, though

From the oxygen measurement the amount of air in the sample can be readily calculated, assuming the oxygen is present as a component of air. However, the problem that exists in using oxygen as a basis for calculating hydrocarbon content is that any error in detection is magnified five times. Therefore, a great deal of uncertainty exists using this technique if the hydrocarbon content of a sample is low. For sample streams containing high hydrocarbon content (low oxygen), though, this technique may be more suitable since the analyzer can be run at a higher sensitivity, thereby reducing hydrocarbon measurement error.

Currently there are four methods for quantitatively measuring oxygen:

1) Selective absorption
2) Paramagnetic susceptibility
3) Polarographic analysis
4) Ionization

Gas Densitometers

The gas densitometer technique calculates the hydrocarbon loss based on the assumption that the difference between the mass of vapor leaving a cargo tank and the mass of air represents the mass emission of hydrocarbon. This technique also assumes that the difference in the masses of air entering and leaving the cargo tank is negligible over a reasonable period of time.

Densitometers based on one of three principles are available:

1) Bouyancy
2) Centrifugal force
3) Mass vibration

Summary

Numerous methods are available for analyzing the hydrocarbon concentration of vent streams from marine vessels loading gasoline or crude oil and from tankers ballasting after unloading gasoline or crude oil. All equipment must be handled properly and correctly calibrated to assure accurate results. Only two instruments, though, offer the ability to analyze for individual hydrocarbon components in a vent stream - gas chromatography and mass spectrometry.

Several instruments are portable and are reasonably accurate in measuring total hydrocarbon concentrations, e.g., combustible gas indicators and thermal conductivity meters. Some are more expensive than others, but they offer measurement accuracy, e.g., infra-red spectrometers.

Besides accuracy and expense, another important consideration for a testing apparatus is its safety. On board a marine vessel a testing apparatus must meet stringent safety specifications. All equipment and instrumentation used must be labeled intrinsically safe or be suitable for use in Class 1, Division 1 atmospheres.

7.3 Sampling Procedure

This section outlines a procedure which could be used for obtaining emission factors for marine vessels loading gasoline and crude oil as well as for crude oil and gasoline ship ballasting operations. The basic principle involved in this procedure is to record with an accurate hydrocarbon analyzer the hydrocarbon concentration of the vented vapors as a function of ullage for both loading and ballasting. This information along with a tank's final ullage and average hydrocarbon concentration just prior to loading or ballasting can be used to generate reasonably accurate emission factors.

7.3.1 Test Measurements

7.3.1.1 Vented Vapor Concentration Profile

Measurements during actual loading or ballasting operations shall be recorded for the hydrocarbon concentrations of the vented vapors using a suitable instrument. The probe shall be positioned as shown in Figure 7.3-1.

A. Frequency Of Measurements

Ships - From maximum tank ullage to the 20 ft. true ullage mark, measurements will be recorded every 5 ft. From 20 ft. to 10 ft. true ullage, measurements are recorded every 2 ft. From 10 ft. to the final ullage, measurements are recorded every 1 ft. See Figure 7.3-2.

