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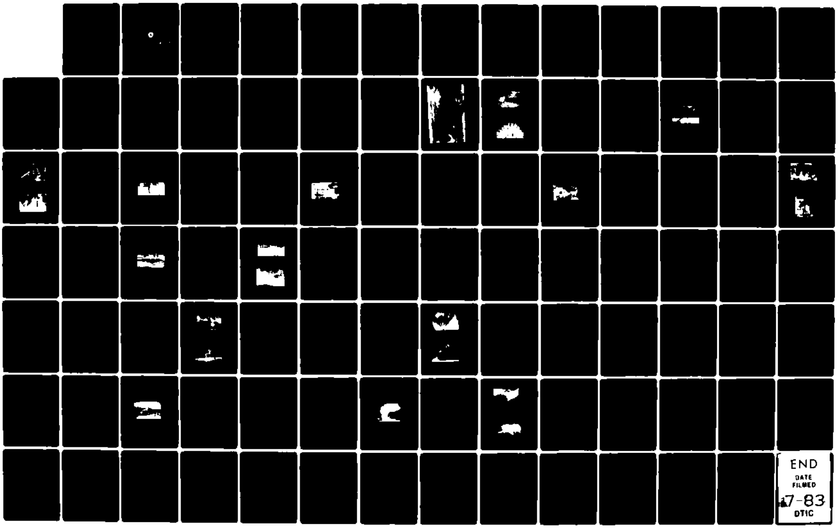

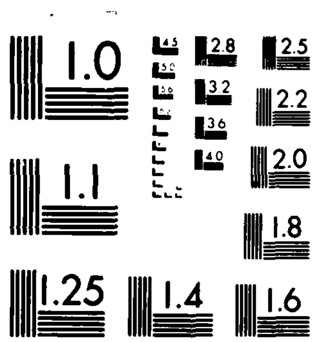

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Report No. CG-D-13-83

DEVELOPMENT OF A FLARING BURNER DISPOSAL SYSTEM

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May 1983

FINAL REPORT

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16. Abstract

This report describes the work performed to develop a flaring burner system for spilled and recovered oils. The system is capable of flaring 180 gpm of light oil or 90 gpm of oil with a viscosity of up to 1,600 centistokes. Smokeless burning can be achieved in certain cases. The system is designed to be portable, such that the entire system can be broken down into modules and transported in a C-130 aircraft, and each module is light enough to be carried to a remote spill site by a Coast Guard helicopter. The system is self-erecting and is capable of operating safely in hazardous environments and in arctic conditions. The report describes the initial burner selection and the tests that were conducted to determine the burning parameters. The performance test program conducted on the completed prototype system is also described. These tests were successfully completed, with the conclusion that the prototype could be used for operational flaring at this time.

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Unclassified	Unclassified	80	

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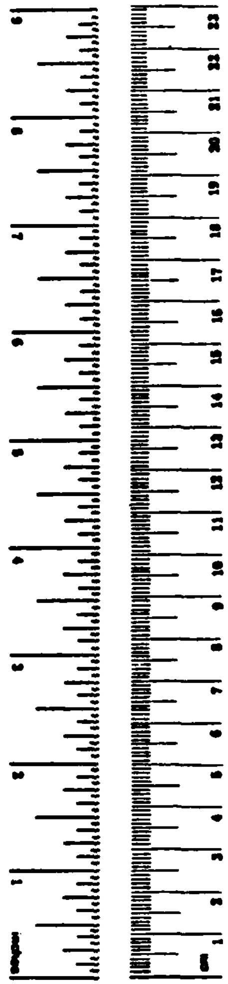
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

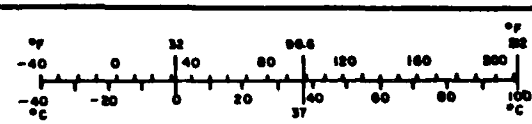
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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 (2000 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 (1000 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



FOREWORD

This report describes the work performed to develop a flaring burner system for spilled and recovered oils. Seaward International, Inc., along with the John Zink Company, and William Krause as consultants, performed the work under contract DOT-CG-930636-A during the period of October 1979 through July 1981.

Mr. Kenneth R. Goldman served as the Project Officer during this program. R. L. Beach served as Project Manager from Seaward International, Inc. Design work was performed by W. T. Lewis, E. Schildtknecht, N. B. Davis, R. Goldhammer, and R. P. Bishop. Much of the equipment fabrication effort was performed by Patrick Brown. Mr. Mike Keller served as Project Manager for the John Zink Company, and the test programs were conducted by R. Schwartz, D. Presnell, and D. Henderson.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

1. EXECUTIVE SUMMARY

A high-volume flaring burner system for disposal of oil recovered from oil spills has been successfully developed. The system meets Coast Guard goals for portability and flexibility in deployment under a wide range of environments and sites, and has demonstrated the burning of oils with viscosities up to 1,600 centistokes (cs) without the aid of a special oil heating system. The maximum burning rate of 180 gallons per minute (gpm) has been demonstrated to be about the maximum rate that can be flared, and still maintain an adequate degree of operator comfort and safety, especially where the operating environment is confined (barge deck, etc.).

The system consists of the following components:

1. Burner: A John Zink Company OWB-12 flaring burner is utilized. This burner utilizes both compressed air and pressure atomization to produce a fine spray of burnable oil. Twelve identical burner nozzles are utilized to provide a fan-shaped flame pattern that provides maximum exposure to combustion air (wind). Both large-orifice and small-orifice nozzles are provided for light and heavy oils, respectively. To eliminate or minimize smoke, water jets are utilized to spray water into the flame. Individual propane pilots are used to initiate burning and to maintain burning of hard-to-burn oils.

2. Boom: The burner is held 40 feet off the ground or deck by a 78-foot long aluminum boom. The boom is a tubular structure that utilizes the four corner tubes as conduits to transport the oil, air, and water to the burner. The boom itself is supported at an angle of 30 degrees to the ground by an A-frame assembly and cables; the lower end is held on the ground by the weight of two air compressors. The boom is made in two sections, which nest together to permit shipping in a 40-foot long space. The boom is self-erecting through the use of an air-winch, and requires no cranes to assemble the system.

3. Air Compressors: Three identical diesel-driven screw compressors provide atomizing air to the burner nozzles. Each compressor is the largest unit that can be transported by Coast Guard HH-3 helicopter.

4. Oil Pump: A diesel-driven, high pressure screw pump is utilized to pump oil to the burner. The pump system can provide 180 gpm at 430 psig, or 90 gpm at 700 psig, depending on the oil viscosity.

5. Water Pump: A two-stage diesel-driven centrifugal pump provides high pressure water to the smoke suppression nozzles on the burner, and to a second set of spray nozzles on the boom to absorb thermal radiation from the flame.

6. Pilot Gas System: Storage of 1,400 pounds of liquified propane is provided for pilot gas. A vaporizer system is provided for cold temperature environments. The propane is also used to supply a remotely-operated ignition system for the pilots.

7. Other: Rubber hoses are used to connect the various components together. Pillow tanks are provided for temporary oil storage. Special shipping pallets are also provided to facilitate C-130 shipping of the disassembled system.

The key to the system is the burner, which was selected after studying the features of several other large flaring burners that are used in oil well production testing. This burner was then tested by itself to determine utility requirements (oil, air, and water flow rates and pressures) and performance while burning a variety of oils and water-in-oil mixtures. After these preliminary tests, the remaining components of the system were designed and fabricated. Several of the design goals were the following:

1. Burn oils and water-in-oil (W/O) emulsions of up to 1,000-cs viscosity without a heating system.

2. Be able to set up the system using only a forklift or helicopter.

3. Transport all components by HH-3 helicopter (3,000 pounds maximum weight), and the entire system by C-130 transport plane (25,000 pounds maximum weight) or 40-foot flatbed truck.

4. Be able to operate from a barge deck or on land, in climates ranging from temperate to arctic (-40° C).

5. Incorporate an 8-hour supply of fuel.

All of these goals are met with this system. Although a goal for maximum burning rate was not achieved (limited by system weight), it is felt that the rate of 180 gpm is a practical maximum for this type of portable operation where a confined operating environment may exist.

After completion of the system fabrication, assembly, and checkout, the system was shipped to the John Zink Company test site for performance testing. The system was successfully deployed and operated, burning a variety of simulated waste oils. Smokeless burning of No. 2 diesel oil was demonstrated at a rate of 140 gpm, as well as a maximum rate with light smoke of 175 - 180 gpm. Oils of up to 867 cs, W/O emulsions, and simulated tank bottoms were also burned. In general, smokeless burning of low viscosity oils could be achieved at a high rate if water spray was utilized, and at a reduced rate without water. Smoke production increased with increasing viscosity, even with water spray added. With oils over approximately 20 to 50 cs, the small-orifice nozzles appeared to be the most effective, although they limited the maximum flow rate to 90 gpm. Water-in-oil mixtures (free water) could be burned as long as a low viscosity oil was present, and the water content did not exceed 50 percent. A 30-percent stable W/O emulsion could be burned, but a 40-percent emulsion could not. Droplet fallout (unburned oil from the flame) was negligible at low viscosities, but was probably substantial at high viscosity (800 to 1,600 cs). Thermal radiation was fairly high, but did not exceed safe levels for protected workers (long sleeves, hard hats, etc.). Noise generation was not excessive.

Arctic operation and shipboard setup should be tested in any future work. No major breakdowns occurred in any of the system components, and the prototype would be suitable for operational burning in its present state of development.

2. INTRODUCTION

Oil burning as a disposal method has frequently appeared to be an attractive alternative to the logistical headaches of shipping, trucking, and storage, especially in remote or inaccessible spill locations (1, 2). However, the technology to accomplish this has been lacking, particularly where large volumes of contaminated oil were involved and/or where "clean" and complete burning would be desirable. Although equipment is available for burning crude oil at high rates (200 to 400 gpm), most of it is cumbersome to move about and deploy, and, therefore, it is almost always confined to permanent or semi-permanent installations such as fixed disposal sites or drillships. What the U.S. Coast Guard has accomplished with the present project is the development of a highly portable and easy-to-deploy burner system, with specific features built in for handling a wide variety of spilled and contaminated viscous oils at high rates.

The system that was developed does not require any unique Coast Guard capabilities to deploy and operate. In fact, commercial entities such as spill cleanup co-ops or independent cleanup contractors could easily handle the system. However, the system was designed to accommodate certain Coast Guard transport capabilities, including shipping of the entire system in a single C-130 transport aircraft (25,000-pound weight limit, and overall envelope dimensions of 7'10" wide, 8'6" high, and 40'0" long), and transport of each equipment module by HH-3 helicopter (3,000-pound maximum weight). The system can also be transported on a single 40-foot flatbed truck, and all components can be handled by forklift or crane.

As design criteria, the Coast Guard prescribed a range of oil types that were typical of what could be expected in an oil spill or vessel lightering operation. These oils included light crude and refined products (to be burned at the highest rate); water-in-oil (W/O) emulsions; and weathered oils or tank bottoms containing non-emulsified water. It was recognized that oil burner performance is adversely affected by high viscosities, and that at some point heating of the oil would be required to reduce its viscosity. However, to avoid having to have a heater in the primary system, the design was to permit burning of as high a viscosity as possible (1,000 centistokes or more). This is well in excess of conventional oil burners, which are limited to viscosities on the order of 50 cs.

In many spills, one of the recovery products is oiled debris, such as vegetation, tree limbs, etc. The flaring system is not designed to handle this type of material, although when used with a portable incinerating system (3) almost any spill disposal situation can be handled. Clean fluids are not essential to burner performance, however, as adequate straining is provided in the system.

The following sections describe the prototype system in detail, and discuss the decisions and test programs leading up to the final design. Prototype test results are presented, and operating procedures and performance guidelines are presented.

3. PROTOTYPE DESCRIPTION

3.1 OVERALL FEATURES

The complete Flaring Burner Oil Disposal System would consist of a primary package, which is the initial C-130 deliverable shipment, and a secondary package, which is the oil heating subsystem. Although an oil heating subsystem was not constructed during this program, a preliminary design was prepared and will be described later on in this section. The primary package would be completely independent of the second, which could be added to the primary system as necessary to accommodate high-viscosity oils. In addition, additional fuel modules would be required for resupply of the primary system (propane and diesel oil). Support equipment such as lighting and personnel comforts are assumed to be provided separately by the Coast Guard Strike Teams.

The primary system consists of eight functional areas. These include the following:

a. Burner
b. Burner Support Boom and Stand
c. Oil Pump
d. Air Compressors
e. Water Pump
f. Pilot Gas System
g. Hoses and Tankage
h. Transport Packaging

Figure 1 shows a schematic diagram of the system with the principal components identified. The burner contains air-atomizing oil nozzles, and therefore requires a source of compressed air (from three air compressors operating in parallel: AC-1, AC-2, and AC-3). A high pressure oil pump is also required to supply oil to the nozzles from various sources such as external low pressure pumps (e.g., Coast Guard ADAPTS pumps), external tanks

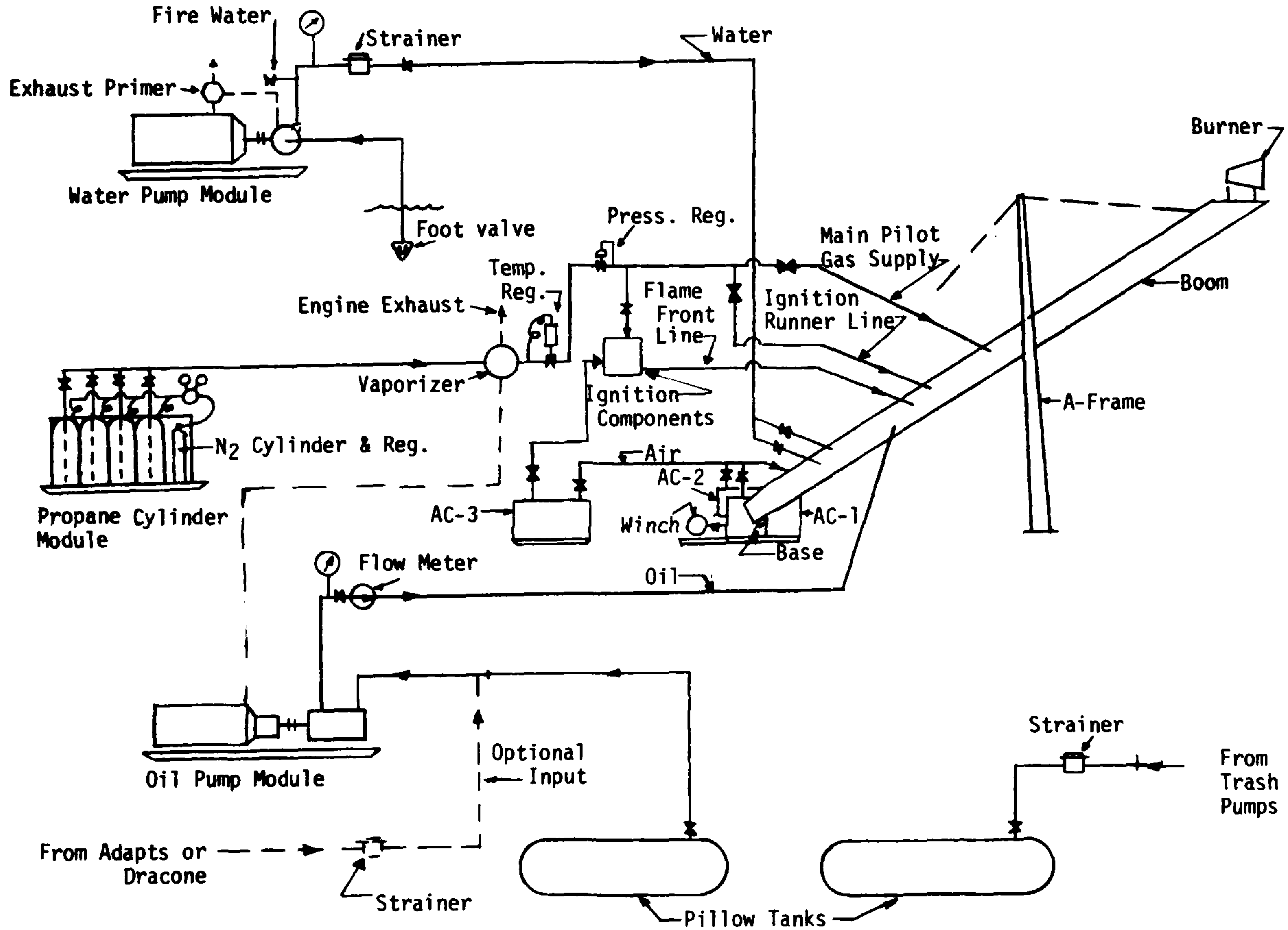


FIGURE 1. PRIMARY SYSTEM SCHEMATIC

of oil (such as a Dracone Barge), or from oil accumulated in the system pillow tanks. A high pressure water pump is required to supply spray water to the burner for smoke suppression and for thermal radiation control. Pilot lights are required on the burner, and, therefore, a supply of liquid propane is required along with a means of vaporizing the propane when ambient temperatures are low. A remotely-operated pilot ignition system is also provided. Finally, a means is required to support the burner a substantial distance off the ground and away from the deck (if deployed on a barge or ship). For this, the boom, A-frame, base, and winch are provided, along with appropriate rigging. Figure 2 shows an overall picture of the prototype system with the principal components in view (except the pillow tanks).

