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Southern California Bunkering Operations Get On Board with Volatile Organic Compound Abatement

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ABSTRACT

Volatile organic compound (VOC) abatement regulations in Southern California have driven the development of a vapor processing plant that is suitable for the bunkering barges it serves. A system was required that could be mounted on board existing bunker barges, could be operated by existing tankerman crews and had no need for additional pumps and blowers, which would require additional power generation capacity. Foss Maritime Long Beach teamed with The Glosten Associates, Inc., to develop and deploy a system that allows the existing fleet to practice VOC abatement at any of the active tank terminals in the ports of Long Beach and Los Angeles.

This paper discusses: VOC environmental impact, the costs and benefits of practicing VOC abatement for bunkering products in terms of dollars per ton of abated VOCs, benefits to tankermen's health and welfare, an overview of available VOC abatement technologies, and specifics of the Foss-Glosten system, including system installation and operating costs.

INTRODUCTION

In July 1991, California's South Coast Air Quality Management District (SCAQMD) adopted Rule 1142 requiring marine tank vessels to practice volatile organic compound (VOC) abatement if cargo vapor emissions during loading events exceed two pounds of VOCs per one thousand barrels loaded (5.7 grams per cubic meter) (SCAQMD 2001). The marine industry responded by fitting vapor collection systems aboard marine tank vessels and installing shoreside processing facilities to control high vapor pressure cargoes, including gasoline and crude oils. Until recently, the low vapor pressure cargoes handled in bunkering operations, which include heavy oils and diesels, were ignored. When considering VOCs per thousand barrels loaded, it should be noted that gasoline and crude oils can produce 125 pounds, and bunker product emissions are typically less than six pounds.

SCAQMD is now enforcing Rule 1142 for loading bunker products. Foss Maritime teamed with The Glosten Associates, Inc., to develop a system to bring Foss's bunker barge fleet into compliance with this regulation. In addition to supporting regional pollution abatement efforts, the installed systems are also providing the tankermen relief from exposure to cargo fumes that were previously freely vented to the atmosphere. However, these benefits come at a cost that must be considered when pollution abatement regulations are drafted and enforced.

This paper outlines the development and installation of the system Foss used on its bunker barge fleet. Its intention is to share this experience with regulators, owners and designers considering VOC abatement for bunker products.

- The section below looks at environmental impacts, and is an attempt to assess cost-benefit ratio of pollution control agency regulations.
- The next major section is an evaluation of system options and costs that owners must consider when they contemplate emission abatement.

ENVIRONMENTAL IMPACT

In adopting Rule 1142 requiring marine tank vessels to practice VOC abatement, SCAQMD was targeting a source of low level ozone, commonly referred to as smog. In considering whether the benefits of this abatement system compensate the costs, this section will look at: VOC environmental impact, bunker product source test data, quantitative analysis of VOC abatement and calculations of cost-benefit ratio. In addition, benefits to the tankerman will be considered.

VOC Environmental Impact

VOC emissions are regulated because they contribute to the formation of ozone, or smog, which forms when VOCs and NOx react in the presence of sunlight. NOx, a combination of Nitrogen Oxide (NO) and Nitrogen Dioxide (NO_2), is a byproduct of fuel combustion and is also regulated. Ozone, O_3, is considered to be a health hazard at certain ambient levels. According to the Air Quality Analysis Guidance Handbook (2001), p 3-10: "Short-term exposures (lasting for a few hours) to O_3 at levels typically observed in southern California can result in breathing pattern changes, reduction of breathing capacity, increased susceptibility to infections, inflammation of the lung tissue, and some immunological changes." Both SCAQMD and the U.S. Environmental Protection Agency (EPA) have assigned ambient air quality standard levels for ozone.

It is worth noting that SCAQMD and the EPA do not consider VOCs to be 'criteria' pollutants and therefore have not assigned them an ambient air quality measurement. However, VOCs are noted to have some impact on individual health. This is discussed in *Benefits to Tankermen*, below.

A consideration of VOCs in relation to global warming touches on the role of methane, ". . . a greenhouse gas [that] traps heat 40-70 times more effectively than carbon dioxide" (SQAQMD 2001, p 3-16). Methane concentrations generally consist of less than ten percent (by weight) of the cargo vapors of bunker products. Rule 1142 does not consider methane to be a VOC, and therefore methane emissions are not regulated. Further investigation is required to determine whether higher chain hydrocarbons break down to methane.

VOCs apparently have no impact on stratospheric ozone depletion, in which ". . . compounds, including chlorofluorocarbons (CFCs,) halons, carbon tetrachloride, methyl chloroform, and other halogenated compounds, accumulate in the lower atmosphere and then gradually migrate into the stratosphere. In the stratosphere, these compounds participate in complex chemical reactions to destroy the upper ozone layer" (SQAQMD 2001, p 3-14).

