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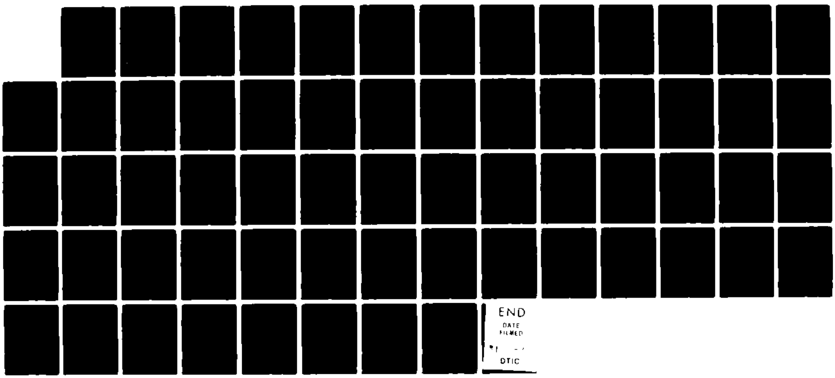

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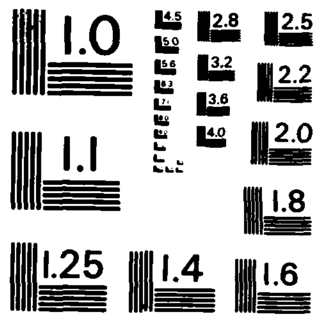


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AUTHOR: T. T. Fu, PhD
C. Semien

DATE: August 1983

SPONSOR: Chief of Naval Material

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# TECHNICAL NOTE

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043





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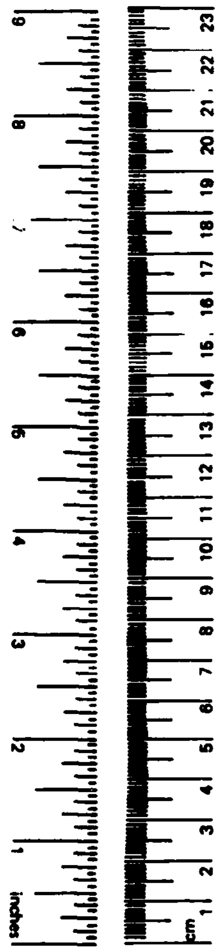
# METRIC CONVERSION FACTORS

### Approximate Conversions to Metric Measures

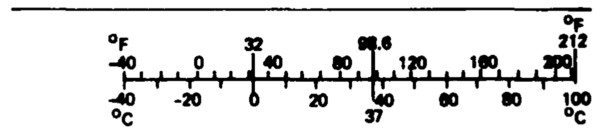
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2,000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



### Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1,000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This technical note provides information for a variety of users at different levels of management and operation. Part 1 contains background information on waste oil generation and a survey of waste oil disposition. Part 2 provides pertinent information to Public Works Officers and planners. Topics include: source of waste oil, a survey of disposition of waste oil, restrictions on use as fuel, boiler fuels, air quality considerations, and economics. Part 3 provides procedural information to operators using waste oil as boiler fuel. Waste oil handling,

continued

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20. Continued

pre-burning treatment, burning methods, equipment modifications, and operational requirements are discussed. Part 4 consists of: a comprehensive survey of the potential for utilizing waste oil by Navy/Marine Corps activities and a compilation of the reported experience of waste oil users.

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1. Wastes oils 2. Boiler fuel I. ZO371-01-311C

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CONTENTS

# PART 1. INTRODUCTION

This handbook is published as a sequel to earlier Naval Civil Engineering Laboratory (NCEL) Technical Notes (Ref 1, 2, and 3), which reported an investigation of the feasibility of burning waste oils as boiler fuel and subsequent boiler firing demonstrations using waste oils. The purpose of this handbook is to provide guidelines for the use of waste oil as a supplemental fuel in Navy boilers.

In the past, waste oils were disposed of by dumping, using for dust control, burning for firefighting training, and contracting for its removal. Environmental regulations now prohibit dumping and using for dust control. Since the waste oils have practically the same energy content or heating value as regular fuel oils of comparable densities, using them as fuel in boilers is a more productive alternative disposal method. At the same time, it will reduce both new fuel oil requirements and fuel costs.

The subject matter presented in this handbook is arranged to provide information tailored to serve various interest groups and to meet the needs of a variety of users at different levels of management and operation. Part 1 contains basic background information on waste oil generation and a survey of waste oil disposition. Part 2 is organized to provide pertinent information to Public Works Officers and planners. Topics include: sources of waste oil, a survey of disposition of waste oil, restrictions on use as fuel, boiler fuel requirements, boiler fuels, air quality considerations, and economics of burning waste oil. Part 3 is designed to provide procedural information to operators using the oil as boiler fuel. Means and methods of segregation and centralized storage are discussed, and the need for treatment of the waste oil prior to burning is outlined. Parameters for physical/chemical testing are provided, and methods of viscosity control and of blending the waste oil into the normal boiler fuel are reviewed. The need for burner/equipment modification and unique maintenance and operational requirements are discussed. Part 4 provides a comprehensive survey of the potential for utilizing waste oil by Navy/MARCORPS activities and the reported experience with handling, blending, and burning the waste oil as boiler fuel.

## Background

Large quantities of waste oils are continuously generated by Navy ships and Navy and Marine Corps shore activities and aircraft facilities. Based on 1972 figures, these quantities were estimated at over 26 million gal/yr. Waste oils generated from these sources are predominantly those recovered from bilge and ballast water. These oils are composed primarily of the fuel used by the particular ship. Used lubricating oils and similar materials from vehicles and ships rank second highest in quantity. Contaminated high flashpoint fuels, such as JP-5, diesel, and kerosene, rank third highest in quantities generated. Quantities produced least consist of solvents and low flashpoint fuels. From the standpoint of utilization as a supplemental boiler fuel, these waste oils may be grouped into three categories:

- Light waste oils - oils recovered from ship bilge and ballast water and contaminated high flashpoint fuels, representing an estimated 87% of the total waste oils generated throughout the Navy.

- Heavy waste oils - turbine engine drainings, shop facility wastes, and tank cleanings, estimated to be 9% of the total waste oils generated.

- Low flashpoint materials - used solvents and contaminated low flashpoint fuels, estimated at 4% of the total waste oils generated.

It should be noted that percentages are Navywide estimates only, and may vary considerably for specific sites.

Light and heavy waste oils are safe and suitable for boiler fuels. Low flashpoint materials are undesirable as boiler fuel for safety and environmental reasons. Of all the waste oil the Navy generates, more than 96% is therefore considered to be a desirable source of energy. Waste oil that can be utilized is of higher quality than the No. 6 fuel oil frequently used in boilers. In addition, this waste oil can be burned with no added adverse environmental effects.

## Generation and Disposition of Waste Oil

Over a 2-year period (1980-82) NCEL has conducted a survey of waste oil generation and disposition by Navy and Marine Corps shore activities. Based on the Defense Energy Information System FY80 DEIS II report only 325 of the 592 Navy and Marine Corps activities with assigned Unit Identification Code (UIC) numbers showed fuel oil consumptions. Since these 325 activities have oil burning capability, they are considered potential candidates for burning waste oil and were therefore contacted during this survey. Results show approximately 19 million gal/yr of waste oil are generated by these 325 activities.

Of these 19 million gallons, only 57% was burned as a boiler fuel. The 43% not burned was disposed of in several ways: (1) local fire-fighting training, (2) NAVSUP, DLA, or DPDO resale, (3) weed/dust control, (4) sold or given to haulers, (5) paid to have hauled away, or (6) stored, no disposition planned.

The above figures and the earlier Navywide estimate of 26 million gal/yr (see Background), show that: (1) a large sum of waste oil is also generated by those activities having no fuel oil burning capabilities and (2) approximately 8 million gallons of waste oil generated Navywide were disposed of by nonburning methods. This illustrates the potential for more productive use of significant quantities of waste oil.

## PART 2. PLANNING WASTE OIL UTILIZATION

This part discusses the planning factors that should be considered and evaluated for waste oil utilization. The sources generating waste oil are discussed, and oil products most likely to be found in the waste oil are categorized and presented with product examples and typical characteristics. Guidelines for oil products that should not be burned in boilers are listed. Air quality considerations and effects of burning waste oil are discussed, and an economic evaluation of burning waste oil is provided in Appendix C.

### Sources of Waste Oil

The basic sources of waste oil generated at Naval activities are ships in port, aircraft fueling and maintenance activities, and other industrial/shop functions performed ashore. While over 80% of the volume of waste oil generated throughout the Navy is that obtained from ship bilge and ballast water brought ashore, activities having no port facilities may also generate enough waste oil to make its use as a supplemental fuel economical and worthwhile as an energy conservation measure. Currently, all activities are collecting and handling waste oils in some fashion. Consequently, the sources of waste oil can be identified, and quantities generated can be estimated. Collection and disposal may be conducted independently in various organizations or functional elements of an activity. Centralized collection and use of the waste oil as a fuel may pay dividends for the activity.

Ships in Port. The primary source of waste oil from ships is the bilge/ballast water pumped ashore. Most activities handle this waste by the use of Waste Oil Rafts (DONUTS), which perform an initial gravity separation function. The waste oil residual is either further treated by oil separation equipment, if available, or transferred to storage tanks for disposal (usually by sale).

Ships may also generate waste oil products that are brought ashore in drums and other containers. The types and quantities of this waste will vary, depending upon the type of ship. For example, industrial-type ships, such as tenders, aircraft carriers, and large amphibious ships, are the most likely generators of significant quantities. Examples of the wastes are contaminated fuels, turbine engine oils, hydraulic fluids, shop lubricants, carrier arresting gear and catapult hydraulic fluids, greases, and solvents of all kinds.

Aircraft-Related Functions. At Naval air stations, a major source of waste oil is the aircraft fueling and maintenance functions. Contaminated fuels that are unacceptable for reuse are a main source of waste oils. In aircraft maintenance shops, fuel tanks are purged, oils drained, etc., thus generating waste oils that must be disposed of. To a minor degree, these functions may be performed aboard aircraft carriers while in port and may generate some wastes to be brought ashore.

Industrial/Shop Functions. Large Naval activities, such as shipyards, Naval air rework facilities, and ordnance plants, will generate quantities of waste oil suitable for boiler firing. The use of these waste oils as supplemental fuel will depend on the economics of collection, segregation, and treatment. Certain products that are used in industrial/shop facilities must not be burned. These are discussed later and are listed in Appendix A.

At nonindustrial activities, waste oil will be generated wherever internal combustion engine equipment is operated and maintained, as in transportation equipment shops, Navy Exchange service stations, automotive hobby shops, public works maintenance shops, and diesel generator plants.

Fuels which cannot be issued as specification fuels, but that become contaminated at storage and dispensing facilities, are another source of waste oil.

Oil products that will most likely be found in the waste oil are categorized into six types in Table 1. The basic characteristics of waste oil that are important from the standpoint of boiler fuels are flashpoint, viscosity, gravity, and any trait that presents a handling or burning problem (see discussions under Fuel Analysis in Part 3).

## Boiler Fuel Requirements

Natural gas and liquefied petroleum gases are the first choices for heating fuels due to ease of use and handling characteristics, cleanliness, and subsequent low maintenance requirements. However, the use of less desirable fuels, such as fuel oils, has become necessary due to their availability and the shortage of natural gas. Waste oils generated at Naval activities are considered attractive substitutes or supplements for fuel oils.

Data for the total consumption of natural gas, liquefied petroleum gases, and fuel oils (GLO) and other energy sources for Naval shore facilities are presented in Table 2. It is seen that about 24% of the total energy consumed by Naval shore facilities is in the form of fuel oils. Generation estimates (Table 3) show that on an overall basis, the Naval shore facilities may substitute waste oils for at least 6% of the total Navywide fuel oil requirements. Depending on the particular activity, as much as 100% of the fuel oil requirements may be met with waste oil. These figures illustrate the potential for waste oil utilization as a fuel.

## Boiler Fuels

Appendix A* of ASTM Specification D-396 classifies fuel oils into grades and places limitations on properties of the oils in each grade. These grades are described as follows:

Grade No. 1 is termed a light distillate oil because it is capable of being vaporized at relatively low temperatures and atmospheric pressure. Its intended use is almost exclusively for domestic heating where vaporizing-type burners convert the oil to a vapor by contact with a heated surface or by radiation. High volatility of the oil is necessary to ensure that vaporization occurs with a minimum of residue. This oil is a little

*Included in this technical note as Appendix B.

heavier than kerosene, but modern-day practice places both No. 1 fuel oil and kerosene in the same class.

Grade No. 2 is a heavier distillate than grade No. 1 and comes from the refinery fractionating tower after the No. 1 oil. Its intended use is in atomizing-type burners, which spray the oil into a combustion chamber where the droplets burn while still in suspension. This grade of oil finds use in both domestic and medium-capacity commercial/industrial applications where its cleanliness and ease of handling sometimes justify its higher cost over that of the residual oils.

Grade No. 4 is a variable and complex mixed classification. It is usually a light residual but is sometimes a heavy distillate. This oil is of lower viscosity than No. 5 or No. 6 fuel oils and is intended for use in burners equipped to atomize oils of higher viscosity than domestic burners can handle. Its limited service includes use in small boilers of schools and apartment buildings, forging furnaces, and low-heat installations. Its viscosity range allows it to be pumped and atomized at relatively low temperatures requiring no preheating for handling except in extremely cold weather. A refinery usually does not attempt to produce this grade of oil because of its low sales volume.

Grade No. 5 is a residual fuel of intermediate viscosity for burners capable of handling fuel more viscous than grades 1, 2, or 4 without preheating. Preheating may be necessary for use in some types of equipment for burning and for handling in colder climates.

Grade No. 6 is a heavy, black residual of the refining process and sometimes referred to as "Bunker C." This is a high viscosity oil used primarily in commercial and industrial heating. It requires preheating in the storage tank to permit pumping and additional heating at the burner to permit atomization. The equipment and maintenance required to handle this fuel usually prevents its use in small installations.

Table 2 of ASTM D-396 lists the various grades of fuel oils with their respective specifications (see Appendix B).

## Air Quality Considerations

The chemical elements that characterize combustion of fuels in air are carbon, hydrogen, nitrogen, oxygen, and sulfur. The primary products arising out of the complete combustion of a fuel are carbon dioxide ($CO_2$), water ($H_2O$), and nitrogen oxides (NO and $NO_2$), plus sulfur oxides ($SO_2$ and $SO_3$) if sulfur is present in the fuel. $CO_2$ and $H_2O$ are considered harmless combustion products in the exhaust gases.

The Environmental Protection Agency (EPA) has identified six exhaust gas pollutants: (1) particulate matter, (2) sulfur dioxide, (3) nitrogen oxides, (4) carbon monoxide, (5) hydrocarbons, and (6) oxidants.

Particulate matter is the nongaseous portion of the combustion exhaust consisting of all solid and liquid material (except water droplets) suspended in the exhaust gases. It is generally defined as any material that would not pass through a very fine filter. Particulate matter can be composed of unburned fuel, sulfur compounds, carbon, ash constituents in the fuel (including many toxic metals), and even noncombustible airborne dust entering the combustion air system. Current devices to remove particulate matter include filtration, mechanical separation, and electrostatic precipitation.

Sulfur dioxide ($SO_2$) is a nonflammable, colorless gas that can be "tasted" in concentrations of less than 1 ppm in the air. In higher concentrations it has a pungent, noxious odor. $SO_2$ is formed in the combustion process when sulfur contained in the fuel combines with oxygen from the combustion air. $SO_2$ and $SO_3$ comprise the total oxides of sulfur, generally referred to as $SO_x$. $SO_3$ is usually no more than 3% to 5% of the total $SO_x$ generated. Essentially all sulfur contained in the fuel is converted into $SO_2$, and $SO_3$ and is not highly affected by boiler operating conditions or design. Although regulating the quantity of sulfur in the fuel is the primary method of controlling $SO_x$ emissions, stack gas scrubbers can also be effective in removing $SO_2$ from the combustion exhaust.

Nitrogen oxides, nitric oxide (NO) and nitrogen dioxide ($NO_2$), are generated in the combustion process. These compounds are referred to as $NO_x$. NO is a colorless, odorless gas that is not considered a direct health threat in the concentrations found in the atmosphere. $NO_2$ is considerably more harmful and comprises typically 5% or less of total $NO_x$ emitted from boiler stacks. Once in the atmosphere, however, a large fraction of the NO is converted into $NO_2$. $NO_2$ is a yellow-brown colored gas having a pungent, sweetish odor. $NO_x$ is formed spontaneously during the combustion process when oxygen and nitrogen are present at high temperatures. Because all three of these (oxygen, nitrogen, high temperature) are essential to the combustion process, it would be difficult to prevent $NO_x$ formation. Nitrogen is present in the combustion air and fuel itself. Lower peak flame temperatures, reduced excess oxygen, or a combination of both have been effective in reducing $NO_x$ formation. Future techniques will scrub $NO_x$ from the exhaust gases before entering the stack.

Carbon monoxide (CO) is a product of incomplete combustion. Its concentration in exhaust gases is usually sensitive to boiler operating conditions. Improper burner settings, deteriorated burner parts, and insufficient air for combustion can cause high CO emissions. CO is toxic, invisible, odorless, and tasteless.

Hydrocarbons also are indicative of incomplete combustion and can be greatly reduced by proper boiler operation. However, hydrocarbons cannot be entirely eliminated; trace quantities will nearly always be present, regardless of boiler operation. Hydrocarbons are active ingredients in the formation of photochemical smog, and under certain atmospheric conditions can be transformed into other potentially more hazardous derivatives.

Oxidants are oxygen-bearing substances that take part in complex chemical reactions in polluted atmospheres. Photochemical reactions that are intensified in the presence of sunlight involve nitrogen oxides ($NO_x$) and reactive organic substances (hydrocarbons and their derivatives) as principal chemical ingredients. These react to form new compounds like ozone and PAN (peroxyacyl nitrates), which are the major oxidants in smog. While ozone and PAN are not generated in the boiler, the principal ingredients (especially $NO_x$) are supplied by the exhaust gases.

The environmental air quality considerations discussed apply whether or not waste oil is burned. However, parameters for emission control may change when waste oil is being burned due to the varied properties of the waste oil. When burning waste oils, depending on the contaminants in them, harmful combustion products, such as halogenated compounds, may be produced. Therefore, caution must be exercised to prevent halogenated waste materials from entering the waste oil.