3.2 COMPONENT DESCRIPTION

3.2.1 Burner:

The burner is a John Zink Model OWB-12 oil flare. This unit consists of twelve independent burner modules, each consisting of an air-atomizing oil nozzle (tip), a pilot light and two smoke-suppression water-spray nozzles. In addition, the unit contains an ignition runner, which provides a ring of pilot flame that intercepts each main pilot and is used only to light all of the main pilots simultaneously. The ignition runner is ignited by a remote flame front generator (FFG) through a pipe. (The flame front generator is described under the Pilot Gas section.) All supply piping on the burner is manifolded together, as can be seen in Figures 3 and 4. The burner is bolted to a large roller bearing, which is attached to a base that bolts the unit to the boom. A burner orientation of up to ± 30° from the boom axis is provided by the bearing. The basic construction material is steel, except where high temperature alloys are required in the tips.

Several unique features were incorporated into the burner design to maximize its capability for burning the more viscous oils and oil-water mixtures:

FIGURE 2. PROTOTYPE BURNER SYSTEM DEPLOYMENT

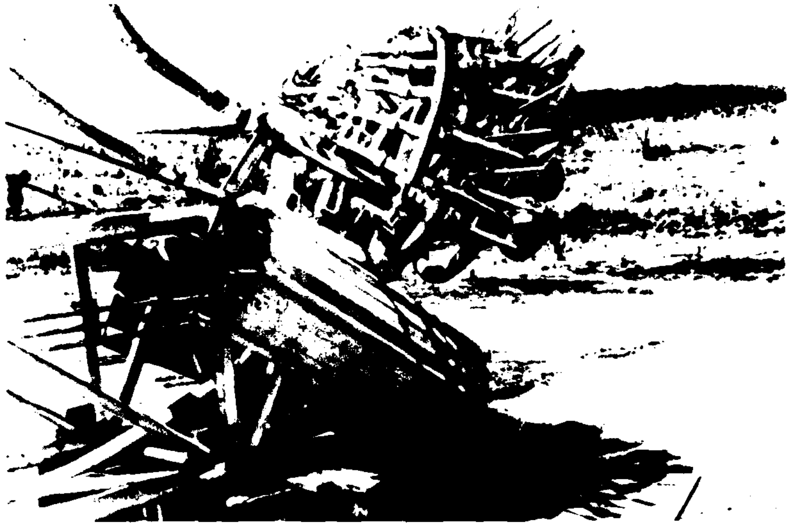


FIGURE 3. BURNER WITH TEMPORARY RADIATION SHIELD INSTALLED

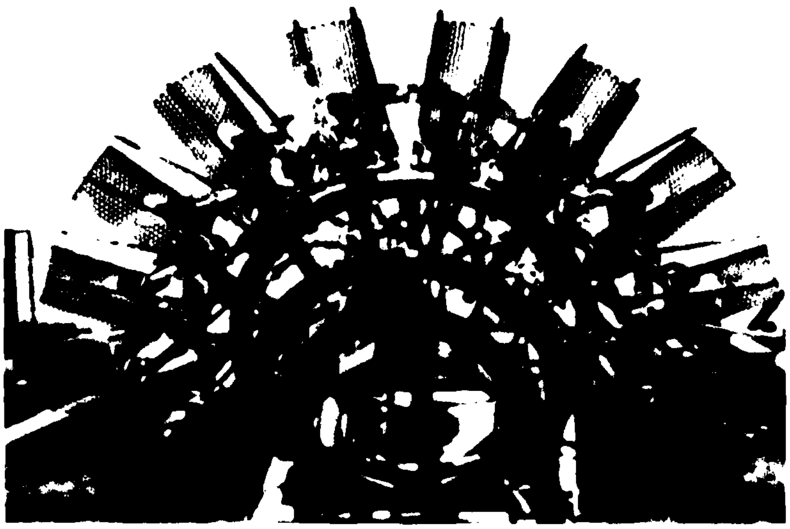


FIGURE 4. BURNER WITH IGNITION RUNNER BURNING

1. The tips are oriented to fire perpendicular to the wind direction in a radial pattern, so that maximum penetration of combustion air into the flame is achieved.

2. Each tip fires an independent flame pattern (minimal interaction of flame envelopes), again helping to achieve maximum penetration of combustion air.

3. Each tip has a separate propane pilot to ensure ignition of difficult-to-burn oils and oil-water mixtures.

4. Different tips can be easily installed to accommodate a range of oil types. Two sizes of tips were extensively tested during the program: a large-orifice tip with a nominal capacity of 15 gpm of light oil (A-tip), and a small-orifice tip with a nominal capacity of 7.5 gpm of heavy oil (C-tip). Air consumption is the same for each tip.

5. A high ratio of atomizing air to oil is utilized (a function of specific tip design) for the more viscous oils.

6. Individual tips can be easily blanked off where a low overall burning rate at high atomizing efficiency is necessary to keep thermal radiation to a minimum (in close quarters, such as burning from a barge deck).

3.2.2 Burner Support Boom and Base

The boom assembly consists of a two-part boom with the burner attached to the forward end, a lifting bridle, supporting A-frame legs, an alignment cable and support, and base assembly weighted down with two compressors (6,000 pounds). Figure 5 shows these features schematically. Figure 6 shows an overall photograph of the boom system in the erected position.

The boom is a welded aluminum structure designed to be loaded in axial compression. The main longitudinal structural members are four 4-inch OD by ¼-inch wall round tubes laced together with 2 x 2 x .058-inch square tubes. The assembled boom is 78 feet long. The cross section tapers from 32 inches square at the foot to 48 inches square at the burner. The taper allows the lower section of the boom and the A-frame

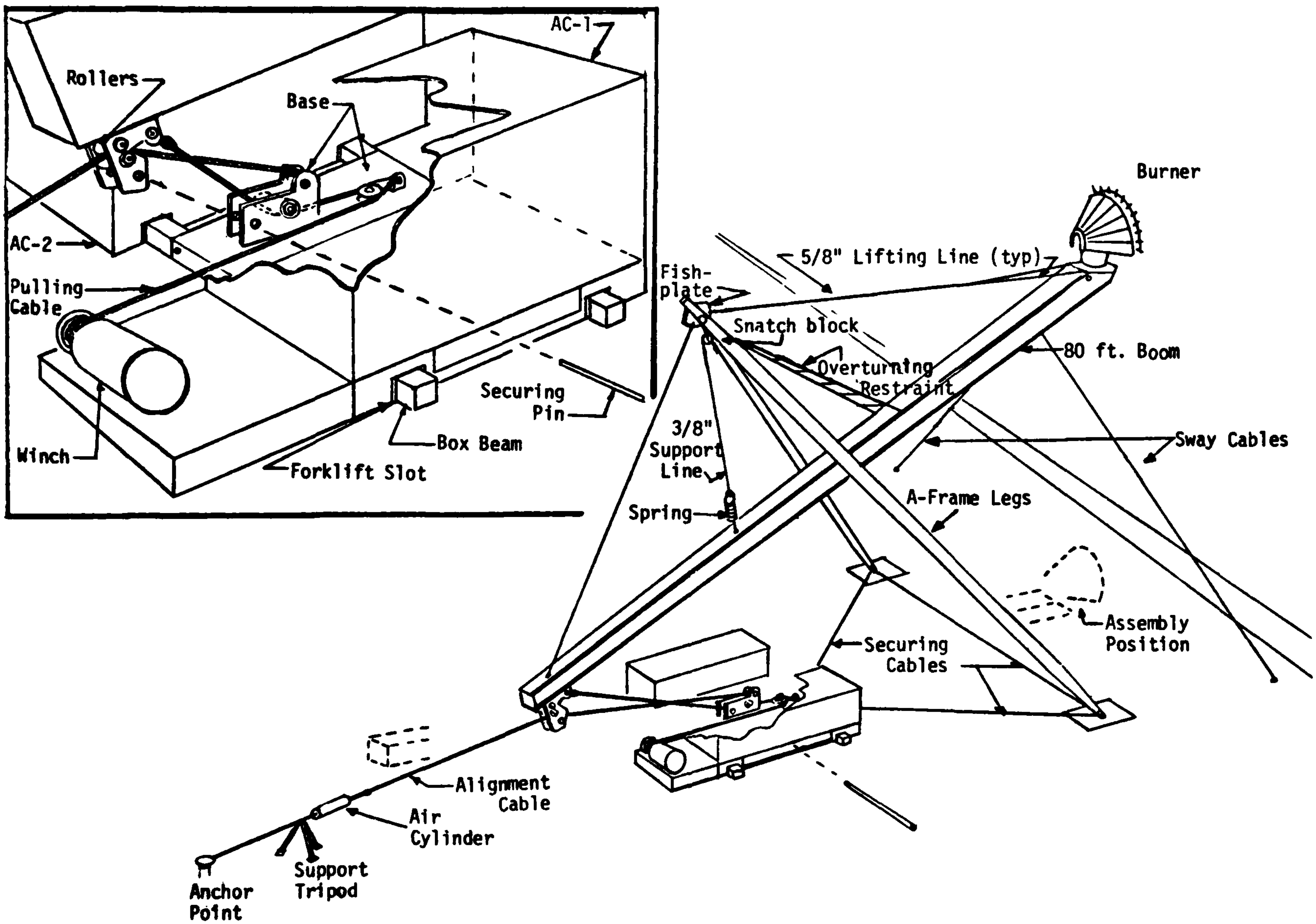


FIGURE 5. BOOM/BURNER ASSEMBLY SCHEMATIC

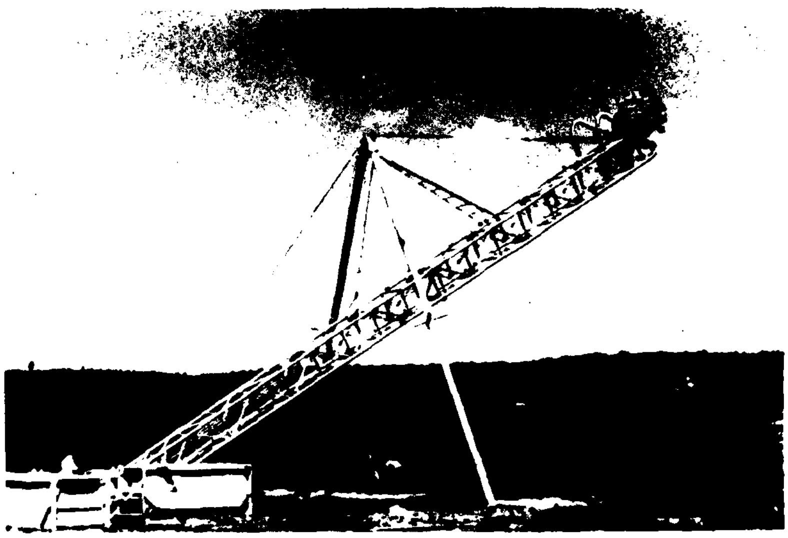


FIGURE 6. ERECTED BOOM

legs to be stored inside the upper boom section for shipping. Each of the four tubes carries one of the fluids for the system: oil, air, smoke suppression and radiation suppression water. Hydraulic connections between the two nearly equal length sections are made with flanged fittings that also provide the mechanical connections. Pilot light connections are made by separate, one-inch diameter aluminum tubes attached to the boom. Just in back of the boom flanges, an array of water spray nozzles is installed to provide a fan-shaped radiation suppression screen between the flame and the operating area.

The weight of the burner and boom is supported primarily by a lifting bridle consisting of two 5/8-inch wire rope assemblies connecting the top of the A-frame legs to the ends of the boom. An additional 3/8-inch support cable near the center of the boom provides additional support to minimize bending stresses caused by the boom weight and pitching accelerations if the system is barge mounted. (Studies reported by Beach, et. al., (4) showed that for a typical 195-foot sea-going barge, the significant accelerations at the bow would reach 0.11 g in a Sea State 5 at a Froude number of 0.1.) This 3/8-inch cable, which runs through a snatch block at the top of the A-frame, connects at its forward end to an A-shaped structure on the boom that counteracts any overturning movement caused by the high center of gravity of the burner. At its other end the cable is attached to a coil spring which minimizes shock loads in a seaway.

The entire boom is supported by two A-frame legs, which are constructed of 8-inch OD by 1/8-inch wall aluminum tubing. The legs are each stiffened by a set of four wire stays attached to fold-up spreaders in the middle of the legs. At the base of each leg is a pivoting support plate.

The tops of the legs are connected together with a pin, which also supports the fishplate used to connect all of the boom support cables to the A-frame. The support plates on the bottom of the A-frame legs are connected to each other and to the counterweight compressors by wire ropes, thus locking the base arrangement in a triangular pattern.

After the boom is erected, the bottom end of the boom is locked to the counterweight assembly by a pin. The counterweight assembly consists of two air compressors, which are joined together by two aluminum box beams inserted through the compressor forklift holes. A locking mechanism bolted to the box beams between the compressors serves to receive the securing pin, and also supports the pulleys that guide the hoisting cable.

Before the boom is erected it lies between the counterweight compressors with its lower end approximately 30 feet behind the locking mechanism. The A-frame legs are assembled and positioned, and all of the support cables are connected between the fishplate and the boom. To erect the boom, the lower end is pulled forward by the hoisting cable, which feeds through the pulleys on the locking mechanism and wraps around the drum of an air-operated winch. The winch is bolted to a skid, which in turn is bolted and braced to one of the counterweight compressors (AC-1). To keep the lower end of the boom from "kicking up" when the center of gravity of the boom assembly is pulled forward of the A-frame legs, the lower end of the boom rides on a separate alignment cable, which is connected between the locking mechanism and an anchor point behind the boom. The alignment cable is kept under 2,400 pounds tension during the hoisting procedure. The design of the locking mechanism and the mating assembly on the end of the boom ensures that the securing pin holes are pulled into alignment as the boom is erected. Figure 7 shows the end of the boom pinned in place, and Figure 8 shows the same location with the manifolds and hoses in place. Note the winch on the right side of Figure 8, and the edge of the FFG on the left side.

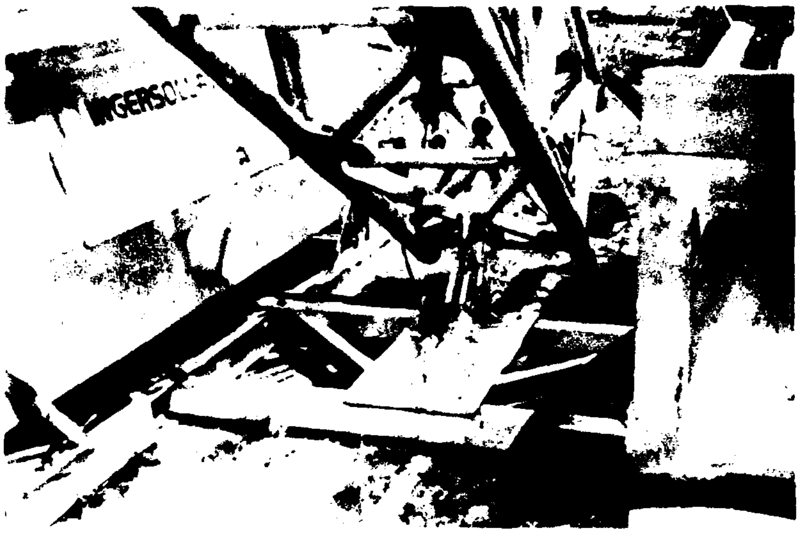


FIGURE 7. END OF BOOM PINNED IN PLACE

FIGURE 8. BOOM END WITH MANIFOLDS AND HOSES ATTACHED

In addition to the anchor point at the other end of the alignment cable, anchor points are needed to secure two cables from a point high on the boom to the ground or deck in front of and to the sides of the A-frame legs. These cables prevent the boom from swaying once it is erected. Turnbuckles are used to take up the slack. Anchor points can be convenient deck fittings, or for land setup, ground anchors can be used. Military style Arrowhead-type anchors are supplied with the system, and are driven into the ground using a jackhammer and a special driving rod (both supplied with the system). The anchors have a wire rope pendant for attaching the load. For safety, it is wise to secure the after ends of the counterweight compressors with cable and anchors to ensure that they will not overturn in case of an abnormal load on the boom.

