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EVALUATION OF CONTROL TECHNOLOGY FOR BENZENE TRANSFER OPERATIONS

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

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by

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SECTION 1.0
INTRODUCTION

The specific objectives of the study were to:

1) Assess the feasibility of applying vapor control technology for benzene transfer operations including tank cars, railcars, barges, tankers, storage tanks, and pipeline operations.
2) Determine the achievable emission level and emission reduction for each vapor control alternative.
3) Determine any secondary emissions that would result from applying each vapor control alternative.
4) Quantify the capital and annualized costs of the control alternatives.

Visits were made to the plants of two benzene producers to gather information on liquid benzene storage and transfer operations. A literature search was conducted to obtain data on benzene handling and storage, as well as to investigate technological alternatives to control emissions. This activity was brief because of the desire to evaluate technologies that could readily be applied to industry. Equipment manufacturers were consulted to determine the state-of-art of commercially available equipment and ascertain the effectiveness, cost, and operating history of their treatment units. Three technologies exhibited promise as effective methods to reduce benzene emissions, and were selected for further study. These were a refrigeration and lean oil absorption unit, vacuum regenerated carbon adsorption, and thermal incineration.

Hypothetical models were prepared to represent a typical current-day benzene producer, and two benzene consumers. These models serve as base cases for the study. Six control schemes were developed and applied to the base cases. Four were applied to the producer, and two to the consumers. Each of the three control technologies discussed above were applied utilizing their respective achievable emission levels to the control schemes resulting in 16 case studies. The cost effectiveness of each case study was calculated, and the technologies rated.

SECTION 2.0
SUMMARY

The three control technologies evaluated were:

1) Condensation of benzene vapors by refrigeration followed by absorption of benzene vapors in an oil absorbing/stripping system.

2) Carbon adsorption beds regenerated by vacuum.

3) Thermal incineration using supplemental fuel.

Other technologies were considered, but dropped because of lack of design information and/or commercial availability.

The control technologies were evaluated by applying them in various configrations to hypothetical models which were prepared to represent facilities and operations typical of current-day producers and consumers of benzene.

Each of the technologies embody basic principles whose successful application to hydrocarbon processing has been well demonstrated, and for which large data bases exist. Their application to benzene emission control is very limited and actual performance data was not available. The transfer of technology from other hydrocarbons services to benzene service is not expected to create unusual problems. All of the technologies are currently being applied to gasoline emission control, and this experience is useful.

The claimed removal efficiencies of the three technologies studied are all high. The predicted benzene emission concentration levels that are practical to achieve are:

Refrigeration-absorption	-	1000 ppm
Carbon adsorption	-	10 ppm
Thermal incineration	-	10 ppm

The technologies were evaluated using the above emission levels. The economic penality for installing and operating a thermal incinerator at 10 rather than 1000 ppm is small. This is not the case with carbon adsorption and a meaningful economic comparison of this technology can only be made when it and competing technologies are evaluated at the same emission concentration level. Using the above emission levels, refrigeration-absorption has a cost effectiveness very close to that of thermal incineration. Average cost effectiveness of the refrigeration-absorption systems is $3.83/lb reduction, while that of thermal incineration is $3.78/lb reduction. (Note: Units used in this report are the same as used by suppliers of raw data. A metric conversion chart is contained in Appendix A.) This is a negligible difference. A slight rise in the value of benzene and/or the cost of natural gas relative to electricity would make refrigeration-absorption the most cost effective. Although there is no single component in the system that is unique; i.e., closed loop refrigeration vapor scrubbing tower, gas-oil separation by distillation; the combination of these components into a single package for remote automatic efficient operation is not yet demonstrated. This system is thought to need more control and fine tuning than the other technologies to achieve efficient operation. A great deal more operating experience would likely be required to make this technology widely accepted. What makes refrigeration-absorption particularly attractive is its potential to be the most cost effective and its conservation of benzene.

Thermal incinerator technology has been used more in the control of storage and transfer emissions than the other two technologies. The transfer of gasoline handling knowledge to benzene handling is much more direct than that of the other technologies. The state of the art for thermal incineration is at a high level, and potential improvements are possible with energy recovery by heat exchangers. Advantage was not taken for heat recovery in the case study models. Also the particular commercially available thermal incinerators investigated did not offer heat recovery as a regular option. If heat recovery is a possibility for any particular plant, thermal incineration would be even more cost effective. Standard thermal incineration units are available as "off the shelf" items from at least two manufacturers.

Vacuum regenerated carbon adsorption with 10 ppm emissions was calculated to be the least cost effective means of controlling benzene emissions but at 1000 ppm emissions may be competitive with other technologies. On a functional basis, carbon adsorption stands out as the most attractive technology. It has a very high efficiency of benzene recovery and removal, relatively simple operation well suited for automation, and wide turndown ranges. Experience with benzene is presently limited to extrapolation of results gained from gasoline service with gasoline containing benzene. Substantial advancement in the state of the art is expected as more experience is obtained.

Steam regenerated carbon systems have wide experience in the treatment and recovery of solvents from solvent contaminated air in extremely dilute concentrations. These units are available from several manufacturers as standard package items. However, no experience was found pertaining to benzene, gasoline, or high concentration hydrocarbon usage. No pricing estimates for benzene applications of steam regenerated systems were available. Some means for disposal of benzene contaminated condensate is necessary for this type system.

Calculations revealed that there is considerably more benzene lost as a result of loading and storage (per unit of benzene handled) by producers than for consumers. The emission factor for the base case producer is 2.608 $lb/10^3$ gallons compared to .468 for the consumer case. Floating roof tanks represent a high level of control. (Texas state regulations require floating roof tanks for the base case.) Conversely if a plant has cone roof tanks, the first efforts should be directed to reducing storage losses by conversion to either open floating roof or internal floating cover depending on their relative cost effectiveness. Either method is highly cost effective.

When the implementation of carbon adsorption technology is desired, the most cost effective design will incorporate features to reduce the capacity (in terms of benzene loading and volumetric flowrate) of the individual treatment units, permit higher ppm emissions, and minimize the number of units required. Capacity reducing features might include vapor holders to act as flow equalizers and displacement of vapor from tank to tank or carrier to tank. The additional cost due to capacity reducing measures will be more than offset by the savings in capital costs of the carbon adsorption units. Capacity reducing measures do not provide similar cost effectiveness gains for refrigeration-absorption and thermal incineration technologies. The increased cost of the capacity reduction measures outweighs the cost savings obtained by reducing the size and number of treatment units.

SECTION 3.0
CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are:

1) It is concluded that thermal incineration offers the best means for control of benzene vapor to levels of 10 ppm benzene. The risk in applying this technology to benzene service is considered to be low. Thermal incineration systems have the distinct advantage of being able to dispose of other pollutants.
2) Thermal incineration at the level of 10 ppm benzene emission and refrigeration-adsorption at 1000 ppm are equal in cost effectiveness.
3) Carbon adsorption is not as cost effective as thermal incineration when both are compared at 10 ppm.
4) The cost of carbon adsorption is sensitive to final benzene emission level and a true cost comparison to other technologies can only be made when all technologies are evaluated at the same emission level.
5) Benzene emission control efforts are more cost effective in producer rather than consumer facilities. Plants with cone roof storage tanks should receive attention before those using floating roof tanks. When the producer plant is equipped with floating roof tanks, the priority shifts to controlling the loading losses.
6) Modifications to carriers to reduce transit losses (defined as breathing losses during shipment) should receive the lowest priority. Modifications to carriers

should be limited to those which are required to reduce loading losses.

7) Secondary emissions for the control systems evaluated were low, and do not present a significant problem.

8) Air-benzene mixtures in pipe lines to recovery systems introduce significant explosion hazards, and designs must incorporate equipment to avoid this hazard. (This was done for designs evaluated in this report.)

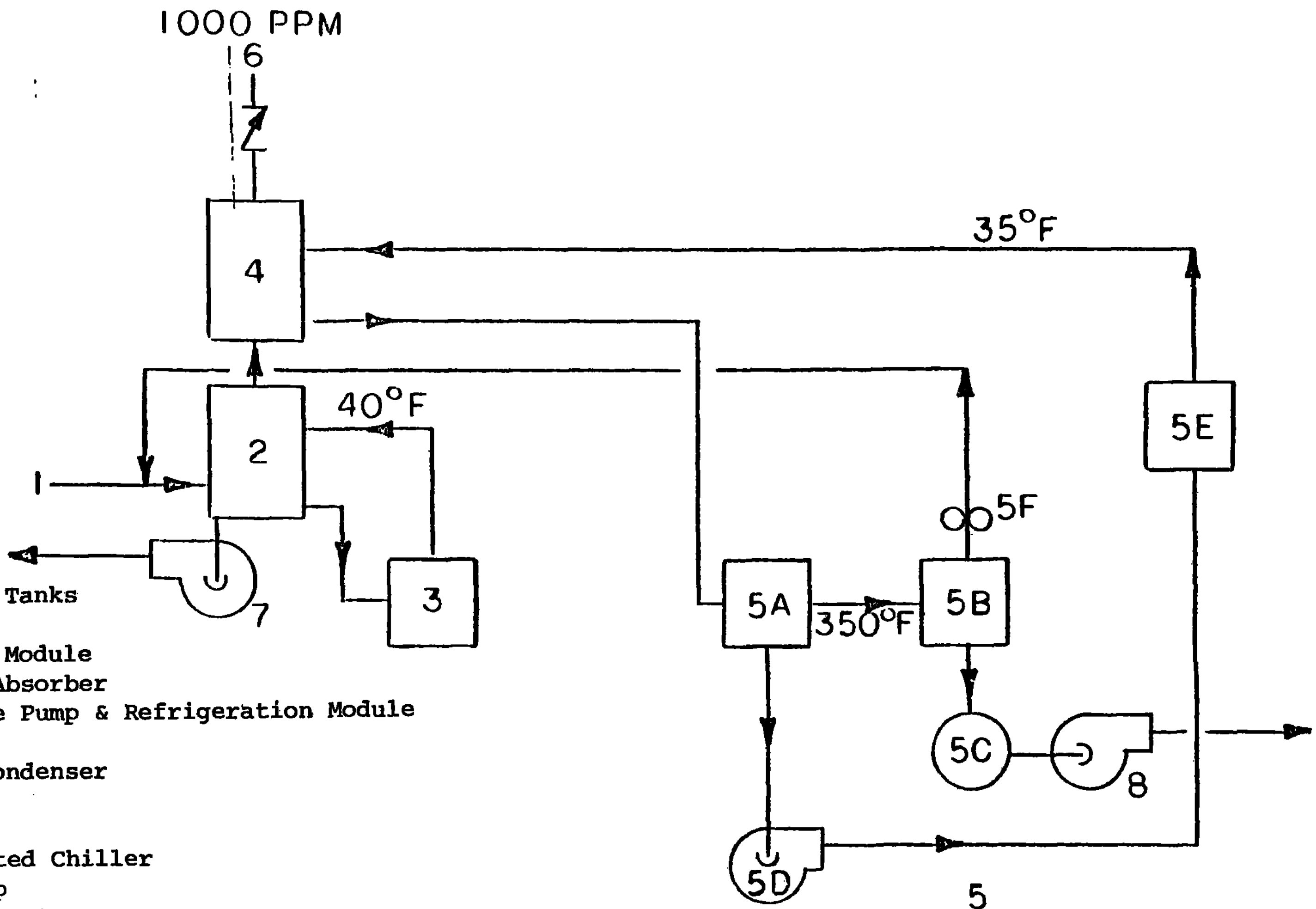
SECTION 4.0
DISCUSSION

4.1 CONTROL TECHNOLOGIES

4.1.1 Refrigeration - Condensation - Absorption
(See Figure 4.1.1)

This type of recovery system removes benzene vapor from air in two stages. The first stage consists of passing the vapor mixture over a surface condenser maintained at 45°F. The temperature is controlled to prevent the freezing of benzene. Up to 60 weight percent of the benzene vapor is condensed and collected along with some water. The condensed benzene is returned to storage. The remaining vapor mixture is passed through the second stage which consists of a lean oil scrubber maintained at 35°F. The benzene vapor is absorbed into the lean oil. The lean oil is collected and either regenerated or stored for later regeneration. The vent to atmosphere from this type unit contains approximately 1,000 ppm benzene by volume.

The regeneration process heats the benzene-rich oil to 350°F where benzene is stripped from the oil. This benzene vapor is then condensed, collected, and returned to storage. The hot lean oil is cooled down to 35°F and reused. The non-condensed benzene vapor is recycled to the first stage by means of a vacuum pump. All of the condensing and cooling is provided by a closed loop refrigeration unit.



1. Vent From Tanks
2. Condenser
3. Pump-Ref. Module
4. Scrubber-Absorber
5. Regenerate Pump & Refrigeration Module

5A Heater
5B Benzene Condenser
5C Receiver
5D Pump
5E Refrigerated Chiller
5F Purge Pump

6. Tail Gas Vent
7. Benzene Return Pump
8. Benzene Return Pump

Basic Drawing Courtesy of
Ecology Control Inc.

FIGURE 4.1.1 REFRIGERATION-CONDENSATION-ABSORPTION UNIT

Several variations of this type system can be made. Where a high flowrate of vapor is scrubbed (such is the case during a barge loading), the benzene-rich oil can be stored and regenerated at a later time using a smaller regenerator unit. This reduces the capital cost.

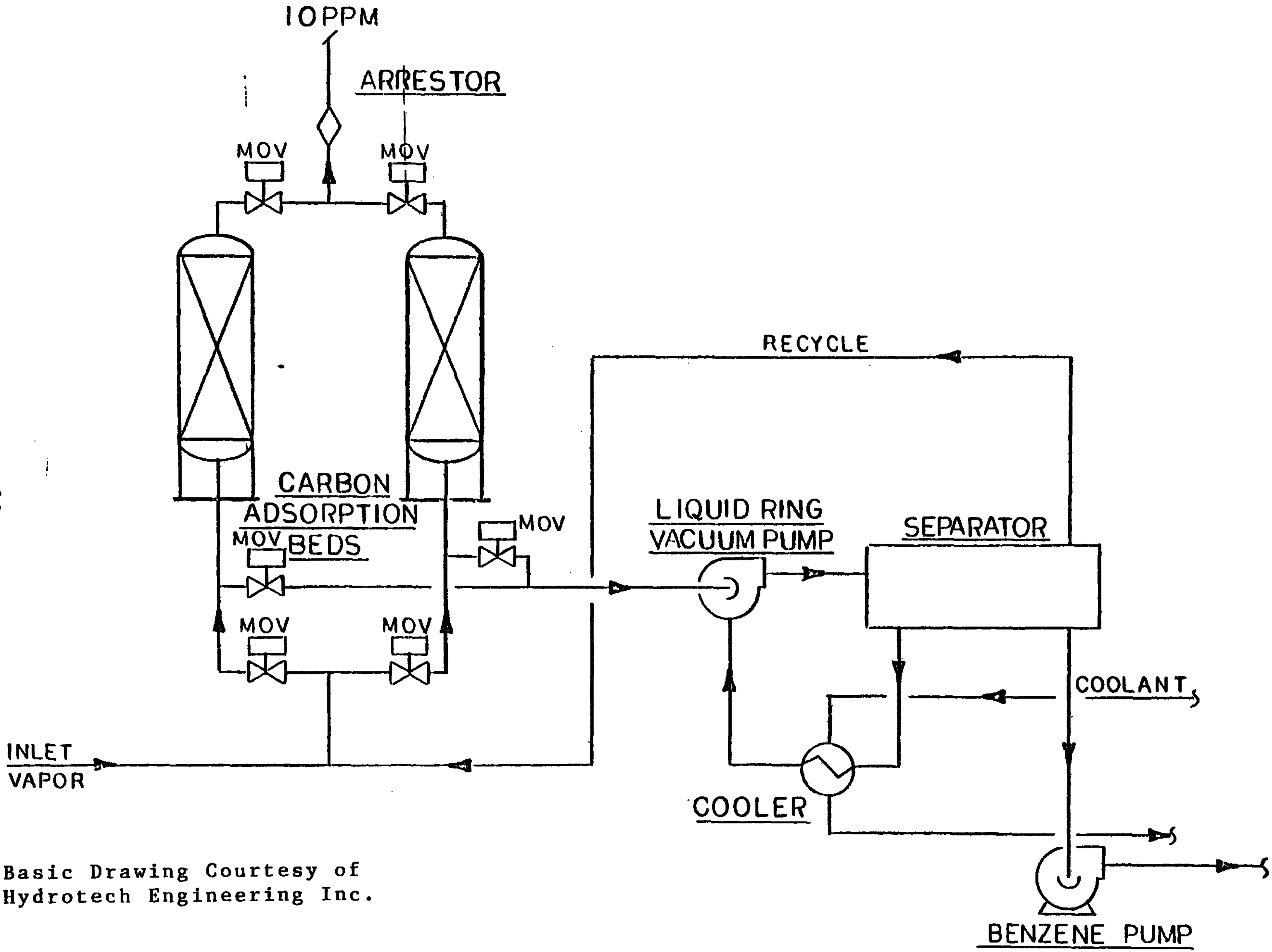
Another variation separates the condensor and scrubber tower from the electrically driven hardware so that a smaller size and weight unit could be placed in a crowded spot such as a loading dock.

Still another variation does away with the refregeration-condensation first stage and used only lean oil absorption. The refrigeration load required however is about the same and the rich oil regnerator increases in size.

The two-stage system is being used successfully on West Texas crude in Silsbee, Texas. Ecology Control Inc. manufactures these units. A unit capable of handling 2,000 gpm of displaced benzene vapors costs about $87,000.

