WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Guidelines for Determining Oil Spill Volume in the Field

Terminology, Ranges, Estimates & Experts

February 1996
Publication No. 96-250

printed on recycled paper

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1. Introduction

Introduction

Foreword

This guide was prepared for the Washington State Department of Ecology to enhance the ability of Ecology response staff to determine the volume of petroleum products that have been released into the environment during a spill. It is intended for use by trained Ecology response staff in conjunction with existing Ecology standard operating procedures including Ecology safety & health plans and documentation protocols. Information is provided on oil terminology, ranges (expected volumes), methods to estimate volumes and expert contacts.

Concerns about safe operating practices at oil spills should be referred to the Ecology Safety Office or reviewed in the Ecology Spill Response Operations Manual.

Oil volume estimation is required by Ecology in support of the Natural Resource Damage Assessment (NRDA) program. Ecology's goal is to provide an estimate of spilled oil volumes that is legally defensible with a level of investigative effort appropriate to the scale of the incident.

Three types of information are typically evaluated by responders when investigating volumes of petroleum products that have been released into the environment; **1) source** (initial volume - final volume = amount spilled), **2) recovery** (vacuumed product, oiled debris, etc..), and **3) oil on water** observations.

Source

Of the three methods, source is considered the most reliable, repeatable and defensible. Whenever possible, Ecology staff should make every effort to gather as much information as possible on the source of a spill and attempt to estimate volume based on that data.

It is important to note that even under normal controlled conditions, inherent subjective observations (temperature, measuring tapes, gauges, etc..) often lead to disagreements in the amount of product measured. This requires remeasurement or compromise between involved parties. Acceptable variance in measurements differ considerably throughout the industry. Some companies insist that they know volumes within a few gallons, others are satisfied when they are within several thousand gallons. One company might have an allowable discrepancy up to 0.25%. On a transfer of 10,000 gallons (about the size of a gasoline tanker truck) of product this could result in a difference of up to 250 gallons.

The process of accurately measuring petroleum volumes is made even more difficult when factors such as tank damage, vessel instability, product mixing, etc.. are incorporated. In these situations it may be necessary to completely off load the damaged or leaking container into a container of known volume, then compare the resulting difference in volume of the receiving container (following recognized API/ASTM standards throughout the process).

Recovery

Recovery information can be valuable if proper records are kept and Ecology responders are on-scene quickly enough to keep track of recovered oil, sorbent materials and debris. Collection of spilled oil during cleanup operations by methods such as suction, absorbent materials, and transfer to stable containment is a viable method for reducing environmental damage and should be encouraged. Quantification of amounts collected is best accomplished by requiring responsible parties to collect and store recovered oil using standard API/ASTM methods. The resulting quantity of oil recovered can then be subtracted from oil spilled to arrive at a total amount that has remained in the environment. Proposed California State regulations are included in this guide's appendix and provide useful guidance on recovery of oil products.

Oil on Water

Oil on water observations may be useful to estimate the magnitude of a spill if observational conditions are appropriate. Oil on water is dramatic evidence of a spill, but not the most verifiable way to determine volumes of spilled product.

The combination of information collected from all three methods can be used to estimate the volume of a spill. Again however, the source method is the most defensible and Ecology staff should concentrate their efforts on obtaining information there first.

This guide provides useful checklists as reminders for Ecology staff when responding to oil spill incidents. In addition, pertinent diagrams, terminology and industry standard methodology is included to help guide Ecology staff through an investigative process. For example, responders to a petroleum barge incident will find the guide contains diagrams of typical petroleum barges and an extensive glossary of terms they might encounter. Ecology responders attempting to estimate volumes of oil based on oil on water observations will find guidelines, charts and a scientific paper on the topic.

Experienced field responders understand that although helpful, no checklist can contain every topic or item they might encounter at a spill. This guide provides a wealth of information, but the investigative process inherent to environmental emergency investigations requires Ecology responders to think on their feet and obtain useful information, even if it isn't listed on the checklist they have been provided.

When faced with unfamiliar situations, or when placed in a situation beyond the scope of their training, Ecology staff can contact subject area experts listed in Appendix B of this guide.

2. Oil Characteristics

Oil Characteristics

Petroleum is a highly complex mixture of straight-chain, branched, cyclic, saturated, unsaturated and aromatic hydrocarbons, containing a low percentage of sulfur and trace amounts of nitrogen and oxygen compounds. It is normally found at great depth underground or below seabeds and is presumed to have originated from both plant and animal sources some 10-20 million years ago.

Crude oil is the common name given to the liquid form of petroleum. *Natural gas* is the gaseous form of petroleum, consisting mostly of methane (CH_4). Associated with liquid petroleum underground, it comes to the surface as “wet gas” mixed with heavier hydrocarbons that can later be purified into ethane, propane (LPG), butane, and hydrocarbon liquids (natural gas condensate). A “dry gas” is normally associated with solid hydrocarbons such as coal, wherein recovered methane typically is not associated with significant other hydrocarbons.

Refineries receive petroleum by means of pipelines, tank trucks, barges and ocean-going vessels. A breakdown by transportation method of the crude oil received by U.S. refineries and for Washington state refineries are shown in Table 1.1. The substantial percentage of refinery feedstock that must be received via water dictates the current high volume of bulk marine transport and the prevalence of refineries near navigable bodies of water.

TABLE 1.1 Method of Transportation for Crude Oil Received by U.S. Refineries, 1979[C] and by Washington State Refineries, 1980[E]

U.S. Refineries

Transportation method	*Vol %*
Domestic crude oil	
Pipelines	42.9
Tank cars and trucks	2.1
Tankers and barges	11.0
Subtotal	56.0
Foreign crude oil	
Pipelines	12.7
Tankers and barges	31.3
Subtotal	44.0
Total receipts	100.0

Washington State Refineries

Transportation method	*Vol %*
Domestic crude oil	
Pipelines	00.2
Tank cars and trucks	00.0
Tankers and barges	54.7
Subtotal	54.9
Foreign crude oil	
Pipelines	06.3
Tankers and barges	38.8
Subtotal	45.1
Total receipts	100.0

Petroleum Product Names and Specifications

Petroleum yields both petrochemicals (specific hydrocarbons such as a benzene and toluene) and “refined products” (fractions refined from crude oil such as gasoline and diesel fuel containing a relatively large group of hydrocarbons). In the United States, the American Society for Testing and Materials (ASTM) and the American Petroleum Institute (API) are recognized for establishing specifications involving both products and product testing methods. *Boiling range* is the major distinction between both refined products and individual refinery streams. A summary of ASTM specifications for fuel boiling ranges is given in Table 1.2.

Table 1.2 Major Petroleum Products - Specified Boiling Ranges[c]

Product Designation	*ASTM designation*	*Specified temperature for volume % distilled at 1 atmosphere, °F.* 10%	50%	90%
Liquefied petroleum gas (LPG)	D1835			
Commercial propane		(a)		(b)
Commercial butane		(a)		(c)
Aviation gasoline (Avgas)	D910	158 max	221 max	275 max[d]
Automotive gasoline	D439			
Volatility class A		158 max	170-250	374 max[e]
Volatility class B		149 max	170-245	374 max[e]
Volatility class C		140 max	170-240	365 max[e]
Volatility class D		131 max	170-235	365 max[e]
Volatility class E		122 max	170-230	365 max[e]
Aviation turbine fuel	D1655			
Jet A or A-1		400 max		(f)
Jet B		(g)	370 max	470 max
Diesel Fuel oil	D975			
Grade 1-D				550 max
Grade 2-D				540-640
Grade 4-D		-	not specified	-
Gas turbine fuel	D2880			
No. 0-GT		-	not specified	-
No. 1-GT				550 max
No. 2-GT				540-560
No. 3-GT		-	not specified	-
No. 4-GT		-	not specified	-
Fuel oil	D396			
Grade No. 1		420 max		550 max
Grade No. 2		(h)		540-640
Grade No. 4		-	not specified	-
Grade No. 5		-	not specified	-
Grade No. 6		-	not specified	-

(a) vapor pressure specified instead of front end distillation
(b) 95% point, -37 °F max
(c) 95% point, 36 °F max
(d) final point, 338 °F max
(e) final point, all classes, 437 °F max
(f) final point, 572 °F max
(g) 10% point, 290 °F max
(h) flash point specified instead of front end distillation

Most refined products at the consumer level are blended from a number of refinery streams. Nomenclature describing refined products can be confusing, as several names are often used to describe substantially similar products. In Table 1.3, the column on the left identifies basic crude oil distillation fractions, the middle column lists other commonly used terms for refinery blends, and the right column identifies common names for corresponding consumer products.

Table 1.3 Equivalent Names for Refined Petroleum Products[c]

Crude oil cuts	*Refinery blends*	*Consumer products*
Gases	Still Gases	Fuel gas
	Propane/Butane	Liquefied petroleum gas (LPG)
Light/Heavy naptha	Motor Fuel	Gasoline
	Aviation turbine, Jet-B	Jet fuel (naptha type)
Kerosene	Aviation turbine, Jet-A	Jet fuel (kerosene type)
	No. 1 fuel oil	Kerosene (range oil)
Light gas oil	Diesel	Auto and tractor diesel
	No. 2 fuel oil	Home heating oil
Heavy gas oil	No. 4 fuel oil	Commercial heating oil
	No. 5 fuel oil	Industrial heating oil
	Bright stock	Lubricants
Residuals	No. 6 fuel oil	Bunker C oil
	Heavy residual	Asphalt
	Coke	Coke

Petroleum Refining - An Overview

The appearance and character of crude oil as it is extracted from the ground varies widely; it may be yellow to green to reddish to black, as thick as tar or nearly as thin as water. The type of crude oil feedstock preferred by a given refinery will depend upon the desired distribution of refined products to be obtained. The three most commonly specified properties are density, chemical characterization, and sulfur content.

API gravity is a contrived measure of density defined by the equation:

$$°API = [141.5/(\text{specific gravity } @60\ °F)] - 131.5$$ [A]

According to this system, an oil with the same density as water (specific gravity of 1.0) would be 10° API oil; oils with higher than 10° API gravity are lighter than water. Petroleum products fall into a relatively narrow range of specific gravity values (0.600 to 1.03); the use of API gravity values (5.35 to 104.33) facilitates identification by density with greater specificity.

Sour and sweet are terms used to specify the sulfur content of crude oil. Crude oil containing more than 0.5% sulfur by weight is said to be sour, and if less than 0.5%, sweet.

Near the well site, crude oil undergoes gravity *field separation* in large vessels designed to remove dirt, water, and gases that accompany it from the ground. At the refinery site, *crude desalting*, basically a water washing operation, is performed in an attempt to further remove water, dirt, water-soluble minerals and entrained solids. Once desalted, crude oil can be separated into fractions of differing boiling ranges in a process called *crude oil distillation*. Distillation separates crude oil into fractions typically as represented in Table 1.4.

Table 1.4 Separating Desalted Crude Oil into Fractions[c]

Stream Name	***% by Volume***	***Boiling Point Range, °F.***
Gas	-	<50
Light Naptha	8	50 - 200
Heavy Naptha	21	200 - 400
Kerosene	11	400 - 500
Gas Oil	15	500 - 650
Residue	45	650

Crude oil is seldom distilled at temperatures above approximately 650 °F. At higher temperatures, a carbonaceous residue referred to as *coke* forms, plugging the lower section of the distillation tower. *Residual oil* is a general term for the heavy, viscous liquid that does not vaporize during distillation, from which such products as industrial fuel oils, road oils, etc. are later derived. The collected and condensed fractions which do vaporize can be collectively referred to as *distillates*.

In the developed world, demand tends to be highest for transportation fuels and high quality heating oils. Crude oil distillation alone tends to produce relatively too little of these lighter fractions and correspondingly too much residual oil. *Cracking* refers to the process of breaking larger hydrocarbon molecules into two or more smaller molecules. Refineries typically utilize one or more cracking processes in order to increase the percentage of crude oil feedstock that can be refined into gasoline and other lighter products. *Thermal cracking* accomplishes this by means of intense heat and pressure. *Catalytic cracking* is a more widely used process, as it requires less extremes of temperature and pressure and produces higher octane gasolines (see *Glossary of Technical Terms* for a definition of *octane number*).

3. Estimating Volume from Spill Source

A. Marine Sources

Marine Vessels

Spill Volume Estimation Checklist:

1. **Collect information (for example:)**
   - Type of vessel
   - Identification markings, numbers, name
   - Company name
   - Shipping papers (bill of lading, oil record book, oil transfer log, vessel transfer diagram or vessel diagram.)
   - Identification numbers from the tank(s) involved
   - Interview crew (master, chief engineer, tankerman)
     Ship: The vessel master (captain) is responsible for the vessel and should have access to all records. The master may delegate responsibility for oil volume recordkeeping in this manner: Chief Mate (first officer), Chief Engineer, First Assistant Engineer or even Second Asst. Engineer. While in port, the Captain is typically either in their "in port" office or on the bridge. Fueling operations are usually monitored in the "bunkering and cargo handling office" or from the Engine room. The "bunkering" office is usually abovedeck near where the bunkering connections are located. Crewmembers onboard should be able to direct an Ecology responder to the proper person and location.
     Barge: The Tankerman should be onboard. In addition, a shoreside person should be present, often in a small weather shack on the pier, immediately adjacent to the loading manifold.
   - Take photos of scene, tank(s)
2. **Determine volume present in the tank prior to spill**
   - maximum volume will be the maximum volume of the tank
   - subtract any fuel used or discharged since the tank was last filled
   - use Manual Gauging Checklist on the following page when attempting gauging
3. **Determine post-spill volume in the tank**
   - off load the tank into a stable container of known volume, gauge volume using Manual Gauging Checklist on the following page
   - estimate remaining fuel in tank using onboard gauging equipment
4. **Calculate spill volume**
   - pre-spill volume minus post spill volume = spill volume

Manual Gauging Checklist

This checklist is provided as a guide for marine manual gauging of oil products. Gauging should only be done by trained competent personnel who are familiar with and using API/ASTM standard methods. The Manual Gauging Worksheet in this section may be used to record the following information.

1. **Exit prompts - when to call marine gauging or measurement contractor.**
   - When condition of tanks prevents gauging.
     - Datum blocked or damaged.
     - Reference point missing or damaged.
     - Tilting, listing, (more than 2%),vessel is sinking
   - When the gauging equipment is damaged or accuracy is doubtful.
     - Gauge tape is stretched, crimped, cut, etc.
     - Bobs are blunted and/or damaged.
     - Sounding data is unreadable, or does not match tank. (plug in line?)
   - When vessel personnel are untrained, or equipment for gauging is unavailable.
   - When vessel personnel don't speak English.
   - When technical nature of spill is outside of worksheet and responder capabilities.
     - Unusual vessel systems.
     - Complex piping.
     - Complex pumping.
     - Complex valving.
     - While product transfer is ongoing.
2. **Collect the following documentation from the Vessels Master, Tankerman, Chief Mate or Chief Engineer.**
   - Bill of lading, Cargo Transfer Procedures Manual. or Preload Plan
   - Key to the codes used on the documentation (e.g. "H" = bunkering)
   - Oil Record Book, Oil Transfer Log, Fueling Book.
     - e.g. U.S.C.G. and/or MARPOL documents.
   - Sounding Charts/tables (may be called strapping tables or trim tables).
3. **Record Vessel Tank Number**
   - Typically found in vessel documentation.
     - Oil record books, fueling logs, vessel diagrams, blueprints.
4. **Record Trim & List of vessel at stern & bow (port and starboard)**
5. **Gauging should not be attempted until the tank has been at rest and settled. This could range from 2 to 24 hours.**
6. **Record Auto Gauge Reading**
   - Typically found in engine room spaces.
   - Older, or smaller tanks may have no auto gauge.
7. **Identify location of gauging access (sounding tube).**
8. **Establish whether "innage or outage" method will be used to gauge.**
   - Use innage (amount of liquid in the tank, see the glossary) when possible.
   - If datum plate is damaged or debris is blocking datum access, outage method will be used.

9. **If using innage method, water level can be checked at the same time.**
   - Use the innage bob and tape. This may be a round bob, pointed at the end about 4" to 6" inches in length.
   - Coat innage bob with water-indicating paste.
   - Lower the bob and tape into the tank, keeping the tape in constant contact with the metal reference point. This prevents a static spark
   - When the expected level, (read from the auto gauge) presents itself, place a light coat of oil-indicating paste on the tape.
   - Stop lowering bob a few inches prior to contacting the bottom, slowly continue until the bob just "taps" the bottom.
   - Retrieve and record oil and water levels to the nearest 1/8"
   - Repeat the innage gauge again.
     - If the reading is the same, continue.
     - If the reading is different, repeat until 2 gaugings are the same.

10. **Outage or Ullage method**
    - Use the outage (amount of "free space" in the tank, see the glossary) bob and tape. This may be a square bob squared at the end about 4" to 6" in length.
    - Reference the gauge table to determine the tank depth (reference height or striking height) to ensure that the bob reaches the datum plate. This is also necessary to help determine when to slow down lowering of the bob.
    - Record the reference height of the tank.
    - Coat the bob and tape with oil indicating paste (for refined products).
    - Lower the bob on the tape while keeping the tape in constant contact with the metal reference point or ullage tube. This prevents static spark.
    - Submerge the bob a few inches at the expected liquid level.
      - This will be the reference height minus the auto gauge reading.
    - Record the tape cut at the reference point.
      - The "cut" is the tape reading at the reference point.
    - Retrieve the bob and subtract the liquid level on the bob from the cut.
    - Subtract the net cut from the reference height to determine liquid level.

11. **Take and record product temperature**
    - Lower thermometer probe into the center of the liquid, at least 12" from the side of the tank. Preferably in the middle of the tank.
    - Raise and lower the probe about a foot for one minute to stabilize product in the probe cup.
    - Wait 5 minutes then retrieve and record the temperature.

12. **Take product sample**
    - Using "thief" lower sample jar into lower 3 feet of liquid. Open thief and retrieve at a constant speed. Jar should be filled no more than 3/4. If it is full, empty and repeat procedure.
    - If tank level is < 10' one sample is sufficient.
    - If tank level is 10 to 15', two samples will need to be taken. One from lower half, one from upper half.
    - If tank level is > 15', three samples will need to be taken from each third of the tank.

13. **Evaluate findings**
   - Determine API gravity and Temperature from the sample.
   - Determine B.S.& W. (basic sediment and water)
   - Convert API gravity to 60F.
     - Use standard API gravity conversion table.
   - Determine volume conversion factor.
     - Use standard API volume conversion table.
     - Find converted API gravity to 60F at the top of the table. Follow the matching column down to the tank temperature that you recorded at the far left column.
   - From the sounding table for this specific tank determine gross product and water in tank.
   - Deduct the water from the gross product.
   - Multiply Gross product times volume conversion factor to get a corrected volume to 60F (net barrels).
   - Multiply corrected volume times B.S.&.W to get a net volume for this tank.
14. **This process should be observed by a trained Ecology representative and performed by a competent vessel representative or gauging professional, fully trained and familiar with the procedure.**
15. **Together with the vessel representative or gauging professional, record and concur on all measurements.**
16. **Prior to leaving vessel sign and have the vessel representative or gauging professional sign the finished gauging worksheet.**
17. **You both should agree on the volume of product in the tank.**

Washington State Dept. of Ecology
Manual Gauging Worksheet

CASE NUMBER [ ]

TANK INFORMATION **OSC** ______

TANK TYPE ❑ fixed facility ❑ marine vessel TANK NUMBER ______

TANK DESCRIPTION ❑ internal floating roof ❑ external floating roof ❑ cone roof ❑ other
❑ bunker (ships fuel) ❑ vessel cargo (internal) ❑ vessel cargo (external tank)

TANK STATUS ❑ damaged/leaking ❑ overfilled ❑ supply in transfer ❑ recovery ❑ other

SERVICE: Check applicable ❑ Gasoline ❑ Diesel/Jet ❑ Crude ❑ Asphalt ❑ AvGas
❑ GasOil ❑ fuel oil ❑ Slop ❑ Distillate ❑ other

LIST OTHER AFFECTED TANKS IN CONTAINMENT OR VESSEL:

Comments/ Notes:

NOTE: Record the draft, trim and list of the vessel:

note: fill out one sheet for each tank gauged

OPENING GAUGE All hand gauging must be checked at least twice. Accuracy will be to the nearest 1/8"

OPENING GAUGE: Auto: Ft. ___ In. ___ Hand: Ft. ___ In. ___ Tank Temperature ______ °F

Observed API Gravity ______ @ ______ °F API Corrected Gravity to 60°F ______

Water Level: Ft. ___ In. ___ Gross H_2O (From Strapping) ______ B. S. & W ______ %

OPENING CONVERSION TO 60°F Indicate measurement unit, e.g. barrels, gallons, liters, etc.

1 Overall **GROSS** (From Strapping) ______

2 Minus Gross H_2O (From Strapping) ______

3 Temperature Correction Factor to 60°F ______

4 #2 X #3 = **GROSS** Corrected TO 60°F ______

5 B. S. & W. X #4 ______

[ ]

#4 Minus #5 = **NET** ↑

CLOSING GAUGE Accuracy of all math computation shall be to the nearest 100th

OPENING GAUGE: Auto: Ft. ___ In. ___ Hand: Ft. ___ In. ___ Tank Temperature ______ °F

Observed API Gravity ______ @ ______ °F API Corrected Gravity to 60°F ______

Water Level Ft. ___ In. ___ Gross H_2O (From Strapping) ______ B. S. & W ______ %

CLOSING CONVERSION TO 60°F

1 Overall **GROSS** (From Strapping) ______

2 Minus Gross H_2O (From Strapping) ______

3 Temperature Correction Factor to 60°F ______

4 #2 X #3 = **GROSS** Corrected TO 60°F ______

5 B. S. & W. X #4 ______

[ ]

#4 Minus #5 = **NET** ↑

CALCULATIONS AND QUANTIFICATION

NET OPENING GAUGE OF TANK: ______ [ ]

NET CLOSING GAUGE OF TANK: ______ [ ]

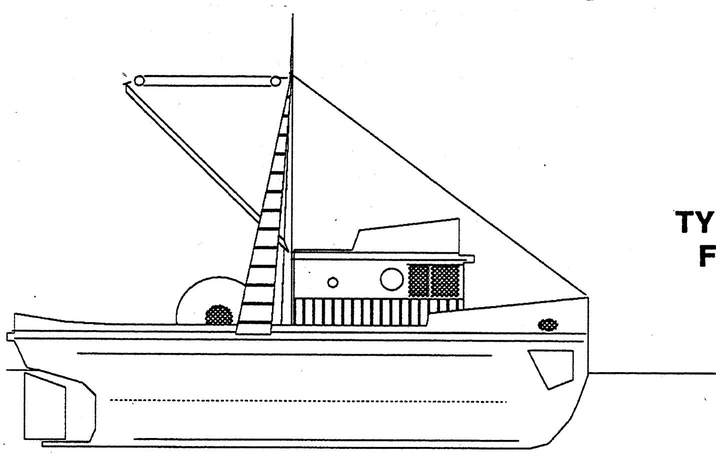
NET DIFFERENCE OPENING/CLOSING THIS TANK ——→ [ ]

Comments/ Notes:

Facility/Vessel Signature: ______

Ecology OSC Signature: ______ Date: ______

Fishing Vessels

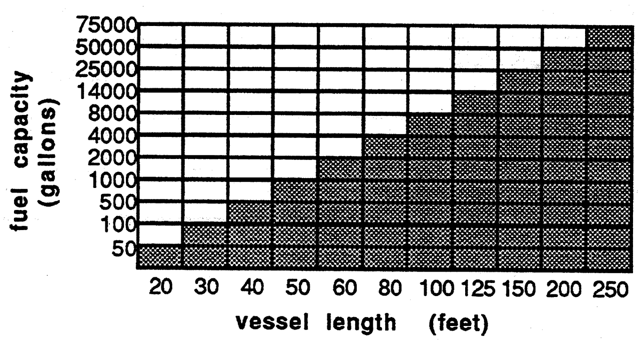


TYPICAL WEST COAST FISHING VESSEL

The above drawing is of a typical commercial fishing vessel commonly found along the west coast and inland waters of the United States and Canada. Accurate information on the quantity of petroleum products typically carried onboard fishing vessels is not available for the following reasons:

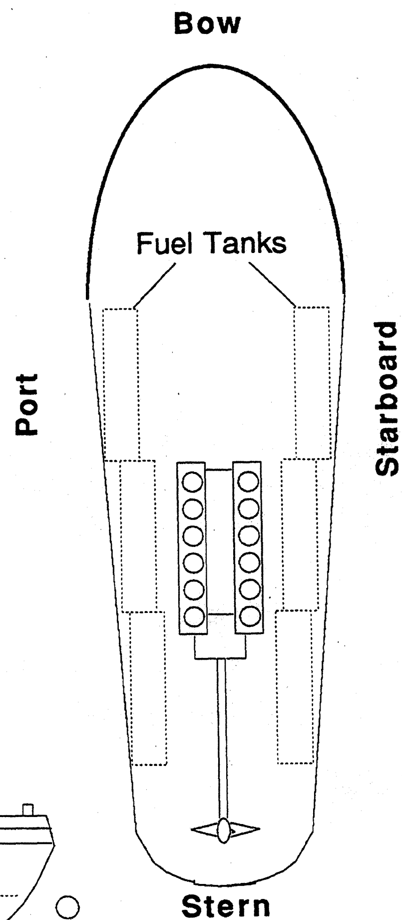
1) Unlike other commercial fleets such as Harbor Tugs and Ferries there is no identified, organized common engineering for the commercial fishing fleet.
2) There are literally hundreds of small to large builders of fishing vessels, most of which build custom, one-off designs (one of a kind).
3) Those vessels that appear to be identical to each other usually are configured to hold different quantities of petroleum products.
4) Average vessel size ranges from 32 feet to over 250 feet.
5) Petroleum quantities range from less than 100 gallons to over 75,000 gallons of combined fuel, lubricating oils and hydraulic fluids.

The following graph can be used as a guide to determine the average maximum quantity of petroleum products carried onboard a fishing vessel:



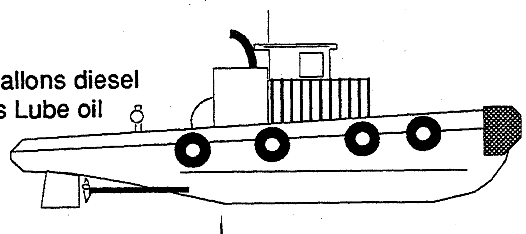
Tug Boats

Tug boats are commonly classified into 4 basic categories: **Harbor, Harbor/River**, **Harbor/Ocean** and **Ocean** tugs. A Harbor /Ocean Tug can have a fuel capacity of 120,000 gallons but may only carry 60,000 gallons if it is working in the harbor and be ballasted with water to keep the prop low, providing more power. **Fuel tanks** are generally located belowdecks on the **Port** and **Starboard** sides of the tug with equal volumes distributed to enhance stability.



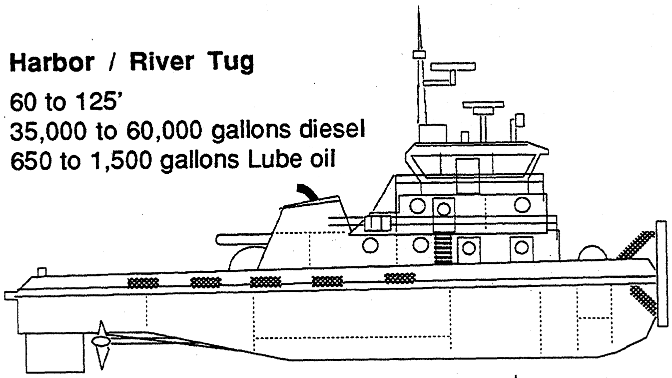
Harbor Tug

30 to 60'
1,500 to 25,000 gallons diesel
200 to 400 gallons Lube oil



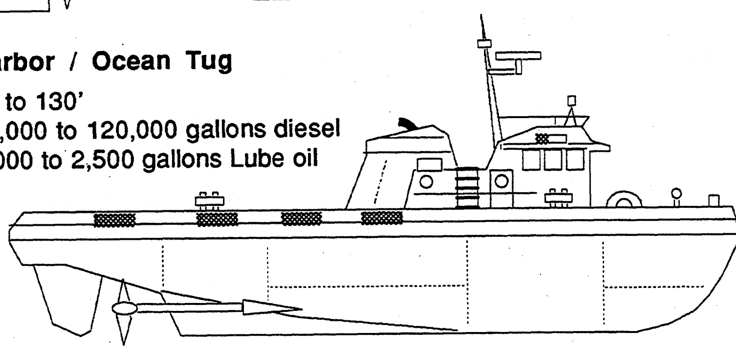
Harbor / River Tug

60 to 125'
35,000 to 60,000 gallons diesel
650 to 1,500 gallons Lube oil



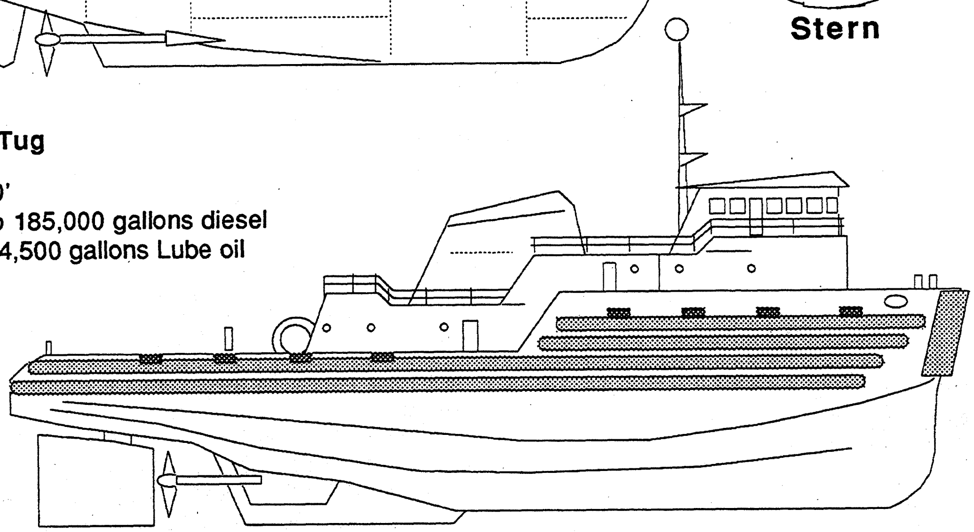
Harbor / Ocean Tug

90 to 130'
50,000 to 120,000 gallons diesel
1,000 to 2,500 gallons Lube oil



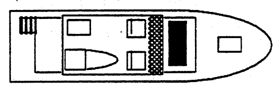
Ocean Tug

90 to 150'
90,000 to 185,000 gallons diesel
1,500 to 4,500 gallons Lube oil



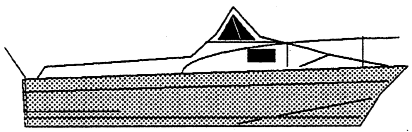
Pleasure Craft

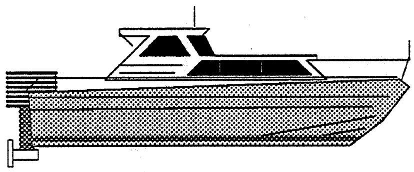
Average Fuel Capacities on Pleasure Craft

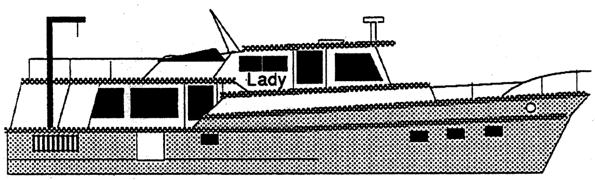


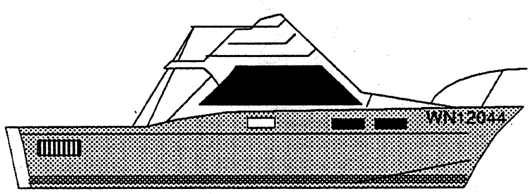
POWER VESSELS:

LENGTH (feet)	FUEL (gal) CAPACITY	(TANKS)
Runabouts		
12 to 20	6 to 20**	1 or 2
Day Cruisers		
18 to 26	30 to 50 **	1 or 2
Cruising Vessels		
25 to 33	45 to 120 **	1 or 2
34 to 41	60 to 225 *	2 to 4
42 to 48	200 to 650 *	2 to 4
49 to 65	450 to 1200 *	4 to 6
over 65'	800+ Diesel	4 and up
Sport Fishing		
22 to 30	60 to 125 **	1 or 2
31 to 40	75 to 250 **	2 to 4
41 to 60	200 to 800*	4 to 8



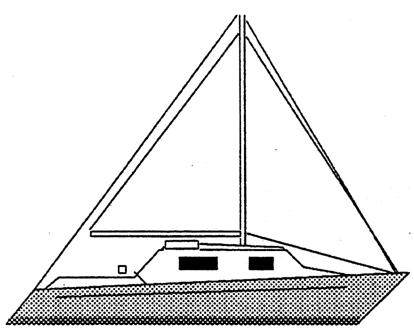






Racing craft
Generally are inshore and carry minimal fuel due to weight restrictions for speed.

Sailing Vessels



Sailing Vessels	
20' to 32'	18 to 35**
33' to 45'	30 to 120 *
46' to 65'	100 to 250*
over 65'	150 to 800 *

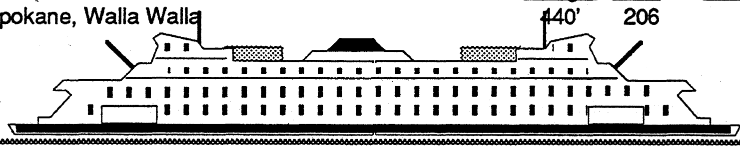
* Usually carry diesel fuel.
** Outboard powered vessels usually use a gasoline/oil mixture and carry from 1 to 20 gallons of fuel.

Northwest Boat Manufacturers:
Tollycraft Yachts (206) 423-5160
Bayliner Marine Corp. (360) 435-5571
Sea Ray Yachts (206) 284-3800
Nordic Tugs (pleasure) (360) 757-8847

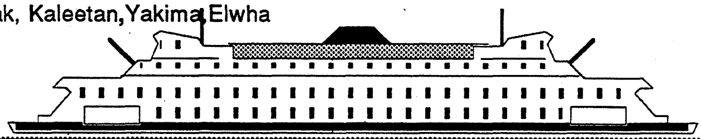
Washington State Ferries

There are five major classes of ferries within the Washington State Ferry System.