Bunker Product Source Test Data

Source test data are presented in Table 1. These data and those shown in Table 2 demonstrate the difficulty of assigning a VOC concentration to a specific cargo. However, operating experience has shown that these data accurately predict emissions quantities when considering multiple loads. Typical bunker products include:

CFR [1] Listed Cargo Name	Common Name
Fuel Oil 2	Home Heating Oil, Marine Diesel Oil
Fuel Oil 2-D	Diesel Oil Medium
Fuel Oil 4	Residual Fuel Oil, No. 4
Fuel Oil 5	Residual Fuel Oil, No. 5
Fuel Oil 6	Residual Fuel Oil, Bunker Fuel Oil, No. 6
Gas Oil Misc, High Pour	Vacuum Gas Oil, Cutter Stock, TKN Feed
Gas Oil Misc, Low Sulfur	FCC Feed Compound
Oil Misc, Aromatic	Light Cycle Oil, Cat Cracked Distillate

[1] U.S. Code of Federal Regulations

Table 1, below, shows VOC concentrations in the range of 2.19 to 4.86 lbs per one thousand barrels loaded. The values for bunker fuel oil No. 6 (Case 1) represent the low VOC range for bunker products. The TKN Feed value represents the high VOC range for bunker products. These products are commonly blended to make intermediate fuel blends including fuel oil 4 and fuel oil 5. The marine diesel oil value represents non-residual bunker products.

Table 1 – Source Test Data, Average VOC Concentrations

Product	Total lbs per 1,000 bbl(1) (2)
Bunker Fuel Oil, Case 1(3)	2.19
Bunker Fuel Oil, Case 2(4)	2.44
Marine Diesel Oil(3)	2.76
TKN Feed(3)	4.86

(1) Totals are based on speciation data in ppmv. Data are converted into weight per volume displacement based on mol weights of each VOC.

(2) Concentrations are averages of samples taken throughout loading events.

(3) Glosten 2002

(4) Almega 2003

The values in Table 1 are from specific loading events. A comparison of Bunker Fuel Oil Case 1 and Case 2 shows a significant difference in VOC concentrations. This difference highlights the variables between specific loads of the same cargo name. Variables affecting VOC concentrations include: loading rate, cargo tank configuration, cargo and ambient temperatures, cargo characteristics (flash point, specific gravity, viscosity) and relative humidity. Of additional concern are vapors from residual cargo, either from prior marine tank vessel loads or shore facility storage tanks and pipelines. With mixed cargoes, it is likely that the more volatile cargo vapors will dictate the VOC concentrations.

Table 2, below, provides source test data which corroborate the contention that cargo vapor concentrations tend to be highest at the liquid-vapor interface (International Safety Guide for Oil Tankers and Terminals, 1996). VOC concentrations increase with increases in cargo tanks levels. A graphical representation of these data is provided in the Appendix, Figures 2 and 3.

Table 2 – Source Test Data, Concentrations Through Load

Product – Tank Volume	Total lbs per 1,000 bbl
Bunker Fuel Oil, Case 1 - Average	**2.19**
Bunker Fuel Oil, Case 1 – 20% (1)	1.08
Bunker Fuel Oil, Case 1 - 40% (1)	2.15
Bunker Fuel Oil, Case 1 - 60% (1)]	2.69
Bunker Fuel Oil, Case 1 - 80% (1)	2.82
TKN Feed - Average	**4.86**
TKN Feed - 20% (1)	3.63
TKN Feed - 40% (1)	4.73
TKN Feed - 60% (1)	5.22
TKN Feed - 80% (1)	5.88

(1) Glosten 2002

Quantitative Analysis

Table 3 provides an estimate of bunker product VOC emissions, both for a single marine tank vessel and for the ports of Long Beach and Los Angeles (LB/LA). Transfers within shore facilities and loading events with marine vessels taking bunker products as fuel, not cargo, have not been considered. The operating profile of the Foss tank barge WT-30 is considered in Table 3.

Table 3 – VOC Emissions Totals, Marine Tank Vessel Loadings, Single Vessel and Ports of LB/LA

Single Tank Vessel (1)	
TKN Feed (VOC Emissions)	
Barrels/Load	30,000
VOCs (lbs/1,000 bbls) (2)	4.86
VOCs (lbs/load)	146
Annual Loads	12
Annual Subtotal (lbs VOCs)	1,750
Bunker Fuel (VOC Emissions)	
Barrels/load	30,000
VOCs (lbs/1,000 bbls) (3)	2.32
VOCs (lbs/load)	70
Annual Loads	65
Annual Subtotal (lbs VOCs)	4,524
Average Load (pounds VOCs)	**82**
Annual Total (short tons VOCs)	**3.14**
All Marine Vessels Ports of LB/LA	
Annual Bunkers (bbls) (4)	22,050,000
VOC Concentration (lbs/1,000 bbls) (5)	2.92
Annual VOCs (lbs)	64,298
Annual VOCs (short tons)	**32.1**

(1) Single vessel load based on Foss barge WT-30 operations.