4.1.2. Carbon Adsorption

Carbon adsorption utilizes the principle of carbon's affinity for non-polar (hydrocarbon) solvents to remove benzene from the vapor phase. Although benzene applications of carbon adsorption do not have a large amount of commercial operating experience, carbon adsorption for recovery of other organic vapors is proven, and transfer of this technology to benzene should not prove difficult. A typical benzene carbon adsorption unit consists of a minimum of two carbon beds and a regeneration system. (Refer to Figure 4.1.2.) Two or more beds are necessary to keep the unit onstream, so that one will be ready for use while the other bed is being regenerated. Regeneration can be performed by two



Basic Drawing Courtesy of
Hydrotech Engineering Inc.

FIGURE 4.1.2 CARBON ADSORPTION UNIT

different methods. Both rely on elevating the vapor pressure of the adsorbed benzene in relation to the absolute pressure in the void space of the bed and sweeping the void space. In the steam regeneration system steam heats the carbon (raising the benzene vapor pressure) as it is circulated through the bed. Thus the benzene evolved is removed along with the steam. The steam-benzene mix is condensed (usually by an indirect cooling water stream) to recover benzene and water in a separator. The benzene is decanted and returned to storage and the water is sent to the plant wastewater system for disposal. For a steam regeneration system cooling water, electricity, and of course, steam are the required utilities. While it is possible to use a closed loop freon refrigeration system for the condenser, the large duty required makes it impractical. Vacuum regeneration is performed by drawing a high vacuum on the carbon bed with a liquid ring seal vacuum pump. The benzene vapor thus desorbed is condensed by indirect cooling and returned to storage. The condenser may be cooled either by a closed loop freon refrigeration unit or by circulating cooling water. The only utility required for vacuum regeneration is electricity unless a water cooled condenser is used instead of a freon refrigeration unit. This method eliminates the problem of disposing of water containing trace amounts of benzene. A 2000 gpm unit for benzene service was priced at $742,000 by Hydrotech Engineering Inc. as an order of magnitude engineering estimate for the particular loading system in the study.

4.1.3 Thermal Incineration

Thermal incineration is the most direct means of benzene vapor disposal, uses the fewest moving parts, and is the simplest to operate. The vapor mixture is injected via a burner manifold into the combustion area of the incinerator. Pilot burners provide the ignition source and supplementally fueled burners add heat when required to maintain the flame temperature between 1400°F and 1500°F. The fuel was assumed to be natural gas; however, its future availability is questionable. A negative aspect of thermal incineration is the fact that benzene is destroyed.

The amount of combustion air needed is regulated by temperature controlled dampers. Benzene emission from the tail gas of an incinerator can be limited to as little as 10 ppm. (See Figure 4.1.3.)

Flash back prevention and burner stability are achieved by either saturating the vapors to a concentration above the upper explosive limit or inerting them with nitrogen. (See Figure 4.5.1.) In addition, two water seal flame arrestors are used to assure that flash backs do not propagate from the burner to the rest of the piping system.

Thermal incinerators are being used successfully to dispose of gasoline vapors collected from tank truck loading operations. National Air Oil manufactures ten sizes of units ranging from 500 gpm to 5,000 gpm. They have successfully tested their standard unit (with a few modifications) with benzene vapor. These units range in cost from $35,800 to $51,700. A significant advantage of ~~thermal~~ incinerators is that they can dispose of a wide range of hydrocarbons. This is especially important at a loading dock where numerous hydrocarbons are loaded, and industry is uncertain of what materials in the future will have to be controlled.

4.1.4 Other Technologies Considered

Catalytic oxidation was considered for benzene vapor control service but was dropped because of problems associated with catalyst fouling. The catalytic oxidation system in general offers a

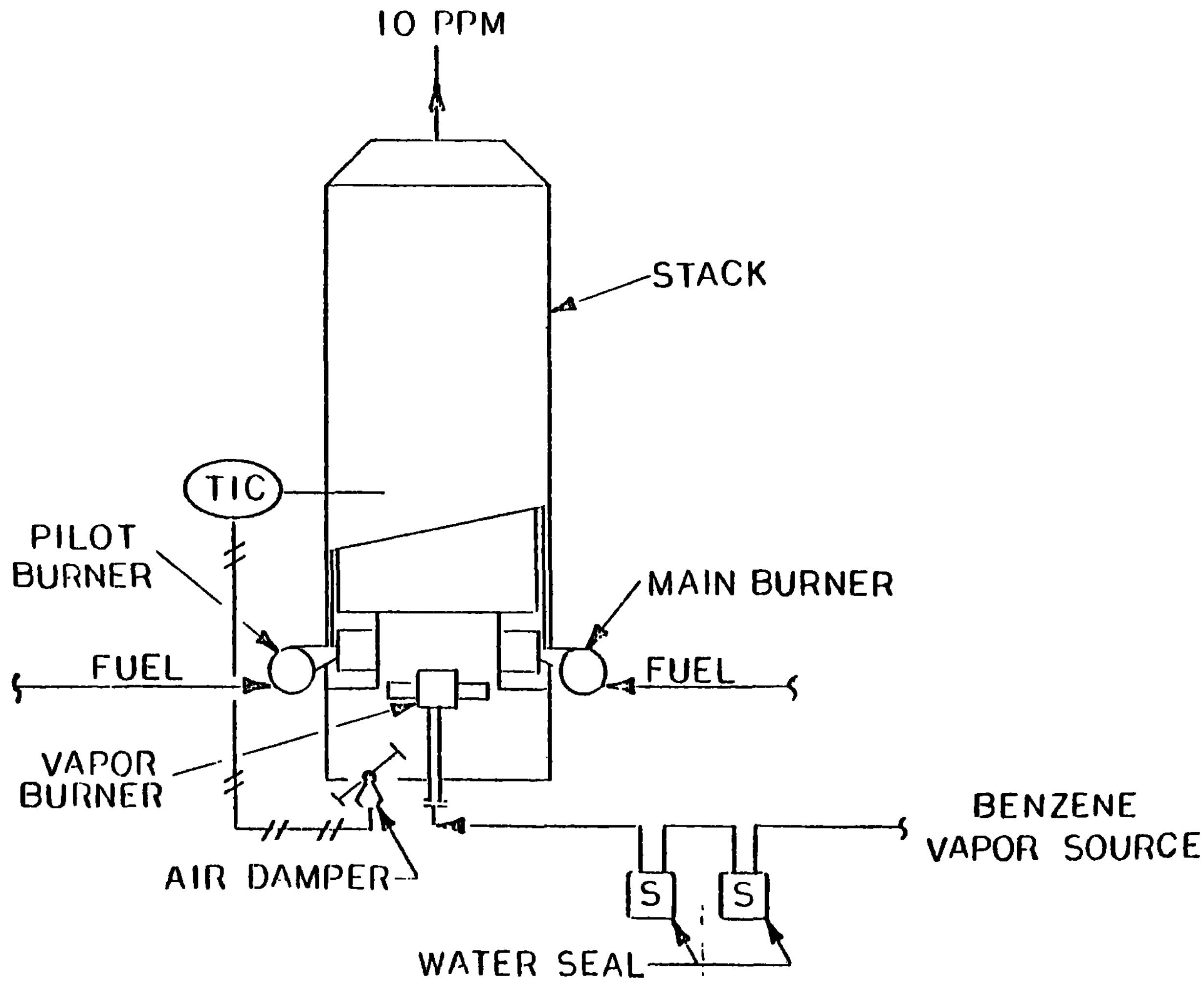


FIGURE 4.1.3 THERMAL INCINERATION UNIT

savings in fuel over thermal incineration due to lower operating temperature.

Another technology considered was straight refrigeration. This system recovered the benzene vapor in two stages. In the first precooler condenser, the vapors are cooled to 43°F where the benzene and water vapor condense and are removed from the vapor stream. In the final condenser, vapors are cooled to -100°F. The residual benzene vapor and residual moisture collect as a frost on the condenser fins. At the end of the flowing period, the condenser is warmed to 43°F and both benzene and water are drawn off. There are currently no commercial installations of this type system although the claim is made by the manufacturer that an emission level as low as 10 ppm can be achieved. The cost for a unit that will handle 2,000 gpm of displaced benzene vapors runs between $95,000 to $110,000 as provided by Edwards Engineering. The technology was not evaluated in the case studies because of the state of development of the technology and the availability of design information within the time limitations of the study.

4.2 BASE STUDY CASES

Three base study cases were selected to represent "typical" uncontrolled benzene producers and consumers. The characteristics of these cases were formulated from information obtained from plant visits, published data, and conversations with operating personnel. These cases will be described below. The three base cases are:

- o Producer
- o Large consumer
- o Small consumer

4.2.1 Benzene Producer

A Texas Gulf Coast location was chosen as the site of the benzene producer for two reasons; 1) a large number of benzene plants are located on the Gulf Coast in Texas and Louisiana, and 2) all modes of benzene transfer are possible from such a location. The capacity of the production unit is 40 million gallons per year of petroleum-derived benzene. Benzene is pumped from the production unit into a pair of intermediate storage tanks known as rundown tanks, where it is inspected for product quality.(Figure 4.2.1) The rundown tanks are of pontoon, double seal floating roof construction, with welded steel shells. The height of the tanks are 48 feet and the diameters are 25 feet. The working capacity per tank is 125,000 gallons, approximately one day of production. The tanks are alternately filled, the product tested, and then emptied to other storage tanks. The bulk liquid temperature of the benzene in the rundown tanks is approximately 100°F, with an associated vapor pressure of 3.30 psia. From the rundown tanks the benzene is transferred to one of two sets of final product shipping tanks. One set is for railcar/truck loading and the other set is for barge loading. The transfer rate from the

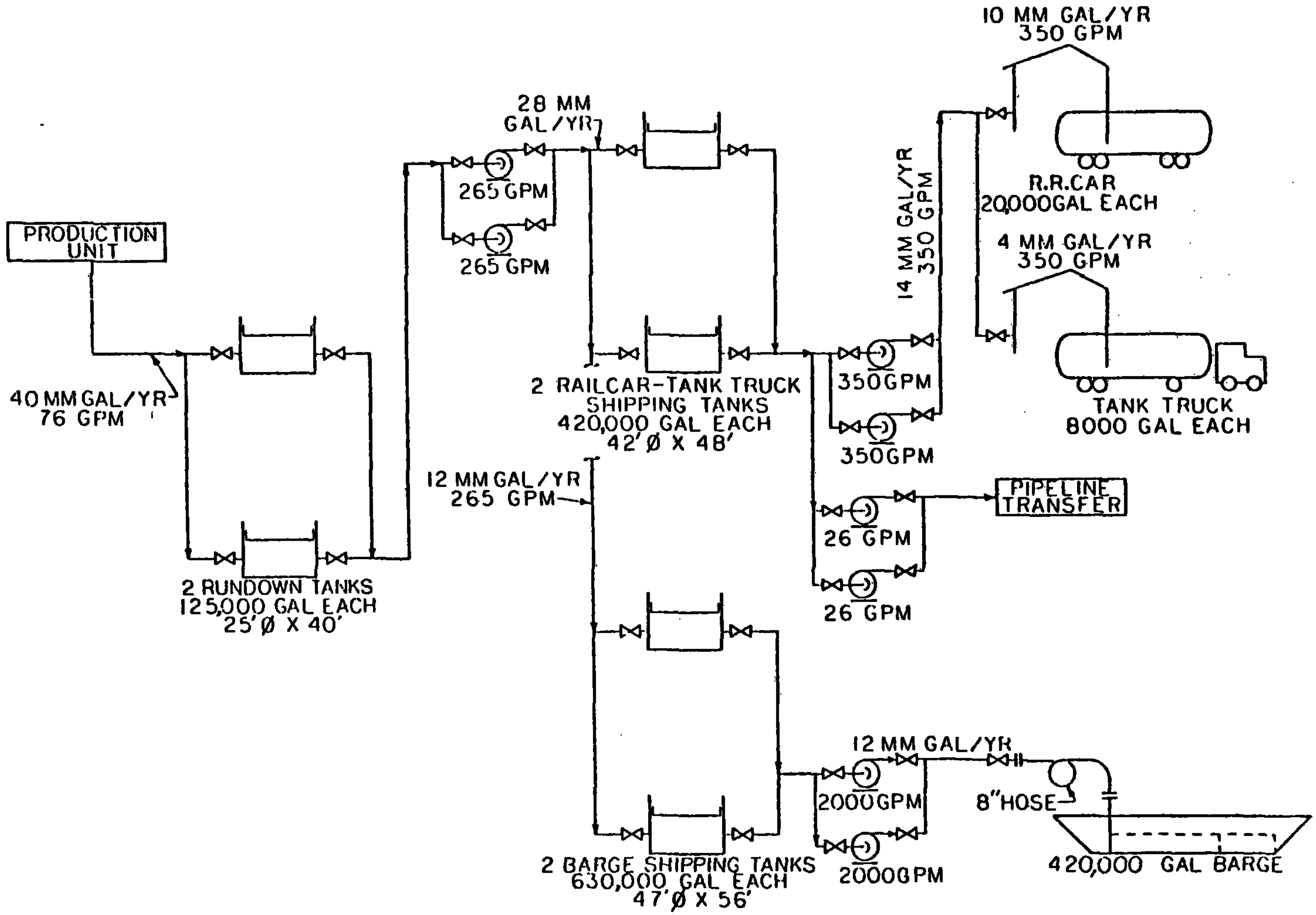


FIGURE 4.2.1. BASE CASE #1 - BENZENE PRODUCER

rundown tanks is 265 gpm, thus eight hours are required for transfer. Two 100% capacity pumps are provided for this service.

The two tanks provided for railcar/truck shipping service are fitted with pontoon, double seal floating roofs and welded steel shells. The tanks are 42 feet in diameter and 48 feet high, with a net working volume of 420,000 gallons each. The annual benzene fill for the railcar/truck shipping tanks is 28 million gallons. Of this volume, 14 million gallons are shipped directly out of the plant by pipeline. The pipeline transfer rate is assumed to be a continuous 26 gpm and one of two 100% capacity pumps are used. The remaining 14 million gallons per year are shipped out by railcar and truck. Railcars receive 10 million gallons per year and the truck tankers receive the remaining 4 million gallons per year. The capacities of the railcars and trucks are assumed to be 20,000 gallons and 8,000 gallons respectively. Thus there are 500 railcar shipments and 500 truck shipments each year. The railcars and trucks are filled by loading arms on two separate dedicated racks. The normal fill rate is 350 gpm and two 100% capacity pumps are provided.

Loading procedures for railcars and trucks are similar. After the vehicles are properly spotted, checked, and grounded, the loading hatches are opened and the loading arms connected. Although other loading styles are commonly employed for hydrocarbon liquid loading, it was assumed that submerged fill top loading is used. This is the style that was observed on plant visits. In submerged fill top loading, the loading nozzle is inserted into a fixed standpipe which is kept submerged in the liquid near the bottom of the tanker to minimize splashing and subsequent benzene losses. The vapor in the tanker is displaced by the liquid benzene during filling and is expelled through the open hatchway to the atmosphere. No vapor recovery system is employed in the base case.

Loading is under manual control, tank gauging is performed either by visual inspection of liquid level through the hatchways or floatsticks. As the liquid level nears the maximum the flowrate is reduced while the operator monitors the level closely. The tank is then topped off to 2% outage, the loading arm valve is blocked off, the pump is shut off, the arm is removed, and the hatchway is closed.

The remaining 12 million gallons per year is sent to the barge shipping tanks. The barge shipping tanks are 630,000 gallons net working capacity each. These tanks are also pontoon, double seal, floating roof, welded shell construction. The tank height is 56 feet and the diameter is 47 feet. The benzene is pumped to a loading dock manifold where it then enters a marine loading hose which is connected to the barge loading manifold. A minimum of three persons are involved when loading a barge. A barge inspector must certify that the barge is clean enough to prevent benzene contamination. Next the dockside operator must connect the hose to the dock manifold. Last the barge operator connects the hose to the barge manifold and "lines up" the barge compartments by opening the correct valves. Initially the benzene is permitted to gravitate from the tanks to the barge before the pumps are switched on. The normal flowrate for barge loading pumps is 2,000 gpm and two 100% pumps are provided. The loading is monitored by the barge operator who observes either the level in the compartments by inserting dipsticks through the ullage hatches above each compartment (the usual manner) or (less often) by observing the draft of the barge. Observation of the draft limit is practiced when barges must be sent through shallow channels. Benzene vapor is expelled from the barge through the ullage hatches during loading. It is assumed that any ship loading will be done from the barge dock. It is estimated in the United States only a small amount of benzene is loaded onto ships. The United States is a net importer of benzene. As of 1972 estimates, 26 million gallons were exported compared with imports of 125 million gallons and total consumption of 1,282 million gallons. None of the plants visited loaded bėnzene onto ships.

Sources of benzene emissions for the base case producer have been divided into three general categories for convenience. These categories are storage tank losses, loading losses, and miscellaneous losses. Storage tank (floating roof) losses can be subdivided further into standing losses and withdrawal losses. Standing losses are due to liquid benzene evaporating past the perimeter roof seals. Withdrawal losses occur as the tank is drawn down. All losses are calculated according to the emission factors per EPA publication "Compilation of Air Pollutant Emission Factors, Supplement Number 7," April 1977. New calculation methods are being developed by others but were not used because a standard and widely known method was desireable. It is recognized that the methods used for calculating losses may lead to larger than observed losses. The losses are tabulated in Table 4.2.1.