When the boom hoisting process is started (initial winch pull), the lower end of the boom tends to drag along the ground; after the boom center of gravity shifts forward part way through the lift, the lower end of the boom tends to lift, as described previously. The alignment cable, which is kept under constant tension by an air cylinder located near the anchor point, tends to resist these vertical movements of the boom end, but does not prevent them entirely. Therefore, to prevent the boom end from dragging, a set of pneumatic wheels is installed on the end of the boom. These wheels are merely pinned in place and can be quickly removed by one man as soon as the boom end lifts sufficiently. The wheels must of course be reinstalled when the boom is being taken down. A tripod stand between the air cylinder base and the anchor point prevents a large downward force component from the alignment cable on the pneumatic wheels. More than one ground anchor should be used, depending on the soil conditions, and a come-along and chain should be used to take up the slack that develops in the cable system as the anchors settle in under load. Once the anchors are set, the air cylinder stroke (20 inches) will automatically compensate for changes in the alignment cable configuration as the boom end trys to rise during the hoisting process. An automatic brake on the winch will hold the boom in any partially erected position if the winch control handle is released or if the air supply is disrupted. Figure 9 shows the alignment cable anchoring system.

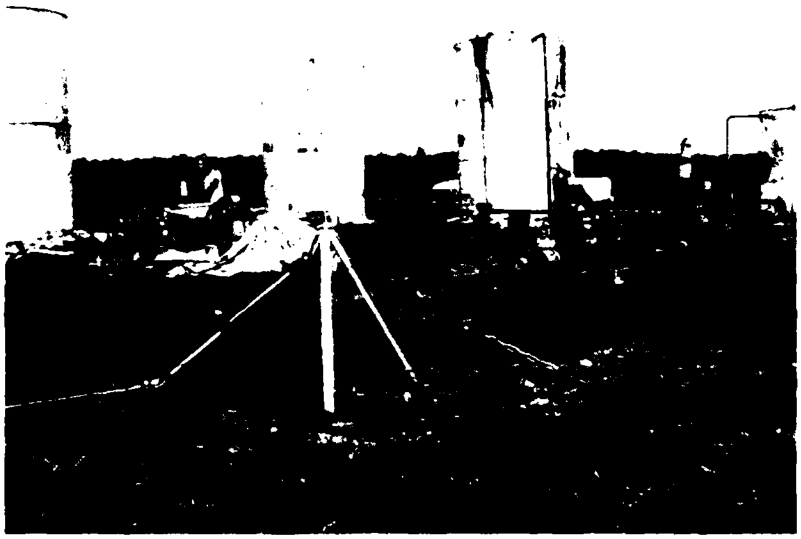


FIGURE 9. ALIGNMENT CABLE ANCHORING SYSTEM

The upper end of the boom (under the burner) must generally be supported off the ground before hoisting in order to keep the boom cross-members from interfering with the locking mechanism. If the ground is level, setting the boom on the edge of the burner shipping skid may be sufficient. The burner skid is designed to accommodate this situation. If the ground is not level, some expedient means (timbers, etc.) must be utilizied. Jacks are provided with the system to assist in lifting the end of the boom once the burner is in place, if a forklift is not available.

The burner shipping skid is equipped with a hinged deck so that the deck can be raised at an angle to permit sliding the burner up onto the mounting location on the boom. Again, jacks are used to raise the skid deck. Two come-alongs (Griphoists) are used to pull the burner up onto the boom. Bolts are used to secure the burner to the boom, and to the skid deck for shipping.

The considerable amount of heat generated by the flame caused the temperature of the aluminum boom structure immediately below the burner to exceed desirable levels during tests (as indicated by thermocouple measurements). To intercept the thermal radiation before it affects the boom structure, a heat shield was fabricated and fit over the end of the boom. This effectively limited boom temperatures to safe levels. The rubber hoses supplying oil, air, and water from the boom to the burner are protected from the heat with fiberglass braid insulation. The propane hoses in this area are corregated metal (stainless).

To permit the burner to be pivoted on its bearing, two "reins" made of ¼-inch wire rope are led from each side of the burner to securing points at the base of the boom. By tensioning one side and slacking the other, the burner can be pivoted in the desired direction while the boom is erected and firing.

3.2.3 Oil Pump Module

The oil pump module consists of an IMO A6D312 screw pump, a Deutz F4L912 diesel engine with a Warner Gear T19A transmission, a butterfly valve, flow meter and skid. The propane vaporizer system is also included in this module, as the engine exhaust is used as a heat source in the vaporizer (see Section 3.2.7). Figure 10 shows the pump module.

The IMO pump had low weight, price, and power requirements compared to other pumps investigated. Sizing was performed for two cases: 180 gpm of 10-cs oil at 430 psig, and 90 gpm of 1,000-cs oil at 630 psig. These two cases require 63 hp at 1915 rpm, and 49 hp at 820 rpm, respectively. The design conditions were determined by burner tests conducted early in the program.

Although a smaller pump size would have been adequate to deliver the required delivery performance, the maximum suction lift would be limited. With the A6D312 pump, suction lift for the low viscosity case is estimated at 14 inches Hg (Delaval conservatively claims at least 7 in. Hg); for the high viscosity case, the pump is rated for 19 in. Hg. Because of the variable suction conditions that may exist (oil supplies from anything from a Dracone to an ADAPTS pump), as much suction lift as possible was sought in the selected pump, commensurate with reasonable pump weight and cost. (The actual pump used in the prototype test program was a smaller IMO pump, which was utilized temporarily because of delivery problems with the A6D312 pump.)

The decision to use the Deutz F4L912 engine was in part influenced by the air compressor selection, which utilizes an identical engine. (A Deutz F5L912 also appeared to be a good choice for the water pump because of its 2,800 rpm maximum operating speed.) With all of the system engines being of the same series, operator training and maintenance problems are minimized (most spare parts are interchangeable within all engines of the same series.) Also, the solutions to the problems of hazardous atmosphere

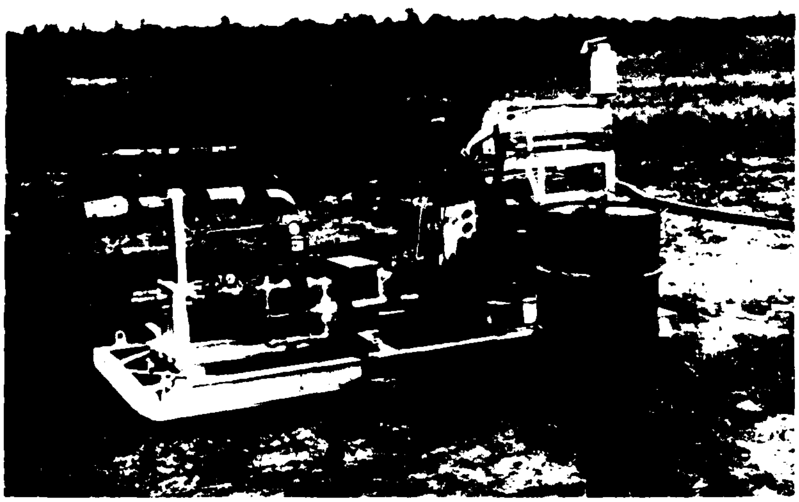


FIGURE 10. OIL PUMP MODULE WITH PROPANE VAPORIZER AND CONTROL SYSTEM

and cold temperature operation are then common to all of the engines in the system. Finally, these engines have the advantage of having no water cooling system to deal with, and are similar in concept to the familiar Bernard diesel used on the ADAPTS pumping system. A further description of the engines is presented in Section 3.2.6.

The oil pump engine (and the water pump engine) was selected on the basis of its intermittant power curve (Din "B"), because of the relatively short duration of most flaring operations, and the opportunity for maintenance between operations. A 2,000-hour total system operating life should be achievable under those conditions.

The engine is not equipped with an integral fuel tank. Fuel is provided directly from a 55-gallon drum using a pair of hoses (supply and overflow return) equipped with quick-disconnect fittings, and a dip tube.

To provide the range of speeds needed to match the oil pump speed/power requirements, a two-speed transmission was required. Several transmissions were investigated, but the most readily adaptable to the Deutz engine was a Warner Gear T19A 4-speed automotive transmission (only two forward gears are utilized.) This unit bolts directly to the clutch/flywheel of the engine, resulting in a compact unit. With the reverse gear, the pump can also be used to pump the oil back out of the boom and hoses upon shutdown. A mechanical flow meter (20 - 200 gpm) and pressure gauge (0 - 1,000 psig) on the pump discharge are included in the pump module. The inlet oil connection is a 4-inch Kamlok hose connector, and the discharge fitting is a grooved pipe for connecting with a 4-inch Victaulic connector.

An aluminum skid (6061-T6 grade aluminum) is used to support the components. The skid has forklift slots and channels built in to permit handling with 3,000 to 10,000-pound forklifts. The skid will also permit helicopter pickup from the four corners. Tiedown points are provided for securing the module to the deck and to the shipping pallet. The overall dimensions permit packaging on the C-130 shipping pallet without interfering with other components.

3.2.4 Air Compressors

Three identical Ingersoll-Rand Spiro-flo Model P-250 air compressors are used to provide atomizing air. The rated capacity of each unit is 250 scfm, although during testing the engine speeds were increased to provide approximately 280 scfm at 105 to 110 psig. The compressors are rotary-screw types, driven by Deutz F4L912 diesel engines. Each unit contains a U.S. Coast Guard approved oil separator. This compressor model provides a larger rate of air for a 3,000-pound module than any other compressor investigated. The compressors can be seen in Figure 6.

The stock P-250 was modified by the manufacturer to include most of the diesel safety and low temperature startup features discussed for the oil pump (Section 3.2.6). Seaward added a low pressure drop spark arrestor, manufactured by the Discojet Corporation, to each compressor. The Discojet unit is U.S.D.A. Forest Approved, and is rated at 99.4 percent spark arresting efficiency.

Each compressor was supplied with a protective enclosure and an integral 33-gallon fuel tank, which will provide for eight hours continuous operation. Seaward enclosed each compressor in an aluminum skid and framework for handling, shipping, and operation. For identification purposes the compressors were designated AC-1, AC-2, and AC-3.

AC-1 is provided with a skid designed to provide enough clearance immediately beneath the compressor to permit the boom locking mechanism pin to be inserted from outside of the compressor (see Figure 5). This eliminates the need for an assembler to get getween the boom and and the compressor at the time the pin is inserted. An aluminum angle framework around the compressor permits the A-frame legs to be leaned on the compressor during assembly, provides helicopter lift points, and provides a point for attaching the disassembled boom during C-130 transport. The skid is provided with oversize forklift holes to permit the box beams (for attaching the boom base) to be inserted through them. After the beams have been inserted, they are connected to the skid. The skid is also provided with attachment connections for the air-winch skid, so that it can be secured during operation.

AC-2 has a skid and framework similar to AC-1, but shorter in height. The reduced overall height is needed to permit C-130 packaging and is acceptable because no clearance space is needed between the compressor and the skid as on AC-1. However, because of the shorter height, a temporary bracket must be added to the top of the framework for the A-frame leg to lean on during assembly. AC-3 has a skid and framework like AC-2. This compressor stands alone in the layout, i.e., it is not used as a counterweight for the boom end.

3.2.5 Water Pump Module

The water pump module consists of an Ingersoll-Rand model 5 x 3 x 11 GTB two-stage horizontally split case centrifugal pump, a Deutz F5L912 diesel engine, a 3-inch Hayward Series 72 single basket strainer, a butterfly valve, pressure gauge, and a skid. Figure 11 shows this module.

The Ingersoll-Rand pump weighed almost 400 pounds less than any other pump investigated and had the lowest power requirement. The pump provides for 250 gpm of smoke suppression water flow, plus 120 gpm for thermal radiation suppression at a pressure of 220 psig (508 feet of water head). The power requirement is approximately 69 brake horsepower at a speed of 2,700 rpm. Construction is of bronze-fitted cast iron, which should be adequate for the limited service the pump is likely to see, even with sea water. The NPSH requirement of approximately 12 feet will permit a maximum suction lift of 21 feet (less line loss).

The pump is not self-priming, but an exhaust-operated primer on the engine is used to exhaust the air from the four-inch suction line. A foot valve on the inlet end of the suction hose is used to hold the prime during temporary shutdowns.

The 3-inch single-basket strainer is used to filter out particles passing through the foot valve strainer that are too large for the water spray

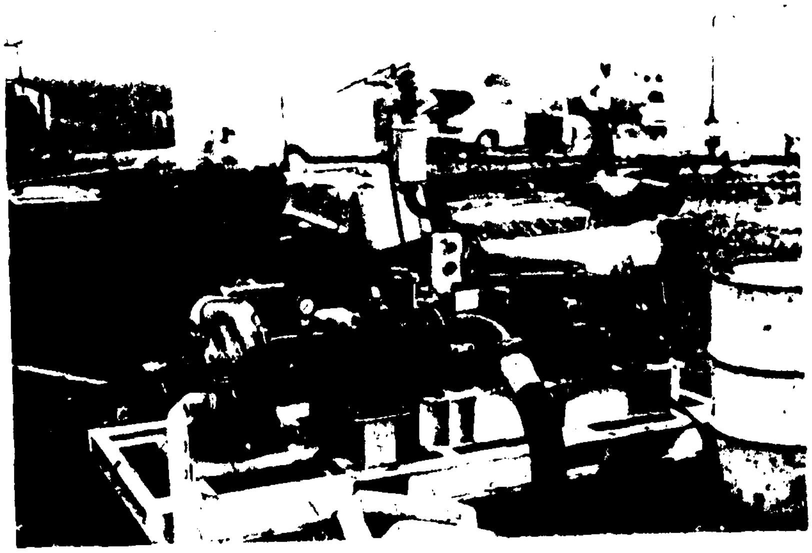


FIGURE 11. WATER PUMP MODULE

nozzles (greater than 0.12 inches diameter). The pump can be shut down whenever the basket needs cleaning (flaring should be stopped first), and the butterfly valve will prevent backflow through the discharge line.

The engine provides 90 bhp (Din "B" curve) at a speed of 2700 rpm. It includes the same safety and low temperature starting features as the other system engines. A power take-off with a clutch drives the pump through a flexible shaft coupling. Fuel is provided directly from a 55-gallon drum, as described for the oil pump. The aluminum skid is similar to, and performs the same function as the oil pump skid. A Kamlok hose fitting is used on the pump suction connection, and a Victaulic (grooved pipe) fitting on the discharge side.

As a safety precaution, an extra connection was added on the pump discharge for fitting a fire hose. In addition to extinguishing any fires, the water may be used to cool or screen portions of the equipment or operating area not adequately protected by the radiation suppression spray nozzles.

3.2.6 Diesel Engines

Each Deutz engine was modified to permit hazardous atmosphere and cold temperature operation in the following manner:

a. Starting. To make the engine suitable for hazardous atmospheres, all electrical components were eliminated. The electrical starter was replaced with an inertia spring starter, which utilizes an external winding handle to compress a spring pack, which in turn rotates the flywheel ring gear when released. Although hydraulic start systems were also investigated, Deutz recommended the spring starter based on successful cold weather operation in the Antarctic. To aid in cold weather starting, a heavy duty starting fluid system (ether) kit was also installed on each engine. This type of system proved successful for the Arctic ADAPTS pumping system modifications, and should (according to Deutz) permit starting at -40° C. Deutz engines have in the past been modified for Canadian service with a cooling air intake louver to provide faster warmup; however, this modification was not made on the present pump engines (it was on the air compressors).

b. Indicators and shutdown. Mechanical instruments were installed on all engines to avoid any electrical devices. Because five diesels are utilized in the primary system, it was also felt that an automatic engine shutdown system should be employed so that constant monitoring of the gauges was not necessary. Therefore, an Amot Emergency Shutdown System was installed on each engine. This device will close off the fuel supply in the event of high head temperature or low oil pressure (or high outlet air temperature in case of the compressor engines). The system is completely mechanical, and utilizes engine lube oil as a control fluid. The engine must be warmed up so that the oil is of sufficiently low viscosity before the shutdown system can be assured of operating at -40^{o} C (a bypass is provided for startup). Special low-temperature lubricants must be utilized in the engine to minimize starting difficulties and maintain lower viscosities during warmup in Arctic conditions.

c. Hazardous atmospheres. In addition to eliminating all electrical components, a spark arrestor was added to the exhaust system of all diesels. If "dieseling" occurs while operating in a flammable atmosphere (engine running on only the flammable air mixture), a cover or rag can be placed over the air intake to shut off the engine.

d. Other cold temperature aids. The Gates rubber belts used on the engines (and compressors) are claimed to be suitable to -40^{o} C, but lower temperatures can cause cracking. (Special low temperature belts can be obtained, but only in quantity orders.) Arctic-grade diesel fuel should also be used.