(2) TKN Feed data from Table 1.

(3) Bunker Fuel data averaged from Table 1.

(4) Port of Long Beach & Port of Los Angeles 2002.

(5) Assumes bunkers average 20% TKN Feed (4.86 lbs/1,000 bbls), 20% marine diesel oil (2.76 lbs/1,000 bbls), and 60% bunker fuel oil (2.32 lbs/1,000 bbls).

These data indicate that a typical 30,000 barrel marine tank vessel may release 3.14 tons of VOCs annually during loading events. LB/LA annual VOC emissions from marine tank vessel loading events are approximated at 32.1 tons.

Table 4 estimates expected benefit from VOC abatement systems in terms of tons of VOCs. The first set of totals is based on the Rule 1142 requirement that emissions be controlled to either 95% or a maximum of 2 pounds per 1,000 barrels loaded. For bunker products, the 2 pound limit appears to be the controlling number. Based on this restriction, LA/Long Beach could reduce its total emissions by 10.1 tons.

The second set of totals in Table 6 is based on the efficiency rates and operating profile of the Foss barge WT-30. Source test data of carbon canister efficiencies (see *System Configuration Options and Costs*) indicate efficiencies between 93% and 99%. Based on 93% efficiency, a single tank vessel installation could reduce annual VOC emissions by 2.91 tons. LA/LB could reduce its annual VOC emissions by 29.9 tons.

Table 4 – VOC Emissions Abatement, Marine Tank Vessel Loadings, Single Vessel and Ports of LB/LA

Abatement Totals: SCAQMD Rule 1142 Required Efficiencies				
Case	Barrels	Avg Emissions	SCAQMD Max	VOCs Abated (s.tons)
		(lbs/1,000 bbls)		
Single Vessel Load (1) (2)	30,000	2.71	2	0.011
Single Vessel Annual Load (1) (2)	2,310,000	2.71	2	0.820
LB/LA Annual Total (3)	22,050,000	2.92	2	10.1
Abatement Totals: Carbon Canister Efficiencies				
Case	Barrels	Avg Emissions (lbs/ 1,000 bbls)	Efficiency Rate (% Removal)	VOCs Abated (s.tons)
Single Vessel Load (1) (2)	30,000	2.71	93	0.038
Single Vessel Annual Load (1) (2)	2,310,000	2.71	93	2.91
LB/LA Annual Total (3)	22,050,000	2.92	93	29.9

(1) *Single Vessel Loads* based on Foss barge WT-30 operations.

(2) Assumes bunkers average 20% TKN Feed (4.86 lbs/1,000 bbls), 20% marine diesel oil (2.76 lbs/1,000 bbls), and 60% bunker fuel oil (2.32 lbs/1,000 bbls).

(3) Port of Long Beach & Port of Los Angeles 2002.

Cost-Benefit

The emissions reductions estimated in Table 4 can be given a per-pound and per-ton cost, when compared to the system installation costs detailed in *System Configuration Options and Costs*, below. Consideration here will be given to the Foss barge WT-30. This cost-benefit analysis will be compared with a VOC abatement program in Portland, Oregon, which yields similar VOC reductions.

Table 5 (see *System Configuration Options and Costs*, below) gives $61,448 as an annualized cost for practicing VOC abatement for the WT-30. This considers an annual VOC emissions reduction of 2.91 tons, and a 12 year system life cycle. Consideration of the estimated reductions in Table 6, gives a cost-benefit ratio of:

- $21,109 per short ton of VOC abated, or
- $10.55 per pound of VOC abated.

An example of a cost-benefit analysis of similar quantities of VOC reductions is given in EPA's Lawn Mower Buyback Program Case Study. This program, currently being run by the City of Portland, gives rebates when an old gasoline lawn mower is turned in with the receipt for a new electric mower. During 1997, 481 gasoline mowers were turned in, and rebates totaling $23,385 were issued. This resulted in an estimated annual reduction of VOC emissions of 3.5 tons (EPA 1998). If 20% administrative costs on those rebates and a ten-year lawn mower life (Sondalini 2001) are assumed, this program has the following cost-benefit ratio:

- $802 per short ton of VOC abated, or
- $0.40 per pound of VOC abated.

Comparing the cost of the reducing a single bunker barge emissions to a program with a similar VOC reduction impact highlights the expense of targeting these low vapor pressure cargoes.

Benefits to the Tankerman

VOC abatement has the added benefit of relieving operating personnel from working in an environment awash in cargo vapors. Typical open loading of marine tank vessels involves freely venting of vapors directly from individual cargo tank waterports. Installation of a vapor collection system offers a significant improvement, collecting vapors to a single release point, often a high riser that allows VOC dispersion – generally away from the working area. Installation of a vapor processing system offers perhaps the most significant improvement, with systems generally removing over 90% of non-methane VOCs before venting to the atmosphere.