Class / Vessels	Length	Cars	Passengers	Diesel Fuel Cap(gal)	# of Tanks
JUMBO CLASS: Spokane, Walla Walla	440'	206	2000	130,000	4

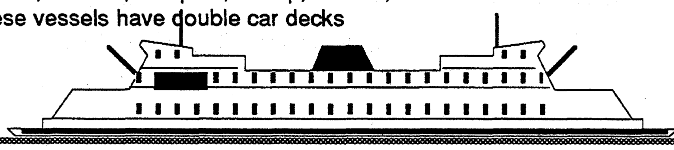


Class / Vessels	Length	Cars	Passengers	Diesel Fuel Cap(gal)	# of Tanks
SUPER CLASS: Hyak, Kaleetan, Yakima, Elwha	382'	160	2500	70,000	3

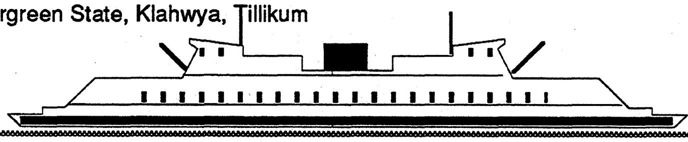


Class / Vessels	Length	Cars	Passengers	Diesel Fuel Cap(gal)	# of Tanks
ISSAQUAH CLASS: Chelan*, Sealth*, Issaquah, Kitsap, Kittitas, Cathlamet	328'	100/130*	1200	100,000	4

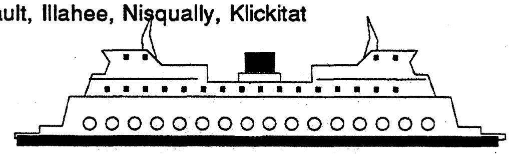
*These vessels have double car decks



Class / Vessels	Length	Cars	Passengers	Diesel Fuel Cap(gal)	# of Tanks
EVERGREEN STATE CLASS: Evergreen State, Klahwya, Tillikum	310'	100	1200	30,000	2

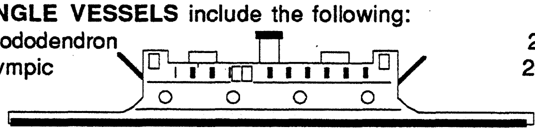


Class / Vessels	Length	Cars	Passengers	Diesel Fuel Cap(gal)	# of Tanks
STEEL ELECTRIC CLASS: Quinault, Illahee, Nisqually, Klickitat	256'	75	800	9,000	2

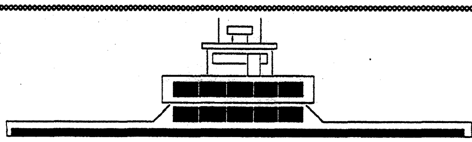


SINGLE VESSELS include the following:

Vessel	Length	Cars	Passengers	Diesel Fuel Cap(gal)	# of Tanks
Rhododendron	227'	65	546	9,000	2
Olympic	207'	55	605	9,000	2

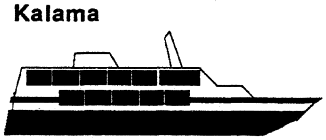


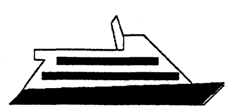
Vessel	Length	Cars	Passengers	Diesel Fuel Cap(gal)	# of Tanks
Hiyu	162'	40	200	12,000	2



PASSENGER ONLY VESSELS:

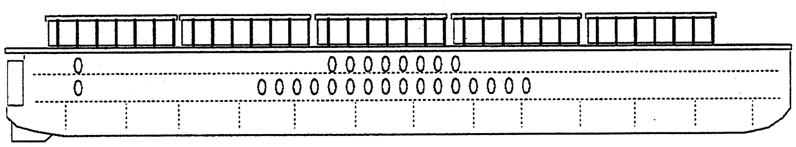
Vessel	Hull	Type	Diesel Fuel Cap(gal)	# of Tanks
Tyee	Catarmaran Hull (Twin Hulls)	Small, Passenger only	2,000	2
Skagit, Kalama		Large, Passenger only	3,000	2





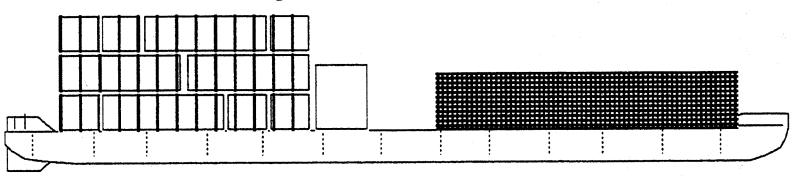
General Cargo and Petroleum Barges

Ocean Double & Triple Deck Cargo Barges



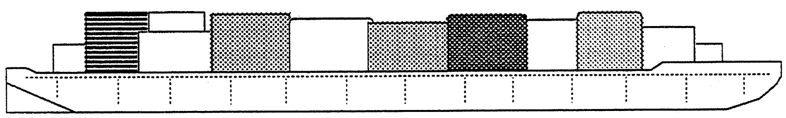
200' to 450'
Hauls rail cars and trailers
Tank capacity up to 10,000 bbls
(420,000 gals)

Covered House barges



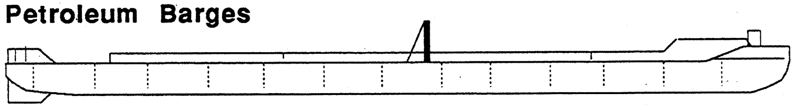
250' to 450' in length
Covers cargo that can be damaged at sea. Tank capacity up to 16,000 bbls (672,000 gals)

Dry Bulk Barge



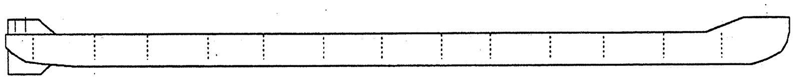
350' to 430' in length
Hauls dry bulk general cargo
Has tanks for general liquid cargos from 50,000 to 150,000 bbls (2,100,000-6,300,000 gals)

Petroleum Barges



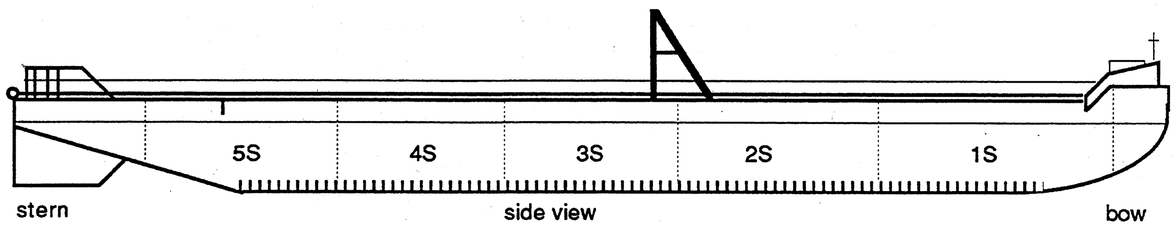
100' to 450' in length
Hauls petroleum products
10,000 to 200,000 bbls
(420,000-8,400,000 gals)

General Cargo Barges



50' to 250' in length
Hauls general cargo, containers, modular units, drilling rigs, capacity to 20,000 bbls
(840,000 gals)

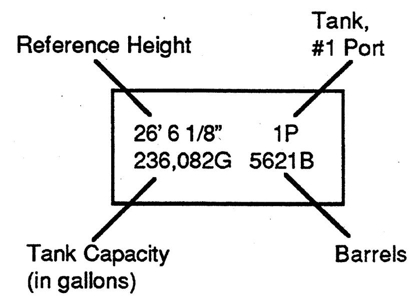
Petroleum Barge



Typical Petroleum Barge Cargo Tank Specification Sheet

Key:

IS = Inside Tanks (e.g. tanks 1CP and 1CS are #1 inside tanks)
OS = Outside Tanks (e.g. tanks 1P and 1S are #1 outside tanks)
G = gallons
B = barrels



bow tanks

Port Tanks	Center Port Tanks	Center Starboard Tanks	Starboard Tanks
26' 6 1/8" 1P 236,082G 5621B	27' 9 3/4" 1CP 259,560G 6180B	27' 10 1/8" 1CS 259,812G 6186B	26' 6 1/4" 1S 235,704G 5612B
26' 6 3/8" 2P 344,568G 8204B	27' 10 5/8" 2CP 365,820G 8710B	27' 10 5/8" 2CS 364,812G 8686B	26' 6 3/8" 2S 344,946G 8213B
26' 6 1/8" 3P 344,946G 8213B	27' 10 1/2" 3CP 365,568G 8704B	27' 11 0" 3CS 364,980G 8690B	26' 6 3/8" 3S 344,232G 8196B
26' 6 3/8" 4P 345,492G 8226B	27' 11 0" 4CP 365,862G 8711B	27' 11 1/2" 4CS 365,064G 8692B	26' 6 1/2" 4S 345,618G 8229B
21' 6" 5P 242,550G 5775B	21' 10 1/2" 5CP 249,060G 5930B	21' 11 3/8" 5CS 249,270G 5935B	21' 6 1/2" 5S 243,138G 5789B

stern tanks

Totals
6,237,084G
148,505B

Typical Petroleum Barge Transfer Procedures

1) The deck discharge containment system should consist of built-in drip pans and an ecology dam which encompasses the entire perimeter of the barge.

2) Scuppers must be plugged and watertight during any transfer operation. Scupper plugs may be removed as necessary to allow runoff of water only if a vessel crew member stands watch to close the scuppers in order to prevent an oil discharge.

3) The drip pans located under each cargo manifold are to be plumbed in to the barge cargo tanks to facilitate draining or removing discharged oil. Sorbent materials must be readily available, in case of an overflow, to minimize loss of oil. At no time may contents of the drip pan be allowed to spill into the water. The contents in drip pans must be drained before the vessels departure.

4) There will be at least one qualified tankerman, acting as the Person In Charge (PIC), on duty during oil transfer operations.

5) Person in Charge (PIC) must hold valid U.S.C.G. rating and be on deck during all critical operations.

6) Ensure the vessel's mooring is secure and capable of holding under unusual conditions.

7) An emergency shutdown, located near the discharge header, will stop the engine and pump when the shut down device is activated.

8) A continuous positive communication link must be established and periodically tested between the barge and the facility or vessel involved. One or more of the following communication methods must be used (intrinsically safe hand-held portable radios, sound powered telephones or hailing devices, verbal, visual).

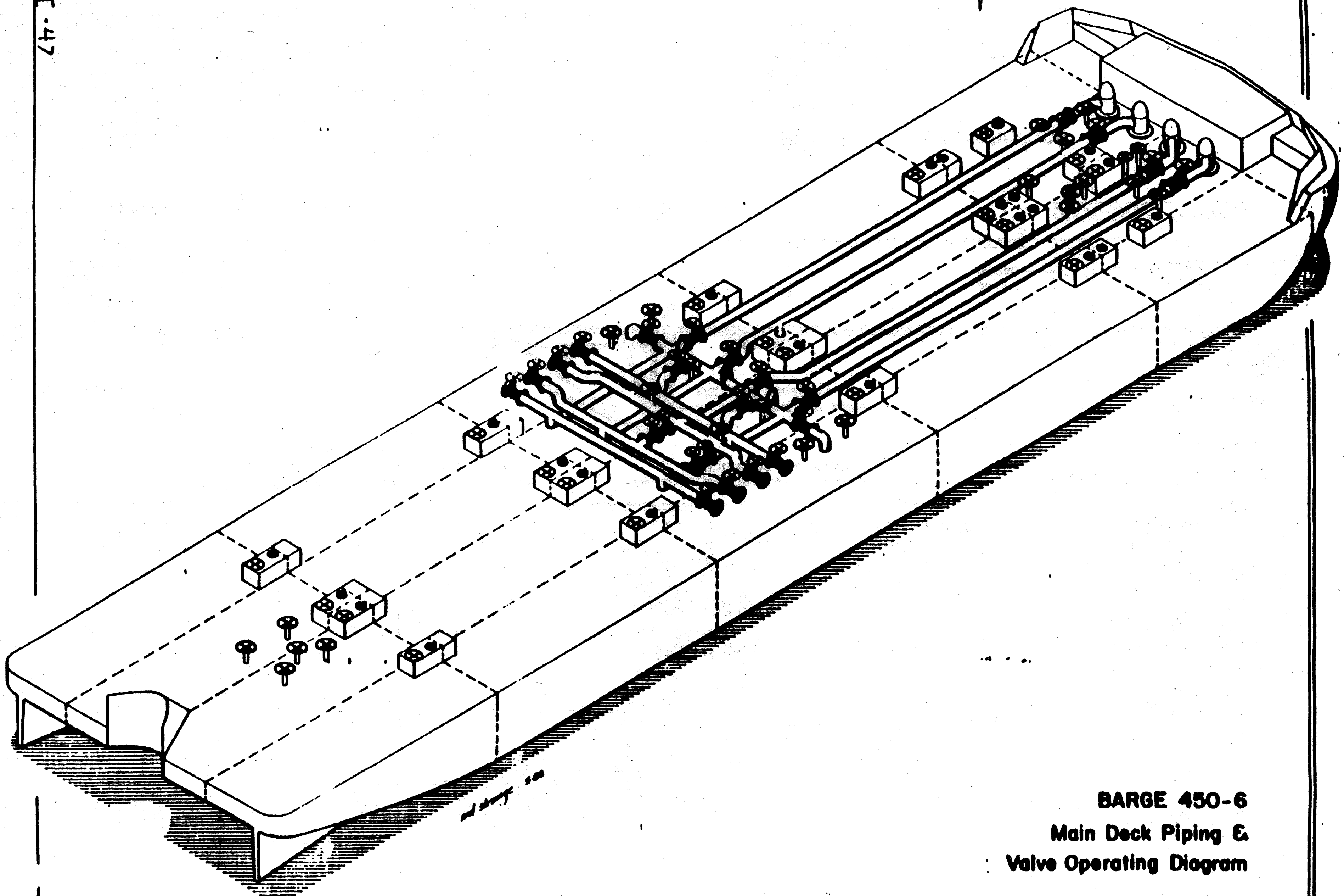
9) Ship and shore personnel should be clearly identifiable whenever possible.

10) Constant attention must be paid during the topping off process to avoid overfilling a tank. Tanks may be topped at reduced rates and/or connected to a spill tank.

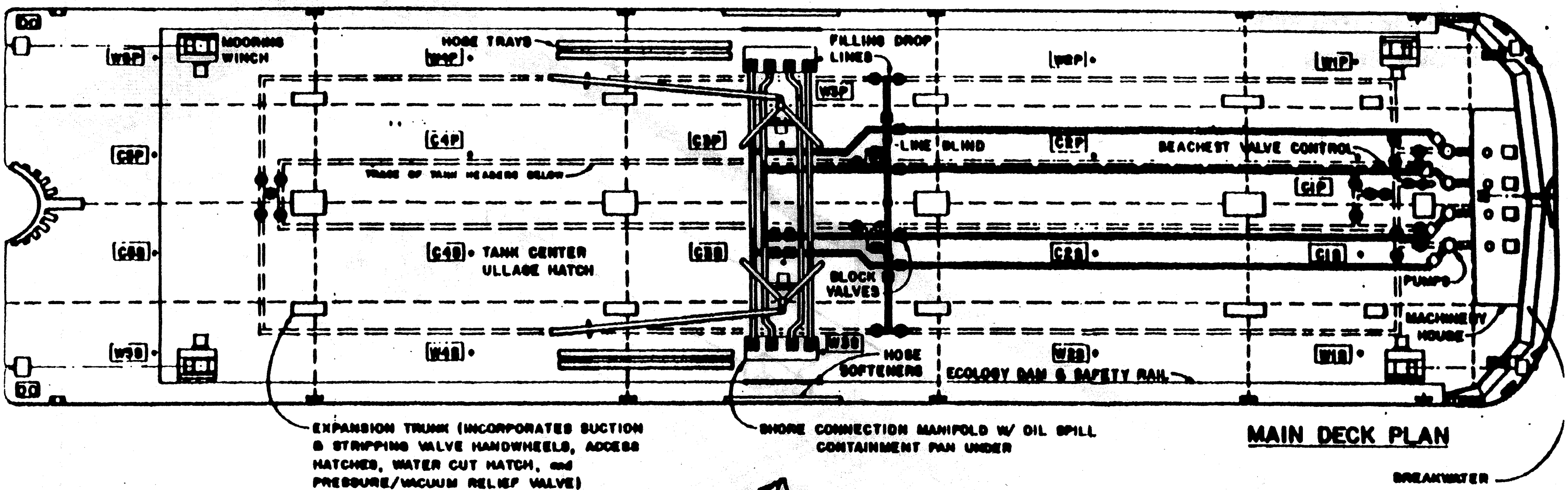
11) Upon completion of any transfer or closure of any valve located on the transfer system, all valves will be lashed in the closed position.

12) If a spill occurs:

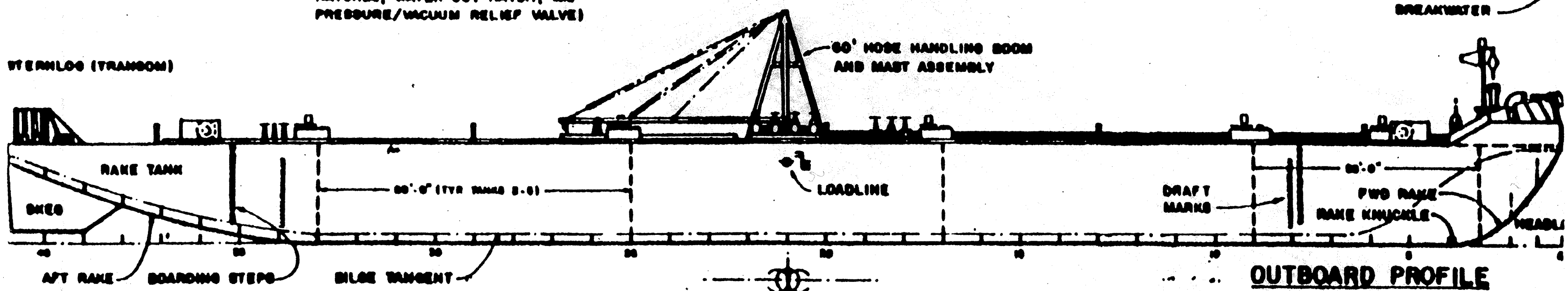
- a) stop all transfer operations
- b) locate spill source and secure if possible
- c) eliminate source of ignition, ensure personnel safety, secure vessel
- d) stop flow of oil into water, use absorbent material or oil pads
- e) initiate immediate containment methods using boom, etc..
- f) notify terminal supervisor or vessel master
- g) notify local company dispatch office, ensure Federal/State agencies are notified.



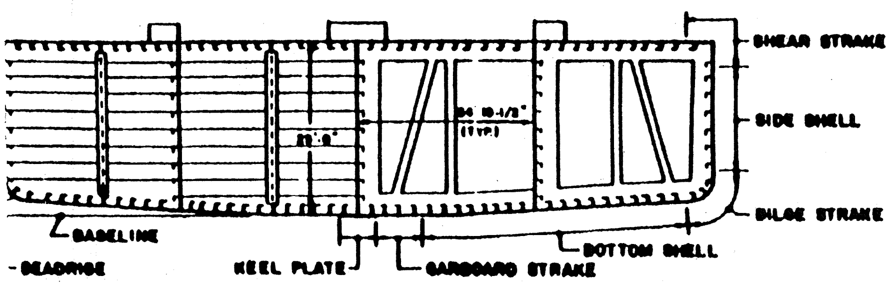
BARGE 450-6
Main Deck Piping &
Valve Operating Diagram



MAIN DECK PLAN



OUTBOARD PROFILE



TYPICAL MIDBODY SECTION

PRINCIPAL CHARACTERISTICS

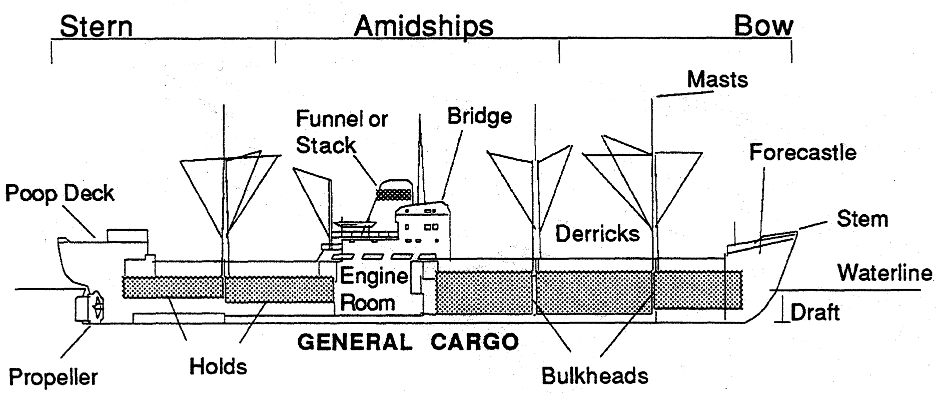
LENGTH OVERALL	400'-0"
BREADTH	[illegible]
DEPTH	[illegible]
DRAFT (MAXIMUM OCEAN SERVICE)	18'-10 1/2"
DEADWEIGHT TONNAGE	16,200 Long Tons
CAPACITY (GASOLINE at 60°F. TO LOADLINE)	140,000 Bbls

BARGE 450-6 GENERAL ARRANGEMENT & NOMENCLATURE

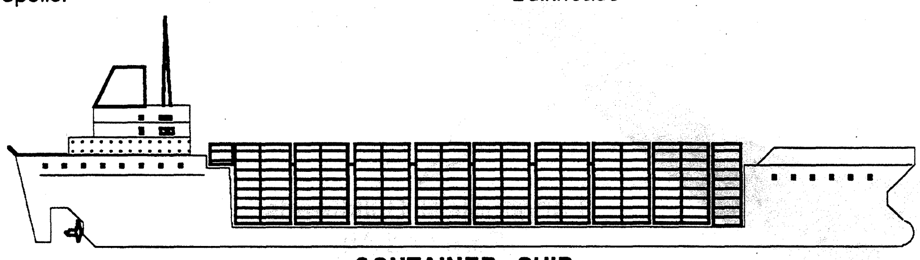
Ships

Fuel stowed onboard a ship to power it's engines & generators is typically referred to as "bunker fuel". Information on the bunker fuel or cargo carried onboard can be found in the ships logs (e.g., oil transfer log, oil record book, MARPOL oil records). Typically the vessel Master (Captain) or Chief Engineer is a good source of this information.

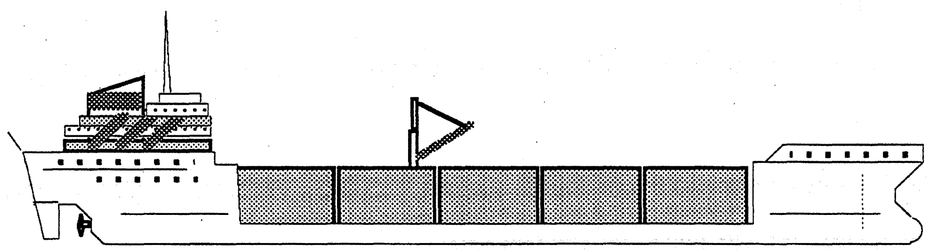
Typical bunker oil quantities for oceangoing ships: 50,000 to 150,000 bbl (2,100,000 to 6,300,000 gals)



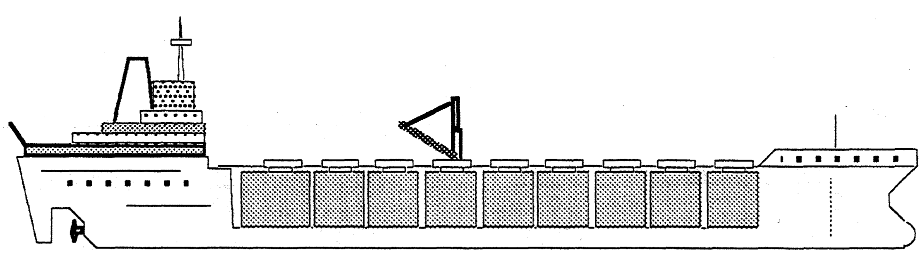
GENERAL CARGO



CONTAINER SHIP

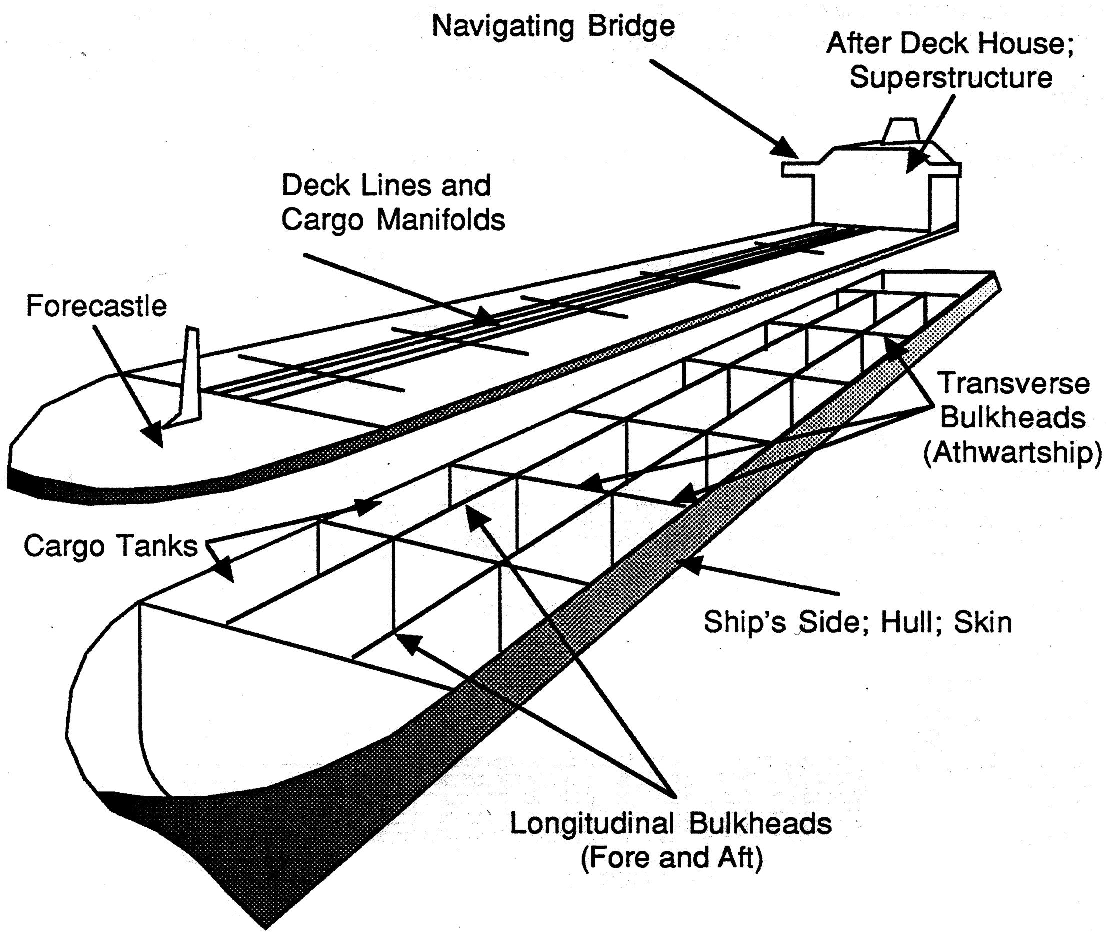


TANKER



DRY BULK HAULER

Layout of Typical Oil Tanker



source: Petroleum Tankship Operations, Arthur McKenzie, Tanker Advisory Center, Inc., New York, NY

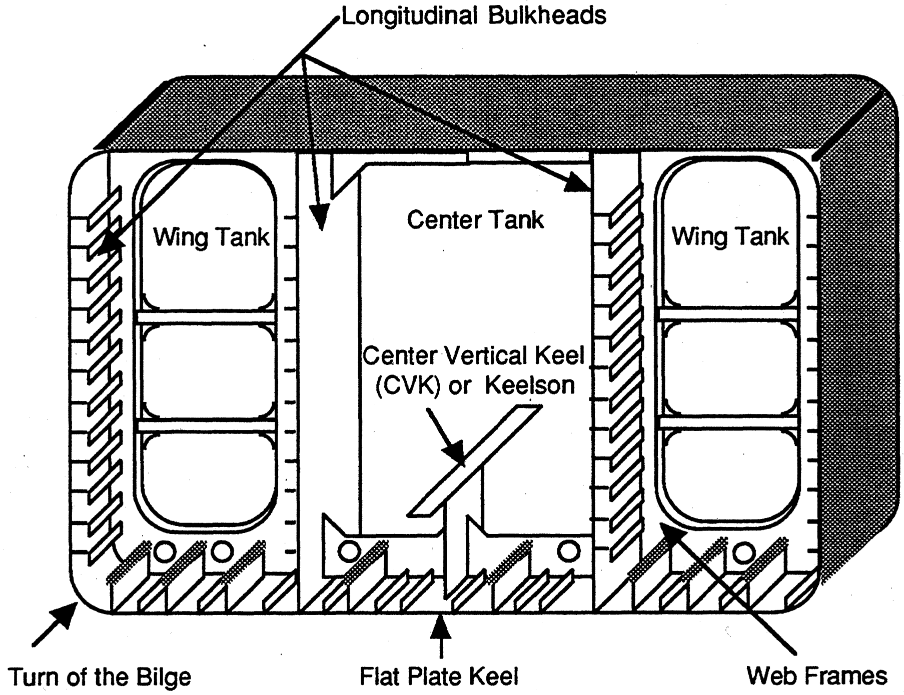
Cargo Capacity for Oil Tankers common to Puget Sound: (source, U.S.C.G., Vessel Inspection, Seattle)

60,000 DWT to 125,000 DWT (18,471,600 to 38,482,500 gals)

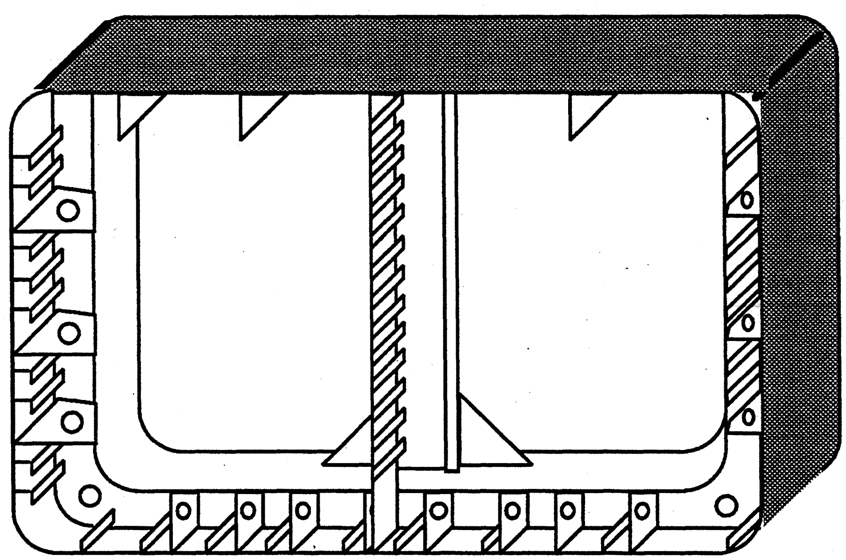
Comparison of oil tanker capacities to length: (source - General Electric brochure 750301, Tanker Registry 78)

Name	length in feet	DWT	capacity in barrels (gallons)
Eastern Sun	641	30,252	224,000 (9,408,000)
Texas Sun	752	50,864	364,800 (15,321,600)
Mediterranean Sun	889	134,835	1,027,000 (43,134,000)
Atlantic Sun	1,117	255,850	1,800,000 (75,600,000)
Esso Atlantic	1,200 (approx.)	508,731	3,762,000 (158,004,000)

Cross Section of Typical Single Hull Tanker



Cross Section of Typical Double Hull Tanker



source: Petroleum Tankship Operations, Arthur McKenzie, Tanker Advisory Center, Inc., New York, NY

3. Estimating Volume from Spill Source

B. Facility Sources

Facilites

Spill Volume Estimation Checklist for Facility Tanks:

1. **Collect information (for example:)**
   - Type of tank
   - Identification markings, numbers, description
   - Company name
   - Documentation (transfer logs, inventory statements, etc.)
   - Interview facility or transfer personnel
   - Take photos of scene, tank(s)
2. **Determine volume present in the tank prior to spill**
   - maximum volume will be the maximum volume of the tank
   - subtract any oil used or discharged since the tank was last filled
   - use Manual Gauging Checklist when attempting gauging
3. **Determine post-spill volume in the tank**
   - off load the tank into a stable container of known volume, gauge volume using Manual Gauging Checklist
4. **Calculate spill volume**
   - pre-spill volume minus post spill volume = spill volume

Spill Volume Estimation Checklist for Pipelines:

1. **Record Pipeline Identification**
    - Location, number, size, etc.
2. **Collect the following**
    - Pipeline owner, central office location
        - e.g. Olympic Pipeline, Renton
        - e.g. U.S. Oil, Tacoma
    - Responsible Party
    - L.A.C.T. documents
    - Pressure recording charts
    - Temperature charts
    - Flow rate charts
    - Gravitometer charts
3. **Have trained personnel evaluate documentation or call gauging contractor to evaluate documentation**

3. **If gauging contractor is called, Ecology staff should monitor calculations and maintain documentation.**

Manual Gauging Checklist

This checklist is provided as a guide for manual gauging of oil products. Gauging should only be done by trained competent personnel who are familiar with and using API/ASTM standard methods. The Manual Gauging Worksheet may be used to record the following information.

1. **Exit prompts - when to call gauging, measurement contractor**
   - When condition of tanks prevents gauging
     - Datum blocked or damaged
     - reference point missing or damaged
     - Tilting, listing, etc. makes strapping table unusable
   - When the gauging equipment is damaged or accuracy is doubtful
     - Gauge tape is stretched, crimped, cut, etc.
     - bobs are blunted and/or damaged
     - strapping is unreadable, or does not match tank
   - When facility personnel are untrained, or equipment for gauging is unavailable.
   - When technical nature of spill is outside of worksheet and responder capabilities
     - unusual facility systems
     - complex piping
     - complex pumping
     - complex valving
2. **Record Facility Tank Number**
   - Large numbers, stenciled on side of tank
     - note: numbers <u>often</u> indicate tank size and series, e.g. tank No. 80017, indicates an 80,000 barrel tank that is the 17th such tank built at this facility. Tank No. 1,205 indicates a 1,200 barrel tank that is the 5th tank in a series.
3. **Optional, record tank manufacturer, date, and serial No. from Tank Strapping Sheet. API 620 label can be used to confirm.**
4. **Gauging should not be attempted until the tank has been at rest and settled. This could range from 2 to 24 hours.**
5. **Record Auto Gauge Reading**
   - Varec gauge, typically read in feet and inches
   - Older, or smaller tanks may have different or no auto gauge
6. **Record Tank Temperature**
   - Thermometer on side of tank, should located near Varec auto gauge
7. **Proceed to gauging platform**
   - Should be at top of manway
   - Never climb down onto a floating roof. This is considered a confined space and requires training, and PPE. Floating roof tanks will be gauged from the top-of-manway gauging platform. A cord or cable will be attached from the gauging port to the platform.
8. **Identify location of gauging access**
9. **Note the tank reference height**
   - should be clearly stenciled near reference point

10. Establish whether "innage or outage" method will be used to gauge.
- Use innage when possible
- if datum plate is damaged or debris is blocking datum access, outage method will be used

11. If using innage method, water level can be checked at the same time
- Use the innage bob and tape. This is a round bob, pointed at the end about 4" to 6" inches in length.
- Coat innage bob with water indicating paste.
- Lower the bob and tape into the tank, keeping the tape in constant contact with the metal reference point. This prevents a static spark
- When the expected level, (read from the auto gauge) presents itself, place a light coat of oil indicating paste on the tape
- Stop lowering bob a few inches prior to contacting the bottom, slowly continue until the bob just "taps" the bottom.
- Retrieve and record oil and water levels to the nearest 1/8"
- Repeat the innage gauge again.
  - if the reading is the same, continue
  - if the reading is different, repeat until 2 gaugings are the same

12. Outage or Ullage method
- Use the outage bob and tape. This is a square bob squared at the end about 4" to 6" in length.
- Record the reference height of the tank.
- Coat the bob with oil indicating paste.
- Lower the bob on the tape while keeping it in constant contact with the metal reference point.
- Submerge the bob a few inches at the expected liquid level.
  - This will be the reference height minus the auto gauge reading.
- Record the tape cut at the reference point.
  - The "cut" is the tape reading at the reference point.
- Retrieve the bob and subtract the liquid level on the bob from the cut.
- Subtract the net cut from the reference height to determine liquid level.

13. Take and record product temperature
- Lower thermometer probe into the center of the liquid, at least 12" from the side of the tank. Preferably in the middle of the tank.
- Raise and lower the probe about a foot for one minute to stabilize product in the probe cup.
- Wait 5 minutes then retrieve and record the temperature.

14. Take product samples
- Using "thief" lower sample jar into lower 3 feet of liquid. Open thief and retrieve at a constant speed. Jar should be filled no more than 3/4. If it is full, empty and repeat procedure.
- If tank level is < 10' one sample is sufficient
- If tank level is 10 to 15', two samples will need to be taken. One from lower half, one from upper half.
- If tank level is > 15', three samples will need to be taken from each third of the tank.

15. **Evaluate Findings**
- Determine API gravity and Temperature from the sample
- Determine B.S.& W. (basic sediment and water)
- Convert API gravity to 60F
  - Use standard API gravity conversion table.
- Determine volume conversion factor
  - Use standard API volume conversion table
  - Find converted API gravity to 60F at the top of the table. Follow the matching column down to the tank temperature that you recorded at the far left column.
- From the strapping table for this specific tank determine gross product and water in tank
- Deduct the water from the gross product
- Multiply Gross product times volume conversion factor to get a corrected volume to 60F
- Multiply corrected volume times B.S.&.W to get a net volume for this tank.

16. **This process should be observed by a trained Ecology representative and performed by a Facility person, fully trained and familiar with the procedure.**
17. **Together with the facility person, record and concur on all measurements**
18. **Prior to leaving facility sign and have the facility person sign the finished gauging worksheet.**
19. **You both should agree on the volume of product in the tank.**

Washington State Dept. of Ecology
Manual Gauging Worksheet

CASE NUMBER [ ]

TANK INFORMATION OSC ______

TANK TYPE ❑ fixed facility ❑ marine vessel TANK NUMBER ______

TANK DESCRIPTION ❑ internal floating roof ❑ external floating roof ❑ cone roof ❑ other ❑ bunker (ships fuel) ❑ vessel cargo (internal) ❑ vessel cargo (external tank)

TANK STATUS ❑ damaged/leaking ❑ overfilled ❑ supply in transfer ❑ recovery ❑ other

SERVICE: Check applicable ❑ Gasoline ❑ Diesel/Jet ❑ Crude ❑ Asphalt ❑ AvGas ❑ GasOil ❑ fuel oil ❑ Slop ❑ Distillate ❑ other

LIST OTHER AFFECTED TANKS IN CONTAINMENT OR VESSEL:

Comments/ Notes:

note: fill out one sheet for each tank gauged

OPENING GAUGE All hand gauging must be checked at least twice. Accuracy will be to the nearest 1/8"

OPENING GAUGE: Auto: Ft. In. Hand: Ft. In. ______ Tank Temperature ______ °F

Observed API Gravity ______ @ ______ °F API Corrected Gravity to 60°F ______

Water Level: Ft. ______ In. ______ Gross H_2O (From Strapping) ______ B. S. & W ______ %

OPENING CONVERSION TO 60°F Indicate measurement unit, e.g. barrels, gallons, liters, etc.

1 Overall **GROSS** (From Strapping) ______

2 Minus Gross H_2O (From Strapping) ______

3 Temperature Correction Factor to 60°F ______

4 #2 X #3 = **GROSS** Corrected TO 60°F ______

5 B. S. & W. X #4 ______

[ ]

#4 Minus #5 = **NET** ↑

CLOSING GAUGE Accuracy of all math computation shall be to the nearest 100th

OPENING GAUGE: Auto: Ft. In. Hand: Ft. In. ______ Tank Temperature ______ °F

Observed API Gravity ______ @ ______ °F API Corrected Gravity to 60°F ______

Water Level Ft. ______ In. ______ Gross H_2O (From Strapping) ______ B. S. & W ______ %

CLOSING CONVERSION TO 60°F

1 Overall **GROSS** (From Strapping) ______

2 Minus Gross H_2O (From Strapping) ______

3 Temperature Correction Factor to 60°F ______

4 #2 X #3 = **GROSS** Corrected TO 60°F ______

5 B. S. & W. X #4 ______

[ ]

#4 Minus #5 = **NET** ↑

CALCULATIONS AND QUANTIFICATION

NET OPENING GAUGE OF TANK: ______ [ ]

NET CLOSING GAUGE OF TANK: ______ [ ]

NET DIFFERENCE OPENING/CLOSING THIS TANK ——→ [ ]

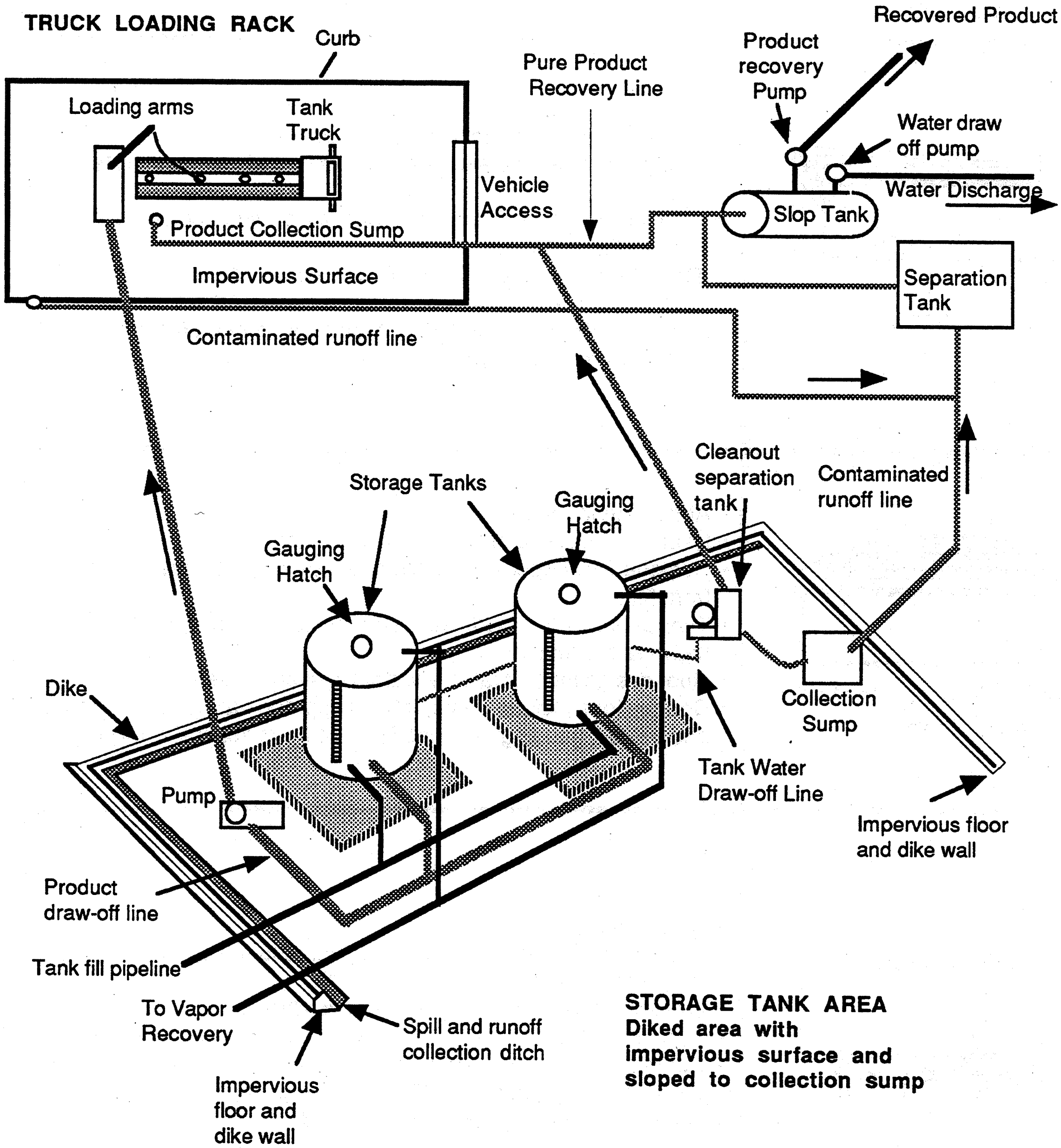
Comments/ Notes:

Facility/Vessel Signature: ______

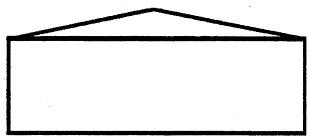
Date: ______

Ecology OSC Signature: ______

Selected Components of an Above-ground Storage Facility

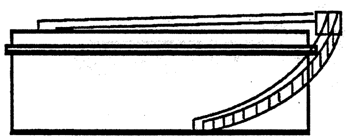


Atmospheric Tanks 0 to 0.5 psig (0 to 25mmHg) Design pressures



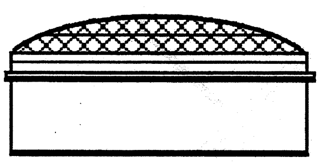
Coned Roof Tank

- Simplest of the atmospheric tanks.
- Usually large, field-erected steel structure, can reach 300 feet in diameter and 64 feet in height.
- Used for storage of liquids with low volatility.
- Typical contents include fuel oils like diesel and heating oils.
- Connections include vents, flame arrestor, inlet piping and valves, outlet piping and valves, gauging, and possibly fire foam application piping.