3.2.7 Pilot Gas System

The pilot gas system consists of a supply of liquid propane, a vaporizer for use in cold weather, and an igniter unit for the pilots.

The Zink pilot units are designed for 2,400,000 Btu/hr of propane burning equivalent, which translates to 120 lb/hr of propane consumption at a pressure of approximately 15 psig. Actual consumption can be less than this depending on the ease of maintaining combustion of the flaring oil (a pressure of 5 psig was successfully used in burning No. 2 fuel oil). Because resupply of propane may be more difficult than that of diesel oil, as much propane as possible must be supplied in a 3,000-pound module.

The propane cylinder module contains seven DOT-4BW240 steel cylinders, each having a 200-pound (propane) capacity. These are the largest capacity cylinders that will comply with shipping requirements. Each cylinder weighs 167 pounds empty; therefore, seven filled to maximum propane capacity weigh 2,569 pounds. With the skid and framework, a nitrogen cylinder (discussed later), and manifolds, regulator and valves, the module weighs less than 3,000 pounds. The total propane content is, therefore, 1,400 pounds, enough for almost 12 hours continuous usage. At least one other cylinder module should be available for resupply from a bulk propane tank to permit continuous operations (not provided with the prototype system). The skid and framework is similar in design to the air compressor skids. The cylinders are securely fastened to the skid, but could be easily removable for individual filling, if necessary. Figure 12 shows the cylinder module.

The propane vapor must be regulated at approximately 5 to 15 psig for pilot gas use. The natural vapor pressure of the propane is normally sufficient to provide this pressure. However, in Arctic conditions the pressure may have to be artifically boosted. This will be accomplished by pumping with an inert gas (nitrogen) blanket over the liquid in the tank and taking off a liquid propane stream. A specification DOT-3AA2265 125-SCF nitrogen cylinder and regulator is included with the module, which will provide

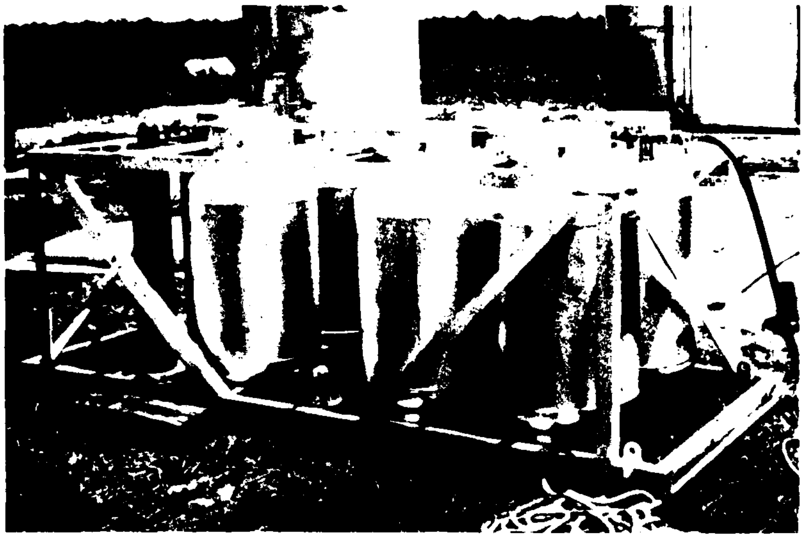


FIGURE 12. PROPANE TANK MODULE

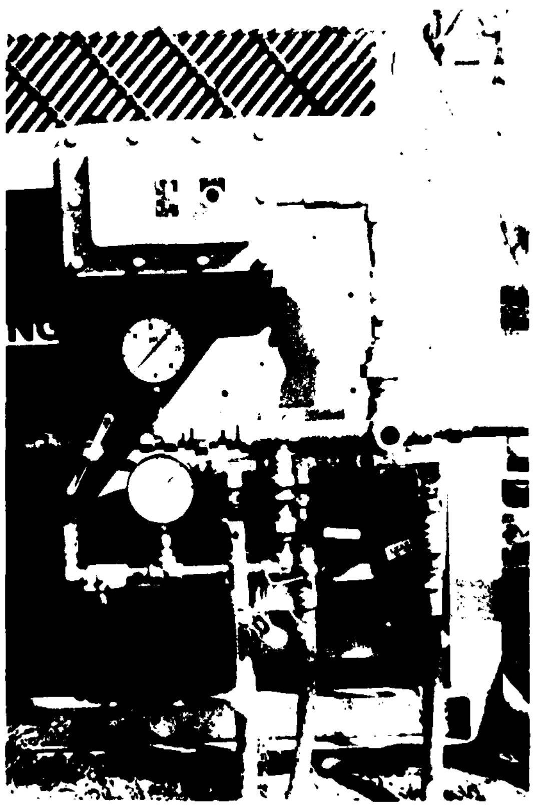


FIGURE 13. FLAME FRONT GENERATOR (FFG) PANEL

enough inert gas to force out all of the liquid propane at a 15-psig pressure. The liquid drawoff is provided by a dip tube in each cylinder, and the nitrogen is supplied through the vapor withdrawal connection. In more temperate conditions a vapor drawoff can be used, and the nitrogen cylinder disconnected. However, if the vapor withdrawal rate exceeds the natural vaporization rate inside the tank, the pressure will drop and the nitrogen cylinder should be reconnected.

In liquid drawoff conditions, a means of vaporizing the liquid propane is required. This is provided by a Thermax exhaust superheater, which is a coil-type heat exchanger utilizing diesel exhaust as the heating medium. This system also includes a mechanically-actuated temperature control system to ensure that the vapor is superheated sufficiently to eliminate any possibility of propane liquid breakthrough. The oil pump engine exhaust is used for the heat source, and the vaporizer and controls are mounted on this module. The vaporizer can be seen above the engine in Figure 10.

To ignite all 12 main pilots simultaneously, an "ignition runner" is utilized. This device is essentially a small propane burner that provides a continuous ring of flame from a perforated pipe, which intercepts all of the pilot flames (see Figure 4). The ignition runner itself, which is only used for pilot ignition and then turned off, has to be ignited independently.

To ignite the ignition runner, a flame-front generator (FFG) is used. This apparatus provides a flammable mixture (propane/air) into a 1-inch pipe leading to the ignition runner, and then ignites the remote end of the pipe mixture with a manually-actuated electrical sparker. The flame front then travels to the open end of the pipe to light the ignition runner. This operation is repeated as necessary until the ignition runner lights (usually only once if the air and propane pressures are set properly). The electrical sparker is enclosed in an explosion-proof housing, with primary power supplied by a rechargeable 6-volt battery. The module is mounted on AC-2 near the base of the boom (Figure 13).

3.2.8 Hoses and Tankage

Oil can be provided to the oil pump from several sources, including an ADAPTS pump, Dracone barge, trash pumps, steel barge, or portable tank. For all cases except the trash pump, a 25-foot suction hose is connected from the source (adaptors may be needed) to a 4-inch single-basket strainer provided with the system, while another 25-foot hose connects the strainer to the pump inlet. (The two 25-foot water suction hoses are identical to the oil suction hoses, and various combinations of lengths can be used.) The strainer is a 4-inch Hayward Model 72, which has a pressure drop of 0.4 inch Hg at 90 gpm of 1,000-cs oil (7/64-inch openings), and 1.1 inch Hg at 180 gpm of 10-cs oil (80 mesh openings). The two sizes of mesh openings were recommended by the pump manufacturer. Hose pressure drops for 50-feet are approximately 10 inches Hg and 1 inch Hg for the two viscosity cases, respectively. The actual suction lift capability, therefore, could be on the order of 9 feet. (Higher lifts could be obtained with only 25 feet of hose.)

For the trash pump case, temporary storage in the form of two 6,000-gallon pillow tanks is provided. Trash pumps could be anything from centrifugal pumps to diaphragm pumps, and would unlikely be suitable for pumping directly into the high pressure oil pump suction. During operation, one pillow tank can be filled from the trash pump(s) while the contents of the other is being flared. The 4-inch basket strainer is used to filter the flow into the pillow tank, utilizing the higher head available from a pump discharge. Therefore, the feed to the high pressure pump needs no further filtering. Each tank contains a fill/empty, vent, and drain connection. Kamlok fittings are used on the fill connections. The drain can be used for separating out free water. The tank material (reinforced polyurethane) is suitable for -40° C temperatures, and each tank is supplied with a separate ground cloth (Figure 14).

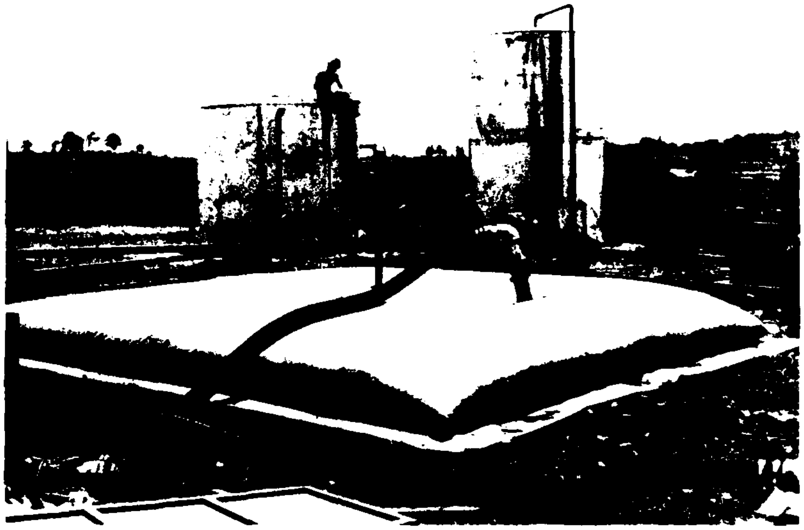


FIGURE 14. PILLOW TANK PARTIALLY FILLED

The 4-inch oil discharge hose was constructed with a new super-strength polyester cord which gives it a 1,700-psig burst strength at a weight of only 2.68 pound/foot. Two 50-foot lengths are provided, with grooved ends for connecting with Victaulic couplings. The water discharge hoses are similar to the ADAPTS hose construction, and two 50-foot lengths of these hoses are provided also with Victaulic connections. All of the propane hoses are rubber except the short lengths near the burner and the FFG hose at the boom base.

3.2.9 Transport Packaging

The major components are designed to fit into the allowable space in a C-130 aircraft without exceeding the envelope dimensions prescribed in the contract. The C-130 layout is also adequate for truck transport on a standard 40-foot flatbed. The system loaded for truck transport is shown in Figure 15.

To secure the system for C-130 transport, all components are secured to two 20-foot long Brooks and Perkins Airdrop Modular Platforms, Type II. These platforms (referred to as the pallets) are comprised of five panels, each 48 x 108 x 2-5/8-inch in size, assembled by using special aluminum side extrusions that attach to the Dash 4-A rail system installed in Coast Guard C-130's. Each panel is of bonded sandwich construction, with a balsa core and aluminum top and bottom surfaces.

The component skids are all designed so that they can be strapped or shackled onto the pallets. Components that must be stacked are bolted together so that all restraint loads are ultimately transfered to the pallet. The USAF safety-of-flight minimums for airdrop restraint were used in the design, which provides for restraint factors of 4.0 g forward, 2.0 g aft, 1.5 g sideways, 2.0 g up, and 5.1 g down. The system consists of ten helicopter-deliverable modules, including the boom package and two skids of small and loose equipment. The term "small and loose equipment" loosely refers to the fuel drums, strainer, pillow tanks, hoses, adapters, boom cables and fittings, etc. The two skids for these parts (one of which is the winch skid) are similar to the other component skids

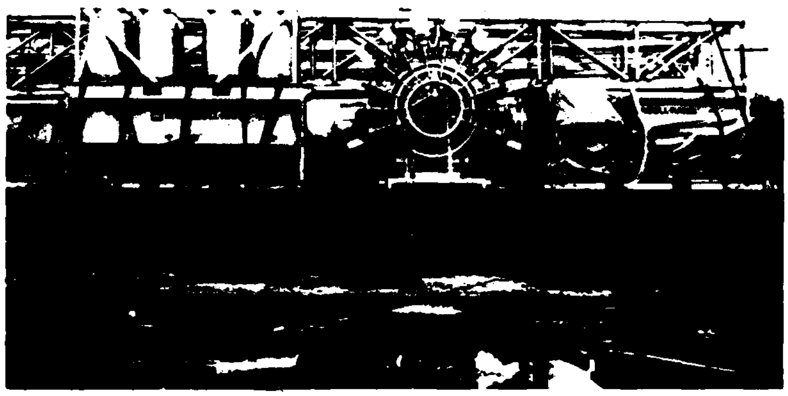


FIGURE 15. SYSTEM ON 40-FOOT FLATBED TRUCK

with regard to forklift and helicopter transport features. Equipment is secured to the skids with straps and brackets which are appropriate to satisfy the minimum restraint criteria.

The boom is constructed in two sections, so that the base section can be nested inside the upper section for transport. The A-frame legs are also included in the boom shipping package, and are stored inside the nested pieces. The boom rests on, and is secured to, two of the compressor frames for shipping. Because the boom spans two pallets, only a single point of attachment on each pallet is made. To load a plane, the boom must already be secured to the compressors, so the two pallets must be joined together with a flexible connection. This will help to avoid damage to the boom that could be caused by displacing one pallet significantly from the other. Roller pipes are needed under the pallets on the truck bed while the pallets are being transferred to or from the plane. Each pallet can be crane lifted to load the truck, and then the boom can be attached to the compressors after both pallets are aboard.

All components were weighed at the conclusion of the prototype test program, using a Dillon Dynamometer. All of the items shipped in the compressor tool compartments (hoses, rigging, other gear) would have to be shipped on other skids to reduce the compressor weights to the 3,000-pound maximum for helicopter transport. The overall weight is slightly in excess of the 25,000 pound design goal. Table 1 lists the component weights.

3.2.10 Oil Heating Subsystem

A conceptual design for an oil heating subsystem was developed during the project, although the system was not constructed. This subsystem was designed to be used as an auxiliary means of heating oils that are too viscous to be handled by the primary flaring system. As stated previously, this subsystem would not be part of the primary package, and, therefore, it would be treated as a separate planeload for shipping purposes. Figure 16 shows the schematic of the system.

TABLE 1. PROTOTYPE SYSTEM WEIGHTS

	Weight, lbs
Burner on skid, with tool box (200 lbs) mounted for shipping	2,300
Air compressor AC-1 with approximately half-full fuel tank and with extra gear loaded into tool compartments (weight without extra gear 3,030 lbs)	3,250
Air compressor AC-2 (as above)	3,200
Air compressor AC-3 (as above)	3,300
Oil pump module	2,000
Water pump module	2,140
Propane module (approximately 2/3 full of propane)	2,600
Boom, A-frame legs, insulated hoses, etc.	3,000
Winch skid with pillow tanks, strainer FFG, second tool box, etc.	1,730
Skid with 4-inch system hoses	500
Pallets (2)	1,500
TOTAL	25,520