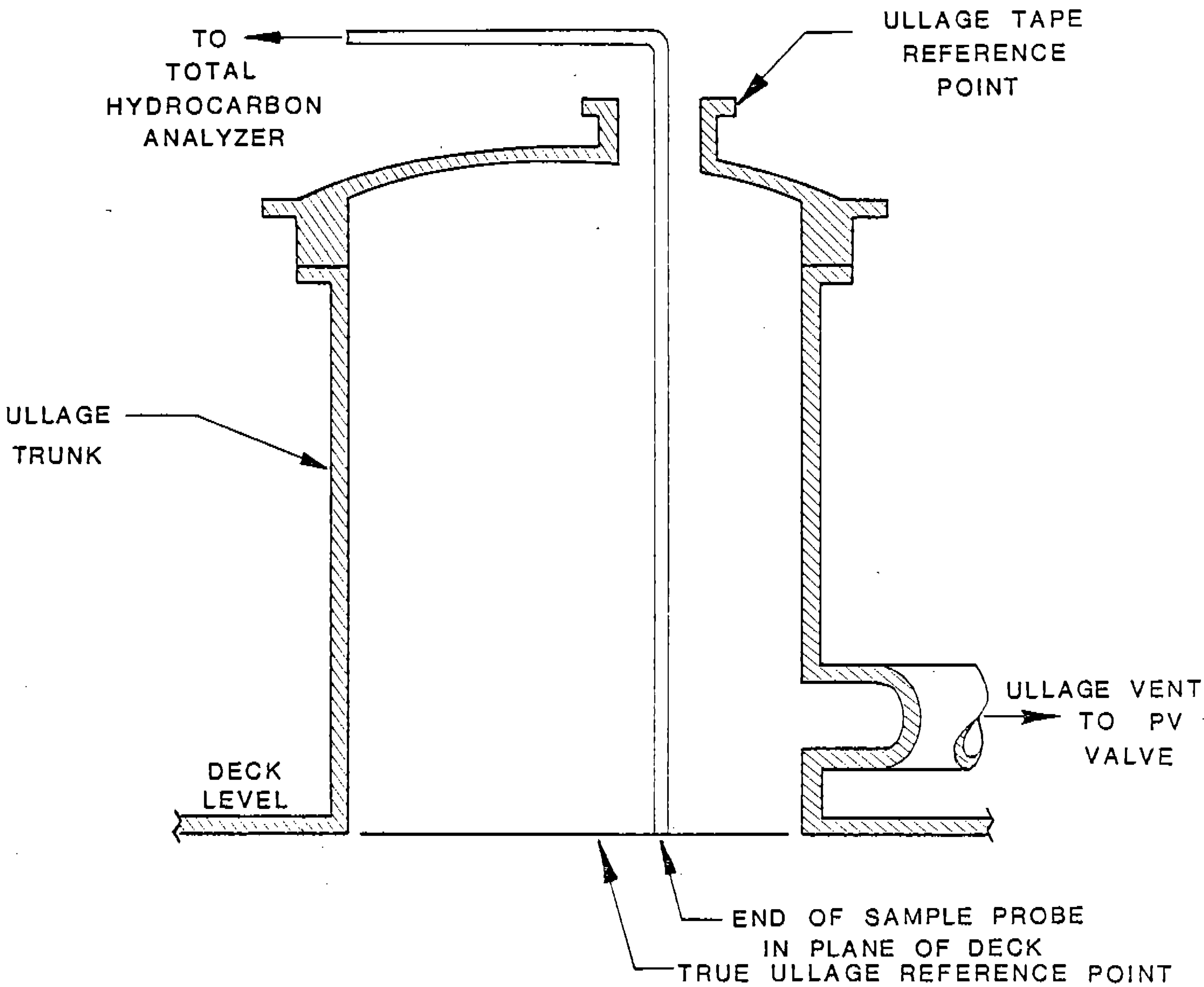
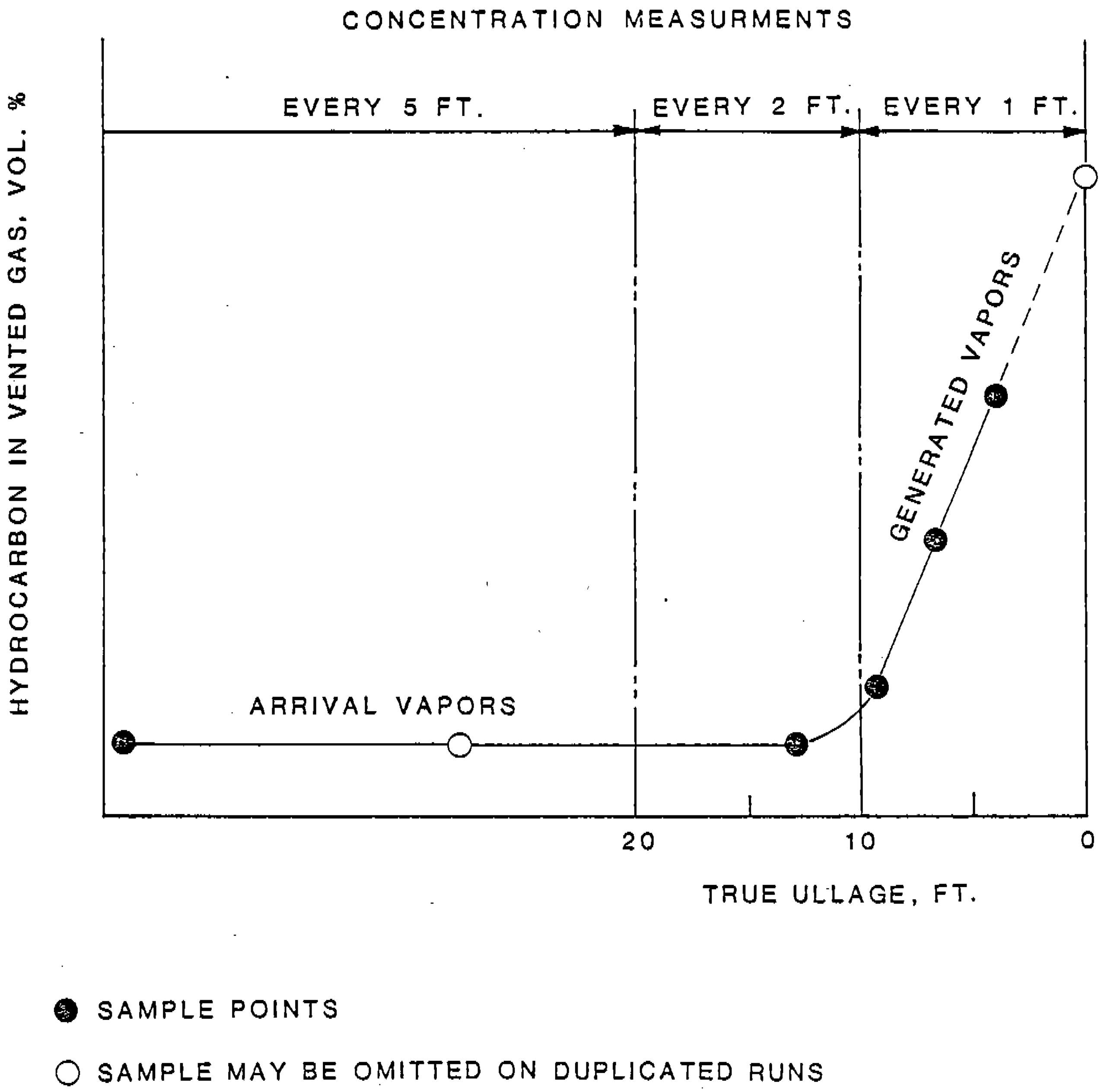