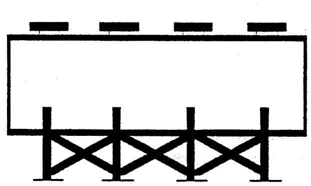
Exterior Floating Roof

- Atmospheric tank.
- Usually large, field-erected steel structure.
- Designed to reduce evaporation losses and increase protection from fire.
- Typical products include all grades of gasoline and products with similar volatility.
- Roof design includes rain water drainage system.
- Connections include vents, flame arrestor, inlet piping and valves, outlet piping and valves, gauging, roof drains, and possibly fire foam application piping.



Interior Floating Roof with Geodesic Dome

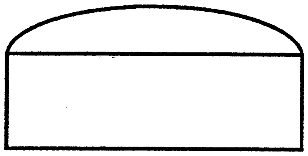
- Atmospheric tank.
- Usually large, field-erected steel structure.
- Designed to reduce evaporation losses and increase protection from fire.
- Typical products include all grades of gasoline and products with high vapor pressure.
- Roof design incorporates a vapor recovery system.
- Connections include vents, inlet piping and valves, outlet piping and valves, gauging, and possibly fire foam application piping.



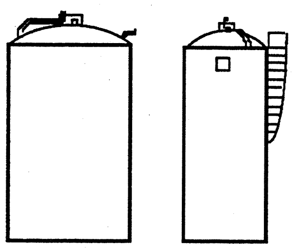
Horizontal Cylindrical Tank

- Atmospheric tank.
- Usually shop-erected and thus restricted to transportable sizes (e.g. 11 -12' diameter and 60' length).
- Used for storage of liquids with low volatility.
- Typical contents include fuel oils like diesel and heating oils.
- Connections include vents, flame arrestor, inlet piping and valves, outlet piping and valves, and gauging.
- Connections will typically be at the ends.

LOW PRESSURE 0.5 to 15 psig (26 to 760mmHg)



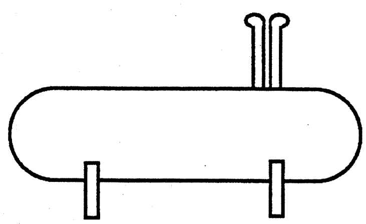
Hemispheroid Tank



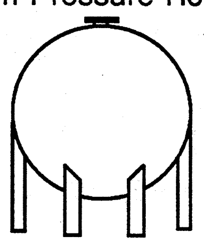
Dome Roof Tanks

- Low pressure tanks.
- Usually large field erected steel structure.
- Used for storage of liquids with high volatility.
- Typical products include all grades of gasoline and products with similar volatility.
- Connections include vents, flame arrestor, inlet piping and valves, outlet piping and valves, gauging, and possibly fire foam application piping.

HIGH PRESSURE >15 psig or (>760 mmHg)



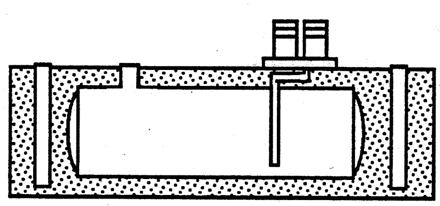
High Pressure Horizontal



High Pressure Spherical

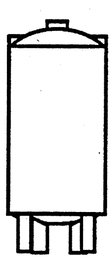
- High pressure tanks constructed from steel.
- Common at oil storage facilities, often called "bullets".
- Do not contain low volatility materials.
- Typical contents include propane, butane, LNG (liquefied natural gas, (LPG) liquefied petroleum gas, hydrogen, ammonia, and other liquefied gases.
- Tanks will include relief vents and product level gauges.
- Typically no permanent piping will be attached.

OTHER TANKS



Under Ground Storage Tank

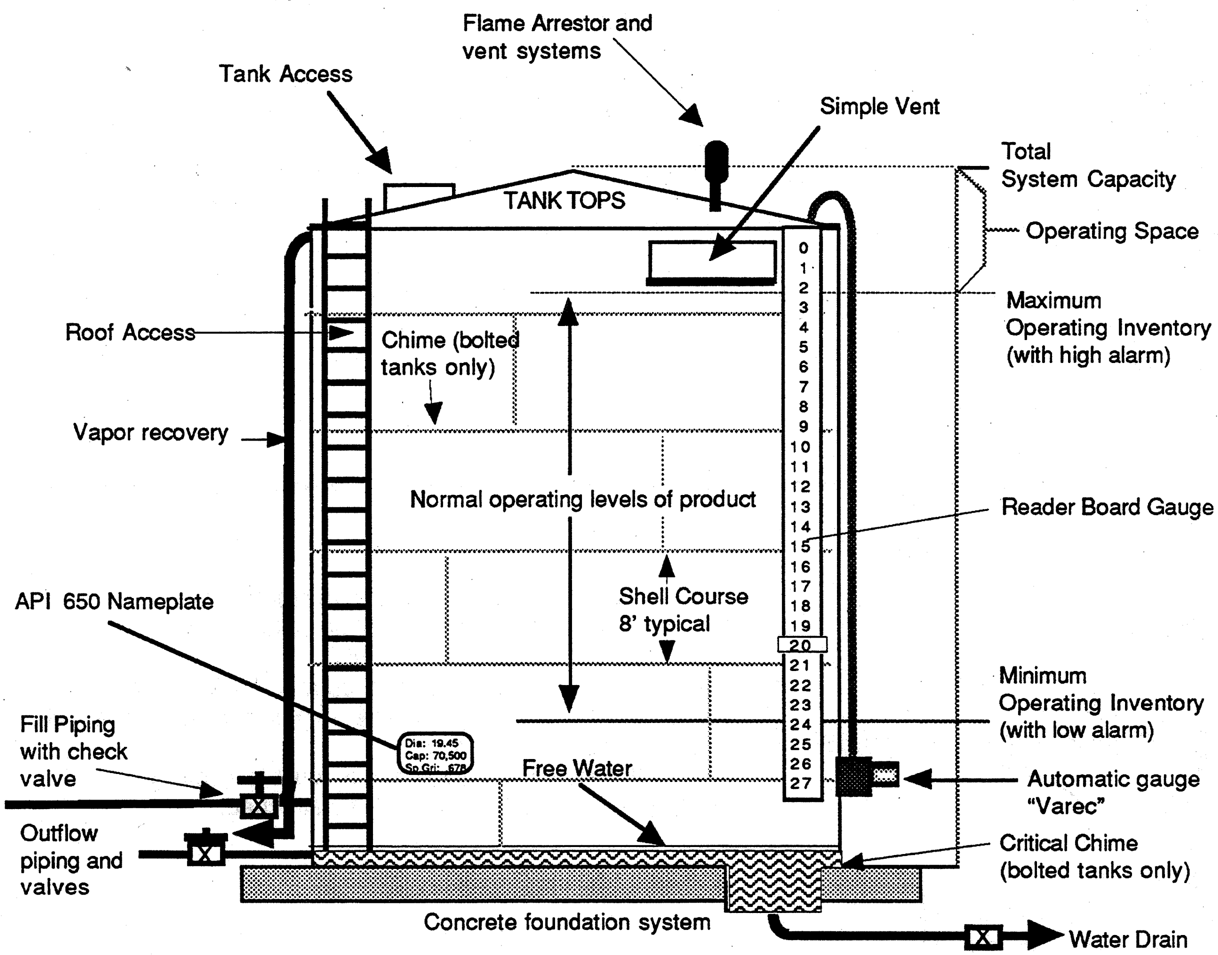
- <u>Atmospheric tank</u>
- Usually shop-erected and thus restricted to transportable sizes.
- Often constructed from reinforced plastic.
- Typical contents include both gasoline and diesel.
- Connections include vents, inlet piping and valves, outlet piping and valves, and gauging.
- Vent pipes will extend above nearby buildings.
- All connections and the tank are designed to withstand underground conditions.



Cryogenic Liquid Storage tank

- Heavily insulated <u>low pressure tank</u>
- Designed to maintain product temperatures < -200°F.
- Connections will include piping and valving typically at the bottom.
- Contents include liquid nitrogen, oxygen, argon, and similar cryogenics.
- Vapor seen venting is normal and necessary.

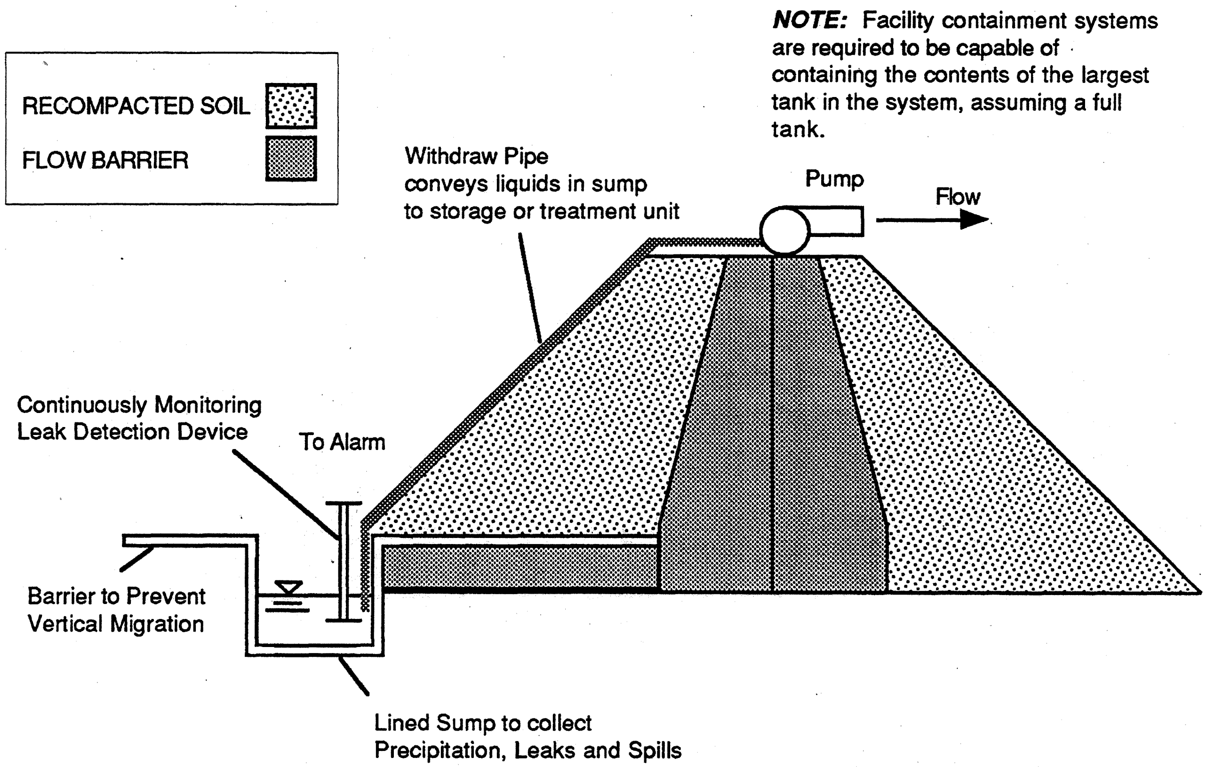
Atmospheric Tank Terms



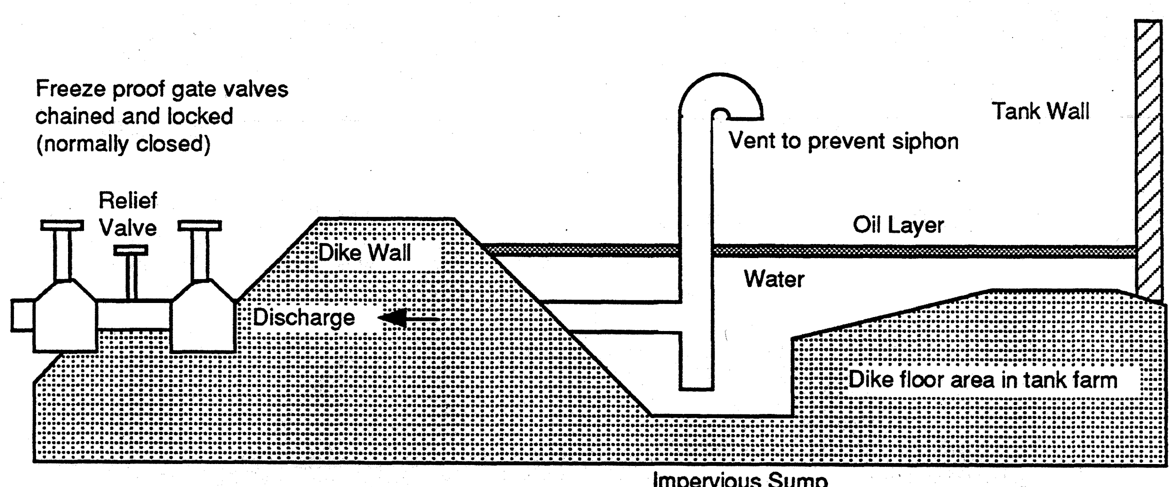
API Nameplate: "American Petroleum Institute". Requires a nameplate, that provides critical information specific to this tank, be permanently affixed, see nameplate description.
Check Valve: Allows flow of product in one direction. Can be installed in series for added protection.
Chime: The welded or bolted joint between shell courses, and between the shell and the tank bottom.
Flame Arrestor: Required when flammable vapors are present, and on all class 1 flammable liquids (like gasoline). Prevents flame from flashing back into tank.
Foundations: Specially designed to support the size and use of the tank. May include leak control and detection.
Gauges: Vary in design. Usually read in feet and inches which is converted to gallons using the strapping chart for a particular tank. Usually operate in conjunction with an internal float device.
Minimum Operating Inventory: Minimum product required to have an operable system and avoid problems i.e.: run out.
Operating Space: Space in the system which is needed to maintain a workable operating system and to provide safety.
Vents: Must be provided on all tanks to allow for filling and emptying. For non volatile liquids a vent without a flame arrestor would be allowed.
Valves: Vary as to size and configuration. Usually made of steel. Required as close to the tank outlets as possible.

Designed from API Standards 570, 620, 650, and Spec 6D

Dike Systems



Through the Dike Storm Water Discharge

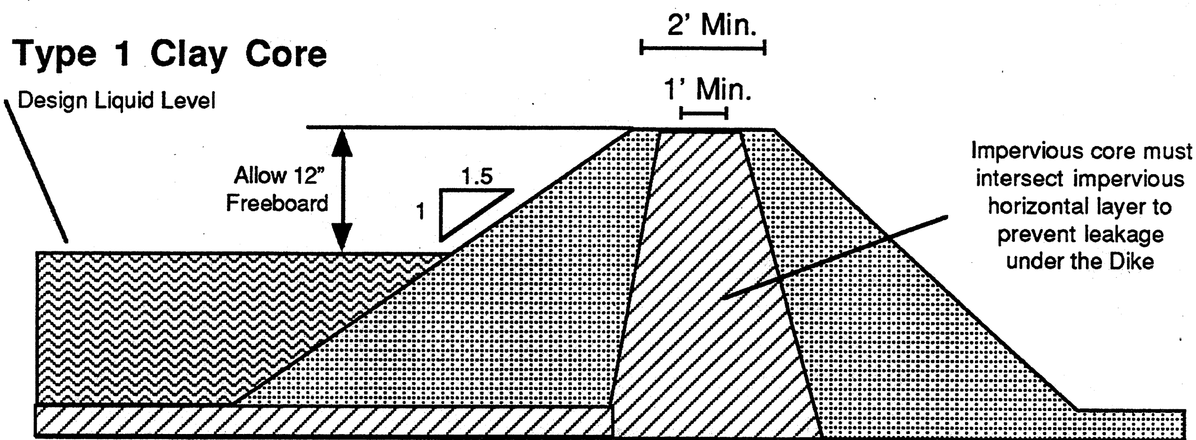


Earthen Dikes

NOTES

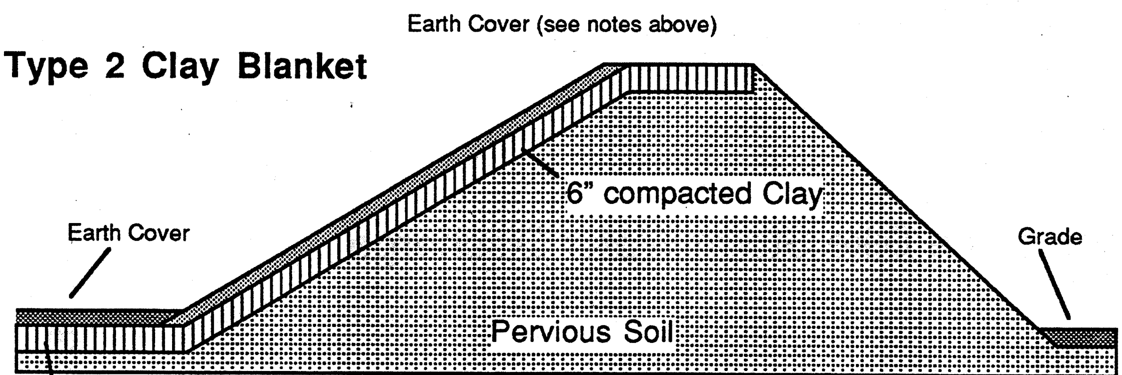
1. All earth material to be compacted in 6" lifts using mechanical equipment where possible.
2. Remove boulders, stones and large lumps of earth and protect surfaces from erosion.
3. Earth cover 12" thick recommended for clay blanket to retain moisture content.
4. Manufactured membrane must be installed according to manufacturers instructions.

Type 1 Clay Core



Cross Section

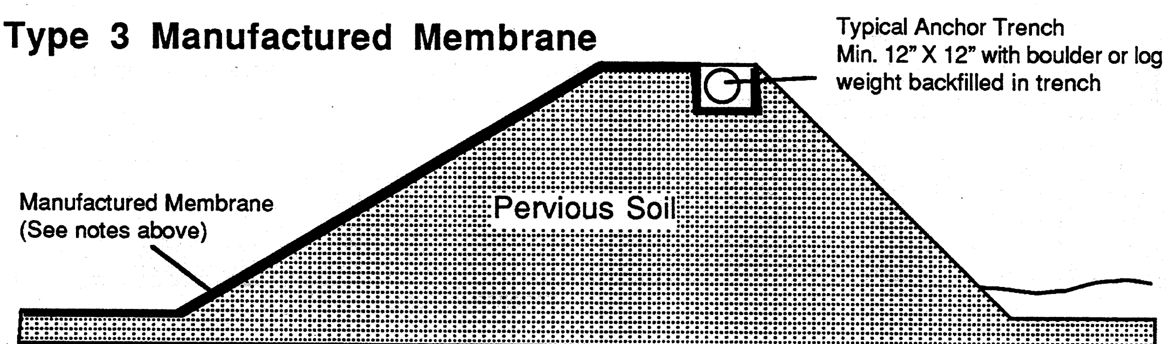
Type 2 Clay Blanket



Cross Section

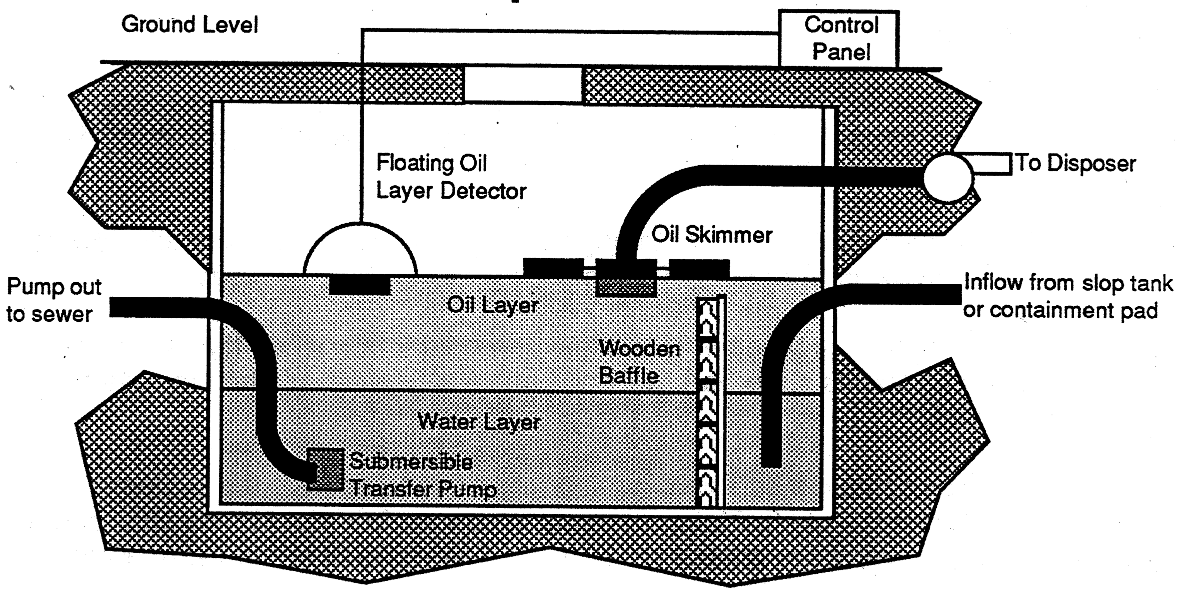
Impervious Clay Blanket to be continuous with or keyed into impervious floor

Type 3 Manufactured Membrane

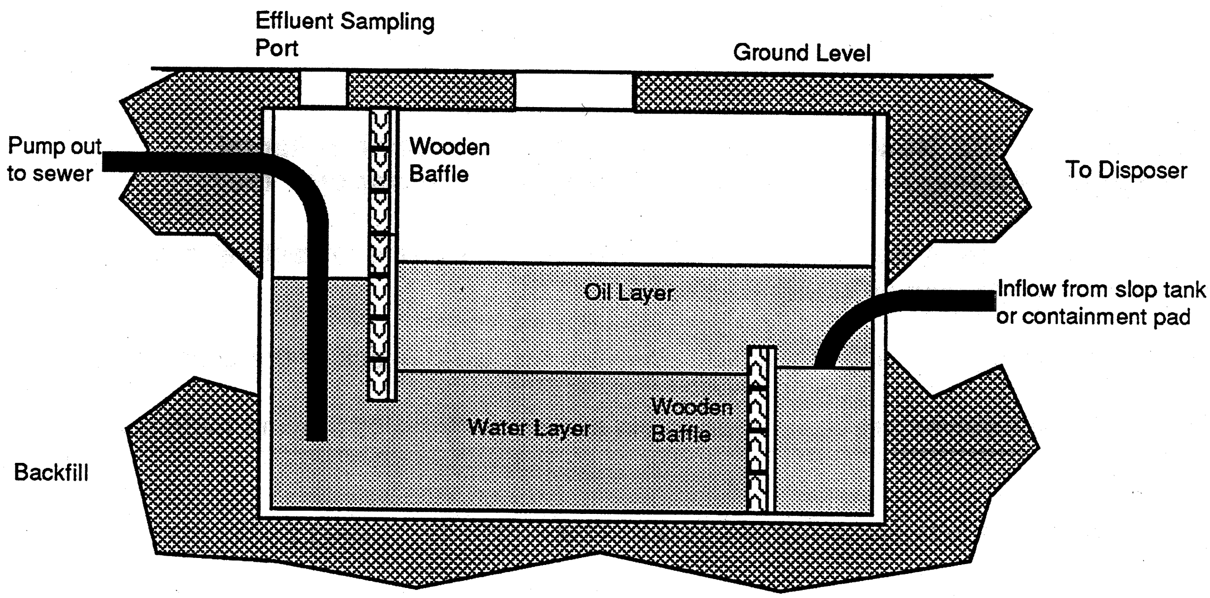


Cross Section

Separators



Low Velocity Separator



Low Cost - Low Velocity Separator

NOTE: Requires tank access for periodic oil layer removal.

Valves

- **NFPA 30 Requirements:**

  - Each connection to an aboveground tank through which liquid can normally flow shall be provided with an internal or an external valve located as close as practical to the shell of the tank.

  - Each connection below the liquid level through which liquid does not normally flow shall be provided with a liquid tight closure. This may be a valve, plug, or blind.

  - Valves at storage tanks may be other than steel or modular iron when the chemical characteristics of the liquids stored are not compatible with steel or when installed internally to the tank.

  - Piping systems shall contain a sufficient number of valves to operate the system properly and to protect the plant. Piping systems in connection with pumps shall contain a sufficient number of valves to control properly the flow of liquid in normal operation and in the event of physical damage.

  - Each connection to piping by which equipment such as tank cars, tank vehicles or marine vessels discharge liquids into storage tanks shall be provided with a check valve for automatic protection against backflow.

Excerpted from the New York State Department of Environmental Conservation *Aboveground Storage of Petroleum Products*, 1987:

- Valves should be steel, not cast iron. Cast iron valves are prone to fracture at low temperature and are not as strong as steel.

- Slow closing valves are recommended to prevent hydraulic shock to the piping system.

- "No Slam" check valves are recommended in discharge lines, to prevent hydraulic shock.

- Valves should be arranged so that they cannot be struck by passing traffic.

- Valves at the inlet and outlet of tanks should be of the normally "closed" variety to prevent flow out of the tank when other valving in the pipe system may be activated.

- Block valves installed on pressure lines must have a pressure relief system.

- Pipes in and out of valves should be directly supported. This will prevent loss of support when the valve is removed for maintenance.

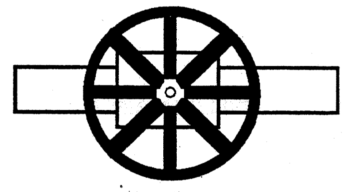
- Valves should never support the weight of the attached pipe.

Types of Valves

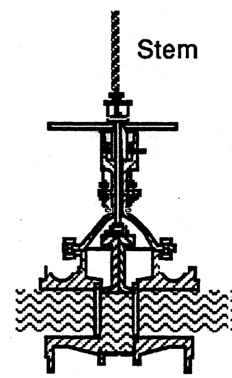
GATE VALVE

- The gate valve is the most common valve at facilities.
- It is made from steel and constructed to withstand high pressure.
- It is a slow operating valve which prevents hydraulic hammer, a sudden pressure rise which can result in system failure when the flow of fluid is stopped too rapidly.
- It can be used to regulate flow by partially closing.
- It can be equipped with an electric motor and operated from a remote location
- When the stem is "up" the valve is in the open position.
- When the stem is down, not visible, the valve is in the closed position.

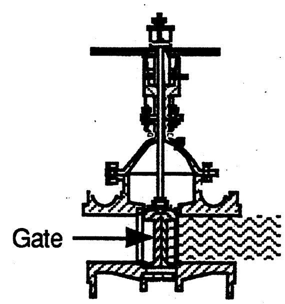
Gate Valves "Slow Closing"



Top View



Cutaway Side View
Valve Open

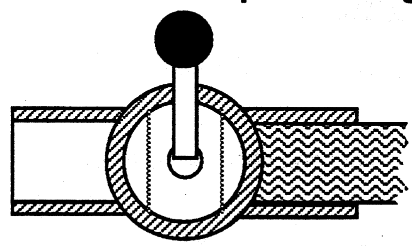


Cutaway Side View
Valve Closed

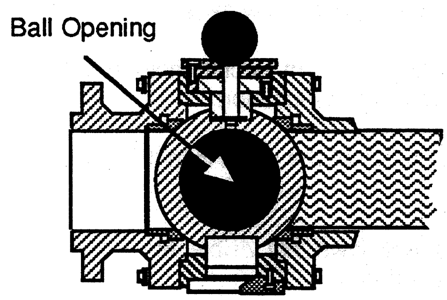
BALL VALVE

- The ball valve is a very common valve at facilities.
- Usually made of steel.
- It is generally found on small diameter piping with relatively low pressures.
- It is a very rapid action valve, therefore care must be taken to prevent hydraulic hammer.
- When the control handle is perpendicular to the pipe the valve is in the closed position.
- When the control handle is parallel to the pipe, the valve is in the open position.

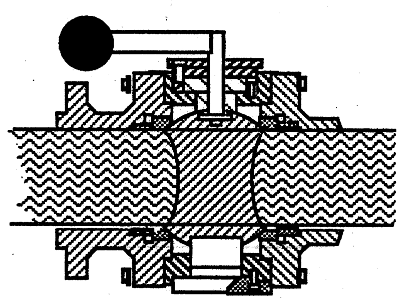
Ball Valves "Rapid Closing"



Top View
Valve Closed



Cutaway Side View
Valve Closed

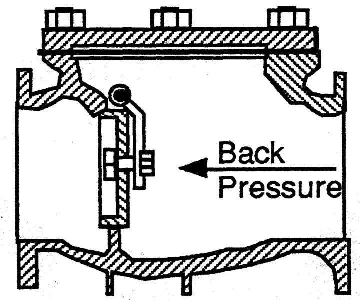


Cutaway Side View
Valve Open

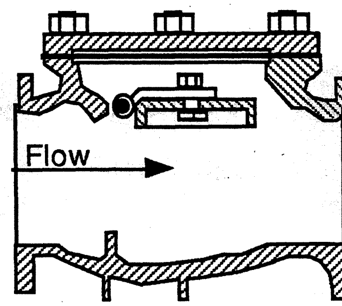
CHECK VALVE

- Designed to prevent back flow. Generally found in the fill line of aboveground tanks, where the head pressure would allow product to flow "back" down the pipe system.
- Allows liquid to flow in only one direction.
- Also required at critical points in the waste water and containment systems.

Check Valve "One Direction"

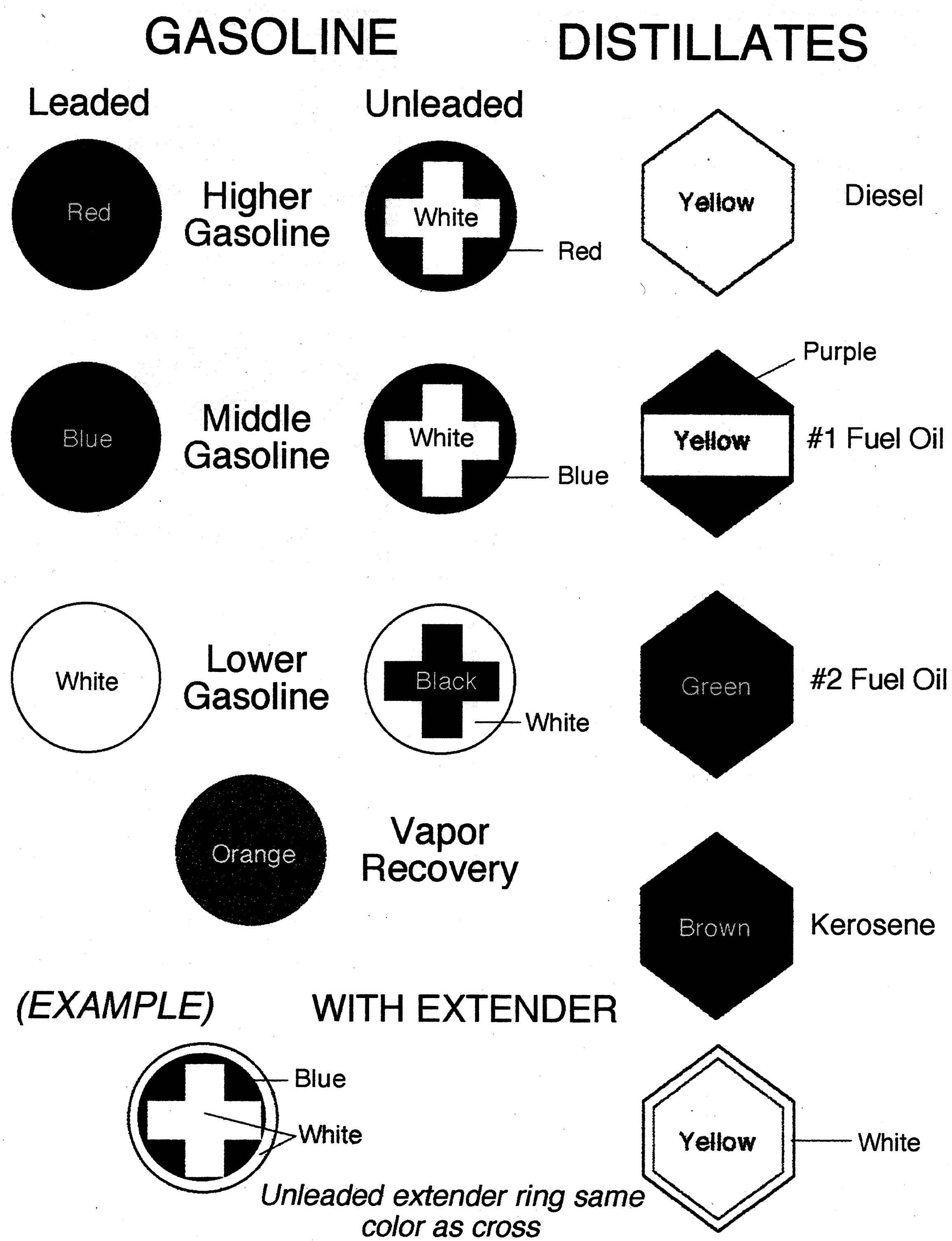


Cutaway side view
Valve Closed



Cutaway side view
Valve Open

API EQUIPMENT MARKING COLOR-SYMBOL SYSTEM



API Standard 620 Nameplate

API STANDARD 620

APPENDIX		YEAR COMPLETED	
EDITION		REVISION NUMBER	
NOMINAL DIAMETER		NOMINAL HEIGHT	
NOMINAL CAPACITY		DESIGN LIQUID LEVEL	
DESIGN SPECIFIC GRAVITY		MAXIMUM TEST LEVEL	
DESIGN PRESSURE		DESIGN METAL TEMP.	
PURCHASER'S TANK NO.		MAXIMUM OPERATING TEMP.	
MANUFACTURER'S SERIAL NO.		PARTIAL STRESS RELIEF	
MANUFACTURER			

SHELL COURSE	MATERIAL

- **Appendix:** applicable to this tank from API Standard 620 "Design & Construction of Large, Welded, Low Pressure Storage Tanks"
- **Edition:** Applicable edition and revision number of API Standard 620
- **Nominal diameter and height:** in feet and inches
- **Nominal capacity:** in barrels, at 42 gallons per barrel
- **Design liquid level:** in feet and inches
- **Design specific gravity:** the specific gravity of the liquid to be stored in the tank
- **Maximum test level:** Hydrostatic test level in feet and inches
- **Design pressure:** For gas of vapor space at the top of the tank, in pounds per square inch gauge (pisg)
- **Design metal temperature:** in degrees Fahrenheit.
- **Maximum operating temperature:** shall not exceed 250°F
- **Manufacturer info:** Name of manufacture and serial number that will identify specific tank
- **Partial stress relief:** if thermal stress relief is applied to a part the nameplate shall be marked "SR" and the part shall be identified on the manufacturer's certificate.

Also:

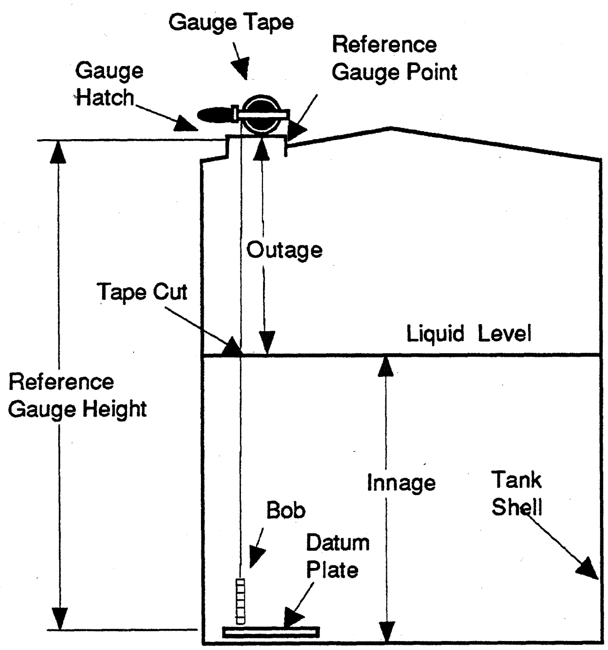
- The material specification number for each shell course is to be listed.
- Attached adjacent to a manhole or to a manhole reinforcing plate immediately above the manhole.

Estimated* Capacity of Cylindrical Tanks

Estimated Capacity per foot U.S. gallons = $\pi D^2 \div 4 \times 7.481$ (D = inside diameter in feet)
(For Example: a cylinder 12 feet in diameter would contain 846.08 gallons per foot of height)
*These estimates do not take internal tank features such as piping & supports into account.
Tank strapping tables must be used for more accurate volume calculations.