Health considerations are difficult to quantify. Personnel are trained to protect themselves from toxic vapors. The principal tool in this effort is the use of the Material Safety Data Sheet (MSDS), which instructs personnel concerning health hazards and appropriate precautions required for handling specific cargoes. In general, bunker products are free of toxic substances and do not require special handling. However, VOCs have been noted to have some impact on individual health. Quoting from SCAQMD Air Quality Analysis Guidance Handbook, 2001, p 3-13: ". . . ambient VOC concentrations in the atmosphere are suspected to cause coughing, sneezing, headaches, weakness, laryngitis, and bronchitis, even at low concentrations."

The Foss-Glosten installation has been met with the approval of the tankermen. While this system may be reducing the health impact of cargo loading events, it has clearly improved working conditions.

SYSTEM CONFIGURATION OPTIONS AND COSTS

Whether to meet environmental regulations or provide improved working conditions for tankermen, there are several vapor control system (VCS) options. This section identifies a framework for selecting a viable system and gives an overview of several VCS options. The selection of carbon adsorption for the Foss-Glosten system, including configuration and life cycle costs, is also presented.

VCS Framework

The specifics of typical bunker product marine tank vessels and the supporting shoreside infrastructure present both challenges and advantages when considering a VCS. It should be assumed that all systems can be developed to meet regulated VOC reduction requirements. The challenges may include:

- Lack of shoreside VOC abatement infrastructure at the bunker product marine tank terminals.
- Limitation of marine tank vessels, generally as follows:
  - Limited non-redundant power capabilities, typically enough to run a small capstan and battery charger.
  - Limited fire fighting capabilities, consisting of portable and semi-portable fire extinguishers.
  - Limited manning capabilities, consisting of two tankermen and no engineers.
- Typically, a majority of the open deck area of the marine tank vessel is considered to be in the hazardous zone (requiring class 1, division 1 equipment).

Characteristics that can be used to an advantage include:

- There are low VOC concentrations in bunker product vapor streams (typically less than six pounds/ 1,000 bbls loaded).
- Loading rates are typically less than 10,000 bbl/hr.
- Vessel cargo tanks are typically rated for 2.9 psig head pressure (as per American Bureau of Shipping regulations).

Based on these conditions, the framework for a viable system is as follows:

- VCS meets the regulations as required. ABS, DNV and USCG have specific requirements governing on-board VCS.
- Vessel must carry a VCS that includes its own vapor processing plant.
- Low VOC concentrations permit on-board storage of captured VOCs, in addition to traditional destruction and recovery processes.

- VCS demand on tankermen should be minimized. Tasks outside typical tankermen expertise should be avoided.
- VCS should have limited power demands (self-contained or battery powered). VCS use of blowers, compressors or pumps is a disadvantage.
- VCS should be passive, requiring limited interface with operators.
- VCS should present limited hazards to marine tank vessel, and provide adequate means of hazard mitigation.
- Life cycle costs should be considered.

Available VCS Options

Several VCS options are presented below. These are discussed in relation to *VCS Framework*, above. For comparison between options, a 30,000 bbl tank barge is used as the system baseline.

Activated Carbon Adsorption

Activated carbon adsorption utilizes a carbon bed through which the vapor stream is directed. VOCs are adsorbed while the vapor stream passes through the carbon bed. Highlights from *VCS Framework*, above, are as follows:

- System stores captured VOCs in a carbon bed eliminating need for complex destruction or recovery equipment. Spent carbon can be off-loaded for handling at a shore facility. A single 2,000 lb carbon bed can process between 100,000 and 300,000 bbls of bunker product before requiring regeneration.
- Carbon beds can be sized such that the loading cargo displaces the cargo vapors through the carbon bed without overpressurizing the cargo tanks. This eliminates the need for vapor movers. Only electrical power requirements are for alarm, monitoring and control.
- Tankermen interaction involves valve line-up and alarm, monitoring and control system checks. No system equipment "starting" is required.
- Carbon bed fires present a significant hazard to the marine tank vessel. Mitigation equipment, including a dedicated suppression system and devices to isolate hazard from cargo tanks, is recommended.

Activated Carbon Adsorption/Absorption

Activated carbon adsorption/absorption utilizes two activated carbon beds, each cycling between the adsorption and absorption processes. In the first process VOCs are adsorbed while the vapor stream passes through the carbon bed. Next, the VOCs captured in the carbon bed are absorbed through a vacuum and purge air process, reactivating the carbon bed. Highlights from *VCS Framework*, above, are as follows:

- System regenerates captured VOCs returning this to the cargo tanks as usable product. The expense of the regeneration equipment is difficult to justify given the small quantities of recovered product, between 8 and 22 gallons per 30,000 bbl load. A lack of shoreside regeneration facilities could work to the advantage of this system.
- Power requirements for this system can be estimated between 100 – 150 kW. This will frequently exceed the available power, and require improvements to the marine tank vessel existing power generation system.
- Tankermen interaction involves some system operations specific to the absorption system in addition to valve line-up and alarm, monitoring and control system checks.
- Carbon bed fires present a significant hazard to the marine tank vessel. Mitigation equipment, including a dedicated suppression system and devices to isolate hazard from cargo tanks, is recommended.