## Restrictions on Use as Fuel

The majority of waste oils considered here are petroleum-based products. Synthetic/chemical- (nonpetroleum-) based products require segregated collection. Appendix A lists synthetic/chemical-based waste oils, low flashpoint materials, and halogenated solvents that should not be burned. Special precautions are required to avoid dumping solvents or residues that contain halogens into waste oils being collected for boiler firing. Shops must segregate all halogenated compounds when practical, because high enough concentrations may result in accelerated corrosion of boiler components and produce unhealthful stack emissions. This type of waste can be added to waste oils only after the individual batch has been determined to be free of halogen. If the oil fails the tests outlined in Part 3, it is probably due to improper segregation and should be disposed of separately. Suspect materials are trichloroethane (O-T-620C), trichlorotrifluoroethane (MIL-C-81302), constant speed drive fluid (MIL-S-81087), and various cleaning compounds.

NOTE

> Used lubricating oils should be re-refined whenever possible. DOD Directive 4165.60 incorporates formal policy on methods for disposal of used lubricating oil. DOD guidance consists of two methods: (1) examine the feasibility of re-refining in order to conserve natural resources and (2) if re-refining is not economical, use it as a boiler fuel in order to recover the energy content. Other methods, such as use for dust control, are not allowed. If used lube oil is burned as a boiler fuel, a written justification which outlines the reason for not re-refining the oil must be prepared.

Because of their nature, Type A products in Table 1, such as gasoline, JP-4, and used solvents, are undesirable as boiler fuels. Low flashpoint characteristics make these materials hazardous to handle and burn. Likewise, type F wastes create a hazard in handling and burning and should not be used as a substitute fuel.

Type B, C, D, and E wastes can be utilized readily as a burner fuel by blending with the fuel oil in use or by providing a separate waste oil burner in the boiler. Certain basic requirements must be met, but in general, a wide range and large quantity of waste oil from these types can be reused with no resulting mechanical or environmental problems and with negligible loss in heat generation.

## Economics of Burning Waste Oil

The economics of burning waste oil as a supplemental fuel are of interest in public works management and in justifying facility projects for utilization of waste oil. While the specifics will be different for each Naval activity, most of the economic factors are common, and guidelines for calculating costs and savings can be determined (see Appendix C for elements to be considered). The following functions are required for using the waste oil as a fuel and for selling it from a central storage tank.

Burning as a Fuel:

- collection and segregation
- transportation and centralization
- water and sludge removal
- testing
- storage
- mixing/blending

Sale:

- collection
- transportation and centralization
- water and sludge removal (not required in some cases)
- storage

The following comments on the functions of these two alternatives apply to most activities:

- The cost of collection and transportation of the waste oil will be the same for both methods of disposal.

- Certain waste oil products must not be burned and must be segregated and handled separately. Under many sale contracts and other disposal methods this segregation is not required. Consequently, there may be a unique cost of segregation associated with burning.

- At most sites, the only treatment required prior to burning or sale is gravity separation of the water and solids. The costs will be about equal for both cases.

- The cost of storage for sale is unique. A tank must be dedicated to waste oil. If water/solids removal is accomplished elsewhere, the waste oil to be burned may be placed directly into boiler fuel tanks. For convenience, a separate dedicated waste oil tank may be installed at the boiler plant, and the costs of storage will be essentially equal for any disposal alternative.

Cost of Burning Waste Oil. Based on the above, typical cost and savings factors for use in calculating the economics of burning the waste oil are as follows:

Recurring Costs -

- Segregation required only for burning.

- Testing to determine safe burning properties.

- Mixing/blending of waste oil with new fuel, if required.

- Price that waste oil could be sold for under contract. (If waste oil is burned, the income loss from potential sale is a cost of burning.)

One-Time Costs -

- New facilities and equipment required to use waste oil as a fuel.

Savings -

- Cost of new fuel not purchased due to burning waste oil.

If the savings in fuel purchases are greater than recurring costs, the payback period for the one-time cost can be calculated (see Appendix C for details). The Energy Conservation Investment Program (ECIP) Criteria of NAVFAC Instruction 11010.14M also includes similar guidelines for economic evaluation and cost savings analysis and may be used as it applies (see also Ref 4).

ECIP Considerations

The Department of Defense (DOD) Energy Conservation Investment Program (ECIP) (Ref 4) is a Military Construction (MILCON) funded program for retrofitting existing DOD facilities to make them more energy efficient while providing substantial savings in utility costs. While the ECIP is not fully applicable to the burning of waste oils as boiler fuel (usually no retrofitting of existing facilities), it may be beneficial and relevant to consider the purpose and goals of the ECIP when evaluating the cost/savings involved.

Energy-to-Cost Ratio. Under the ECIP (Ref 4), all projects must produce an energy-to-cost ratio (E/C) of MBtus of energy saved yearly per thousand dollars ($K) of current working estimate (CWE) investment equal to or greater than a specified minimum value.

$$E/C = \frac{\text{MBtu saved/yr}}{\text{\$K CWE}} \geq \text{the specified minimum*}$$

This may not be directly applicable, as we are anticipating a net saving rather than a net cost as we use waste oils in place of some or all of the regular fuel oil.

Benefit/Cost Ratio. Also, there is an ECIP requirement that the benefit/cost ratio exceed 1.0 for each project. This, too, may not be directly applicable for the same reason: we are anticipating a net saving rather than a net cost.

Simple Payback Period. In some cases there may be an initial investment (e.g., for waste oil storage tanks or facilities for mixing or blending waste oil with fuel). In these cases, a simple payback period may be calculated as outlined in Appendix C.

*FY82 = 19; FY83 = 18; FY84 = 17.

## PART 3. PROCEDURES FOR BURNING WASTE OIL AS BOILER FUEL

This part discusses segregation and collection of waste oil, centralized storage, treatment, quality control, and delivery to the boiler plant. The specifics will vary with each shore activity; therefore, only general discussions for each type of source are included. Fuel analyses in terms of physical/chemical constraints and tests for evaluation of the waste oil are prescribed. Blending and viscosity control of the waste oil are described to provide insight into necessary operational changes, modifications to existing equipment, and additional equipment required. Unique maintenance and operational requirements that may be encountered are discussed, and recommendations regarding recordkeeping for documentation of future waste oil burning experience are provided.

### Segregation

Presence of caustic, acidic, and halogenated compounds in waste oils may cause corrosion to fuel system components and produce combustion products which are harmful to the boiler and which may pollute the environmental air. Such compounds may come from detergents, industrial wastes, solvents, cleaning fluids, synthetics, etc. Proper segregation not only will minimize the possible hazards due to undesirable contaminants but also will lessen the effort and cost of treating the waste oil.

The segregation of nonburnable* wastes at the source is relatively simple. Oil products that must be segregated are listed in Appendix A. The identification and separate collection of nonburnable products at shore industrial areas and shops is within the control of the activity and can be accomplished through indoctrination of personnel and by providing facilities that make segregation easy. The segregation of those wastes aboard ship before they enter the bilge is not within the control of the shore activity, but there are steps that can be taken to improve the quality of the waste pumped ashore.

Ship Waste Oil Segregation. Segregation is not applicable to the oily wastewater pumped from bilges. Any undesirable contaminants present in that waste will have to be accepted and, once the waste is dewatered, testing must determine if the waste oil is suitable for burning. In most cases, nonburnable type wastes in the oil will be so diluted by quantity that no problems will be encountered with burning. Nevertheless, if the hazardous oil products in use aboard ships can be identified and publicized and the ships prevailed upon to segregate such wastes and move them ashore separately, the quality of the waste oil will be improved. Waste oils brought ashore in properly labeled drums/containers can be segregated at the source if the products are identified ahead of time and containers provided.

*As boiler fuels.

Segregation in Industrial Areas. If an aggressive program for collecting and burning waste oil is established by an activity, publicizing the results in dollar savings and energy conservation will help in obtaining cooperation in segregation. Containers and collection at necessary frequencies must be provided to lessen the workload of separate handling. Once it becomes standard procedure in a shop to handle certain wastes separately, the procedure will continue. Original containers may be saved and reused for waste collection. Drums, with appropriate signs or labels, may be placed in or near shops for disposal of "dirty" and "clean" waste oil products. As with other types of recyclable products (such as paper and metals) the difference in time, labor, and trouble required to reclaim the item rather than throw it away is very small once it becomes part of the routine.

## Centralized Storage

Burnable waste oil should be centralized in storage prior to delivery to the boiler plant or contractor-receiving points. It is costly to have a waste oil buyer pick up small quantities at many locations. Tank trucks or trailers may serve as mobile storage for collecting and storing the waste oil between source and boiler plant.

Unless the waste oil is stringently treated prior to burning, or unusually clean when collected, gravity separation will be required to remove water and solids. Large quantities of "clean" waste oil generated at one time should be delivered directly to the boiler plant when possible to avoid further degradation by mixing with other waste oils (e.g., contaminated jet fuel declared unusable for aircraft).

## Treatment -- Water/Sludge Removal

Waste oil may contain varied amounts of water, sludge, and solids. Excessive water in oil may cause flame out; sludge and solids may plug up the fuel system, cause excessive wear in nozzle tip and pump components, etc. They must be removed from the waste oil before it can be safely fired in a boiler. At present, an oil that contains no free water* and that can pass through an 80-mesh screen filter is considered reasonably adequate for boiler firing.

Water, sludge, and solids may appear in the waste oil either in a form more or less separated from the bulk of the oil or suspended in it in various emulsified states. In general, they may be removed simply by gravitation separation. By leaving the oil in a tank undisturbed for enough time, they will eventually settle at the tank bottom and can be easily removed. When sufficient time is not available, the gravitation separation process may be accelerated by heating up the oil to some safe temperature (e.g., with a steam coil heater to 150°F) or by using a centrifuge. If the waste oil appears to be a stable emulsion (having poor demulsibility by the above methods) mixing it with light fuels such as contaminated JP-5 or diesel will help accelerate the demulsification

*Refer to water visibly separated from the oil as distinguished from water suspended in the oil in an emulsified state.

before the gravitation separation process. (The amount of light fuel to be used depends on the nature of the emulsion. Adding one part of fuel in five parts of waste oil would be a good starting point.)

## Fuel Analysis

Waste oils obtained through proper segregation and water/sediment removal as described above are mixtures primarily of hydrocarbons. Other than the appearance, they should have similar properties as regular fuel oils. To illustrate, the characteristic properties of a variety of randomly selected oil samples were measured and the results are shown in Table 4. Since specifications are concerned only with ranges and limits, fuel oils of the same grade are likely to have different property values. The variability of properties of waste oils is expected to be even greater. Fortunately, detailed knowledge of these oils is usually unimportant, and only the properties directly affecting the safety and operations of a boiler need be determined occasionally. These properties are discussed below (see Appendix B for the applicable ASTM test methods):

1. Gravity (or degrees API). This is an indirect measure of the fuel density. The carbon-to-hydrogen ratio and heating value of fuel oils can be reasonably well estimated from their gravities as shown in Figure 1. Carbon-to-hydrogen ratio affects the combustion air requirements (the fuel-air ratio), and heating value affects the burner firing rate. Adjustment of the burner for efficient burning, therefore, will be required when fuels of different gravities are fired.

2. Viscosity. This is a measure of the resistance of the oil to flow and atomization. For a burner to function properly, the fuel must be within a certain viscosity range. Since viscosity is highly temperature dependent, this is achieved by heating the oil to the appropriate temperature (see "Viscosity Control" later).

3. Flashpoint. This is the lowest temperature at which a fuel may be ignited under specified conditions. It is, therefore, a measure of safety. The minimum flashpoint for commercial grade fuel oils is 100°F (see Appendix B).

4. Water and Sediment. Water in oil may cause unstable flame or flame out. Sediment may cause fuel system blockage and accelerated wear. Excessive amounts of these must not be tolerated. If the waste oil collection procedure described earlier is followed, no difficulty should be encountered during burning.

5. Chemical Contamination. Due to the uncontrollable nature of individual practice in waste oil collection, contamination by undesirable chemicals may still be possible. The following simple methods may be used to periodically determine the quality of the waste oil.

(a) Copper Corrosion Test. Maintain the oil at 50°C and immerse in it a properly polished sample copper strip for 3 hours. The relative corrosiveness of the oil is determined by the extent of tarnishing of the strip. For example, the maximum allowable tarnish designation number for commercial grade No. 1 and No. 2 fuel oils is 3, and no maximum is specified for heavier oils. No. 4 tarnishing was reported from occasional tests of the waste oils generated in San Diego and Norfolk areas. No adverse experience on these oils has been reported, however.

(b) Copper Wire Test. The undesirable contaminants found in waste oils are primarily chlorinated compounds. This test will determine the acceptable level of chlorine in the waste oil.

A clean copper wire is heated in a clear, blue gas flame to red heat until no green shows in the flame. The wire is dipped while still hot into a sample of waste oil and then put back into the flame. No green shall show in the flame. For practice, a blend of 1% trichloroethane in DFM or other distillate fuel may be used as an example of an oil which fails this test. The oil sample should be purged of any sodium chloride prior to the test by washing with freshwater.

If an oil fails this test, it is probably due to improper segregation. It can be salvaged by blending it into known good quality oil so that it becomes acceptable or is disposed of in accordance with Reference 5.

6. Sulfur Content. Maximum allowable sulfur in oil is regulated by local authorities (e.g., $\leq$ 0.5% in California). Since the main ingredients of waste oil (e.g., JP-5, DFM, lubricating oil) are primarily low sulfur materials, the sulfur content of waste oils, therefore, is usually low. Occasional determination of the sulfur content in waste oil would be adequate.

A sufficient overview of the waste oil properties can be achieved if testing is performed once or twice each month for a 6-month period. Although the physical/chemical properties of the waste oil may vary considerably between shore activities, the properties should remain fairly uniform for any one given activity. If the above properties are known, the waste oil is then somewhat predictable and necessary adjustments for burning and blending can be properly accomplished.

## Blending

Two possible methods of blending are considered here: direct and in-line blending. Direct blending is the addition of the waste oil directly into existing fuel oil tankage. If the waste oil being added to the tank is lighter than the normal fuel oil, it should be pumped in at the bottom of the tank. The lighter oil will tend to mix as it rises through the heavier oil. If the waste oil is heavier than the fuel in the tank, it should be pumped in on top. The heavier oil will tend to mix as it falls into the fuel. The tank contents should then be circulated to achieve a homogeneous mixture. Direct blending tests show that results are predictable, and no special attention is required to burn the waste oil, except to adjust the temperature of the blend so that its viscosity is nearly the same as that of the regular fuel oil.

In-line blending is simple and practical with either distillate or residual fuels. Even though additional equipment is necessary, the effort and expense are minimal. A proposed waste oil supply and in-line blending scheme is shown schematically in Figure 2. In this scheme, the waste oil is introduced into the suction side of the main fuel pump of the existing system to insure thorough mixing. Temperatures are taken at three locations, and a sampling port is provided downstream of the pump so that the waste oil concentration can be measured by either the "Temperature Method" or the "Specific Gravity Method" described below. The low-pressure pump near the waste oil tank is used for stirring the waste oils in the tank, as necessary, to insure a homogeneous mixture. It may be used during actual boiler operation. Experience gained thus far shows that in-line blending is simple to implement and works satisfactorily.

Specific Gravity Method. Let $\gamma_1$, $\gamma_2$, and $\gamma_3$ be the specific gravities, respectively, of the regular fuel oil, waste oil, and their blend at the same temperature. Assuming constant volume mixing, the waste oil concentration in percent would be:

$$\frac{\gamma_3 - \gamma_1}{\gamma_2 - \gamma_1} \times 100\% \quad = \quad \% \text{ of waste oil in blend}$$

For this method, an ordinary hydrometer, a thermometer, a glass cylinder, and a sampling port close to the burner nozzle in the fuel system will be required. This is a one-time measurement, but the accuracy is good, the procedure is simple, and the initial investment is minimal. The accuracy of this method increases with the difference between $\gamma_1$ and $\gamma_2$.

Temperature Method. Let $T_1$, $T_2$, and $T_3$ be the temperatures, respectively, of the regular fuel oil, waste oil, and their blend. If these temperatures are measured at locations fairly close to one another, and assuming that the specific heats of the oils are the same and the mixing takes place without the loss or gain of heat, by conservation of energy the waste oil concentration may be calculated as follows:

$$\frac{T_3 - T_1}{T_2 - T_1} \times 100\% \quad = \quad \% \text{ of waste oil in blend}$$

Some inherent errors exist due to the assumptions used. This method is ideal for continuous monitoring if automatic recording devices are used and is particularly helpful when blending oils of nearly equal specific gravities.

## Viscosity Control

Waste oil added to regular fuel affects the viscosity of the blend, the fuel flow rate, and nozzle spray characteristics. To minimize the requirements for burner adjustments, the firing temperature of a blend should be controlled so that its viscosity is nearly the same as that of the regular fuel oil at its normal firing temperature. The viscosity variation with the temperature of typical fuel oils may be estimated by using the viscosity-temperature charts for liquid petroleum products in Reference 6. A working chart for determining the approximate operating temperature of fuel oil blends is shown in Figure 3.

Figure 3 consists of two separate graphs. The one on the left is used to determine the viscosity of a blend of two oils of different viscosities (all in SUS* at 100°F), and the one on the right shows the temperature variation of viscosity for oils whose viscosities at 100°F are known. The use of these graphs is illustrated in the following example:

EXAMPLE

A burner is designed for burning a type of heavy fuel oil having a viscosity of 1,000 SUS at 100°F. This oil is heated to 180°F to achieve satisfactory firing. A light waste oil on hand, which has a viscosity of 50 SUS at 100°F, will be blended into the heavy fuel oil to supplement the boiler fuel. To fully utilize this light waste oil, its concentration in the blend is determined to be 30%. What is the satisfactory operating temperature of this blend?

From the right-hand graph of Figure 3, along the line labeled 1,000 SUS, we find that the viscosity of this oil at 180°F is 125 SUS. From the left-hand graph, the viscosity of a blend of 30% waste oil is slightly less than 300 SUS. Again on the right-hand side of the graph, along the line labeled 300 SUS, we find that to attain 125 SUS the oil should be heated to 140°F. This is shown in the graphical construction.

## Burner Modifications

If the firing temperature of the blend is adjusted to compensate for the change in viscosity as discussed above, no special modifications to burner equipment are required to fire waste oil blends. Minor adjustments are sometimes necessary, however, to correct unstable combustion and smoke emission similar to the routine adjustments for firing clean fuel. Other than relatively high ash accumulation when firing blends of high concentrations of used lubricating oil, no apparent emission problems should be encountered (Ref 1, 2, and 3). Therefore, no special provisions should be required to monitor stack gas emissions. To insure efficient boiler operations, oxygen is the only critical item for stack gas monitoring.

*Saybolt Universal Seconds.