D(ft)	Gallons	Barrels	D(ft)	Gallons	Barrels	D(ft)	Gallons	Barrels
1	5.88	0.14	51	15282.34	363.87	101	59936.62	1427.06
2	23.50	0.56	52	15887.52	378.27	102	61129.36	1455.46
3	52.88	1.26	53	16504.46	392.96	103	62333.85	1484.14
4	94.01	2.24	54	17133.14	407.93	104	63550.10	1513.10
5	146.89	3.50	55	17773.58	423.18	105	64778.09	1542.34
6	211.52	5.04	56	18425.77	438.71	106	66017.83	1571.85
7	287.90	6.85	57	19089.71	454.52	107	67269.33	1601.65
8	376.04	8.95	58	19765.40	470.60	108	68532.57	1631.73
9	475.92	11.33	59	20452.84	486.97	109	69807.57	1662.09
10	587.56	13.99	60	21152.03	503.62	110	71094.32	1692.72
11	710.94	16.93	61	21862.97	520.55	111	72392.82	1723.64
12	846.08	20.14	62	22585.67	537.75	112	73703.07	1754.84
13	992.97	23.64	63	23320.11	555.24	113	75025.07	1786.31
14	1151.61	27.42	64	24066.31	573.01	114	76358.83	1818.07
15	1322.00	31.48	65	24824.26	591.05	115	77704.33	1850.10
16	1504.14	35.81	66	25593.96	609.38	116	79061.58	1882.42
17	1698.04	40.43	67	26375.41	627.99	117	80430.59	1915.01
18	1903.68	45.33	68	27168.61	646.87	118	81811.35	1947.89
19	2121.08	50.50	69	27973.56	666.04	119	83203.86	1981.04
20	2350.23	55.96	70	28790.26	685.48	120	84608.12	2014.48
21	2591.12	61.69	71	29618.72	705.21	121	86024.13	2048.19
22	2843.77	67.71	72	30458.92	725.21	122	87451.89	2082.19
23	3108.17	74.00	73	31310.88	745.50	123	88891.40	2116.46
24	3384.32	80.58	74	32174.59	766.06	124	90342.67	2151.02
25	3672.23	87.43	75	33050.05	786.91	125	91805.68	2185.85
26	3971.88	94.57	76	33937.26	808.03	126	93280.45	2220.96
27	4283.29	101.98	77	34836.22	829.43	127	94766.97	2256.36
28	4606.44	109.68	78	35746.93	851.12	128	96265.23	2292.03
29	4941.35	117.65	79	36669.39	873.08	129	97775.25	2327.98
30	5288.01	125.90	80	37603.61	895.32	130	99297.03	2364.21
31	5646.42	134.44	81	38549.57	917.85	131	100830.55	2400.73
32	6016.58	143.25	82	39507.29	940.65	132	102375.82	2437.52
33	6398.49	152.34	83	40476.76	963.73	133	103932.85	2474.59
34	6792.15	161.72	84	41457.98	987.09	134	105501.62	2511.94
35	7197.57	171.37	85	42450.95	1010.74	135	107082.15	2549.57
36	7614.73	181.30	86	43455.67	1034.66	136	108674.43	2587.49
37	8043.65	191.52	87	44472.14	1058.86	137	110278.45	2625.68
38	8484.31	202.01	88	45500.36	1083.34	138	111894.23	2664.15
39	8936.73	212.78	89	46540.34	1108.10	139	113521.77	2702.90
40	9400.90	223.83	90	47592.07	1133.14	140	115161.05	2741.93
41	9876.82	235.16	91	48655.54	1158.47	141	116812.08	2781.24
42	10364.49	246.77	92	49730.77	1184.07	142	118474.87	2820.83
43	10863.92	258.66	93	50817.75	1209.95	143	120149.40	2860.70
44	11375.09	270.84	94	51916.48	1236.11	144	121835.69	2900.85
45	11898.02	283.29	95	53026.96	1262.55	145	123533.73	2941.28
46	12432.69	296.02	96	54149.19	1289.27	146	125243.51	2981.99
47	12979.12	309.03	97	55283.18	1316.27	147	126965.05	3022.98
48	13537.30	322.32	98	56428.91	1343.55	148	128698.35	3064.25
49	14107.23	335.89	99	57586.40	1371.10	149	130443.39	3105.79
50	14688.91	349.74	100	58755.64	1398.94	150	132200.18	3147.62

Manual Gauging Terms



- **Observed Gauge Height.** The existing distance from the datum plate or tank bottom, to the reference gauge point.

- **Reference Gauge Point.** A point marked on the gauge hatch of a tank to indicate the position at which gauging shall be carried out. Gauging from the reference gauge point is crucial to the achievement of repeatability among individual gauge readings. This point may be a stenciled mark, a small fixed plate inside the gauge hatch, a narrow groove cut horizontally on the inside of the hatch, or the edge of a fixed metal arm which projects a short distance above the gauge hatch but does not contact the hatch.

- **Reference Gauge Height.** The standard distance from the datum plate or tank bottom to the reference gauge point. This distance should be clearly marked on the tank top near the gauge hatch.

- **Datum Plate.** A level metal plate located directly under the reference gauge point to provide a fixed contact surface from which liquid level measurement can be made.

- **Cut.** The line of demarcation on the measuring scale made by the material being measured.

- **Innage Gauge.** (Dip) The level of liquid in a tank measured from the datum plate or tank bottom to the surface of the liquid.

- **Outage Gauge.** (Ullage) The distance from the surface of the liquid in a tank to the reference gauge point of the tank (top of tank).

- **Opening Gauge.** An innage or outage gauge taken before the transfer of material into or out of the tank.

- **Closing Gauge.** An innage or outage gauge taken after the transfer of material into or out of the tank.

- **Free Water.** Water present in a tank which is not in suspension or dissolved in the petroleum. Free water should be gauged with the innage gauging procedure. Free water may also be gauged with the outage gauging procedure if the reference gauge height has not changed from the opening to the closing condition. If the reference gauge height has changed, the innage gauging procedure should be used.

- **Critical Zone.** The distance between the point where a floating roof is resting on its normal supports and the point where the roof is floating freely is referred to on a tank capacity table as the "Critical Zone".

- **Suspended Sediment and Water.** Or B. S. & W. (Basic Sediment and Water). The sediment and water which is entrained or suspended in the petroleum. Suspended sediment and water cannot be determined with innage or outage gauging procedures.

- **Tank Capacity Table.** (Tank Gauge Table or Strapping Table) is a table showing the capacities of, or volume in, a tank for various liquid levels measured from the datum plate or reference gauge point. The volume shown on the table may be in gallons, barrels, cubic meters, liters, or cubic feet.

- This page reserved for LACT ticket.

• This page reserved for pipeline pressure recording chart.

3. Estimating Volume from Spill Source

C. Highway Sources

Highway

Spill Volume Estimation Checklist:

1. **Collect information (for example:)**
   - License plate numbers
   - Identification numbers from the tank(s)
   - Company name
   - Cargo Shipping Papers (should be in the cab, within reach of the driver)
   - Records for when tank was last filled, when fuel was last transferred
   - Interview driver or operator
   - Capacity of the tank
   - Are there individual tanks or sections of a tank in one container?
   - Take photos of scene, tank(s)
2. **Determine volume present in the tank prior to spill**
   - maximum volume will be the maximum volume of the tank
   - subtract any fuel used or discharged since the tank was last filled
3. **Determine post-spill volume in the tank**
   - off load the tank into a stable container of known volume, gauge volume
   - estimate remaining fuel in tank using onboard gauging equipment
4. **Calculate spill volume**
   - pre-spill volume minus post spill volume = spill volume

Highway Vehicles(7)

Type of Vehicle	Fuel (gal)	Oil (gal)	Coolant (gal)	Hydraulic* (gal)	Type of Tank	MPG
Commercial Vehicles						
Trucks						
Ladder Truck	50	5 to 6	5 to 7	7 to 45	Frame	3 to 5
Fire Engine	50	5 to 6	5 to 7	7 to 15	Frame	3 to 5
Semi Truck(6)	75 to 450	5 to 6	5 to 7	7 to 9	Saddle/Step	8 to 10
Commercial Body(4)(6)	45 to 75	2.5 to 5	3 to 5	3.75 to 7	Saddle/Step	10 to 16
Pickup Truck Body(3)	35 to 40	1.5 to 2	2 to 2.5	2.5 to 3.75	Frame	12 to 20
Step Van(2)	35 to 40	1.5 to 2	2 to 2.5	2.5 to 3.75	Frame	10 to 18
Van Body(1)	22 to 40	1.5	2 to 2.5	2.5 to 3.5	Frame	11 to 16

Trailers

Day tanks for refrigerated trailers = 25 to 75 gallons, typically diesel

MC-306 (gasoline tankers) = typically 11,300 gallon capacity including bobtail & trailer

Type of Vehicle	Fuel (gal)	Oil (gal)	Coolant (gal)	Hydraulic* (gal)	Type of Tank	MPG
Bus						
Commercial						
Greyhound Type	145 to 170	6 to 8	5 to 10	7 to 9	Frame	6.5 to 7
Transit, Articulated	125 to 145	5 to 7	5 to 7	10	Frame	4 to 6
Transit, Gas, 28' to 40'	25	5 to 7	5 to 7	10	Frame	7 to 10
Transit, Diesel, 28' to 40'	100 to 125	5 to 7	5 to 7	10	Frame	5 to 7
School Van Type(1)	30 to 35	1.5 to 2	3 to 4	2.5 to 3.75	Frame	11 to 16
Large Bus Type	75 to 100	5 to 7	5 to 7	5 to 7	Frame	6.1
Medium, Conventional(4)	50 to 70	3 to 4.5	3 to 5	3 to 5	Frame	7.5
Pickup Trucks						
1 Ton	35 to 40	1.5	2. to 2.5	2.5 to 3.75	Frame	12 to 20 (5)
3/4 Ton	35 to 38	1.25	2. to 2.5	2.5 to 3.75	Frame	13 to 20 (5)
1/2 Ton	30 to 35	1.25	2. to 2.5	2.5 to 3.5	Frame	14 to 22 (5)
Small	13 to 22	1.25	1.5 to 2	2.5 to 3.5	Frame	18 to 30 (5)
Vans/Motorhomes						
Full Size	22 to 40	1.25	2. to 2.5	2.5 to 3	Frame	11 to 18 (5)
Mini Vans	18 to 27	1.25	2. to 2.5	2 to 2.5	Frame	15 to 26 (5)
Motorhome	35 to 120					
Sport Utility Vehicles						
Full Size (Suburban Type)	22 to 40	1.25	2. to 2.5	2.5 to 3	Frame	13 to 23 (5)
Mid Size (Bronco Type)	18 to 27	1.25	2. to 2.5	2 to 2.5	Frame	17 to 26 (5)
Passenger Car						
Full Size	22 to 26	1.25 to 1.5	2 to 2.5	2.5 to 3.75	Frame	15 to 30 (5)
Mid Size	16.5 to 22	1.25	2 to 2.5	2.5 to 3.5	Frame	17 to 36 (5)
Compact	14 to 16	1 to 1.5	1.5 to 2	2.0 to 2.5	Frame	18 to 40 (5)
Sub Compact	9 to 14	.75 to 1	1.5 to 2	1.5 to 2.0	Frame	14 to 45 (5)

*Hydraulic capacities assume the vehicle has an automatic transmission

(1) Van front with a storage or utility box on back, i.e. ambulance, tow truck, delivery van, small bus.

(2) UPS delivery van, mobile restaurants, tool trucks.

(3) Pickup truck front with a storage or utility box on back, i.e. ambulance, tow truck.

(4) Large full size Ford, GMC type front with a storage or utility box on back, i.e. Hertz, Ryder, Jartran.

(5) US DOE Fuel Economy Guide 1996.

(6) Some fuel capacities can be found stamped around the filler cap. Rule of thumb, 1 foot of tank length = 25 gallons of fuel. (Step and Saddle tanks)
Up to 5 or 6 tanks can be carried on the vehicle to equal the 450 gallon capacity.

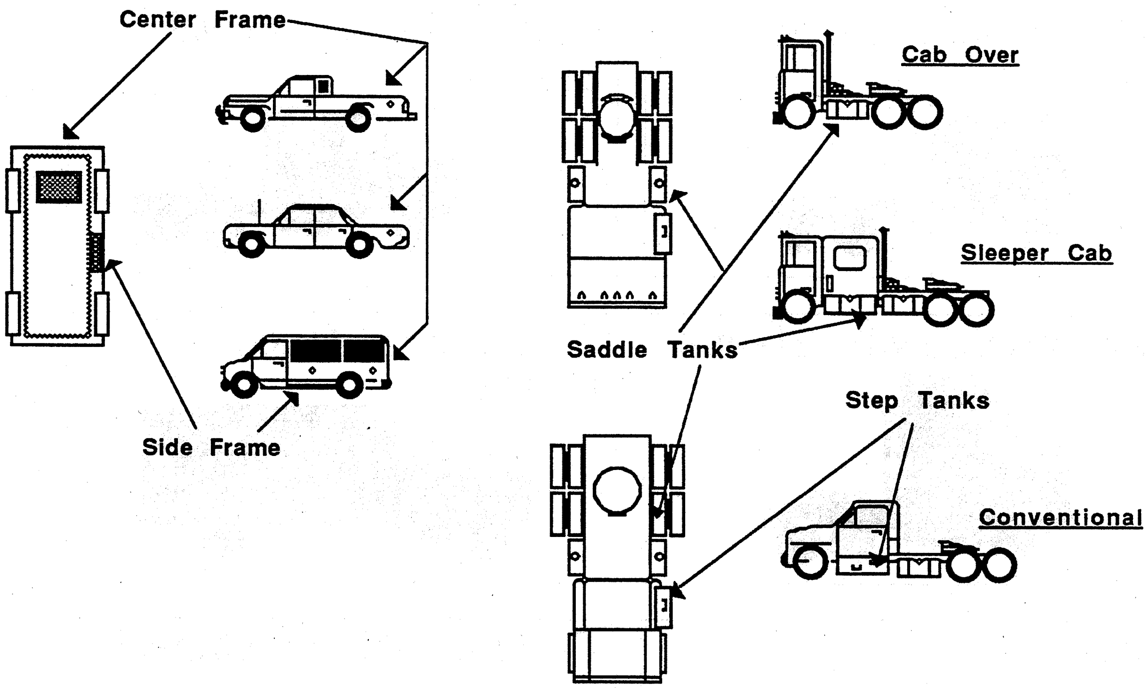
(7) Average from facilities polled.

Commercial body refers to truck bodies manufactured by either Ford, Dodge, Chevrolet, GMC or other manufacturers also known for manufacturing automobiles.

Semi-truck refers to large custom style trucks similar to those manufactured by Kenworth, Peterbuilt, Freightliner, Mack, International, and GMC & Ford cab over series trucks.

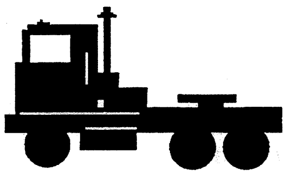
Car/Truck/Van — **Commercial/Semi Truck**

View from the Bottom | **View from the Side** | **View from the Bottom** | **View from the Side**

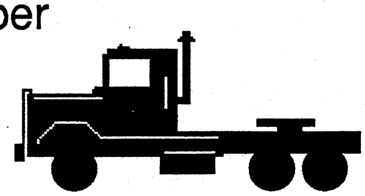


Highway Truck Silhouettes

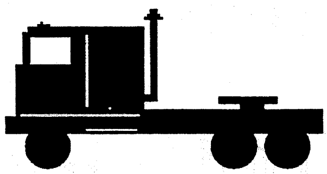
Cabover without Sleeper



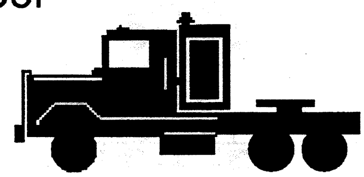
Conventional Cab without Sleeper



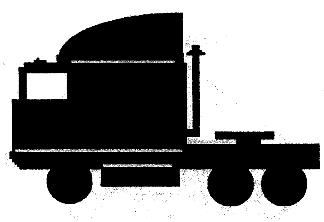
Cabover with Sleeper



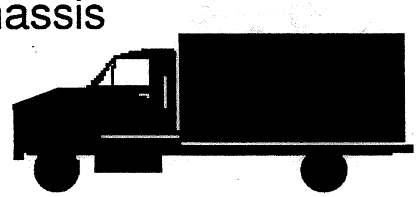
Conventional Cab with Sleeper



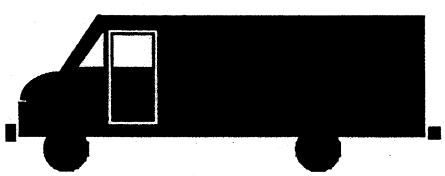
Cab Forward with Sleeper



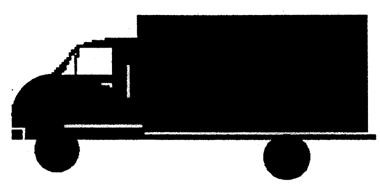
Commercial Truck Chassis



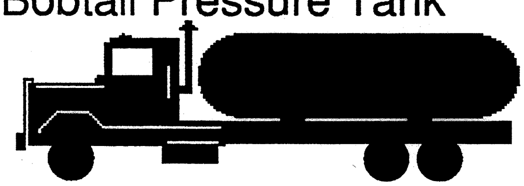
Step Van



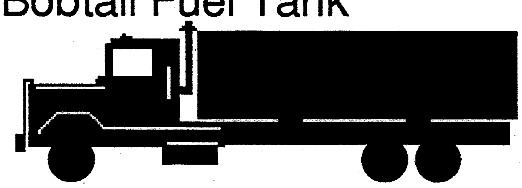
Commercial Van Chassis



Conventional Cab with Bobtail Pressure Tank



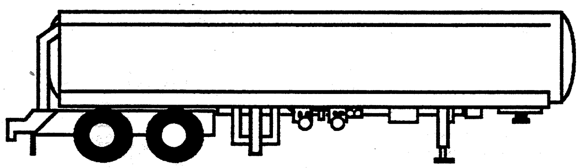
Conventional Cab with Bobtail Fuel Tank



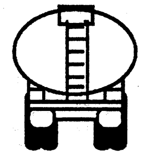
Common Highway Tank Trailers

Petroleum Containers

MC-306 or DOT 406 Atmospheric Pressure Tank Truck



Side View



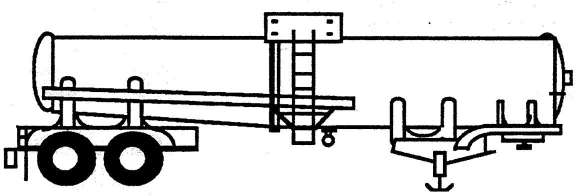
End View

Construction / Contents

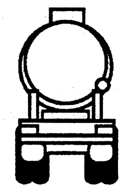
- Up to 11,300 gallons of liquids
- Less than 3 psi in tank
- Oval Cross section
- Plumbing on the bottom
- Aluminum or Steel Construction

- Gasolines, Fuel Oil etc.

MC-307 or DOT 407 Low Pressure Tank Truck



Side View



End View

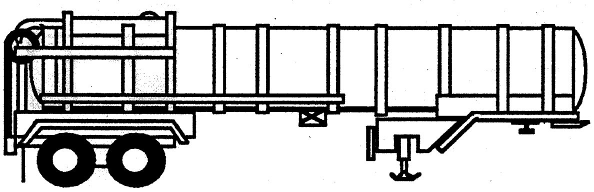
Construction / Contents

- Up to 7,000 gallons of liquid
- Pressures up to 25 psi.
- Circular Cross Section
- Stainless steel shell, can be Insulated

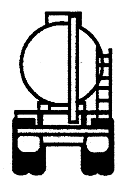
- Flammable and Combustible Liquids, Mild Corrosives, most Chemicals, Juices, food grade liquids.

Gas, Corrosive and Cryogenic Containers

MC-312 or DOT 412 Corrosive Cargo Tank Truck



Side View



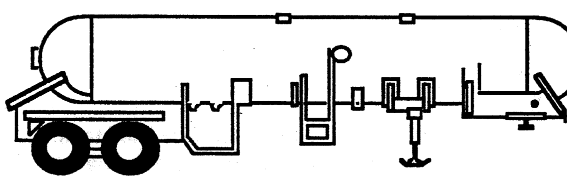
End View

Construction / Contents

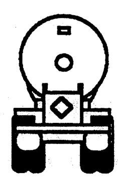
- Up to 6,000 gallons of strong Corrosives
- Not pressurized
- Circular Cross section with Reinforcing Ribs
- Can be Insulated

- Hydrochloric Acid, Muriatic Acid, Sulfuric Acid, Sodium Hydroxide Solution.

MC-331 High Pressure Gas Tank Truck



Side View



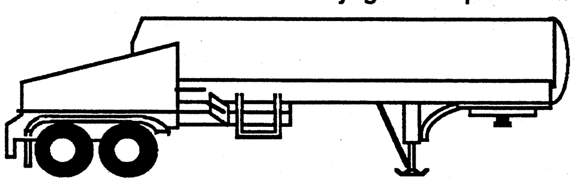
End View

Construction / Contents

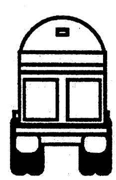
- 2,000 gallons ("Bobtail" truck, local delivery) •11,500 gallons Highway Cargo Truck
- Pressurized single shell
- Upper 2/3 painted white or reflective color

- LP gases and Anhydrous Ammonia.

MC-338 Cryogenic Liquid Tank Truck



Side View



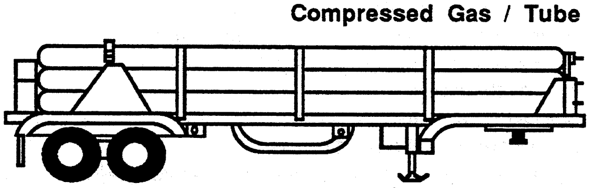
End View

Construction / Contents

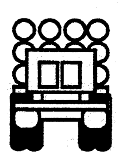
- Thermos Bottle design with flat ends
- Double shell with relief protection
- Valve housing in the rear

- LOX, Carbon Dioxide, Liquid Nitrogen

Compressed Gas / Tube Trailer



Side View



End View

Construction / Contents

- Cylinders are stacked and Manifolded
- 3,000 to 5,000 psi
- Manifold at rear

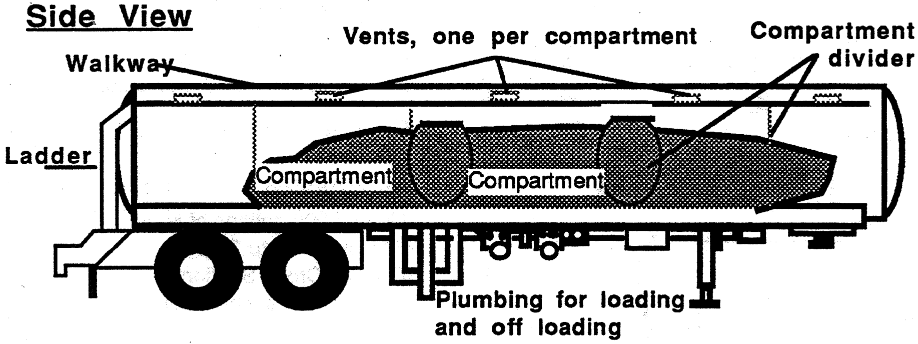
- Compressed gases, Oxygen, Nitrogen, Hydrogen.

Highway Petroleum Cargo Tanks

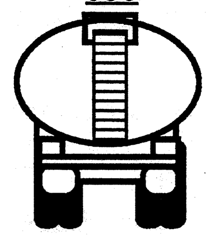
MC-306, 307 or DOT 406, 407 Atmospheric Pressure Tank Truck

Features on the 306 and 307 are very similar

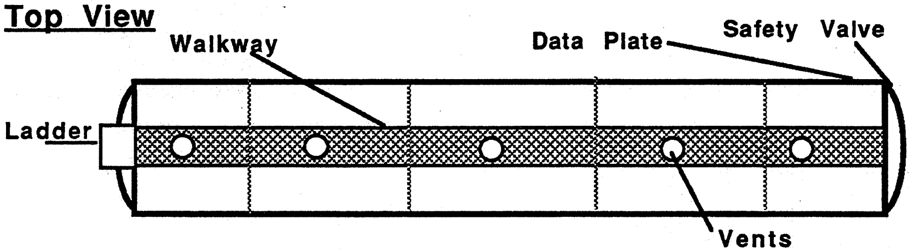
Side View



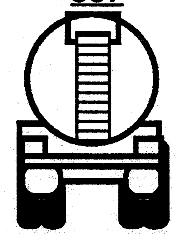
Rear View 306



Top View



Rear View 307



Atmospheric liquid hauler. May have numerous compartments.
Usually 3/16" thick, new DOT standard is 1/4". MC, DOT 307 is usually made from stainless.
Typical volume of a "Bobtail" is 4,000 gals; typical volume of a trailer is 8,300 gals.
Vents located on the manway. 1 vent per compartment.
Ensure proper grounding prior to product removal.
Air or spring loaded valves.
Flammable, Poison 6, Combustible

Terms for Tanker Trucks

Baffle	An intermediate partial bulkhead that reduces the surge effect in a partially filled tank.
Blow-down valve	A manually operated valve to quickly reduce the tank pressure to atmospheric pressure.
Bobtail Hauler	A truck chassis with a frame mounted tank; capacities ranging from 2,000 to 4,000 gallons.
Bulkhead	A structure used to protect damage caused by shifting cargo.
Capacity Indicator	Device installed to indicate capacity at a specific level.
Certification Label	A label permanently affixed to the front right and front left of the cargo tank.
Check Valve	A valve designed to allow fluids to travel in only one direction.
COFC	Abbreviation for Container on Flatcar.
Commodity Capacity	Total Internal Tank Volume.
Curbside	Side of the trailer nearest the curb when the trailer is traveling in a forward direction.
Emergency Valve	A self-closing tank outlet valve.
Emerg. Valve Remote	A secondary means of operating emergency valves from a remote location.
Fill Opening	An opening in the top of the tank to fill the tank.
Head	The front and rear closures of the tank.
Kingpin	Attaching pin on a semi-trailer that mates with and allows the truck and trailer to pivot.
Lift Pads	Jacks located on the sides of the trailer to relieve stress on the cross members.
Manhole	Openings usually with removable, lockable covers large enough to allow access into the tank.
Manifest Box	A storage container of records related to the cargo.
Manifold	Used to join a number of pipelines into a common inlet or outlet.
Sump	A low point in the tank at which the emergency valve is attached.
Vents	Devices used to control the tank pressure. these include; pressure & vacuum relief.
Walkway	Portion on the top of the tank to walk on.
"Y" Valve	A valve that can be used for both bottom loading and off loading.

3. Estimating Volume from Spill Source

D. Rail Sources

Rail

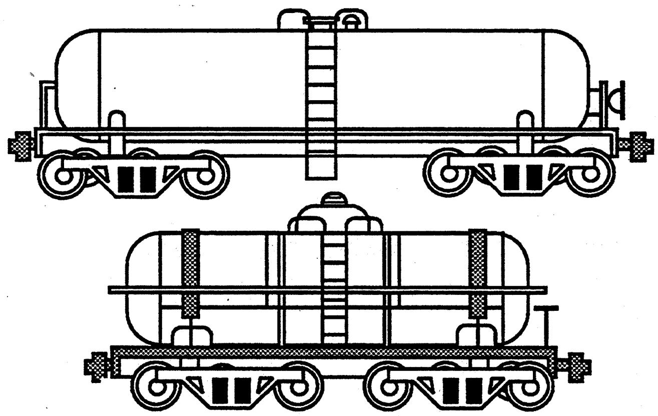
Spill Volume Estimation Checklist:

1. **Collect information (for example:)**
   - Engine or railcar identification numbers
   - Type of railcar
   - Company name
   - Shipping papers (Consist or Waybills) (should be with a train crewmember)
   - Records for when engine was last filled
   - Identification numbers from the tank(s)
   - Company name
   - Interview traincrew
   - Take photos of scene, tank(s)
2. **Determine volume present in the tank prior to spill**
   - maximum volume will be the maximum volume of the tank
   - subtract any fuel used or discharged since the tank was last filled
3. **Determine post-spill volume in the tank**
   - off load the tank into a stable container of known volume, gauge volume
   - estimate remaining fuel in tank using onboard gauging equipment
4. **Calculate spill volume**
   - pre-spill volume minus post spill volume = spill volume

Common Rail Tank Cars

Petroleum Containers

Non-Pressurized Railroad Tank Car



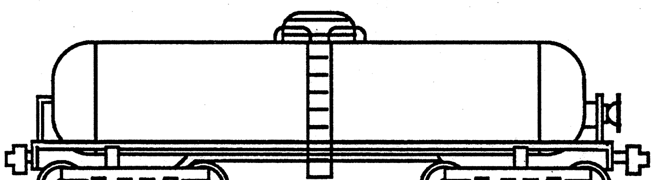
Construction / Contents

- Up to 30,000 gallons of liquids
- Round cross section
- Pressures of liquids usually <25 psi.
- Plumbing on the top unprotected
- May have up to 6 compartments

- Gasolines, Fuel Oil, Poisons, Juices, Tomato pastes, etc.

Gas and Cryogenic Containers

Pressurized Railroad Tank Car

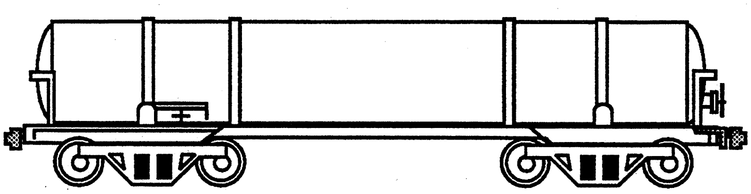


Construction / Contents

- Up to 33,500 gallons
- Pressures are greater than 40 psi
- Circular cross section
- Dome cover to protect valves
- Can be insulated

- Flammable and Non-Flammable gases, and Class "A" Poisons

Cryogenic Railroad Tank Car

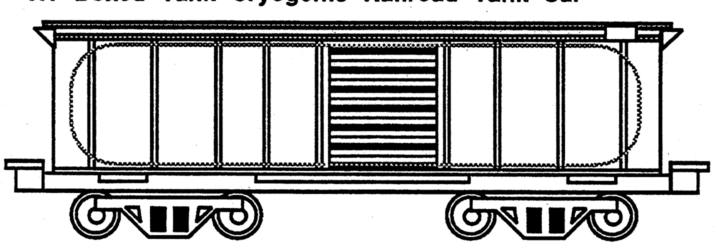


Construction / Contents

- 33,000 gallons
- Insulated double shell
- Low pressure refrigerated liquids < 25psi
- No top fittings
- Loading and unloading from side mounted cabinets

- Liquid Hydrogen, Liquid Nitrogen.

XT Boxed Tank Cryogenic Railroad Tank Car

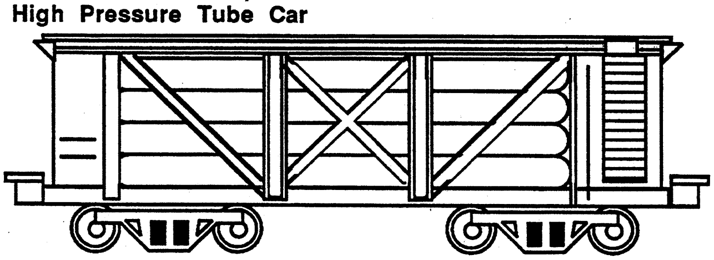


Construction / Contents

- 33,000 gallons
- These are an older style of Cryogenic Tank Cars
- Low Pressure Refrigerated Liquids <25psi
- Loading and unloading from the railcar doors

- LOX, Carbon Dioxide, Liquid Nitrogen

High Pressure Tube Car



Construction / Contents

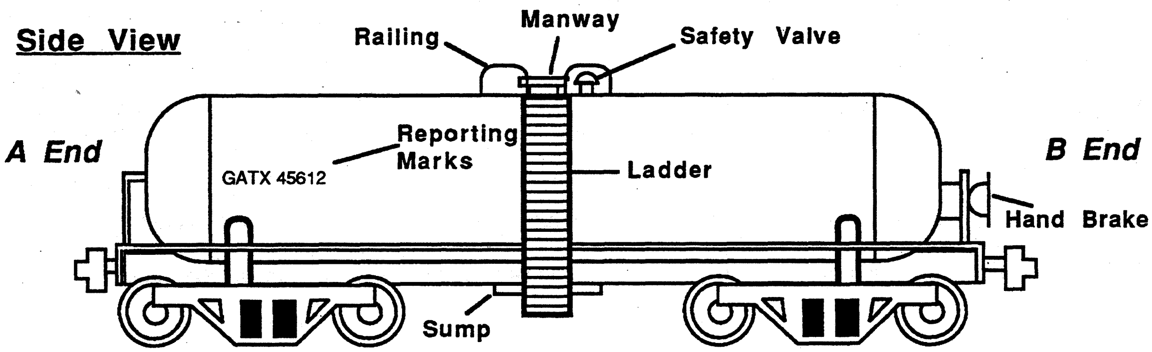
- 30 Cylinders are stacked and Manifolded
- 3,000 to 5,000 psi
- Manifold at rear

- Compressed gases, Oxygen, Nitrogen, Hydrogen.

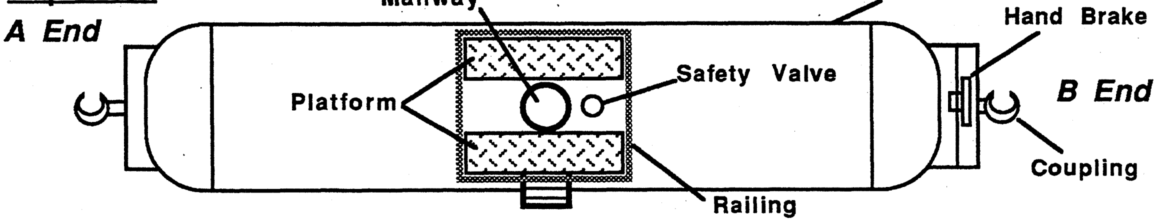
Over Rail Petroleum Cargo Tank Cars

Non-Pressurized Rail Tank Cars

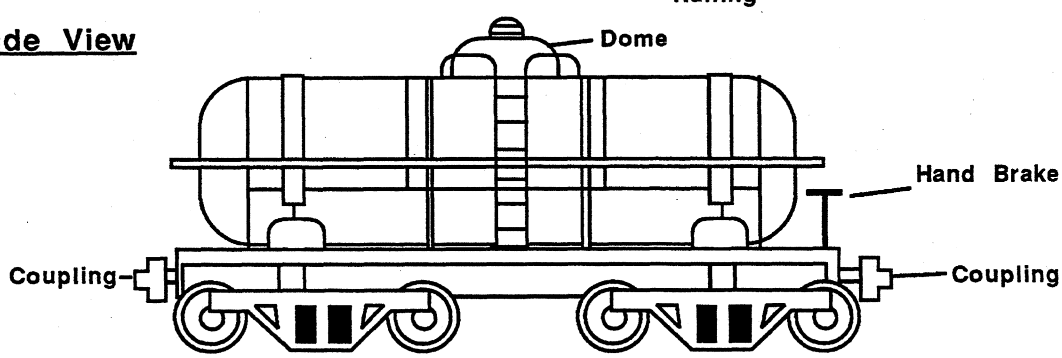
Side View



Top View



Side View



Railroad Terms

"A" End	The end of the Rail Car opposite the end equipped with a hand brake.
"B" End	The end of the Rail Car with a hand brake.
Consist	A list of all cars in the train, their position, type, contents and destination.
Dome	A large "dome" at the top center of a rail car to protect top outlet piping.
Flange	Used to connect pipes and valves together.
Gauging device	Used to measure the amount of product in the tank.
Heel	Residue in the tank after the car has been unloaded to its fullest extent.
Jacket	A metal covering designed to protect and cover the insulation.
Lading	The contents of the car.
Manway	The place on the tank car that you gain access to the interior of the car.
Non-Psi. Car	Tank cars built to transport products with a vapor pressure less than 25 psig or 40 psig @ 105 to 115 deg. F.
Outage	The vacant space required to be left in the tank to allow for product expansion.
Pressure Car	Tank cars built to transport commodities with a vapor pressure greater than 40 psig @ 105 to 115 deg. F.
Reporting Marks	Usually three to four letters ending in an X which are used to identify a specific car.
Safety Vent	A pressure relief device designed to activate at a determined pressure and remain open.
Safety Valve	A spring loaded device designed to operate at a preset pressure and shut off when the pressure drops.
Shell	The cylindrical section of the tank car that holds the product.
Shipping papers	Bill of lading, manifest or other papers containing information required by the DOT.
Sump	A depression in the bottom of the tank to allow as much product to unload as possible.

Locomotive Capacities (in gallons)

Type of Vehicle	Fuel	Oil	Coolant	Hydraulic	Type of Tank	MPG
Commercial Vehicle						
Train Engine						
(Small) Yard Switchers	1000 to 1500	150 to 180	Water(1)	None	Saddle	4 to 6 GPH(2)
(Large) Road Power	2500 to 6000	230 to 250	Water(1)	None	Saddle	10 to 15 GPH(2)

(1) Trains use water with an additive called Nalco, a rust inhibitor that turns the water red. 3 to 4 gallons Nalco to 250 gallons water.
(2) GPH = Gallons Per Hour, figures are for train at idle. If the train has been transporting, fuel consumption would be higher.

Information Sources

Emergency Contact only
Burlington Northern Command Center 800-832-5452

3. Estimating Volume from Spill Source

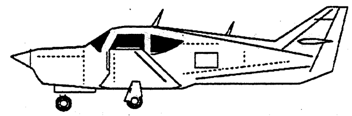
E. Aircraft Sources

Aircraft

Spill Volume Estimation Checklist:

1. **Collect information (for example:)**
   - Tail identification numbers & company name
   - Cargo Shipping Papers (should be in the cockpit, within reach of the pilot)
   - Records for when tank was last filled, when fuel was last transferred
   - Interview pilot or groundcrew who last fueled aircraft
   - Take photos of scene
2. **Determine volume present in the aircraft prior to spill**
   - subtract any fuel used or discharged since the aircraft was last filled
3. **Determine post-spill volume in the aircraft**
   - off load the aircraft into a stable container of known volume, gauge volume
   - contact the NTSB for commercial aircraft, they have access to detailed records
   - estimate remaining fuel in tank using onboard gauging equipment
4. **Calculate spill volume**
   - pre-spill volume minus post spill volume = spill volume

The following range of fuel capacities can be used to estimate total fuel on board. However, after-market and add-on fuel tanks may be present adding to the volume carried. In cases where fuel capacity is typically measured in pounds, capacities are listed as such with gallons in parentheses (Jet-A fuel is typically calculated by the aviation industry @ 6.7 pounds/gallon).