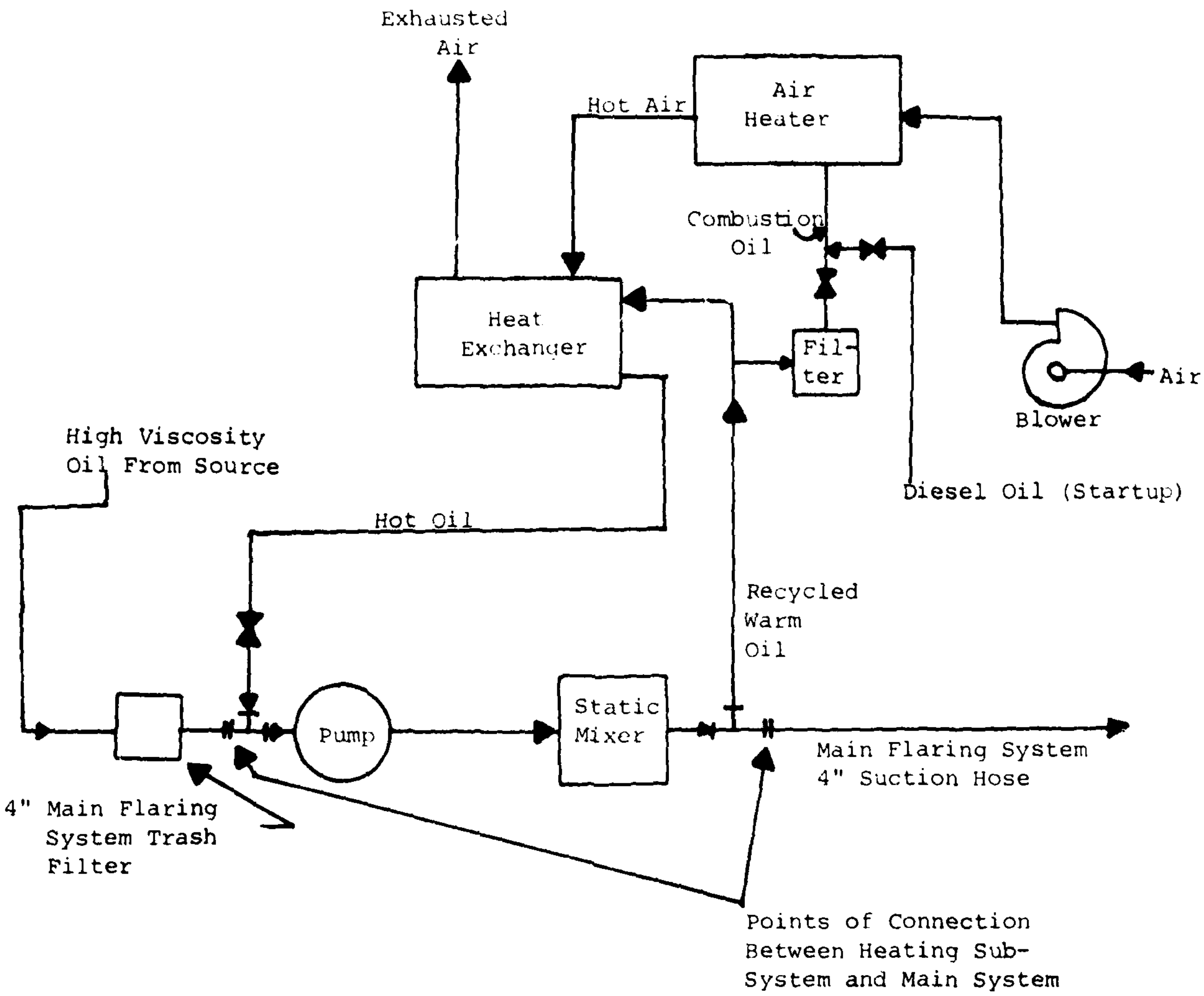


FIGURE 16. OIL HEATING SUBSYSTEM SCHEMATIC

To heat recovered oil, a recycle stream of the oil is pumped through a heat exchanger, where it is heated to the degree required to provide enough heat to reduce the viscosity of the inlet oil to approximately 200 centistokes (cs). The hot oil is combined with the inlet oil and pumped through a static mixer (no moving parts). The mixed stream, of the desired viscosity, is then pumped to the main oil pump to be flared. The recycle stream, made up of the volume of oil pumped by the heater subsystem pump above that required by the flare, is processed as above. A side stream of oil in the recycle stream is filtered and burned to heat air, the heating fluid in the heat exchanger. (However, the unit must be started up on diesel fuel.)

The primary service of the system would be to heat oil of up to 20,000 cs to a viscosity of 200 cs, at a design flow rate of 90 gpm. However, lower viscosity oils could also be heated to improve their combustion characteristics (less smoke or fallout) and/or to burn them at higher rates (up to 180 gpm). This subsystem would be provided in three modules, each of which weighs less than 3,000 pounds. The equipment was sized to handle a heating requirement of 1,600,000 Btu/hour.

3.3 OPERATION

The operation of the system is straight-forward, once the equipment is properly set up. Complete system setup is not described in detail here, although many of the assembly features and potential problem areas have already been discussed in previous sections. Once the boom system is assembled and erected, the other components (pumps, compressors, propane tanks, etc.) are merely connected together with the proper hoses.

The location for setup is important, as sources of oil and spray water must be close at hand. Also, the burner must be oriented downwind and away from materials or terrain features that are sensitive to heat radiation and possible oil fallout. A horizontal level area is desirable for easy setup. For land setup, a firm soil or sand is necessary to support the A-frame legs and ground anchors. Where the pillow tanks are laid out, the ground should be cleared of sticks and stones, and a shallow trench should be scraped out for the drain hose.

Once the equipment is set up and connected together, the first step is to light the pilots. The propane supply is regulated at 15 - 20 psig and the valve to the ignition runner is opened. The FFG air and propane supply pressures are set at approximately 5 and 10 psig respectively, and the ignition button on the FFG is pushed. When the ignition runner ignites, an orange ring of flame will be visible on the burner. The FFG gas supplies can then be shut off. When the main pilot valve is opened, the main pilots will light. The ignition runner valve can then be shut off, and the main pilot pressure adjusted downward.

All of the air compressor output is directed into the air line. The oil pump is started and put into the correct gear (second gear for C-nozzles or third gear for A-nozzles), and the clutch is engaged to start the oil flow. The water flow is started about the same time (make sure the pump is primed before starting the oil flow, to ensure that smoke suppression and shield water is available when needed). The water pump can be started before the oil, if desired. Keep the flame oriented generally downwind by adjusting the burner reins. Adjust the oil and water valves as necessary to optimize performance (keep air operating at full rate). When temporarily shutting down to change oil sources (if necessary), only the oil need be shut off, and the pilots, air, and water can be kept running. The flame stabilizes rapidly, and therefore can be shut on and off whenever desired without loss of performance.

Optimum smoke suppression water flow is approximately 1.5 gallons per gallon of oil. Too much water may tend to quench the flame and cause oil droplet fallout, and too little water will permit excess smoke generation. Shield water should be kept on full. Although there is no flow meter on the water pump, a correlation between smoke suppression water flow (with shield spray running simultaneously) and water pump discharge pressure was prepared during the prototype test program.

If too much smoke is being generated using the A-nozzles (180-gpm flow rate), change to the C-nozzles and burn at a lower rate (higher pressure drop and higher atomizing air-to-oil ratio will maximize performance). The atomizer nozzles can be changed out with wrenches while the boom is lying on the ground or deck. If emulsion or weathered oil is being burned, maintain a high pilot gas pressure (10 - 20 psig); if a light oil or crude is being burned a lower pilot pressure can be used to conserve propane. Because of the flame separation, crosslighting is not likely to occur if one of the burners goes out. If a burner does go out or burn poorly, nozzle plugging may be the cause. In this case, the nozzle must be disassembled and cleaned. Both the oil and air orifices should be checked. To prevent plugging, the proper filters must be installed, and care must be taken when setting up the system to avoid getting debris into the lines and hoses.

4. DESIGN CONSIDERATIONS LEADING TO PROTOTYPE DEVELOPMENT

Development of the prototype flaring system design involved the following four phases:

- Burner Evaluation - Study Phase
- Preliminary Burner Testing
- System Design Studies and Tradeoffs
- Establishment of Final Design Basis

The first phase was performed with the aid of flaring experts from the John Zink Company, and an independent consultant with considerable experience and expertise in offshore oil flaring systems. The second phase was conducted by the John Zink Company at a special test site located on their property near Tulsa, Oklahoma. Based on the results of these first two phases, Seaward International performed the last two phases and established the detailed system design.

4.1 BURNER EVALUATION - STUDY PHASE

The object of this phase was to determine the most suitable burner for the system, so that this key component could be tested for performance, and the utility requirements determined. Selection of the burner required consideration of several of the Coast Guard's original design goals. In general, the object was to achieve as much burning rate capability as possible within the constraints of system weight. It was important, therefore, to consider tradeoffs in the objectives to achieve the best all-around performance potential.

The original design goals that had the most tangible impact on the burner selection were in the areas of disposal rates and oil types, and system transportability. A summary of the most significant goals is given in Table 2.

TABLE 2. SIGNIFICANT COAST GUARD DESIGN GOALS

1. Capable of flaring light crude and refined products at rates up to 500 gallons of oil/minute.

2. Capable of flaring residual oils, heavy weathered oils, and tank bottoms at rates up to 250 gallons/ minute.

3. Capable of handling oils and emulsions with viscosities that range from 30 to 1,000 centistokes without the need for a fuel heating subsystem.

4. Capable of handling residual oils and weathered crudes that range from 1,000 to 20,000 centistokes with the use of a heater subsystem.

5. Capable of handling water-in-oil emulsions in which the water content can reach 50% of the fluid volume.

6. Capable of disposal of weathered oil or tank bottoms in which the water content in a non-emulsified state approaches 30%.

7. Capable of being deployed from central storage to staging area with either a C-130 aircraft or on a single 40' standard highway flatbed trailer.

   7.1 The total system weight limit is 25,000 lbs.

   7.2 The maximum shipping volume is: 7'10" wide
8' 6" high
40' long

8. Modularized for deployment from the staging area to spill cleanup site by Coast Guard HH-3F helicopter, forklift, or buoy tender.

   8.1 The maximum module weight for Coast Guard HH3F helicopter external sling delivery is 3,000 pounds.

9. Capable of operating at maximum design flaring rate for eight hours without shutdown for routine service or refueling of the power pack. (Affects fuel supply volume/weight.)

The approach chosen for selecting the burner to be used in the system included a quasi-quantitative appraisal of certain burner features with respect to the goals, and an appraisal of various intangible factors such as the potential for manufacturer support, the likelihood of success in achieving the design goals, and flexibility in adopting the system to various operational situations. Most burners on the market were designed for crude oil burning in oil well production testing facilities; none were designed specifically for the unique conditions in which the Coast Guard was interested. Therefore, even the quantitative aspects of the evaluation process were subject to considerable subjectivity.

Commercially available burners from five different companies were considered in the evaluation process, plus a special design for spilled oil disposal developed by the John Zink Company. Although most manufacturers appeared to have burning rate data and utility requirements for the flaring of low-viscosity crude oil, the evaluation team was not confident in extrapolating this data to the more significant (from an oil spill standpoint) higher viscosity cases. To hopefully increase the confidence level, questionnaires on burner performance were prepared and sent to the appropriate manufacturers or to representatives who were considered knowledgeable of specific burners. Although most questionnaires were answered indicating the ability to burn viscous oil at high rates, in no case was sufficient evidence offered to substantiate the claims.

Based on the information received from the questionnaires, utility rates for each burner (air and water rate and pressure, and oil pressure) were estimated for an assumed viscous oil burning rate, and a weight estimate for the system was prepared. The weight estimates for the pumping systems and compressors were based on correlations of weight versus horsepower data obtained through an extensive review of manufacturer's component literature. (Oil heating subsystems were not included in the system weights in order to permit the maximum amount of essential equipment in the basic system packages.) If a 25,000-pound weight estimate did not result for a particular burner system at the assumed burning rate, a revised burning rate was projected for the burner, such that the revised utility requirements would result in a system that would weigh an estimated 25,000-pounds.

Based on the estimated burning rates for 25,000-pound systems, and considering the goals and intangible factors outlined, the project team decided to pursue the John Zink Company design. This design offered several advantages:

1. The design was more specific for the relatively "dead" light and heavy oils and oil-water mixtures likely to be encountered.

2. An extensive background in designing all types of burners for a wide range of conditions was present in the John Zink Company.

3. Because the test site was only a short distance from Zink's manufacturing facilities, modifications and repairs to the burner could be accomplished quickly by qualified personnel.

4. Reasonable burning rates (although not up to the original Coast Guard goals) could be expected for a wide variety of waste oil types and viscosities.

4.2 PRELIMINARY BURNER TESTING

The John Zink Company of Tulsa, Oklahoma, was subcontracted to secure a test site, procure and install all of the test equipment and burner, and conduct testing on the burner that was to be selected by the project team. A site was selected at a remote location on the John Zink Foundation Ranch, approximately 25 miles from Zink's manufacturing plant and headquarters in Tulsa. After selection of the burner, the site was developed and outfitted with all of the facilities necessary to test the Zink burner. These facilities included storage tanks for two different oils, an oil blending tank, a pond-water tank (for smoke suppression water spray), a pilot gas (LPG) tank, diesel driven oil and water spray pumps, an air compressor, and the necessary valves and piping. A schematic layout of the test setup is shown in Figure 17. Figure 18 shows a photograph of the test setup taken from the burner stand, and Figure 19 shows the test burner on the 15-foot high test stand. The boiler and its feed water tank were for steam heating and cleaning purposes, but were not needed during the tests. The water pump that is directed into the oil pump suction line was for sparging water into the line to simulate water-in-oil emulsions.

The test burner was the actual OWB-12 prototype system burner, with the following exceptions:

1. Only ten of the twelve nozzle assemblies (atomizer, pilot, and spray nozzle set) were installed.
2. Flexible joints and metal hoses were used in certain places to allow for adjustments to be readily made during testing. Many of these were later replaced with rigid connections.
3. No ignitor system (ignition runner and FFG) were installed, as the pilots could be manually ignited from the stand.
4. The inlet piping was slightly different.

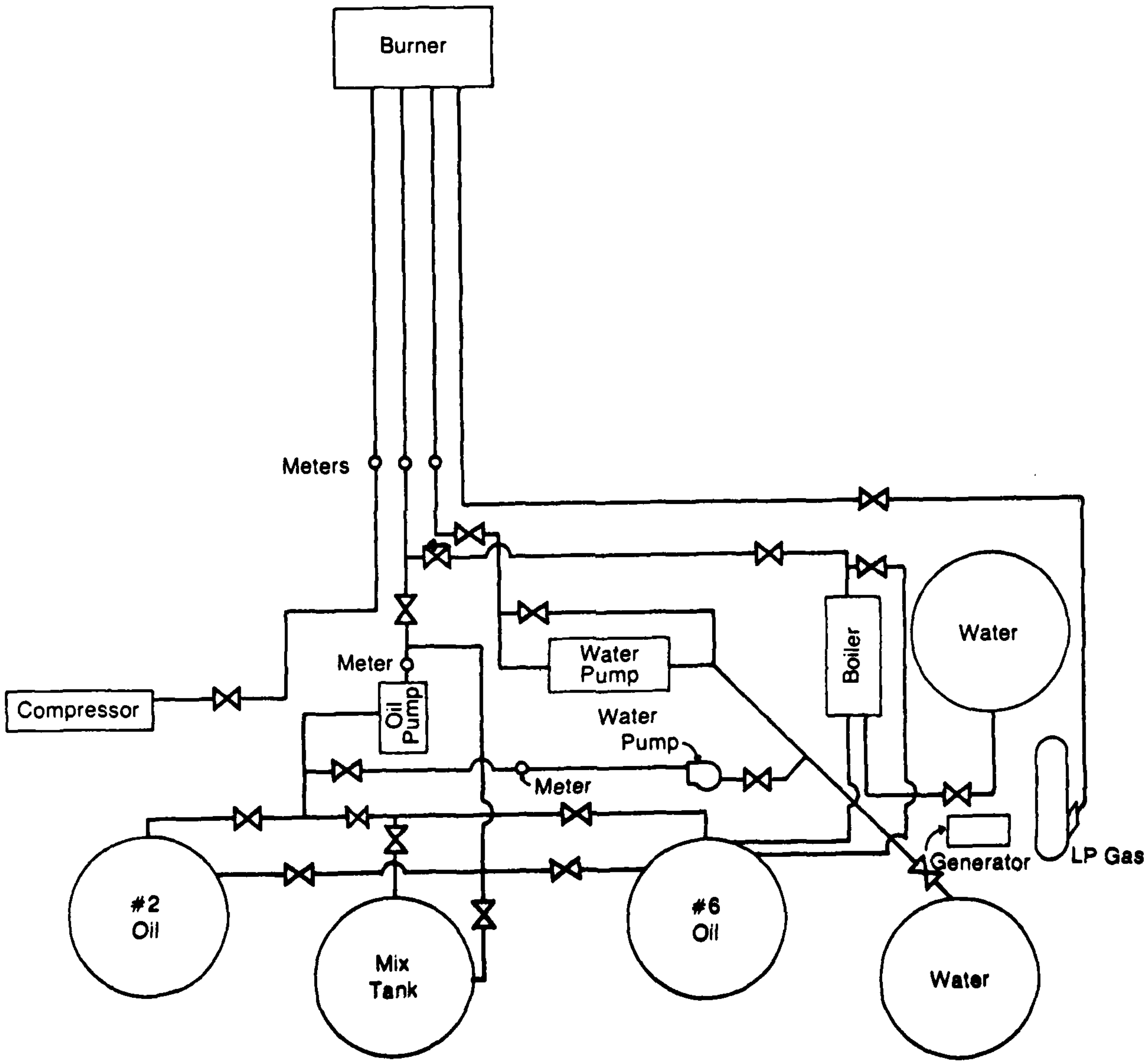


FIGURE 17. PRELIMINARY BURNER TEST SETUP SCHEMATIC

FIGURE 18. TEST SETUP VIEWED FROM BURNER STAND

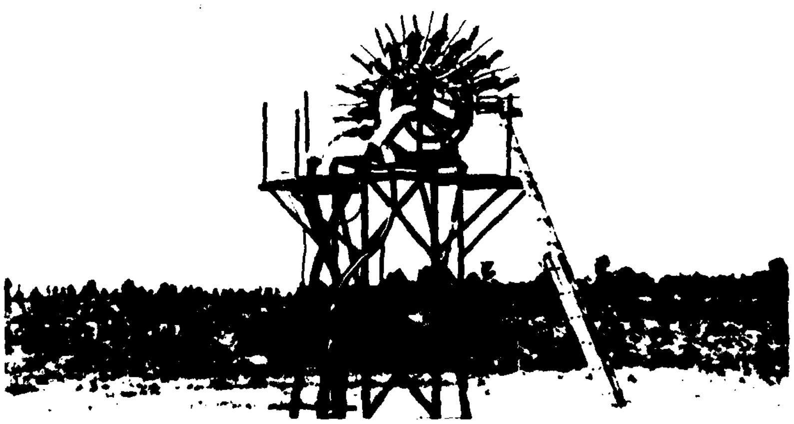


FIGURE 19. TEST BURNER

Because of oil pump limitations many tests were performed with six nozzle assemblies blanked off, leaving only four for testing. With light oil, this was the only way to achieve the maximum flow rate per nozzle. However, because of the good flame separation between nozzles, the results were felt to be directly extrapolatable to 10 or 12 nozzles.