Loading losses are produced as liquid benzene is pumped into the carriers and the benzene vapors are displaced. These losses are also tabulated in Table 4.2.1 for barge, truck, and railcar transports. These vapor losses have two components. One component is the existent vapor in the tanker resulting from previous cargoes. The second component is that benzene vapor generated during loading. It has been assumed that empty tankers have not been cleaned or degassed and contain vapors from previous benzene hauls. The vapor emitted from railcar and

TABLE 4.2.1

Benzene Emissions

Inventory for Producer Base Case

	Storage Losses (lb/yr)		
	Rundown Tanks	Railcar-Truck Tanks	Barge Tanks
Standing Loss	5,600	10,200	12,100
Withdrawal Loss	5,100	2,200	800
Subtotal	10,700	12,400	12,900

Total Storage Losses: 36,000

Loading Losses (lb/yr)		
Rail/car	Truck	Barge
28,900	11,600	28,900

Total Loading Losses: 69,400

Total Plant Losses (lb/yr): 105,400

trucks is assumed to be 60% saturated by benzene. Barge vapor is assumed to be 50% saturated.

Miscellaneous losses include "fugitive" losses and transit losses. Fugitive losses have been defined as those losses occuring from poorly sealed and leaking pipelines, flanges, and pumps. These losses have been calculated by the application of EPA emission factors for refinery hydrocarbon losses (from these sources in their uncontrolled state) to the benzene producers. It has been assumed that all hydrocarbon losses are benzene and that the emission factor is transferable to a benzene producer per se. Transit losses have been defined as benzene lost by carrier vessels "breathing" out benzene vapors as atmospheric conditions cause the pressure settings of the pressure-vacuum relief valves to be exceeded. While this applies to all types of carriers, it has been suggested that due to the short travel time of railcar and truck shipments (under two days) no transit losses occur, and therefore only barges (with longer travel times) are likely to show significant transit losses. It has been assumed that average barge shipments must travel one week to their destination. These losses seem unduly high in our opinion if transit losses are to be attributed to breathing losses. The pressure settings on railcars and trucks are higher than any pressure buildup that could reasonably be expected to occur through normal changes in atmospheric conditions. Relief valve pressure settings for these carriers are on the order of tens of psig. Pressure settings for barge relief valves are approximately 1.1 psig. The pressure build up for a daily 30°F temperature rise (70° to 100°) for an ideal gas initially at atmospheric pressure is approximately 0.8 psig. By comparing the pounds of benzene transit losses with the corresponding outbreathing volume for a week long barge trip it is found that the results do not agree with each other. (The expelled vapor would be supersaturated.)

Control technologies have not been applied to the fugitive losses because these non-point sources are more related to general plant housekeeping and not within the scope of our report. Transit loss control has not been pursued because calculations indicate that losses as defined and calculated by the stated guidelines are contrary to the actual situation, and that actual quantity of transit losses are much lower.

4.2.2 Benzene Consumers

The base case consumers are shown in Figure 4.2.2. The basic principles of receiving and storage for the two consumers is the same. The benzene is accepted from the transports and sent directly to floating roof, double seal, welded shell storage tanks prior to final consumption. The major differences deal with the method of transport and quantities of benzene handled.

The large benzene consumer receives its feedstock by barge and pipeline. Total consumption is 26 million gallons per year or an average of 50 gpm. Of this volume 12 million gallons is delivered by barges and 14 million gallons is delivered by pipeline. The barges are unloaded at 2,000 gpm into two storage tanks. The storage tanks have a working capacity of 420,000 gallons, the diameter is 42 feet and the height is 48 feet. The benzene entering the pilot plant by pipeline is stored in the same tanks. The pipeline flowrate is 26 gpm and is continuous.

The small benzene consumer receives feedstock by railcar and tank truck at a rate of 14 million gallons per year. Of this volume 10 million gallons arrive by railcar and 4 million gallons arrive by tank truck. The tankers are unloaded at 325 gpm. The benzene is stored in two 125,000 gallon (net working capacity) storage tanks. The tank diameter is 25 feet and the height is 48 feet. The benzene is withdrawn from the tanks at an average rate of 26 gpm.

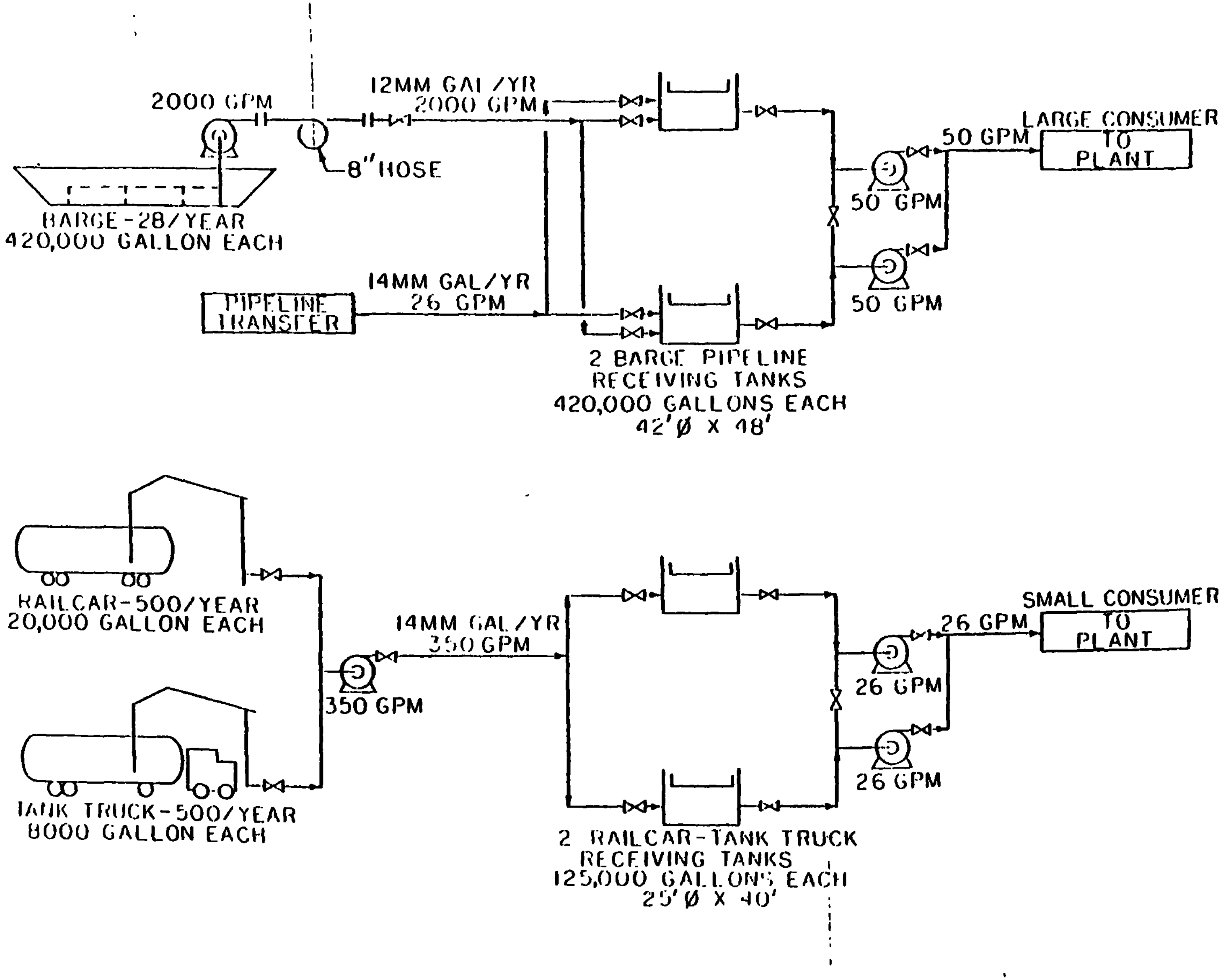


FIGURE 4.2.2 BASE CASE #6 - BENZENE CONSUMERS

The two major categories of benzene losses are storage tank losses and miscellaneous losses. Storage tank losses are tabulated for each case in Table 4.2.2. Miscellaneous losses can be reduced by general plant housekeeping and their control will not be discussed further.

TABLE 4.2.2

Benzene Emissions Inventory for Consumers Base Case

	Standing Loss	Withdrawal Loss
Large Consumer Tankage Losses (lb/yr)	10,213	2,013
Small Consumer Tankage Losses (lb/yr)	4,690	1,821
Total Losses (lb/yr) 18,737		

4.3 APPLICATION OF CONTROL TECHNOLOGIES TO BASE CASES

4.3.1 Producer Cases

As stated earlier in Section 4.2.1, the sources of benzene emissions from benzene producers were divided into three categories, storage tank losses, loading losses, and miscellaneous losses. Miscellaneous losses can be subdivided further into two sources, fugitive losses and transit losses. Control technologies have not been applied to fugitive losses because these non-point sources are more related to general inplant housekeeping and not within the scope of this report. Gas flow rates are given in gpm by vendors, and this convention has been followed in the report.

4.3.1.1 Case Number Two - First Level of Control

The first level of controls over the base case is depicted as shown in Figure 4.3.1.1 for Case Number Two. Case Number Two involves the reduction of storage tank losses by adding cone roofs and reducing loading losses by adding vapor recovery units to treat collected vapors. The addition of cone roofs with louvers to allow air to circulate between the fixed and floating roofs are expected to reduce standing losses by 48%. Withdrawal losses are considered unchanged. Loading losses are collected as they exit the carrier vessels and transported to the vapor recovery units. Railcar and truck loading require some modifications to both the loading arms and the carrier tanks. Special fittings are required to attach the vapor collection hoses to the loading arms. The vapor hoses are mounted piggyback fashion on the arms. The driving force to transport the vapor through the collection system to the recovery unit is provided by liquid benzene displacing vapors as tanks are filled. Vapor collection

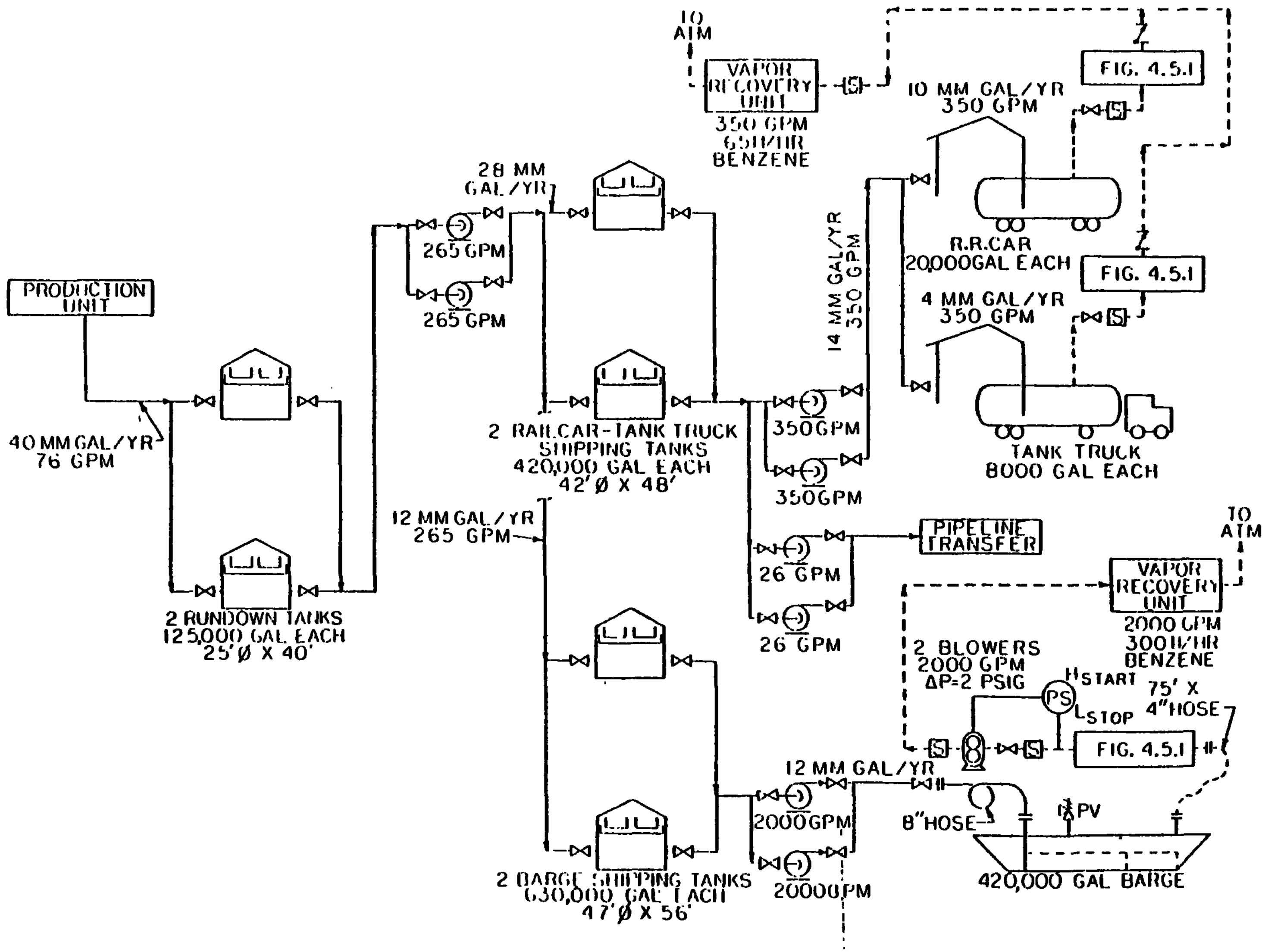


FIGURE 4.3.1.1 CONTROL CASE #2 - BENZENE PRODUCER

for a barge requires the common manifolding of the ullage hatches or pressure vacuum relief lines to permit the attachment of a collection hose. The onshore portion of the collection system requires blowers to transport the vapor to treatment. This is necessary because the required pressure exceeds the design pressure of barges. The blowers have been sized to match the benzene fill rate, and a 100% spare blower is provided.

Saturators are incorporated into the collection system as close to the carrier as possible. The detail of the saturator is shown in Figure 4.5.1. The saturators cascade benzene in a tower through which the collected vapor is passed to saturate the vapor with benzene and raise the concentration above the upper explosive limit. This step greatly reduces the possibility of fire or explosion in the collection system by ensuring that the vapor is over rich. The vapor recovery units are designed to operate only during loading operations. Two units are used, one to handle railcar and truck losses, the other to handle barge losses. Three types of technology, refrigeration-absorption, carbon adsorption, and thermal incineration are used for vapor recovery and these are discussed in Section 4.1.

4.3.1.2 Case Number Three (See Figure 4.3.1.2)

Case Number Three maintains the same control schemes as Case Number Two for vapor recovery of loading losses. For storage tank losses, however, a more elaborate control scheme is used. The floating tanks are covered with cone roofs and pressure-vacuum vent valves installed. The vapor space is blanketed by nitrogen gas and regulated by pressure control to admit N^3 during inbreathing by the tank.

Vapors are collected and transferred by blowers to the recovery units. One hundred percent capacity spare blowers are provided

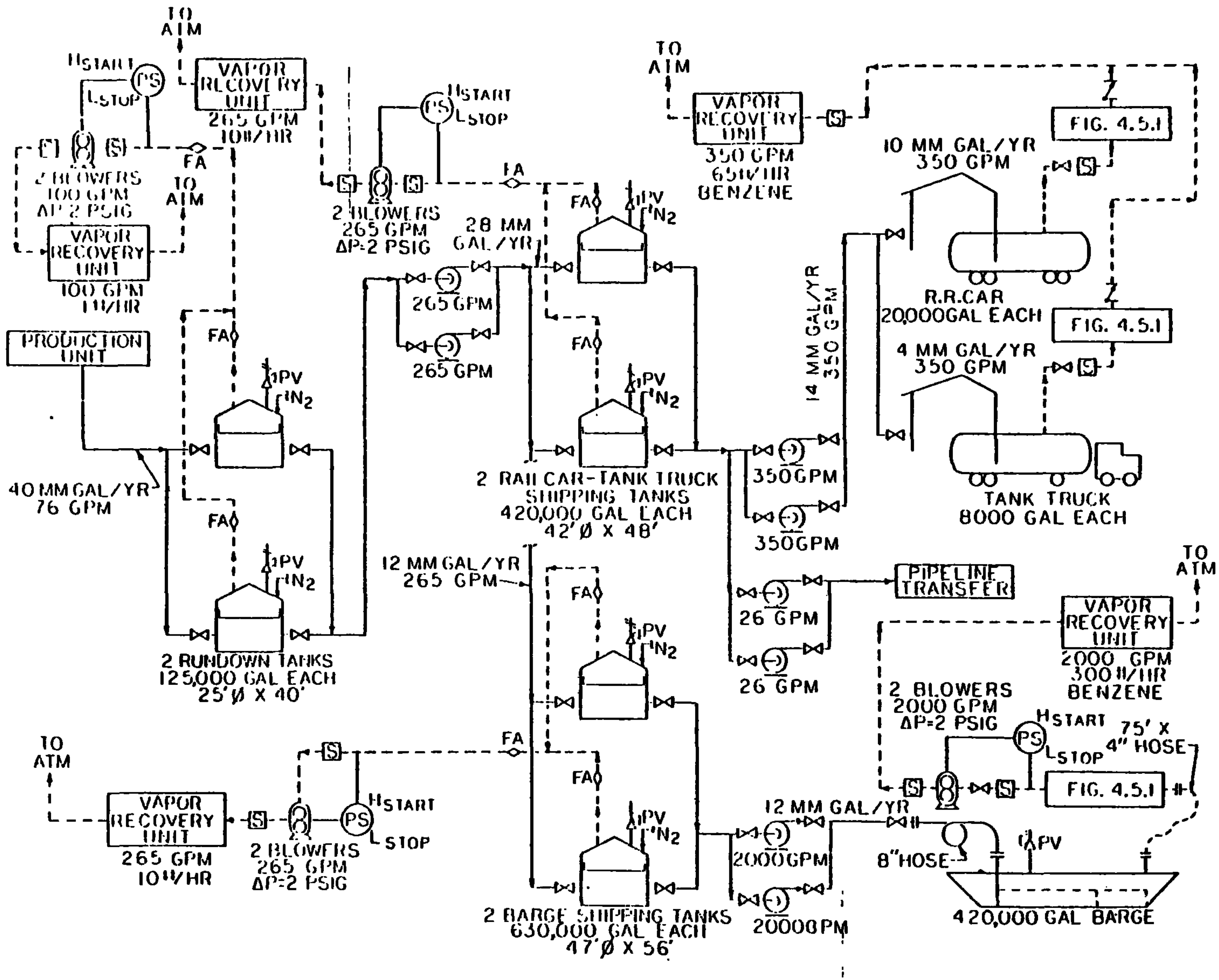


FIGURE 4.3.1.2 CONTROL CASE #3 - BENZENE PRODUCER

in this service. The blowers are controlled by a pressure switch sensing pressure buildup as liquid flows to each tank, thus the blowers start as liquid benzene enters the tank and stop when liquid flow stops. All pieces of equipment are isolated by water seals and/or flame arrestors for safety reasons. Carbon adsorption, thermal incineration, and refrigeration-adsorption technologies are used for vapor recovery and are further discussed in Section 4.1.