1. General Aviation Aircraft

single engine piston powered aircraft

A. Piston Power
Fuel: AvGas 100-110 (blue) & AvGas 80-87 (red)
Fuel typically measured in gallons.
Single Engine 30-130 gallons
Example: Cessna 172, 37 to 54 gallons
Twin Engine 70-180 gallons
Example: Beechcraft Baron, 72-144 gallons

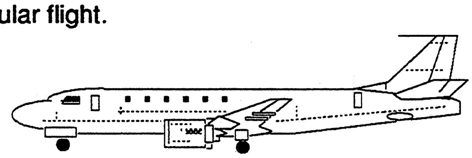
B. Turboprop (jet engine, propeller driven)
300-700 gallons
Fuel: Jet-A, clear
Fuel typically measured in gallons.
Example: Piper Turbo Cheyenne, 570 gallons

C. Jet (charter and corporate travel)
5,600-39,000 pounds (836-5,821 gallons)
Fuel: Jet-A, clear
Fuel typically measured in pounds.

Example: Lear Jet, 8,000 pounds (1,194 gallons)

2. Commercial Aircraft

Commercial airlines can calculate how much fuel is onboard their aircraft at any given time. Fuel status is critical and carefully monitored throughout the fueling process and while in flight. For example, when a commercial pilot declares an emergency they are asked for 3 pieces of information; souls on board, intentions and fuel onboard (remaining time aloft). The Federal Aviation Administration (FAA) will have access to detailed information on fuel onboard a particular flight.



Commercial Airliner

A. Commercial Turboprop (some can dump fuel) 3000 - 12,500 pounds (448-1,866 gallons)
Fuel: Jet-A, clear
Fuel typically measured in pounds.
Example: Dehavillon Dash 8 - 5,700 to 10,200 # (851-1,522 gallons)

B. Commercial Jet (all have ability to dump fuel)
22,500 to 360,000 pounds (3,358-53,731 gallons)
Fuel: Jet-A, clear
Fuel typically measured in pounds.
Examples: (general estimates of total fuel capacity)

Boeing
727, 60,000# (8,955 gals)
737, 42,000# (6,269 gals)
747, 360,000# (53,731 gals)
757, 80,000# (11,940 gals)
767, 160,000# (23,881 gals)
777, 290,000# (43,284 gals)

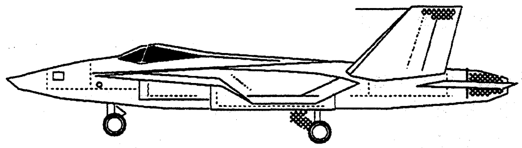
Airbus
300, 120,500# (1,567 gals)
310, 120,600# (17,910 gals)
320, 40,200# (6,000 gals)
330, 167,500# (25,000 gals)
340, 241,000# (35,970 gals)

McDonnell Douglas
DC-9, 40,200# (6,000 gals)
MD-80, 51,600# (7,701 gals)
DC-8, 160,800# (24,000 gals)
DC-10, 183,000# (27,313 gals)
MD-11, 228,000# (34,030 gals)

3. Military

Most military aircraft (all tactical) have inflight refueling capability so even after hours of flight they may be at or near capacity.

Fuel: Jet-A (JP-4 or JP-5)
Fuel typically measured in pounds.



Military Tactical Aircraft

A. Tactical, 7,000 to 26,500 pounds (1,045 to 3,955 gallons)

Examples: (always have internal tanks, sometimes use external tanks)

FA-18 internal 12,000# + external 6,500 #= 18,500# (2,761 gallons)
F-15 internal 13,000 + 4200 = 17,200 (2,567 gallons)
A-6 internal 16,000 + 10,500 = 26,500 (3,955 gallons)

B. Military Transport

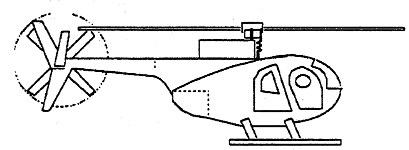
1. **Turboprop** 63,000 pounds (9,403 gallons)
   Example: Lockheed P-3 Orion

2. **Jet** 150,000 to 340,000 pounds (22,388 to 50,746 gallons)
   Examples:
   Lockheed C-141 Starlifter, 150,000# (22,388 gals)
   KC-135 (refueling tanker), 200,000# (29,851 gals) (includes cargo)
   E6A, 155,000# (23,134 gals)
   KC-10, 305,000# (45,522 gals)
   C5A, 340,000# (50,746 gals)

Helicopters

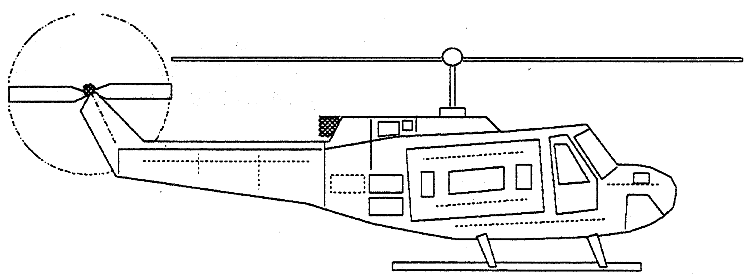
The following range of fuel capacities can be used to estimate total fuel on board. However, after market and add on fuel tanks may be present adding to the volume carried.

1. **Sport or homebuilt helicopters:**
   16-20 gallons (gasoline)
   Examples: Rotorway Exec., Scorpion
2. **Two passenger traffic watch helicopters:** 19 gallons (gasoline)
   Example: Robinson R-22
3. **Single turbine business helicopter:** 75-150 gallons (gasoline)
   Examples: Bell Jet Ranger, McDonnell Douglas MD 500, MD 600



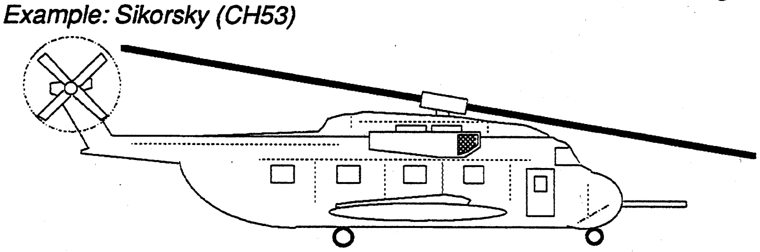
MD 500

4. **Twin Turbine Helicopter:** 160-240 gallons (JP-4/5)
   Examples: BK-117, McDonnell Douglas MD900
5. **Light Commercial Cargo, multi-engine:** 220-495 gallons (JP-4/5)
   Example: Bell 212 (Huey)



Huey

6. **Medium Commercial Cargo:** 533-1,035 gallons (JP-4/5)
   Example: Aerospatiale Super Puma
7. **Military Tactical:** 375 to 500 gallons (JP-4/5)
   Examples: Sikorsky UH-60
   McDonnell Douglas AH-64A (Apache)
8. **Military Cargo, multi-engine:** 1,000-2,090 gallons (JP-4/5)
   Examples: Boeing Vertol CH46
   Boeing Vertol CH47
9. **Military Heavy Tactical:** 1,017-2,017 gallons (JP-4/5)
   Example: Sikorsky (CH53)



CH53

4. Estimating Volume from Oil-on-Water

Oil on Water

Observations of oil on water often provide dramatic evidence of a spill. Large oil slicks can be visible for miles while even small oil slicks can be created by only a few tablespoons of product. The characteristics of oil, sea conditions and the nature of "oil on water" act together to create a wide variety of appearances one can observe. Oil slicks can vary in color, size, continuity, etc.. Some may appear feet thick, when they are only 0.00004 inches (1 micron) thick. Even oil spills that are barely visible (approx. 0.04 microns thick) can create a slick. The term "slick" is derived from the appearance oil has on water, making it look "slick" by dampening out small wavelets on the surface of the water. Refer to Appendix A ("Trajectory Analysis for Oil Spills" - Galt) in this guide for additional technical information on "oil on water."

Observing oil on water is a highly subjective science, many say art. Factors affecting oil on water observations include; visibility, time of day, cloud cover, wind speed, weathering, type and age of oil, spreading, air temperature, sea temperature, sea state, natural interferences (kelp, windrows, debris, etc.) observer experience, height of observation, evaporation, and corralling.

All of these inherent observational complications combine to limit an observers ability to accurately estimate volumes of oil on water. Inclement weather or nighttime conditions may make any observation impossible. High winds can quickly move oil, spreading it into patches making an overall estimate of surface area covered difficult. Weathering allows volatile (quickly evaporating) fractions of oil to enter the atmosphere, leaving behind heavy non-volatile fractions of oil that often mix with the water column or in some cases sink. Such oil cannot be readily observed on the surface of the water.

Natural interferences (kelp, windrows, debris, etc..) often resemble oil slicks by dampening out surface waves and making the water look "slick". This can confuse observers and lead to false positives. Observations made from high elevations will afford the capability to see a larger overall area, but inherently limit the observers ability to see small details (such as tar balls) in the water. The resolution of the human eye is limited. Some of these observational complications can be minimized by having an experienced oil on water observer observe the slick immediately after the incident.

Oil on water observations are typically used for two purposes, to determine where the oil is and/or where it is going (trajectories), and how much was spilled.

Oil Trajectories

Oil on water observations can be very helpful when determining the source of a spill or identifying potential spill impact areas. Tracing a slick upstream, or up-current to a leaking tank can be a viable method for identifying the source of a spill. Observing the movement of oil on water can assist in predicting future movement, allowing for efficient placement of cleanup equipment and protection of sensitive areas. This guide was prepared to assist Ecology responders in estimating volumes of petroleum products and as such is not intended to be an authoritative guide on oil on water observations for trajectory analysis purposes. Refer to Appendix A for additional information on this subject.

Oil Volumes

Estimating the volume of oil spilled from oil on water observations is not the preferred method for determining volumes of spilled petroleum products. Research for this project revealed a considerable variety of charts, tables, graphs and methods for attempting this process. All contained substantial caveats for the use of their methods, and repeated recommendations to look at the source for spill volume information. Of the variety of methods reviewed, none eliminate the subjective observational and dynamic oceanographic/chemical factors associated with observing oil on water. These inherent and substantive factors make oil on water observations for the purpose of oil volume estimation an inexact science when compared to standard industry methods used to determine oil volumes (gauging, temperature, density, etc.)

Subject area experts contacted for this project report that error factors for determining oil volumes from oil on water observations of 3 to 10 x (+/-) are to be expected during typical response operations, under good conditions. None of the subject area experts contacted recommended oil on water observations as the preferred and most accurate method for determining oil volumes.

However, in the absence of information on the source volume, oil on water observations may be able to provide some valuable information on the volume of product released. Clearly, if the Columbia River is coated with oil from bank to bank for miles, the spiller has released more than a few hundred gallons of oil. Common sense also tells us that a 10,000 gallon spill will create a slick larger than a tablespoon of oil. With this thought in mind, use of the following tables for estimating volumes of oil from a slick may assist Ecology responders. They include terms for observing oil including barely visible, silvery, etc. These terms are subjective. Photographs for comparison are recommended.

The best observations will typically be made immediately after the spill occurs, before the spill has a significant chance to break up into discontinuous patches or significantly evaporate, by experienced observers. The worksheet on page 4 of this section can be used to record observations.

Oil Thickness Estimation

sources: *Field Operations Guide.* 1995. U.S. Coast Guard. ICS-420-1 (Oil)
Oil Pollution Control Technology Training Manual, 1971. U.S. E.P.A, Edison Water Quality Laboratory

Approximate Film Thickness

Standard Term*	Inches	Millimeters	Microns	Approx. Quantity of Oil in Film
Barely visible	0.0000015	0.00004	0.04	25 gallons per square mile
Silvery	0.000003	0.00008	0.08	50 gallons per square mile
Slightly colored	0.000006	0.00015	0.15	100 gallons per square mile
Brightly colored	0.000012	0.0003	0.3	200 gallons per square mile
Dull	0.00004	0.001	1.0	666 gallons per square mile
Dark	0.00008	0.002	2.0	1,332 gallons per square mile

*key to terms
Barely visible - seen only under ideal lighting conditions
Silvery - visible from all angles
Slightly colored - first trace of color can be observed (may also be called "rainbow")
Brightly colored - bright bands of many colors observed (may also be called "rainbow")
Dull - colors beginning to turn brownish
Dark - obviously brown and much darker

Oil Slick Volume Estimation

source: *An Introduction to Oil Spill Physical & Chemical Processes and Information Management.* 1992. NOAA, Hazmat Response Division, Seattle, WA

Volume (in U.S. barrels) =	[4.14×10^5] x [Area (sq. miles)] x [Average Thickness (inches)]
Volume (in U.S. gallons) =	[1.74×10^7] x [Area (sq. miles)] x [Average Thickness (inches)]
Volume (in U.S. barrels) =	[647] x [Area (acres)] x [Average Thickness (inches)]
Volume (in U.S. gallons) =	[2.717×10^4] x [Area (acres)] x [Average Thickness (inches)]
Volume (in U.S. gallons) =	[6.85×10^2] x [Area (sq. miles)] x [Average Thickness (microns)]
Volume (in U.S. gallons) =	[1.774×10^3] x [Area (sq. kilometers)] x [Average Thickness (microns)]

EXAMPLE: If you wanted to estimate the volume of an oil slick in U.S. gallons and you knew its area in square kilometers, you would use the last formula listed above.

Area = 5 square kilometers
Average thickness = 1 micron

Volume (in U.S. gallons) = [1.774×10^3] x [5] x [1] = 1774 x 5 x 1 = 8870

Oil on Water Observation Worksheet

Observer Name:

Date: Time:

Observation Platform (helicopter, etc.):

Observation Elevation (feet):

Visibility: Wind Conditions:

Sea State:

Time elapsed since the spill:

Use this space to draw a map of the oil slick. Use the key on the right to label the appearance of observed oil. Note any natural interferences (e.g. kelp beds) which may interfere with observations.

bv	barely visible
si	silvery
sc	slightly colored
bc	brightly colored
du	dull
dk	dark

scale: 1 inch = ______ miles

notes:

5. Estimating Volume from Oil Recovery

Recovery

Oil recovery operations can remove spilled oil from the environment minimizing the impact of a spill. Common methods of recovery include skimmers, oily absorbent materials (pads, pigs, boom, etc..) and oily debris (sticks, plants, dirt, etc..) removed from areas where the spill has occurred.

Oil recovered by skimmers can be placed into stable tanks and later gauged to determine the volume of product recovered. Procedures listed in section 3B of this manual should be followed to determine volumes of oil from recovered oily liquids.

Oily absorbent materials can be wrung out to remove free liquid. The resulting oily liquid can then be handled much the same as that from skimmers. It can be placed in a tank and gauged, again following proper methodology listed in section 3B of this manual.

Oily absorbent material that has been wrung out and oily debris can both be weighed and sampled for total petroleum hydrocarbons (TPH). Laboratory analysis will be required. The % of TPH can then be factored in to determine the total amount of hydrocarbons present in the oily debris.

Appendix F in this manual (California Code on Hydrocarbon Recovery, Title 14, Div. 1, Subdivision 4, Chapter 7., Subchapter 2., Sections 877-880, January 5, 1996) provides methodology for calculating recovery of oil. Additional responder recommendations include:

1. **Collect information (for example:)**
   - location and type of skimmers, absorbent materials
   - storage and transfer locations for all oily materials, oil liquids
   - ensure gauging of all receiving tanks takes place prior to receiving oily liquids
   - collect representative sample of spilled oil to match oil that is being collected
   - interview recovery personnel (methods used, location, amounts, etc..)
   - Take photos of scene, recovery methods
   - receiving tank gauging records (see section 3B of this manual)
2. **Calculate recovered volume**
   - As listed in the CA Code "the total recovery of petroleum hydrocarbons shall be the sum of the total volume of petroleum hydrocarbons from contaminated sediment, oil boom, sorbent and debris, and liquid petroleum hydrocarbons..."

Appendix A

Conversions

Conversions

Volume

Converting To [Multiply by Factor Listed] [3,7]

Converting From	Gallon U.S.	Barrel U.S.	Gallon Imperial	Cubic Feet	Liter
Gallon U.S.	1.0	0.02381	0.83268	0.134	3.79
Barrel U.S.	42	1.0	34.97	5.61	158.98
Gallon Imperial	1.2009	0.02859	1.0	0.1605	4.55
Cubic Feet	7.4805	0.1781	6.2288	1.0	23.316
Liters	0.2641	0.00629	0.2199	0.03532	1.0

EXAMPLE: 40,000 barrels of a given fuel have been spilled; how many U.S. gallons?

[40,000 barrels] x [42 (U.S. gallons per barrel)] = 1,680,000 U.S. gallons

1 Imperial pint	= 0.5683 liter	(5)
1 quart	= 0.9464 liter	(3)
1 liter	= 1,000 cubic centimeters	(5)
	= 1.7597 pints	(5)
	= 0.26417 U.S. gallon	(5)
	= 0.21997 Imperial gallon	(5)
	= 0.035314 cubic foot	(5)
1 hectoliter	= 100 liters	(5)
1 U.S. gallon	= 231 cubic inches	(5)
	= 3.7854 liters	(5)
	= 0.83268 Imperial gallon	(5)
	= 0.0037854 cubic meter	(5)
	= 0.00324823 Deadweight Ton (DWT)	(2)

Volume (cont.)

1 Imperial gallon	= 277.42 cubic inches	(5)
	= 4.54609 liters	(5)
	= 0.160544 cubic foot	(5)
	= 1.20094 U.S. gallons	(5)
	= 0.028594 U.S. barrel	(5)
	= 0.0045461 cubic meter	(5)
1 cubic foot	= 28.317 liters	(5)
	= 6.2288 Imperial gallons	(5)
	= 7.4805 U.S. gallons	(3)
	= 0.17811 U.S. barrel	(5)
1 U.S. barrel	= 158.99 liters	(5)
	= 42 U.S. gallons	(5)
	= 34.9726 Imperial gallons	(5)
	= 0.15899 cubic meter	(5)
	= 0.136425648 Deadweight Tons (DWT)	(2)
1 cubic meter (m^3)	= 35.315 cubic feet	(5)
	= 1,000 liters	(5)
	= 264.17 U.S. gallons	(5)
	= 219.97 Imperial gallons	(5)
	= 6.2898 U.S. barrels	(5)
1 U.S. barrel per hour	= 0.699 U.S. gallons per minute	(7)
	= 2.65 liters per minute	(7)
1 U.S. barrel per day	= 0.0292 U.S. gallons per minute	(7)
1 Deadweight Ton	= 7.33 U.S. barrels	(2)
	= 307.86 U.S. gallons	(2)

Density Estimations

Materials	Barrels Per Long Ton [1 Long Ton = 2,240 pounds] (7)	Ave. (6)
Crude Oils	6.7 - 8.1	7.4
Aviation Gasolines	8.3 - 9.2	8.8
Motor Gasolines	8.2 - 9.1	8.7
Kerosenes	8.2 - 9.1	8.0
Gas Oils	7.2 - 9.1	7.6
Diesel Oils	7.0 - 7.9	7.5
Lubricating Oils	6.8 - 7.6	7.2
Fuel Oils	6.6 - 7.0	6.8
Asphaltic Oils/Bitumens	5.9 - 6.5	6.2

(2) NOTE: "Gallon" and "barrel" measure volume; a "ton" is a measurement of weight. Precise conversion from tons to gallons (or barrels) must account for the fact that not all oils have the same specific gravity. Pure water has a specific gravity of 1.0; the specific gravity of petroleum products varies from about 0.735 for gasoline to about 0.95 for Bunker C (No. 6 fuel oil).

(2) The density of petroleum products is often expressed as °API in accordance with the formula:

°API = (141.5/sp. gr.) - 131.5

(Specific gravity will be taken at 60°F. See *API* in Glossary.)

(2) As can be seen from the formula, a low °API corresponds to a high specific gravity, e.g.,

°API from 1-15° (sp. gr. 0.97 - 1.06) =	heavy crude
°API from 15-35° (sp. gr. 0.85 - 0.97) =	medium crude
°API over 35° (sp. gr. less than 0.85) =	light crude

(1) Additional examples:

°API = 50-70 (sp. gr. 0.70 - 0.78) =	unleaded motor gasoline
°API = 38-44 (sp. gr. 0.80 - 0.83) =	kerosene

(5)

Degrees API	Specific Gravity(*)	Barrels/metric ton	Barrels/long ton
25	0.904	6.98	7.09
26	0.898	7.02	7.13
27	0.893	7.06	7.18
28	0.887	7.10	7.22
29	0.882	7.15	7.27
30	0.876	7.19	7.31
31	0.871	7.24	7.36
32	0.865	7.28	7.40
33	0.860	7.33	7.45
34	0.855	7.37	7.49
35	0.850	7.42	7.54
36	0.845	7.46	7.58
37	0.840	7.51	7.63
38	0.835	7.55	7.67
39	0.830	7.60	7.72
40	0.825	7.64	7.76
41	0.820	7.69	7.81
42	0.816	7.73	7.85

[(*) - @ 15 deg. C., 60 deg. F]

EXAMPLE: An airplane carrying 10,000 pounds of fuel with a density of 38 degrees API skids off a runway after an aborted takeoff. How many U.S. gallons could be spilled?

(10,000 pounds) /(2,204.6 pounds per metric ton) = 4.536 metric tons of fuel

(4.536 metric tons) x (7.55 U.S. barrels per metric ton) = 34.247 barrels of fuel

(34.247 U.S. barrels) x (42.0 U.S. gallons per barrel) = 1,438.37 U.S. gallons

Weight

Converting From	Converting To [Multiply by Factor Listed] (7) Pounds	Ton (Short)	Ton (Long)	Ton (Metric)
Pounds	1.0	0.005	0.000446	0.000454
Ton (short)	2,000	1.0	0.89286	0.907
Ton (long)	2,240	1.12	1.0	1.016
Ton (metric)	2,204.6	1.1023	0.984	1.0

1 pound (lb)	= 0.453592 kilogram	(5)
1 kilogram (kg)	= 2.20462 pound	(5)
1 metric ton	= 1,000 kilograms	(5)
	= 0.98421 long ton	(5)
	= 1.10231 short tons	(5)
	= 2,204.6 pounds	(5)
1 long (English) ton	= 1.01605 metric tons	(5)
	= 1.12 short tons	(5)
	= 2,240 pounds	(6)
1 short ton	= 0.892857 long ton	(5)
	= 0.907185 metric ton	(5)
	= 2,000 pounds	(5)

Area & Distance

1 inch	= 0.0254 meter	(5)
1 foot	= 0.305 meter	(5)
1 yard	= 0.914 meter	(5)
1 meter	= 1.094 yards	(5)
	= 3.281 feet	(5)
	= 39.37 inches	(5)
	= 0.001 kilometer	(5)
1 kilometer	= 1,000 meters	(5)
	= 0.621 mile (statute)	(5)
1 statute (land) mile	= 1.609 kilometers	(5)
	= 5,280 feet	(5)
1 nautical mile	= 1.15152 statute miles	(5)
1 square foot	= 0.093 square meter	(5)
1 square meter	= 10.764 square feet	(5)
1 square kilometer	= 0.386 square mile	(5)
	= 100 hectares	(5)
1 square mile	= 2.590 square kilometers	(5)
	= 259 hectares	(5)

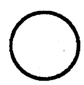
Speed

1 knot	= 1 nautical mile per hour	(4)
1 knot	= 1.852 kilometers/hour	(2)
1 knot	= 1.151 statue miles/hour	(2)
1 knot	= 0.515 meter/second	(2)
1 mile/hour	= 0.8684 knot	(2)

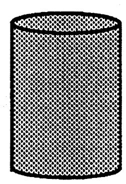
Temperature

Converting degrees Fahrenheit to degrees Centigrade:	(F-32) X (5/9) = C	(6)
Converting degrees Centigrade to degrees Fahrenheit:	(C X 1.8) + 32 = F	(6)

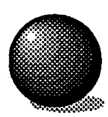
Commonly Used Equations



Circle: Area = 3.14 x radius^2 Circumference = 3.14 x diameter



Cylinder/Pipe/Tank: Volume = 3.14 x radius^2 x length



Sphere: Surface Area = 12.56 x radius^2 Volume = 4.18 x radius^3

The Metric System

deca (or deka) =	ten	[1 decameter =	10 meters]
hecto =	one hundred	[1 hectometer =	100 meters]
kilo =	one thousand	[1 kilometer =	1,000 meters]
mega =	one million	[1 megawatt =	1,000,000 watts]
deci =	one tenth	[1 decimeter =	1/10th meter]
centi =	one hundredth	[1 centimeter =	1/100th meter]
milli =	one thousandth	[1 millimeter =	1/1,000th meter]
micro =	one millionth	[1 micrometer = 1 micron = 1/1,000,000th meter]	

Conversions Reference List

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[3]Environmental Protection Agency (EPA). 1992. *Oil and Hazardous Substances Manual*. August.

[4]Merriam-Webster, Inc. 1994. *The Merriam Webster Dictionary.* Springfield, MA: Merriam-Webster, Inc.

[5]National Oceanic & Atmospheric Administration (NOAA). Hazardous Materials Response and Assessment Division. 1992. *An Introduction to Oil Spill Physical and Chemical Processes and Information Management.* Draft. Seattle. April.

[6]United States Coast Guard (USCG). 1995. *Field Operations Guide.* ICS 420-1(OIL). July.

[7]USCG. Atlantic Strike Team. *Incident/Site Assessment.*

Appendix B

Expert Contacts

Expert Contacts

These individuals may be contacted by Ecology staff to provide expert assistance when quantifying oil products. Some may require contractual arrangements for the use of their services beyond an initial phone consultation.

American Petroleum Institute: (202) 682-8000

Aircraft:
Sam Aldrich, Helicopter Design Engineer (reach through CADRE) (206) 883-8007
Ted Morrison, Commercial Pilot (reach through CADRE) (206) 883-8007

Facility Tanks, Pipelines, Vessels, Gauging & Recovery Methods
Dave Blurton, State of CA, Office of Oil Spill Prevention & Response (916) 323-4699

Gauging Services for Oil Products:
Inchcape Testing Services/Caleb Brett, (360) 671-0919 (facility tanks, vessels, pipes)
Saybolt, Inc. (206) 622-8989 (facility tanks, vessels)

Interpreters:
Dynamic Language Center, (206) 244-6709

Marine Oil Spill Investigators - Emergency Contracting Resources List:
Albert F. Dugan, Jr., Hull and Cargo Surveyors (415) 485-1300
Bill Milwee, Milwee & Assoc. (503) 297-7474
Ian T. Coffer (206) 232-2288
Peter Johnstone, Admiralty Marine Surveyors NW (206) 232-6393
Ian Hogben, London Salvage Assoc. (206) 441-7587
M.A. Stream, Stream & Assoc. (206) 282-1311
Walter Thornhill, Protechtor (504) 581-7465
David Hall, Quantum Marine, Inc. (215) 459-4069

Marine Pleasure Vessels:
U.S. Coast Guard, Marine Safety Office, (206) 217-6200
Gordon Fox, Pleasure Vessels (reach through CADRE) (206) 883-8007

Marine Tugs & Petroleum Barges:
U.S. Coast Guard, Marine Safety Office, (206) 217-6200
Lee Egland, Crowley (206) 443-7809
Steve Collar, Crowley (206) 340-2950
Gary Faber, Crowley (206) 443-8014
Richard Roth, Crowley (206) 340-2904

Marine Ships & Ferries:
U.S. Coast Guard, Marine Safety Office, (206) 217-6200
Washington State Ferry System, (800) 843-8779

Oil on Water Observations:
Sharon Christopherson, NOAA/HAZMAT Branch, (206) 526-6317

Oil Sampling, Analysis & Chemistry:
Bob Carrell, Manchester Laboratory, (360) 871-8804
Charlie Henry, Louisiana State University (504) 388-4295

Rail:
Burlington Northern, emergency number (800) 832-5452
Burlington Northern Freight Office (206) 625-6210

Recovery, Transfer of Product, Tank Gauging & Safety:
CleanSound Cooperative, (206) 744-0948
Marine Spill Response Corporation (MSRC), (206) 252-1300
Global Environmental Services (206) 623-0621

Appendix C

Glossary

Glossary

A letter following each definition refers to its source found in the Glossary Reference List on the last two pages in this section.

Abaft. To the rear of.[R]

Absorption. The take up of a substance into another substance.[L]

Additives. Product manufacturers (Refineries) often add chemicals to their products. They are added to improve some characteristic of the product. Some of these "additives", such as anti icing, and lead compounds cause problems for product carriers.[G]

Adsorption. The adherence of a substance to the surface of another substance.[L]

Aft. Toward, at or near the stern.[R]

Amidships. In the middle part of a vessel; halfway between the bow and stern.[R]

API. American Petroleum Institute.

API Gravity. A method of specifying the density of crude oils and petroleum products. Defined by the equation:

$$°API = [141.5/(\text{specific gravity } @60°F)] - 131.5$$ [H]

Petroleum products fall into a relatively narrow range of specific gravity values (0.600 to 1.03), so the use of API gravity values (5.35 to 104.33) provides a numerical series with greater facility for identifying petroleum product variations. (see *Specific Gravity*)

API Nameplate. API Standard 620 requires a nameplate that provides critical information specific to a tank. The nameplate must be permanently affixed adjacent to a manhole or to a manhole reinforcing plate immediately above the manhole.[C] (See nameplate illustration on page 29).

Aqueous Solubility. The percentage of a material (by weight) that will dissolve in water at ambient temperature.[L]

Aromatic. Organic compounds containing any of a series of benzene ring compounds. They are unsaturated organic ring compounds with low to high boiling points. The lighter components are generally acutely toxic to aquatic life.[K]

Asphalt. Black, solid or semisolid bitumens which occur in nature or are obtained as residues during petroleum refining.[O]

AST. Above-ground Storage Tank.

ASTM. American Society for Testing and Materials.

Atmospheric Tank. A storage tank which has been designed to operate at pressures from atmospheric through 0.5 psig.[M]

AvGas. Aviation Gasoline.[G]

Ballast. Seawater or any other heavy substance carried in the deepest holds to help keep a ship stable.[R]

Barrel. For petroleum products, an historic measure equaling 42 U.S. gallons. Actual barrels (or drums), normally used by oil and chemical companies, hold 55 gallons.[M]

Barrel, U.S. Forty-two U.S. gallons.[L]

Beam. The width of a vessel at its widest point.

Below. Under the main deck.[R]

Bilge Oil. Waste oil which accumulates, usually in small quantities, in the lower spaces in a ship, just inside the shell plating. Usually mixed with large quantities of water.[O]

Bitumen. Any of several hard or semisolid materials obtained as asphaltic residue in the distillation of petroleum, or occurring as natural asphalt.[P]

Black Oil. Area of black-colored oil sometimes appearing with a latex texture. Often confused with kelp beds and other natural phenomenon.[L]

Blender Board. This is both an operation and a position in many refineries. This operation is involved in mixing the components of oil products, gauging tank levels, and transferring products into and out of tanks.[E]

Boiling Point. The temperature at which the vapor pressure of a liquid is equal to the pressure of the atmosphere.[O]

Bottom Loading. A method for loading liquid into a tank truck from ground level which usually incorporates a dry disconnect type fitting and a system designed to provide overflow protection.[M]

Bow. The front part of a vessel.[R]

Bridge. The elevated platform above the main deck from which a ship is navigated.[R]

Brown Oil. Typically a 0.1mm - 1.0mm thick layer of water-in-oil emulsion (thickness can vary widely depending on wind and current conditions).[L]

BS and W. See *Suspended Sediment and Water.*

Bulkheads. Walls that divide a ship into compartments.[R]

Bunker "C" Oil. A general term used to indicate a heavy viscous fuel oil.[O]

Bunker "C" Oils. A general term used to indicate No. 6 oil, a heavy fuel oil. Commonly used in marine fuel service.[M]

Bunker Fuel. A general term for heavy oils used as fuel on ships and in industry. It refers to No. 5 and No. 6 fuel oils, which contain higher heat energy (BTUs) than lighter fuels.[M]

Bunkering. The process of fueling a ship.[O]

Carrier. A firm, person, vehicle, or method for transport or transfer of petroleum from one pipe or tank to another.[M]

Check Valve. Allows flow of product in one direction. Can be installed in series for added protection.[B]

CIC. ...CIC stands for Cargo Information Card, and the carrier must have one for every product on the vessel. ...the CIC contains information about the hazards of the product, and the prescribed safety measures required to safely work with it.[G]

Closing Gauge. An innage or outage gauge taken after the transfer of material into or out of the tank.[A]

Cloud Point. The cloud point is the temperature at which a haze or cloud appears in a chilled fluid.[G]

Coker Feed (or Fuel). A special fuel oil used in a coker furnace, one of the operating elements of a refinery.[O]

Combustible Liquid. Any liquid having a flashpoint at or above 100°F and below 200°F.[M]

Companionway. Steps that lead from one deck of a ship to another.[R]

Compensation Schedule. A simplified natural resource damage assessment model which estimates damages based on dollars per gallon spilled.[I]

Containment System. A structure having an impervious surface (concrete, asphalt, membrane, etc.) surrounded by drains, curbs, gutters, dikes, etc. The purpose is to prevent any flow from leaving the immediate area.[M]

Cracking (catalytic). ... a catalyst is used to accelerate the thermal cracking process. A catalyst is a substance that sets off or speeds up a chemical reaction without being changed by the reaction. ...Catalytic cracking is more widely used than thermal cracking because it requires less pressure and produces higher octane gasoline.[Q]

Cracking (thermal). ..heavy fractions are subjected to intense heat and pressure in order to weaken the bonds that hold large, complex molecules together. The heat and pressure crack (break down) these molecules in to the simpler ones that make up light fractions.[Q]

Cracking Processes. Convert heavy fractions into lighter ones, mainly gasoline.[Q]

Critical Zone. The distance between the point where a floating roof is resting on its normal supports and the point where the roof is floating freely is referred to on a tank capacity table as the "Critical Zone."[A]

Crude Oil. Petroleum as it is extracted from the earth. There may be several thousands of different substances in crude oil, some of which evaporate quickly, while others persist indefinitely. The physical characteristics of crude oils may vary widely. Crude oils are often identified in trade jargon by their regions of origin. This identification may not relate to the apparent physical characteristics of the oil. Commercial gasoline, kerosene, heating oils, diesel oils, lubricating oils, waxes, and asphalts are all obtained by refining crude oil.[O]

Crude Oil. Raw, liquid petroleum as it is extracted from the earth. It might be as thick as tar or nearly as thin as water. Its color can vary from yellow to green to reddish to black. Crude oil can be "sweet" (with low sulfur content) or "sour" (high sulfur content).[M]

Cut. The line of demarcation on the measuring scale made by the material being measured.[A]

Datum Plate. A level metal plate located directly under the reference gauge point to provide a fixed contact surface from which liquid level measurement can be made.[A]

Deadweight Tonnage. Tankers are usually measured in deadweight tonnage (also known as deadweight capacity), i.e. the carrying capacity of a ship to the nearest thousand metric tons.

- "small" tanker = 1,000 - 15,000 DWT (307,860 - 4,617,900 gallons)
- "medium" tanker = 35,000 DWT (10,775,100 gallons)
- "large" tanker = 118,000 - 155,000 DWT (36,327,480 - 47,718,300 gallons)
- "supertanker" = 215,000 DWT (e.g. Exxon Valdez) (66,189,900 gallons)

To calculate the amount of oil cargo in a (full) tanker from its dead weight tonnage (DWT):

- DWT x 7.33 = barrels of oil
- DWT x 307.86 = US gallons of oil[H]

Density. See also specific gravity. The ratio of weight to volume of a substance, usually expressed as grams per cubic centimeter.[L]

Density water = $1.0 g/cm^3$

Derricks. Lifting devices that lower cargo into or hoist it out from the holds of a ship.[R]

Diesel. Fuel Oil No. 2. Fuel for diesel engines obtained from the distillation of petroleum, chiefly composed of unbranched alkanes, with a volatility similar to that of gas oil. Flash point can range from 110-190°F.[N]

Dispatcher. Typically the person in charge of the ordering, sale, and delivery of oil products at a facility. This person will keep and have access to facility documentation regarding these transactions. [E]

Dispersant. Chemical agent formulated to emulsify, disperse, or dissolve oil by reduction of surface tension. Dispersed oil is removed from the water surface and dispersed into the water column leading to enhanced biodegradation.[L]

Dispersability. A relative term describing an oil's capacity to be dispersed, either chemically or through natural processes.[L]

Displacement. The term "displacement" refers to the weight of the ship measured in terms of the amount of water it displaces when floating. This can be measured when the ship is either loaded or empty. The difference between these two measures is its deadweight tonnage (see *Deadweight Tonnage*). A ship with a displacement of 1,000 metric tons weighs 1,000 metric tons.[H]

Dissolution. The process of oil dissolving into the water column. The extent of dissolution depends on the oil's solubility in water.[L]

Distillate. A refined hydrocarbon which is obtained by collection and condensation of a known vapor fraction of the crude oil.[L]

Draft. The depth of a ship in the water; the distance from the water line to the bottom of the keel.[R]

Emulsification. The process by which oil is mixed with water.[K]

Emulsion. A permanent suspension or dispersion of water in oil. Water-in-oil emulsions may contain 20%-80% water.[L]

Evaporation. The process occurring when a substance changes from a liquid to a gas.[L]

Fire Point. The lowest temperature at which an oil vaporizes rapidly enough to burn for at least five seconds after ignition, under standard conditions.[O]

Flame Arrestor. Required when flammable vapors are present, and on all class 1 flammable liquids (like gasoline). Prevents flame from flashing back into tank.[J]

Flammable Liquid. Any liquid having a flash point below 100°F, and a vapor pressure not exceeding 40 psi at 100°F. Also know as a NFPA Class 1 liquid.[J]

Flash Point. The lowest temperature at which an oil gives off sufficient vapor to form a mixture which will ignite, under standard conditions.[O]

Forecastle. A raised deck near the bow of a ship; also refers to the crews quarters in the forward part of a ship. Pronounced *Fohk suhl.*[R]

Forward. Toward the front of a ship.[R]

Foundations. Specially designed to support the size and use of the tank. May include leak control and detection.[B]

Fraction. Refinery term for a product of fractional distillation having a restricted boiling range.[O]

Fraction. Any of the groups of hydrocarbons that make up crude oil. Fractions are separated during refining.[Q]

Fractional Distillation. ...is a process that separates crude oil into some of its fractions. It is based on the principle that different fractions vaporize (boil) at different temperatures. For example, gasoline vaporizes at about 75 deg. F (24 deg C), but some of the heavy fuel oils have boiling points higher than 600 deg F (316 deg C).[Q]

Free Oil. See mobile oil.[L]

Free Water. Water present in a tank which is not in suspension or dissolved in the petroleum. Free water should be gauged with the innage gauging procedure. Free water may also be gauged with the outage gauging procedure if the reference gauge height has not changed from the opening to the closing condition. If the reference gauge height has changed, the innage gauging procedure should be used.[A]

Freeboard. The distance between the water line and the main deck of a vessel.[R]

Fuel Oil Grade. Fuel oils are graded numerically from 1 to 6. The lower the grade number, the thinner the oil and the more easily it evaporates. A high number indicates a relatively thick, heavy oil. No. 1 and 2 fuel oils are usually used in domestic heaters, while the heavier fuels and the others are used by industry and ships. No. 5 and 6 oils are solids which must be liquefied by heating. Kerosene, coal oil, and range oil are all No. 1 oil. No. 3 fuel oil is no longer used as a standard term.[O]

Fuel oil no. 1. Jet Fuel[H]

Fuel oil no. 2. Home heating oil, heating fuel oil.[H]

Fuel oil no. 4. Residual fuel oil.[H]

Fuel oil no. 5. Bunker B Fuel oil, heavy fuel oil no. 5, Navy special.[H]

Fuel oil no. 6. Bunker C fuel oil.[H]

Funnel. The smokestack of a ship.[R]

Gasoline. A mixture of volatile hydrocarbons suitable for use in a spark-ignited internal combustion engine and having an octane number of at least 60. The major components are branched alkanes, cycloalkanes, and aromatics. *Cracked gasoline* is produced by the catalytic decomposition of high-boiling components of petroleum; it is characterized by relatively high octane ratings (80-100). *Natural gasoline* is obtained by recovering the butane, pentane and hexane present in small proportions in certain natural gases; high volatility, relatively low octane rating. *Straight run gasoline* is produced from petroleum by distillation without use of cracking or other chemical conversion processes; relatively low octane rating.[N]

Gauges. Vary in design. Usually read in feet and inches which is converted to gallons using the strapping chart for a particular tank. Usually operate in conjunction with an internal float device.[M]

Gross Barrels. The measured volume of a product regardless of its temperature or density.[G]

Gross Observed Volume (GOV). Gross observed volume is the total measured volume of all petroleum liquids, including S & W, but *excluding* free water, at observed temperature and pressure.[S]

Gross Standard Volume (GSV). Gross standard volume is the total measured volume of all petroleum liquids and S & W but *excluding* free water and corrected by the appropriate temperature correction factor for the observed temperature and API gravity (or density), to a standard temperature, 60 F. (or 15 C) and also corrected by the applicable atmospheric pressure correction factor.[S]

Gross Tonnage/Gross Registered Tonnage. Ship size is also sometimes expressed in gross tonnage (GT) or gross registered tonnage (GRT), which is a measure of the ship's capacity in units of 100 cubic feet of enclosed space. (A 1,000 gross ton ship has a capacity of 100,000 cubic feet.)