Unique Maintenance and Operational Requirements

Generally, waste oils free of water and sludge can be satisfactorily fired in boilers either straight or in blends with regular fuel oils. However, maintenance requirements are higher for blends with higher concentrations of used lube oils.* Problems that may be encountered in burning of waste oil are:

- Fine lint buildup in barrels and nozzles which are hard to clean
- Substantial ash buildup in the fire box, deposits on boiler tubes, and fly ash
- More frequent cleaning of fuel strainers, up to four times as often
- Rise in flue gas temperature due to deposit buildup on heat transfer surfaces
- Excessive wear of fuel pumps and nozzle tips, inoperative valves, plugged strainers, and flow passages
  - (a) Rotary vane pumps are especially intolerant to solids; damage includes scored liners and pitted vanes
  - (b) Burner tips become enlarged, elongated, and pitted
- Increased firing rate due to the lower Btu value of the waste oil
- It may be necessary to preheat the boiler with natural gas

To minimize maintenance, if used lube oil must be burned, a concentration of less than 25% in the blend is recommended.*

Large amounts of water and bottom sediment are commonly found in waste oils. Excessive amounts of water in oil can cause flameouts. Excessive solid concentrations can cause accelerated wear and damage to boiler equipment. Removal of water and solids from the waste oil prior to burning is essential. Gravity settling is usually satisfactory. Accelerated settling may be achieved by heating the oil, blending with other light oil, or using a centrifuge.

Even though the waste oil cannot be expected to meet the standard specification of fuel oil, it can be used satisfactorily, provided some precautions are taken. Synthetic- and chemical-based liquids may be hazardous in handling and burning. These materials must be segregated at the source of generation or collected and disposed of according to Reference 5. Identification of these liquids is discussed in Part 2. It is necessary that the waste oil be free from halogenated material to

*Burning of used lube oil must comply with DOD Directive 4165.60. See NOTE on page 7.

prevent toxic gas emissions and accelerated corrosion of the fire side surfaces of the boiler. Testing of the waste oil to determine the presence of such contaminants is discussed earlier.

## Recordkeeping

In order to (1) further its use, (2) improve upon current technique and procedure, and (3) show achieved dollar savings, information pertaining to the utilization of waste oil as a supplemental fuel should be included as part of the record for boiler operations. A recommended outline of information to be recorded is listed below:

I. Sources of waste oil

II. Quantity of waste oil burned

III. Quality control

- A. Methods of segregation
- B. Treatment methods
- C. Physical/chemical testing
- D. Blending methods

IV. Effects of use and unique maintenance and operation requirements

- A. Problems in operation
- B. Unusual maintenance requirements
- C. Equipment modification and adjustment requirements
- D. Stack emissions

V. Achieved savings

## PART 4. REPORTED EXPERIENCE USING WASTE OIL AS BOILER FUEL

The information presented here was obtained through a limited survey, and its accuracy and completeness depend on the effectiveness of the survey communications, the knowledge of the respondent, and the rapport and understanding achieved during the communications. It is, therefore, the best obtainable at this time and should be considered as a "lower limit," with additional data and information yet to be obtained. Periodic updating of this information will be required as circumstances, equipment, and operation of the activities continually change. The information does, however, depict the status of waste oil generation and burning by Navy activities and can serve as guidelines for planning and implementing the use of waste oil as boiler fuel.

### Survey of Navy Activities

Waste oil has been burned routinely or used as a supplementary boiler fuel in tests at a number of military activities. The experience gained can be of value to other activities investigating or considering its use. Over a period of 2 years, NCEL has conducted surveys by telephone and by mail of Navy and Marine Corps shore activities on waste oil generation and utilization. As indicated earlier, of the total 592 Navy/Marine Corps activities with UIC numbers, 325 indicated fuel oil usage. These 325 activities are located in 153 geographical locations. Successful telephone contacts were made with Public Works officers and environmental engineers at 94 of the 153 locations. These were followed by survey forms with 130 returns.

Activities burning waste oil reported no major problems. Minor problems encountered when burning large amounts of waste oil included fireside deposits and plugging of burner tips. Boiler operations were kept efficient by slightly increasing regular maintenance duties (e.g., cleaning or changing strainers and burner tips).

### Narrative Summaries of Experience with Burning Waste Oils as Boiler Fuel

Summaries of the information gathered from the survey and results of experience by the Army and Air Force are presented in the paragraphs that follow. Where indicated, the information pertains primarily to the individual activity identified (e.g., Camp S.D. Butler, Japan). Where only areas or locations are indicated (e.g., Charleston, S.C.), the information pertains to a group of activities in the area.

U.S. Army, Aberdeen Proving Ground, Md. During 1968-1972, the Army burned approximately 40,000 gallons of used lube oils each year in a boiler plant (60 MB/hr, water tube boiler with steam atomization burner) at Aberdeen Proving Ground. This oil was simply dumped into the FO6 tank at a proportion of 1:3 (or 25% used lube oil in the mixture). Since no deliberate blending or mixing was attempted, the exact concentration of the blend may have varied considerably. No difficulty was encountered. In 1972, when low sulfur oil had to be used to limit the $SO_2$ emissions, two series of short-term tests were conducted burning FO2 and used lube oil blends using a rotary cup burner in a 5.4 MB/hr fire tube boiler. The results showed that with up to 27% used lube oil in the blend, no stack emission problem was encountered.

NAVSTA Adak, Alaska. This activity collects waste oils generated throughout the island. In FY80 this amounted to 34,000 gallons, and in FY82, approximately 26,000 gallons. These oils were generated from power plants, ships, and shops, and consisted of contaminated JP-5, used crankcase oil, solvents, and miscellaneous waste oily products. Except for 1,000 gallons used for firefighting training, the oil was burned in boilers by blending one part of crankcase oil into four parts of contaminated JP-5. The total waste oil generated could replace 0.3% of the total fuel oil consumption.

U.S. Air Force Tests (Ref 7 and 8). A systematic test series was conducted by the Air Force. Used lube oils containing aviation piston engine oils, synthetic turbine lubricant, hydraulic fluid, Stoddard solvent, etc., were mixed with FO2 and FO6 at concentrations of 0.1%, 1%, and 10%. These blends were then fired for 30 minutes each to determine the firing characteristics. No difficulty was encountered, and no ill effects (e.g., emissions, corrosions, degradation of boiler systems) were observed. A series of 2- to 3-hour tests were then conducted at 5% concentration. Satisfactory firing was achieved, and no increase in particulate emissions was measured. As a result, long-term in-service boiler tests were recommended. Tests of this nature were conducted at three Air Force bases. Up to 26% used lube oil in FO2, 6% JP-4 in FO5, 16% JP-4 in FO2, 4% and 11% of 50/50 JP-4/used lube oil, respectively, in FO2 and FO5 oils were tested. Results showed that relatively clean burning fuel (e.g., JP-4) mixed in relatively dirty fuel (e.g., FO5) would not adversely affect emissions. But relatively dirty fuel (e.g., used lube oil) mixed in clean fuels will significantly increase the particulate emissions although the emissions are still below standards. Overall, the combustion performance either remained the same or improved.

Andros Island, Bahamas. This area generates 300 gal/mo of used SAE 40 lube oil from diesel engines at the power house. About half of this waste oil is burned by direct blending in four Cleaver Brooks, diesel-fuel-fired, fire tube boilers, ranging from 15- to 60-hp boilers. These boilers have pressure atomizing burners with fail-safe controls and operate on a load factor. Waste oil is mixed with diesel engine fuel and fired in the boiler system direct. The total waste oil generated could replace 0.2% of the total fuel oil consumption.

Bangor, Wash. This area generates and burns 156,000 gallons of waste oil a year at the submarine base (54% from ship and the rest from shops). Waste oil, primarily contaminated FO2 and diesel, is collected and sent to NSC Puget Sound by base support haulers. Puget Sound Manchester treatment facility purifies the waste oil prior to burning. The total waste oil generated could replace 30% of the total fuel oil consumption.

Barking Sands, Hawaii. This activity generates 6,200 gallons of waste oil a year, and an estimated 96% of the waste oil collected is burned. Used lube oil from aircraft, shops, and automotive vehicles is blended in-line with DF2. A filter separator is used in the waste oil feed line to control contaminants. The activity had experienced excessive corrosion on intake and return lines before using the filter. Burning takes place in a 15-hp fire tube boiler with an automatic full modulation control. The boiler operates on a load factor with a waste oil/fuel oil ratio of 1:10. The total waste oil generated could replace 8% of the total fuel oil consumption.

Bethesda, Md. This area generates 5,600 gallons of waste oil a year, with an estimated 2% being burned. Used lube oil from automotive equipment, gear boxes, and air compressors is blended with F06 and burned in five water tube boilers ranging in size from 30,000 to 50,000 lb/hr. All boilers have air atomizing nozzles with semi-automatic controls and operate in a continuous mode. The total waste oil generated could replace 0.1% of the total fuel oil consumption.

Brunswick, Maine. This area generates 8,600 gallons of contaminated JP-5 a year from aircraft and shop waste of which 1,200 gallons are blended directly with F06 in the fuel storage tank, and burned in six water tube boilers, ranging in size from 26,000 to 60,000 lb/hr. These boilers all have mechanical atomizing burners with automatic controls. The total waste oil generated could replace 0.3% of the total fuel oil consumption.

Camp Pendleton, Oceanside, Calif. This Marine Corps base generates and sells 96,000 gallons of waste oil a year from primarily shop operations. Over 384,000 gallons of FOR from the Point Loma Fuel Depot, San Diego, are burned annually, along with 6,000 gal/mo of waste oil from NAVSTA. There are 514 boilers of sizes from a fraction to 20 MBtu/hr, with an estimated 90% being fire tube type. The operating mode is intermittent. During winter, the load factor is 90% at 15 hr/day. During summer, the load factor is 50% at 8 hr/day. Two 25,000-gallon storage tanks are being converted into waste oil gravity separation/storage tanks. The total waste oil generated could replace 6% of the total fuel oil consumption.

Camp S. D. Butler, Japan. This base generates from 50,000 to 60,000 gallons of waste oil annually. Sources include aircraft, shops, and motor pools. An estimated 10,000 gal/yr of contaminated DF2, JP-4, kerosene, and NSFO are being burned intermittently at the Marine Corps Air Station. Most of the 190 boilers are the dry back, marine, and locomotive types. The boilers range in size from 0.14 to 2.13 MBtu/hr. The total waste oil generated could replace 2% of the total fuel oil consumption.

Charleston, S.C. This area generates 1,300,000 gallons of waste oil annually, primarily from bilge and ballast waste from the Naval Shipyard. Aircraft and hydraulic training devices are additional sources. An estimated 20% of the waste generated is recycled through an oil-water separator and blended into NSFO and burned as boiler fuel. The viscosity of the blend is constantly monitored to keep it within required specifications for NSFO. Since FY80, 1.2 million dollars have been credited to NAVSUP because of this burning. The total waste oil generated could replace 23% of the total fuel oil consumption.

NWC China Lake, Calif. In 1978 and 1979, NCEL and NWC China Lake conducted a series of controlled tests burning waste oil in one boiler. The boiler utilized was a single-burner, water tube boiler producing 125-psi saturated steam at 20,700 lb/hr rated capacity. These tests were run blending the waste oil in concentrations of 8% to 90% with FO6. Control tests were also conducted with FO6 alone and burning 100% waste oil. The results were reported in Reference 2.

NWC China Lake generates approximately 3,300 gallons of waste oils per month that are comprised primarily of contaminated JP-4, JP-5, diesel fuels, and used lubricating oils. The mixture of these oils is a dark-colored liquid resembling light fuel oil and is somewhat heavier and higher in viscosity than diesel fuel. This material had been used in the past for firefighter training and dust control. Only high flashpoint waste oils (e.g., used lubricating oils, contaminated JP-5 and diesel fuels) were used for the tests. Low flashpoint and other materials (e.g., contaminated JP-4, gasoline, solvent) were collected separately for firefighters' training and were not mixed with the high flashpoint materials.

The NWC waste oil resembled a light grade fuel oil. After removal of water and solid contaminants, this waste oil was satisfactorily fired in boilers, either straight or in blends of any concentration with the regular FO6. To minimize the requirement for burner adjustments, the firing temperature of a blend was controlled so that its viscosity was nearly the same as that of the regular fuel oil at its normal firing temperature. No operational or environmental emission difficulties were encountered due to the presence of waste oil during either batch or in-line blending tests. In-line blending was successfully achieved by combining two oil streams using a "T" arrangement. The total waste oil generated could replace 8% of the total fuel oil consumption.

Crane, Ind. This area generated 9,615 gallons of used motor oil from June 1981 to June 1982. About 23% of this oil was burned in three water tube boilers: one at 18,000 lb/hr and two at 20,000 lb/hr. All three have air atomizing burners and operate in a continuous mode. Waste oil is blended directly with FO6. The total waste oil generated could replace 0.3% of the total fuel oil consumption.

El Toro, Calif. This area generates 195,000 gallons of waste oil annually. An estimated 75% of this used motor oil, AVGAS, and kerosene is burned. Of the 54 water tube and fire tube boilers reported, all were gas/oil fired with automatic controls and air atomizing burners. Operating modes are both continuous and intermittent. They have had approximately 3 years of experience burning waste oil. The total waste oil generated could replace 70% of the total fuel oil consumption.

NAS Fallon, Nev. This air station generates approximately 59,000 gallons of waste oils per year, of which about 94% is JP-5 from aircraft maintenance hangars and 6% is lubrication oils from transportation shops. About 44,000 gal/yr of the JP-5 is burned directly in 23 boilers 15 to 200 hp in size - three water tube continuously operated 448-hp boilers and 20 intermittently operated fire tube boilers. Four of the burners use air atomization, and 19 use mechanical pressure atomization. The waste oil was burned by directly dumping into existing fuel tanks. About 10,000 gallons of the JP-5 is used for firefighting training. The 3,600 gallons of lube oils and 2,000 gallons of the JP-5 are used for weed and dust control. The total waste oil generated could replace 6% of the total fuel oil consumption.

Guam. In FY80, PWC Guam reported generating two types of waste oil. They reported further that approximately 8,000 gal/yr of used lube oil results from oil changes of diesel engine generators. As much as 600,000 gallons of contaminated DFM each year is generated from pipeline purging at the tank farm. No quality assurance measures are taken since the fuel is not really dirty but contains water and, maybe, small amounts of FO6. This waste oil is not burned on a regular basis but, rather, only when a supply accumulates or becomes available from the tank farm. It is direct-blended into existing FO6 tankage by first filling the tank half full with the waste oil and then filling the tank with FO6. This oil is utilized by three 200,000-lb/hr and three 150,000-lb/hr boilers using approximately 190,000 gal/day of fuel oil. No modification to existing equipment was necessary and the results were within normal boiler operation guidelines. There was no report received from PWC Guam in the 1982 survey. However, in 1982, NAS, NAVSHIPREPFAC, and NAVFAC Guam, reported generating 151,000 gal/yr of waste oils, consisting mainly of lube oils, with some fuel and hydraulic fluids. Most of it (99.8%) is sent to NSD Guam for recycling, while a small amount is used for firefighting training. The total waste oil generated could replace 22% of the total fuel oil consumption.

NAVSTA Guantanamo Bay, Cuba. In FY80 this activity reported burning about 180,000 gallons of waste oil a year in a combination desalination steam power plant. The waste oil consisted of used lube oil, hydraulic fluid, and contaminated fuel from transportation and maintenance service areas. The oil was collected and stored in a Ship Waste Offload Barge (SWOB). Future plans included the use of a Waste Oil Raft (DONUT) to aid in separation of water and solids from the oil. Transported to the plant, the waste oil was direct-blended into existing tankage with NSFO at a concentration of about 5% (typically 2,000 gallons in 40,000 gallons regular fuel) and burned at the normal rate. Analysis of the waste oil showed an average heating value of 135,000 Btu/gal. No major problems with burning were encountered. However, early problems included flameouts due to high water concentrations in the oil and clogging of burners and equipment by "globs" and sediment. Increased settling time prior to burning has greatly reduced operational problems. Unknown quantities of abandoned fuel found in oil underground storage tanks were also being salvaged and utilized as a supplemental fuel. In FY82 the station reported generating and burning 110,000 gallons of waste oils per year, which includes 90,000 gallons from ships and 20,000 gallons from shops. The waste oil resembles NSFO and is recycled and used in three 103,000-lb/hr and one 120,000-lb/hr boilers at power plant No. 4. The boilers are water tube with automatic control and are operated continuously, activated by flow. The total waste oil generated could replace 0.8% of the total fuel oil consumption.

Honolulu, Hawaii. The activities in this area generate and burn 1,470,000 gallons of waste oil annually. Bilge and defueling operations send the waste oils to a reclamation plant for water removal prior to burning. Diesel fuel fired fire tube boilers, ranging in size from 0.56 to 1.7 MBtu were used. The total waste oil generated is 15 times the total fuel oil consumption.

NAC Indianapolis, Ind. In FY80 this center reported burning approximately 5,000 gallons of waste oil in one of three 17,000-lb/hr steam boilers. The major source was machine shop cutting oil. Metal filings present in the oil were the major problem and were removed by a centrifuge prior to storing or burning. Used lube oil was the secondary source and was collected from 60 vehicles in the transportation department and from a collection center provided for individuals. The boilers are designed to burn natural gas as primary fuel and FO5 as backup. Storage of FO5 was maintained in six 1,500-gallon tanks, one of which was set aside to receive waste oil. Clean FO5 and waste oil were mixed at about a 50/50 ratio in this tank prior to burning. Problems of increased smoke emission and clogged filters due to dirt and sediment suspended in the waste oil were sometimes experienced. In FY82, they reported generating and burning 2,692 gallons of waste oil per year (to get this, they averaged quantities for 1979, 1980, 1981) in three of five boilers: two water tube and one fire tube gas or oil fired types. The fire tube boiler is rated at 500 hp, has mechanical atomization, and operates intermittently. The waste oil is lube oil from shops and "used motor oil brought in by employees." The total waste oil generated could replace 19% of the total fuel oil consumption.

Kaneohe Bay, Hawaii. This area generates 924,000 gallons of waste oil annually. An estimated 10% of this waste oil is contaminated JP-5 and is being burned in boilers. The waste oil is treated at the reclamation facility. Two 300-MBtu/hr fire tube boilers operating intermittently with air atomizing burners were used. The total waste oil generated equals 1.7 times the total fuel oil consumption.

Keflavik, Iceland. This area generates 20,000 gallons of waste oil annually consisting of used lube oil, contaminated JP-4, diesel, and fuels from aircraft defueling operations. About half of this is burned at 10% waste oil concentration. Minor problems have occurred when JP-4 is excessively contaminated. The total waste oil generated could replace 0.3% of the total fuel oil consumption.

NAVSTA Mayport, Fla. This station burned 650,000 gallons of waste oil during FY80, 750,000 gallons during FY79, and 500,000 gallons during FY78. The major source is ship discharge, which consists of very dirty DFM (greater than 90%), water, and sediment. For treatment of the waste oil, the ship discharge was placed in series of three 157,500-gallon tanks, allowed to settle, and water drained off the bottom each time. The third time it was allowed to settle for 24 hours. The top 4 to 5 feet of oil was skimmed off the tank and trucked to the boiler plant. The three 33,500-lb/hr water tube boilers are designed to burn FO5. The waste oil, which resembles basically FO2, blends in well with the regular fuel and has an estimated heating value of 140,000 Btu/gal, which closely approximates that of DFM. Samples of the waste oil burned are periodically taken and analyzed.