4.3.1.3 Case Number Four (See Figure 4.3.1.3)

Case Number Four utilizes vapor balance to reduce the number of vapor recovery units required. In a vapor balance system, the liquid transferred from a tank to a carrier displaces vapor from the carrier which is returned to the vapor space of the tank. Vapor displaced from the tank during liquid fill can be sent to treatment or displaced to another tank in a vapor balance system. Blowers to transfer vapors from tanks are controlled by pressure switches. The collection systems from the carriers include saturators to maintain the vapors above the upper explosive range. Nitrogen blanketing is used on the storage tank vapors to reduce the possibility of explosive mixtures. Breathing losses are not treated because the turndown capability of the collection and vapor recovery units do not permit it. The control technologies of refrigeration-adsorption, carbon adsorption and thermal incineration to be used are covered in Section 4.1.

4.3.1.4 Case Number Five (See Figure 4.3.1.4)

Case Number Five is very similar to Case Number Four except that the use of vapor holders is introduced to reduce the breathing losses by capturing them for treatment. The vapor holder is a tank containing a flexible diaphragm which adjusts according to the volume of vapor stored. Vapor holders are installed in the

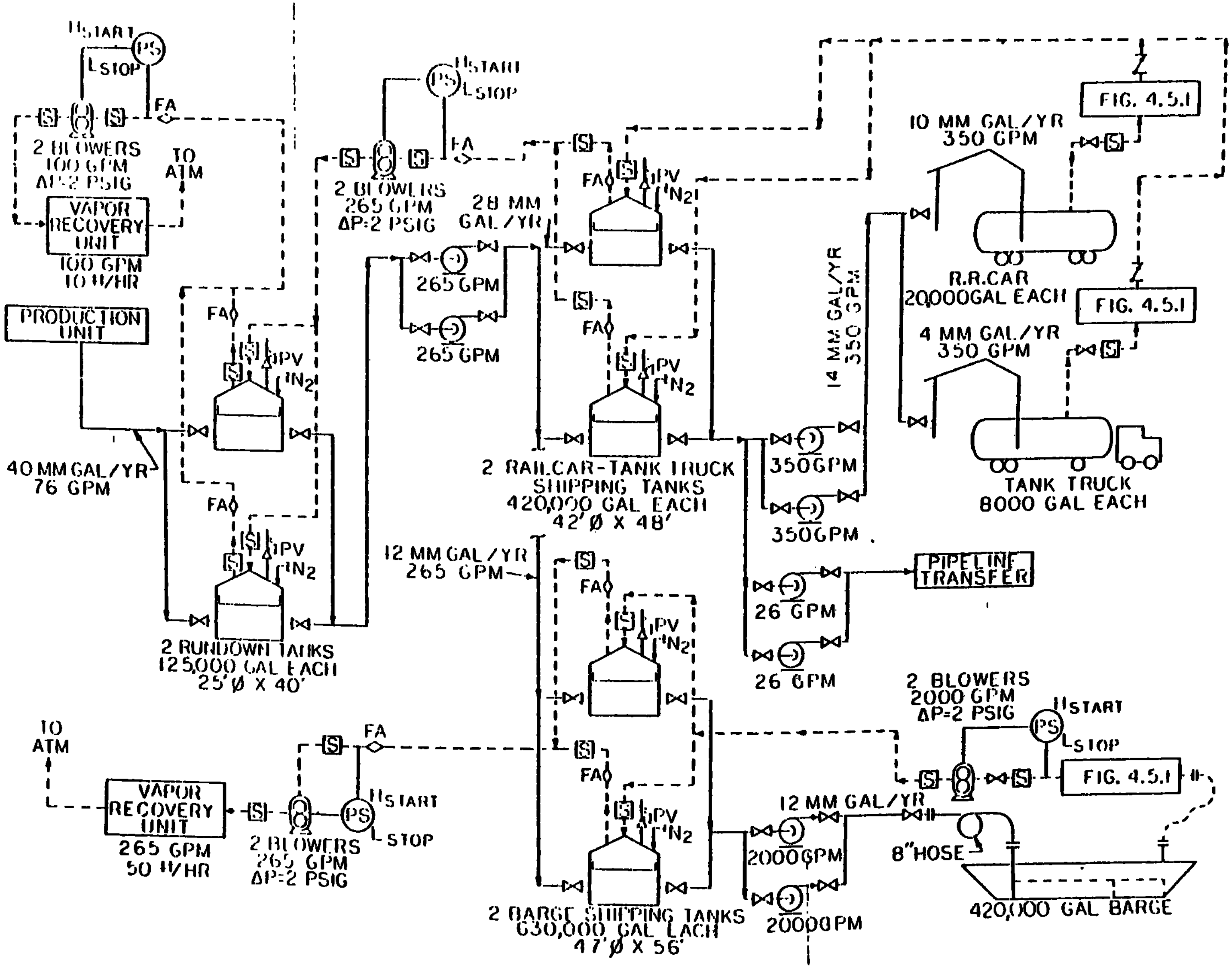


FIGURE 4.3.1.3 CONTROL CASE #4 - BENZENE PRODUCER

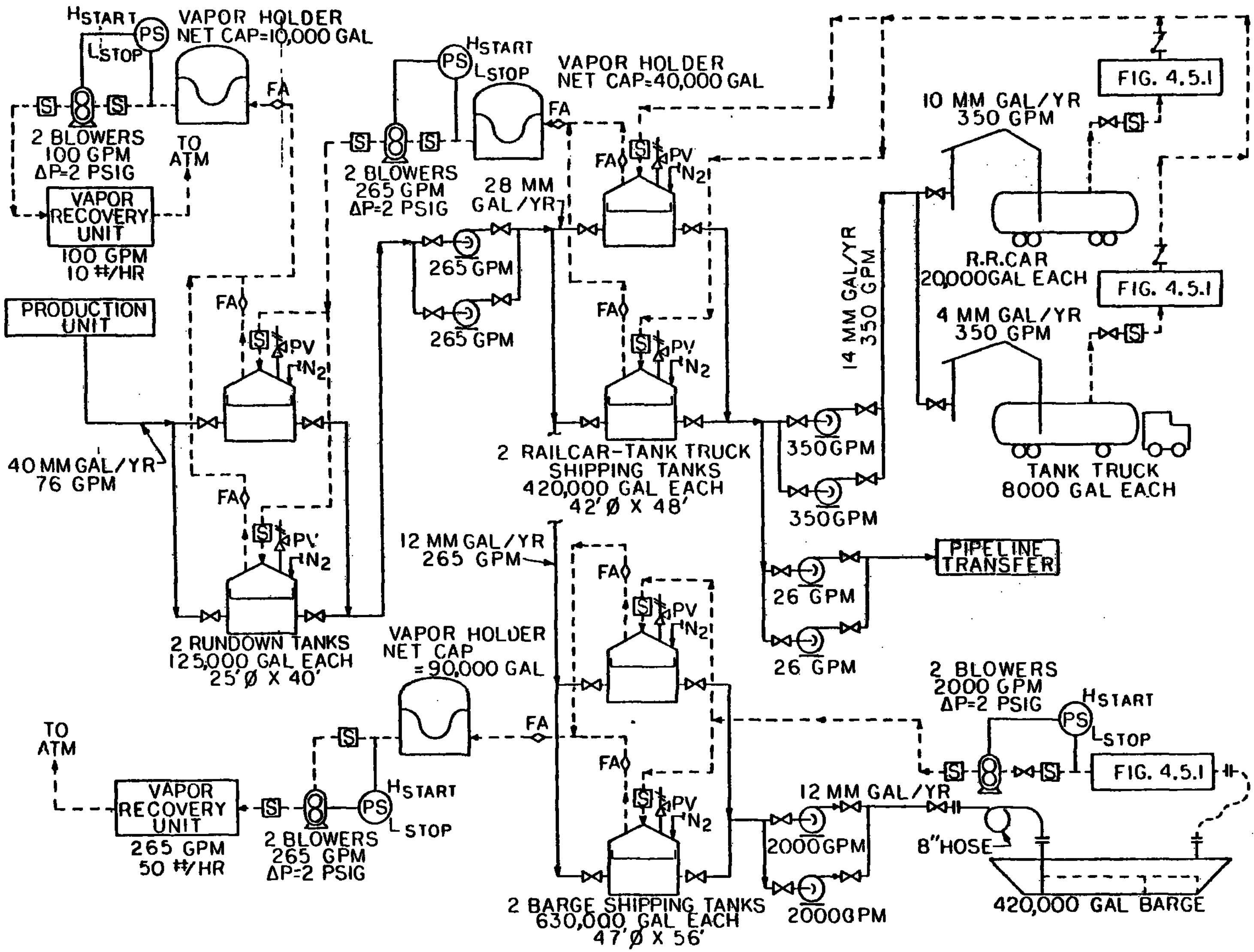


FIGURE 4.3.1.4 - CONTROL CASE #5 - BENZENE PRODUCER

vapor lines out of the storage tanks to receive outbreathing losses throughout the day. If the capacity of the vapor holder is not exceeded by the end of the day, then the same vapor can be used for night time inbreathing volume thereby reducing nitrogen usage. When the capacity of the vapor holder is exceeded, however, the excess vapor is drawn off by a blower and sent to the vapor recovery unit. The starting of the blowers can be controlled either by pressure switch in the vapor holder or by sensing the position of the vapor holder diaphragm. Control technologies to be used in Case Number Four are discussed in Section 4.1.

4.3.2 Consumer Cases

The benzene consumer base case is described in 4.2.2 and is referred to as Case Six. (See Figure 4.2.2.) The first degree of vapor emission reduction is referred to as Case Seven. (See Figure 4.3.2.1). The second degree of control is Case Eight.

4.3.2.1 Case Number Seven

4.3.2.1.1 Large Consumer

The addition to the base case is retro-fit covered floating roof tanks. This reduces the tank emissions approximately 40% below Case Six by lowering the average wind velocity across the roof. Louvers are placed in the top of the tank wall above the floating roof to allow ventilation. This is done to prevent an explosive vapor mixture from accumulating in the tank top. When the barge cargo is pumped into the tank at 2,000 gpm, the roof rises and the vapors are displaced to atmosphere through the louvers. During the daily usage of benzene at 50 gpm, air is drawn in through the louvers. The same exchange of vapors accures when the pipeline fills the tank at 26 gpm.

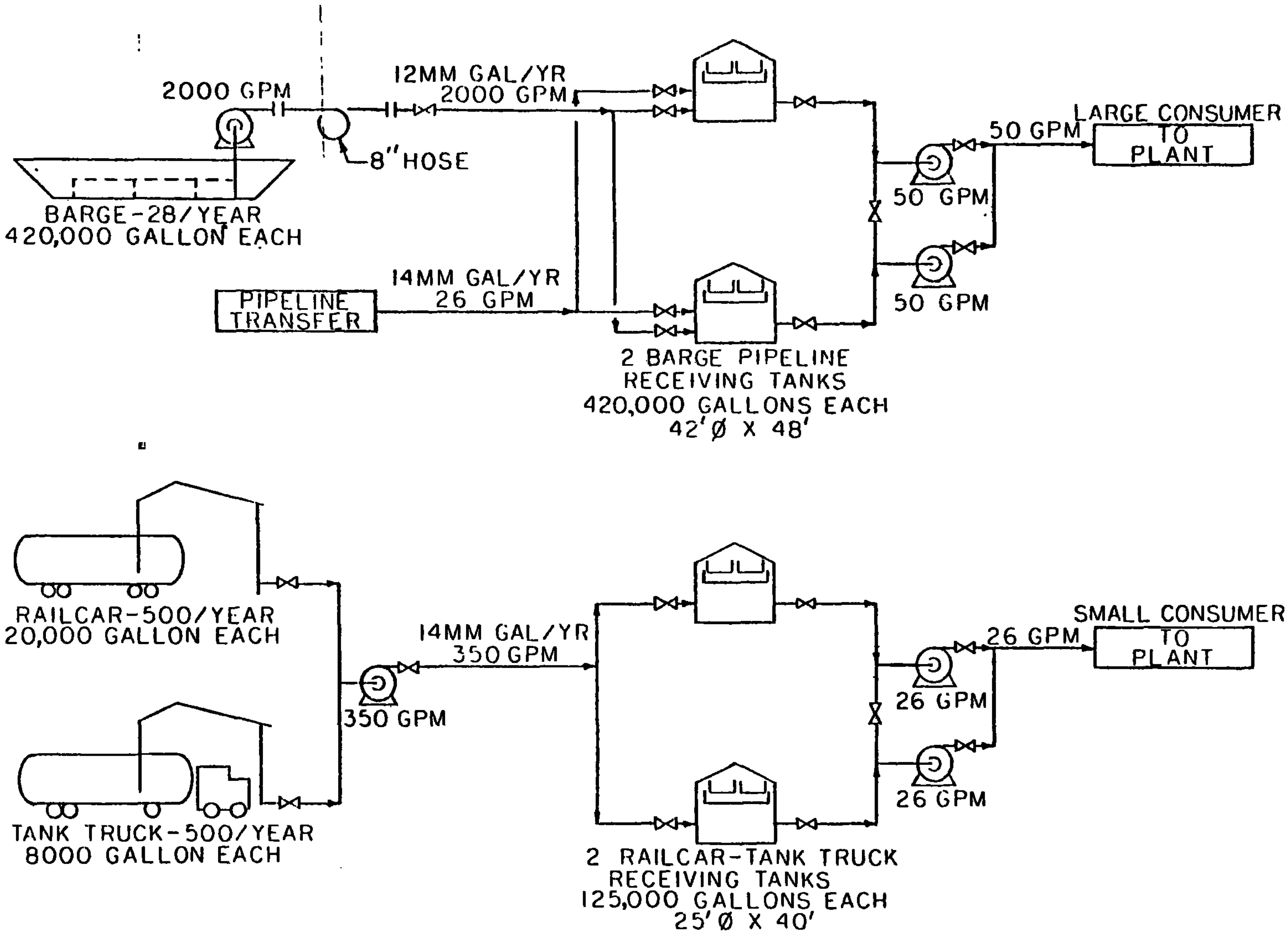


FIGURE 4.3.2.1 CONTROL CASE #7 - BENZENE CONSUMERS

4.3.2.1.2 Small Consumer

The small consumer uses retro-fit covered floating roof tanks with louvers and the tank emissions are reduced approximately 35% below Case Six by lowering the average wind velocity across the roof. The operation is similar to the large consumer except that flowrate from the railcar/truck pumps is 350 gpm and the daily usage rate is 26 gpm.

The safety of the consumer base Case Six is not lowered by Case Seven technology. This first stage of reduction in benzene emission is relatively simple in concept and requires little additional operating expense. The reduction in emissions is shown in Table 4.4.1.1.

4.3.2.2 Case Number Eight

The second degree of vapor emission reduction is referred to as Case Eight. (See Figure 4.3.2.2.) Case Eight is divided into the large and small consumer. The large consumer will be discussed first.

4.3.2.2.1 Large Consumer

The equipment additions to the base case are retro-fit covered floating roof tank, nitrogen inerting, a vapor holder, blower, and three types of vapor treatment units.