Lean Oil Absorption

Lean oil absorption consists of a tower in which refrigerated lean oil, a liquid absorbent, flows down through the up-flowing cargo vapors. This process scrubs the VOCs from the vapor stream, returning liquefied VOCs to the cargo tanks. Highlights from *VCS Framework*, above, are as follows:

- System regenerates captured VOCs returning this to the cargo tanks as usable product. The expense of the regeneration equipment is difficult to justify given the small quantities of recovered product, between 8 and 22 gallons per 30,000 bbl load. A lack of shoreside regeneration facilities could work to the advantage of this system.
- Power requirements for this system can be estimated at 95 kW. This will frequently exceed the available power, and require improvements to the marine tank vessel existing power generation system.
- Tankermen interaction involves system operations specific to the lean oil system in addition to valve line-up and alarm, monitoring and control system checks.
- Electrical components, and static charges build-up from falling lean oil presents some hazard to the marine tank vessel. Mitigation equipment is recommended.

Thermal Oxidation

Thermal oxidation methods range from a simple flare to complex machinery that adjusts the combustible mixture to meet specific emission requirements and may even include a quench cycle for cooling emissions. Current regulations likely require the more complex system. Highlights from *VCS Framework*, above, are as follows:

- Combustion relieves the system from storing or handling of recovered VOCs. Emissions trades should be considered. Are NOx and COx emissions acceptable replacements for VOCs?
- Power requirements for this system can be estimated at 200 kW. This will frequently exceed the available

power, and require improvements to the marine tank vessel existing power generation system.

- The low concentration of VOCs in the vapor stream, and certain regulatory requirements will likely require an enrichment system. The carriage of propane or other enrichment gases require considerable hazard abatement systems, with considerable added expense.
- Tankermen interaction involves significant system operations specific to the thermal oxidizer and auxiliaries. An addition to manning is likely.
- The very nature of oxidation requires redundant safety systems to protect the cargo tanks from exposure to this constant source of ignition.

Other Vapor Processing Systems

There are a myriad of other vapor processing systems which have not been considered here. These include: zeolite absorption, liquid nitrogen condensation and recovery, membrane separation and recovery, catalytic oxidation. These and other systems may provide viable solutions to specific systems, but are not evaluated here.

Hazards Identification and Mitigation

VOC abatement systems present significant hazards to the marine tank vessel. These hazards extend beyond the familiar considerations of cargo tank overfill and overpressurization. With bunker product vapor concentrations in the 0 - 5% hydrocarbon range, and non-inerted tanks typical for bunker product carriers, an explosive mixture should be assumed present at all times.

Each VOC abatement system presents additional hazards. Hazard mitigation of these, in addition to those required by the regulations, must be considered in any installation.

Foss-Glosten VCS Selection

The activated carbon adsorption system was selected as the most suitable technology for the Foss-Glosten VCS (see *Activated Carbon Adsorption*, above). System costs, detailed below under *Capital Expenditure and Operating Cost*, were the most favorable of all options evaluated. With no compressors, blowers or other rotating machinery, it was felt that this system was the least likely to place a burden on the tankermen. Maintenance of the system could be performed on a monthly basis by select personnel. Carbon exchange for off-site regeneration, while considered expensive and resource intense, is limited to less than once per month. This effort is felt to be offset by the limited burden this system places on the tankermen when compared with oxidation and regeneration systems.

Foss-Glosten VCS Configuration

The Foss-Glosten VCS is configured, as shown in Figure 1, to achieve the following:

- Minimum demand on operator
- Minimum power requirements
- Minimize system hazards
- Maximum system reliability
- Matching existing cargo handling capacity

The VCS requires a total of 60 minutes from each of the two operators per loading event. This includes preloading checks, system alignment, operational checks and securing of the system when loading has been completed. System checks include checking low point drains, energizing the control and monitoring system and additional paper work. Foss has not had to increase crewing, and their current personnel have adapted to operating this system.

The system has no rotating machinery, and requires only a battery operated control and monitoring system. The system's single moving part, the facility vapor connection valve, has a self contained power operator that closes on a fault or loss of power to the control and monitoring system.