To calculate the amount of oil cargo in a (fuel) tanker from it's gross tonnage (GT) you need to also know how much of this capacity is taken up by non-cargo areas, such as the crew's quarters, navigation machinery, and engine room. Any calculations you make on cargo using gross tonnage are going to be overestimates because they would assume that non-cargo areas of the ship are also carrying oil. *(See Net Tonnage.)*[H]

H_2S. Hydrogen Sulfide gas is frequently encountered around petroleum products.

Hatch. An opening in a ship's deck through which cargo is lowered into or hoisted out of a hold. A *hatch cover* fits over a hatch and keeps water from going below.[R]

Head. The pressure produced by a vertical column of liquid. Used to calculate the pressure of product in pipes that are gravity fed as opposed to pump fed.

Helm. A ship's steering wheel.[R]

Herding Agent. Chemical agent which confines or controls the spread of a floating oil film by increasing its viscosity.[L]

HF. Heating Fuel.[G]

HFO. Heavy Fuel Oils, Bottoms, and Residiums.[G]

Holds. On a ship, areas below deck in which cargo is stored.[R]

Holiday. A "bare" spot in a coating where there was little or no coating applied.[M]

IFO. Intermediate Fuel Oil.[G]

Innage. Space occupied in a product container.[O]

Innage Gauge. (Dip) The level of liquid in a tank measured from the datum plate or tank bottom to the surface of the liquid.[A]

Intermediate Fuel Oil (IFO). A means of further specifying the viscosity of heavier fuel oils such as Fuel Oil #6 (Bunker C) based on a desired viscosity. The IFO rating (e.g., IFO 280, IFO 380) indicates the midrange viscosity of the fuel in centistokes. The desired IFO rating is typically achieved by means of adding one or more "cutters" such as diesel.[F]

Common IFO ratings include IFO 40 and IFO 180 (essentially #6 oil cut with diesel).

JA-50. Jet Fuel for commercial jets.[G]

JP-4. Gasoline Kerosene Mixture.[G]

JP-5. Kerosene, Navy Jet Fuel.[G]

JP-8. Military fuel (now being phased in as a supplement/replacement for JP-4 or JP-5)

Keel. The backbone of a ship; a ridge that runs along the lowest part of the hull from the stem to the stern.[R]

Kerosene. Water-white, oily petroleum distillate characterized by a strong odor, flash points from 100-150°F. and used in jet engine fuels, domestic heating, insecticidal sprays, diesel and tractor fuels.[N]

Kinematic Viscosity. See *Viscosity*. A measure of viscosity in stokes. Can be related to viscosity by taking the viscosity of a liquid in poise divided by its density, expressed in stokes.

Kinematic viscosity	water	=	1.0	centistokes
Kinematic viscosity	milk	=	1.64	centistokes
Kinematic viscosity	olive oil	=	91.30	centistokes[L]

Knot. One nautical mile per hour.[R]

L. Leaded.[G]

LACT. Lease Automatic Custody Transfer. Typically a positive displacement or turbine meter that meters the flow of petroleum products during transfers.[D]

Lee side. The side of a ship away from the wind.[R]

Light Sheen. A light, almost transparent layer of oil. Sometimes confused with windrows and natural sheen resulting from biological processes.[L]

LNG. Liquid Natural Gas. LNG is stored at bulk facilities under refrigeration and transported under pressure to remain in a liquid state.[M]

Load On Top. A procedure for ballasting and cleaning unloaded tankers without discharging oil. Half of the tanks are first filled with seawater while the others are cleaned by hosing. Then oil from the cleaned tanks, along with oil which has separated out in the full tanks, is pumped into a single slop tank. The clean water in the full tanks is then discharged while the freshly-cleaned tanks are filled with seawater. Ballast is thus constantly maintained.[O]

Lower Explosive Limit. The lowest concentration (lowest percentage of the substance in air) that will produce a flash of fire when an ignition source is present.[L]

LPG. Liquefied Petroleum Gas, such as propane or butane, commonly known as bottled gas. LPG is stored at bulk facilities under refrigeration and transported under pressure to remain in a liquid state.[M]

MAWP (Maximum Allowable Working Pressure)

MDO. Marine Diesel Oil. Dirty Diesel.[G]

Minimum Operating Inventory. Minimum product required to have an operable system and avoid problems i.e.: run out.[M]

Mobile Oil. Oil that can refloat when water is applied (as in high tide).[K]

MoGas. Motor Gasoline.[G]

Moor. To keep a ship in place with ropes tied to a pier, to a buoy attached to an anchor, or to another ship.[R]

Mousse. A type of oil/water emulsion which can contain up to 70 percent water.[K]

Mousse Streaks. Dark-colored oil with obvious textured appearance oriented in lines or streaks. Brown oil and mousse can be easily confused with algae scum collecting in convergence lines, algae patches, or mats of kelp or fucus.[L]

MSDS. MSDS stands for "Material Safety Data Sheets". The manufacturer must provide this information to carriers for every product he ships.[G]

Nautical mile. 1.15152 statute miles; 6,076.1149 feet.[P]

Net Barrels. The volume of a product corrected to what it would be at a temperature of 60 degrees F.[G]

Net Observed Volume (NOV). Net observed volume is the total measured volume of all petroleum liquids *excluding S & W and free water*, at the observed temperature and pressure. S & W can be estimated by centrifuge, but standard petroleum sale contractes call for S & W measurement by filtration and chemical titration respectively.[S]

Net Standard Volume (NSV). Net standard volume is the total measured volume of all petroleum liquids *excluding S & W and free water*, and corrected by the appropriate temperature correction factor for the observed temperature and API gravity (or density), to a standard temperature such as 60 F (15 C) and also corrected by the applicable pressure correction factor. The NSV is the commercially important result of the calculation process, since it is the basis on which the cost of the cargo of oil is determined.[S]

Net Tonnage/Net Registered Tonnage. The term "net tonnage (NT)" describes the ship's cargo capacity in units of cubic feet (having taken into account the non-cargo areas of the ship). It is also known as "net registered tonnage (NRT)."

To calculate the cargo of a tanker from its net tonnage (NT):

- NT x 748.1 = US gallons of oil
- NT x 17.8 = barrels of oil[H]

NFPA. National Fire Protection Association. Recommends codes which are generally accepted standards in petroleum handling.[J]

NL. Non leaded.[G]

Nomograms. Scales used for indicating variables in a problem which are so distorted and so placed that a straight line connecting the known values on such scales provides the unknown values at that line's intersection with other scales.[P]

Non-persistent. Decomposed rapidly by environmental action.[K]

N/S. Navy Special.[G]

Observed Gauge Height. The existing distance from the datum plate or tank bottom, to the reference gauge point.[A]

Octane. Octane is any of 18 chemical compounds that consist of 8 carbon atoms and 18 hydrogen atoms. Octanes are among the main ingredients of gasolines. An octane called isooctane is used in a test mixture to determine how well a gasoline resists knocking (see Octane number). Gasoline with a high octane number prevents engine knock better than one with a low octane number.[Q]

Octane Number. Octane number is a number that tells how well a motor fuel resists "knocking". "Knocking" occurs when the last of the fuel in an engine cylinder burns too soon or too fast. The octane number of a motor fuel is found by comparing the fuel's knocking tendency with that of reference fuels in a test engine. Each reference fuel is a blend of normal heptane (a knock prone fuel) and isooctane (a knock resistant fuel). Normal heptane has an octane number of zero, and isooctane a value of 100. A motor fuel has an octane number of 85 if it produces the same knock as a reference fuel made of 85 percent isooctane and 15 percent normal heptane. Most gasolines have octane numbers from 80 to 100.

...Octane numbers above 100 are measured with a reference fuel containing pure isooctane and chemical antiknock compounds, such as Methyl-tert-butyl-ether (MTBE).

...Automobile engineers measure octane number in three ways. Thus, every gasoline has three octane numbers: (1) a research octane number (RON), (2) a motor octane number (MON), and (3) a road octane number. The RON is determined in a special one-cylinder engine in a laboratory. The MON is also determined in a test engine but under conditions more like those found in an ordinary engine. The road octane number is arrived at by comparing the gasoline with various reference fuels in a moving automobile. ...The octane number quoted on the pump at a gas station is usually the average of the RON and the MON.[Q]

Oleophilic. A material that has affinity for oil.[K]

Opening Gauge. An innage or outage gauge taken before the transfer of material into or out of the tank.[A]

Operator. The person or persons in responsible charge of the day-to-day operation and maintenance of a oil storage facility.[E]

Outage (or Ullage). Space left in a product container to allow for expansion during temperature changes it may undergo during shipment and use. Measurement of space not occupied. "Head" space, or empty space in a storage tank at any time.[M]

Outage Gauge. (Ullage) The distance from the surface of the liquid in a tank to the reference gauge point of the tank.[A]

Pancakes. An isolated patch of oil shaped in a mostly circular fashion, pancakes can range in size from a few meters across to hundreds of meters in diameter. Sheen may or may not be present.[L]

Paraffin. The waxy saturated component of crude oil, having relatively high boiling point and low volatility. Any member of the methane series having the general formula CnH2n+2.[L]

Peak Tank. A tank found far forward, up on the bow, may be referred to as a peak tank.

Penetration. Downward motion of oil into sediments from the surface driven by gravitational forces.[K]

Permeability. The degree to which fluids can flow through a substance. Measured in Darcys. Permeability is not equal to porosity. High porosity of a material does not insure high permeability. A substance cannot be permeable without having some degree of porosity.[K]

Petrochemicals. Chemicals processed from oil and gas.[Q]

Photo-oxidation. Exposure to sunlight that begins to change the oil chemically.[H]

Pooled Oil. Oil thickness exceeds one centimeter. This need not be uniform.[K]

Poop. A short raised deck at the rear of a ship.[R]

Porosity. The volume of void spaces in a sediment mass, measured in percent.[K]

Port. The left side of a ship when facing toward the bow.[R]

Pour Point. The lowest temperature at which a substance will flow by gravity from a specified container under standard conditions.[L]

ppb. Parts per billion, a unit of concentration. One ppb can be approximated by one teaspoon in 1,300,000 gallons.[L]

ppm. Parts per million, a unit of concentration. One ppm can be approximated by one teaspoon in 1,300 gallons.[L]

Quarter. Refers to a section on each side of a ship near the stern.[R]

Rainbow Sheen. Sheen that reflects colors.[L]

Reference Gauge Height. The standard distance from the datum plate or tank bottom to the reference gauge point. This distance should be clearly marked on the tank top near the gauge hatch.[A]

Reference Gauge Point. A point marked on the gauge hatch of a tank to indicate the position at which gauging shall be carried out. Gauging from the reference gauge point is crucial to the achievement of repeatability among individual gauge readings. This point may be a stenciled mark, a small fixed plate inside the gauge hatch, a narrow groove cut horizontally on the inside of the hatch, or the edge of a fixed metal arm which projects a short distance above the gauge hatch but does not contact the hatch.[A]

Reid Vapor Pressure (RVP). The RVP of a fluid is a measure of its tendency to evaporate. This pressure is read when the liquid is at 100 degrees F.[G]

Residual Oil. A general term referring to the heavy viscous remains after refining crude oil.[O]

Scuppers. Openings around the deck of a vessel which allow water falling onto the deck to flow overboard. Should be plugged during fuel transfer.[O]

Sea Chest. Typically below the waterline, a sea chest is an area inside the hull open to the sea. Grates or screens are used to eliminate large debris from being sucked into intake lines connected to a sea chest. Water pulled into a sea chest is typically used for engine cooling, fire water or ballasting purposes.

Secondary Containment. Means containment which prevents any materials spilled or leaked from reaching the land or water outside the containment area before cleanup occurs.[M]

Sheen. Thin layer of floating oil which may appear as silver (0.00007mm), rainbow (0.00015mm), or grey (0.001mm), depending on thickness.[L] You can visualize these thicknesses as follows:

Light sheen	A light, almost transparent layer of oil. Sometimes confused with windrows and natural sheen resulting from biological processes.
Silver sheen	A slightly thicker layer of oil that appears silvery or shimmery.
Rainbow sheen	Sheen that reflects colors.[L]

Silver Sheen. A slightly thicker layer of oil that appears silvery or shimmery.[L]

Slick. A smooth area on the surface of water, as resulting from a film of oil; an oily film on the surface of water.[P]

Slop Tank. Underground tank used to collect waste oils/greases and contaminated run-off from loading/unloading transfer areas.[M]

Sludge Oil. Muddy impurities and acid which have settled from an oil.[O]

Slurry. A suspension of particles in water.[K]

Solubility. The amount or fraction of a substance (e.g., oil) that dissolves into the water column, measured in ppm.[K]

Solvent. A chemical agent that will dissolve oil.[K]

Sorbent. All sorbent materials work on the same principles--oil adheres to the outside of the material or sorbs into the material by capillary action. There are three basic types of sorbent materials: mineral based, natural organic, and synthetic organic. Currently, only synthetic organic sorbents are being used in the field in the form of booms, pads, and mops. Peat is currently in the testing and demonstration phase.[K]

Spalling. Concrete, stone, grout foundations or pilings which are flaking or chipping off in layers parallel to the surface.[M]

Specific Gravity. The measure of the density of a substance such as oil or sea water, usually determined at 20°C, compared to the density of pure water at 4°C. Thus, specific gravity varies slightly with temperature.[K]

Spontaneous Ignition Temperature (SIT). The temperature at which an oil ignites of its own accord in the presence of oxygen under standard conditions.[O]

Stain. Oil that is visibly present but cannot be scraped off with a fingernail.[K]

Starboard. The right side of a ship when facing toward the bow.[R]

Static. Static is the surface electric charge caused by the friction of one material with another. It may form within the material, but it always migrates to the surface.[G]

Stem. The foremost part of a ship.[R]

Stern. The rear part of a ship.[R]

Stoke. The unit of kinematic viscosity.[O]

STP. Submerged Turbine Pump.[M]

Strapping Sheet. See *Tank Capacity Table.*

Striker Plate. A 12" by 12" steel plate welded at bottom interior of a tank under the fill opening to protect the tank bottom from puncture or corrosion.[M]

Superstructure. All of the structures on a ship above the main deck.[R]

Suspended Sediment and Water. Also referred to as Basic Sediment and Water or B.S. and W. The sediment and water which is entrained or suspended in the petroleum. Suspended sediment and water cannot be determined with innage or outage gauging procedures.[M]

Tank Capacity Table. (Tank Gauge Table or Strapping Table) is a table showing the capacities of, or volume in, a tank for various liquid levels measured from the datum plate or reference gauge point. The volume shown on the table may be in gallons, barrels, cubic meters, liters, or cubic feet.[A]

Tankerman. This is the title given to the person in charge of a marine vessel delivering or receiving oil products.[E]

Tarballs. Generally pliable fragments of weathered oil ranging in size from a pinhead to about 30 centimeters in diameter. The texture of tarballs varies from soft to very hard. Sheen may or may not be present.[L]

Tar Mats. Non-floating mats of oily debris (usually sediment and/or plant matter) found on beaches or just offshore.[L]

T/F. Turbine Fuel.[G]

Ton, long. A unit of weight equal to 2,240 pounds.[P]

Ton, metric. 1,000 kilograms; 2,204.6 pounds.[L]

Ton, register. A unit of internal capacity of ships, equal to 100 cubic feet (or 2.8317 cubic meters).[P]

Ton, short. A unit of weight equal to 2,000 pounds.[P]

Total Calculated Volume (TCV). Total calculated volume is the GSV *plus* any freee water measured at the observed temperature and pressure. The TCV is important to the chief officer because it will be the reference quantity against which transit differences will be measured at the discharge port. Since the vessel has no control over the amount of water contained in the cargo, such water will often settle out during the voyage, resulting in a much higher free water quantity at the discharge port than at the loading port. Since free water is not corrected for temperature, this quantity has to be added back to the GSV in order to accurately compare the TCV 'after loading; to the TCV 'before discharge.[S]

Total Observed Volume (TOV). Total observed volume is the total measured volume of all petroleum liquids, including sediment & water (S & W) and free water, measured at the observed temperature and pressure. It is determined by converting the observed ullage readings to voumes using the vessel's tank calibration tables and adjusting the volumes with the necessary trim and list corrections. This is for designated cargo tanks only. The slop tanks may or may not be included, but this must be clearly indicated in the report.[S]

Ullage. The amount of which a tank or vessel lacks of being full (see also *Outage*).[O]

Upper Explosive Limit. The highest concentration (highest percentage of the substance in air) that will produce a flash of fire when an ignition source is present.[L]

Valves. Vary as to size and configuration. Usually made of steel. Required as close to the tank outlets as possible.[B]

Vents. Must be provided on all tanks to allow for filling and emptying. For non-volatile liquids a vent without a flame arrestor would be allowed.[B]

Vessel Experience Factor (VEF). The vessel experience factor (VEF) is used to compare ship and shore figures. Before an accurate ship to shore comparison can be made, the vessel's VEF must be determined. ... Information from all load or discharge terminals should be used to calculate the respective VEF's. ... A minimum of five qualifying voyages is needed to calculate a VEF, however, a larger number is desirable. ... 'a qualifying voyage must be' within +/- 0.0030 of the average ratio of all voyages listed. (As an example, if the average of all voyages listed is 1.00105, all voyages within the range from 0.99805 through 1.00405 would qualify).[S]

Viscosity. The property of liquids which causes them to resist instantaneous change or shape, or instantaneous rearrangement of their parts, due to internal friction caused by molecular attraction. Viscosity of oils is usually expressed in Saybolt Seconds, Universal (SSU) and is the number of seconds at a specific temperature required for a standard quantity of oil to flow through a standard apparatus.[M]

Viscosity. See also *Kinematic Viscosity*. Also referred to as absolute viscosity, this is a measure of the resistance to flow or motion of a fluid in response to external forces, measured in poise. Viscosity is a function of oil type and temperature. The more complex the molecular organization the greater its viscosity.[L]

Viscosity	water	=	1.0	centipoise[L**]
Viscosity	milk	=	2.13	centipoise[L**]
Viscosity	maple syrup	=	2,232	centipoise[L**]

Viscous. Thick, resistant to flow having a high viscosity.[O]

Volatility. The tendency for a liquid to vaporize.[L]

Waterline. The point on the hull of a ship that the surface of the water reaches.[R]

Water-soluble Fraction. The portion of an oil which will dissolve in water.[L]

Weathering. Processes of evaporation, dissolution, and dispersion which act on oil and affect its physical properties and its chemical composition. (The longer the oil remains in the environment, the more weathered it becomes.)[L]

Windrows. Rows of floating debris, aligned in the wind direction, formed on the surface of a lake or ocean by Langmuir circulation.[L]

Windward side. The side of a ship from which the wind is blowing.[R]

Working Capacity. The normally available full capacity of the tank, leaving a space for product expansion and protection against overfill - often about 5% of the volume at tank top.[M]

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- Robinson Helicopter Co., Torrance, CA (213) 539-0508
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Appendix E

Trajectory Analysis for Oil Spills

by J.A. Galt

Trajectory Analysis for Oil Spills

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ABSTRACT

Trajectory analysis used for decision support during spill response activities is a complex process that must merge information from a variety of sources. Included in the analysis must be an understanding of the characteristics of the pollutant and how it might change or modify its characteristics once it is released into the environment. It is also necessary to describe the characteristics of the oceanographic and meteorological processes that contribute to the movement and spreading of the pollutant. Computational procedures that can be used to represent these processes must be developed and implemented in such a way that they can be run on the typically sparse data sets that are available during actual spills.

Given the tools of trajectory analysis it is necessary to develop a clear understanding of what has been left out of the procedures so that known deficiencies and uncertainty can be factored into the final analysis. It is then necessary to explore possible alternate scenarios that might result from errors in any of the forecast data that are used to carry out the analysis. Alternate model use strategies can provide short term forecasts and long term threat distribution probabilities as well as statistical estimates of other situations that could develop.

All of the information components that are developed as part of the trajectory analysis must be synthesized into a technical briefing that focuses on the needs of the spill responders and is relevant to the possible options that are available to them. This briefing should cover physical processes that could effect response operations, such as weather and sea conditions, as well as the expected movement and spreading of the pollutant. The briefings must also provide estimates of the reliability of the forecasts and careful exploration of alternate, less probable, scenarios which may threaten high value resources. Finally, the briefing should provide suggestions for ways to resolve uncertainties, including proposed measurement techniques, reconnaissance or monitoring operations.

This paper will to go through a description of some of the more important processes that need to be factored into trajectory analysis considerations and the preparation of a trajectory briefing.

Introduction

Research on oil spills is a difficult job. The reason for this is that research spills are extremely rare events. Even the few that manage to get through the permitting process are hard to manage because the ocean is not a very easy place to find transient micro-concentrations of complex chemicals. In general, then, the understanding of how spilled oil behaves in the marine environment has had to be inferred from some laboratory studies and observations at accidental spills. Both of these methods of investigation have added to our understanding of the behavior of spilled oil. Over the years many research organizations have contributed, particularly centers such as the Institutt for Kontinentalsokkel-Undersokelser (IKU) in Norway, Warren Springs Laboratory in England, the Centre National Pour L'exploitation des Oceans (CNEXO) in France, scientists from Environment Canada, researchers from my own organization in the National Oceanic and Atmospheric Administration (NOAA), and a number of industry sponsored research projects. (I will not try and outline particular papers or reports since most of them will be found in the Oil Spill Conference proceedings, or in the Arctic and Marine Oilspill Program (AMOP) proceedings; interested readers will want to review these sources in some detail anyway.) Having spent a number of years looking at accidental oil spills, I have had an opportunity to make a number of observations which were typically done under uncontrolled conditions and during the intense and conflicting pressures that occur during emergency response activities. Any of these observations taken by themselves are little more than anecdotal but, taken together, and woven in with the information from laboratory studies, they have led to some opinions which seem to me to be generally true. I will attempt to outline some of these observations and explain them to my present level of understanding.

When oil spills into the marine environment a number of different processes take place; some of these processes are somewhat unique to oil, some could be expected for any floating fluid substance, and some are more closely related to the behavior of floating particles. In all these facets of spilled oil behavior, an understanding of the complex geophysical fluid dynamics of the upper ocean is important for the determination of the movement and spreading of the pollutant. The complex interaction of all of these processes is difficult to predict, or even formally describe, and, as a result, the history of trying to predict the movement of spilled oil is filled with "rules of thumb", algorithmic solutions, and simple models that are borrowed from somewhere else. All presently available oil spill models show this patchwork and heuristic ancestry.

The use of any model or algorithmic procedure to describe the movement of pollutants is subject to all sorts of errors and the resulting prognostications will be more or less useful, depending on the context of their use. Clearly, the task of deciding whether a model is any good (i.e., useful) cannot be carried out independent of the system which provides the input data for the model or models, the hardware or software for it to run, and the communication procedures that are used to present the results in a meaningful way. Ultimately, the information that is available for estimating the movement and spreading of pollutants along with an understanding of the potential uncertainties inherent in the procedures must be factored into the response capabilities and plans put together to react to threats that are associated with accidental releases.

Pollutant trajectory analysis is a synthesis procedure that should include; 1) a description of physical processes, 2) development of the computational and statistical analysis procedures, 3) algorithmic error analysis, and 4) the melding of information products into the broader response activity. This paper will go through a description of some of the more important processes that need to be factored into trajectory analysis considerations. By this, I mean that the processes mentioned have all appeared to significantly affect, or even control, the movement and spreading of spilled oil, the understanding and correct interpretation of observations obtained during spills, or the use of analysis results in the broader context of spill response.

The next section describes the characteristics of oil that are relevant in determining its behavior once it has been spilled. The third section discusses the physical processes that take place in the upper ocean that are of importance in determining the movement and spreading of a pollutant. The fourth section describes the use of historical and forecast information about the ocean and atmosphere and the statistical implications of using this data in trajectory analysis. The fifth section of this paper describes the various ways that oil spill models use algorithmic procedures to explore situation space, interact with observational data so as to self-calibrate and improve performance and, finally, to understand potential uncertainty in predicted results. The final section considers a number of alternate model use strategies and the various options for the use of information available from model results, within the larger context of oil spill response.

Characteristics of Spilled Oil

When oil is being transported in bulk it approximates a homogeneous material and has a number of macroscopic properties that help describe its initial behavior if spilled. These include its pour point, density, surface tension, and viscosity.

The pour point of an oil is a variable that is hard to precisely measure. Individual measurements of the same oil may vary, but the concept is clear enough. As the temperature is reduced, oils will eventually congeal and take on the character of a semi-solid. As a practical matter, when the ambient temperature is below the pour point, the cargo is typically shipped at elevated temperatures. Obviously if the spilled pollutant is a solid or semi-solid then it behaves quite differently than if it is a fluid. For example, during a spill in the Delaware River of a heavy industrial grade oil whose pour point was greater than the temperature of the water (the*Presidente Rivera, 1989*) the clean up, at times, consisted of picking up melon sized globs of oil that were about the consistency of Vaseline (Dale, 1989). It is common for asphalt and some bunkers to congeal when spilled and form floating patches or blobs of oil.

The density of oils vary from about 0.85 to 1.07 g/cc. This density is the major factor in determining whether the oil will float, or sink. The vast majority of oils are lighter than water and float (the density of freshwater is 1.0 g/cc, ocean water densities are about 1.02+ g/cc). Gravitational forces are initially responsible for the spreading of oil that is spilled. The surface tension and the viscosity of the oil will determine how easily it flows and whether it tends to form a thin film or breaks up into smaller floating droplets. The various potential balances between the processes described by these three properties was the subject of an early laboratory study on oil spreading (Fay, 1971) and has been revisited by later field studies (Lehr, et. al., 1984). These later algorithms provide some insight into the very early spreading that takes place when oil is spilled, but they fail relatively quickly because the dynamics of the ocean wave field will dominate these weak forces, and, because the actual properties of the oil start to change as a result of weathering. As a practical matter, these balance algorithms can describe the thicker segments of an oil spill for a few hours under light and moderate wind conditions but are not successful in describing sheen boundaries even during the initial period of spills.

During the early part of a spill (particularly under low wind conditions) when the oil is still relatively fluid and homogeneous, the equilibrium thickness of the oil is very thin; what is typically seen is a thin film (on the order of microns thick). Since the thicknesses of these thin films are on the order of wave lengths of light, normal sunlight interacts with the thin oil film and the colors that result can give some indication of oil thickness. There are a number of references that give approximate oil thickness based on the following sequence of visual clues (Fingas, et. al., 1979).

-- transparent sheen (no color, just a change in surface roughness)
-- silver sheen (lighter sky color reflected back to observer)
-- first trace of color
-- bright colors
-- dull colors
-- dark colors

It is tempting to try and use these visual clues when trying to estimate the amount of oil that is observed during an overflight. It turns out, however, that this is not generally possible. In a very short time the oil starts to weather and may form a crust that changes the way the thin films behave and the upper ocean dynamics become dominant in controlling the thickness distribution.

We have already made several references to upper ocean dynamics and the fact that they will tend to dominate the spreading of oil films. This is invariably the case unless the winds are very light. The essence of this process is that as wind starts to blow over water, waves start to form and these result in the surface being deformed. This deformation alternately stretches and compresses segments of the sea surface. For even relatively light winds these small scale deformations are able to rupture thin oil films and they start to appear as streaks and streamers rather then as a continuous patch of pollutant. As oil films are torn apart and compressed into streaks the equilibrium thicknesses are no longer controlled so much by the initial properties of the oil as they are by the wind. As a general rule, for oils that float the initial properties are of some importance, during the first couple of hours of the spill, but very quickly it is the weather and ocean dynamics that determines the distribution of the oil.

After oil spends even a very short time floating on the ocean surface it starts to weather and change its physical characteristics. Initially, the more volatile components of the oil evaporate and, to a lesser extent, some fraction of the oil will dissolve into the water. This process will continue and, for very light crude oils and light refined products (i.e., gasoline or kerosene), it may eventually account for the loss of a major fraction of the pollutant. For heavier oils, a more likely process is for the weathering oil to reach a stage where it can form a mousse, or water-in-oil emulsion. When this happens the oil starts to form a water in oil emulsion and some dramatic changes take place in its physical characteristics. As mousse forms, the viscosity of the mixture increases rapidly and the color changes from blacks to colors that may range from black, to brown, to the color of red- lead paint. As the water content of the mousse goes up, other weathering processes such as evaporation and dissolution slow down. Eventually, mousse formation may lead to a mixture that is up to about 75% water, which of course just about quadruples the oil volume. Since this mix may be as sticky as peanut butter, the problems of clean-up and recovery are magnified considerably.

As the viscosity of the mousse and its stickiness increase, it often becomes so stiff that it no longer behaves like a simple viscous fluid and it actually takes on the characteristics of a visco-elastic material. This gives it enough structure so that additional weathering causes a surface skin to form and you are likely to see a non-homogeneous material with a crust of slightly more weathered mousse surrounding a less weathered core. As this coated mousse is subject to increased mixing from energetic wave action, the crusts can be torn or ruptured and relatively less weathered mousse is released. This leads to spills occasionally showing apparent rejuvenation in their physical and chemical behavior. This phenomena has been noted at a number of spills. A good example occurred during a spill of crude oil in the Gulf of Mexico (the*Mega Borg, 1990*) (Research Planning, Inc., 1992 and Pearlman et. al., 1992).

The continued exposure of weathered mousse to wave action and small scale surface divergences continues the process of stretching and tearing patches of mousse into smaller bits. This often leads to a more or less continuous breakdown of large slicks into smaller and smaller patches. It is not uncommon to see large spills degenerate into fields of dinner plate size patches, and then into hand size tarballs, which ultimately go to coin size tarballs. On the macro scale there seems to be a minimum size tarball which is about the size of a small coin. A possible physical reason for this is that this corresponds pretty well to the minimum size of small capillary waves. Alternate explanations might be that below this size routine observations would be very difficult or that very small tarballs would be the ones most likely to be quickly weathered by photo-oxidation or bacterial processes.

At this point it is interesting to note that the oil which was initially spilled as a homogeneous fluid has gone through a number of transitions that first make it less homogeneous, then tends to make it behave more like a visco-elastic material and ultimately more like a collection of solid particles. Perhaps not surprisingly, simple algorithms that try and concentrate on initial bulk properties are not valid descriptors of spilled oil behavior over the life of a spill. This also suggests that simple computational procedures that are used during spills should be tied to observational data and must be corrected with real time feedback. Although this is pretty standard for weather forecasting, it somehow does not seem to be as widely understood within the oil spill research community.

It is possible for some hydrocarbons to dissolve into water and the amount varies depending on the particular components that are being considered. The actual amount of oil that thermodynamically dissolves is very small and, if this was all there was to it, we could safely say "oil and water don't mix". However, this is not all there is to it. Most oils have at least some molecules that have natural surfactants attached to them. In addition, some weathering processes create surfactant groups that attach to the oil. Finally, an active response strategy may add surfactants (dispersants) to the oil. In any of these cases small droplets of oil can form with oil interiors (non-polar molecules) and a coating of slightly polar molecules (typically with an -OH group) that fit well into the water structure. These micelle-like droplets can disperse into the water orders of magnitude more oil than could actually dissolve and this can become a significant factor in the overall oil budget. A number of experiments have been carried out to determine the droplet size distribution associated with this process (Thomas and Lunel, 1993). The interest in this data is due to the fact that very small droplets will have such small buoyancy forces that turbulence in the ocean will dominate their movement and they will not return to the surface. On the other hand larger droplets will refloat and potentially coalesce to reform a surface slick. As a practical matter, droplets that are smaller then 50-70 microns will resurface so slowly that they can be considered as dispersed into the water column.

How dispersed oil droplets are formed is determined by the available ocean turbulence that provides the mixing and the viscous or visco-elastic properties of the oil. There is not a great deal of data on this process, but there are some fragments that can lead to the following speculations. For a wide variety of oils the initial size distribution of droplets appears to be independent of the type of oil. In these cases the length scales of the ocean turbulence seem to control the process and peaks in the size distribution are typically in the 30 micron range. These particles would properly disperse. A closer look at the typical turbulent kinetic energy spectra for the ocean show an inertial sub-range that ends in a dissipation region where length scales are in the 10's of microns. For fresh oils the smallest scale shear stresses present in the ocean are sufficient to overcome the viscous resistance of the oil and thus tear it into a small droplet distribution that is determined by the water (viscous dissipation spectra) rather than the oil.

An obvious next question is what do we expect to happen as the oil weathers and the viscosity increases. At some point the available energy in the smaller length scales of ocean turbulence will not have enough shear stress forces to overcome the viscosity of the oil. When this happens larger droplets are still formed (since the larger length scales in the inertial sub range of the turbulent spectra have increasing kinetic energy available), but the smaller ones just can't be produced. As this process continues it becomes dependent on the oil rather then the ocean turbulence and eventually the mean in the droplet size distribution shifts to sizes greater then 70 microns. At this point, the dispersion into the water column is greatly reduced and droplets that are formed and forced under water tend to resurface and cannot be considered as permanent losses to the floating pollutant mass balance. Observational data indicates that oils are difficult to disperse if they have weathered to the point where their viscosity is in the two and a half thousand centistoke range. This, then, might be a reasonable guess for the viscous range where the balance between available turbulent kinetic energy in the ocean and shear resistance in the oil shift the mean in the particle size distribution over the 70 micron limit. As oil continues to weather and form a mousse, the viscosity and combined shear resistance continues to rise and we expect this process of increased particle size to continue. Ultimately, after the oil has a viscosity in the thousands of centistokes range, the oil particles appear to have a maximum probability of being in the small tarball range, i.e. about a centimeter or two. It is interesting that this coincides pretty well with the energy scale available from the smallest gravity waves that are typically present in the ocean and, at this point, the process may depend more on the stretching and bending of the surface boundary of the ocean, than its 3-dimensional internal turbulence.

The fact that oil is floating means that it is constrained to remain near the air/water interface and this has some profound implications with regard to its behavior. First, both the atmosphere and the ocean are important in determining its motion. Secondly, 2-dimensional surface movement is fundamentally different from the 3-dimensional movement that takes place within a fluid. It is hard to overstate the significance of this 2-dimensional versus 3-dimensional movement. If oil were to dissolve in the water column and spread as a 3-dimensional dissolved constituent, then spill response as we presently know it would not exist. This is because no known recovery procedures would be practical. (The problem would be like trying to recover smoke after it left a smoke stack.) In addition, the oil could never re-coalesce or re-aggregate to form high concentrations on distant beaches, or surface ocean convergence zones. And, finally, the dispersion and spreading processes would localize the size of the impact area reducing it by typically an order of magnitude. To put this in perspective one can consider the differences in the results of the spills from the *Exxon Valdez* (NOAA, 1989) and the *Braer* (Thomas and Lunel, 1993).

In general, any oil is subject to the same physical processes and tend to go through the various phases that are outlined above but there are significant variations for particular refined products and some crude oils. Some of these are perhaps worth a brief comment.

Light refined oils such as gasoline, jet fuel and diesel typically have very high evaporation rates and do not tend to create persistent slicks. They very quickly go to thin films and show lots of rainbow and silver sheens. If they reach a coastline within a few hours, a slight staining, or soot-like bathtub ring (in the case of diesel) is common. These oils don't usually form a mousse and don't result in a heavy or sticky residual to clean up. It should be noted that these lighter refined products do have a relatively high amount of light aromatics and tend to be more soluble and more toxic than heavier oils. So, even though these oils may not present an involved cleanup problem, they can result in an initial toxic shock to biota and persist as a biological threat problem in low energy marine environments.

Heavy refined products such as intermediate fuel oils (IFO) and bunkers are, in some ways, the opposite of the lighter oils. The refining process has removed the lighter components and left them somewhat pre-weathered. As a result they don't change as much as they age and may result in quite persistent floating pollutant problems. These oils can occasionally form a mousse, but usually only slowly, and after a period of days. These oils may not spread into very thin films and often simply break up in smaller patches and then tarballs. It is also common for these oils to lose enough of their light ends so that they do not rapidly form sheens and the resulting scattered tarball fields are very difficult to observe using visual, or remote sensing techniques (Pearlman et. al., 1992). This, combined with the persistence of the tarballs, makes these spills quite likely to result in long range, and occasionally unexpected, beach impacts.

There are a few crude oils and some heavy bunker fuels that are heavier than water and thus don't float. These sinking oils are rare and any reliably documented observations of them are even more rare, but from the few encounters that we have seen, some behavioral characteristics are apparent. In anything but calm currents (i.e., a very small fraction of a knot), the oil will not settle out on the bottom without additional weathering or sedimentation. If the temperature of the water is above the pour point of the oil the differential surface tension seems to be such that the fluid oil typically disaggregates into small "BB-size" droplets that disperse and move throughout the water column pretty much like a neutrally buoyant tracer. In some cases, there is some indication that the distributed oil may favor the lower part of the water column. A good example of a very heavy residual oil that moved along the lower part of the water occurred in the Columbia River (the*Mobiloil ,1984*) (NOAA, 1984). In any of the cases that we have investigated, there is no tendency for the oil to aggregate or pool up and the dispersion processes appeared to follow 3-dimensional spreading laws, thus limiting the distances where the spill is directly observable to a few tens of kilometers. Again, this is in the absence of sedimentation. The incorporation of sediment with heavy oils has resulted in some aggregation offshore of impacted areas in the form of tarmats.