The tanks are not provided with louvers in Case Eight, instead they are fitted with pressure-vacuum vents to prevent benzene vapor from entering the atmosphere. Nitrogen is used to blanket and inert the tank vapor space to prevent an explosive mixture. As liquid is removed from the tank, nitrogen is bleed in. As

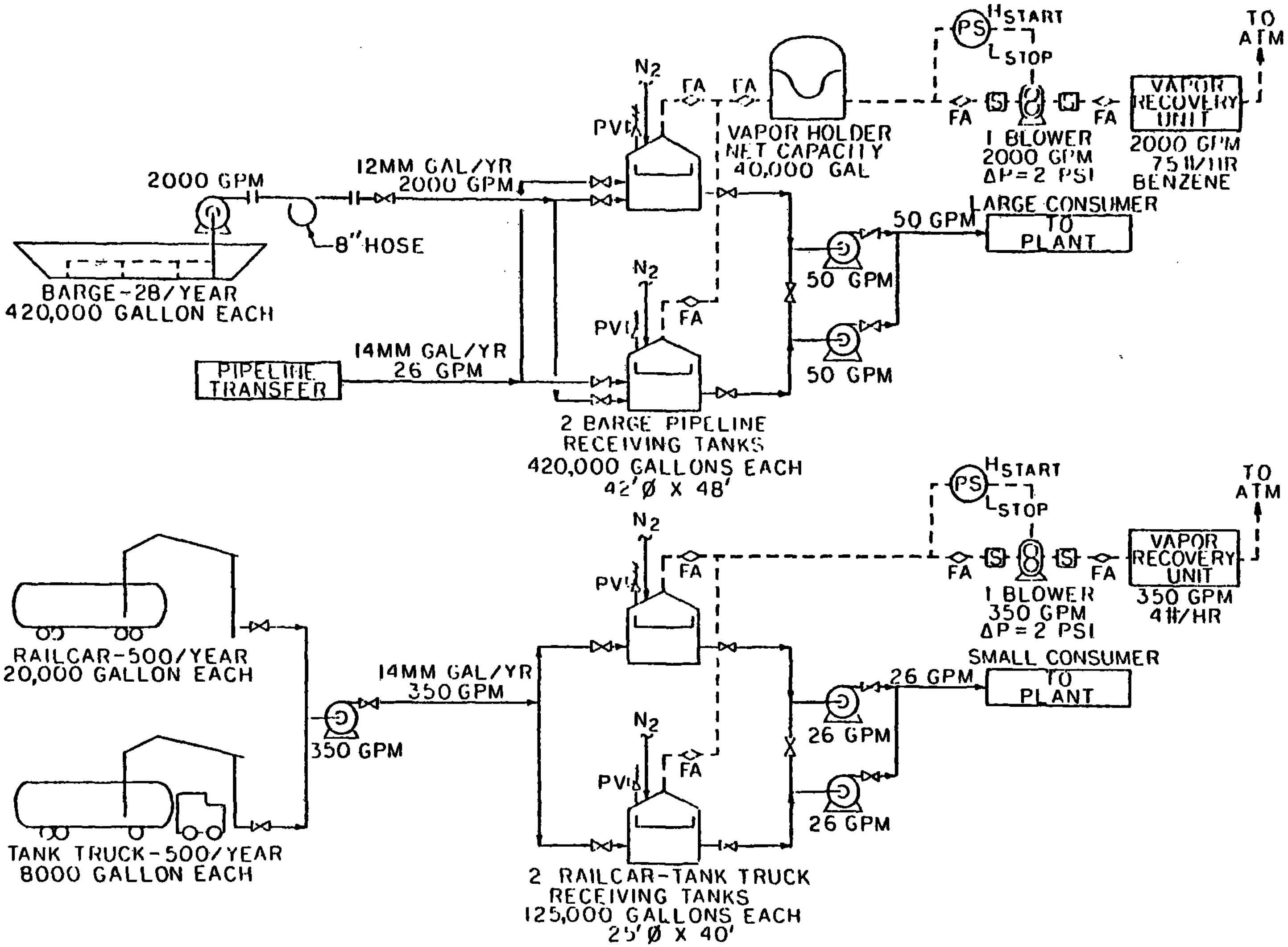


FIGURE 4.3.2.2 CONTROL CASE #8 - BENZENE CONSUMERS

heating occurs and the tank vapors expand, the nitrogen-benzene vapor mixture flows to the vapor holder. A 40,000 gallon (5,350 ft^3) vapor holder is used with the large consumer. Day to day breathing due to temperature change is accomodated by passage to and from the vapor holder. Two sources of tank filling are handled as follows:

(1) When a barge is unloaded every 28 days at 2,000 gpm for 3.5 hours; the pressure in the tank vapor space and vapor holder rises and a pressure switch starts the blower. The vapors flow to the treatment unit. After the barge is unloaded, the blower continues to run until the vapor holder is emptied and then shuts down.

(2) As the pipeline fills the tank at 26 gpm continously, the displaced vapors flow in to the vapor holder. When the vapor holder is full and the pressure rises; the blower is cut on and the pressure rises; the blower is cut on and pumps to the treatment unit.

A flame arrester is installed in the piping between the storage tank vapor space and the vapor holder. The piping on either side of the blower has a flame arrester and water seal. Each treatment unit has a flame arrester and water seal upstream. All of this is done to prevent any accidental explosion from propagating to other parts of the system. The vapors are monitored in the blower upstream piping to assure that a non-explosive mixture does not exists and when a hazard is present, neither the blowers nor the treatment system is allowed to work. The sequence of operation is start treatment unit, start barge pump, the blower starts as the pressure rises. Should the blower remain on too long, the vacuum vents are sized to pass the full 2,000 gpm air flow. The only emission to atmosphere is in the treatment unit tail gas. See Table 4.4.1.2 for emission data.

4.3.2.2.2 Small Consumer

The small consumer utilizes equipment additions to the base case that consist of retro-fit covered floating roof tanks, nitrogen inerting, blower and one of the three types of vapor treatment units. The tanks are not provided with louvers, but use pressure-vacuum vents. Nitrogen is used to inert as discussed above. Day to day breathing due to temperature change is vented to the atmosphere. When the tank is filled from a railcar or tank truck at 350 gpm, the pressure rise turns on the blower and the vapor is pumped through the treatment unit. An interlock system differentiates between a pressure rise due to breathing and that due to tank filling. When the vapor flow stops, the blower turns off. Breathing losses are expected to be low because the benzene liquid withdrawal rate is approximately equal to the daytime breathing rate.

The precautions are the same as for the large consumer. The reduction in emissions is shown in Table 4.4.1.2.

4.4 EMISSIONS

For a complete assessment of emissions when applying control technologies, one must consider both primary emissions (benzene) and secondary emissions (those non-benzene emissions produced as a result of controlling benzene emissions). In the present discussion the evaluation of primary emissions will entail a summary of benzene losses for each case, the basis for calculations of losses, and the calculated emission factors. The emission factors will allow a means of comparing control effectiveness for the different cases. Secondary emissions will receive a less quantitative approach and will center mostly on an inventory discussion.

4.4.1 Primary Emissions

Only two major categories of benzene losses will be discussed; storage losses and loading losses. Fugitive losses will not be addressed because they are not considered within the scope of the study.

Losses from open floating roof storage tanks are subdivided into standing and withdrawal components. Methods for calculating these losses are abstracted from EPA emission factors. When covered floating roof tanks with louvers are considered, the standing losses are reduced because although the same equation is used, a credit for reduced wind speed from 10 mph to a suggested 4 mph is permitted. The reasoning for the reduction in wind speed is that freedom of air movement circulating between the two roofs is reduced. When covered floating roof tanks without louvers are considered, the characteristics of benzene emissions are changed. This type of loss is considered to occur by outbreathing by the pressure vacuum vents, the problem is calculating the volume and benzene concentration of the vapor lost.

Several assumptions to facilitate this calculation are made and are discussed below:

1) The vapor mixture behaves as an ideal gas as temperature experiences a daily cycle in the vapor space of the tanks. The temperature increase is from 70°F to 100°F and barometric pressure is constant.
2) The benzene vapor in the mixture is derived from three sources; standing losses, withdrawal losses, and any additional benzene returned to the tank via vapor balance sources.
3) An average benzene concentration is calculated by dividing the benzene losses by the vapor volume expelled from the tank.

For those cases that a vapor holder is incorporated the breathing losses have ben assumed to be reduced by 90% from the non-vapor holder case.

The calculation of loading losses is complicated by the addition of vapor recovery systems. The effects of benzene saturators, efficiencies of the collection-treatment systems, intermingling of the loading and storage losses by vapor return must be accounted for. When benzene vapors are recovered from a carrier in the explosive range, benzene must be added to bring the concentration up to saturation and therefore out of the explosive range. The quantity of benzene that can be potentially lost is greater than just the loading loss.

There are some losses associated with the collection systems from poor connections, leaks, faulty operation, etc. Finally, because the vapor treatment units are not 100% effective, there is still some small amount of benzene that escapes untreated.

4.4.1.1 Case Number One

A discussion of primary losses for the base case has been presented in Section 4.2.1 and will not be repeated here.

4.4.1.2 Case Number Two

For Case Number Two the calculation of storage losses is straight forward for the covered floating roof tanks. Standing losses for the covered floating roof tanks are calculated with the same equation as an open floating roof except that the wind speed used is 4 mph rather than 10 mph. Withdrawal losses are unchanged because wind speed is not a factor. Storage tank losses are tabulated in Table 4.4.1.1.

Loading loss calculations are best illustrated by an example. The example used here is barge loading loss. The barge is loaded at 2000 gpm with liquid benzene at 85°F and 25 psig. The emission factor for these conditions is 2.41 lb/10^3 gallons loaded. Since this vapor stream is not saturated, 2.41 lb/10^3 gallons benzene must be added in the saturator to comply with safety goals. This additional benzene becomes susceptible to loss downstream in the treatment system. The total amount of benzene entering the collection system is 57,900 pounds. The ~~collection~~ system is assumed to have an efficiency of 98%, thus the benzene reaching the treatment unit is 56,700 pounds, and 1,200 pounds is lost to the atmosphere. Efficiencies for the vapor treatment units are based on vendor reported emission levels and saturated benzene- air mixtures. For the refrigeration-absorption system, the benzene recovered is 56,400 pounds and the benzene released to atmosphere is 300 pounds. The calculated emission factor for carbon adsorption or thermal oxidation is .684 lb/10^3 gallons of benzene produced. For

TABLE 4.4.1.1

Benzene Emissions Summary For Benzene Producer Control Cases

	2			3			4			5		
	A	B	C	A	B	C	A	B	C	A	B	C
Treatment Unit Technology	Refrigeration Absorption	Carbon Adsorption	Thermal Incineration									
Tankage Losses (lb/yr)	22,809	22,809	22,809	2,874	2,874	2,874	26,082	26,082	26,082	2,608	2,608	2,608
Collection Losses (lb/yr)	4,531	4,531	4,531	4,929	4,929	4,929	8,067	8,067	8,067	8,746	8,746	8,746
Losses Through Treatment Units (lb/yr)	664	12	156	734	14	182	609	11	143	752	14	182
Total System Losses (lb/yr)	28,004	27,352	27,496	8,537	7,817	7,985	34,758	34,160	34,292	12,106	11,368	11,536
%Reduction From Base Case #1	73.4	74.1	73.9	91.9	92.6	92.4	67.0	67.6	67.5	88.5	89.2	89.1

refrigeration-absorption it is .700 lb/10^3 gallons. The factor for thermal incineration is .687 lb/10^3 gallons.

4.4.1.3 Case Number Three

In Case #3 the covered floating roof tanks are not equipped with louvers. The benzene vapor which evaporates remains in the space between the two roofs and is emitted by breathing, or when the tank is filled with liquid and the roof rises. No attempt is made to capture or treat breathing losses. Vapor expelled during tank filling is handled by a vapor treatment system dedicated for each set of tanks. Loading losses for Case #3 are unchanged from Case #2. A Summary of Case #3 losses is shown in Table 4.4.1.1 The emission factor for Case Number Three is .195 lb/10^3 gallons produced for thermal oxidation or carbon adsorption, and .213 lb/10^3 gallons for refrigeration absorption, and .200 lb/10 gallons for thermal incineration.

4.4.1.4 Case Number Four

Calculations of losses for Case #4 are complicated by the mixing of loading losses and storage losses, as loading vapors are saturated and returned to the vapor space of the tanks. Thus the vapors lost from tank vapor spaces are richer in benzene. This causes the breathing loss from tanks to increase. Losses for Case #4 are tabulated in Table 4.4.1.1. The emission factor is .854 lb/10^3 gallons for carbon adsorption, .869 lb/10^3 gallons for refrigeration absorption, and .857 lb/10^3 gallons for thermal incineration.

4.4.1.5 Case Number Five

Case #5 is identical to Case #4 except for the addition of vapor holders to provide surge capacity to contain breathing losses.

Thus the losses for Case #5 are similar to Case #4 except that breathing losses are drastically reduced. Case #5 losses are shown in Table 4.4.1.1. The emission factor for Case #5 is .284 $lb/10^3$ gallons for carbon adsorption, .303 $lb/10^3$ gallons for refrigeration absorption, and .288 $lb/10^3$ gallons for thermal incineration.

4.4.1.6 Case Number Six

A discussion of primary emissions for the base case is presented in Section 4.2.2 and will not be repeated here.

4.4.1.7 Case Number Seven

Case #7 represents the first control case for the benzene consumers. The method used to reduce benzene emissions from tankage is to cover the floating roof tanks. This step reduces the standing losses. Emissions for Case #7 are presented in Table 4.4.1.2. The emission factor for this case is .287 $lb/10^3$ gallons.

4.4.1.8 Case Number Eight

Case #8 uses covered floating roof tanks blanketed by N_2 and vapor treatment units to reduce emissions. The large consumer utilizes a vapor holder in addition to the other measures to further reduce breathing losses. Table 4.4.1.2 lists the results. The emission factor for Case #8 is .027 $lb/10^3$ gallon for carbon adsorption and thermal incineration technologies and .028 $lb/10^3$ gallons for refrigeration absorption.

TABLE 4.4.1.2

Benzene Emissions Summary For Benzene Consumer Control Cases

Case Number	7	8	8	8
Treatment Unit Technology	None Required	Refrigeration Absorption	Carbon Adsorption	Thermal Incineration
(lb/yr) Tankage Losses	11,482	853	853	853
(lb/yr) Collection Losses	0	217	217	217
(lb/yr) Losses Through Treatment Units	0	59	1	13
(lb/yr) Total System Losses	11,482	1,129	1,071	1,083
% Reduction From Base Case #6	38.7	94	94.3	94.2

4.4.2 Secondary Emissions

The three types of secondary emissions (solid, liquid and gaseous) for each of the control technologies are discussed in the following sections.

4.4.2.1 Solid Emissions

It is unlikely that either the refrigeration-absorption or thermal incineration systems will generate any significant waste solids. Carbon adsorption will lose some small amount of carbon dust during normal operations. This dust is produced as the carbon granules abrade against each other and escapes through the support medium and out the vapor exit. At the end of the carbon bed's useful lifetime the entire carbon bed must be replaced with new carbon. This carbon will still have some small residual benzene along with other hydrocarbon based impurities not previously desorbed.

4.4.2.2 Liquid Emissions

One source of liquid wastes common to each technology is benzene contaminated water in the many water seals. The magnitude of this pollution is considered relatively small, the equilibrium concentration of benzene in water (@ 100°F, 1 atm.) is approximately 30 mg/l. An overflow rate of .5 gpm per seal is necessary to insure safety. Liquid emissions for thermal oxidation, neglecting water seals, is zero. Refrigeration-absorption and carbon adsorption technologies both have condensers which condense benzene and atmospheric water vapor. The water must be drawn off in a decanting separator and disposed. The condensers of the refrigeration-absorption system will also condense some diesel oil out with the benzene and water.

4.4.2.3 Gaseous Emissions

No secondary gaseous emissions are anticipated from the carbon adsorption systems. Diesel vapors may be released from the refrigeration absorption systems, but the expected level is low due to the low volatility of diesel oil. The thermal incineration systems will be the largest generator of secondary gaseous emissions. The gaseous emissions from thermal incineration are the normal combustion products, and include NO_x, CO, and unburned hydrocarbons. If fuel oil is used instead of natural gas, SO_x will be produced also.

4.5 OPERATION OF CONTROL SYSTEMS

4.5.1 Safety

4.5.1.1 General Discussion

Safety is always of paramount importance when designing equipment to handle flamable materials. It is necessary that systems added to reduce benzene emissions not introduce significant fire and explosion hazards. Vapors vented to atmosphere from carriers and storage tanks quickly dilute to a concentration below the lower explosion limit. When vapors are collected and piped to a disposal or recovery unit, the danger of an explosion is more prevalent because the vapor concentration is in, or close to, the explosive range. The safety hazard increases as more machinery is required to handle explosive vapors and as longer piping runs are required. A partial listing of ignition sources includes: (1) Static electrical sparks, (2) Sparks or hot spots created by machinery such as blowers or vapor pumps, (3) External damage to piping which causes leakage along with a spark or hot surface, (4) Flash back from flame in vapor incinerators.

When applying vapor control systems to benzene facilities, means must be found to (a) prevent explosive vapor mixtures, (b) reduce ignition sources, (c) isolate systems so that flame fronts will not travel through whole systems.

4.5.1.2 Case Studies

All case studies required that special systems be provided to prevent undue explosion hazards. The intent has been to design benzene vapor control systems that can be added to existing benzene transfer facilities so that the potential for an explosion for the modified facility will not have increased. The following special systems and features were incorporated in the designs and included in the estimates for the study cases:

4.5.1.2.1 Cases 2, 3, 3, 4 - Benzene Saturator
(See Figure 4.5.1)

The vapors from the carriers to the storage tanks or treatment units are made safe by saturation with benzene. A benzene saturator is used in Cases 2, 3, 4 and 5 in association with barges, railcars and tank trucks. The purpose of the saturator is to increase the benzene concentration of the benzene-air mixture and therefore avoid an explosive mixture. The saturator consists of a pressure vessel, spray nozzel, heat exchanger, recycle pump, demister pad and control devices to maintain a constant liquid level and to shut down the pump if the level gets too low. A no flow switch shuts off the heat exchanger. A vent pipe is attached to the saturator such that an over pressure and under pressure can be handled at the carriers loading pump design flow rate (2,000 gpm for barges, 350 gpm for railcars and tank trucks).