Primary mitigation meeting regulatory requirements includes the facility vapor connection valve, the detonation flame arrestor and end-of-line flame arrestors. Additional hazard mitigation includes a monitoring system that controls the facility vapor connection valve, and which detects temperature, VOC concentrations and carbon monoxide levels. Primary response to a combustion hazard is automatic isolation of the system from the vapor collection system. Additionally, the VCS is serviced by a self-contained purging and extinguishing system.

System reliability is dependent on a single facility valve, a single detonation arrestor, and a non-redundant control system. The processing of the vapors, however, is dependent only on the adsorption of the VOCs as the cargo vapor stream passes through the carbon bed. When one carbon bed becomes saturated, the control system alarms and automatically secures the facility vapor connection after a delay that allows the operator to secure operations. At this point a second parallel bed can be put on line.

The movement of the vapors is achieved through displacement by the loading of liquid cargo. Loading rate is governed by system piping, carbon canister size, and product loaded. Loading rates up to 12,000 barrels an hour can be achieved with the carbon bed canister selected for the Foss-Glosten VCS; this exceeds the vessel loading rate. Parallel systems can handle capacities at any multiple of this rate.

Capital Expenditure and Operating Costs

Capital expenditure and operating costs depend significantly on specific installation parameters. For example, a vessel with adequate deck space outside the hazardous zone, a significant power generation plant, and annual through-put of over 4.5 million barrels may find cost advantages in a carbon adsorption/absorption or a lean oil system. A vessel with limited facilities and through-puts less than 4.5 million barrels per year will likely find cost advantages in a carbon adsorption system with off-site regeneration. Additional considerations are specific to a particular owner's needs. These include availability of service facilities for carbon exchange, reliability requirement and the burden placed on tankermen.

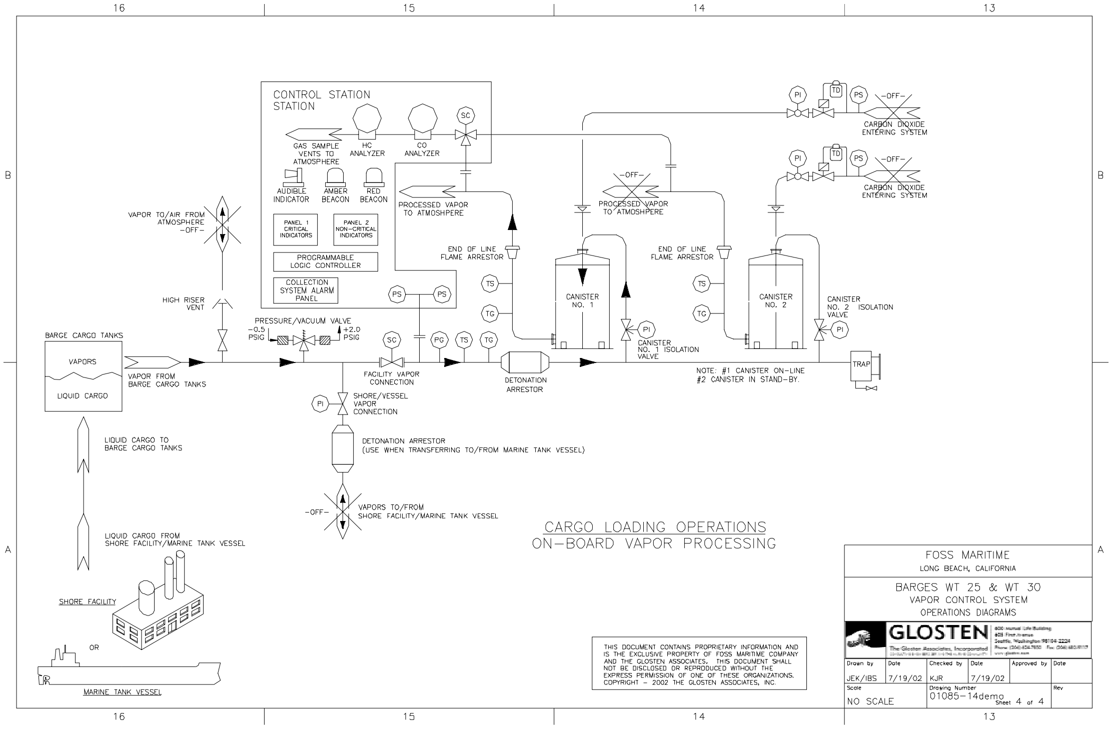

Figure 1 – Example Carbon Adsorption VOC Abatement System

The life cycle cost of a carbon adsorption/absorption and lean oil systems, considered similar, are explored here. This analysis follows similar considerations as that outlined in Tables 4 and 5. Capital expenditure costs, including collection and processing plants, can be estimated at $550,000 per vessel, including upgrade of the power generation plant. Operating/maintenance costs can be estimated at $35,000 per year. The resulting cost per ton of VOC abated is estimated at $28,000, much higher than the activated carbon adsorption system costs. A modern thermal oxidizer suitable for marine tank vessel mounting has capital costs, operation costs and manning requirements an order of magnitude greater than the other VCS options discussed here.