Maintenance and operational problems include:

- Pumps - rotary vane pumps used for fuel transport were especially intolerant to solids. Damage included scored liners and pitted vanes.

- Strainers - strainers required cleaning up to four times as often when using waste oil.

- Burner tips - deformation of burner tip orifices increased. The orifices became enlarged, elongated, and pitted.

Removal of water and especially solids from the waste oil prior to burning is important in reducing maintenance and repair of boiler equipment.

In FY82, the activity reported generating and burning 400,000 gallons of waste oil annually, consisting of contaminated DFM and lubricants. The oil was mixed with FO5 (light) and burned in five water tube boilers with mechanical steam CDL atomizers and Todd "V" register, operated in continuous mode: three at 35,000 lb/hr and two at 30,000 lb/hr. Boiler plant operators have complained about abnormal maintenance caused by excessive contaminants. Sand, lead, and sodium chloride have impaired two pumps in 2 years, have coated furnace walls, and have created sand-blasting effects from atomizers. Packaged boilers make frequent cleanings impossible, though larger boilers are cleaned readily. Burner tip life has been shortened from 3 to 4 years to a 1-year maximum. Blending ratios ranging from 50/50 to 90/10 are used. Future plans include the installation of a 100 gal/hr centrifuge to remove water and sediment prior to burning. When this facility is completed, waste oil can be hauled or pumped directly to the boiler plant without lengthy settlement periods. The total waste oil generated could replace 16% of the total fuel oil consumption.

<u>NAS Miramar, Calif</u>. This air station reports 1,608,000 gallons of waste oil generated annually. An estimated 86% of this contaminated JP-5 and ship bilge is being burned. Boilers with a capacity of 38 MBtu/hr are water tube type and operate in continuous mode. Routine maintenance is slightly increased. Fireside deposits and residue plugging nozzles and strainers caused an increase in the changing or cleaning of these items. FOR from the Point Loma treatment facility is also burned. The total waste oil generated is 1.1 times the total fuel oil consumption.

<u>Newport, R.I</u>. This area generates a calculated 19,800 gallons of contaminated JP-5 and used lube oil annually. About 94% of this oil is burned in boilers. Boilers are both water tube and fire tube and range in size up to 110,000 lb/hr. Operating modes are both continuous and intermittent. From 50,000 to 75,000 gallons of oily waste (75% water and contaminants) are placed in storage tanks and allowed to settle out.

The waste oil extracted is then tested and blended with NSFO in a power house tank. The total waste oil generated could replace 0.3% of the total fuel oil consumption.

PWC Norfolk, Va. In FY80, PWC Norfolk utilized two different sources of supplemental fuel. The major source (4 million gal/yr) was the FOR obtained from Craney Island and burned independently in a separate burner with little or no operational changes required. Although existing FO6 pumps will handle the lighter weight FOR, they were being replaced with pumps designed specifically to handle fuel of FO2 consistency when ordinary wear and service life dictates. This activity has been burning FOR since 1979 with no problems or deviations from normal boiler operation. The secondary source of waste oil was used lube oil and hydraulic fluid that never amounts to more than 10,000 gal/yr. This waste oil was collected from the motor pool and service areas and transported to the boiler plant where it was direct-blended into existing FO6 tankage and burned along with the regular fuel. Prior to burning, waste oil and FOR are tested for specification compliance.

In FY82 PWC, NAVSTA, NAS, and FTC, Sewells Point, Norfolk, generated a total of 128,095 gallons of waste oils, consisting mainly of JP-5, lube, DFM, FO2, hydraulic fluids, and solvents. These come from ships, oil spills, shops, and aircraft areas. Of this quantity, 10,000 gallons are burned, a small amount is used for firefighting training, and some is sold, but the most part goes to the reclamation facility at Craney Island. Along with the 10,000 gallons burned, a larger quantity (2,655,000 gallons) of FOR received from Craney Island is also burned by PWC in two water wall, 60,000 lb/hr boilers with Peabody steam atomizers, one on line continuously, with a 75% load factor. These waste oils are blended with NSFO prior to burning. The total waste oil generated (aside from that obtained from Craney Island) could replace 0.4% of the total fuel oil consumption.

NAS Oceana, Va. This station operates four boilers totaling 210,000 lb/hr, all of which periodically burn FOR obtained from Craney Island. FOR is placed in the main tanks in the same manner as regular fuel and burned at a 50% concentration with FO6. No handling differences from that of regular fuel are experienced. However, the Btu rating of the FOR (135,000 to 140,000 Btu/gal) is lower than that of FO6; as a result, an increase in the firing rate is required to offset the deficit. In FY82, the station reported having generated 4,310 gallons of waste oil in 1981. This included lube, hydraulic fluids, and solvents. They reported also that in 1981, 952,000 gallons of FOR from the reclamation facility at Craney Island was burned as boiler fuel, blended 26% with 74% FO6. The total waste oil generated (aside from that obtained from Craney Island) could replace 0.1% of the total fuel oil consumption.

Pearl Harbor, Hawaii. This area reports 1,730,884 gallons of waste oil generated annually. An estimated 79% of this - mostly FOR, ship bilge, and used transformer oils* - is burned. Boilers are both water tube and fire tube. The largest three boilers are 40,000 lb/hr, steam atomized burners, with pneumatic controls. At least one of these three boilers is operating in a continuous mode at all times. Waste oils are

*PCB's are forwarded to DPDO for proper disposal.

sent to the NSC reclamation plant prior to burning. Downgraded DFM is blended at a 1:9 ratio with primary fuel oil and burned. The total waste oil generated could replace 57% of the total fuel oil consumption.

Puget Sound, Wash. This area generates 423,340 gallons of waste oil annually. An estimated 0.8% of this used lube oil, gasoline, and solvents is being burned in boilers by blending into F06. The total waste oil generated could supply 1.9 times the total fuel oil requirements.

Quantico, Va. This area generates 5,000 gallons of waste oil annually. An estimated 96% of this used JP-4 and crankcase oils is being burned in boilers. The boilers reported were water tubes, ranging in size from 0.2 to 20 MBtu/hr. The contaminated JP-4 is blended with the primary boiler fuel and burned at irregular intervals. The total waste oil generated could replace 0.1% of the total fuel oil consumption.

NAVSTA and NAVCOMMSTA, Rota, Spain. These activities reported burning approximately 201,000 gallons of contaminated fuel during FY82 in two 85,000-lb/hr boilers that normally burn F06. In FY80 the amount was 115,000 gallons. The sources of this oil are fuel pier spillage and fuel/water pumped from fuel tankers during tank cleaning. The fuel pier is equipped with spillage drains and holding tanks. Fuel spilled during unloading operations is collected and stored. Contaminated fuel unloaded from ships, and oils from shop operations, are placed in holding tanks. The fuel mixture is then transferred to an API separator for gravity separation and then into either low or high flashpoint tanks (the flashpoint is checked by a chemist). When the power plant calls for it, the fuel is transferred first to a direct blending tank and then pumped into a plant tank where it is held for 72 hours before burning at a concentration of 5% to 10%. Few or no adverse effects of use have been identified. The total waste oil generated could replace 3% of the total fuel oil consumption.

Washington, D.C. This area generates 3,500 gallons of used lube oil from automotive shops annually. An estimated 63% of this is burned in two 85,000-lb/hr water tube boilers. Primary fuels are F06 and DF2, and the operating mode is continuous with steam atomizing high-pressure burner nozzles. A separation system removes excessive contaminants. The waste oil fuel line is tapped into the fuel oil feed line and provides a 1:10 blending ratio. The total waste oil generated is less than 0.1% by volume of the total fuel oil consumption.

NAS Whidbey Island, Wash. In FY80, this activity reported collecting and burning approximately 60,000 gallons of waste oil and contaminated fuel. The waste oil burned consisted of a wide range of solvents, phenols, JP-5, hydraulic fluids, and used lube oils. Enlisted personnel collected fuel, solvents, and used lube oil from the flight line in mobile bowsers (700- to 1,000-gallon capacity) and transported it to the boiler plant, where it was stored in a 25,000-gallon underground tank. This oil was not treated. Secondly, Public Works collected used lube oil from garages, service areas, and other locations throughout the base and placed it in a 5,000-gallon tank to settle. The oil that rises is skimmed off the top and placed in a 3,000-gallon second tank to settle, and water is drained off the bottom periodically. After settling, this oil was transported to the underground tank at the boiler plant. The waste oil was burned in one of three 44-MBtu/hr boilers which use natural gas as the primary fuel and FO2 as backup. No modifications to the burner itself were required. The waste oil was pumped from the underground holding tank through a fine strainer and into the burner. While the waste oil was burned, adjustments of the natural gas burners were made to compensate for fluctuations of the waste oil burner. Increased boiler cleaning efforts have been observed. The boiler utilizing waste oil has increased ash accumulation and requires cleaning twice a year. Boilers burning regular oil may be cleaned only every year or two. In FY82 NAS Whidbey reported generating 180,000 gallons of waste oil per year. Oily water goes to Manchester Naval Fuel Depot. Low flashpoint oils go to the firefighting school. Waste oils and JP-5 fuel are burned in one of three boilers at a rate of 7,500 gal/mo for 3 months of the year, totaling 22,500 gal/yr. This boiler was modified to accept waste oil as a fuel. It is a Coen style "MW" No. 2 mechanical atomizing boiler which burns natural gas, FO2, and intermittently waste oil. It has Fireye nonself-checking combustion controls and a capacity of 50,000 lb/hr, continuous operation. Natural gas is used to preheat this boiler for burning waste oil. The total waste oil generated could replace 54% of the total fuel oil consumption.

PWC Yokosuka, Japan. This PWC reported in FY80 that it was burning approximately 2,000 gal/yr of used lube oil from the transportation shop and transformer oil not containing PCB. The waste oil burned was only that generated and collected by PWC. This waste oil was collected in 55-gallon drums and poured through a fine screen filter into a 1,000-gallon tank where it settled. The oil was then burned straight (at 100% concentration) in a boiler specified for the purpose. By FY82 the quantity of waste oil burned had increased to 12,000 gal/yr and consisted of used lube and fuel oils from the power plant, boiler plant, and transportation shop. After solvents are removed, the oil is blended in appropriate portions and burned in water tube and fire tube boilers. The total capacity of 22 boilers is 574 MBtu/hr. These are automatic steam/air and rotary cup atomization burners burning low sulphur fuel oil and DFM. They are operated continuously at a 76% load in winter and a 68% load in summer. Although PWC, NAVSHIPREPFAC, and NAVCOMMSTA generate about 145,000 gallons of waste oils per year, the waste oil burned is still only that generated and collected by PWC. Ship bilge waste oil generated dockside is collected in DONUTS and SWOB barges and transported to the Naval Supply Depot, where the waste oil goes through gravity separation and is blended into FO6 and sold. The total waste oil generated could replace 1% of the total fuel oil consumption.

## Tabulated Results of Survey

Table 5 provides an overview of pertinent experience, listed by activity. Table 6 summarizes the energy usage and waste oil generation and distribution by these activities grouped into 153 locations and totaled by Naval district. A more detailed breakdown by locations within each Naval district is presented in Table 3, A through L and includes alphabetical listings of the locations surveyed, with energy usage and waste oil generation and distribution data.

Table 6 shows that 19 million gallons of waste oil were generated.* Of this quantity, 57% was burned as boiler fuel, and 43% was distributed in several ways (see footnote e of Table 3). Table 3 also shows that 20% of the locations surveyed burned waste oil as boiler fuel. Furthermore, not all of the locations surveyed indicated waste oil generation.** The data show that 26% of those who reported having generated waste oil had burned it as boiler fuel. An overall observation is that there is a potential for more productive use of significant quantities of waste oil.

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*(2,607,785 MBtu)/(0.1357 MBtu/gal) = 19 million gallons.

**Some contacted were reluctant to report the quantity of waste oil generated.

## DEFINITIONS

| | |
|---|---|
| API | American Petroleum Institute |
| ASTM | American Society for Testing and Materials |
| CHIL LIST | Consolidated Hazardous Item List (Ref 5) |
| Contaminated Fuel | Fuel that has been contaminated by foreign material such as water, sediment, other fuels, oil, and solvents, and cannot be used for its intended purpose. |
| DEIS | Defense Energy Information Service |
| DF, DF2, DFM | Diesel Fuel, Diesel Fuel #2, Diesel Fuel Marine |
| DLA | Defense Logistics Agency |
| DONUT | Waste oil raft that performs initial gravity separation |
| DPDO | Defense Property Disposal Office |
| ECIP | Energy Conservation Investment Program (Ref 4) |
| FO, FO2, FO5, FO6 | Fuel Oil, Fuel Oil No. 2, Fuel Oil No. 5, Fuel Oil No. 6 |
| FOR | Fuel Oil Reclaimed. Oil that has been processed by a Naval Supply activity through a low-temperature heating and settling facility to remove suspended water and sediment. It is then usually reissued or blended into other fuel. |
| NAVFAC | Naval Facilities Engineering Command |
| NAVSUP | Naval Supply Systems Command |
| NEESA | Naval Energy and Environmental Support Activity (Port Hueneme, Calif.) |
| NSFO | Navy Special Fuel Oil |
| SUS | Saybolt Universal Seconds (a measure of viscosity) |
| SWOB | Ship Waste Offload Barge |
| UIC | Unit Identification Code |
| Waste Oil | The descriptive term applied to used or contaminated petroleum-based and synthetic/chemical-based oil products that are no longer suitable for use as originally intended. |

Table 1. Oil Product Types

| Type | Characteristics[a] | Product Examples |
|---|---|---|
| A - Gasolines and solvents | Hazardous, very low flashpoint | Automotive gasoline<br>Aviation gasoline<br>JP-4 |
| B - Kerosenes | Clean burning light fuel, low flashpoint (100°F minimum), less volatile than gasolines | FO1<br>JP-5 |
| C - Diesel Fuels | Flashpoint 100°F minimum, slightly viscous | FO2<br>Marine diesel<br>Automotive diesel |
| D - Other Fuel Oils | No. 4-Moderately viscous, odoriferous, flashpoint 130°F minimum<br><br>No. 5-Viscous, odoriferous, flashpoint 130°F minimum<br><br>No. 6-"Black oil," very viscous, odoriferous, flashpoint 140°F minimum | FO4 through FO6 |
| E - Petroleum-Based Oils | Generally high flashpoint, viscous fluid or semisolid greases | Lubricating oils/greases<br>Hydraulic fluids<br>Transmission fluids |
| F - Synthetic/Chemical-Based Oils and Halogenated Solvents | Similar to petroleum-based oils but may contain halogens, combustion products may be toxic and hazardous | Lubricating oils/greases<br>Hydraulic fluids<br>Brake fluids |

[a]Flashpoint values taken from ASTM D-396, Standard Specification for Fuel Oils (App B).

Table 2. Estimated Annual Energy Consumption by Naval Shore Facilities

| Type of Energy Used | Energy Consumption[a] | |
|---|---|---|
| | $10^6$ MBtu | Total (%) |
| GLO | | |
| Natural gas | 28 | 15 |
| Liquid petroleum gases | 0.6 | <1 |
| Fuel oils | 43 | 24 |
| Electricity | 104 | 57 |
| Coal | 3 | 2 |
| Steam and hot water | 2 | 1 |
| Total | 181 | 100 |

[a]Figures are illustrative only; 1 MBtu ≈ 7.37 gallons light fuel oil.

Table 3. Energy Usage and Waste Oil Generation and Usage, by Locations Surveyed[a]

| Location Surveyed[b] | Energy Usage[c] | | | | | Waste Oil Distribution[d] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Types of Energy (MBtu) | All Types of Fuel (MBtu) | Fuel Oil (MBtu) | Ratios (%) | | Generated (MBtu) | Disposal Methods[e] | Ratios (%) | | Source | Composition |
| | | | | All Fuel/ All Energy | Fuel Oil/ All Fuel | | | Burned/ Generated | Generated/ Fuel Oil Used | | |
| **Part A. Naval District Four** | | | | | | | | | | | |
| Bloomfield, CT (1) | 93,933 | 24,147 | 24,147 | 25.7 | 100 | | | | | | |
| Brooklyn, NY (2) | 372,055 | 149,314 | 86,436 | 40.1 | 57.9 | 326 | D | 0 | 0.4 | automotive | lube |
| Brunswick, ME (2) | 651,084 | 345,401 | 345,401 | 53.1 | 100 | 1,166 | B | 14 | 0.3 | aircraft | JP-5 |
| Cutler, ME (2) | 329,615 | 273,413 | 273,391 | 82.9 | 100 | 1,018 | B | 0 | 0.4 | generators | lube |
| Davisville, RI (2) | 112,711 | 56,219 | 33,240 | 49.9 | 59.1 | 580 | B | 0 | 1.7 | shops | lube |
| Earle, NJ (3) | 314,435 | 152,696 | 151,722 | 48.6 | 99.4 | 7,192 | B | 0 | 4.7 | automotive | lube |
| Garden City, NY (1) | 32,289 | 6,714 | 5,812 | 20.8 | 86.6 | 0 | -- | -- | -- | | |
| Lakehurst, NJ (3) | 742,731 | 469,377 | 459,136 | 63.2 | 97.8 | 3,664 | A,B | -- | 0.8 | aircraft, auto | JP-5, lube |
| Mechanicsburg, PA (1) | 841,391 | 276,761 | 255,543 | 32.9 | 92.3 | 733 | D | 0 | 0.3 | shops | lube |
| New London, CT (1) | 2,866,707 | 1,480,519 | 1,479,982 | 51.6 | 100 | 24,433 | B | 0 | 1.7 | ships, shops | lube, DFM, FO6 |
| Newport, RI (7) | 2,102,949 | 1,185,029 | 1,026,344 | 56.4 | 86.6 | 2,694 | B | 94 | 0.3 | ships | JP-5, DFM |
| Philadelphia, PA (13) | 5,138,029 | 3,683,836 | 1,096,982 | 71.7 | 29.8 | 10,335 | B,D | 0 | 0.9 | ships | bilge, lube |
| Pittsfield, MA (1) | 431,272 | 115,392 | 61,397 | 26.8 | 53.2 | | | | | | |
| Portsmouth, NH (4) | 1,689,445 | 1,379,986 | 1,379,986 | 81.7 | 100 | 13,570 | E | 0 | 1.0 | ships | bilge, lube |
| Ravenna, OH (1) | 75,519 | 45,343 | 4,234 | 60.0 | 9.3 | 14 | D | 0 | 0.3 | automotive | lube |
| Scotia, NY (1) | 60,539 | 36,225 | 30,375 | 59.8 | 83.9 | 14 | D | 0 | 0.05 | automotive | lube |
| South Weymouth, MA (1) | 164,315 | 97,070 | 97,070 | 59.1 | 100 | 1,086 | D | 0 | 1.1 | aircraft, shops | FO6, lube, solvents |
| Warminster, PA (2) | 474,633 | 171,664 | 141,126 | 36.2 | 82.2 | 679 | B | 0 | 0.5 | auto, aircraft | lube |
| Willow Grove, PA (2) | 327,038 | 171,761 | 29,552 | 52.5 | 17.2 | 366 | D | 0 | 1.2 | auto, aircraft | lube |
| Winter Harbor, ME (2) | 114,405 | 37,822 | 37,822 | 33.1 | 100 | 163 | B | 0 | 0.4 | automotive | lube |
| Total (52) | 16,935,096 | 10,158,689 | 7,019,698 | 60.0 | 69.1 | 68,033 | -- | 4 | 1.0 | | |
| **Part B. Naval District Five** | | | | | | | | | | | |
| Camp Elmoore, VA (1) | 57,763 | 41,836 | 38,542 | 72.4 | 92.1 | 1,493 | D | 0 | 3.9 | automotive | lube |
| Camp Lejeune, NC (2) | 4,970,742 | 2,553,592 | 2,287,538 | 51.4 | 89.6 | 13,570 | B | -- | 0.6 | automotive | lube |
| Chesapeake, VA (3) | 187,536 | 30,471 | 30,146 | 16.2 | 98.9 | 27 | D | 0 | 0.1 | shops | lube |
| Dahlgren, VA (3) | 913,312 | 285,160 | 282,020 | 31.2 | 98.9 | 4,071 | B,D | 0 | 1.4 | ships, shops | lube, bilge, solvents |
| Little Creek, VA (3) | 1,972,310 | 1,049,158 | 968,641 | 53.2 | 92.3 | 46,898 | B | 0 | 4.8 | ships, shops | JP-5, DFM, lube |
| Norfolk, VA (19) | 11,044,511 | 4,802,791 | 4,283,132 | 43.5 | 89.2 | 17,380 | D | 2,100[f] | 0.4 | ships | JP-5, DFM, lube |
| Oceana, VA (2) | 1,455,340 | 642,934 | 531,342 | 44.[illegible] | 82.6 | 585 | A | 22,000[f] | 0.1 | shops | lube, solvents |
| Portsmouth, VA (4) | 4,343,776 | 2,530,[illegible]20 | 2,291,840 | 58.2 | 90.6 | 145,878 | D | 0 | 6.4 | ships, shops | DFM, bilge, solvents |