4.5.1.2.2 Cases 3, 4, 5 - Nitrogen Inerting

A nitrogen inerting system is used in cases 3, 4, and 5 in association with vapors stored or generated in the vapor space above the covered floating roof tanks. The purpose of the nitrogen is to lower the oxygen content to below 5% volume, and therefore, avoid an explosive mixture. The nitrogen system consists of a storage tank of liquid nitrogen, a vaporizer, and pressure control valves to maintain the pressure in the benzene-nitrogen mixture to a positive level, but below the pressure setting of the pressure-vacuum vent.

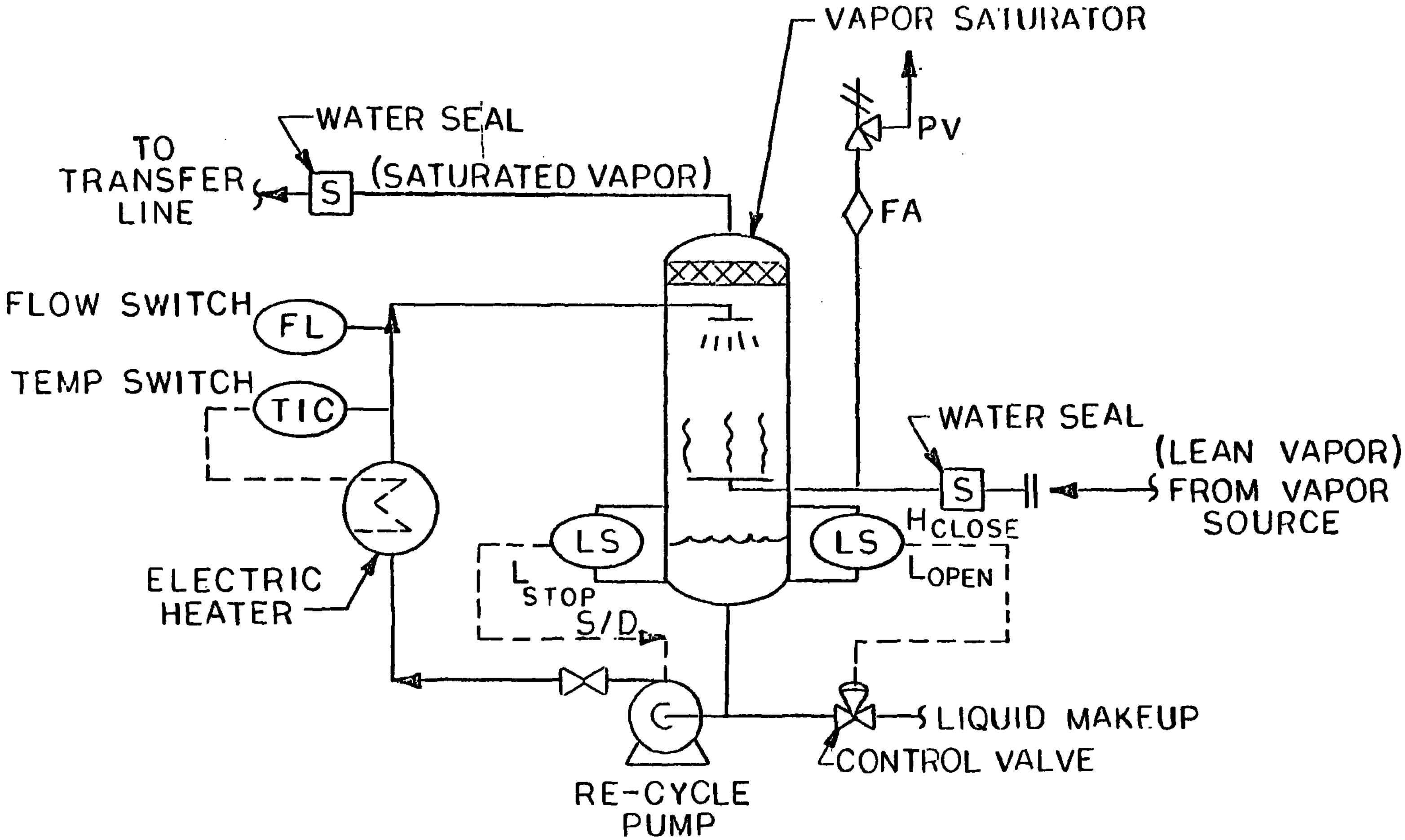


FIGURE 4.5.1 BENZENE VAPOR SATURATOR

Therefore, because the vapors above a floating roof tank would be difficult to keep saturated, the nitrogen takes over as the safety system from the tanks onto the treatment unit.

Metal heat sink flame arrestors and water seals are used to prevent flame front propogation. Monitors are used to detect explosive mixtures and to shut down blowers and treatment units when a danger does exist.

4.5.1.3 Other Considerations

The safest and least usage of nitrogen would be a system where both the producer and consumer use nitrogen blankets and carriers were in dedicated service. This system was dropped from the study since it is thought that it would be impractical to require industry to use all dedicated carriers.

Another way to avoid an explosive mixture is to dilute the vapor by injecting air. Enough air is added to keep a saturated vapor well below the lower explosion limit (L.E.L.) of 1.4% volume benzene. This would mean adding about 20 parts of fresh air for every part of saturated benzene vapor. High flow rate blowers would draw in fresh air and mix with the vapors drawn in from the carrier hatches or vents. This lean mixture would then be incinerated using supplemented fuel. Detection and control devices would be used to ensure that enough fresh air is added to maintain vapor concentrations below the L.E.L. However, at some point in the dilution process the mixture is in the explosive range. Incineration is the only practical treatment for diluted vapor systems because of the high volumetric flow rates involved. The increased flowrate (due to dilution) would increase the equipment sizes for refrigeration-adsorption and carbon adsorption. The only practical service for diluted vapor systems is direct disposal of carrier displacement vapors. This system was dropped from the study since it could only be used with one type of treatment (thermal incineration) and its increase in safety was not sufficiently large to outweigh its negative aspects.

4.5.2 Reliability

The reliability of the three types of vapor treatment units cannot readily be established for benzene operation. Some of the units have been tested in benzene service and some have been used in a service similar to benzene. An attempt will be made to rate the reliability of each type of unit based primarily on its mechanical simplicity where the unit having the fewest moving parts is considered to be the most reliable.

Using the reasoning stated above, the most reliable vapor treatment unit is the thermal incinerator. Its principle moving parts are the air damper, fuel control valve and pilot burner ignitor.

The next most reliable vapor treatment unit would be carbon adsorption. Its principle moving parts are the motor operated valves, liquid ring vacuum pump for regeneration, benzene pump, float controls in the regeneration separator, and the coolant refrigeration unit. (The coolant refrigeration unit can be omitted if a 60°F source of cooling water is available.) The regeneration system does not have to work when the adsorbing is actually taking place as long as the carbon bed is sized large enough. Under this condition the handling of benzene vapors can be done by a completely passive system. The vapors need only flow through the regenerated carbon bed. The carbon bed has an estimated twenty year life because vacuum regeneration eliminates thermal induced stresses in the carbon and a low bed working capacity (2% benzene to carbon by weight) is used for design thus allowing tolerance for degradation.

Refrigeration-condensation-absorption is the least reliable. Its principle moving parts are the first stage refrigeration unit, the first stage benzene removal pump, the first stage refrigeration pump, the second stage scrubber lean oil refrigeration unit, lean oil pump, regenerator vacuum purge pump and second stage benzene removal pump. The parts that have to work during benzene vapor flow are the first and second stage units, refrigeration, lean oil, regenerator vacuum purge, and two benzene removal pumps. Because of this large number of parts which must work all at one time, the benzene vapor cannot flow through a passive system.

Preventive maintenance is necessary with the refrigeration-condensation-absorption system. If pure absorption is used, the first stage parts are eliminated and reliability is improved.

4.5.3 Operation

The basic transfer operations required for operating the vapor control systems described in this report are:

1. a) Transfer of vapor from carriers to storage tank vapor space prior to treatment or
   b) Transfer of vapors from carriers directly to the treatment systems without intermediate storage
2. Storage of benzene vapors using a nitrogen gas blanket.
3. Transfer of vapor from storage to treatment.

4.5.3.1 Transfer of Vapors from Carriers to Treatment Units or Storage Tanks

Transfer of vapors from carriers requires vapor saturators, blowers (as required), and associated piping. Liquid pumped into the carrier displaces vapors through a vent header collection system located on the carrier, through a vapor hose, through a metal flame arrestor and water seal, and into a benzene vapor saturator. (See Figure 4.5.1 and Section 4.5.1.2) From the saturator, the vapors flow through a metal flame arrestor, a water seal, a blower, a water seal and metal flame arrestor to the pipe line that takes them to the treatment unit or storage tank. The blower is not necessary if the design pressure of the carrier is sufficient to provide the pressure differential necessary for flow. The blower is of the positive displacement involute gear type. Special packing glands are used to isolate the lubricated parts of the blower from contact with the benzene vapor. Before entering the treatment unit the vapors again pass through a metal flame arrestor and water seal.

4.5.3.2 Transfer to Treatment Units

When vapors are treated directly from the carrier, additional operations are required. These steps are specific for each technology, and are discussed below.

<u>Thermal Incineration Unit</u>

Before the incinerator can be started, a series of interlocks must be proved. These include a liquid level control in the water seal, and a preliminary electrical check for the unit's ~~controller~~ flame safeguard controls. Each pilot has its own flame scanner which must prove ignition before the unit controller takes over and turns on the main fire burners. These units are started in diagonal pairs to assure optimum flame symmetry and complete oxidation of vapor[1]. Once the burners

(1) Description courtesy of National Airoil Burner Company, Inc.

are operating, the benzene vapor saturator liquid pump is started. The blower, which is located close to the saturator, has a combustible gas monitor located in the inlet and outlet piping. The blower can be started when the vapors are saturated. Next the liquid benzene fill is opened and benzene flows into the carrier by gravity. Vapors are displaced into the saturator slowly until the benzene pumps are started. In the interim period, air is drawn in through the saturator pressure vacuum vent to prevent the blower from surging. This air saturates with benzene as it flows through the saturator and is burned in the incinerator. When the air flow stops, benzene loading pumps are turned on because sufficient vapor is displaced ~~to build a~~ positive pressure in the system.

When the carrier is filled with liquid, the liquid loading valve is closed and the loading pump shut down. The blower is then shut down and finally the incinerator is shut down. As the last bit of combustible vapor is burned, the flame out is prevented from proprogating upstream by the action of the water seals.

Carbon Adsorbtion Unit

Before the adsorber can be used, at least one of the carbon beds has to be regenerated and ready to receive flow. The saturator liquid pump is then started.

If no explosive mixture exists, then the blower is started, the loading valve opened to fill the carrier, and finally the loading pump started. The vapor flows through a metal flame arrestor and water seal into the carbon bed and to atmosphere. Instrumentation is provided to monitor the tail gas hydrocarbon content and to give an alarm if the desired benzene level is exceeded.

The sequence for shut down is the same as for the incineration system discussed above.

Refrigeration-Condensation and Absorption Unit

The refrigeration system is operated to cool down itself prior to introducing benzene vapors. This is done by the first stage cooling unit refrigerating the first stage vent condenser. The lean oil pump circulates a stream of lean oil through the second stage scrubber absorber. When the unit is ready to receive vapors; the saturator pump is started, then the blower, the benzene liquid valve opened, and the loading pump started. The vapor flows through a metal flame arrestor and water seal before entering the first stage refrigeration-condensation unit. A non-explosive vapor mixture must be present upstream of the blower before the blower or treatment unit can be started.

The sequence for shutting down is: shut down the benzene loading pump, close loading valve, shut down blowers, and shut down vapor saturator. When the vapor flow is stopped, the first stage refrigeration unit will shut down. The rich oil regeneration system will continue to operate until the oil is stripped of benzene.

4.5.3.3 Storage of Benzene Vapors Using a Nitrogen Gas Blanket

The tank vapor space is maintained at a positive pressure by regulating a makeup stream of nitrogen. As the pressure in the tank lowers during liquid withdrawal or by ambient cooling, the pressure control valve bleeds in nitrogen before the vacuum vent opens.

4.5.3.4 Transfer of Vapors from Storage to Treatment

Vapor saturators are not used to assure a non-explosive mixture, instead the nitrogen blanket serves this purpose.

For thermal incineration, carbon adsorption and refrigeration-condensation-absorption, the vapors are pumped from storage by the use of a blower. The sequence is similar to the description given in 4.5.3.2. The pressure rise in the vapor space activates a switch and starts the blower and treatment unit.

4.6 ECONOMICS

4.6.1 Capital Cost

4.6.1.1 Basis for Estimates

Capital cost estimates were generated for each of the control cases previously described. All cost figures are given in U.S. dollars for 1977 fourth quarter. The capital cost estimates cover the entire monentary outlay required to purchase and install all the equipment associated with any particular control scheme at an existing plant. Prices for specialty vapor control equipment were obtained from vendors as "budget price" (thermal incineration and refrigeration absorption) and "order of magnitude estimates" (carbon adsorption). It should be recognized that wide variations in prices may occur for these specialty equipment items due to development costs and the uniqueness of each vendor's item. Bulk commodity items such as piping, steelwork, foundations, electrical supply equipment, and paint were estimated and priced by Pullman Kellogg's estimating department. Prices of spare parts for the major treatment equipment were estimated as percentages of the equipment price. No spare or backup treatment units as such were included. Spare blowers were specified for each service to match spare liquid transfer pumps, thus matching fluid handling reliability. It was assumed that power and fuel gas are available at the site of the control equipment and only short distribution lines were necessary, thus no costs were included for cross plant distribution lines. Home office costs (insurance, taxes, engineering, commissioning, overhead, and profit) were estimated as a percentage of subcontract, labor, and total direct materials costs.

Cost for modification of transport tankers; railcars, tank trucks, and barges; were not included in the costs of the various control cases since most carriers are not owned by the benzene producer or consumer but are leased from and operated by others. These costs were estimated separately.

Each control case will require the same modifications to the carriers. It is virtually impossible to accurately estimate the cost of modifying the entire fleet of benzene carriers due to unresolved question ownership, dedicated service, and actual number of carriers requiring modification. The cost of modifying each carrier can be estimated and these costs are given. The cost of modifying a railcar or tank truck is estimated at $4,000/vehicle. A barge modification cost of $68,000 per barge, has been reported in the literature.[1]

Comparing non-installed capital equipment costs for the three control technologies, we find that the costs of refrigeration-adsorption systems and thermal incineration systems for similar sized units are similar and the cost for vacuum regenerated carbon adsorption is several times higher. The cost of thermal incierators probably does not vary much between vendors. The cost of thermal incinerators increases slowly with increased capacity, one vendor quotes a 45% price increase for increasing capacity tenfold on a volume basis from 500 gpm to 5,000 gpm. Note: Vendors rate their units in gpm of vapor rather than cubic feet per minute.) The cost of the refrigeration-adsorption systems (on the basis of a single vendor) variation with capacity is more difficult to evaluate due to scarcity of information. A similar conclusion was reached for the carbon adsorption systems evaluated.

(1) Background Information on Hydrocarbon Emissions from Marine Terminal Operations. Volume I, Radian Corporation, EPA Report No. 450/3-76-038a.

It should be noted that several of the design criteria used for the models have an economic bias peculiar to the carbon adsorption system and should be discussed. The decision to evaluate the technologies at their lower but unequal emission limits subjects the carbon adsorption system to a cost disadvantage. Although both carbon adsorption and thermal incineration are evaluated at 10 ppm, only carbon adsorption suffers a significant cost handicap. This is because the extra cost of building a thermal incinerator to reach a 10 ppm limit rather than a 1000 ppm limit is small, since the difference in achieving the lower limit is due primarily to the method of operation. However, the cost difference for building a carbon adsorption system to go from 1000 ppm to 10 ppm is very large due to the larger bed volume and therefore larger vessel required. The extra vessel capacity adds significantly to the cost because of the vacuum design. Another bias against the carbon adsorption systems occurs due to the back-to-back barge loading requirement. This again requires a larger carbon bed capacity or alternately an extra bed due to the lack of time for regeneration of a spent bed. This loading requirement does not materially affect the incinerator (which can operate continuously) or the refrigeration-absorption system (which can regenerate continuously). Each of these biases can cause a several fold cost increase for the carbon adsorption systems. The possibility of these dramatic reductions of capital and annualized costs as well as increased cost effectiveness for carbon adsorption systems should be taken into account when weighing alternatives.

4.6.1.2 Discussion of Cases (See Table 4.6.1)

4.6.1.2.1 Case Number Two

Case Number Two provides the lowest capital cost (to producers) for refrigeration-absorption technology cases and the lowest cost for thermal incineration cases at $664,000 and $603,000 respectively. This is due to the fact that Case #2 has the least amount of equipment of any case. The carbon adsorption system, however, ranks as the second most costly among carbon adsorption systems. This is due directly to the fact that it also has the second highest special equipment cost. This result is to be expected since the cost of carbon adsorption systems increases drastically with increases of capacity when compared to the other technologies. The costs of the small and large carbon adsorption units for Case #2 are $215,000 and $742,000 respectively. The costs of the two treatment units for refrigeration-absorption are $33,000 and $82,000. Costs of the thermal incinerator units are $36,000 and $44,000.

4.6.1.2.2 Case Number Three

Capital costs for Case #3 are greater than Case #2 for each type of technology, which is to be expected since Case #3 requires three additional vapor treatment units over Case #2. The projected capital cost for refrigeration-absorption technology is $1,068,000 and that for thermal incineration is $1,096,00. Carbon adsorption technology will require $2,878,000 dollars, Case #3 represents the most costly case for this technology.