Tables 5 and 6 detail the associated costs of a carbon adsorption system. This assumes that an existing vessel is outfitted with a new vapor collection system. An estimated capital expenditure of $326,250 can be expected for a parallel two-canister system. Operating costs for an annual 2.31 million barrel through-put is approximated at $34,260 per year. With capital expenditures averaged over 12 years, annual system cost is $61,448. It is noteworthy that the annual system cost, before carbon regeneration fees and handling, is $41,588. The estimated carbon regeneration and handling costs are directly dependent on system through-put.

Table 5 – Activated Carbon Adsorption VCS Life Cycle Costs

Capital Expenditure (4 Vessel Fleet)			
Item	Units	Unit Cost	Total
Collection System Engineering	4	$25,000	$100,000
Collection System Installation	4	$150,000	$600,000
Processing System Engineering	1	$125,000	$125,000
Processing System Installation	4	$100,000	$400,000
Approvals and Testing	4	$20,000	$80,000
Total Cost			$1,305,000
Average Cost/Vessel			$326,250
Operational Costs (Single Vessel/Year)			
Item	Units	Unit Cost	Total
Carbon Consumption (lbs)	18,600	$1	$17,460
Monthly Canister Rental	24	$300	$7,200
Operational Costs of Carbon Exchange	8	$400	$2,400
System Maintenance	12	$500	$7,200
Total Cost			$34,260
Annualized System Costs (Single Vessel over 12 years)			
Item		Total	Annualized
Capital Expenditure		$321,250	$27,188
Operational Costs			$34,260
Total Cost			$61,448

*Values based on Foss WT-30 installation.

Table 6 – Activated Carbon Adsorption
Cost to Benefit Ratio

Cost per ton VOC abated		
Total cost/VOC abated ($/short ton)	Tons VOCs abated (annual)(1)	System costs (annual)(2)
$21,109	2.91	$61,448

Abatement totals: carbon canister efficiencies(1)				
Case	Barrels	Avg Emissions (lbs/ 1,000 bbl)	Efficiency Rate (% Removal)	VOCs Abated (s.tons)
Single Vessel Load	30,000	2.71	93	0.038
Single Vessel Annual Load	2,310,000	2.71	93	2.91

(1)Values based on Table 4.

(2)Values based on Table 5.

CONCLUSION

The practice of VOC abatement with currently developed vapor control systems during bunker product loading can reduce annual emissions in the ports of Long Beach and Los Angeles by over 30 tons. However, it should be noted that the cost-to-benefit ratio of these systems is over 20 times that of similar abatement programs. In addition, bunker product loading accounts for a small percentage of overall VOC emissions in many areas. This effort may be a feasible pollution abatement solution for some areas, but not all.

Where VOC abatement of marine bunker products is determined to be a feasible part of an area pollution control plan, the Foss-Glosten VCS presents a reasonable approach that has minimal impact on current operations, and a significant improvement to the tankermen's working conditions.