continued

Table 3. Continued

| Location Surveyed[b] | Energy Usage[c] | | | | | Waste Oil Distribution[d] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Types of Energy (MBtu) | All Types of Fuel (MBtu) | Fuel Oil (MBtu) | Ratios (%) | | Generated (MBtu) | Disposal Methods[e] | Ratios (%) | | Source | Composition |
| | | | | All Fuel/ All Energy | Fuel Oil/ All Fuel | | | Burned/ Generated | Generated/ Fuel Oil Used | | |
| **Part B. Naval District Five (continued)** | | | | | | | | | | | |
| Quantico, VA (1) | 1,952,256 | 1,166,101 | 702,965 | 59.7 | 60.3 | 679 | A | 96 | 0.1 | aircraft | JP-5, lube |
| Sugar Grove, WV (2) | 30,672 | 11,114 | 2,275 | 36.2 | 20.5 | 20 | A | 0 | 0.9 | automotive | lube |
| Thurmont, MD (2) | 82,369 | 19,695 | 19,695 | 23.9 | 100 | | | | | | |
| Virginia Beach, VA (4) | 927,658 | 374,292 | 376,268 | 40.3 | 100 | 430 | B | 0 | 0.1 | shops | kerosene, lube |
| Yorktown, VA (2) | 651,896 | 345,239 | 345,239 | 52.5 | 100 | | | | | | |
| Total (48) | 28,591,140 | 13,852,603 | 12,159,643 | 48.5 | 87.8 | 231,031 | -- | 214[f] | 1.9 | | |
| **Part C. Naval District Six** | | | | | | | | | | | |
| Albany, GA (1) | 880,661 | 269,051 | 7,527 | 30.6 | 2.8 | 4,478 | B | 0 | 59 | shops | lube |
| Athens, GA (1) | 70,915 | 24,666 | 3,518 | 34.8 | 14.3 | 0 | -- | -- | -- | | |
| Atlanta, GA (1) | 71,182 | 24,852 | 2,252 | 34.9 | 9.1 | 679 | | 0 | 30 | aircraft | lube |
| Beaufort, SC (3) | 1,035,879 | 312,433 | 105,099 | 30.2 | 33.6 | 2,069 | B,D | 0 | 2.0 | shops | lube, solvents |
| Cecil Field, FL (2) | 791,390 | 221,981 | 24,866 | 28.1 | 11.2 | 10,856 | A,B | 0 | 44 | aircraft | JP-5, lube |
| Charleston, SC (14) | 5,046,195 | 1,690,447 | 767,563 | 33.5 | 45.4 | 175,340 | E,D,C | 20 | 23 | ships, shops | bilge, lube |
| Cherry Point, NC (2) | 2,991,173 | 1,513,322 | 1,224,323 | 50.6 | 80.9 | 46,003 | A,B | 0 | 3.8 | aircraft, automotive | JP-5, lube |
| Gulfport, MS (1) | 331,940 | 94,546 | 64 | 28.5 | 0.1 | 1,954 | B | 0 | 3,100 | shops | lube |
| Homestead, FL (1) | 42,737 | 1,429 | 1,420 | 3.3 | 99.4 | 37 | D | 0 | 2.6 | automotive | lube |
| Jacksonville, FL (5) | 2,417,704 | 958,068 | 13,520 | 39.6 | 1.4 | 25,498 | A,B | 0 | 190 | aircraft, shops | JP-5, lube |
| Key West, FL (2) | 491,093 | 25,179 | 25,069 | 5.1 | 99.6 | 388 | B | 0 | 1.5 | automotive | lube |
| Mayport, FL (3) | 1,660,248 | 340,214 | 339,130 | 20.5 | 99.7 | 54,280 | -- | 340[f] | 16 | ships | bilge, lube |
| Memphis, TN (4) | 1,910,265 | 1,003,196 | 77,110 | 52.5 | 7.7 | 1,160 | D | 0 | 1.5 | aircraft, automotive | lube |
| Orlando, FL (2) | 1,094,753 | 199,790 | 20,244 | 18.3 | 10.1 | 1,251 | B | 0 | 6.2 | automotive | lube |
| Panama City, FL (2) | 152,129 | 14,751 | 14,596 | 9.7 | 98.9 | 2,036 | D | 0 | 14 | ships, shops, aircraft | bilge, lube |
| Parrish Island, SC (1) | 1,196,660 | 865,504 | 74,481 | 71.5 | 8.7 | 679 | B | 0 | 0.9 | shops, automotive | lube, solvents |
| Pensacola, FL (8) | 3,984,249 | 2,487,337 | 41,053 | 62.4 | 1.7 | 8,142 | D | 0 | 19.8 | auto, shops, aircraft | lube, solvents |
| Saufley Field, FL (1) | 32,057 | 19,135 | 1,967 | 59.7 | 8.9 | 0 | -- | -- | -- | | |
| Total (56) | 24,201,230 | 10,055,901 | 2,743,802 | 41.6 | 27.3 | 334,850 | | 65 | 12 | | |

continued

Table 3. Continued

| Location Surveyed[b] | Energy Usage[c] | | | | | Waste Oil Distribution[d] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Types of Energy (MBtu) | All Types of Fuel (MBtu) | Fuel Oil (MBtu) | Ratios (%) All Fuel/ All Energy | Ratios (%) Fuel Oil/ All Fuel | Generated (MBtu) | Disposal Methods[e] | Ratios (%) Burned/ Generated | Ratios (%) Generated/ Fuel Oil Used | Source | Composition |
| **Part D. Naval District Eight** | | | | | | | | | | | |
| Dallas, TX (1) | 259,201 | 69,205 | 5,846 | 26.7 | 8.4 | 380 | B | 0 | 6.5 | aircraft, automotive | JP-4, lube |
| Driver, AR (1) | 152,562 | 1,402 | 1,402 | 0.9 | 100 | | | | | | |
| New Orleans, LA (3) | 89,851 | 36,897 | 11,353 | 41.1 | 30.8 | 54 | D | 0 | 0.5 | automotive | lube |
| Total (5) | 501,614 | 107,504 | 18,601 | 21.4 | 17.3 | 434 | -- | 0 | 2.3 | | |
| **Part E. Naval District Nine** | | | | | | | | | | | |
| Crane, IN (3) | 956,667 | 477,123 | 473,044 | 49.8 | 99.1 | 1,305 | B | 23 | 0.3 | shops | lube |
| Great Lakes, IL (3) | 3,139,267 | 2,263,908 | 21,008 | 72.1 | 0.9 | 305 | B | 0 | 1.5 | automotive | lube |
| Indianapolis, IN (1) | 1,386,712 | 86,108 | 1,890 | 6.2 | 2.2 | 365 | -- | 100 | 19 | shops | lube |
| Minneapolis, MN (3) | 1,159,117 | 427,343 | 202,994 | 36.9 | 47.5 | | | | | | |
| Olathe, KS (2) | 47,258 | 27,839 | 8,709 | 58.9 | 31.3 | 0 | -- | -- | -- | | |
| Total (12) | 6,689,021 | 3,282,321 | 707,645 | 49.1 | 21.6 | 1,975 | -- | 34 | 0.3 | | |
| **Part F. Naval District Eleven** | | | | | | | | | | | |
| Alameda, CA (4) | 2,239,395 | 995,978 | 281,487 | 44.5 | 28.3 | 22,610 | A,B | 0 | 8.0 | ships, aircraft, shops | bilge, lube solvents |
| Barstow, CA (1) | 617,608 | 316,310 | 88,869 | 51.2 | 28.1 | 22,798 | B | 0[f] | 26 | automotive | lube |
| Camp Pendleton, CA (1) | 2,682,556 | 1,240,502 | 234,616 | 46.2 | 18.9 | 13,027 | B | 480 | 5.6 | shops, FOR, ships | lube, FO |
| Centerville Beach, CA (1) | 68,855 | 28,969 | 28,969 | 42.1 | 100 | 0 | -- | -- | -- | | |
| China Lake, CA (2) | 1,561,849 | 639,412 | 69,262 | 40.9 | 10.8 | 5,428 | A | 75 | 7.8 | aircraft, automotive | JP-4, JP-5, lube |
| Concord, CA (2) | 260,591 | 98,783 | 54,363 | 37.9 | 55.0 | 1,357 | B,D | 0 | -- | shops | lube |
| Coronado, CA (1) | 290,862 | 110,552 | 514 | 38.0 | 0.5 | 14,113 | E | 0 | 2,700 | ships | bilge |
| El Centro, CA (1) | 129,530 | 10,038 | 2,160 | 7.8 | 21.5 | 109 | A,B | 0 | 5.0 | aircraft | JP-5 |
| El Toro, CA (1) | 1,032,293 | 318,464 | 38,936 | 30.9 | 12.2 | 26,462 | A | 75 | 68 | aircraft | JP-5 |
| Fallon, NV (2) | 319,801 | 161,403 | 128,310 | 50.5 | 79.5 | 8,077 | A,C | 74 | 6.3 | aircraft, shops | JP-5, lube |
| Lemoore, CA (2) | 908,407 | 347,906 | 47,387 | 38.3 | 13.6 | 2,714 | B | 0 | 5.7 | aircraft, shops | JP-5, lube |
| Long Beach, CA (4) | 2,180,322 | 743,755 | 3,196 | 34.1 | 0.4 | 293,381 | B | 0 | 9,200 | ships, shops | bilge, lube |
| Mare Island, CA (4) | 2,435,690 | 1,002,648 | 146,544 | 41.2 | 14.6 | 0 | -- | -- | -- | | |
| Miramar, CA (2) | 927,441 | 325,335 | 207,371 | 35.1 | 63.7 | 218,206 | A | 86 | 105 | aircraft | JP-4, JP-5 |
| Moffett Field, CA (2) | 661,958 | 269,820 | 11,011 | 40.8 | 4.1 | 8,142 | A,B | 0 | 74 | aircraft, automotive | lube |
| Monterey, CA (2) | 342,082 | 125,730 | 1,053 | 36.8 | 0.8 | 0 | -- | -- | -- | | |
| North Island, CA (1) | 892,494 | 65,795 | 4,540 | 7.4 | 6.9 | 19,039 | A,D | 0 | 420 | aircraft, shops | JP-5, AV gas, lube |

continued

Table 3. Continued

| Location Surveyed[b] | Energy Usage[c] | | | | | Waste Oil Distribution[d] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Types of Energy (MBtu) | All Types of Fuel (MBtu) | Fuel Oil (MBtu) | Ratios (%) All Fuel/ All Energy | Ratios (%) Fuel Oil/ All Fuel | Generated (MBtu) | Disposal Methods[e] | Ratios (%) Burned/ Generated | Ratios (%) Generated/ Fuel Oil Used | Source | Composition |
| **Part F. Naval District Eleven (continued)** | | | | | | | | | | | |
| Oakland, CA (3) | 434,885 | 144,062 | 49,234 | 33.1 | 34.2 | 113,988 | B | 0 | 230 | ships, automotive | bilge, lube |
| Pasadena, CA (1) | 1,294 | 250 | 39 | 19.3 | 15.6 | 0 | -- | -- | -- | | |
| Point Loma, CA (1) | 474,787 | 34,254 | 4,581 | 7.2 | 13.4 | 113,988 | B | 0 | 2,500 | ships, automotive | bilge, lube |
| Point Mugu, CA (1) | 945,566 | 261,630 | 119,978 | 27.7 | 45.9 | 3,800 | A | 0 | 3.2 | aircraft | JP-5, lube |
| Point Sur, CA (2) | 28,681 | 13,740 | 11,575 | 47.9 | 84.2 | 7 | D | 0 | 0.1 | automotive | lube |
| Port Hueneme, CA (5) | 645,526 | 231,023 | 21,232 | 35.8 | 9.2 | 4,750 | B | 0 | 22 | ships | DFM |
| San Bruno, CA (1) | 33,898 | 9,434 | 286 | 27.8 | 3.0 | 0 | -- | -- | -- | | |
| San Diego, CA (13) | 6,859,028 | 752,800 | 37,450 | 11.0 | 5.0 | 254,021 | D | 0 | 680 | ships | bilge, DFM |
| San Francisco, CA (1) | 41,240 | 5,640 | 113 | 13.7 | 2.0 | 0 | -- | -- | -- | | |
| Seal Beach, CA (2) | 245,563 | 50,335 | 2,180 | 20.5 | 4.3 | 679 | B,D | 0 | 31 | shops | lube |
| Skaggs Island, CA (1) | 101,660 | 25,216 | 1,261 | 24.8 | 5.0 | 27 | -- | -- | 2.1 | | |
| Stockton, CA (1) | 374,562 | 40,807 | 41 | 10.9 | 0.1 | 136 | D | 0 | 330 | shops | lube |
| Treasure Island, CA (1) | 17,101 | 7,995 | 1,087 | 46.8 | 13.6 | 0 | -- | -- | -- | | |
| 29 Palms, CA (1) | 901,203 | 372,885 | 187,597 | 41.4 | 50.3 | 18,998 | A,B | 0 | 10 | automotive | lube |
| Utah (1) | 237,936 | 185,655 | 26,254 | 78.9 | 14.1 | 0 | | | | | |
| Yuma, AZ (1) | 584,694 | 97,042 | 1,029 | 16.6 | 1.1 | 2,720 | A | 0 | 260 | aircraft, shops | JP-5, solvents |
| Total (69) | 35,087,772 | 18,034,168 | 1,812,526 | 51.4 | 10.1 | 1,168,577 | -- | 24 | 58.0 | -- | -- |
| **Part G. Naval District Thirteen** | | | | | | | | | | | |
| Adak, AK (3) | 1,101,336 | 1,101,336 | 1,101,336 | 100 | 100 | 3,528 | A | 96 | 0.3 | aircraft | JP-5, lube |
| Bangor, WA (2) | 1,295,776 | 359,709 | 70,407 | 27.8 | 19.6 | 21,169 | -- | 100 | 30 | ships, shops | FO2, lube, DF |
| Barrow, AK (1) | 353,723 | 353,723 | 353,723 | 100 | 100 | | | | | | |
| Bremerton, WA (4) | 3,137,141 | 1,434,840 | 1,326,384 | 45.7 | 92.4 | 0 | -- | -- | -- | | |
| Coos Head, OR (1) | 19,329 | 4,179 | 4,179 | 21.6 | 100 | 163 | D | 0 | 3.9 | generators, automotive | lube |
| Jim Creek, WA (1) | 133,977 | 2,073 | 1,345 | 1.5 | 64.9 | | | | | | |
| Keyport, WA (3) | 1,170,714 | 391,341 | 387,826 | 33.4 | 99.1 | 6,785 | D,B | 0 | 1.7 | ships, shops | bilge, lube |
| Manchester, WA (1) | 29,339 | 20,395 | 20,395 | 69.5 | 100 | | | | | | |
| Pacific Beach, WA (1) | 28,438 | 12,036 | 12,036 | 42.3 | 100 | 49 | D | 0 | 0.4 | shops | lube |
| Puget Sound, WA (2) | 143,091 | 30,767 | 30,767 | 21.5 | 100 | 57,447 | B,D | 0.8 | 190 | ships, shops | lube, gasoline |
| Seattle, WA (4) | 427,642 | 201,358 | 98,494 | 47.1 | 48.9 | 574 | D | 0 | 0.6 | shops, ships | lube, bilge |
| Whidbey Island, WA (4) | 1,226,042 | 433,716 | 45,304 | 35.4 | 10.4 | 24,426 | A | 13 | 54 | shops, aircraft | |
| Total (27) | 9,066,548 | 4,345,173 | 3,451,896 | 47.9 | 79.4 | 114,141 | -- | 25 | 3.3 | | |