4.6.1.2.3 Case Number Four

In Case #4 the capital cost for carbon-adsorption decreases dramatically from that of Case #3 as the number and capacity of treatment units is reduced. The capital cost for Case #4 carbon adsorption is $1,507,000. This reduction is made possible by taking advantage of returning vapors from carriers back to the storage tanks thus reducing the number of treatment units and their capacities. However, similar cost reductions were not observed for the refrigeration-absorption or thermal incineration technologies, whose costs increased by 4% and 10% respectively. Capital cost for refrigeration-absorption is $1,111,000 and thermal incineration is $1,216,000. This divergence in cost effects is explained by the relative costs of buying and installing the treatment units and that of the extra vapor collection systems. The cost reduction for carbon adsorption units is greater than the increase due to added vapor piping systems, thus making Case #4 less than Case #3. For the other two technologies the added cost of vapor collection systems outweighs the cost reduction for the vapor treatment units. The net effect of Case #4 is that carbon adsorption compares more favorably with the other technologies.

4.6.1.2.4 Case Number Five

Case #5 contains all the items included in Case #4 and adds three vapor holding tanks to reduce breathing losses. As such the capital costs of all three technologies are increased over that of Case #4 by the costs of the vapor tank additions. The capital costs of the Case #5 technologies are:

Refrigeration-Absorption	$1,301,000
Carbon Adsorption	$1,971,000
Thermal Incineration	$1,349,000

4.6.1.2.5 Case Number Seven

Case #7 represents the first stage of benzene emissions control for consumers. The capital cost of $129,000 for Case #7 includes both large and small consumers. Case #7 does not require any vapor treatment units, it uses covered floating roof tanks as the control method.

4.6.1.2.6 Case Number Eight

Case #8 includes all items in Case #7 and Case #8 adds vapor treatment units to both the large and small consumers. The cost of a vapor holder required by the large consumer is included. The capital costs of the refrigeration-absorption and thermal incineration systems are respectively $490,000 and $520,000. The carbon adsorption technology costs $2,069,000 for Case #8.

4.6.2 Total Annualized Costs

The calculation of total annualized costs for the various control cases includes costs for utilities, maintenance, labor, capital charges, and credits for recovered benzene. The utility costs include electricity, fuel (natural gas), and inert gas (nitrogen) costs. Electrical and natural gas rates were obtained from local utility companies as current costs for industrial users. Nitrogen costs include leasing costs for liquid N_2 storage tank and vaporizer as well as the cost of the N_2 used. Maintenance costs have been estimated as a percentage of the capital costs for each case. The cost of operating labor for control cases is estimated as a percentage of the labor required for the non-controlled case. This percentage varies with the complexity of the technology. Labor rates are approximately that of Texas Gulf Coast operators receiving union scale wages plus fringe benefits. Capital charges represent two components; one for capital recovery and one for general administrative costs; both are calculated as fractions of the total capital cost. The capital recovery factor is calculated using a 10% annual interest rate and equipment life of 15 years and is equal to .13147. The factor for general and administrative costs is 4%. The credit taken for recovered benzene is based on a price of $.10/lb. Total annualized costs are the sum of utility, maintenance, labor, and capital charges minus benzene recovery credits. Because maintenance,

TABLE 4.6.1

Total Capital Costs of Control Cases for Each Technology

Case Number	Refrigeration Absorption ($)	Carbon Adsorption ($)	Thermal Incineration ($)
2	664,000	2,134,000	603,000
3	1,068,000	2,878,000	1,096,000
4	1,111,000	1,507,000	1,216,000
5	1,301,000	1,791,000	1,349,000
7	129,000	(No technologies added)	
8	490,000	2,069,000	520,000

capital charges, and general administrative costs are all calculated as a fraction of the capital cost, the capital cost has the largest effect on the annualized cost. For each case capital charges represent the largest single cost. A listing of annualized costs for each case is contained in Tables 4.6.2.1 and 4.6.2.2. The annualized costs follow a trend similar to that observed in capital costs. Carbon adsorption costs are significantly higher than its rivals in each case and compares best in Case #4 and Case #5. For carbon adsorption producer cases, Case #3 is the most expensive to operate followed by Case #2, Case #5, and Case #4. Annualized costs for refrigeration-absorption and thermal incineration technologies are close (within $25,000) to each other in any particular case. The annualized costs for refrigeration-absorption ranked from highest to lowest for the producer schemes are Case #2, Case #4, Case #3, and Case #5. The cost difference between Case #4 and Case #3 is very small (less than $1,000). The rankings from highest to lowest for the producer cases using thermal incineration technology are Case #2, Case #3, Case #4, and Case #5. The cost spread between Cases 3, 4, and 5 is under $30,000, which is approximately 11% of Case #3 annualized costs.

Annualized costs of benzene emission control for the carriers (railcars, tank trucks, and barges) is reported on a cost per carrier basis. Due to the simplicity of the modifications to railcars and tank trucks, the annualized costs are small. No utilities are required. Extra maintenance and labor over the standard procedures is estimated at less than $100/yr. Capital charges against the small capital cost ($4,000) is less than $700/yr. No credits have been taken. The total annualized cost for railcars and tank trucks is $800 per carrier. Annualized costs for barges is $18,000 per barge. This cost takes into account maintenance, labor, and capital charges, but not utility costs or benzene credits.

TABLE 4.6.2.1

Total Annualized Costs for Benzene Producer Control Cases

Case Number	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C
Vapor Treatment Unit Technology	Ref-Abs*	Carb-Ads*	Therm-Inc*	Ref-Abs	Carb-Ads	Therm-Inc	Ref-Abs	Carb-Ads	Therm-Inc	Ref-Abs	Carb-Ads	Therm-Inc
Cost Components (in thousands at $/yr												
A. Utilities[a]	0.4	1.4	0.3	53	55.7	58.8	26	25.8	28.1	18.6	18.4	20.7
B. Maintenance and[b] Labor	35.1	21.7	18.6	55.3	29.1	33.4	57.5	15.4	37	67	18.2	41
C. Capital Charges and[c] Administrative, Ins., Taxes	115.9	365.9	103.4	183.1	493.5	187.9	190.5	258.4	208.5	223.1	307.1	231.3
D. Benzene Recovery[d] (Credits)	(7.7)	(7.8)	4.3	(9.7)	(9.8)	4.3	(7.1)	(7.1)	4.3	(9.3)	(9.4)	4.3
Total	141.7	381.2	126.6	281.7	568.5	284.4	266.9	292.5	277.9	299.4	334.3	297.3

[a] Unit cost for Utilities: Electricity - $0.0151/KWH Fuel Gas - $2.73/$10^3$ scf N_2 vapor - $.265/$10^2$ scf

[b] Maintenance estimated as percent of total capital cost: Refrigeration-Absorption - 5% Carbon Adsorption - 1% Thermal Incineration - 3%

Labor rate = $\frac{\$8}{\text{manhour}}$ x 1.5 (fringe benefits, etc.)

[c] Capital charges calculated with 10% interest rate and 15 year equipment life for capital recovery factor of .13147

[d] Benzene value = $.10/lb, credit (or debit) calculated as benzene recovered (or lost) compared to Base Case #1 benzene loses

* Refrigeration Absorption - Carbon Adsorption - Thermal Incineration

TABLE 4.6.2.2

Total Annualized Costs for Benzene Consumer Control Cases

Case Number	7	8 A	8 B	8 B
Vapor Treatment Unit Technology	None Required	Ref-Abs*	Carb/Ads*	Therm-Inc.*
Cost Components (in thousands of $/yr)				
A. Utilities[a]	0	26.1	27.4	31.4
B. Maintenance[b] and Labor	2.6	26.4	21	16.1
C. Capital Charges[c] and Administrative, Ins., Taxes	22.1	84	354.8	89.2
D. Benzene Recovery[d] (Credits)	(.7)	(1.3)	(1.3)	0
Total	24	135.2	401.9	136.7

[a]Unit cost for Utilities: electricity - $.0151/KWH fuel gas - $2.73/10^3 scf - N_2 vapor - $.265/10^2 scf

[b]Maintenance estimated as percent of total capital cost: Refrigeration-Absorption - 5%; Carbon Adsorption - 1%; Thermal Incineration - 3%

Labor rate = $8/manhour x 1.5 (fringe benefits, etc)

[c]Capital charges calculated with 10% interest rate and 15 year equipment life for capital recovery factor of .13147

Administrative, Insurance, and Taxes = 4% of total capital cost

[d]Benzene value = $.10/lb, credit (or debit) calculated as benzene recovered (or lost) compared to Base Case #1 benzene losses

*Refrigeration-Absorption - Carbon Adsorption - Thermal Incineration

4.6.3 Economic Analysis

Cost effectiveness, the most performance per dollar spent over the period of consideration, is the basis of economic analysis used to evaluate the control systems. The concept of cost effectiveness centers on three notions:

1) In the case of two alternatives with the same useful life giving identical performance, the less costly unit is more cost effective.
2) In the case of two alternatives with similar useful lifetimes and equal costs, the unit with the better performance is more cost effective.
3) In the case of two alternatives with different performance and different costs, then the alternative which delivers the greater performance for unit costs is more cost effective.

The parameter of cost that will be used for the analysis is annualized cost (in dollars). The performance parameter is the amount of benzene emission reduction from the base case of zero cost, uncontrolled emissions (in lb/yr). For convenience the cost effectiveness index is expressed as $/lb reduction, rather than lb reduction/$. Thus the lower the index, the more cost effective the alternative. The cost effectiveness for each case is given in Table 4.6.3.1 and 4.6.3.2. It is observed that the carbon adsorption technology represents the least cost effective system for each case. The differences between refrigeration-absorption and thermal incineration are small within most cases, and is greatest in Case #2 where the difference is less than 12% of the less costly technology (thermal incineration). The average cost effectiveness of thermal incineration is higher by a very small margin. The carbon adsorption technology compares closest with the others in Case #4 and Case #5.

TABLE 4.6.3.1

Cost Effectiveness of Producer Control Cases

Case Number	2			3			4			5		
	A	B	C	A	B	C	A	B	C	A	B	C
Treat Unit Technology	Ref-Abs*	Carb-Ads*	Therm-Inc*	Ref-Abs	Carb-Ads	Therm-Inc	Ref-Abs	Carb-Ads	Therm-Inc	Ref-Abs	Carb-Ads	Therm-Inc
Capital Cost (in thousands of $)	644	2,134	601	1,008	2,878	1,096	1,111	1,507	1,216	1,301	1,791	1,340
Annualized Cost (in thousands of $/yr)	141.7	381.3	126.6	267.6	554.1	270.3	266.9	292.4	270	318	353.1	297.3
Net Reduction of Benzene Emissions (lb/yr)	77,407	78,059	77,915	96,874	97,594	97,426	70,653	71,251	71,119	93,305	94,043	93,075
Cost Effectiveness Index ($/lb Reduction)	1.83	4.88	1.63	2.76	5.67	2.76	3.78	4.11	3.90	3.41	3.75	3.17

*Refrigeration Absorption - Carbon Adsorption - Thermal Incineration

TABLE 4.6.3.2

Cost Effectiveness of Consumer Control Cases

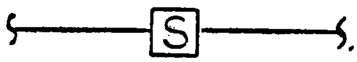
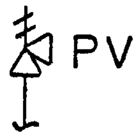
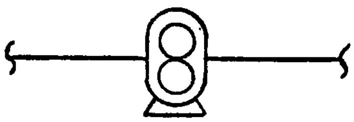
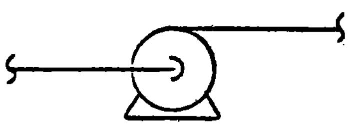
Case Number	7	8		
		A	B	C
Treatment Unit Technology	None Required	Refrigeration Adsorption	Carbon Adsorption	Thermal Incineration
Capital Cost (in thousands of $)	129	490	2,069	520
Annualized Cost (in thousands of $/yr)	24	135.2	401.8	136.7
Net Reduction of Benzene Emissions (lb/yr)	7,255	17,608	17,666	17,654
Cost Effectiveness Index ($/lb Reduction)	3.31	7.68	22.74	7.74

In the producer cases, the order of cost effectiveness for the refrigeration-absorption and thermal incineration technologies in descending order is Case #2, Case #3, Case #5, and Case #4. The descending order of cost effectiveness for carbon adsorption is Case #5, Case #4, Case #2, and Case #3.

The most cost effective control scheme is Case #2 with thermal oxidation at $1.63/lb, and Case #2 with refrigeration is the next most cost effective at $1.83/lb. If the cost of benzene increased and/or the price of natural gas increased relative to electricity, the cost effectiveness of refrigeration-absorption would increase relative to thermal incineration.

The most judicious area to spend money on benzene emissions is in the loading area. One pound of benzene emission can be reduced for $1.63 in Case #2 with thermal incineration, where both storage and loading losses are controlled, compared with $3.30 spent for an equal unit reduction of standing storage losses in Case #7. The least attractive investment for control expenditures is to attempt to control both standing and withdrawal losses as in Case #8. A base case starting with cone roof tanks rather than floating roof tanks would show that the most effective place to begin benzene emission control is with the storage tanks, because emissions from cone roof tanks are approximately 5-10% of cone roof tank emissions.

APPENDIX A
LEGEND

SYMBOL	DESCRIPTION
	Metal Heat Sink Flame Arrestor
	Water Seal
	Pressure-Vacuum Vent Valve
	Rotary Type Blower
	Pressure Switch
	Vapor Flow Lines
	Liquid Flow Lines
	Check Valve (showing flow direction)
	Centrifugal Pump

APPENDIX B

English to Metric Conversion Chart

1 pound	equals	.4536 KG
1 gallon	equals	3.785 liter
1 ft^3	equals	.02832 m^3

APPENDIX C
CAPITAL COST DATA

EST SVCS 3A (8-76)

CLIENT: EPA			DESCRIPTION: CONTROL CASE #2	
LOCATION: Texas Gulf Coast				
CLASS OR A.C NO	DESCRIPTION	Refrigeration Absorption	Carbon Adsorption	Thermal Oxidation
B	FURNACES			
C	EXCHANGERS			
D	CONVERTERS			
E	TOWERS			
F	DRUMS & TANKS	8,000	8,000	8,000
J	PUMPS AND COMPRESSORS	8,000	8,000	8,000
L	SPECIAL EQUIPMENT	132,000	985,000	96,000
U	UTILITY EQUIPMENT			
V	TRANSPORTATION & CONVEYING EQUIP			
Z	FIRE & SAFETY EQUIPMENT			
	SUBTOTAL MAJOR EQUIPMENT	148,000	1,001,000	112,000
A	SITE PREP FOUNDATIONS & CONC STRUC	5,000	10,000	3,000
H	STEEL STRUC PLATFORMS & INDUST. BL.	5,000	5,000	5,000
K	ARCHITECTURAL BUILDINGS			
M	PIPING	24,000	28,000	28,000
N	ELECTRICAL	7,000	25,000	5,000
O	INSTRUMENTS	7,500	15,000	7,500
P	INSULATIONS AND PAINT	1,000	1,500	1,500
*	CATALYST AND CHEMICALS			
	SUBTOTAL BULK MATERIAL	49,500	84,500	50,000
113A	FREIGHT - UNALLOCATED	1,000	5,500	1,000
115	STORAGE - DIRECT MATERIAL			
116	EXPORT PACKING - UNALLOCATED			
	ESCALATION MATERIAL			
	TOTAL DIRECT MATERIAL	198,500	1,091,000	163,000
	TOTAL SUBCONTRACTS INCL. ESCALATION	104,000	104,000	104,000
310	CONSTR FORCE - WAGES & FRINGE	136,000	206,000	133,000
330	CONSTR FORCE - PAYROLL ASSESSMENTS			
200	FIELD ADM DIRECT SUPERVISION & SVC			
400	TOOLS & FREIGHT ON TOOLS			
500	FIELD OFFICE & OTHER FIELD EXPENSE			
130	INDIRECT MATERIAL (ST & Y)			
	ESCALATION - LABOR			
	SPARE PARTS	8,000	22,000	6,000
600	HOME OFFICE CONSTRUCTION			
700	HOME OFFICE PROCUREMENT			
800	HOME OFFICE COMBINED ENGINEERING	44,500	140,000	40,000
941	CENTRAL STAFF			
	HOME OFFICE CLIENT SERVICE			
150	SALES & USE TAX - UNALLOCATED	8,000	43,000	6,500
181	IMPORT DUTIES			
182&183	OCEAN FRT MARINE INSURANCE, ETC.			
910	OTHER COSTS (LIC FEES ROYALTIES)			
918	INSURANCE (ALL RISKS ETC)	6,000	20,400	5,500
	PROJECT COMPLETION	5,000	17,600	5,000
	CONTRACTORS OH&P	110,000	350,000	100,000
	CONTINGENCY	44,000	140,000	40,000
	TOTAL COST	664,000	2,134,000	603,000