Table 3 presents a general matrix of the types of tests conducted. Different oil viscosities were prepared by blending No. 2 fuel oil with No. 6 fuel oil (except as indicated). These oils are fairly indicative of the rather "dead" oils (minimum volatiles for a given viscosity) that could be encountered in oil spill cleanup work.

The major independent variables were the oil flow rate and pressure, atomizing air flow rate and pressure, water spray rate and pressure, nozzle sizes, and oil or oil/water mixture type and viscosity. Wind speed and direction and ambient temperature were secondary variables in the performance. Dependent variables were somewhat subjective in nature, including smoke generation (as quantified by the Ringleman scale for intensity), degree of unburned oil fallout, thermal radiation intensity, and noise intensity. Each of these dependent variables is discussed in terms of the independent variables in the following discussions of the test results.

4.2.1 Smoke: General criteria established early in the program were that a smoke intensity of Ringleman 1 or 2 could be tolerable in many cases, but that the intensity should not exceed Ringleman 3 (R3). At R3 the smoke billows out fairly black and dense; at R1 the smoke is more gray colored, fairly easy to see through, and dissipates rapidly. (R0 is smokeless.)

Proper atomization is the prime means of controlling smoke generation. Where the air-to-oil flow ratio and oil and air pressure drops were high, smoke generation was reduced. At a rate of 6 gpm/tip or less for 6-cs oil through the C-nozzle very little (less than R1) smoke was produced, with no water spray added. The smaller flame envelope at these

TABLE 3. MAXIMUM OIL FLOW RATES (GPM PER TIP) TESTED

Oil Viscosity, cs[1]	NOZZLE TYPES [2] "A"	"B"	"C"
6 (#2 fuel oil)	15		6
19	16		
35	15	15	
215	15		7.5
225	15		
347			7.5
535			9
644			7.5
733			7.3
1413 (#6 fuel oil)			11
1600 (#6 fuel oil)			8
approx. 10 (crude)	9.5		
50% water in 6 cs oil	15		
30% water in crude oil	11		

(1) Determined with a Brookfield viscometer and specific gravity information, at storage temperature.

(2) "A" - drilled for high oil flow and high air flow

"B" - drilled for high oil flow and low air flow

"C" - drilled for low oil flow at high oil pressure drop, and high air flow rates, and consequently better exposure to combustion air, may also have had a positive effect.

At higher viscosities, atomization to a small enough droplet size is more difficult to achieve, and more smoke was generally produced. However, surprisingly little smoke was generated at viscosities of 500 - 600 cs using the C-nozzles and high oil pressure (approximately R1 level) with no water addition. Even pure No. 6 oil (1400 - 1600 cs) burned with comparatively little smoke (in the R1 to R2 range); fallout was appreciable however (Figure 20). Fairly high winds (15 - 25 knots) may have helped reduce smoke in the No. 6 oil tests.

The addition of water spray, which enters into the combustion process, generally helped suppress the smoke, although at viscosities exceeding 35 cs the effect was less noticeable, and was almost non-existant at oil viscosities over 200 cs. With 6-cs oil and water spray, essentially smokeless burning could be achieved at 15 gpm/tip (Figure 21). Water-in-oil mixtures (50 percent No. 2 fuel oil) also burned smokeless without any water spray addition. Oil-water mixtures with more viscous oils could not be tested because of pumping problems.

4.2.2 Droplet Fallout: Ideally, no droplet fallout should occur, as this represents unburned oil that may not be recoverable, and that may be an undersirable contaminant. However, situations may occur where some fallout is acceptable, such as where the land or water downwind of the burner is already contaminated with spilled oil.

Estimating the quantity of oil droplet fallout is difficult because of the effect of varying wind strength and direction on any measuring scheme. One attempt involved collecting a pattern of droplets on an absorbent material during a known time duration, and then counting the droplets per unit area. For a run with 347-cs oil (C-nozzles), such an estimate indicated less than one percent fallout. On this run fallout was considered light, based on visual estimates by Zink experts.

FIGURE 20. NO. 6 OIL, 1400 - 1600 CS

FIGURE 21. NO. 2 OIL, 15 GPM PER TIP WITH WATER SPRAY

High ratios of atomizing air to oil, and high oil pressure drops (C-nozzles), were useful in reducing apparent fallout. With lower viscosity oils under good atomizing conditions, fallout did not occur. However, with higher viscosities the amount of fallout appeared to increase as viscosity increased. Fallout from pure No. 6 oil (1400 to 1600 cs) was considered heavy.

Water spray did not appear to affect fallout appreciably, although it may have had a quenching effect on the flame at higher viscosities, thus contributing to increased fallout. However, water spray was generally not used at viscosities exceeding 300 cs.

Wind probably had an impact on fallout, also. To some point, increasing wind velocity helps the combustion process and probably reduces fallout. However, at higher velocities, the cooling and dissipative effects of the wind become more dominant, and fallout probably increases. The actual effect in these tests was not known.

4.2.3 Thermal Radiation: Maximum thermal radiation was measured at 1150 Btu/ft^2-hr using a Land Pyrometer 100 feet behind the burner while burning 110 gpm of No. 2 fuel oil through ten nozzles. Other data indicated that when the smoke suppression spray water was turned on (there was no shield spray system installed), the radiation was reduced by approximately 60 percent. Rough tests on the effect of an independent radiation-suppression (shield) water spray indicated that the radiation could probably be cut by 60 percent more if such a spray system were installed. Radiation levels perpendicular to the burner axis were slightly lower than at the same distance directly behind. An aluminum plate equipped with a thermocouple was placed on the burner close to the flame. The maximum recorded temperatures at the 110 gpm burning rate were 124° C without the smoke-suppression spray, and 95° C with the spray.

4.2.4 Noise: A burner noise level of 86 dbA was recorded 100 feet behind the burner at the 110 gpm burning rate, exclusive of background machinery noise. A B&K Noisemeter was used.

4.2.5 Conclusions: The following conclusions were drawn from the testing:

1. The burner is capable of performance levels at least equivalent to the following:

   a. Smokeless burning of light oil at a design rate of 180 gpm (with water spray addition).

   b. Burning of 200-cs fuel oils with acceptable smoke and low droplet fallout at rates up to 90 gpm.

   c. Burning of 1,600-cs fuel oil with smoke and droplet fallout levels that may be acceptable under certain circumstances. This viscosity is in excess of the Coast Guard design objective.

   d. Smokeless burning of low-viscosity water-in-oil emulsions.

   e. Nearly smokeless burning of light oils at reduced rates with no water spray addition.

2. Although the burner is designed to fire downwind and achieves its best performance in this condition, it can tolerate reasonably large variations in wind direction.

3. Water spray eliminates smoke when lower viscosity oils are burned. However, as oil viscosity increases, the water spray has less effect on smoke suppression.

4. Air consumption should be kept at a high level for the optimum burning of a wide range of oil viscosities.

5. Tolerable levels of noise are generated by the burner.

6. Thermal radiation can probably be reduced to tolerable levels 100 feet behind the burner at maximum burning rates through the use of a water spray system.

4.3 DESIGN STUDIES AND TRADEOFFS

At the conclusion of the test program, sufficient data and experiences had been accumulated to define the utility requirements (air, water, pilot gas, and oil pressure and flow rate) and size the supporting equipment. Several tradeoff studies were required, however, particularly in the design of the boom and support structure, and in the packaging arrangement. Some of the more significant areas of each are discussed briefly below.

a. The requirement for being able to erect the system with the burner out over the end of an anchored or stranded barge restricted the system architecture. A simple erection procedure requiring no cranes or forklifts for lifting was a design objective. Designs such as a post-with-boom, cantilevered boom or telescoping boom turned out to be too heavy or complicated. To minimize the weight, the selected design utilized a boom structure in which the weight of boom and burner was carried by cables connected to the top of the two pivoting A-frame legs. With this approach, the burner weight and restraining force at the foot of the boom cause no significant bending stresses in the boom (the boom is loaded essentially in straight compression), and component weight is minimized. Utilizing the weight of the components (air compressors) to counteract the weight of the boom also minimizes system weight.

b. The module weight limit of 3,000 pounds and the system weight limit of 25,000 pounds indicated a need for light-weight construction. Aluminum, magnesium, titanium, fiber composite and high strength steel were considered. Of these, aluminum appeared to have the best combination of properties, including strength, weight, corrosion resistance and cost. All aluminum parts were fabricated from 6061-T6 alloy.

c. The large amount of thermal radiation from the flame required consideration for the protection of the operator and the equipment. Several schemes were considered, including heat shields, high temperature materials, insulation, and water spray. High temperature materials were ruled out as being too costly and/or heavy. Insulation was used on the burner rubber hoses, and the need for a heat shielding over the aluminum structure under the boom was determined during the prototype tests. Heat shield screens in front of some of the equipment items proved useful during the early burner tests, but were of marginal value during the prototype tests. Water spray appeared to be the best overall approach to radiation control based on the early boom tests, but how to implement it remained a design problem. Although a fan spray pattern immediately behind the burner would be most effective, it was felt that the spray might adversely effect the burning performance. The location mid-way up the boom was finally selected, but further work is required to optimize the spray pattern. The effect of sea water spray on the boom also needs investigation into the corrosion characteristics.

d. The C-130 packaging arrangement was one of principal constraints on the physical dimensions of the components. The 40-foot length dimension required that the boom be constructed in sections. Because of the space occupied by the other components, particularly the air compressors and the propane tanks, the boom sections had to be telescoped or nested together. This required considerable design effort to incorporate all of the necessary structural and functional elements in the boom, while maintaining sufficient clearances to permit a close nesting of the upper and lower sections. Also, the design of the A-frame legs had to consider packaging inside the nested boom sections; several alternative designs were considered before selecting the spreader approach.

4.4 FINAL DESIGN BASIS

Based on the foregoing studies and testing, a final design basis was established and a system specification was prepared. The principal design features of the primary system design basis are summarized below.

Burner performance:

Oil Type	Viscosity Centistokes	Burning Rate, gpm	Smoke Generation, Ringleman Numbers	Droplet Fallout
No. 2 Fuel Oil or Light Crude	5 - 10	180	0[1]	None
Fuel Oil	35	90	< R1[1]	None
Fuel Oil	200	90	< R2	Little
Fuel Oil	700	90	< R3	Approx. 1%
No. 6 Fuel Oil	1,000	90	R3	Heavy
50% No. 2 Fuel Oil, 50% Water	5 - 10	180	0	None

(1) With water spray addition.

Burner capable of being oriented ± 30° to the boom axis; remote ignition capability with flame front generator and ignition runner.

Boom: 78 feet long; 48 inches square at upper end and 32 inches square at the lower end; constructed in two nesting sections which are joined together with pipe flanges; boom self-erecting with weight supported by an A-frame; boom inclination 30° to ground level.

Oil Pump: Capacity 180 gpm of low viscosity oil at 430 psig (45.2 output hp), and 90 gpm of 1,000 cs oil at 640 psig (33.6 output hp); high suction lift capability; diesel engine drive with clutch and transmission; capable of taking suction from a variety of sources.

Water Pump: Capacity for 270 gpm smoke suppression water (1.5 gallons of water per gallon of oil) and 270 gpm of radiation suppression spray water (based on a Zink suggestion) at 500 feet head; high suction lift capability; fresh or sea water capability; diesel engine drive with clutch.

Air Compressors: 750 scfm total capacity (in three compressors) at 100 - 110 psig discharge pressure; 120 psig idle pressure; diesel engine drive.

Engine Drives: Diesel engines equipped with non-electrical components (starters, instruments, generators), cold temperature (-40° C) startup and operation; spark arrestors; air-cooled; common parts interchangability for ease of repair; automatic shutdown capability upon high head temperature or low oil pressure.

Pilot Gas System: Liquid propane pilot gas supply for at least 12 hours continuous use (2.4 million Btu/hr consumption); containers suitable for air transport (49 CFR and AFR 71-4); pumping and vaporization capability for -40° C operation; regulation capability of 5 to 15 psig.

Packaging: Complete system capable of transport in a single C-130 cargo aircraft and also a 40-foot flatbed truck; no individual component to exceed 3,000 pounds for HH-3 helicopter transport.

Other: Provides 6,000 to 12,000 gallons of temporary oil storage; diesel fuel for a minimum of 8 hours operation at capacity, to be included in packaging; capable of setup and deployment with aid of only forklift or helicopter on land or a vessel; system must be simple and reliable; capable of operation in Sea State 3 and of survival (secured) in Sea State 5.

These and other features of the design basis were used in conducting the detailed design and component fabrication phases of the project. Individual modules were tested for functionality and interferences before conducting the prototype system performance tests.

5. SYSTEM PERFORMANCE TESTS

The prototype system performance tests were conducted at the John Zink Company test site during June, 1981. Prior to conducting the tests, the system was loaded on its aircraft shipping pallets and shipped to the site on a commercial 40-foot flatbed truck. The only incidents occurring during the 1,100-mile trip were that some of the bolts loosened, and some fraying of the 6,000-pound cargo tiedown straps occurred at the corners of the equipment. These problems were fixed on the return trip at the conclusion of the testing.

The system was assembled by four members of the Seaward Project Team, with some assistance from Zink personnel (forklifting, hauling). The system layout is shown in Figure 22, along with the Zink supporting equipment (oil and water supply tanks, blending pumps, and piping). The only tie-ins to the existing Zink facilities were at the oil and water supply connections.

5.1 TEST MATRIX AND PROCEDURES

The test plan called for running the tests outlined in Table 4. The actual tests conducted are also shown in this table.

The procedure for conducting each test involved lighting the pilots, opening the correct valves to the oil feed tank, and turning on the air compressors, oil pump and water pump. The desired oil flow rate was established using the flow meter on the oil pump discharge. Oil pressure was not permitted to exceed 700 psig for safety reasons. The water pressure was adjusted to give a suitable flow rate for minimizing smoke generation. When high water rates were being utilized, the pond water supply pump was also turned on to keep the water feed tank full. After stabilization of the flame (up to two minutes were required to purge the previous oil from the lines), Zink personnel recorded the performance data.

FIGURE 22. PROTOTYPE SYSTEM TEST SETUP, BOOM LYING DOWN

TABLE 4. PROTOTYPE TEST MATRIX

NO.	PLANNED TEST	ACTUAL TEST	COMMENTS
1	No. 2 Fuel Oil	No. 2 Diesel Oil	A-nozzles, 10 min
2	20 cs Blend	19.5 cs Blend	A-nozzles, then change to C-nozzles, 10 min each
3	50 cs Blend	47 cs Blend 59.5 cs Blend	A-nozzles, 10 min C-nozzles, 10 min
4	100 cs Blend	111 cs Blend	C-nozzles, 10 min
5	200 cs Blend	195 cs Blend	C-nozzles, 10 min
6	400 cs Blend	350 cs Blend	C-nozzles, 10 min
7	800 cs Blend	867 cs Blend	C-nozzles, 10 min
8	No. 6 Fuel Oil	Not Run	-
9	No. 2 Fuel Oil	No. 2 Diesel Oil	C-nozzles, to find smokeless rate with no water spray
10	No. 2 Fuel Oil	No. 2 Diesel Oil	30 min endurance burn, A-nozzles
11	30 - 40% W/O Emulsion at 200 cs	40% W/O Emulsion, 200 cs	C-nozzles (no burning)
12	30 - 40% W/O Emulsion at 800 cs	30% W/O Emulsion at 350 cs	C-nozzles
13	50% Water Sparged into No. 2 Fuel Oil	40 - 50% Water Sparged into No. 2 Diesel Oil	A-nozzles, 10 min
14	30% Water Sparged into 200 cs Oil	30% Water Sparged into 111 cs Oil	C-nozzles

The tests were conducted for the approximate times indicated in Table 4. Usually the oil flow rate was initiated at a lower rate, and then brought up in steps. Water spray was adjusted accordingly, although some variation was allowed at a given oil rate to observe the effect of more or less smoke suppression water. The atomizing air flow was always kept at the maximum rate attainable at the existing engine speed.