Physical Processes

One of the first questions after a spill is "where will the oil go?". Any floating pollutant will move along with the water that it is floating on. Unavoidably, then, any attempt at spill trajectory analysis will require that we start looking at the currents, or circulation. This turns out to be a non-trivial problem and more often than not is poorly done . To start with, the patterns of the current are important; as well as the time scales of the movement. A single number (or vector) is never enough and, as the spill approaches the shoreline and encounters the complex shapes of cusps, spits, beaches and inlets, a surprising amount of detail may be needed. This turns out to be such a complex problem that virtually all spill models take the approach that some external computational module will solve the problem. The output from this stand alone hydrodynamic program (or perhaps a number of stand alone programs) will be used in the spill model as input data. There are many alternate ways that these stand alone hydrodynamic units can be designed, but there are some minimum general features that seem to be required for anything but the simplest cases. The approach should be able to deal with realistic geophysical shapes and be capable of variable scale resolution (since most significant spills start off small and end up large). To meet both of these requirements finite element analysis methods are useful, but finite difference procedures should also work if they are correctly configured.

In addition to the above mentioned requirements, there is an additional circulation feature that absolutely must be accounted for when describing any current field that is to support a trajectory model of floating pollutants. The divergence field of the flow has a profound influence on oil spill trajectories and, in many cases, dominates how the spill will end up and what options might be available for response activities. To be specific, floating material will collect at convergence points and along convergence lines. This has the effect of gathering together scattered patches of oil and, in some cases, widely separated tarball fields, to form new and greatly concentrated bands of oil. This process is absolutely dependent on the 2-dimensional movement of the oil (which is constrained to float on the surface), and the 3-dimensional movement of the water (incompressible flow where any vertical motion away from the surface must be compensated for by a horizontal flow moving together to replace it). There is no analogous behavior for full 3-dimensional pollutant dispersion and this is what makes the difference between smoke from a stack which is seen to disperse (always leading to smaller concentrations with increased travel time), and oil slicks which may spread out initially and seem to virtually disappear, only to converge again recreating a threatening spill perhaps hundreds of kilometers from where they seem to have gone away. To avoid this problem is one reason why chemical dispersants might be useful on an oil slick. It is also likely that if it were not for this process resulting in re-concentration in convergence zones, skimming operations at sea would be absolutely futile. It is also of interest to note that convergence zones are often associated with increased marine biological activity and become a local habitat for sea birds and, when oil collects in these areas, it can pose a significant threat. Strong and persistent convergence zones also collect great deals of other flotsam such as driftwood, floating kelp, and styrofoam. When this material gets mixed with oil it may complicate the recovery and clean up considerably. It is really impossible to do an initial trajectory analysis without an understanding of the current speed and direction but if the divergence and convergence of those currents are not know then it is equally impossible to understand how the spill trajectory will proceed and where the oil will end up or how it will look when it gets there. The first part of this problem seems well understood, but the second part is less widely recognized and numerous spill models have used statistical or non-coherent derivations for current patterns (such as from a ship drift atlas) which may have significant errors in the divergence fields. Extended trajectories using these methods occasionally lead to peculiar results that are very difficult to interpret. All in all, this is a tough problem and I know of no computational procedures that can fully handle the difficulty, even if the largest available computers were brought into the effort. It seems, for the present, that careful resolution of bathymetry and analysis algorithms that strictly conserve mass will help reduce obvious errors, but observational and empirical input are required for satisfactory operational results.

Ocean waves affect the movement and spreading of oil spills in several different ways and the relative importance of these processes change as the pollutant weathers. Initially, as the oil spreads to form a thin film, short gravity waves are absorbed by the film. This is the reason that an oil film is called a "slick". It looks smooth compared to the water around it. The thinnest transparent films are really only distinguishable by this change in surface roughness. It is a bit like looking at the difference between cotton and corduroy. In any case, as these waves are absorbed by the oil film, there is momentum transferred from the waves to the film. This has two effects. The first is that, as waves approach from a dominant direction, they tend to push the oil film or slick along. This means that floating oil films will actually be moving over the top of the water that they are floating on. This differential oil-water velocity has been measured a number of times at spills and turns out to be between 0.7% and 1.4% of the observed wind speed. Note that although this is a wave dependent phenomena it correlates pretty well with the wind since it is the wind that generates these small waves.

The second effect that small waves have on oil films is that even though there is a dominant wave direction, some small number of waves come from all directions around the slick and as these transfer momentum to the oil there is a slight compressional stress that tends to inhibit the slick from spreading. Although there are a number of other processes that seem to override this effect, there have been occasions in many spills, particularly when the winds are light, where a patch of oil will resist spreading and move for extended periods of time as a single large pancake. This wave/oil-film interaction will tend to be significant as long as the oil continues to make a slick. It will be reduced somewhat as the oil breaks into streaks and streamers. As the oil weathers and forms tarballs this wave stress and momentum transfer becomes negligible.

A third transport mechanism that is associated with ocean waves is that for short, relatively steep, waves there is a slight current generated. This is usually referred to as Stokes drift and will actually result in a small surface current that will move the oil along in the dominant wave direction which, once again, is really in the direction of the observed winds since it tends to generate these type of waves.

A fourth process that is associated with waves is dispersion, which has already been mentioned in the previous section. This process is related to the turbulence created by the waves and is thus not so much dependent on the general wave field, but rather on that fraction of the waves that are breaking. As waves break the plunging water that results creates turbulence and can carry particles of oil down into the water column. If the resulting particles are small enough then their rate of re-floating is so slow that they are essentially removed from the surface and are "dispersed". For larger particles these excursions below the surface are only temporary and they can be thought of as only spending some fraction of their time away from the surface. When there are large breaking waves present, oil particles or tarballs can be driven some distance below the surface; this process is often referred to as overwashing. As larger fractions of the oil particles are driven below the surface the actual spill becomes progressively more difficult to observe from the air. Under these conditions it is not uncommon for reconnaissance flights to report that the spill has dissipated, only to find that it has returned to be very much in evidence when the weather gets a bit better. This disappearing act and the fact that from a boat it is often possible to observe a tarball below the surface has led to reports at nearly every major spill that the oil is sinking. During the *Ixtoc I* spill in the Gulf of Mexico, divers were used to collect information on the subsurface distribution of tarballs and it was found that the concentration distribution had a similar pattern to what is seen in dust distributions over the ground. Under strong wind conditions the tarballs extend deeper into the water and during quiet conditions they move back towards the water surface. It appears that oil sinks in the same way that dead leaves fly from the ground. Actual sinking, in the sense that oil is removed from the surface for good, only occurs if the density of the pollutant is greater than the water or the pollutant has been mixed with enough sediment; these are relatively rare events.

It is commonly understood that wind has a significant effect on the movement and spreading of oil spills. This is true, but the effects are not direct, but rather through other processes that the winds cause, which in turn effect the movement of the pollutant. The wave processes that were mentioned above are examples of this indirect wind forcing. As we have seen, it is not the wind that is interacting with the oil, but rather the waves which, in turn, are well correlated with the observed winds. Therefore, from an algorithmic point of view, the winds become one of the primary prediction parameters.

In addition to forming waves, wind stress on the ocean drives a number of complex surface currents that will also contribute to the movement of floating oil. The actual dynamic processes of how the wind moves the water are very involved and require extensive non-linear mathematics to develop a reasonably complete theory. Fortunately, it is not necessary to understand all of these details, and, for the purposes of trajectory analysis, it is enough to use simple theories and settle for a description of the processes that we cannot technically predict. The primary current directly caused by the wind is the movement of a thin surface layer. In the original theories to describe this current the flow direction was at 45 degrees to the right of the wind, in the northern hemisphere. A more detailed analysis suggests that the deflection angle is considerably less than that and is more likely to be in the 10 degree range. As a practical response algorithm it is usually adequate to simply assume a wind driven surface current that has a velocity which is 2% of the wind speed and in approximately the same direction as the wind. (It should be remembered that when forecasted winds are being used for trajectory analysis, they are typically only specified by quadrant direction so that the errors associated with a few degrees are usually not significant.)

The 2% wind drift rule is a reasonably good approximation to the primary wind driven flow, but a closer look shows that the actual first order flow is unstable and tends to break up into more complex patterns called Langmuir cells. Langmuir cells are particularly important to floating oil because they result in surface convergences and divergences. As we have already seen, convergence zones can have a profound effect on the distribution of floating oil.

Langmuir cells begin to appear if the wind becomes stronger then a few knots. This flow is characterized as a series of alternating bands which are oriented in the direction of the wind. Within every other band the surface flow moves downwind and to the right or left. A small convergence line forms between adjacent bands where the flow comes together and divergence zones form at the boundary between bands where the flow tends to separate. At the convergence zones the water sinks and then returns moving still downwind, but with a crosswind component opposite to that at the surface. In some respects, it is as if the water were moving along a series of alternating right and left handed corkscrews which were laying in the surface and pointing in the direction of the wind. The distance between adjacent corkscrews, or convergence lines, varies from a few meters to some tens of meters. Obviously the surface flow is still generally downwind, but much more complicated in the detail.

A floating oil film will be effected by this current pattern and there will be a tendency for it to thicken and collect in the convergence bands. Between the convergence bands where the surface flow is diverging there will be a tendency for the oil film to rupture and form a banded gap. Putting these together it is likely that the presence of Langmuir cells will result in a distribution of floating oil that is banded, or in streaks and streamers oriented in the direction of the wind. We can note that this process is somewhat counteracted by the compressional wave stresses that are mentioned above so that the rupturing of an initial patch or film of oil is by no means a precise event. Under strong wind conditions oil slicks rupture and become banded quite quickly, often within minutes to hours, depending on the type of oil and the size of the spill.

There are some significant implications of floating oil distributions that break up into streaks and streamers under the influence of Langmuir circulation.

It is often thought that oil spills form a more or less continuous layer of oil. Once it breaks into streaks and streamers this is obviously not the case and over any particular region the major portions of the oil may only cover a relatively small fraction of the actual water surface. Many clean-up procedures, such as applying chemical dispersants, suggest that it be applied at rates that depend on the thickness of the oil and the area covered. In this case it is not at all clear what area the oil covers and any spray application will certainly be treating primarily open water. This fractional surface coverage is also significant for many remote sensing attempts to observe oil. It may be that the oil extends over a very large area, but in the vast majority of that region it is present as streaks and bands such that a pixel footprint of the sensor is actually looking at mostly open water and a weak or ambiguous signal is returned.

Up to this point a number of different physical processes have been identified that are related to the observed winds; wave stress, wave compression, Stokes drift, dispersion, over-washing, surface drift and Langmuir circulation. It is quite common in spill trajectory simulations to lump all of these together into a wind drift factor which is usually taken to be 3% of the wind speed. This is an extremely useful approach, but it does simplify a great deal of what is going on. When the oil initially forms a film the wave stress, Stokes drift, and surface drift might add up to something closer to 4.5% of the wind speed. At the other extreme, as the oil weathers to tar balls and over-washing takes place, the oil may spend a significant part of its time away from the surface and out of the influence of most of the processes associated with the wind and an average drift factor of less then 2% of the wind might be more appropriate. More advanced algorithmic approaches should at least have the ability to treat wind drift factors as something more then a constant, but even with this there will still be the need for observational support and feedback during actual spill events. Once again, an understanding of these processes has some implications on spill response activities. A number of experiments have been carried out to try and design a buoy that will drift on the surface of the ocean in much the same way as oil so that it can be used as a tracking device during spills. Considering how varied the processes are that the buoy would have to replicate this is a difficult task. At the extremes; during the initial part of the spill it would have to act like an oil film and absorb wave stress like a slick, and during the later parts of the spill it would have to behave like a particle, perhaps being uncoupled from wind effects altogether for a fraction of the time. Dispite this, the approximate Lagrangian data from drifters has provided useful initialization information for planning reconnaissance flights to track moving oil slicks

As oil approaches the coastline it becomes a threat to the beach face or intertidal area. In many spills this threat and/or the actual oiling of the beach becomes a major issue and the focus of most of the spill response activities. As is often the case a number of different processes interact to control how, or if, the oil actually impacts the shoreline. To start with, ocean currents cannot actually bring the oil in contact with the beach face unless there is some kind of flow that actually penetrates the coast, such as percolation into a marsh or mangrove swamp. The reason for this is that as currents approach the coast, the volume of water is deflected from the normal to the beach and the flow must elongate along the beach face. Large scale currents never run into the beach, but rather turn and run along the beach. Along a relatively exposed beach the small scale processes associated with flow in the surf zone also become important. Wave transport and possibly wind drift will transport oil through the surf to within the swash zone. In this area, alongshore currents develop as a result of the wave transport and these will advect the oil parallel to the shore between the surf zone and the beach face. "Rip currents" develop when these alongshore currents build up to something on the order of a knot. These rip currents extend perpendicular to the coast and out through the surf zone to a distance of several hundred meters offshore. Putting this all together it, as oil approaches the shore it moves laterally through the surf zone to be re-injected outside the surf zone by the rip current process, where the process starts again. The net result is that as oil approaches the coast it seems to change directions and spread out parallel to the beach over a longer section of coast than would be suggested by its angle of approach.

The actual beaching of oil occurs when there is a component of the wind that is onshore. This allows the floating oil to actually be pushed against the shoreline. If the wind is very weak or is offshore then essentially no beach impacts are seen. An additional factor that greatly increases or decreases the amount of oil stranded is whether the tide is rising or falling. Heavy oiling takes place with onshore winds and falling tides. While the tides are rising or winds are calm, steady coastal oiling is greatly reduced. One of the consequences of this mechanism is that most oil is stranded in the upper intertidal zone. From a statistical analysis of this process, about 75% of the oil should strand within the upper half of the intertidal region; observations certainly tend to support this.

Once oil has stranded on the shore it will start to wet the surface and may soak into the interstitial spaces in the beach. Subsequent high tides and a wind with an offshore component will tend to wash some portion of the oil back into the water and may act like a secondary source to the trajectory analysis problem. The amount of re-washing that takes place will depend on the type of oil and the character of the beach face. For example, rocky headlands may release most or their oil over a few tidal cycles and protected marshes may retain heavy oil concentrations for years.

Oceanographic and Meteorological Factors

It will not be possible to outline all of the physical oceanographic and meteorological processes that are relevant to the pollutant transport problem in the ocean in this paper, but an attempt will be made to point out some of the most important factors and consider their relative scales of significance.

Nearshore the strongest currents are often associated with the tides. The ebb and flow of the water in bays and inlets will certainly carry pollutants back and forth, it is always useful to have some idea about how important these might be. Assuming that the tides are simple harmonics, with a major semidiurnal component, then the total movement over a tidal cycle will be given by;

$$excursion = 12.4 \times V_{max}/\pi$$

Where V_{max} is the maximum expected flood current. In other words the tides are likely to move the oil back and forth nearly 4 times the maximum velocity. (For a 1 knot current the excursion will be about 4 nautical miles over a 12 hour period.) This gives a quick estimate of the relative importance of the tides in the trajectory problem. If this distance turns out to be less then needed, or expected, accuracy of the estimates it may not be necessary to include detailed tidal current analysis in the considerations. There are a lot of regions where tidal current velocities are not accurately known, particularly in small inlets. For this type of region an alternate scaling estimate can be obtained by calculating the volume of the tidal prism (area of the bay * rise in tide) and divide that by the cross sectional area of the inlet mouth. Once again this kind of estimate can be used as an initial screening for the decision of whether to include a tidal analysis as part of the trajectory problem. Both of the estimation procedures mentioned will only give an indication of the current at the mouth of a bay. What is actually needed is a pattern of the currents as they fan out both inside the bay and outside the mouth. To solve this problem it is absolutely essential that the analysis include a realistic representation of the bathymetry. For this type of detail, local data is needed, but once this is available, a relatively simple numerical procedure can give quite satisfactory estimates of the tidal displacements within a bay and the region of influence ("inhale distance") from which a pollutant might be pulled into the inlet on a tide cycle.

There are other transport processes associated with tidal currents that are much more difficult to estimate, but which may be very important in the trajectory analysis problem. These are the eddies and horizontal mixing that are caused by the shear in the tidal flows. In particular, during strong ebbs and floods the movement of pollutants is pretty well specified by the simple considerations that are outlined above. As the currents approach slack water, however, the currents don't actually stop, but rather tend to break up into a series of eddies. These swirls make a significant contribution to the cross-channel mixing and spreading of pollutants, but the details are virtually impossible to model using presently available procedures. The solution which has been useful in operational forecasts is to increased diffusion, or mixing coefficients in the formulations and use care in the interpretation of the results.

Another tidal process that may be significant for oil spill problems is the flows that are associated with internal tides. In some stratified areas a tidal wave forms on the interface between lighter surface layers and the more dense lower layers. The currents that result from these tides are generally weak, but they may create surface convergences that can collect the floating oil. Like other convergence phenomena these will control, at least locally, the distribution of the pollutant. Internal tidal flows can be calculated numerically, but it is a significant effort and is usually not done for spill response. In present day operations it is more typical that a trained observer will recognize the process and include descriptions of it in the trajectory analysis briefings.

After the tidal considerations are settled, the residual, or background current is of interest. Unfortunately, the residual currents can be made up of a staggering array of dynamic possibilities including estuarine flow, geostrophic shelf currents, mesoscale eddies and all sorts of shelf waves. To try and put these in perspective is properly in the domain specialty of an experienced physical oceanographer. At this point we will not try and make any attempt to sort this dynamic zoo, but we can note that the oil spill trajectory analysis problem is essentially related to floating oil. This means that the most useful computational or analysis procedures will be the ones that concentrate on the surface currents. It turns out that these are typically also the most technically accessible so, with not quite the conviction of a rule, it is certainly advisable to start out with simple approaches and add complexity only at the demand of operational necessity. This advice may seem to be counter to the so called "state of the art" capabilities of modern computational oceanography, so some sort of a discussion of the spill response environment is in order.

The initial alert associated with a spill is typically in a data starved situation. It is not uncommon to only have a vague idea where the spill took place. The amount of product that was spilled is hardly ever known during the initial response and a significant fraction of the time multiple cargoes may be involved in unknown ways. With this much uncertainty the one thing that is sure is that additional information will be required and, as the spill goes on, the best source of data will be the details of the Lagrangian experiment and field test that is going on, i.e. the spill itself. It has been demonstrated over and over that it is useful to have relatively simple computational procedures which can be quickly reinitialized as new data becomes available. These more basic approaches (provided that their limitations are known and factored into the final trajectory analysis), are invariably preferable to more complex and complete dynamic simulations that cannot be supplied with real time boundary conditions. It is also clear that any successful trajectory analysis support activity will require an immediate tie-in with the actual response operation, preferably with trained observers from the trajectory analysis team as part of the response.

In the face of all the complexity and difficulties that are associated with understanding the oceanographic and meteorological processes that are required to support operational trajectory analysis it is tempting to think that a good deal of the setup and description of the wind and flow fields could be done before the spill occurs and the idea of a model based on climatology has been proposed a number of times. In this case, a most probable statistical representation based on past history would provide the input for a quick response model. Although this idea has considerable merit for planning and training models, it is a conspicuously bad choice for a response model. If you were trying to plan an office picnic for next spring it would be useful to know that May is generally a dry month. On the other hand, if you were trying to decide whether to go for a picnic this afternoon you would look out the window; the average conditions are not of interest. Similarly, climatological data will be of some use in spill response and planning to establish the range of possibilities that one might expect, but, even as vague as it usually is, the initial spill notification will do more to establish where the spill is in terms of geophysical situation space than relying on an unguided statistical guess.

In previous sections, the importance of surface convergence zones has been stressed. These oceanographic processes have a profound effect on the outcome of most spills and it is worthwhile to consider the oceanographic conditions that lead to their formation. Within the ocean, divergences occur at all scales from the smallest ones associated with surface waves and Langmuir cells to basin wide phenomena such as in the Sargasso Sea around Bermuda. For most spill response activities we are specifically concerned with the intermediate size convergences; these are typically associated with two particular processes.

The first of these is where a barotropic current moves over a change in depth. In this case we can think of a column of water that moves in a horizontal direction. As it encounters deeper water the length of the column must stretch so that it extends from the surface to the bottom. Since the volume of the column cannot change (water is incompressible at this scale), the vertical elongation must be compensated for by a horizontal compression. Oil floating on the horizontal surface will of course also compress and thicken. A common form of these convergence zones is referred to as "tidal rips" and they are often semi-permanent features of coastal and estuary regions, at least during some stage of the tidal cycle. This particular type of convergence zone depends on relatively simple dynamics (barotropic flow) and detailed bathymetric data. As such, it is often possible to calculate or predict where and when these convergence zones will occur and factor them into the overall trajectory analysis.

The second type of intermediate size convergence is associated with density variations in the water and occur in conjunction with sources of fresh water, either from large estuaries or where rivers meet the ocean. The mechanism that leads to the convergence is that a relatively light layer of water will spread out as a thin layer or wedge. As horizontal currents run into this layer they will typically slide under them, the surface where they meet forms a convergence zone. The common oceanographic description of this type region is a front. This type of convergence zone is quite difficult to predict since they fundamentally depend on baroclinic processes and small scale turbulence as well as upper ocean dynamic processes. The usual operational approach for factoring these into trajectory analysis is to observationally map them during the initial reconnaissance phase of a spill. There are some areas where this type of convergence zone, or front is a semi-permanent feature. Good examples of this type of convergence can be seen in Lower Cook Inlet, at the mouth of the Columbia River and along the Louisiana Coast. It should be noted that in some respects these fronts often act as a trap that holds the oil offshore and thus protects beaches and coastal areas (this configuration. however is still a significant threat to sea birds). The most pressing trajectory analysis problem is to try and determine under what conditions the density front will break down and release the oil, thus threatening the beaches. Breakdown of a density front can occur when there is major wind mixing, like tropical storms, or when the tidal velocities through an inlet are strong enough to provide the energy to mix the stratification, such as at the mouth of Galveston Bay. These occurrences are technically very difficult to handle and the typical results of trajectory analysis on this class of problem are not particularly impressive.

Trajectory analysis requires a description of the wind field distribution for at least as long as the desired forecast period and, in many cases, this is what sets a practical limit on how long into the future a projection can be carried out. Detailed forecasts are difficult to make, particularly in coastal areas that may have sparse reporting stations and significant localized effects such as sea breezes, or drainage winds. In carrying out a trajectory analysis it is essential to compare forecasts with observational data so that accuracy estimates and potential variability can be factored into the overall uncertainty analysis that goes with the trajectory forecast. As the required forecast period extends farther into the future more uncertainty is inevitable and, eventually, a fallback to climatological statistics is about the only practical option. Obviously the presentation of the analysis results and the technical briefing that goes with it must make the degree of uncertainty clear.

Modeling Procedures and Error Analysis

At the core of many trajectory analysis procedures are a series of computational algorithms or numerical look-ups into databases. These are usually referred to as trajectory models and, for many people in spill response, it is assumed that these models are totally responsible for the trajectory analysis process. For the present this view is naive. There are really no available systems that can be used as stand alone, or turnkey trajectory analysis components in an operational spill response and, if experienced personnel are not available to set up and interpret results, then there is a significant chance of getting results which are of marginal use, or perhaps even misleading. In spite of the fact that computational systems cannot answer the entire trajectory analysis problem they are still a substantial help and it is worthwhile to consider some of the computational features of algorithms that have proved useful in a number of practical models.

In previous sections it has been mentioned that trajectory analysis must be able to handle variable scale resolution because most significant spills start off small (usually from a point source) and become large. To handle this numerically, all major spill models have gone to a mixed Eulerian/Lagrangian formulation where the oil is represented as a number of particles that are embedded in a series of vector fields that represent the advective processes due to winds and currents. Each of these particles represents some amount of oil and can have associated with it attributes that describe its age, type, weathering state, beached status, etc.. The actual distribution of the oil is then represented by clusters or swarms of oil particles. This type of formulation has proven extremely powerful and is free from the numerical dispersion that would be a problem from small sources in a purely Eulerian formulation. There are some facets of this approach that are limiting. The first is that as the pollutant particles move and spread, the spacing between them may become large and, for any particular area, the oil may be represented by a small number of particles. Such distributions are clearly patchy and it is not clear how to interpret or describe the results. One solution to this problem is to let large initial particles partition into numerous smaller particles, but that typically only puts off the problem. A statistical presentation is often appropriate but, to get useful statistics, it is sometimes necessary to use a large number of particles and, as usual, the briefing or description of what the model is showing must be carefully prepared. The models that are presently in use typically represent spills using between several hundred to several thousand particles. Using the higher numbers it is possible to talk meaningfully about distributions around the fringe of the spill that are in the few percent range, but none of the presently available models are reliable for details below this limit.

A second implication of representing the pollutant distribution as a cluster of points is that oil density data is not directly available. This mean that algorithmic processes that are non-linear in terms of the oil distribution cannot be directly represented. Considering the accuracy to which background geophysical fields are known and the overall computational sensitivity of the trajectory analysis process, this is not a serious handicap for the forecasts of the pollutant distribution. The same is not necessarily true for looking at the implications of the spill as it interacts with sensitive resources. For example, to determine the impacts of oil on sensitive coastal resources it is often desirable to have an estimate of the actual oil density. There are several ways to go from a Lagrangian point distribution to a Eulerian density distribution and many models provide for some mechanism to do this as part of a post-processor step that displays the data. The simplest way to do this is to divide the domain into cells and count the number of particles in each cell, then present the results as a rastor map. This is a very fast routine but has the weakness that it becomes patchy around the fringes and the answer will depend, to some extent, on cell size. An alternate approach is to partition the point distribution domain into Thiessen polygons and a triangular mesh. This is computationally more difficult but provides a continuum and contourable representation of the pollutant density data.

In most trajectory models advection processes, which include currents and wind drift factors, are handled as external data that is calculated, or entered as though they came from an independent procedure. Computationally, they can be thought of as functions that any Lagrangian particle can call, with position and time as parameters, and an advective displacement is returned. In its most general form, these are multi-dimensional look up tables which could be handled by very large databases or interactive programs, but a number of simplifications are possible and, in general, they seem to provide sufficient accuracy to be operationally useful. An example of this is to use a separation of variable approach, where a spatial pattern is modulated by a separate time dependent amplitude function. Then combinations of patterns and modulation functions are added together to represent complex flows. Models that handle up to a dozen alternate advective patterns usually provide enough flexibility to represent at least as much of the flow complexity as is understood at the time of the trajectory analysis.

For anything except solid objects that float in the ocean there will be small scale shear effects caused by turbulence and unsteadiness in the currents, or wind. Because of this, any collection of particles will tend to spread out and the mean distance between them will increase with time. This process in independent of convergence zone effects and acts in a way that is opposite to them. For small convergences, these turbulence effects will tend to dominate and, even though the oil distribution might remain banded in Langmuir cells, the convex hull of the oil distribution will continue to increase in area with time. For large scale convergences, turbulence effects will tend to be overshadowed and the oil distribution may be compressed into quite narrow zones. The standard approach that is used to simulate these turbulence processes is to use a Monte Carlo representation of the diffusion operator. This amounts to applying a statistical random walk algorithm to each of the Lagrangian particles for each time step. The size of the random step is usually adjusted to simulate observational data as soon as it is available. Prior to observational input, nominal standard oceanographic values give acceptable results. There are cases where some improvement in the model results may be possible by using anisotropic dispersion step sizes, or shear dependent scaling, but in general the potential improvement in model results would be insignificant compared to the other uncertainties and a simple uniform random walk is adequate.

There are a number of processes that are associated with the local winds and most models represent them with a simple wind drift factor. As has been pointed out, this collection of processes will depend somewhat on the sea state, age, and weathering stage of the oil. Since the oil is represented as particles that can have attributes which may include much of this information some of this variability can easily be included into the algorithms. A relatively simple and yet operationally useful approach is to specify a range of wind drift factors (typically 2% - 4.5% of the wind speed) and then use a Monte Carlo procedure for applying this as an advective process to each Lagrangian oil particle. A slight advance on this approach is to modify the drift factor based on the individual mass, or age of the particles.

As oil weathers its physical characteristics alter significantly and, subsequently, the processes that affect its movement and spreading change. To represent these effects the weathering algorithms must be applied to individual Lagrangian oil particles. There are a number of different approaches that have been used for these computations, but generally they are simple and tend to concentrate on mass balance considerations such as evaporative loss and dispersion into the water column, rather than physical properties of the remaining oil such as emulsion formation. It is safe to say that this is an area where operational needs are not met by presently available models and a number of research projects are looking at ways to make improvements in the algorithms. Several stand-alone oil weathering models are being tested and compared with various forms of data and this may be a case where the restriction on non-linear algorithms in the mixed Lagrangian/Eulerian formulation leads to some limitations.

Oil beaching processes can be modeled using wind and tidal data. Typical algorithms exclude the possibility of currents beaching the oil, but strand it if the winds are onshore and the tides are at a neutral, or falling stage. Lagrangian oil particles that are beached are flagged as such and then subject to refloating algorithms that depend on the shoreline characteristics and whether the tide is at such a stage that the individual particles are in the water. Obviously, oil that strands on a spring tide may not even get an opportunity to refloat for a two week period and the computational procedures should consider this possibility.

Use Strategies For Trajectory Models

When most people think of trajectory analysis or trajectory modeling they assume that the modeling activity will forecast the future distribution of the pollutant based on the initial or present distribution of the oil. In this sense the models are used in much the same way as a standard weather forecast model. In fact, this is the most common first request that comes in during operational spill responses. However, this is only one of the potential ways to use trajectory models or analysis techniques. Forecasts of where the oil will go are very useful for immediate response activities, but they are limited by the length of time that weather forecasts are available. Most significant spills will last a great deal longer than that. For major spills it is necessary to carry out advanced planning that covers contingencies well beyond the time scales that are reliably covered by direct forecasts. To provide information for this longer range planning several other modeling and analysis techniques are available.

One alternate trajectory analysis approach is to focus attention on the locations of high value resources, rather than the oil distribution. This technique is referred to as receptor mode analysis. In this approach, a high value target, such as a sensitive environmental region, is identified and the problem is formulated in terms of where the oil or pollutant could come from such that it might impact the target. To solve this problem the transport processes are reversed and the spill is hypothesized to come from the target. If the results are done in a statistically correct way the output is a joint probability distribution map that gives the probability that oil coming from any particular point could move to the target. In essence this is a threat zone map. As oil moves into the threat zone it starts to represent a threat to the high value target and some protective response may be called for. It is also possible to use this same inverse modeling procedure to overlay minimum time of travel contours on the threat zone map so that response personnel can estimate not only whether a threat is developing but also how long they may have to respond to it. During large spills it is generally a good idea to look in a "down stream" direction for the spill movement and carry out receptor analysis for all major high value targets. This then turns out to be very useful for staging equipment and committing scarce resources only to threats that have a significant probability of developing.

A third type of trajectory analysis is based on a statistical use of climatological distributions for transport processes. In this statistical analysis a particular weather forecast and current regime is replaced with a sequence of wind and current patterns that represent a statistically accurate synthetic climatology. Since each realization is independent, the resulting distribution is a probabilistic representation of an ensemble of spill centroids. The correct interpretation of this representation is that it presents an envelope of the potential locations that may be threatened by the spill. It is a composite of all the places that might need protective consideration during a spill.

Obviously either of the two previous analysis techniques could be done prior to the spill and thus equally well contribute to contingency planning for spills. If they have not been done as part of a planning activity they should of course be carried out as part of the package of analysis techniques that are used to compile the overall spill response recommendations from the trajectory team.

During any complex spill response the focus and degree of concern within the activities will shift from place to place and encompass more or less detail. Modeling and analysis procedures will need to be flexible and easy to use. It is absolutely essential that any models must have the capability to quickly assimilate any new data that may become available so that they can re-establish their initial conditions. In operational response this requirement is typically far more important then trying to include progressively more complex representations of dynamic processes that may give a better explanation of the physics but cannot be supported with real time data corrections. It is important to remember that the very best full-scale representation of the spill process is the actual spill itself. If the trajectory analysis techniques cannot recognize this fact and take advantage of it, then the results will be substandard no matter how complex the algorithmic representations and colorful the data presentation turn out to be.

As important as it is to take full advantage of the information that is gathered during actual spill events, a good deal of care must be exercised to make sure that the information that is used in the analysis is self consistent. For example, current pattern observations that do not conserve mass must be re-analyzed or the extraneous convergences or divergences will destroy the usefulness of any analysis results. In addition, during any major spill literally hundreds of observers will report oil position data from overflights. Many of these observers are untrained and may not have very much experience in looking at oil floating on the sea. Under these conditions a surprising number of false positive sightings are reported. If all reports are used to correct model output the results will be chaotic at best. Under these conditions, there are statistical analysis techniques that make it possible to identify and classify variations between predicted and observed results. In many cases it is quickly possible to divide the discrepancies into physically inconsistent cases, which are likely to be false positives and errors in the transport processes, which can be used to update and calibrate model results. The small number of remaining ambiguous discrepancies can usually be easily investigated in future reconnaissance fights by experienced observers.

Conclusions

The major physical processes that affect the movement and spreading of oil have been outlined. In addition, a number of trajectory analysis procedures and possible model use strategies have been discussed. At some stage it becomes necessary to consider how to put these components together so that they can be used to support operational spill response activities. Clearly, the results should be packaged in such a way that they relate to required operational decisions and realistic response options. In general the product of trajectory analysis is a focused, detailed briefing to response personnel. Wonderful explanations of subtle oceanographic process may thrill the trajectory analyst but have no place in the operational briefing unless they relate to the questions at hand. Various data and graphic components, model output, etc. may be used; but these are component parts and tools, and individual pieces can never carry out the important synthesis that views the data in terms of the overall response activities. An important component of any briefing that the trajectory analyst must consider is the processes that are not represented and the potential errors that might occur. In can't be overstated that whenever trajectory models are used it is at least as important to know what they cannot say as it is to know what they do say. Responders absolutely want to know how much they can count on the analysis results and what the potential unresolved questions may be. A detailed briefing should also be ready to suggest additional investigations that might help resolve outstanding questions if they become critical.

It is important to remember that trajectory analysis is more then just a map of where the oil may go. Physical process data has many uses throughout the response. Weather forecasts are important for planning field operations. Current data is critical for designing boom placement and mooring strategies. The sensitivity of recommendations to possible errors in the scenario description and input data should be a standard part of the analysis procedures and the results of these uncertainties should be part of the briefing package. Models should be run forwards and backwards and statistically. The implications of uncertain input data should be explored and the error bounds mapped through to the final recommendation. In some respects trajectory analysis could be thought of as a task which tries to explore all potential situations that result from the release, movement and spreading of pollutants. This task is, of necessity, interactive because each new view of the spill as it develops changes it initial reality and requires a new round of investigations and synthesis.

Given all the pieces and components that go into trajectory analysis the ultimate usefulness of the information will depend on how relevant the advice that is generated is to the actual response. It is clear that more than just trajectory models, oceanography and meteorology are required for successful trajectory analysis support. An understanding of the spill response options and available tools is also critical. In addition, it is very important to understand operations in an environment that is initially data sparse, and driven by truly phenomenal pressures to respond immediately. Many formal and very powerful computational and analysis procedures are simply not available because the required input information is not known and could not be obtained in time to be applied to the problem. The fragments of information that are available may have high uncertainty and any projections into the future, with regard to forecasted environmental conditions or the arrival of needed response equipment will also be uncertain. In the face of all this the response community must sort out what is known, grab what can be had, in terms of equipment, and get it to the places it might do some good. While this is going on hundreds of non-responders - in government, industry, private groups and the press - are forming their own opinions based on sparse and possibly wrong data. These opinions quickly get translated into advise, or demands to the response personnel and the stage is set for the general cacophony that characterizes most large oil spills. This process seems unavoidable in a free country with an active press. The question turns out to be; is there anything that trajectory analysis can do to help guide the response, to make sure that what gains in environmental protection are possible can actually happen, and, to keep the deflection of critical attention and resources from focusing on false positives.

In some way the above situation sounds like the description of a small war, and people who have been through it at least think of it as a battle. This gives a cue as to where to look for additional analysis tools. In particular, the Navy has developed a number of procedural techniques that are referred to as operational research and operational analysis. These components are directed at the task of collecting information on how to respond to situations that have many of the characteristics that are found in the spill scenario that is described above. Of particular interest is some applications of what is called "Game Theory". In any game where chance plays a part, the player can take all of the information available and try and respond so that they will achieve a "maximize win". This would provide the best chance of maximizing their return. An alternate and generally different, game strategy might be appropriate if the player is protecting very high value resources. In this case the player would attempt to "minimize regret" rather then "maximize win".

In spill response it seems like the inherent uncertainties in understanding the spill situation and its potential to unfold into the future suggest that trajectory analysis should be aimed at supporting a "minimum regret" rather then a "maximum win" strategy. To put this into context; a " maximum win" strategy would be one where the very best estimate of winds, currents and initial distribution of the pollutant were collected and the resulting forecast taken as "the" threat that needs to be responded to. This is where a trajectory model, or analyst would "give it their best shot" and come up with a most probable scenario. A "minimum regret" strategy, on the other hand, would use whatever analysis techniques are available to investigate the sensitivity of various estimates to errors in the input data and explore the implications of alternate, plausible scenarios in the geophysical forcing functions. For example, what is the significance of an atmospheric frontal passage six hours before the forecasted time of arrival. Or, is there any historical data that suggests a coastal current reversal this time of year and if so what would the trajectory look like then. As this type of analysis takes place the investigator is exploring situation space and the briefing documents can then provide the response organization with the "best guess" and at the same time cover alternate possibilities that might present a significant threat. The major difference between these two approaches is that the second one can identify less likely, but extremely dangerous or expensive, scenarios that may require the development of alternate protection strategies. These might include the set-up of monitoring or reconnaissance activities and the identification of reserve supplies of equipment or personnel should the need arise.

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Appendix F

Quantification of Recovered Materials
Tank Gauging and Sampling
Liquid Petroleum Hydrocarbons

by David Blurton

QUANTIFICATION OF RECOVERED MATERIALS
TANK GAUGING AND SAMPLING
LIQUID PETROLEUM HYDROCARBONS

17. Gauging instructions

18. Water cut method

19. Temperature measurement

20. Equipment

21. Tank temperature procedures

22. Automatic gauging devices

23. Gauging precautions

24. Temperature measurement locations

25. Sampling of petroleum products

26. Tank sampling

27. API gravities

1. Introduction

Accurate gauge readings, average temperatures, API gravity, and the percentage of suspended sediment and water are necessary to calculate the net volumes of petroleum and its products at the standard temperature of 60°F.