continued

Table 3. Continued

| Location Surveyed[b] | Energy Usage[c] All Types of Energy (MBtu) | All Types of Fuel (MBtu) | Fuel Oil (MBtu) | Ratios (%) All Fuel/ All Energy | Ratios (%) Fuel Oil/ All Fuel | Waste Oil Distribution[d] Generated (MBtu) | Disposal Methods[e] | Ratios (%) Burned/ Generated | Ratios (%) Generated/ Fuel Oil Used | Source | Composition |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Part H. Naval District Fourteen** | | | | | | | | | | | |
| Barbers Point, HI (2) | 270,482 | 22,729 | 22,297 | 8.4 | 98.1 | 6,785 | D | 0 | 30 | diesel engines | DFM |
| Barking Sands, HI (1) | 104,932 | 10,090 | 10,090 | 9.6 | 100 | 841 | A | 96 | 8.3 | shops | lube |
| Camp H. M. Smith, HI (1) | 135,916 | 17,376 | 17,123 | 12.8 | 98.5 | 14 | B | 0 | 0.1 | shops | lube |
| Honolulu, HI (1) | 597,845 | 13,727 | 13,727 | 2.3 | 100 | 199,479 | -- | 100 | 1,500 | ships | bilge, lube |
| Kaneohe Bay, HI (1) | 926,867 | 74,151 | 72,002 | 8.0 | 97.1 | 125,387 | D | 9.9 | 170 | aircraft | JP-5, lube |
| Lualualei, HI (1) | 122,230 | 9,246 | 9,246 | 7.6 | 100 | 28 | D | 0 | 0.3 | automotive | lube |
| Midway Islands (2) | 148,287 | 148,287 | 148,287 | 100 | 100 | 333 | A,D | 0 | 0.2 | generators | lube |
| Pearl Harbor, HI (7) | 3,172,928 | 441,464 | 409,965 | 13.9 | 92.9 | 234,881 | A,B | 79 | 57 | ships | bilge |
| Total (16) | 5,479,487 | 737,070 | 702,737 | 13.5 | 95.3 | 567,748 | | 70 | 81 | | |
| **Part I. Naval District Twenty-One** | | | | | | | | | | | |
| Alleghany Ballistic Laboratory, MD (1) | 567,929 | 265,169 | 265,169 | 46.7 | 100 | | | | | | |
| Annapolis, MD (5) | 1,485,824 | 695,679 | 75,902 | 46.8 | 10.9 | 0 | -- | -- | -- | | |
| Bethesda, MD (2) | 1,695,624 | 573,220 | 573,220 | 33.8 | 100 | 757 | B | 2 | 0.1 | gear boxes | lube |
| Indian Head, MD (4) | 1,588,869 | 1,473,368 | 1,473,368 | 92.7 | 100 | 951 | B | 0 | 0.1 | auto, shops | lube |
| Patuxent River, MD (4) | 1,478,949 | 652,601 | 650,194 | 44.1 | 99.6 | 4,071 | A,B | 0 | 0.6 | aircraft, shops | lube, solvents |
| Washington, DC (13) | 3,633,509 | 1,706,645 | 1,658,093 | 47.0 | 97.2 | 475 | B | 63 | 0.1 | shops | lube |
| Total (29) | 10,450,704 | 5,366,682 | 4,695,946 | 51.4 | 87.5 | 6,254 | | 5 | 0.1 | | |
| **Part J. Naval District Thirty** | | | | | | | | | | | |
| Andros Island, Bahamas (1) | 218,693 | 218,693 | 218,693 | 100 | 100 | 489 | A | 50 | 0.2 | generators | lube |
| Antigua, West Indies (1) | 21,101 | 5,383 | 5,383 | 25.5 | 100 | 27 | A,C | 0 | 0.5 | automotive | lube |
| Argentia, Newfoundland (2) | 275,503 | 167,240 | 167,240 | 60.7 | 100 | 244 | D | 0 | 0.1 | shops | lube |
| Bermuda (3) | 409,186 | 324,112 | 321,424 | 79.2 | 99.2 | 163 | F | 0 | 0.1 | compressors | lube |
| Canal Zone (1) | 101,963 | 393 | 393 | 0.4 | 100 | | | | | | |
| Eleuthera, Bahamas (2) | 14,065 | 14,065 | 14,065 | 100 | 100 | | | | | | |
| Grand Turk, West Indies (1) | 11,622 | 11,622 | 11,622 | 100 | 100 | | | | | | |
| Guantanamo, Cuba (6) | 1,944,993 | 1,944,993 | 1,944,993 | 100 | 100 | 14,927 | -- | 100 | 0.8 | ships, shops | bilge |
| Keflavik, Iceland (4) | 1,502,247 | 954,970 | 954,970 | 63.6 | 100 | 2,714 | A | 50 | 0.3 | aircraft | lube, JP-4, DF |
| Ponce, Puerto Rico (1) | 186,434 | 3,108 | 3,108 | 1.7 | 100 | 68 | B | 0 | 2.2 | generators | lube |
| Roosevelt Roads, PR (2) | 631,908 | 27,676 | 26,762 | 4.4 | 96.7 | | | | | | |
| Sabana, Puerto Rico (1) | 81,756 | 3,885 | 3,885 | 4.8 | 100 | 204 | D | 0 | 5.3 | automotive | lube |
| Total (25) | 5,399,471 | 3,676,140 | 3,672,538 | 68.1 | 99.9 | 18,836 | -- | 88 | 0.5 | -- | -- |

continued

Table 3. Continued

| Location Surveyed[b] | Energy Usage[c] | | | | | Waste Oil Distribution[d] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Types of Energy (MBtu) | All Types of Fuel (MBtu) | Fuel Oil (MBtu) | Ratios (%) | | Generated (MBtu) | Disposal Methods[e] | Ratios (%) | | Source | Composition |
| | | | | All Fuel/ All Energy | Fuel Oil/ All Fuel | | | Burned/ Generated | Generated/ Fuel Oil Used | | |
| Part K. Naval District Thirty-One | | | | | | | | | | | |
| Brawdy, UK (1) | 81,546 | 34,369 | 34,369 | 42.1 | 100 | 556 | E | 0 | 1.6 | generators | lube |
| Edzell, UK (2) | 238,850 | 88,947 | 87,959 | 37.2 | 98.9 | 27 | D | 0 | 0.1 | shops | lube |
| Holy Loch, UK (1) | 33,987 | 12,829 | 9,366 | 37.7 | 73.0 | | | | | | |
| La Maddalena, Italy (2) | 21,041 | 3,243 | 2,875 | 15.4 | 88.7 | 814 | B | 0 | 28 | generators | lube |
| London, England (1) | 100,446 | 19,200 | 18,663 | 19.1 | 97.2 | 7 | D,A | 0 | 0.1 | auto, generators | lube |
| Naples, Italy (4) | 351,759 | 69,323 | 66,641 | 19.7 | 96.1 | 560 | D | 0 | 0.8 | automotive | lube |
| Nea Marki, Greece (1) | 185,423 | 174,020 | 174,020 | 93.9 | 100 | | | | | | |
| Rota, Spain (4) | 972,323 | 858,944 | 858,944 | 88.3 | 100 | 27,519 | B | 99 | 3.2 | shops, generators | lube, fuel |
| Sigonella, Italy (2) | 495,506 | 76,428 | 75,907 | 15.4 | 99.3 | 0 | -- | -- | -- | | |
| Souda Bay, Greece (1) | 20,317 | 4,808 | 4,808 | 23.7 | 100 | 136 | A | 0 | 2.8 | auto, shops | lube |
| Thurso, UK (2) | 120,862 | 15,233 | 15,233 | 12.6 | 100 | 45 | A,D | 0 | 0.3 | automotive | lube |
| Total (21) | 2,622,060 | 1,357,344 | 1,348,785 | 51.8 | 99.4 | 29,664 | -- | 92 | 2.2 | -- | -- |
| Part L. Naval District Forty | | | | | | | | | | | |
| Atsugi, Japan (2) | 606,546 | 355,151 | 355,151 | 58.6 | 100 | 1,254 | B | 0 | 0.4 | shops | lube |
| Camp S. D. Butler, Japan (1) | 2,139,146 | 508,812 | 508,480 | 23.8 | 99.9 | 8,142 | A,D | 17 | 1.6 | aircraft, shops | FO2, JP-4, lube |
| Cubi Point, Philippines (1) | 516,319 | 136,349 | 136,349 | 26.4 | 100 | 7,353 | B,A | 0 | 5.4 | | |
| Diego Garcia (1) | 287,483 | 287,483 | 287,483 | 100 | 100 | | | | | | |
| Guam (7) | 1,745,462 | 92,311 | 92,311 | 5.3 | 100 | 20,530 | A | 99 | 22 | shops, generators | fuel, lube |
| Harold E. Holt, Australia (1) | 462,119 | 462,119 | 462,119 | 100 | 100 | 679 | E | 0 | 0.1 | shops, generators | FO2, lube |
| Iwakuni, Japan (1) | 662,884 | 252,522 | 252,522 | 38.1 | 100 | 8,142 | A,D | 0 | 3.2 | aircraft | JP-5, JP-4 |
| Korea (3) | 35,562 | 8,036 | 8,036 | 22.6 | 100 | 149 | B | 0 | 1.9 | automotive | lube |
| Okinawa, Japan (1) | 61,393 | 22,104 | 22,104 | 36.0 | 100 | 136 | E | 0 | 0.6 | | |
| Sasebo, Japan (4) | 157,940 | 56,510 | 53,383 | 35.8 | 94.5 | | | | | | |
| Subic Bay, Philippines (9) | 3,460,020 | 1,318,528 | 1,318,528 | 38.1 | 100 | 180 | A,C,B | 0 | 0.1 | auto, settling tank | lube, sludge |
| Yokosuka, Japan (9) | 3,287,070 | 1,897,795 | 1,897,795 | 57.7 | 100 | 19,677 | B | 8.3 | 1.0 | shops | lube |
| Total (40) | 13,421,944 | 5,397,720 | 5,394,261 | 40.2 | 99.9 | 66,242 | -- | 35 | 1.2 | -- | -- |

continued

Table 3. Continued

[a]Data for only the surveyed locations where fuel oil was consumed as indicated in the FY80 DEIS II report. Therefore, the totals are not Navywide totals.

[b]Figure in parentheses indicates number of activities surveyed at each location.

[c]For FY80, based on Reference 4.

[d]FY82 data, based on NCEL's waste oil generation/combustion experience survey, and represent responses from 94 of the 153 locations surveyed. (One gallon waste oil = 0.1357 MBtu.)

[e]Disposition method notation:

| | | |
|---|---|---|
| A. Local firefighting training | B. NAVSUP, DLA, or DPDO handles resale | C. Weed/dust control |
| D. Sell or give to haulers | E. Pay to haul away | F. Stored; no disposition planned |

Unless otherwise stated, locations reported no major modifications or problems when burning waste oil. Information shown is for primary sources at respective locations.

[f]Some shore facilities burn reclaimed oil received from the nearby reclamation facility (e.g., Craney Island, VA; Mayport, FL; North Island or Point Loma, CA).

Table 4. Properties of Some Oils Tested

| Properties | Fuel Oil | | | Heavy Shale Oil | Used Lube Oil | Ship's Waste Oil | Contaminated JP-5 |
|---|---|---|---|---|---|---|---|
| | No. 6 | No. 5 | No. 2 | | | | |
| API Gravity | 23 | | 34 | 22 | 26.1 | 29.1 | 40.6 |
| Heating Value (HHV, Btu/lb) | 19,150 | 18,576 | 19,560 | 18,420 | 19,270 | 19,390 | 19,770 |
| Viscosity, SUS @ 100°F | 324 | | 35 | 150 | 527 | 60 | 31 |
| Flashpoint, °F | 245 | | 168 | 295 | 370 | 260 | 145 |
| Water and Sediment, % | 0.12 | 0.44 | <0.1 | 1.0 | <0.1 | 0.12 | 3.4 |
| Carbon Residue (Ramsbottom), % | 3.44 | | 0.12 | 2.0 | 1.11 | 0.17 | 0.10 |
| Copper Strip Corrosion | S.T.[a] | | S.T. | | S.T. | S.T. | S.T. |
| Carbon, % | 86.61 | 85.02 | 86.11 | 85.8 | 85.08 | 86.18 | 86.05 |
| Hydrogen, % | 12.25 | 11.53 | 12.94 | 11.19 | 13.13 | 13.13 | 13.43 |
| Nitrogen, % | 0.24 | 0.33 | 0.022 | 1.95 | 0.074 | 0.008 | 0.004 |
| Sulfur, % | 0.28 | 1.31 | 0.082 | 0.46 | 0.44 | 0.081 | 0.086 |
| Ash, % | 0.016 | 0.032 | <0.001 | 0.007 | 1.36 | 0.001 | 0.001 |
| Oxygen, % by Difference | 0.60 | 1.78 | 0.85 | 0.59 | 0 | 0.60 | 0.43 |

[a]S.T. = slight tarnish.

Table 5. Summary of Navy and Marine Corps Experience with Burning Waste Oil as a Supplemental Fuel

| Location[a] | Waste Oil Burned: Quantity (gal.) FY80 | Waste Oil Burned: Quantity (gal.) FY82 | Waste Oil Burned: Type | Blending Method | Comments[b] |
|---|---|---|---|---|---|
| Adak, AK (13) | 34,000 | 25,000 | JP-5, lube | direct | Blended one part of lube into four parts of JP-5 and burned in base steam plant. |
| Andros Island, Bahamas (30) | | 1,800 | lube | direct | Blended with diesel fuel oil. |
| Bangor, WA (13) | | 156,000 | FO2, DF lube | direct | Treated at Manchester reclamation plant prior to burning. |
| Barking Sands, HI (14) | | 6,000 | lube | in-line | Used lube oils run through a filter separator and mixed with DF2 at a 1:10 ratio. Excessive corrosion on feed lines before separator applied. |
| Bethesda, MD (21) | | 100 | lube | direct | Blended with FO6 before burning. |
| Brunswick, ME (4) | | 1,200 | JP-5 | direct | Blended by dumping into FO6 storage tank. |
| Camp Pendleton, CA (11) | | 460,800 | FOR, lube bilge | direct | FOR from Point Loma and waste oil directly from NAVSTA waterfront operations. |
| Camp S. D. Butler, Japan (40) | | 10,000 | DF2, JP-4, NSFO, kerosene, lube | direct | Burning intermittently in dry back, marine, and locomotive type boilers at MCAS. |
| Charleston, SC (6) | | 258,000 | bilge, lube | direct | Gravitation reclamation system used. Blended into Navy Special. $1.2 million credited NAVSUP since FY80. |
| China Lake, CA (11) | 30,000 | 30,000 | JP-5, DF, lube | in-line | Used lube oils, JP-5 and DF were blended with FO6 and burned. No operational or emission difficulties were encountered. |
| Crane, IN (9) | | 2,200 | lube | direct | Blended with FO6 before burning. |
| El Toro, CA (11) | | 146,300 | lube, JP-5 kerosene | direct | 54 water tube and fire tube gas/oil fired boilers with automatic controls and air atomization burners. |
| Fallon, NV (11) | 2,400 | 44,000 | JP-5, lube, hydraulic fluid. | direct | Waste oil (JP-5) dumped into the existing fuel tanks and burned straight. |
| Guam (40) | 608,000 | | lube, DFM, FO | direct | Blended into regular fuel oil tank when half full. |
| Guantanamo, Cuba (30) | 180,000 | 110,000 | lube, hydraulic fluid, FO | direct | Blended with NSFO in existing tankage at about 5%. Waste oil allowed to settle, burned in 4 boilers. No major problems. |
| Honolulu, HI (14) | | 1,470,000 | bilge, JP-5, lube | direct | Reclamation facility removes excessive water, blended with NSFO. |

continued

Table 5. Continued

| Location[a] | Waste Oil Burned: Quantity (gal) FY80 | Waste Oil Burned: Quantity (gal) FY82 | Waste Oil Burned: Type | Blending Method | Comments[b] |
|---|---|---|---|---|---|
| Indianapolis, IN (9) | 5,000 | 2,700 | lube, grease | direct | Metal filings are removed by a centrifuge prior to burning. Of 5 boilers, 3 can burn waste oil. Primary fuel FO5. |
| Kaneohe, HI (14) | | 91,900 | JP-5, lube | direct | Waste oil containing 10% contaminated JP-5 blended with NSFO. Lube oil treated at reclamation plant. |
| Keflavik, Iceland (30) | | 10,000 | lube JP-4, FO | direct | Waste oil/fuel oil ratio 1:10. Contaminated JP-4 burned straight; problems occur when JP-4 excessively contaminated. |
| Mayport, FL (6) | 650,000 | 1,360,000 | bilge, DFM, lube | in-line, direct | Direct burning of waste oil preblended with FO5 (light). Packaged boilers hard to clean. Investing in a centrifuging system to control contaminants. |
| Miramar, CA (11) | | 1,382,900 | bilge, JP-5, FOR | direct | Problems - fireside deposits, plugged nozzle/strainers. Routine maintenance slightly increased. |
| Newport, RI (4) | | 18,700 | JP-5, DFM DF, lube | direct | Gravitation reclamation system used. Waste oil chemically tested before blending with NSFO. |
| Norfolk, VA (5) | 4,192,000 | 2,690,000 | FOR, JP-5, lube, FO, hydraulic | direct, | Prior to burning, waste oil & reclaimed oil analyzed for special requirements and burned as regular fuel. Some blending with NSFO. FOR from Craney Island. FY81, 2 million gallons FOR. |
| Oceana, VA (5) | | 948,000 | FOR | direct | An increased burn rate of regular fuel is required to offset lower Btu value of FOR. Purchase FOR from Craney Island. Prices as of Oct 1: FOR 90¢/gal, FO6 91¢/gal. 1981 952,000 gallons FOR. |
| Pearl Harbor, HI (14) | | 1,367,000 | FOR | direct | Reclamation plant treats and returns FOR and downgraded DFM for burning. FY81, 32,275 barrels of FOR. |
| Puget Sound, WA (13) | | 3,400 | lube, gasoline | direct | Blended with FO6. |
| Quantico, VA (5) | | 4,800 | JP-4, lube | direct | Blended contaminated JP-4 with FO. Burning at irregular intervals. |
| Rota, Spain (13) | 115,000 | 201,000 | FO, lube | in-line | Fuel loading pier is equipped with drains and holding tank for collecting spillage. Gravity separator used. Over 4 million gal/yr oily waste at 5% waste oil. |
| Washington, DC (21) | | 2,200 | lube | in-line | Separation system removes excessive contaminants. Waste oil feed line tapped into fuel oil feed line with a 1:10 ratio. |

continued

Table 5. Continued

| Location[a] | Waste Oil Burned | | | Blending Method | Comments[b] |
|---|---|---|---|---|---|
| | Quantity (gal) | | Type | | |
| | FY80 | FY82 | | | |
| Whidbey Island, WA (13) | 60,000 | 22,500 | JP-5, FO, lube solvents | burned straight (at 100%) | One of 3 boilers modified for burning waste oil. Waste oil burned 3 months of the year at 7,500 gal/mo. Preheat boiler with natural gas. |
| Yokosuka, Japan (40) | 2,000 | 12,000 | lube, transformer oil (no PCB) | direct | Waste oil is burned in a boiler specifically for the purpose. |

[a]Figures in parentheses indicate the Naval Districts in which the locations are situated.