The test oils were prepared as in the preliminary burner test program, using blends of No. 2 diesel oil and No. 6 fuel oil. Mixing was performed using Zink's oil feed pump.

The 40-percent water-in-oil (W/O) emulsion was prepared according to the emulsifier manufacturer's directions (ICI Americas, Inc.), using Span 80 as the emulsifier. A quantity of emulsifier equal to two percent of the water phase volume was first mixed with the oil (a blend of No. 2 and No. 6 oils). Water was slowly added to the oil through the sparger in the Zink pump suction line as the mixture was circulated through the mix tank. The emulsion formed by this procedure was very stable, and increased the viscosity by a factor of four over the oil phase alone. A 30-percent W/O emulsion was later prepared by adding more No. 6 oil to the existing emulsion, to increase the viscosity and decrease the water content. It is not known if the emulsions prepared by these procedures represent naturally occurring W/O emulsions.

5.2 TEST RESULTS

This section discusses some of the general features of the system performance, as determined from the test results. The discussion centers on the dependent variables of smoke generation, droplet fallout, thermal radiation and noise.

5.2.1 Smoke: With No. 2 diesel oil and the larger A-nozzles, smokeless burning occurred at oil flow rates up to 140 to 150 gpm. A water spray rate of approximately 210 gpm was required. At 175 to 180 gpm of oil the flame was a little smokey, even with the same ratio of spray water to oil as at the lower rate (Figure 23). In both of these cases, the total air flow was approximately 850 scfm, representing the maximum compressor speed attainable. At a 750-scfm air rate, the flame appeared to produce more smoke, thus demonstrating the need to maintain maximum atomizing air rates. With the small C-nozzles, relatively smokeless burning was achieved at a rate of 50 gpm with no water spray addition.

With a 19.5-cs oil blend and the A-nozzles, the flame was fairly smokey even at 120 gpm; oil pressure was only 240 psig, and the lower (750 scfm) air rate was being used. With the smaller C-nozzles the same oil burned with very little smoke; these nozzles burned 90 gpm at a 700-psig pressure and a 750-scfm air rate. This performance appears to demonstrate the value of a higher oil pressure drop through the nozzles and a high atomizing air-to-oil ratio. However, because the A-nozzles were not tested at 90 gpm of oil, the true effect of a high pressure drop, unmasked by the beneficial effect of a high air-to-oil ratio, was not ascertained.

Similar effects were observed for a 50-cs oil, where considerable smoke was generated using the A-nozzles. With the C-nozzles, reducing the rate from 90 gpm to 60 gpm produced less smoke.

When the water spray rate was varied, a high rate tended to produce a yellowish, gray-white smoke that probably contained some fallout; a low rate tended to produce a blacker smoke. In cases where smoke cannot be avoided, the water rate should be set at approximately 1.5 times the oil rate and then varied above and below this rate until the best appearing smoke is produced.

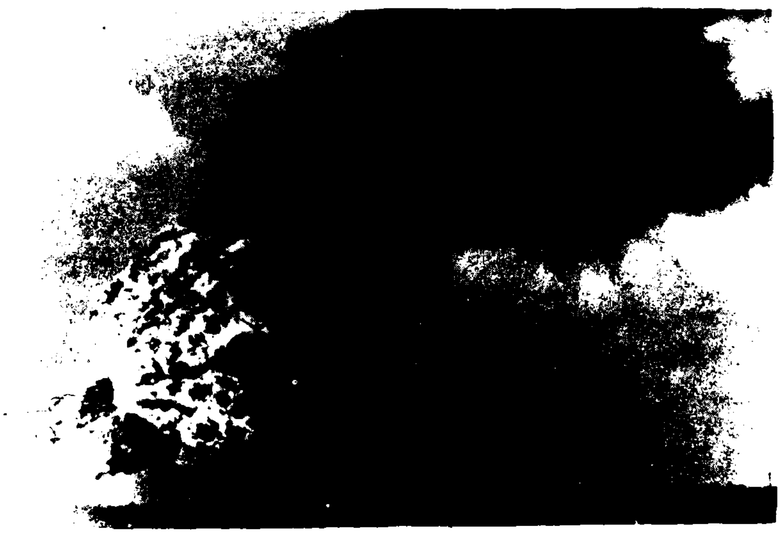


FIGURE 23. NO. 2 DIESEL AT 175 GPM

With higher viscosities (111 to 870 cs) smoke was always produced (C-nozzles only were used), but the smoke was usually white to gray and no higher than Ringleman 3 in intensity. (See Figure 24 for 60 gpm of 195-cs oil with R2 smoke, and Figure 25 for 90 gpm of 867-cs oil with R3 smoke.) The wind was a variable that could not be controlled and no doubt had some effect on the amount and quality of the smoke produced.

When water was sparged into the No. 2 oil stream, little smoke was produced. However, pumping was somewhat erratic, possibly because slugs of water may have been present in the stream. When water was sparged into 111-cs oil, the pump flow and pressure dropped off, and the flame was extinquished when free water reached the nozzles (C-nozzles in use). Evaluation of smoke production was difficult in this case. The results of these sparging tests, to simulate the burning of "tank bottoms," lead to the conclusion that normal burning is possible until a slug of water extinguishes the flow. A strong pilot gas flow will ensure relighting when sufficient free oil is again present.

With emulsions, smoke was generally produced when burning was taking place. However, only the 30-percent emulsion burned with any consistancy, and a strong pilot flame was required to maintain combustion. Twardus (5) discusses the problems of burning emulsions in more detail (albeit in an in-situ condition, i.e., as a slick), and notes that relatively high preheat and ignition times (seconds to minutes) are required for burning certain viscous crude oil W/O emulsions. The heating apparently breaks (separates) the emulsion locally, and therefore permits burning of a relatively water-free oil phase. Such conditions are difficult to achieve in an air-atomizing flaring burner where "preheat" and ignition times are extremely short. As stated previously it is not known whether or not the emulsions prepared for these tests represent naturally occurring emulsions.

FIGURE 24. 195-CS OIL AT 60 GPM

FIGURE 25. 867-CS OIL AT 90 GPM

5.2.2 Droplet Fallout: No attempt was made to measure fallout directly because of the problems observed during the preliminary burner testing. Where high atomizing pressures and high air-to-oil ratios were utilized (C-nozzles with 850 scfm air flow) fallout appeared to be minor, even with oil viscosities up to 870 cs. The water spray systems (smoke suppression and shield) contributed to the difficulty in observing oil droplet fallout. Smoke suppression water was used in nearly every test, even with viscous oils, to take advantage of its thermal-radiation suppression characteristics in order to keep the aluminum structure cool.

In cases where too much water was sprayed into the flame (well in excess of 1.5 gallons of water per gallon of oil) the fallout appeared to increase, although whether this appearance was due to quenched oil or to unvaporized water droplets could not be determined. With free water injection (siumulated tank bottoms) considerable fallout occurred whenever excess water in the oil stream quenched the flame. With emulsions, considerable fallout occurred whenever burning became erratic; at times none of the mixture was ignitied and effectively all of the material was fallout. Fallout sometimes existed when a particular oil nozzle had a malfunction (air, oil, or pilot plugging), but this was an uncommon occurrence. With pure No. 2 oil no fallout was evident under any burning conditions other than a tank bottom simulation where a slug of water broke through.

5.2.3 Thermal Radiation: The most important locations from a heat effect standpoint are at the base of the boom, where operator attention is occasionally required, and on the aluminum boom structure in the vicinity of the burner. Radiation data were taken using a Land Pyrometer.

The maximum radiation level at the base of the boom was measured at 1,080 Btu/hr·ft^2 while burr ng 180 gpm of oil, with both the smoke suppression and shield sprays operating. This is on the order of three times higher than would have been predicted based on the preliminary burner test program. However, the shield spray pattern was not as effective as desired, and the observed radiation actually represents the level expected from the effect of the smoke suppression spray only. This level is within the maximum allowable thermal radiation of 1,500 Btu/hr·ft^2 to which fully clothed workers (long sleeves, gloves, hard hats) can normally be exposed. An improved shield spray pattern could possibly lower the radiation level further.

Some of the radiation data was taken at a point 50 feet to one side of the burner. Because the burner was approximately 40 feet above ground level, the radiation intensity on the ground immediately below the burner could be on the order of 2.5 times the data values. Thus, for 90 gpm of 19.5 cs oil (C-nozzles) the radiation level could be over 3,000 Btu/hr·ft^2 on the ground below the burner.

The radiation on the aluminum structure raised the skin temperature at a single point immediately under the burner to a maximum temperature of 192° C, and had the potential of significantly weakening the aluminum. Higher wind velocities tended to limit the maximum temperature on the structure, but it was felt that a more positive control was needed. Direct water spray on the structure would have helped, but additional complexity would have been introduced if this feature had been added. A temporary shroud over the aluminum (under the burner) proved to be an effective heat shield, limiting the temperature to 104° C, and will be incorporated into the design. This shroud can be seen in Figure 3.

5.2.4 Noise: The maximum noise level was measured at approximately 96 dbA, although the location for this measurement was not identified. The average dbA measurement for all runs was 87. The compressors were designed to meet all EPA noise emission standards. A B&K Noisemeter was utilized.

5.3 TEST CONCLUSIONS

As a result of the prototype test program, several conclusions concerning the system could be reached. These are summarized below.

a. Burner performance is generally as good as or better than that demonstrated during the preliminary burner-only testing.

b. Design rates of 180 gpm of light oil and 90 gpm of heavy oil are achievable.

c. Some smoke is nearly always present, except when burning light oil, but the intensity is usually in the R1 to R2 range and not more than R3 when burning oils up to 870 cs viscosity.

d. Very little oil fallout occurs when the proper nozzles are installed (essentially none with light oils), up to the maximum tested viscosity of 870 cs.

e. Radiation and noise are acceptable.

f. Stable W/O emulsions of over 30-percent water content may be difficult to ignite and burn. A strong pilot flame is required.

g. Tank bottoms can generally be burned if the oil is light and if the flame is not extinquished. With viscous oils, pumping a two-phase mixture (not emulsified) can be erratic and cause surging, disrupting or extinguishing the flame.

h. Component and sub-system designs are adequate, with only minor modifications considered necessary to improve operability and setup.

6. SYSTEM PERFORMANCE SUMMARY

The expected system performance described in this section is based on the results observed during both the preliminary burner tests and the prototype system performance tests. Also incorporated is a certain amount of estimation, as not all combinations of variables could be tested, and certain environmental factors, such as wind velocity and ambient temperature can be significant and could not be controlled. Factors such as smoke generation and fallout could only be evaluated subjectively during the tests, and it was apparent that opinions among experts varied as to the quality of smoke generation. However, the information herein should serve as a guide for setting the equipment variables, and should provide a rough idea of the expected results.

6.1 OBJECTIVES:

The principal objective of a flaring operation could be one or more of the following:

- Maximize Burning Rate
- Minimize Smoke Production
- Minimize Oil Droplet Fallout

In the usual event that all of these objectives are important, compromises will have to be made.

6.2 INDEPENDENT VARIABLES:

The principal independent variables that should be determined or estimated prior to selecting the initial equipment settings are the following:

- Oil or mixture viscosity to within ± 50% (from actual measurement, or based on viscosity/temperature relationships for a known oil type)

- Water content of water-in-oil (W/O) emulsion (burning may be difficult with over 30% water in the emulsion)

- Quantity or rate that must be flared

6.3 DEPENDENT VARIABLES:

The dependent variables (equipment settings) must be determined keeping in mind the objectives and the values of the independent variables. The principal variables are listed below.

- Nozzle type (either large bore/capacity A-nozzles or small bore/capacity C-nozzles)

- Oil flow rate, as determined by engine speed and transmission gear ratio (3rd gear for A-nozzles and 2nd gear for C-nozzles -- do not exceed 700 psig pump discharge pressure)

- Smoke suppression water spray rate (determined from water pressure)

Note that the air flow rate is always kept at maximum rate (850 scfm).

Pilot gas pressure does not affect burning performance, although it should be maintained at a sufficient pressure to ensure quick relight in case a flame is extinguished; with low viscosity oils the pressure can be maintained at 5 to 10 psig, and with high viscosity oils (over 200 cs) the pressure should be 10 to 15 psig, and possibly as high as 20 psig with emulsions that prove difficult to burn.

Water for smoke suppression should generally be maintained at a ratio of 1.5 gallons of water per gallon of oil to minimize smoke generation. However, at oil viscosities in excess of 200 to 300 cs, water does not appear to have a significant effect on smoke reduction; maintaining smoke suppression water flow does reduce thermal radiation, however, and should therefore be maintained at the 1.5:1 ratio in all circumstances. If no water is available, the oil flaring rate may have to be limited to 40 to 60 gpm to keep working conditions tolerable. The physiological effect of radiation is, however, dependent on ambient temperature (at low temperatures more radiation is tolerable) and wind velocities, so that operator discretion must be used in this case.

Figures 26 and 27, based on data taken during the system performance tests, can be used to set the water rate. If the smoke suppression water is controlled by throttling the butterfly valve at the base of the boom, the curve labled "Smoke Suppression Nozzles Only" (Figure 26) can be used to obtain the approximate pressure (ordinate) at the boom base for the desired flow rate. However, a pressure gauge must be installed in the line to do this. If the rate is to be controlled from the pump (by adjusting the engine speed with all valves wide open), the curve in Figure 27 can be used. However, the shield water spray rate also varies when controlling the flow by the engine speed; therefore, Figure 26 may provide the most versatile control approach (pump running full speed to maintain high shield rate while smoke suppression water is throttled back to maintain a 1.5:1 water-in-oil ratio).

6.4 PERFORMANCE EXPECTATIONS

Table 5 presents a summary of the recommended equipment settings for various oil types, as a function of the particular objectives of the operator. Maximum rates for the A and C-nozzles are approximately 180