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APPENDIX

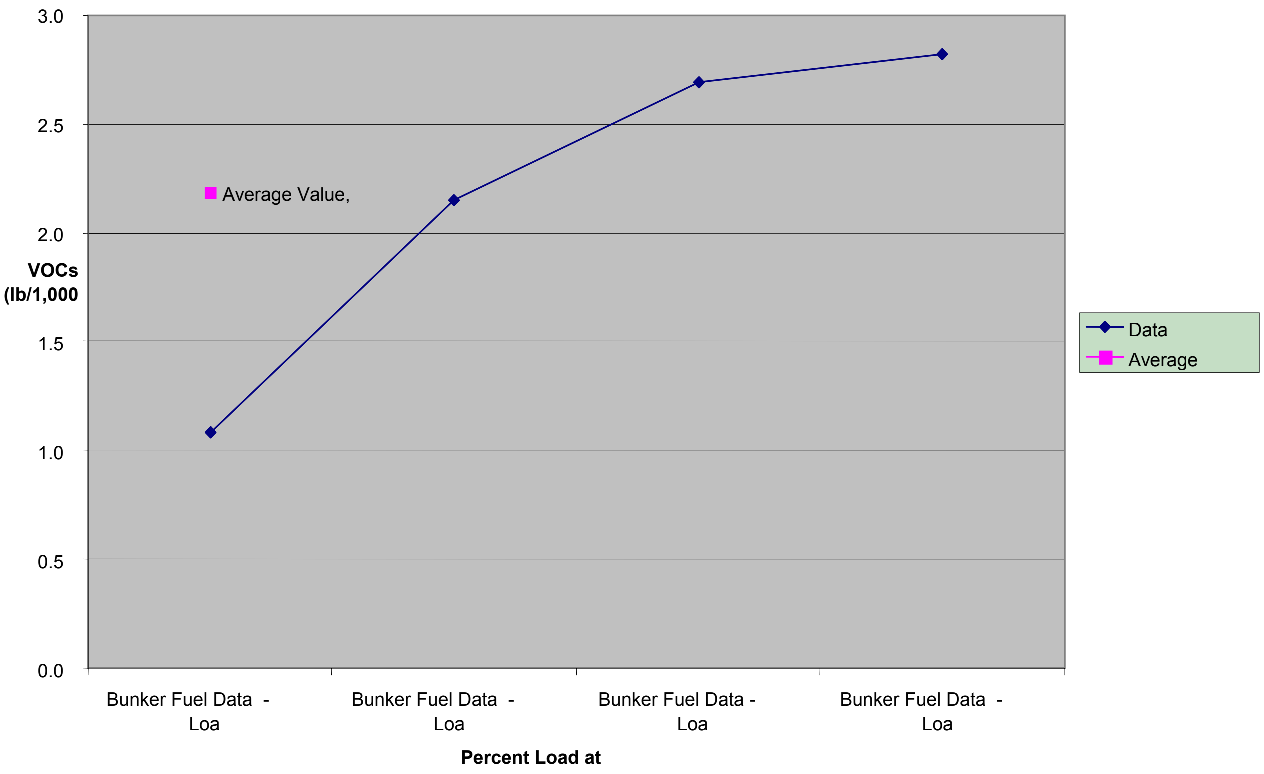

Figure 2 – Bunker Fuel, Percentage Loaded vs. VOC Concentration

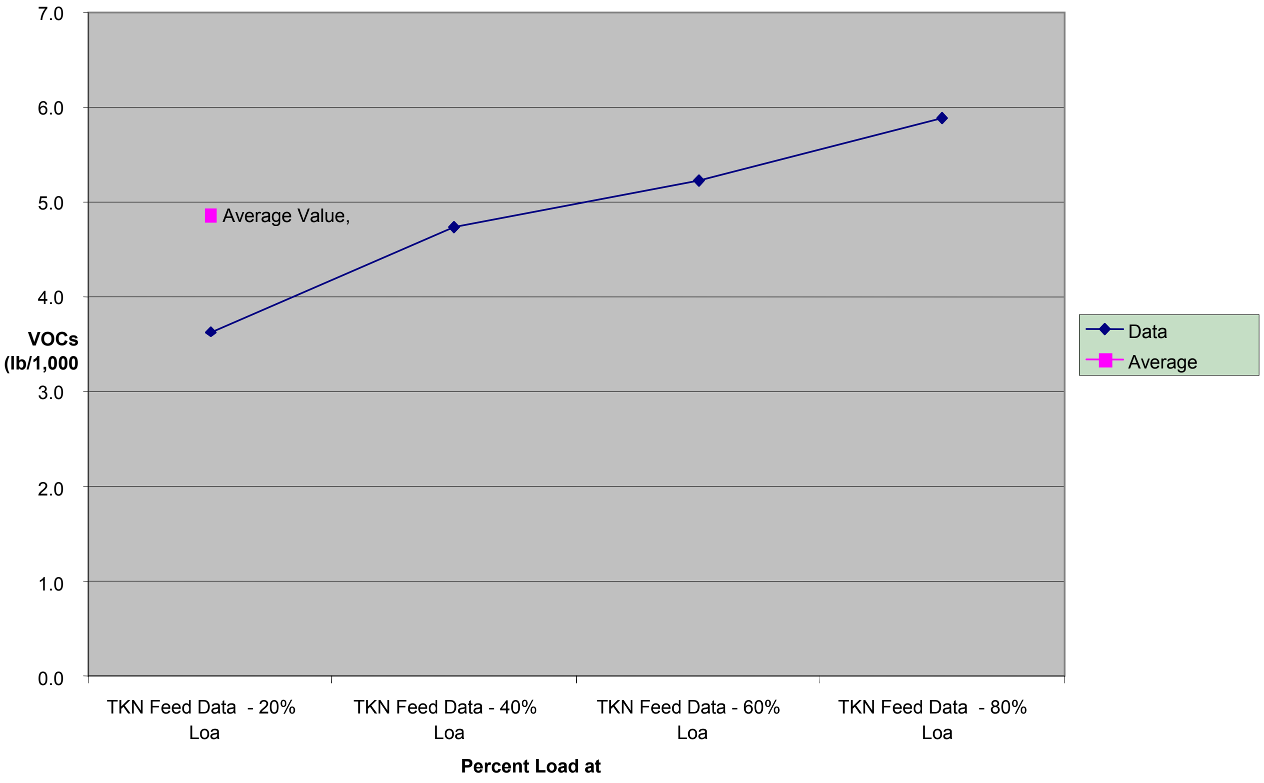

Figure 3 –TKN Feed, Percentage Loaded vs. VOC Concentration