FIGURE 7.3-1. LOCATION OF SAMPLE PROBE



NOTE: COMPOSITION SAMPLES SHOULD BE TAKEN AT THE INDICATED POSITIONS RELATIVE TO PROFILE; ULLAGE VALUES SHOWN ARE ILLUSTRATIVE ONLY

FIGURE 7.3-2 SAMPLE POINTS RELATIVE TO TRUE ULLAGE (CONCENTRATION) AND VAPOR PROFILE (COMPOSITION)

Barges - Since most barges have maximum true ullages around 10 ft., measurements will be recorded every 1 ft. to the final ullage.

B. Information Recorded

The information to be recorded for each measurement is time, true ullage, concentration, product loaded, tank ID, and vented vapor temperature.

Emission factors can be calculated from this information, however, more data and information are needed to categorize the emission factors according to cruise history. The following information will allow proper categorization of the recorded emission data:

1. Previous cargo - type and RVP
2. Transit history
   a. Transit time
   b. Nature of tank cleaning for each tank
   c. Ballast handling, including ullage or percent of tanks ballasted.

C. Vented Vapor Composition

Information will also be obtained on the composition of the vapors vented from crude oil and gasoline loading and ballasting operations. This data will not only allow a component analysis of the emissions for reactivity classification, but it will also provide a check for the concentration measurements taken.

For crude oil and gasoline loading, samples will be collected at six different points during the loading. Figure 7.3-2 shows the sample points with respect to the vented vapor concentration profile. The locations are:

1) just after loading begins
2) midway through the horizontal leg
3) just before the inclined leg
4) just after the start of the inclined leg
5) midway along the incline
6) at the final ullage

If a number of samples are taken for the same test conditions at the same refinery, compositional vapor samples are needed for only two tanks. Also, samples No. 2 and No. 6 above may be eliminated after the first test for each test condition.

The following information shall be attached to a tag on each sample cylinder immediately after sampling and also recorded on a separate data sheet for record:

1) date and time
2) terminal name and location
3) tanker name
4) tank I.D.
5) true ullage reading at time of sampling

6) temperature and pressure in tank at time of sample
7) ambient temperature
8) name of person sampling

For ballasting operations and barges loading gasoline or crude oil, samples shall be taken just after the start, at the midpoint, and at the final ullage. The same information listed above shall be attached to each of the samples.

7.3.2 Recorded Information - Data Sheets

The information and data taken during a test run shall be recorded on data sheets. Examples of a format which might be used follows on the next few pages.

TEST PROGRAM FOR MARINE EMISSIONS

SHORESIDE INFORMATION

DATA SHEET I

General Information:

Date ______________________

Name of Vessel ______________________

Terminal ______________________

Location ______________________

Product(s) Loaded ______________________

Ambient Conditions:

Air Temperature ______________________

Weather Conditions ______________________

Prepared by: ______________________

TEST PROGRAM FOR MARINE EMISSIONS

SHORESIDE INFORMATION

DATA SHEET II

General Information:

Date ______________________

Name of Vessel ______________________

Type ship ________ ; barge ________

Number of cargo tanks ______________________

Vessel size (DWT) ______________________

Cruise History:

Transit Time ______________________

Do tanks have stripper lines? ______________________

Open or closed hatches? ______________________

From ship log, sketch cargo tank layout below and show prior cargo arrangement, and the type of cleaning for each tank and which tanks were ballasted on the return trip:

Prepared by: ______________________

TEST PROGRAM FOR MARINE EMISSIONS

RECORDED DATA

DATA SHEET III

Date: ____________________ Product Loaded ________________

Cargo Tank No. __________ Approx. Loading Rate __________

Time	Ullage (ft)		Concentration	Temperature (°F)		Composition Sample (✓)
	True	Tape		Vapor	Liq.	

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CONVERSION FACTORS

The references used in developing this report generally stated flows, capacities, weights, etc. in English measurement units. The following table can be used to convert these measurements to metric units.

To Convert From	To	Multiply By
lb	kg	0.454
bbl	l	159.0
lb/10^3 bbl	kg/10^3l	.002855
scf	Nm^3	0.0283
ton	MT	0.9072
gal	l	3.785
lb/10^3 gal	kg/10^3l	0.1199
lb/ton	kg/MT	0.5004
Btu/bbl	kcal/l	1.585
ton	kg	907.2
Btu	kcal	0.252