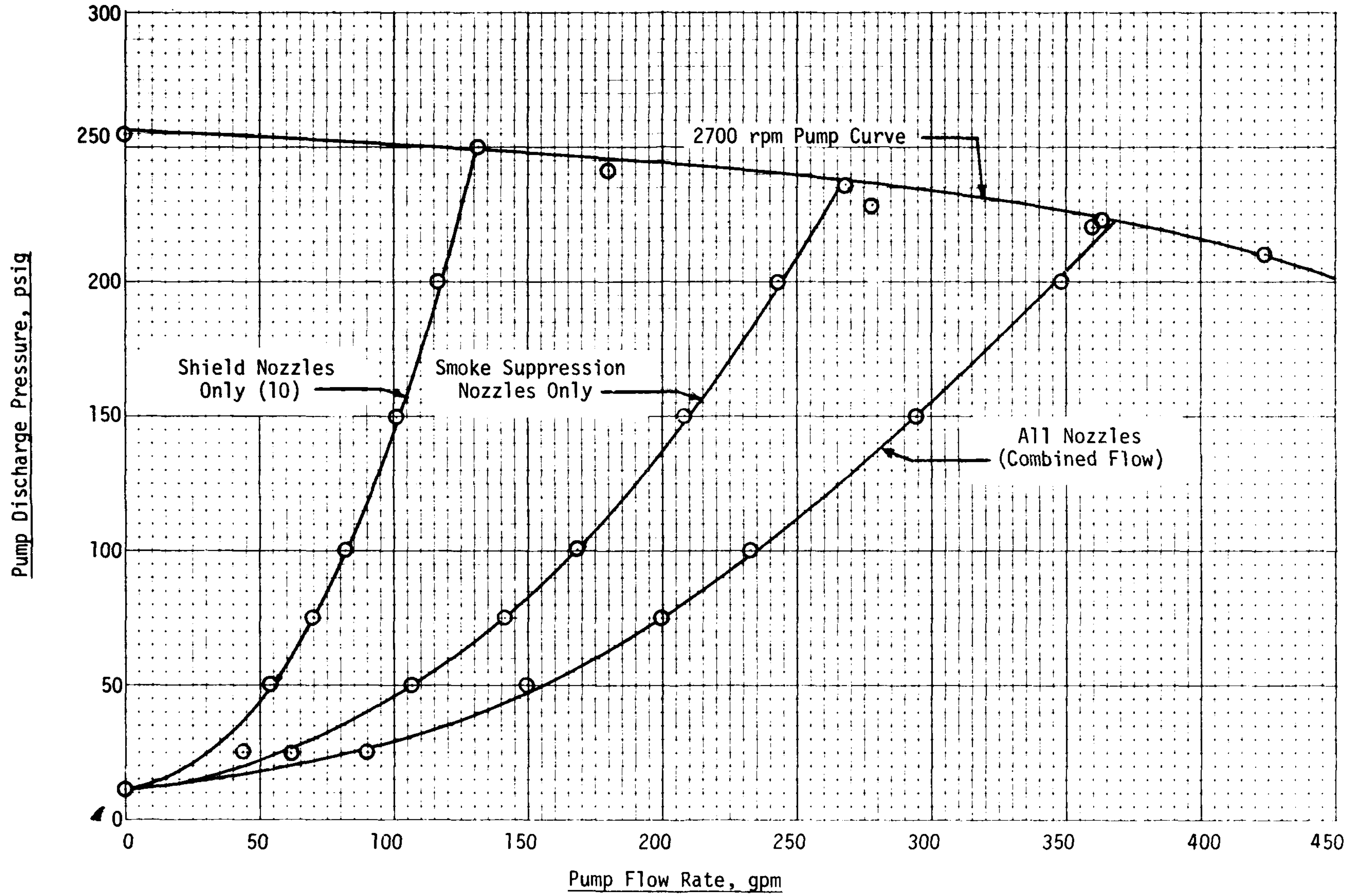


FIGURE 26. WATER PUMP PERFORMANCE

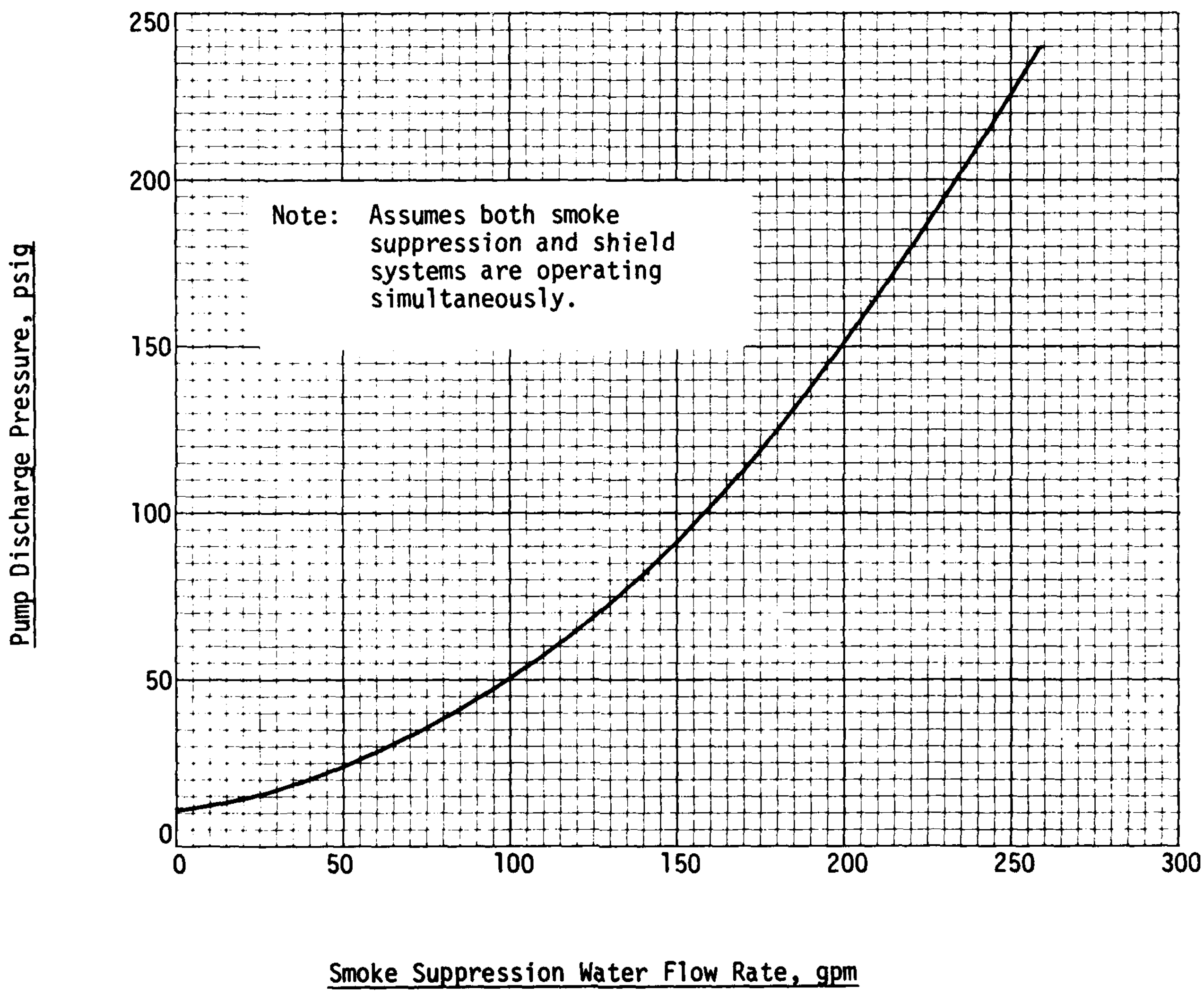


FIGURE 27. SMOKE SUPPRESSION FLOW RATE DURING COMBINED-FLOW WATER PUMP OPERATION

TABLE 5. PERFORMANCE EXPECTATIONS

Fluid Type	Maximize Flaring Rate	Minimize Smoke	Minimize Fallout
Up to approximately 50cs (230 ssu) oil, oil-water mixtures (free water), or low water content emulsions.	A-nozzles, and maximum pump rate.	A-nozzle, and reduced rate to eliminate smoke (1.5:1 water: oil); if flow of 90 gpm doesn't reduce smoke sufficiently switch to C-nozzles and adjust rate.	A-nozzle and maximum pump rate probably okay. If flow rate of 90 gpm or less required (for smoke suppression) switch to C-nozzles.
Approximately 50 to 200cs (925ssu) oil or low water content emulsions (not free water mixtures).	A-nozzles and high pump rate if fallout or smoke not important.	C-nozzles, and possibly reduced (<90 gpm) pump rate (1.5:1 water:oil); gray/white rapidly dissipating smoke probably the best that can be accomplished.	C-nozzles with close to highest flow rate probably best. Nil fallout can probably be attained.
Approximately 200 to 800cs (3700ssu) oil or low water content emulsions.	C-nozzles and high pump rate.	C-nozzles and reduced flow rate (water not critical). Gray to dark, fairly rapidly dissipating smoke expected.	C-nozzles with fairly high flow rate. Some fall-out can be expected, although less than 1%.
Approximately 800 to 1600cs (7400ssu) oil or low water content emulsion.	C-nozzles and maximum pump rate (do not exceed 700 psig).	C-nozzles and reduced flow rate, although differences due to flow rate hard to distinguish. Fairly dark to heavy smoke can be expected (water not critical).	C-nozzles with fairly high flow rate. Fallout may be heavy. Smoking (white) droplets can be observed in flame.
Fluids Over 1600cs	Heating recommended to reduce viscosity (Note: Heating of any emulsion may also enhance its burning performance.)		

gpm and 90 gpm, respectively. In general, better atomizing, and therefore lower smoke and fallout production, will be obtained with the C-nozzles because of their higher oil pressure drop. For most cases of spilled and somewhat weathered oil (viscosity over 50 cs) the C-nozzles will probably give the best all around performance.

7. CONCLUSIONS

The following general conclusions were reached as a result of this program.

1. High volume flaring of viscous oils (up to 1,600 cs) and emulsions (up to 30 percent water) has been proven feasible.

2. It is possible to burn low viscosity oils (light fuel oil, crude oil) with no smoke production, by spraying water into the flame. However, water spray does not eliminate smoke at higher viscosities.

3. Disposal rates of up to 180 gpm can be achieved depending on oil viscosity and the allowable smoke and fallout production.

4. The highest practical flaring rate commensurate with operator safety (from thermal radiation) in a confined area (barge deck) was achieved.

5. A flaring system that will meet Coast Guard goals for transportability and deployment flexibility (land, waterborne and arctic environments) was developed.

8. RECOMMENDATIONS

The following recommendations are made for further development of the system.

1. The cold temperature features of the system should be tested in a simulated or actual low temperature environment.

2. Setup of the system on the deck of a barge should be undertaken to determine any undiscovered handling or operational problems.

3. The system should be loaded on a C-130 and handled by HH-3 helicopter (individual modules only) to determine any problem areas in these transport modes.

4. Burning of actual W/O emulsions, which are produced under natural environmental conditions, should be undertaken to further define operation limits.

5. The effect of sea water on the water spray system should be tested.

6. Development of small systems should be considered to simplify logistics for smaller cleanup operations.

9. REFERENCES

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APPENDIX A

INITIAL TRAINING PROGRAM RESULTS

Introduction

This a summary of the training exercise performed during the period of October 4-7, 1982, at the facilities of Crowley Environmental Systems Corp., in Amchorage, Alaska. The objective of the training program was to acquaint Coast Guard and various oil spill cooperative personnel with the set-up and use of the flaring burner, which is presently on loan to the Arctic Beaufort Sea Oilspill Response Body (ABSORB) for evalution. The program was attended by people from four organizations: ABSORB (three people), Crowley (three people), Alaska Offshore (two people), and the U.S. Coast Guard (two people from the MSO in Anchorage and one from the Pacific Strike Team). R.L. Beach and W.T. Lewis from Seaward International were the instructors.

The results of the training program contained in this appendix were submitted to the U.S. Coast Guard by Seaward International, Inc. Included in this appendix are the training program schedule, new information acquired and anticipated problems and recommendations for future users (specifically ABSORB during the two-year trial period). Copies of the entire training report are available through the Coast Guard Office of Research and Development.

Training Program

Day 1: The morning session was spent in the classroom going over the setup and operation of the system. The two movies made of the prototype tests in Tulsa were shown, as well as slides describing the various items of equipment. Handouts were given out to everyone in attendance. These handouts, which were taken from the Operations Manual, showed the material presented in the slides, and listed the step-by-step setup and operation instructions. It was pointed out that the handout material was also covered in the Operational Manual, two copies of which were left with ABSORB.

After lunch, we began moving the equipment from the shipping pallets to the assembly area in the Crowley warehouse parking lot, using an off-the-road forklift. The equipment had been inspected by Seaward personnel on the previous Saturday, and, except for a missing regulator adjustment screw, a spark arrestor for the oil pump engine, and some nuts and bolts, the system appeared to be in excellent shape considering the duration of the trip to Alaska. By the end of the day, most of the equipment had been positioned for assembly.

Day 2: Following the step-by-step setup instructions, the system was assembled to the point where the boom was raised and pinned in place. No problems were encountered except when attempting to implant the ground anchors. The parking lot was originally constructed of rock fill covered over with earth. The surface was well packed and easy to maneuver the equipment on, but in attempting to drive ground anchors the rock fill was encountered, and the anchors would not penetrate. In fact, two anchors were broken and the effort was abandoned. The critical anchor point for the alignment cable (behind the tripod) was provided by a road grader, which was driven into position when needed to erect the boom. Anchor points for the sway cables were provided by the oil and water pumps, which were positioned as necessary to secure the cables. Compressor AC-1 was anchored by tying it to compressor AC-3, which had been moved close to the winch skid.

Day 3: The final hookup of the equipment was made, and the equipment was started up and operated as much as possible. All of the hoses were connected up, except for the oil and water suction and discharge hoses, which ABSORB felt was not necessary for their understanding. Also, the pillow tanks were not assembled. ABSORB felt that they would probably utilize their own pillow tanks (heavy-duty Goodyear types) if they were ever needed. All of the engines were started (except the water pump engine), although no liquids were pumped (ABSORB had trouble getting a tank truck of water, and no oil was available). ABSORB did get propane put into the tanks, and the pilot system was operated. Also, all of the compressor outputs were manifolded together and air was blown through the burner nozzles.

After operating the equipment, the boom was taken down and disassembly was started. By the end of the day, all of the major components had been broken down into individual items ready for repacking. By this time, Mark Johnson of ABSORB had contacted the Coast Guard, and the decision was made not to assemble the system again. The consensus of the people involved in the assembly was that with the experience they had gained, the entire system could be set up in less than a day.

Day 4: A short classroom session was held in which the key maintenance points were covered. Additional handouts were given out.

Afterwards, the final packing was completed and the pallets and skids were loaded onto the 40-foot flatbed truck. This job was made more interesting by the five inches of snow that had fallen overnight, which had covered up various cables and small pieces that had not been packed the day before.

New Information Acquired

Several modifications to the equipment had been made before the system was shipped. The experience with each one of these modifications is described below.

1. Hydraulic Starting System: This system was a significant improvement for cold weather starting. When first tried on one of the compressors, we found that air had gotten into the engine fuel line, and several starting attempts (and a shot of ether) were required to get it going. Each starting attempt required several minutes of hand pumping to charge up the accumulator. However, once a compressor had been started, the air-powered hydraulic pump made short work of accumulator charging. The accumulator held its charge overnight so that a compressor could be started easily the next day. A slight loss of hydraulic oil from the quick disconnects occurs each time the hoses are connected to, or disconnected from, a starting motor.

2. Drain Plugs on Burner: No problems.

3. New Orifices in the Shield Spray (Water) Nozzles: These could not be evaluated because of the lack of water to pump through the system.

4. Pressure Gauges for Water Manifolds: Same comment as No. 3.

5. Oil Flow Meter Modifications: Could not be evaluated due to lack of oil.

6. Winch Control Modifications: The winch air inlet was modified to include a pressure regulator and a needle valve in series. To operate the winch, the control handle on the winch was held open manually (it has a spring return to the OFF position), and the air flow was controlled with needle valve only. This resulted in a very smooth startup of the winch under load, and eliminated the jerking start that was experienced in Tulsa.

7. Oil Pump Gearshift Template: Worked okay.

8. Anchoring Tools: The paving breaker worked fine for driving anchors, and it proved to be stronger than the anchors when encountering underground rocks.

9. Boom Front Support: The adjustable -height "stand" for the front of the boom proved adequate in supporting the weight of the burner. The skid base made take-off and landing very smooth.

10. Radiation Shield for the Burner: Aluminum radiation shields were bolted to the burner base to intercept radiation from the flame. Their effect could not be determined. Additional bracing at the corners should be incorporated.

The heat exchanger on the oil pump engine exhaust was used for the first time to heat propane. This was not done in Tulsa because of the high ambient temperatures. Although the pilot system operated satisfactorily with the propane being heated, the heater was not able to maintain the 100^{o} F propane temperature that it was supposed to. The main reason for this, of course, was that the engine was only idling, and was therefore not putting out much heat. A good test of the heater in cold weather conditions needs to be performed to insure that it will work properly when required. The nitrogen-pressurized liquid feed system was not tested.

Because the pilot system must be operating before oil is pumped to the burner, there may not be enough heat generated from the engine to provide an adequate supply of pilot gas, and therefore the system may have a hard time starting up. It may be necessary to add a recycling feature to the oil pump, so that the engine can be loaded up without pumping oil to the burner. This could involve adding a short bypass line between the pump discharge (upstream of the butterfly valve) and the pump suction, with a globe valve in the line to generate a back pressure. By recirculating oil before the pilot system is started, a sufficient amount of heat may be generated to vaporize the propane. Also, a lower control temperature setting than 100° F may be necessary to keep the temperature control valve open (the bypass valve must be open, otherwise). Alternatively, an external means of heating may be required (salamander-type heater). Once the flare is operating, radiant heat will help to warm up the system, especially if the equipment is located near the flame.

Anticipated Problems and Recommendations

This section describes some problem areas that may present themselves if the system is used by ABSORB in an actual operation. Recommendations for changes are described.

1. Propane Heating System: This was discussed earlier. More testing of the heating system is recommended.

2. Propane Supply Tanks: It is recommended that another tank module be supplied for the system, so that pilot gas can be resupplied without having to shut down the operation. The propane tanks cost around $175 each, plus the material and labor for the framework, manifolding, nitrogen cylinder and other fittings.

3. Braces for Radiation Shield: The corners of the radiation shield plates (below the burner) should be braced to prevent excessive movement in the wind. This would involve adding some small angle pieces to the corners.

4. Auto Jacks: These manually-operated screw jacks (for raising the hinged burner platform during assembly) could probably be replaced with air-operated jacks. A design would have to be worked out, however.

5. Spare Parts: Because this is a prototype system, a large quantity of spare parts was not provided. A list of spare parts was provided to ABSORB and the Coast Guard.

6. Tools: Installation crews should be fully equipped with wrenches, etc., in order to make assembly proceed smoother and faster.

7. Maintenance: ABSORB should develop and follow a maintenance schedule to periodically check and run all of the rotating equipment.

8. Operating Base: According to ABSORB, the system would probably be set up on a barge, as the tundra is too soft to support the equipment loads. Even normal operations on the North Slope are performed on filled areas, which could be impractical to construct specifically for a one-time flaring operation.

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