The term "gauging" is applied generally to all of the duties of a Gauger, however, it means more specifically the act of manually measuring the height of liquid in a tank expressed in feet, inches and fractions of inches.

All gauges shall be taken with accurate equipment and verified until two (2) successive gauges are identical.

2. Scope

This section establishes policy, general procedures and responsibilities for gauging, temperaturing and sampling crude oil and products.

3. Compliance with Manual Procedures

The procedures outlined herein are designed to accomplish accurate measurement with reasonable effort. Where detailed instructions or procedures are to be followed without deviation unless an exception is granted for a specific location or situation.

4. Insure Accurate

Accurate measurements are of primary importance. Each Individual Performing Quantification Duties (IPQD) is to become familiar with the policies outlined in this manual and with the equipment typically used in order to insure that accurate measurement does indeed occur.

5. Safety

The IPQD must at all times, pay attention to the work at hand and be alert to any unsafe or potentially unsafe condition, practice or equipment. This includes keeping work places and equipment clean and orderly.

Other precautions and safe practices that the IPQD must be aware of are listed as follows:

1. The IPQD should always first visually inspect the site for any leaks or irregularities.

2. Take time. Trying to do the work too quickly is apt to result in careless or unsafe work.

3. Wear a hard hat and other safety equipment, as required.

4. Be conscious of the fact that it takes only a small percent of petroleum vapors combined with air to create an explosive mixture.

5. Caution should be exercised to avoid any ignition sources.

6. Smoking is strictly prohibited.

7. Know where fire extinguishers are located and check them periodically to make sure they are still charged.

8. Wear and maintain H_2S monitors in areas where H_2S has been shown to be a hazard.

9. Know the hazards of H_2S gas, and have a fresh air breathing apparatus handy at all times, when required.

6. IPQD Supplies

A list of typical equipment required for manual measuring, sampling, and testing of oil in tanks should include but is not limited to the following. Equipment necessary for particular tests or procedures is listed in the chapter which covers that test or procedure.

a. 12" crescent wrench.
b. 8" pipe wrench.
c. Vapor-proof flashlight required.
d. API-ASTM Petroleum Measurement Tables or subsets thereof for the type of petroleum or petroleum products to be measured.
e. Gauge line.
f. API Cup-case Thermometer and one refill, verified to API Standards.
g. Two hydrometers and thermometers, for each necessary gravity range (with hydrometer case).

h. Electric centrifuge machine with integral heating provision.
i. Sample Heater, where needed.
j. Four API-ASTM verified 100ml cone centrifuge tubes.
k. Centrifuge tube stoppers.
l. 1 quart weighted beaker type thief.
m. Hydrometer cylinder.
n. Demulsifier, if required.
o. Fresh air breathing apparatus, where required.
p. H_2S Monitor, where required.
q. Rags.
r. Nitrile gloves.
s. Field notebook.

7.	General Conservation	All "responsible parties" involved in the quantification of recovered oil or products are encouraged to witness the quantity and quality of measurement. However, when the responsible party involved in the quantification of recovered oil does not wish to witness or verify the operation, a Waiver should be executed and a signed copy returned to the Office of Oil Spill Prevention and Response (OSPR).
8.	Reference Point	The fixed point at or near the top of a tank from which measurements are made.
9.	Reference Depth (gauge height)	The distance from the reference point to the bottom of the tank or to a datum plate. The gauging height shall be permanently marked on or near gauge hatches or gauging platforms.
10.	Settling Time	An accurate permanent record of the gauge measurement should be made at the time the readings are taken. No gauge should be taken until the oil is at rest. To obtain an accurate gauge, temperature, and gravity, allow a minimum of two (2) hours settling time of the tank, after pumping into with recovered product.
11.	Gauging	There are two basic types of procedures for obtaining gauges:

Methods Innage Method and Outage Method. The Innage Method is preferred, however the Outage Method can be used.

Both procedures are applicable for gauging petroleum liquid in conventional and floating roof tanks which have gauge wells. Care should be taken that the final figure obtained represents accurately the depth of liquid in the tank and rounded to at least the nearest ⅛ inch, however, on tanks of 1000 bbl nominal capacity or less, the gauge should be determined and rounded to at least the nearest ¼ inch.

12. Innage Method An innage gauge or bottom gauge is the depth of liquid in a tank, measured from the surface of the liquid to the tank bottom or to a fixed datum plate.

With the smooth (ungraduated) side of the tape in contact with the rim of the gauging hatch at the reference point, lower the bob and tape into the tank until the bob is within a short distance of the bottom. This may be determined by comparing the length of tape unwound from the reel to the reference depth of the tank. Then lower the tape slowly until the tip of the bob just touches the bottom or datum plate. If the tape is lowered too far, the bob will tilt and an incorrect gauge will be obtained. Record the tape reading at the reference point and not any variance from the reference depth. Withdraw the tape quickly, read, and record the liquid level of the tape as the innage. Obtain a second gauge reading to insure accuracy. A suitable oil-indicating paste, grease, or light lubricating oil may be used on the tape. Use of chalk is not permissible as the oil or product has a tendency to creep on a chalked tape. When obtaining innage gauges, be sure that the tape is lowered to the same reference height for both opening an closing gauges. Serious errors may result if the bob rests on a rivet head, broken bottle, or other foreign material.

13. Outage Method An outage gauge or swing gauge is the distance from the reference point to the surface of the liquid in the tank.

The procedure employed is to measure the distance from the surface of the liquid to the reference point at the top of the tank. Deduction of this measurement from the gauge height will give the innage gauge.

Lower the tape and bob into the tank until the bob is completely submerged and the inch and fraction on the tape at the reference point is the same as the inch and fraction on the gauging reference depth. Withdraw the tape immediately and record the liquid level reading on the tape. Obtain a second gauge reading to insure accuracy. A suitable oil-indicating paste, grease, or light lubricating oil may be used on the tape.

Use of chalk is not permissible as oil or product has a tendency to creep on a chalked bob.

Subtract the tape reading obtained at the reference point from the reference depth. Add the difference, which will be in whole feet, to the oil cut reading on the tape and record the result as the innage gauge.

Example:

Reference Depth	41'2⅛"
Tape Reading at Reference Point	-20'2⅛"
Difference	21'0"
Reading on Tape	+ 1'1⅛"
Innage Gauge	22'1⅛"

14. Fixed Roof Tanks

Conventional tanks with fixed roofs of the cone, dome or flat roof type are not constructed to withstand any appreciable pressure or vacuum. They are designed for the storage of low or intermediate vapor pressure stock. Manual gauging operations are carried out through a gauge hatch installed on the tank top, preferably adjacent to the access ladder top. Where this type of tank has more than one roof hatch, only one hatch should be used for gauging, namely the hatch at which the tank calibrators established the reference point. The gauging hatch should be closed and secured at all times other than when measuring activities are taking place. Automatic tank gauging equipment may be installed, and may be used only as a reference with manual gauging.

15. <u>Floating Roof Tanks</u>

Computing the displacement of a floating roof as deadwood is subject to considerable error, and accurate gauges cannot be made while the roof is partly floating and partly supported on its legs (critical zone). It is essential in quantification measurements that the opening and closing measurements be taken (1) with the roof floating freely or (2) completely supported on its legs, or supports, with the oil level below the low point of the roof. The most accurate gauge can be made when the roof is floating freely for both the opening and closing gauges.

If it is necessary or advisable to lower the oil to a level below the point at which the roof floats, make a notation, "Roof Set On Legs." The Innage Gauge Method must be used when tank is gauged while roof is setting on legs.

Floating roof tanks may be gauged from the roof, only where highly volatile or sour crude oils are <u>not</u> involved. Use the innage method when gauging from the roof. Gauge floating roof tanks from the gauging platform when sour crude or volatile liquids are involved. In gauging from the platform, the outage method may be used by utilizing a reference point on the platform which has been labeled with the exact distance from the bottom. The innage method may also be used from the gauging platform.

The computed displacement of the floating roof could also be affected by the accumulation of water. Should the same conditions exist at both the opening and closing gauge, the error would be the same and cancel itself. If, however, the accumulation occurs between the opening and closing gauges, which could cause an error in measurement, other gauging methods will be used.

16. <u>Safety Precautions</u>

1. Static Electricity Hazards - To eliminate hazard from static electricity, ground your body by touching the steel stair rail, platform, or tank shell when approaching the top of a tank and before opening the gauging hatch of a nonpressure tank. In addition, make certain that contact between the gauging tape and hatch is maintained from the moment the gauge bob enters the hatch until at least such time as the bob enters the product. Never gauge a tank during an electrical storm.

2. Before opening tank gauge hatch, cover rest long enough after climbing tank to restore normal breathing. During and after

removal of gauging hatch cover, stand upwind of the open gauge hatch to avoid inhaling vapors. Be alert and wear fresh air breathing apparatus if the presence of toxic gases is indicated by a gas monitor.

17. <u>Gauging Instructions</u>

It is recommended that all IPQD's perform gauging operations in the same sequence. However, each individual should adopt a regular routine to suit existing conditions. The following is a suggested routine procedure. Actual sequence followed will vary with tank size and the sampling methods used.

Step 1: Check H_2S gas detector and equip yourself with emergency fresh air breathing apparatus, if required.

Step 2: Inspect the tank and connecting lines for leaks.

Step 3: Inspect valves on overflow lines, transfer lines, drawoff lines, etc., making sure that all valves are closed and sealed or locked where necessary.

Step 4: Make sure that the valve on the flow line to the tank is closed.

Step 5: Obtain sample for Gravity and S&W determination.

Step 6: Suspend cup-case thermometer in tank.

Step 7: While waiting for the temperature of the tank, make notes on tank number, and other information of use in completing quantification information.

Step 8: Withdraw cup-case thermometer, read and record temperature.

Step 9: Obtain the opening gauge twice for accuracy, note the time and record. Verify gauge height.

Step 10: Before descending from the tank, clean up spillage around the gauge hatch.

Step 11: After all measurements and tests are made, review the notes taken and be sure that all information is written down as to tank number, seal numbers, gauge, temperature, S&W, etc.

18. Water Cut Method

To determine the amount of water in the tank bottom, the water-cut-paste method may be used.

Water-Indicating Paste Procedures

Free water and sediment in a tank can be measured with water-indicating paste by the following procedures:

1. To facilitate reading of the water cut, apply a thin coat of water-indicating paste to that portion of the bob, or tape which will be at the interface of water and oil or product. Use of chalk or impregnated paper is not permissible. A satisfactory paste will either dissolve or change color on contact with free water, and will be equally effective in slightly alkaline or acidic water. Practice will determine how much paste should be applied to obtain a satisfactory water cut. (A thick coating increases the time required for the water to react with the paste and may give erroneous readings.) Allow the tape and bob to remain in the gauging position 5 to 20 seconds for gasoline, kerosene, and similar light products and 20 to 30 seconds for heavier products.

2. When measuring water in tanks containing heavy viscous products, apply a light, even film of light lubricating oil over the indicating paste to facilitate reading of the cut, and let the bob and tape remain in the gaging position at least 60 seconds. When gauging water in tanks containing black oils, it may be necessary to wash the surface of the paste with a light oil before reading the cut. Presence of water is indicated by change in color of the paste or by its complete removal.

19. Temperature

Tank Temperature is temperature of the liquid in the tank and shall be taken independently of any temperature observed in connection with the gravity test. The tank temperature shall be recorded to the nearest 1.0°F. Temperatures will be taken at both opening and closing gauging periods.

20. Equipment

A total immersion thermometer with etched graduated glass and a cup-base thermometer assembly approved by both API and A.S.T.M. will be used.

21. Tank Temperature Procedures

Tank temperature means the temperature of the petroleum liquids in the tank. Use the cup-case thermometer and suspend at the desired height in the liquid at least 12 inches from the tank shell. Suspend thermometers at least five minutes at each test point; viscous oils and other special conditions may require up to 15-30 minutes.

Refer to API and A.S.T.M standards for specific crude and product immersion times. While suspended at the desired test location in the crude, the thermometer shall be raised and lowered several times in the vicinity of the test point to assist temperature adjustment by intimate contact with crude to be tested. (Stability may be achieved more rapidly by removing the thermometer assembly from the tank, emptying the cup, then reimmersing the assembly several times.) Temperatures shall be taken no closer than one foot above the water oil line. Withdraw the thermometer and read immediately to the nearest degree Fahrenheit (1°F) before the oil is poured from the cup. Special care is required to insure that the temperature obtained accurately represents the temperature of the tank contents.

22. Automatic Gauging Device

Automatic or remote reading gauges may be used for reference purposes only. Do not use automatic gauges for quantification measurements.

23. Gauging - "Precautions"

a. Gauge all tanks prior to filling with recovered oil.

b. Gauges for all tanks shall be taken only if flow into or out of the tank has been shut off.

c. Tanks shall not be gauged until entrained gas and surface foam have dissipated.

d. Always gauge the tank at the "marked" reference point on the gauge hatch, etc.

e. When gauging by the "innage method" take care that the plum-bob touches the bottom of the tank or gauge plate so lightly that it does not deviate from a vertical position.

f. Never use a tank that is filled to a point higher than the "oil height" as stenciled on the tank. Where a tank is filled so that the liquid level is above the oil height, request the owner to lower the liquid level to the stenciled height before taking the gauge.

g. Always measure and record the actual opening and closing gauge. Never rely on gauges taken by others.

24. Temperature Measurement Locations

The number of locations of temperature measurements to be taken shall be as follows:

a. Tanks of 5,000 bbl capacity or less:

One -- midway in height of oil column.

b. Tanks over 5,000 bbl capacity:

1. Oil level less than 10 feet:

   One -- midway in height of oil column.

2. Oil level 10 feet or more but less than 15 feet:

   Two -- the first 3 feet from the top; the second 3 feet from the bottom of the oil column. Average the two temperatures for recording on ticket.

3. Oil level 15 feet or more:

   Three -- the first 3 feet from the top; the second midway; and the third 3 feet from the bottom of the oil column. Average the three temperatures for recording on ticket.

4. The bottom temperature reading should never be taken closer than one (1) foot above the water level.

25. Sampling of Petroleum and Petroleum Products

Samples of petroleum and petroleum products are taken for the purposes of determining API gravity and suspended S&W. It is therefore essential that the samples taken be representative of the general character and condition of the petroleum or petroleum products in question. The importance of proper sampling and sample handling cannot be overemphasized. One basic sampling method is used for tank sampling.

Take samples in sequence from top to bottom of the oil column to avoid disturbing the oil and obtaining erroneous samples.

a. Field Tanks over 1,000 bbl capacity.

   i. Middle Spot (oil height under 10 feet) - Take the sample midway, vertically in the oil column.

   ii. Two-way (oil height 10 to 15 feet) - Take spot samplers one foot below oil surface and at the level of the outlet connection.

   iii. Three-way (oil height over 15 feet) - Take spot samples one foot below oil surface, middle of the oil column, and at the level of the outlet connection.

26. Tank Sampling

All-Levels Sample

Lower a weighted, stoppered bottle or beaker to a level no closer than 1 foot from either the tank bottom or top of water level. Pull out the stopper with a sharp jerk of the line and raise the bottle at a uniform rate so that it is about three-fourths full as it emerges from the liquid. If bottle is full or less than three-fourths full, the sample should be discarded and rerun.

27. API Gravity General

Accurate determination of the API gravity is required for the conversion of measured volumes to equivalent volumes at the standard temperature of 60°F.

Relative Density (specific gravity) is the ratio of the mass of a given volume of liquid (oil) to the mass of an equal volume of pure water at 60°F.

API Gravity (API) is a specific function of relative density (specific gravity) represented by:

$$° API = (141.5/\text{Relative Density } 60/60°F) - 131.5$$

The API Gravity Scale has been adopted industry-wide and is and arbitrary scale that puts gravities in easier terms to use. Each API gravity has a corresponding relative density (specific gravity).

Appendix G

California Code on Hydrocarbon Recovery

DRAFT

No. 7 Date January 5, 1996

CALIFORNIA CODE OF REGULATIONS
TITLE 14. DIVISION 1
SUBDIVISION 4. OFFICE OF OIL SPILL PREVENTION AND RESPONSE
CHAPTER 7. ENFORCEMENT
SUBCHAPTER 2. DETERMINING AMOUNT OF PETROLEUM HYDROCARBONS RECOVERED
SECTIONS 877 - 880

Article 1. General Provisions and Definitions.

877 Purpose and Scope.

The regulations in this subchapter set forth the methods for determining the amount of liquid petroleum hydrocarbons (oil) recovered. These methods will be used to reduce the penalty assessed in Sections 873 through 876 for every gallon of discharged liquid petroleum hydrocarbon that is recovered and properly disposed of in accordance with applicable law. The term "disposed of" shall include liquid petroleum hydrocarbon (oil) that is reprocessed, recycled, or otherwise utilized as an ingredient in the manufacture of petroleum products or other products.

Note: Authority: Section 8670.65.5 Government Code.
Reference: Section 8670.67.5 Government Code.

877.1 Exemption

(a) Unless otherwise exempt, the amount of petroleum hydrocarbons recovered shall be determined pursuant to Sections 877.3, 878, 879 and 880.

(b) Not withstanding Section 877.2(a), for spills of 50 barrels or less, the Administrator and Responsible Party or potentially Responsible Party shall not be precluded from entering into a binding agreement whereby the parties stipulate to the amount of oil spilled and/or recovered. Such agreement shall be binding on the parties for purposes of the civil penalty action only.

Stipulations may be entered into where the parties determine that it is in the interest of justice to do so, or volumetric determinations under these standards would be cost prohibitive on balance.

Note: Authority: Section 8670.65.5 Government Code.
Reference: Section 8670.67.5 Government Code.

DRAFT

No. 7 Date January 5, 1996

877.2 Definitions.

In addition to the definitions provided by Section 790 of Title 14, the following definitions shall govern this subchapter. These definitions shall supersede any duplication in Section 790, Title 14:

(a) "API" refers to the American Petroleum Institute. The American Petroleum Institute, in conjunction with the American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), British Standards Institute (BSI) and the Institute of Petroleum (IP), has developed standardized methods and formulas to calculate measured quantities of petroleum fluids regardless of point of origin, destination or unit of measure used by custom or statute.

(b) "ASTM" refers to the American Society for Testing and Materials. It is a scientific and technical organization formed for the development of standards on characteristics and performance of materials, products systems and services.

(c) "EPA" refers to the United States Environmental Protection Agency.

(d) "EPA Method 8015A" is a procedure used to determine the concentration of various volatile organic compounds. EPA Method 8015A, Nonhalogenated Volatile Organics by Gas Chromatography, June 1992, is hereby incorporated by reference.

(e) EPA Method 8270B" is a procedure used to determine the concentration of semi-volatile organic compounds. EPA Method 8270B, Semi-volatile Organic Compounds by Gas Chromatography/Mass Spectrometer (GC/MS): Capillary Column Technique, September 1994, is hereby incorporated by reference.

(f) "EPA Method 3550A" is a procedure used for extracting non-volatile and semi-volatile organic compounds from solids such as soils, sludges and wastes. EPA Method 3550A, Ultrasonic Extraction, September 1994, is hereby incorporated by reference.

(g) "EPA Method 3540B" is a procedure used for extracting non-volatile and semi-volatile organic compounds from solids such as soils, sludges and wastes. EPA Method 3540B, Soxhlet Extraction, September 1994, is hereby incorporated by reference.

(h) "Flame Ionization Detector (FID)" is a detector, used in combination with a Gas Chromatograph, to analyze for saturated hydrocarbons, alkanes, alkenes and unsaturated hydrocarbons.

(i) "Gas Chromatography (GC)" is an analytical technique used to determine the sample concentration of total petroleum hydrocarbons (TPH).

(j) "Gauge" refers to the act of manually measuring the height of liquid in a tank expressed in feet, inches and fractions of inches.

(k) "Incident Action Plan" is a document that contains objectives reflecting the overall incident strategy and specific tactical actions and supporting information for the next operational period. The Plan may be oral or written.

(l) "LPH" refers to liquid petroleum hydrocarbons. It is a measured volume of recovered product or crude oil.

(m) "Recover" refers to getting or obtaining something again, to get back something lost. This does not include material lost to natural evaporation, or dispersion, in situ burning, or the use of chemical dispersants.

(n) "TPH" refers to total petroleum hydrocarbons. It is a term used to describe the amount of petroleum hydrocarbons which are contained in a solid sample or sediment as a number and will be converted to a liquid measurement.

Note: Authority: Section 8670.65.5 Government Code.
Reference: Section 8670.67.5 Government Code.

877.3 Recovery of Liquid Petroleum Hydrocarbons.

(a) The Responsible Party and the Administrator may identify an alternative method to the method described in Section 877.3(c). This shall be done at the time of the incident and shall be included in the Incident Action Plan or as an attachment thereto.

(b) All material shall be collected and stored at locations that shall be identified in, and consistent with, the Incident Action Plan.

(c) A storage location conforming to approved methods for the storage of LPH shall be pre-identified and verified by the Unified Command (UC) as empty. If it is necessary to use a storage location that already contains LPH, water, or a combination of both, the type of product shall be determined and sampled according to API approved standards in advance and pre-gauged using API approved gauging methods. The petroleum hydrocarbon mixture shall be collected and separated. Gauge readings shall be taken until two (2) successive gauge readings are identical.

Note: Authority: Section 8670.65.5 Government Code.
Reference: Section 8670.67.5 Government Code.

878. Sampling Analysis and Calculation of Petroleum Hydrocarbons in Contaminated Sediment.

(a) The Responsible Party and the Administrator may identify an alternative method to the method described in Section 878(c). This shall be done at the time of the incident and shall be included in the Incident Action Plan or as an attachment thereto.

(b) All contaminated material shall be collected and stored at locations that shall be identified in, and consistent with, the Incident Action Plan.

(c) The UC, or their representatives, shall develop a statistically sound sampling and analysis plan, agreed upon by all parties, which shall be used in quantifying recovered petroleum hydrocarbons. At a minimum, the sampling plan shall include, but not be limited to, the number of samples to be collected, the sampling methodology to be used, and the methods for quantifying sediment and TPH, and moisture.

(d) Sub-samples shall be collected in pre-cleaned boro-silicate glass containers or equivalent. Samples shall not be collected in plastic containers.

(e) The extraction method of TPH shall, at a minimum, be EPA Method 3550A. EPA Method 3540B may be substituted.

(f) The analyses for the quantification of TPH, at a minimum, shall be performed using EPA Method 8015A, by GC-FID. EPA Method 8270B is an alternative method that may be used.

(g) The following calculation shall be used to determine the total amount of petroleum hydrocarbons:

Vs = volume of petroleum hydrocarbons recovered
Sw = weight of sediment
Cp = concentration of petroleum hydrocarbons in sediment (from TPH analysis) reported in dry weight
Pd = density of petroleum hydrocarbon

$$Vs = (Sw) \times (Cp) \times (1/Pd)$$

Note: Authority: Section 8670.65.5 Government Code.
Reference: Section 8670.67.5 Government Code.

879. Oily Boom, Sorbent and Debris.

(a) The Responsible Party and the Administrator may identify an alternative method to the methods described in Section 879(c) and (d). This shall be done at the time of the incident and shall be included in the Incident Action Plan or as an attachment thereto.

(b) All contaminated material shall be collected and stored at locations that shall be identified in, and consistent with, the Incident Action Plan. Oily Boom, Sorbent and Debris shall be separated, according to each individual category.

(c) Oily Boom and Sorbent Pad.
The following methods may be used to determine the amount of recovered petroleum hydrocarbons:

(1) Alternative Number 1.
(A) The petroleum hydrocarbons and water shall be extracted using pressure or other extraction method. A water deluge may be used to effect this process, subsequent to approval by the UC. The petroleum hydrocarbon mixture shall be collected and separated. The petroleum hydrocarbons shall be gauged using API approved gauging methods. Gauge readings shall be taken until two (2) successive gauge readings are identical.

(2) Alternative Number 2.
(A) The UC, or their representatives, shall develop a statistically sound sampling and analysis plan, agreed upon by all parties, which shall be used in quantifying recovered petroleum hydrocarbons. At a minimum, the sampling plan shall include, but not be limited to, the number of samples to be collected, and the sampling methodology to be used and the methods for quantifying the oily boom, sorbent, TPH and moisture.

(B) Subsamples shall be collected in pre-cleaned glass containers or equivalent. Samples shall not be collected in plastic containers.

(C) The extraction method of TPH shall, at a minimum, be EPA Method 3550A. EPA Method 3540B may be substituted.

(D) The analyses for quantification of TPH, at a minimum, shall be performed using EPA Method 8015A, by GC-FID. EPA Method 8270B is an alternative method that may be used.

(E) The following calculation shall be used to determine the total amount of petroleum hydrocarbons:

Vpsb	=	volume of petroleum hydrocarbons recovered
Cps	=	concentration of petroleum hydrocarbons reported in dry weight of sorbent from TPH
Cpb	=	concentration of petroleum hydrocarbons reported in dry weight of boom from TPH
S	=	total weight of sorbents
B	=	total weight of boom
Pd	=	density of petroleum hydrocarbons

$$Vpsb = \{[(Cps) \times (S)]\} + \{[(Cpb) \times (B)]\} \times (1/Pd)$$

(d) Oily Debris.
The following methods shall be used to determine the amount of recovered petroleum hydrocarbons:

(1) Alternative Number 1.
(A) The oily debris shall be washed using water deluge, subsequent to approval by the UC. The petroleum hydrocarbon and water mixture shall be collected and separated. The petroleum hydrocarbons shall be gauged using API approved gauging methods. Gauge readings shall be taken until two (2) successive gauge readings are identical.

(2) Alternative Number 2.
(A) The oily debris shall be collected and homogenized (by grinding or equivalent to effect total homogenization).

(B) The UC, or their representatives, shall develop a statistically sound sampling and analysis plan, agreed upon by all parties, which shall be used in quantifying recovered petroleum hydrocarbons. At a minimum, the sampling plan shall include, but not be limited to, the number of samples to be collected, and the sampling methodology to be used and the methods for quantifying the oily debris, TPH and moisture.

(C) Subsamples shall be collected in pre-cleaned glass containers or equivalent. Samples shall not be collected in plastic containers.

(D) The extraction method of TPH shall, at a minimum, be EPA Method 3550A. EPA Method 3540B may be substituted.

(E) The analyses for quantification of TPH, at a minimum, shall be performed using EPA Method 8015A, by GC-FID. EPA Method 8270B is an alternative method that may be used.

(F) The following calculation shall be used to determine the total amount of petroleum hydrocarbons:

Vpd	=	volume of petroleum hydrocarbons recovered
Cpd	=	concentration of petroleum hydrocarbons reported in dry weight of debris from TPH
D	=	total weight of debris
Pd	=	density of petroleum hydrocarbon

$$Vpd = [(Cpd) \times (D)] \times (1/Pd)$$

Note: Authority: Section 8670.65.5 Government Code.
Reference: Section 8670.67.5 Government Code.

880. Calculation for Total Recovery of Petroleum Hydrocarbons.

(a) The total recovery of petroleum hydrocarbons shall be the sum of the total volume of petroleum hydrocarbons from contaminated sediment (Vs), oily boom, sorbent (Vpsb), and debris (Vpd), and liquid petroleum hydrocarbons (LPH) reported in barrels.

Note: Authority: Section 8670.65.5 Government Code.
Reference: Section 8670.67.5 Government Code.

Appendix H

Facility Tank Information

Facility Tank Information[1]

General:

Tanks may be installed aboveground, underground, or, under certain conditions, inside buildings. Openings and connections to tanks may include venting, gauging, filling and withdrawing piping. Included in the piping will be pumps and valves. Containment systems should also be considered in the storage design. Dikes, drains, and skimmers could all be part of a system. In determining volume, along with understanding the size of the tank, it is necessary to also understand the characteristics of the liquid stored.

Characteristics of Flammable and Combustible Liquids:

Flammable and combustible liquids expand when heated. Gasolines expand about 0.07 percent in volume for each 10° F increase in temperature within ordinary atmospheric temperature ranges. The effect of temperature increase on the volume of acetone, ethyl ether, and certain other flammable liquids with higher coefficients of expansion is greater than in the case of gasoline.

Table 1. Thermal Expansion of Flammable Liquids[2]

Material	Coefficient of expansion Volumetric per degree F	Percent Increase in volume per 100°F rise
Acetone	.00085	08.50 %
Amyl acetate	.00068	06.80 %
Benzol (benzene)	.00071	07.01 %
Butane	.00107	10.70 %
Carbon disulfide	.00070	07.00 %
Ethyl ether	.00098	09.80 %
Ethyl acetate	.00079	07.90 %
Ethyl alcohol	.00062	06.20 %
Fuel oil	.00040	04.00 %
Gasoline ordinary	.00070	07.00 %
Gasoline natural	.00080	08.00 %
Methyl alcohol	.00072	07.20 %
Propane	.00168	16.80 %
Toluene	.00063	06.30 %

Several methods are used to prevent storage evaporation loss and loss of vapors as the tank is filled. Underground tanks reduce evaporation losses, since there is less fluctuation of temperature. Aboveground tanks often are painted with aluminum or white paint to reflect heat, thus decreasing the temperature rise of liquid contents and slowing evaporation of tank contents. Floating roof tanks minimize vapor loss. Storage of gasoline in pressurized tanks reduces the loss of vapor. In some cases, vapors are conserved by the use of lifter roof or vapor dome tanks, or the vents from several cone roofed tanks may be connected through manifolds to a vapor dome or pressure-type tank.

[1] From NFPA 17th edition unless otherwise noted

[2] NFPA 15th edition

Above-ground Storage Tanks:

Storage tanks come in a variety of designs. However, they may be divided into three general categories of pressure design: (1) atmospheric tanks, for pressures of 0 to 0.5 psig (0 to 26mmHg); (2) low-pressure vessels, for pressures from 0.5 to 15 psig (26 to 760 mmHg) ; and (3) pressure vessels, for pressure above 15 psig (760 mmHg).

Construction:

All aboveground storage tanks for flammable or combustible liquids should be built of steel unless the character of the liquid necessitates the use of other materials, eg. corrosive.

Tanks with the label of Underwriters Laboratories Inc, (UL) or those built in accordance with American Petroleum Institute (API) standards meet exacting specifications.

Venting:

API Standard 2000, Venting Atmospheric and Low-Pressure Storage Tanks, provides information on sizing vents for product movement and breathing. Clogged or inadequately sized vents may result in the rupture of tanks from internal pressure or their collapse due to internal vacuum.

In addition to the normal operating vents, emergency relief of internal pressure is required for most aboveground tanks in the event a fire occurs under or around the tank. Unless they are adequately vented, horizontal cylindrical tanks under excessive internal pressure commonly fail at the ends. For vertical cone roofed tanks designed with weakened seams at the roof-to-shell joint, the lifting of the roof or top of the roof-to-shell seam provides adequate emergency pressure relief. Vertical cone roofed tanks are required to have the roof-to-shell seam of weaker construction than the bottom-to-shell seam to prevent failure at the bottom of the tank.

Drainage and Dikes:

Diked enclosures are designed to contain the greatest amount of liquid that can be released from the largest tank within the enclosure, assuming a full tank.

Where needed, diked areas are provided with trapped drains to remove rain water. The best practice is to keep drain valves normally closed, and open them at intervals as needed, since permanently opened drains would discharge liquids in case of leakage from the tank.

Oil separators are effective in skimming off oil flowing on the surface of water, but separators normally will not control oil discharge when the entire flow through the drain is oil.

Underground Storage Tanks:

Underground storage tanks are designed to withstand safely the service to which they are subjected, including the pressure of the earth, pavement, or possible aboveground vehicle traffic. Piping subject to possibly damaging loads or vibrations is frequently protected by sleeves, casing, or flexible connectors to ensure the integrity of the line.

The normal life expectancy of properly installed underground steel tanks is 15-20 years. If improperly installed and in a corrosive soil, they may leak in less than three years. The use of homogeneous, clean backfill and protective coatings prolongs the life of steel tanks and piping. Cathodic protection of buried tanks and piping is often necessary.[3]

Fiberglass-reinforced plastic (FRP) tanks for underground installation eliminate the corrosion problem encountered with steel tanks. However, it is vitally important that they be installed properly. Care should be taken in the use of FRP tanks to ensure that liquids stored in the tanks are not destructive to the plastic tank construction.

Table 2. Typical sizes of Underground Flammable Liquid Tanks[4]

Capacity Gallons	Diameter Feet/Inches	Length Feet/Inches
300	3.0	6.0
560	4.0	6.0
1000	4.0	11.0
1000	5.4	6.0
1500	5.4	9.0
2000	5.4	12.0
2500	5.4	15.0
3000	5.4	18.0
3000	6.0	14.0
4000	5.4	24.0
4000	6.0	19.0
5000	6.0	24.0
6000	6.0	29.0
6000	8.0	16.0
7500	8.0	20.0
10,000	8.0	27.0
10,000	9.0	21.0
10,000	10.0	17.0
10,000	10.6	15.7

Tanks Inside Buildings:

Fuel oil tanks designed for use inside buildings without being enclosed in a fire-resistive cutoff room are normally restricted to less than 660 gallons. Pipe connections for underground tanks and enclosed fuel-oil tanks inside building are in the top of the tank only, whereas unenclosed tanks are provided with bottom outlets for gravity-feed piping.

[3] see NFPA 30 for requirements regarding corrosion protection of underground tanks and piping.

[4] NFPA 17th edition, table 2-25D

Estimating the Volume of a Cylinder:

Facility oil tanks are not a perfect cylinder because they contain internal features such as piping, supports, heating, and a variety of bottom designs. Simple math formulas will not accurately describe actual tank volume. The following formula can provide a general range for estimating the volume of a vertical, cylindrical tank. For accurate volume measurements, follow API "Manual of Petroleum Measurement Standards".

A simple formula[5] for estimating the volume of a cylinder in square feet is:

$$\text{Volume} = \frac{\pi \times D2 \times H}{4}$$

wherein $\pi = 3.14159265$ D^2 = the tank diameter multiplied by itself and H = the Height of the product in the tank. All figures need to be in feet and decimals of feet.

For example: A <u>vertical</u> cylinder has a diameter of 12' 3" and a liquid level of 17 feet. You want to estimate gallons of liquid. D^2 would = (12.25 X 12.25) = 150.0625 X (π) 3.14159265 = 471.43523 X (H) 17 = 8014.3989 ÷ 4 = 2003.5997. 2003.5997 is the square foot area of the tank. This figure can then be multiplied by 7.480 to convert area to liquid gallons. Therefore 2003.5997 X 7.480 = 14986.925. The estimated range for this cylinder is 14,987 gallons of liquid.

This formula will not be effective for partially filled horizontal cylinders. The preferred method to accurately determine facility tank volume is to follow API and ASTM gauging standards which utilizes a tank capacity table or "strapping" for that particular tank. See glossary of terms "tank capacity table."

There are three general methods facilities use to determine product level in a tank.

1. The first method is a written inventory for each tank at a facility. A record is kept, tracking product that has been removed from a tank since its last filling. This tracking, if accurate, shows the current level of each tank. This process includes subtracting outflows from current tank levels, and adding transfers received from barges, pipelines and trucks.

2. The second method to determine tank levels is by use of an automatic or "Varec" gauge.

3. The third method to determine tank levels is to manually gauge the product level in the tank with the use of a gauge tape and bob.[6]

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[5] NFPA 17th edition.

[6] For more information on manual gauging, contact API at (202)682-8000 regarding their "Manual of Petroleum Measurement Standards, Chapter 3, Section 1A .

External Automatic Tank Gauges

There are a variety of automatic gauges used on above-ground tanks. The following is a description of the most common design:

1) Automatic "Varec" Tank Gauge: A 14" diameter stainless steel hollow shell float is used to detect the liquid level. Attached to the float is a perforated stainless steel tape. As the liquid level rises or falls, the perforated tape is taken up or let out from the storage sheave. Constant pullback tension is provided by a stainless steel negator spring motor. The perforated tape engages pins on the sprocket sheave which, in turn, drives the gauge dial counter mechanism and any shaft position devices attached to the gauge head.[7] An electronic sending device can be added to the Varec that sends readings to a remote location for recording inventories.

Manually Gauging a Tank

This procedure, to be accurate, must be done according to API and ASTM standards. These procedures are described in detail in the API "Manual of Petroleum Measurement Standards", Chapter 3, Section 1-A.

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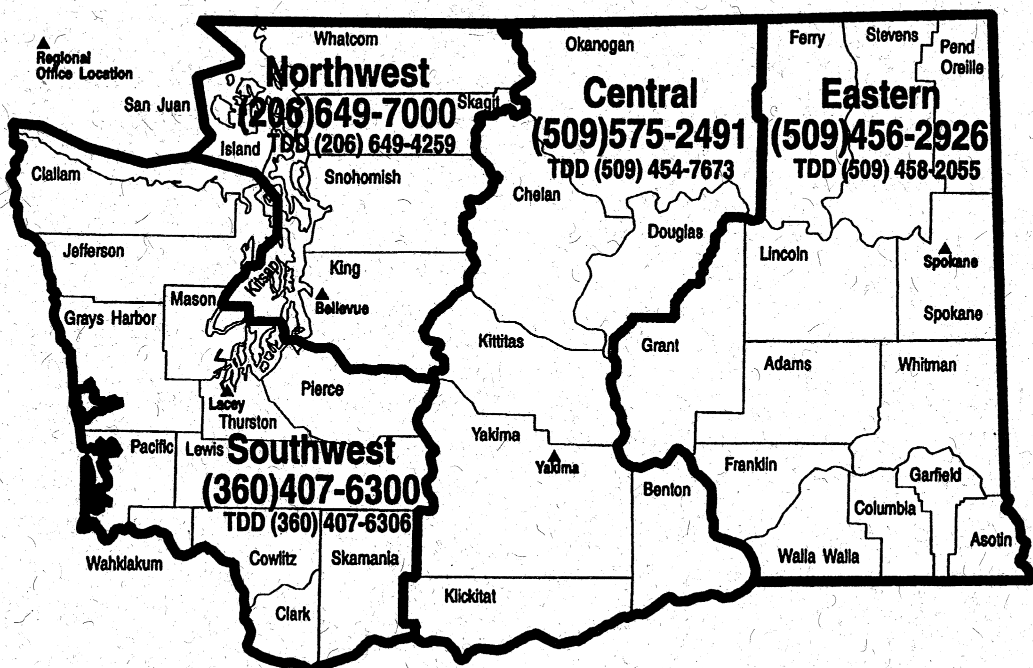
[7] From VAREC® product sheet PDS-2500-3

Washington State
Department of Ecology



When reporting a spill:

Need to Know:

- Reporting Party
- Contact Phone(s)
- Responsible Party
- Material Released
- Resource Damages (i.e. dead fish)
- Quantity
- Concentration
- Location
- Cleanup Status

or call the Department of Emergency Management
24-hour Number: 1-800-258-5990 or 1-800-OILS-911
For EPA and US Coast Guard reporting, call the
National Response Center: 1-800-424-8802

To obtain more information about *Guidelines for Determining Oil Spill Volume in the Field,* please contact John Butler at (206)407-6970.