APPENDIX C
CAPITAL COST DATA

CLIENT: EPA

DESCRIPTION: CONTROL CASE #3

LOCATION: Texas Gulf Coast

CLASS OR A C NO	DESCRIPTION	Refrigeration Absorption	Carbon Adsorption	Thermal Oxidation	
B	FURNACES				
C	EXCHANGERS				
D	CONVERTERS				
E	TOWERS				
F	DRUMS & TANKS	20,000	20,000	20,000	
J	PUMPS AND COMPRESSORS	27,500	27,500	27,500	
L	SPECIAL EQUIPMENT	190,500	1,352,500	203,500	
U	UTILITY EQUIPMENT				
V	TRANSPORTATION & CONVEYING EQUIP				
Z	FIRE & SAFETY EQUIPMENT				
	SUBTOTAL MAJOR EQUIPMENT	[illegible]	1,400,000	251,000	
A	SITE PREP. FOUNDATIONS & CONC. STRUC	17,000	17,000	17,000	
H	STEEL STRUC PLATFORMS & INDUST. BL.	5,000	5,000	5,000	
K	ARCHITECTURAL BUILDINGS				
M	PIPING	20,000	20,000	20,000	
N	ELECTRICAL	36,000	36,000	36,000	
O	INSTRUMENTS	16,000	16,000	16,000	
P	INSULATIONS AND PAINT	1,500	1,500	1,500	
W	CATALYST AND CHEMICALS				
	SUBTOTAL BULK MATERIAL	95,500	95,500	95,500	
113A	FREIGHT - UNALLOCATED	2,000	8,000	2,000	
115	STORAGE - DIRECT MATERIAL				
115	EXPORT PACKING - UNALLOCATED				
	ESCALATION MATERIAL				
	TOTAL DIRECT MATERIAL	[illegible]	1,503,500	348,500	
	TOTAL SUBCONTRACTS INCL. ESCALATION	[illegible]	104,000	104,000	
310	CONSTR. FORCE - WAGES & FRINGE	[illegible]	[illegible]	[illegible]	
330	CONSTR. FORCE - PAYROLL ASSESSMENTS				
200	FIELD ADM. DIRECT SUPERVISION & SVC				
400	TOOLS & FREIGHT ON TOOLS				
500	FIELD OFFICE & OTHER FIELD EXPENSE				
130	INDIRECT MATERIAL (ST & Y)				
	ESCALATION - LABOR				
	SPARE PARTS	13,400	30,500	14,000	
600	HOME OFFICE CONSTRUCTION				
700	HOME OFFICE PROCUREMENT				
800	HOME OFFICE COMBINED ENGINEERING	70,500	188,500	[illegible]	
941	CENTRAL STAFF				
	HOME OFFICE CLIENT SERVICE				
150	SALES & USE TAX - UNALLOCATED	15,500	62,200	16,100	
181	IMPORT DUTIES				
182A	OCEAN FRT. MARINE INSURANCE ETC.				
910	OTHER COSTS (LIC. FEES ROYALTIES)				
918	INSURANCE (ALL RISKS ETC.)	10,500	28,300	10,000	
	PROJECT COMPLETION	8,300	23,700	9,000	
	CONTRACTORS CH&P	176,000	471,300	[illegible]	
	CONTINGENCY	[illegible]	185,500	[illegible]	
	TOTAL COST	[illegible]	[illegible]	[illegible]	

APPENDIX C
CAPITAL COST DATA

EST SVCS 3A (8-76)

CLIENT: EPA

DESCRIPTION: CONTROL CASE #4

LOCATION: Texas Gulf Coast

CLASS OR A C NO	DESCRIPTION	Refrigeration Absorption	Carbon Adsorption	Thermal Oxidation	
B	FURNACES				
C	EXCHANGERS				
D	CONVERTERS				
E	TOWERS				
F	DRUMS & TANKS	12,000	12,000	12,000	
J	PUMPS AND COMPRESSORS	24,500	24,500	24,500	
L	SPECIAL EQUIPMENT	62,500	278,500	98,500	
U	UTILITY EQUIPMENT				
V	TRANSPORTATION & CONVEYING EQUIP				
Z	FIRE & SAFETY EQUIPMENT				
	SUBTOTAL MAJOR EQUIPMENT	99,000	315,000	135,000	
A	SITE PREP FOUNDATIONS & CONC. STRUC.	12,000	12,000	12,000	
H	STEEL STRUC PLATFORMS & INDUST BL.	3,500	3,500	3,500	
K	ARCHITECTURAL BUILDINGS				
M	PIPING	83,000	83,000	83,000	
N	ELECTRICAL	34,000	34,000	34,000	
O	INSTRUMENTS	18,000	18,000	18,000	
P	INSULATIONS AND PAINT	1,500	1,500	1,500	
W	CATALYST AND CHEMICALS				
	SUBTOTAL BULK MATERIAL	152,000	152,000	152,000	
113 & 114	FREIGHT - UNALLOCATED	2,000	2,000	2,000	
115	STORAGE - DIRECT MATERIAL				
116	EXPORT PACKING - UNALLOCATED				
	ESCALATION MATERIAL				
	TOTAL DIRECT MATERIAL	253,000	469,000	289,000	
	TOTAL SUBCONTRACTS INCL. ESCALATION	104,000	104,000	104,000	
310	CONSTR FORCE - WAGES & FRINGE	380,400	385,900	381,400	
330	CONSTR FORCE - PAYROLL ASSESSMENTS				
200	FIELD ADM. DIRECT SUPERVISION & SVC				
400	TOOLS & FREIGHT ON TOOLS				
500	FIELD OFFICE & OTHER FIELD EXPENSE				
130	INDIRECT MATERIAL (ST & Y)				
	ESCALATION - LABOR				
	SPARE PARTS	10,000	9,000	11,200	
600	HOME OFFICE CONSTRUCTION				
700	HOME OFFICE PROCUREMENT				
800	HOME OFFICE COMBINED ENGINEERING	74,000	96,000	77,200	
941	CENTRAL STAFF				
	HOME OFFICE CLIENT SERVICE				
150	SALES & USE TAX - UNALLOCATED	12,100	21,100	14,100	
181	IMPORT DUTIES				
182 & 183	OCEAN FRT MARINE INSURANCE ETC				
910	OTHER COSTS (LIC FEES ROYALTIES)				
918	INSURANCE (ALL RISKS ETC)	11,000	14,400	11,600	
	PROJECT COMPLETION	9,200	12,000	9,700	
	CONTRACTORS OH&P	183,800	299,600	240,600	
	CONTINGENCY	73,500	96,000	77,200	
	TOTAL COST	1,111,000	1,507,000	1,216,000	

APPENDIX C
CAPITAL COST DATA

CLIENT: EPA

DESCRIPTION: CONTROL CASE #5

LOCATION: Texas Gulf Coast

CLASS OR ACC NO	DESCRIPTION	Refrigeration Absorption	Carbon Adsorption	Thermal Oxidation	
B	FURNACES				
C	EXCHANGERS				
D	CONVERTERS				
E	TOWERS				
F	DRUMS & TANKS	12,000	12,000	12,000	
J	PUMPS AND COMPRESSORS	24,500	24,500	24,500	
L	SPECIAL EQUIPMENT	64,000	280,000	[illegible]	
U	UTILITY EQUIPMENT				
V	TRANSPORTATION & CONVEYING EQUIP				
Z	FIRE & SAFETY EQUIPMENT				
	SUBTOTAL MAJOR EQUIPMENT	100,500	315,500	[illegible]	
A	SITE PREP. FOUNDATIONS & CONC. STRUC	15,000	20,000	13,000	
H	STEEL STRUC PLATFORMS & INDUST. BL.	5,000	5,000	5,000	
K	ARCHITECTURAL BUILDINGS				
M	PIPING	84,000	35,000	58,000	
N	ELECTRICAL	13,000	31,000	11,000	
O	INSTRUMENTS	16,500	24,000	16,500	
P	INSULATIONS AND PAINT	2,000	2,000	2,000	
Q	CATALYST AND CHEMICALS				
	SUBTOTAL BULK MATERIAL	135,500	170,000	135,500	
113A	FREIGHT - UNALLOCATED	1,000	2,500	1,500	
115	STORAGE - DIRECT MATERIAL				
116	EXPORT PACKING - UNALLOCATED				
	ESCALATION MATERIAL				
	TOTAL DIRECT MATERIAL	[illegible]	[illegible]	[illegible]	
	TOTAL SUBCONTRACTS INCL. ESCALATION	252,000	252,000	252,000	
310	CONSTR. FORCE - WAGES & FRINGE	376,000	442,500	[illegible]	
330	CONSTR. FORCE - PAYROLL ASSESSMENTS				
320	FIELD ADM. DIRECT SUPERVISION & SVC				
400	TOOLS & FREIGHT ON TOOLS				
500	FIELD OFFICE & OTHER FIELD EXPENSE				
130	INDIRECT MATERIAL (ST & Y)				
	SPARE PARTS	10,000	19,500	11,000	
	ESCALATION - LABOR				
600	HOME OFFICE CONSTRUCTION				
700	HOME OFFICE PROCUREMENT				
800	HOME OFFICE COMBINED ENGINEERING	36,700	112,500	90,000	
341	CENTRAL STAFF				
	HOME OFFICE CLIENT SERVICE				
150	SALES & USE TAX - UNALLOCATED	10,000	20,000	11,000	
181	IMPORT DUTIES				
182A	OCEAN FRT. MARINE INSURANCE ETC.				
319	OTHER COSTS (LIC. FEES ROYALTIES)				
318	INSURANCE (ALL RISKS, ETC.)	12,000	17,500	13,500	
	PROJECT COMPLETION	10,300	14,300	11,500	
	CONTRACTORS CHGE	216,000	[illegible]	224,500	
	CONTINGENCY	36,700	112,500	90,000	
	TOTAL COST	[illegible]	[illegible]	[illegible]	

APPENDIX C
CAPITAL COST DATA

CLIENT: EPA
LOCATION: Texas Gulf Coast
DESCRIPTION: CONTROL CASE #7

CLASS OR A/C NO	DESCRIPTION				
B	FURNACES				
C	EXCHANGERS				
D	CONVERTERS				
E	TOWERS				
F	DRUMS & TANKS				
J	PUMPS AND COMPRESSORS				
L	SPECIAL EQUIPMENT				
U	UTILITY EQUIPMENT				
V	TRANSPORTATION & CONVEYING EQUIP				
Z	FIRE & SAFETY EQUIPMENT				
A	SITE PREP FOUNDATIONS & CONC STRUC.				
H	STEEL STRUC PLATFORMS & INDUST. BL.				
K	ARCHITECTURAL BUILDINGS				
M	PIPING				
N	ELECTRICAL				
O	INSTRUMENTS				
P	INSULATIONS AND PAINT				
W	CATALYST AND CHEMICALS				
113&123	FREIGHT – UNALLOCATED				
115	STORAGE – DIRECT MATERIAL				
116	EXPORT PACKING – UNALLOCATED				
	ESCALATION MATERIAL				
	TOTAL DIRECT MATERIAL				
	TOTAL SUBCONTRACTS INCL. ESCALATION	60,000			
310	CONSTR FORCE – WAGES & FRINGE	25,000			
330	CONSTR FORCE – PAYROLL ASSESSMENTS				
200	FIELD ADM DIRECT SUPERVISION & SVC				
400	TOOLS & FREIGHT ON TOOLS				
500	FIELD OFFICE & OTHER FIELD EXPENSE				
130	INDIRECT MATERIAL (ST & Y)				
	ESCALATION – LABOR				
	SPARE PARTS	1,000			
600	HOME OFFICE CONSTRUCTION				
700	HOME OFFICE PROCUREMENT				
800	HOME OFFICE COMBINED ENGINEERING	8,500			
941	CENTRAL STAFF				
	HOME OFFICE CLIENT SERVICE				
150	SALES & USE TAX – UNALLOCATED	2,600			
181	IMPORT DUTIES				
182&183	OCEAN FRT MARINE INSURANCE ETC				
910	OTHER COSTS (LIC FEES ROYALTIES)				
918	INSURANCE (ALL RISKS ETC)	1,400			
	PROJECT COMPLETION	1,000			
	CONTRACTORS OH&P	21,000			
	CONTINGENCY	8,500			
	TOTAL COST	129,000			

APPENDIX C

CAPITAL COST DATA

CLIENT: EPA		DESCRIPTION: CONTROL CASE #8			
LOCATION: Texas Gulf Coast					
CLASS OR A/C NO	DESCRIPTION	Refrigeration Absorption	Carbon Adsorption	Thermal Oxidation	
B	FURNACES				
C	EXCHANGERS				
D	CONVERTERS				
E	TOWERS				
F	DRUMS & TANKS				
J	PUMPS AND COMPRESSORS	5,000	5,000	5,000	
L	SPECIAL EQUIPMENT	64,500	962,500	93,500	
U	UTILITY EQUIPMENT				
	TRANSPORTATION & CONVEYING EQUIP				
	FIRE & SAFETY EQUIPMENT				
	SUBTOTAL MAJOR EQUIPMENT	69,500	957,500	98,500	
A	SITE PREP. FOUNDATIONS & CONC. STRUC	6,000	11,000	4,000	
	STEEL STRUC PLATFORMS & INDUST. BL	3,500	3,500	3,500	
K	ARCHITECTURAL BUILDINGS				
M	PIPING	15,000	19,000	15,000	
N	ELECTRICAL	3,000	26,000	6,000	
O	INSTRUMENTS	10,500	13,000	10,500	
P	INSULATIONS AND PAINT	1,000	1,500	1,500	
	CATALYST AND CHEMICALS				
	SUBTOTAL BULK MATERIAL	44,000	79,000	40,500	
112A	FREIGHT - UNALLOCATED	1,000	5,500	1,000	
115	STORAGE - DIRECT MATERIAL				
116	EXPORT PACKING - UNALLOCATED				
	ESCALATION MATERIAL				
	TOTAL DIRECT MATERIAL	[illegible]	[illegible]	140,000	
	TOTAL SUBCONTRACTS INCL. ESCALATION	[illegible]	[illegible]	[illegible]	
310	CONSTR. FORCE - WAGES & FRINGE	[illegible]	170,500	[illegible]	
330	CONSTR. FORCE - PAYROLL ASSESSMENTS				
200	FIELD ADM. DIRECT SUPERVISION & SVC				
400	TOOLS & FREIGHT ON TOOLS				
500	FIELD OFFICE & OTHER FIELD EXPENSE				
120	INDIRECT MATERIAL (ST & Y)				
	ESCALATION - LABOR				
	SPARE PARTS	4,500	21,000	5,000	
500	HOME OFFICE CONSTRUCTION				
700	HOME OFFICE PROCUREMENT				
800	HOME OFFICE COMBINED ENGINEERING	32,500	135,500	34,500	
941	CENTRAL STAFF				
	HOME OFFICE CLIENT SERVICE				
150	SALES & USE TAX - UNALLOCATED	4,500	43,000	5,000	
181	IMPORT DUTIES				
182A	OCEAN FRT. MARINE INSURANCE, ETC.				
913	OTHER COSTS (LIC. FEES, ROYALTIES)				
918	INSURANCE (ALL RISKS, ETC.)	5,000	30,500	5,000	
	PROGRAM COMPLETION	4,000	17,000	4,500	
	CONTRACTORS OH&P	31,500	340,000	36,500	
	CONTINGENCY				
	TOTAL COST	[illegible]	[illegible]	[illegible]	

APPENDIX D

REFERENCE LIST

American Petroleum Institute; "API Bulletin 2513: Evaporation Loss in the Petroleum Industry - Causes and Control," American Petroleum Institute, 2101 L. Street, Northwest, Washington, D.C. 20037

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"API Bulletin 2517: Evaporation Loss from Floating-Roof Tanks," (1962)

"API Bulletin 2518: Evaporation Loss from Fixed-Roof Tanks," (1962)

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Pacific Environmental Services, Inc.; "Reliability Study of Vapor Recovery Systems at Service Stations," (1976); Environmental Protection Agency, Air Pollution Technical Information Center, Research Triangle Park, North Carolina 27711

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Radian Corporation; "A Study of Vapor Control Methods for Gasoline Marketing Operations: Volume I - Industry Survey and Control Techniques"; Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711

Radian Corporation; "Background Information on Hydrocarbon Emissions from Marine Terminal Operations, Volumes I and II"; Library Services Office (MD-35), Environmental Protection Agency, Research Triangle Park, North Carolina 27711

APPENDIX E

LIST OF VENDOR BROCHURES

Ecology Control, Inc., "Vapor Management Systems," 6810 La Paseo Drive, Houston, Texas 77017

Edwards Engineering Corp., "Hydrocarbon Vapor Recovery Unit," Form 8-VRBZ-1, 101 Alexander Avenue, Pompton Plains, New Jersey 07444

Hoyt Manufacturing Corp., "Solvent Recovery Systems," 251 Forge Road, Westport, Maine 02790

Hydrotech Engineering Inc., "Vapor Recovery Systems," P. O. Box 45042, Tulsa, Oklahoma 74145

Oxy-Catalyst, "Oxycat Catalytic Abatement Systems," East Biddle Street, West Chester, Pennsylvania 19380

Oxy-Catalyst, "Oxycat CA-66 Solvent Recovery System"

National Airoil Burner Company, Inc., "NVDU NAO Vapor Disposal Unit" Bulletin 39A, 1284 East Sedgley Avenue, Philadelphia, Pennsylvania 19134

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4. TITLE AND SUBTITLE Evaluation of Control Technology for Benzene Transfer Operations		5. REPORT DATE April, 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) S. W. Dunavent, D. Gee, and W. M. Talbert		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Pullman Kellogg 16200 Park Row, Industrial Park Ten Houston, Texas 77084		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-2619, Task 2
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OAQPS Project Officer for this report is David W. Markwordt, MD-13, (919) 541-5371

16. ABSTRACT

This report presents results of a study which selected and evaluated best available technology to control emissions from benzene storage and transfer facilities. Technologies selected and evaluated include refrigeration-absorption, vacuum regenerated carbon adsorption, and thermal oxidation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Control Methods Benzene Tankers and Barges Railcars and Tank Trucks Storage Tanks	Air Pollution Control Benzene Emission Control Organic Vapors Mobile Sources	

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