[b]For more detail, see corresponding narrative paragraphs in text.

*Table 6. Summary of Energy Usage and Waste Oil Generation and Usage by Naval District*[a]

| Naval District[b] | Energy Usage[c] | | | | | Waste Oil Distribution[d] | | | Locations for Burning Waste Oil |
|---|---|---|---|---|---|---|---|---|---|
| | All Types of Energy (MBtu) | All Types of Fuel (MBtu) | Fuel Oil (MBtu) | Ratios (%) | | Generated (MBtu) | Ratios (%) | | |
| | | | | All Fuel/ All Energy | Fuel Oil/ All Fuel | | Burned/ Generated | Generated/ Fuel Oil Used | |
| 4 (20) | 16,935,096 | 10,158,689 | 7,019,698 | 60.0 | 69.1 | 68,033 | 4 | 1.0 | Brunswick, ME<br>Newport, RI |
| 5 (13) | 28,591,140 | 13,852,140 | 12,159,643 | 48.5 | 87.8 | 231,031 | 214[e] | 1.9 | Norfolk, VA<br>Oceana, VA<br>Quantico, VA |
| 6 (18) | 24,201,230 | 10,055,901 | 2,743,802 | 41.6 | 27.3 | 334,850 | 65 | 12 | Mayport, FL |
| 8 (3) | 501,614 | 107,504 | 18,601 | 21.4 | 17.3 | 434 | 0 | 2.3 | -- |
| 9 (5) | 6,689,021 | 3,282,321 | 707,645 | 49.1 | 21.6 | 1,975 | 34 | 0.3 | Crane, IN<br>Indianapolis, IN |
| 11 (33) | 35,087,772 | 18,034,168 | 1,812,526 | 51.4 | 10.1 | 1,168,577 | 24 | 58 | Camp Pendleton, CA<br>China Lake, CA<br>El Centro, CA<br>El Toro, CA<br>Fallon, NV<br>Miramar, CA |
| 13 (12) | 9,066,548 | 4,345,173 | 3,451,896 | 47.9 | 79.4 | 114,141 | 25 | 3.3 | Adak, AK<br>Bangor, WA<br>Puget Sound, WA<br>Whidbey Island, WA |
| 14 (8) | 5,479,487 | 737,070 | 702,737 | 13.5 | 95.3 | 567,748 | 70 | 81 | Barking Sands, HI<br>Honolulu, HI<br>Kaneohe, HI<br>Pearl Harbor, HI |
| 21 (6) | 10,450,704 | 5,366,682 | 4,965,946 | 51.4 | 92.5 | 6,254 | 5 | 0.1 | Washington, DC |
| 30 (12) | 5,399,471 | 3,676,140 | 3,672,538 | 68.1 | 99.9 | 18,836 | 88 | 0.5 | Gauntanamo, Cuba |
| 31 (11) | 2,622,060 | 1,357,344 | 1,348,785 | 51.8 | 99.4 | 29,664 | 92 | 2.2 | Rota, Spain |
| 40 (12) | 13,421,944 | 5,397,720 | 5,394,261 | 40.2 | 99.9 | 66,242 | 35 | 1.2 | Camp S. D. Butler, Japan<br>Guam<br>Yokosuka, Japan |
| Total (153) | 158,446,087 | 76,371,315 | 43,998,078 | 48.2 | 57.6 | 2,607,785 | 57 | 5.9 | |

[a]Data for only the surveyed locations where fuel oil was consumed as indicated in Reference 4; totals are not Navywide totals.

[b]Figure in parentheses indicates the number of locations surveyed in the Naval district.

[c]For FY80, based on Reference 4.

[d]For FY82, based on NCEL's waste oil generation/combustion experience survey; responses from 94 of the 153 locations surveyed. (One gallon waste oil = 0.1357 MBtu.)

[e]Some shore facilities burn reclaimed oil received from the nearby reclamation facility; e.g., Craney Island, VA; Mayport, FL; North Island or Point Loma, San Diego, CA.

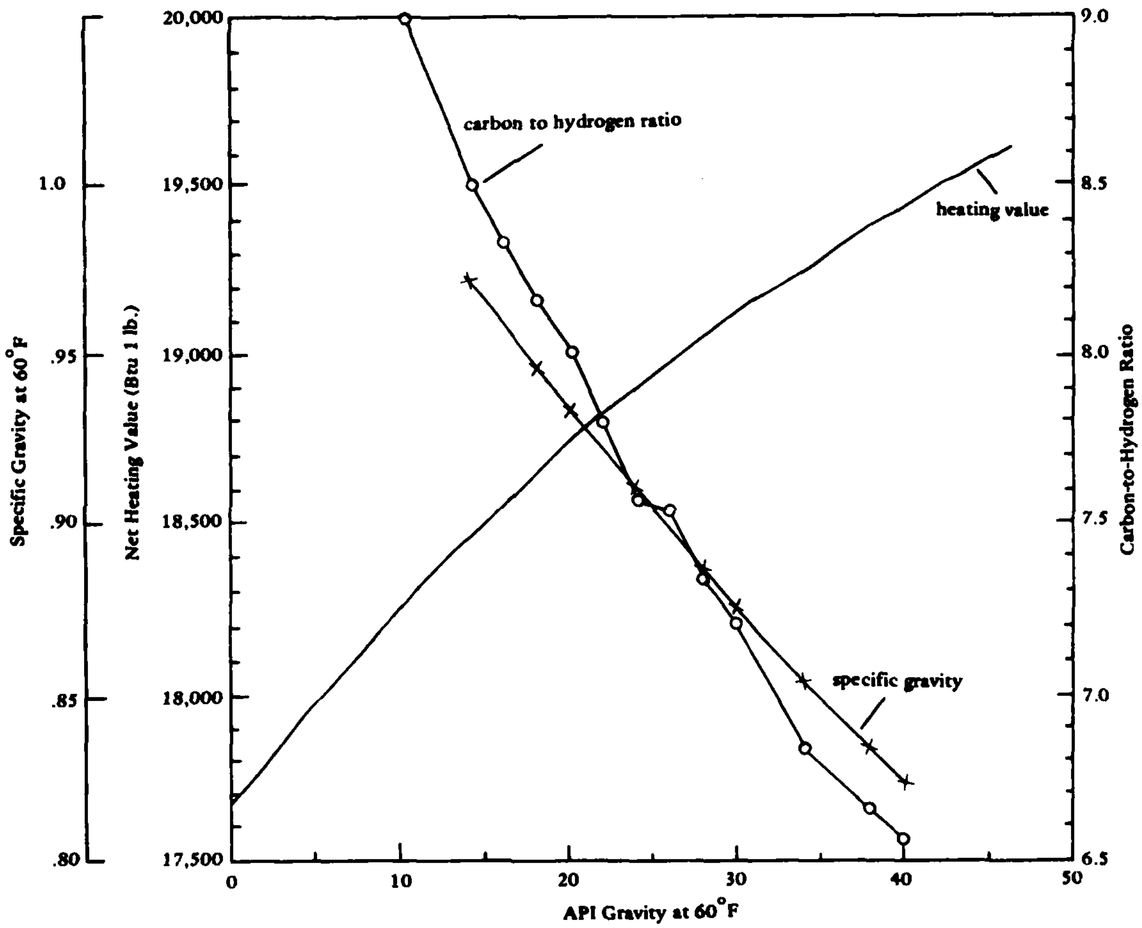


Figure 1. Relationships between heating value, carbon-to-hydrogen ratio, specific gravity and API gravity.

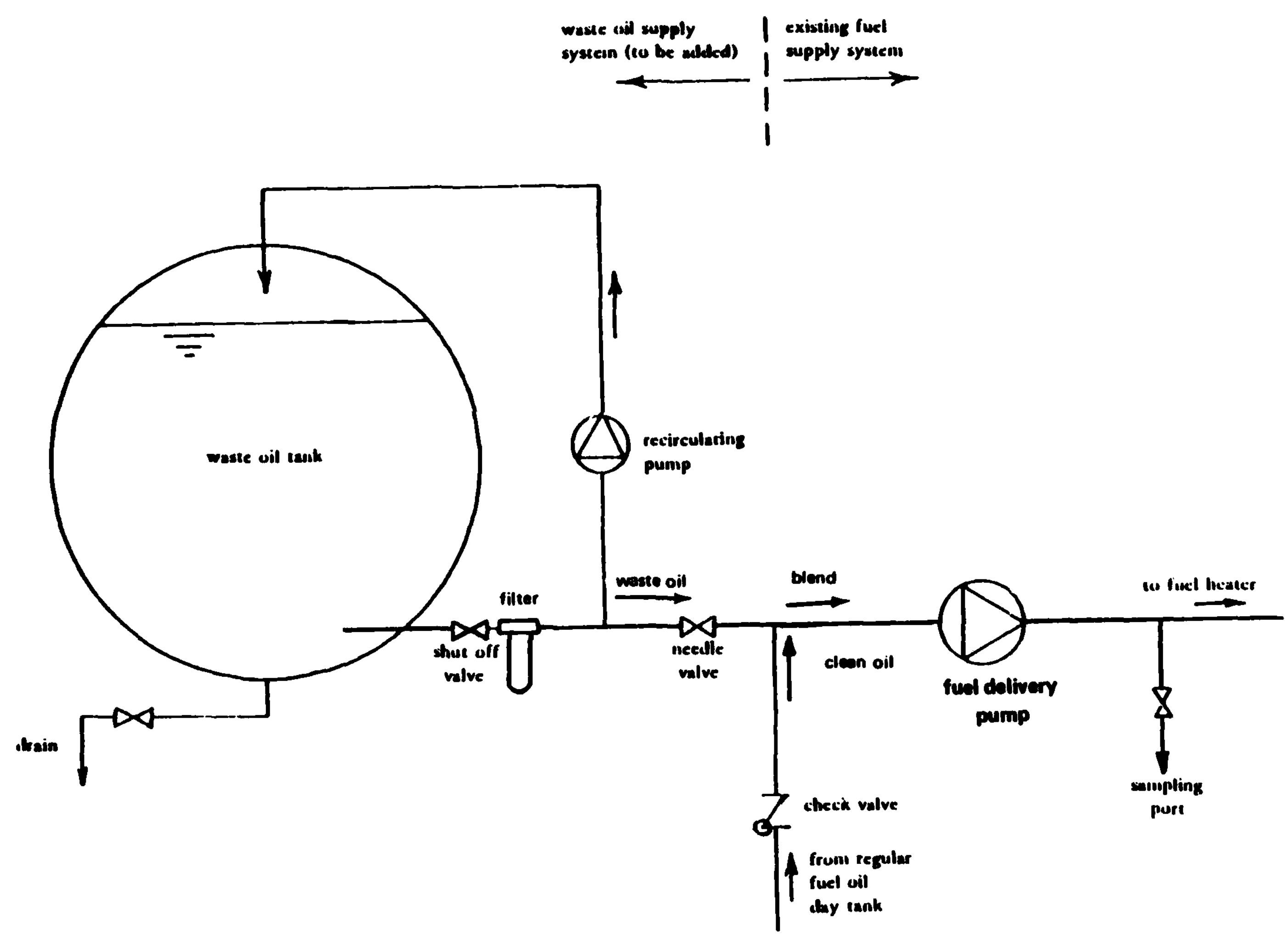


Figure 2. A scheme for in-line blending of waste oil with regular fuel oil.

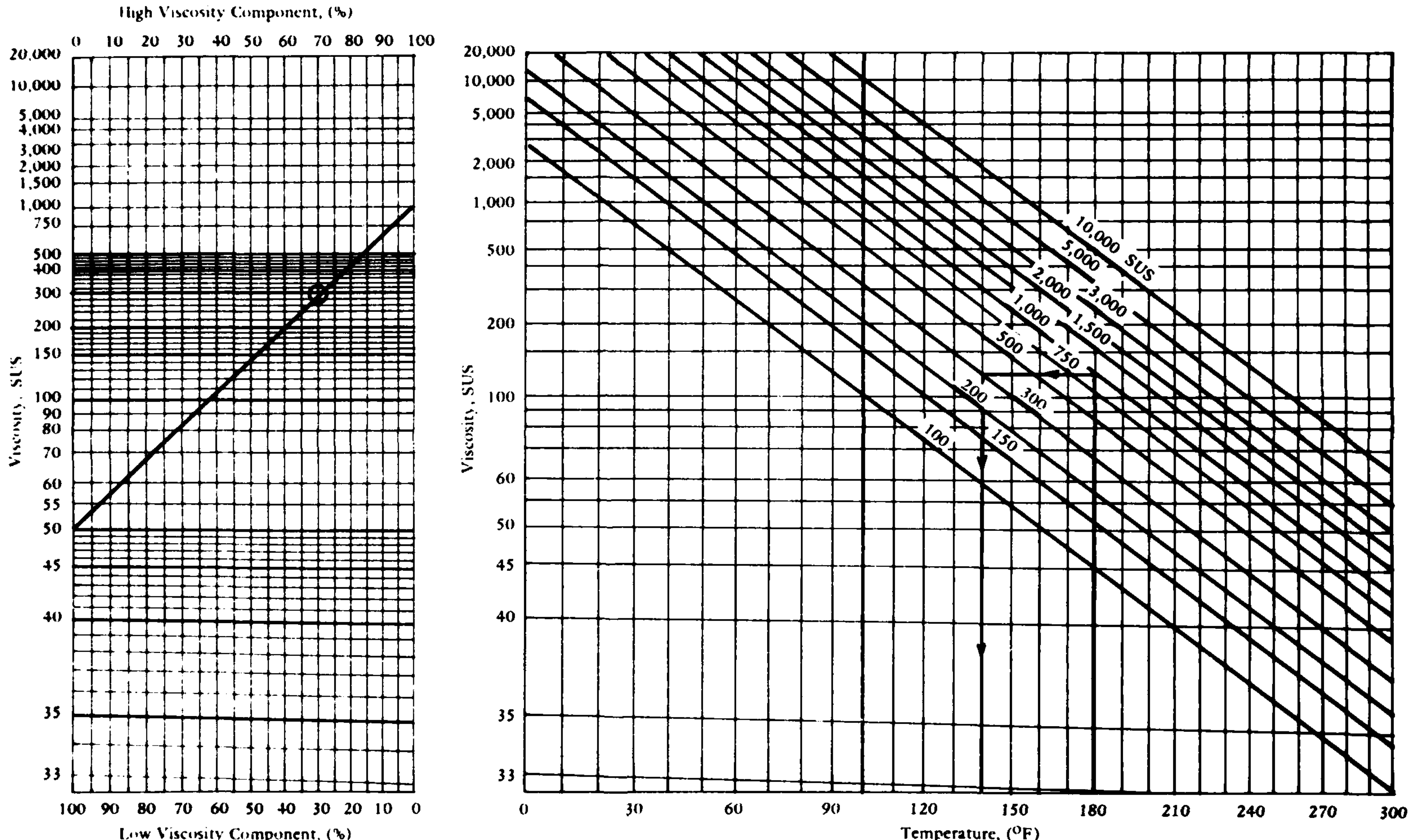




Figure 3. Charts for determination of firing temperatures for blending fuels.

## APPENDIX A

## OIL PRODUCTS NOT TO BE USED FOR BOILER FIRING

| Product Type A (Gasoline and Solvents) | Specification |
|---|---|
| Acetone, Technical | O-A-51F |
| Amyl Acetate | TT-A-511C |
| Amyl Alcohol, Secondary | TT-A-516D |
| Benzene, (Benzol), Technical | VV-B-231C |
| Benzene, Nitration Grade | MIL-B-3137 |
| Butyl Acetate, Normal | TT-B-838A |
| Butyl Acetate, Secondary | TT-B-840B |
| Butyl Alcohol, Normal | TT-B-846B |
| Butyl Alcchol, Secondary | TT-B-848B |
| Cleaning Compound, Solvent, Heavy Duty | O-C-1824 |
| Cleaning Compound, Solvent | O-C-1889 |
| 1,1,1 - Trichloroethane, Technical Inhibited (Methyl Chloroform) | O-T-620C |
| Dry Cleaning Solvent | P-D-680 |
| Ether, Petroleum, Technical Grade | O-E-751B |
| Ethyl Acetate, Technical | TT-E-751C |
| Ethylene Glycol Monobutyl Ether | TT-E-776B |
| Gasoline, Automotive | VV-G-76B |
| Gasoline, Unleaded | VV-G-109A |
| Gasoline, Automotive, Leaded and Unleaded | VV-G-1690A |
| Gasoline, Automotive, Combat | MIL-G-3056D |
| Gasoline, Aviation Grades | MIL-G-5572E |

## OIL PRODUCTS NOT TO BE USED FOR BOILER FIRING (CONTINUED)

| Product Type F (Synthetic/Chemical Based Oils & Halogenated Solvents) | Specification |
|---|---|
| Brake Fluid, Automotive | VV-B-680B |
| Brake Fluid, Silicone, Automotive, All-weather, Operational and Preservative | MIL-B-46167 |
| Cutting Fluids Sulfurized Fatty & Mineral Oils | VV-C-850A |
| Grease, Silicone for use with Ammunition | MIL-G-14931 |
| Grease, Molybdenum Disulfide | MIL-G-21164C |
| Grease, Silicone | MIL-G-46886 |
| Grease, Lubricating, Halofluorocarbon | MIL-G-47219 |
| Hydraulic Fluid, Arresting Gear | MIL-H-5559A |
| Hydraulic Fluid, Nonpetroleum Base, Aircraft | MIL-H-8446B |
| Hydraulic Fluid, Polar Type Automotive Brake | MIL-H-13910B |
| Hydraulic Fluid, Fire Resistant | MIL-H-19457B |
| Hydraulic Fluid, Catapult | MIL-H-22072A |
| Hydraulic Fluid, Rust Inhibited, Fire-resistant, Synthetic Hydrocarbon Base | MIL-H-46170 |
| Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft | MIL-H-83282A |
| Hydraulic Fluid, Fire Resistant, Phosphate Ester Base, Aircraft | MIL-H-83306 |
| Insulating Fluid, Electrical (Non-Combustible) | W-I-1219 |
| Lubricating Oil, Instrument, Aircraft, Low Volatility | MIL-L-6085A |
| Lubricating Oil, Aircraft Turbine Engines, Synthetic Base | MIL-L-7808G |
| Lubricating Oil, Synthetic (for mechanical time fuses) | MIL-L-11734C |
| Lubricating Oil, Aircraft Turbine Engines, Synthetic Base | MIL-L-23699B |
| Lubricant, Molybdenum Disulfide in Isopropanol | MIL-L-24478 |
| Lubricating Oil, Molybdenum Disulfide, Silicone Base, High Temperature | MIL-L-25681C |

OIL PRODUCTS NOT TO BE USED FOR BOILER FIRING (CONTINUED)

| Product Type F (Synthetic/Chemical Based Oils & Halogenated Solvents) | Specification |
|---|---|
| Lubricating Oil, Aircraft Turbine Engine, Ester Base | MIL-L-27502 |
| Lubricating Oil, Instrument, Minus 65 Deg. To Plus 400 Deg. F | MIL-L-27694A |
| Lubricating, Fluorocarbon Telomer Dispersion (for use with ammunition) | MIL-L-60326 |
| Lubricating Oil, Aircraft Turbine Engine, Polyphenyl Ether Base | MIL-L-87100 |
| Silicone, Fluid, Chlorinated Phenyl Methyl Polysiloxane | MIL-S-81087B |
| Cleaning Compound, Solvent, Trichlorotrifluoroethane | MIL-C-81302C |

# APPENDIX B

ANSI/ASTM D 396 - 79

AMERICAN NATIONAL STANDARD

## Standard Specification for
## FUEL OILS[1]

This standard is issued under the fixed designation D 396; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

### 1. Scope

1.1 This specification (Note 1) covers grades of fuel oil intended for use in various types of fuel-oil-burning equipment under various climatic and operating conditions.

NOTE 1—For information on the significance of the terminology and test methods used in this specification, see the Appendix.

1.2 This specification is for the use of purchasing agencies in formulating specifications to be included in contracts for purchases of fuel oils and for the guidance of consumers of fuel oils in the selection of the grades most suitable for their needs.

NOTE 2—Nothing in this specification, shall preclude observance of federal, state, or local regulations which may be more restrictive.

NOTE 3—The values stated in SI units are to be regarded as standard. The values stated in U.S. customary units are for information only.

### 2. General Requirements

2.1 The grades of fuel oil specified herein shall be homogeneous hydrocarbon oils, free from inorganic acid, and free from excessive amounts of solid or fibrous foreign matter likely to make frequent cleaning of suitable strainers necessary.

2.2 All grades containing residual components shall remain uniform in normal storage and not separate by gravity into light and heavy oil components outside the viscosity limits for the grade.

### 3. Detailed Requirements

3.1 The various grades of fuel oil shall conform to the limiting requirements shown in Table 1.

3.2 Modifications of limiting requirements to meet special operating conditions agreed upon between the purchaser, the seller, and the supplier shall fall within limits specified for each grade, except as stated in supplementary footnotes for Table 1.

### 4. Test Methods

4.1 The requirements enumerated in this specification shall be determined in accordance with the following ASTM Methods,[2] except as may be required under 4.1.1.

4.1.1 *Flash Point*—Method D 93, Test for Flash Point by Pensky-Martens Closed Tester,[3] except where other methods are prescribed by law for the determination of minimum flash point. For Grades No. 1 and No. 2, Method D 56, Test for Flash Point by Tag Closed Tester[3] may be used as an alternative with the same limits, provided the flash point is below 79.4°C (175°F) and the viscosity is below 5.8 cSt (45 SUS) at 38°C (100°F). This method will give slightly lower values. In cases of dispute, Method D 93 shall be used as the referee method.

4.1.2 *Pour Point*—Method D 97, Test for Pour Point of Petroleum Oils.[3] Alternative test methods that indicate flow point properties may be used for low sulfur residual fuels by

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[1] This specification is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants.

Current edition approved March 30, 1979. Published October 1978. Originally published as D 396 - 34 T. Last previous edition D 396 - 78.

[2] For information on the precision of the ASTM methods of test for fuel oils refer to "An Evaluation of Methods for Determination of Sulfur in Fuel Oils" by A. R. Crawford, Esso Mathematics & Systems Inc. and G. V. Dyroff, Esso Research and Engineering Co., 1969. This document is available from the Publications Section, American Petroleum Institute, 2101 L. St., N.W., Washington, D.C. 20037.

[3] *Annual Book of ASTM Standards*, Part 23.

TABLE 1 Detailed Requirements for Fuel Oils[A]

| Grade of Fuel Oil | Flash Point, °C (°F) | Pour Point, °C (°F) | Water and Sediment, vol % | Carbon Residue on 10 % Bottoms, % | Ash, weight % | Distillation Temperatures, °C (°F) 10 % Point | 90 % Point | | Saybolt Viscosity, s[B] Universal at 38°C (100°F) | | Furol at 50°C (122°F) | | Kinematic Viscosity, cSt[B] At 38°C (100°F) | | At 40°C (104°F) | | At 50°C (122°F) | | Specific Gravity 60/60°F (deg API) | Copper Strip Corrosion | Sulfur, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Max | Max | Max | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Max | Max | Max |
| No. 1<br>A distillate oil intended for vaporizing pot-type burners and other burners requiring this grade of fuel | 38 (100) | −18[C] (0) | 0.05 | 0.15 | ... | 215 (420) | ... | 288 (550) | | | | | 1.4 | 2.2 | 1.3 | 2.1 | | | 0.8499 (35 min) | No. 3 | 0.5 |
| No. 2<br>A distillate oil for general purpose heating for use in burners not requiring No. 1 fuel oil | 38 (100) | −6[C] (20) | 0.05 | 0.35 | ... | ... | 282[C] (540) | 338 (640) | (32.6) | (37.9) | | | 2.0[C] | 3.6 | 1.9[C] | 3.4 | | | 0.8762 (30 min) | No. 3 | 0.5[H] |
| No. 4<br>Preheating not usually required for handling or burning | 55 (130) | −6[C] (20) | 0.50 | ... | 0.10 | ... | ... | ... | (45) | (125) | ... | ... | 5.8 | 26.4[F] | 5.5 | 24.0[F] | ... | | | | |
| No. 5 (Light)<br>Preheating may be required depending on climate and equipment | 55 (130) | ... | 1.00 | ... | 0.10 | ... | ... | ... | (>125) | (300) | | | >26.4 | 65[F] | >24.0 | 58[F] | | | | | |
| No. 5 (Heavy)<br>Preheating may be required for burning and, in cold climates, may be required for handling | 55 (130) | ... | 1.00 | ... | 0.10 | ... | ... | | (>300) | (900) | (23) | (40) | >65 | 194[F] | >58 | 168[F] | (42) | (81) | | | |

TABLE 1 *Continued*

| Grade of Fuel Oil | Flash Point, °C (°F) | Pour Point, °C (°F) | Water and Sediment, vol % | Carbon Residue on 10 % Bottoms, % | Ash, weight % | Distillation Temperatures, °C (°F) | | | Saybolt Viscosity, s[D] | | | | Kinematic Viscosity, cSt[D] | | | | | | Specific Gravity 60/60°F (deg API) | Copper Strip Corrosion | Sulfur, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 10 % Point | 90 % Point | | Universal at 38°C (100°F) | | Furol at 50°C (122°F) | | At 38°C (100°F) | | At 40°C (104°F) | | At 50°C (122°F) | | | | |
| | Min | Max | Max | Max | Max | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Max | Max | Max |
| No. 6 Preheating required for burning and handling | 60 (140) | G | 2.00[E] | | | | | | (>900) | (9000) | (>45) | (300) | ... | ... | ... | ... | >92 | 638[F] | ... | ... | ... |

[A] It is the intent of these classifications that failure to meet any requirement of a given grade does not automatically place an oil in the next lower grade unless in fact it meets all requirements of the lower grade.

[B] In countries outside the United States other sulfur limits may apply.

[C] Lower or higher pour points may be specified whenever required by conditions of storage or use. When pour point less than −18°C (0°F) is specified, the minimum viscosity for grade No. 2 shall be 1.7 cSt (31.5 SUS) and the minimum 90 % point shall be waived.

[D] Viscosity values in parentheses are for information only and not necessarily limiting.

[E] The amount of water by distillation plus the sediment by extraction shall not exceed 2.00 %. The amount of sediment by extraction shall not exceed 0.50 %. A deduction in quantity shall be made for all water and sediment in excess of 1.0 %.

[F] Where low sulfur fuel oil is required, fuel oil falling in the viscosity range of a lower numbered grade down to and including No. 4 may be supplied by agreement between purchaser and supplier. The viscosity range of the initial shipment shall be identified and advance notice shall be required when changing from one viscosity range to another. This notice shall be in sufficient time to permit the user to make the necessary adjustments.

[G] Where low sulfur fuel oil is required, Grade 6 fuel oil will be classified as low pour +15°C (60°F) max or high pour (no max). Low pour fuel oil should be used unless all tanks and lines are heated.

# Appendix C

## CONSIDERATIONS FOR BURNING WASTE OIL

1. Waste Oil Generated

| Sources | Amounts (gal./yr) |
|---|---|
| Ship Wastewater Treatment | ________ |
| Aircraft Maintenance | ________ |
| Transportation Shop | ________ |
| Navy Exchange Service Station | ________ |
| Auto Hobby Shop | ________ |
| Other Industrial Areas | ________ |
| Total Quantity/yr | ________ |

2. Potential of Waste Oil Burning

$$\frac{\text{Waste oil generated/yr}}{\text{Fuel oil burned/yr}} \times 100\% = \text{\% of fuel oil requirements met with waste oil}$$

3. Capability for Burning Waste Oil

| | |
|---|---|
| Oil-burning Boilers | |
| Number | ________ |
| Size | ________ |
| Type of Burner Equipment | ________ |
| Mode of Operation | ________ |
| Total Fuel Oil Requirement | ________ |
| Fuel Storage | |
| Capacity | ________ |
| Type of Handling Equipment | ________ |
| Blending Required | Yes __ No __ |
| Fuel Testing | |
| In-house | Yes __ No __ |
| Out of house | Yes __ No __ |
| Evaluations | |

4. Analysis of Waste Oil Generated

| | |
|---|---|
| API Gravity | ________ |
| Water and Sediment Content | ________ |
| Flashpoint | ________ |
| Viscosity | ________ |
| Sulphur Content | ________ |
| Chlorine/Copper Wire Test | ________ |

continued

5. Economic Analysis for Burning Waste Oil

a. \$ savings/yr = quantity of waste oil generated/yr x (unit price of new fuel - sale price of waste oil) \$________

b. Initial investment \$________

c. Recurring costs/yr figured from following: \$________

| Function | Labor | | | Material Cost | Total Cost |
|---|---|---|---|---|---|
| | Hours | Rate | Cost | | |
| Nonburnable Waste Segregation<br>Waste Oil Testing<br>Mixing/Blending<br>Other (site specific) | | | | | |
| Total | | | | | |

d. net annual \$ savings* = \$ savings /yr - recurring costs/yr \$________

e. Simple Payback Period (yr) =

$$\frac{\text{Initial investment for one time project}}{\text{net savings}}$$ \$________

*Savings should exceed cost of burning the waste oil.

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MCRD SCE. San Diego CA
NAF PWD - Engr Div. Atsugi. Japan; PWO. Atsugi Japan
NALF OINC. San Diego. CA
NARF Code 612. Jax. FL; Code 640. Pensacola FL; SCE Norfolk. VA
NAS CO. Guantanamo Bay Cuba; Code 114. Alameda CA; Code 183 (Fac. Plan BR MGR); Code 18700. Brunswick ME; Code 18U (ENS P.J. Hickey). Corpus Christi TX; Code 70. Atlanta. Marietta GA; Code 8E. Patuxent Riv.. MD; Dir of Engrng. PWD. Corpus Christi. TX; Dir. Util. Div.. Bermuda; Grover. PWD. Patuxent River. MD; Lakehurst. NJ; Lead. Chief. Petty Offr. PW/Self Help Div. Beeville TX; PW (J. Maguire). Corpus Christi TX; PWD - Engr Div Dir. Millington. TN; PWD - Engr Div. Oak Harbor. WA; PWD Maint. Cont. Dir.. Fallon NV; PWD Maint. Div.. New Orleans. Belle Chasse LA; PWD. Maintenance Control Dir.. Bermuda; PWO Belle Chasse. LA; PWO Chase Field Beeville. TX; PWO Lakehurst. NJ; PWO Sigonella Sicily; PWO Whiting Fld. Milton FL; PWO. Dallas TX; PWO. Glenview IL; PWO. Millington TN; PWO. Miramar. San Diego CA; SCE Norfolk. VA; SCE. Barbers Point HI
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NAVEODTECHCEN Code 605, Indian Head MD
NAVFAC PWO, Brawdy Wales UK; PWO, Centerville Bch, Ferndale CA; PWO, Point Sur, Big Sur CA
NAVFACENGCOM Alexandria, VA; Code 03 Alexandria, VA; Code 03T (Essoglou) Alexandria, VA; Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0454B Alexandria, Va; Code 04B3 Alexandria, VA; Code 051A Alexandria, VA; Code 09M54, Tech Lib, Alexandria, VA; Code 1113, Alexandria, VA; Code 111B Alexandria, VA; code 08T Alexandria, VA
NAVFACENGCOM - CHES DIV. Code 403 Washington DC; FPO-1 Washington, DC; Library, Washington, D.C.
NAVFACENGCOM - LANT DIV. Code 111, Norfolk, VA; Code 403, Norfolk, VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA
NAVFACENGCOM - NORTH DIV. Code 04 Philadelphia, PA; Code 09P Philadelphia PA; Code 111 Philadelphia, PA; Code 04AL, Philadelphia PA
NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; CODE 09P PEARL HARBOR HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 403, Gaddy, Charleston, SC; Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC
NAVFACENGCOM - WEST DIV. Code 04B San Bruno, CA; Library, San Bruno, CA; O9P/20 San Bruno, CA; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACTS AROICC, NAVSTA Brooklyn, NY; AROICC, Quantico, VA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; ROICC, Yap
NAVMAG SCE, Subic Bay, R.P.
NAVOCEANSYSCEN Code 6700, San Diego, CA
NAVORDSTA PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPETRES Director, Washington DC
NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S3T, Norfolk VA; SCE Coronado, SD,CA
NAVREGMEDCEN PWD - Engr Div, Camp Lejeune, NC; PWO, Camp Lejeune, NC
NAVREGMEDCEN PWO, Okinawa, Japan
NAVREGMEDCEN SCE; SCE San Diego, CA; SCE, Camp Pendleton CA; SCE, Guam; SCE, Newport, RI; SCE, Oakland CA
NAVREGMEDCEN SCE, Yokosuka, Japan
NAVSCOLCECOFF C35 Port Hueneme, CA
NAVSCSOL PWO, Athens GA
NAVSEASYSCOM Code 0325, Program Mgr, Washington, DC; SEA 04E (L Kess) Washington, DC
NAVSECGRUACT PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSHIPYD Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, Portsmouth, VA; Code 382.3, Pearl Harbor, HI; Code 400, Puget Sound; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 453 (Util. Supr), Vallejo CA; Library, Portsmouth NH; PW Dept, Long Beach, CA; PWD (Code 420) Dir Portsmouth, VA; PWD (Code 450-HD) Portsmouth, VA; PWD (Code 453-HD) SHPO 03, Portsmouth, VA; PWO, Bremerton, WA; PWO, Mare Is.; PWO, Puget Sound
NAVSTA Adak, AK; CO, Brooklyn NY; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL; Dir Mech Engr 37WC93 Norfolk, VA; Engr. Dir., Rota Spain; Long Beach, CA; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam; SCE, Pearl Harbor HI; SCE, San Diego CA
NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVTELCOMMCOM Code 53, Washington, DC
NAVWPNCEN Code 2636 China Lake; Code 3803 China Lake, CA; PWO (Code 266) China Lake, CA
NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092, Concord CA; Code 092A, Seal Beach, CA
NAVWPNSTA PW Office Yorktown, VA
NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO, Charleston, SC; PWO, Seal Beach CA
NAVWPNSUPPCEN Code 09 Crane IN
NCTC Const. Elec. School, Port Hueneme, CA
NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 430 (PW Engrng) Gulfport, MS; Code 470.2, Gulfport, MS; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI; PWO, Gulfport, MS
NMCB FIVE, Operations Dept; THREE, Operations Off.
NOAA Library Rockville, MD
NRL Code 5800 Washington, DC
NSC Code 54.1 Norfolk, VA

NSD SCE, Subic Bay, R.P.
OFFICE SECRETARY OF DEFENSE OASD (MRA&L) Dir. of Energy, Pentagon, Washington, DC
ONR Code 221, Arlington VA; Code 700F Arlington VA
PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI
PHIBCB 1 P&E, San Diego, CA
PWC ACE Office Norfolk, VA; CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 110, Great Lakes, IL; Code 110, Oakland, CA; Code 120, Oakland CA; Code 154 (Library), Great Lakes, IL; Code 200, Great Lakes IL; Code 400, Oakland, CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Library, Code 120C, San Diego, CA; Library, Guam; Library, Norfolk, VA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic Bay, R.P.; Library, Yokosuka JA; Util Dept (R Pascua) Pearl Harbor, HI; Utilities Officer, Guam
SPCC PWO (Code 120) Mechanicsburg PA
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
USCG (Smith), Washington, DC; G-MMT-4/82 (J Spencer)
USDA Forest Service Reg 3 (R. Brown) Albuquerque, NM
USNA Ch. Mech. Engr. Dept Annapolis MD; ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Environ. Prot. R&D Prog. (J. Williams), Annapolis MD; Mech. Engr. Dept. (C. Wu), Annapolis MD; USNA/SYS ENG DEPT ANNAPOLIS MD
ARIZONA State Energy Programs Off., Phoenix AZ
BERKELEY PW Engr Div, Harrison, Berkeley, CA
BONNEVILLE POWER ADMIN Portland OR (Energy Consrv. Off., D. Davey)
BROOKHAVEN NATL LAB M. Steinberg, Upton NY
CONNECTICUT Office of Policy & Mgt, Energy, Div, Hartford, CT
CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.)
GEORGIA INSTITUTE OF TECHNOLOGY (LT R. Johnson) Atlanta, GA
HAWAII STATE DEPT OF PLAN. & ECON DEV. Honolulu HI (Tech Info Ctr)
LEHIGH UNIVERSITY Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LOUISIANA DIV NATURAL RESOURCES & ENERGY Div Of R&D, Baton Rouge, LA
MAINE OFFICE OF ENERGY RESOURCES Augusta, ME
MISSOURI ENERGY AGENCY Jefferson City MO
MONTANA ENERGY OFFICE Anderson, Helena, MT
NATURAL ENERGY LAB Library, Honolulu, HI
NEW HAMPSHIRE Concord NH (Governor's Council on Energy)
NY CITY COMMUNITY COLLEGE BROOKLYN, NY (LIBRARY)
NYS ENERGY OFFICE Library, Albany NY
STATE UNIV. OF NEW YORK Fort Schuyler, NY (Longobardi)
UNIVERSITY OF CALIFORNIA Energy Engineer, Davis CA; UCSF, Physical Plant, San Francisco, CA
UNIVERSITY OF HAWAII HONOLULU, HI (SCIENCE AND TECH. DIV.)
NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)
TEXTRON INC BUFFALO, NY (RESEARCH CENTER LIB.)
WESTINGHOUSE ELECTRIC CORP. Library, Pittsburgh PA