

**FINAL REPORT**

**DEMULSIFIERS AND MODIFIED  
HELI-TORCH FUELS TO ENHANCE  
IN-SITU BURNING OF EMULSIONS**

**by**

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**for**

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## EXECUTIVE SUMMARY

The onset of water-in-oil emulsion formation in an oil slick often signals the closing of the window of opportunity for in-situ burning as a countermeasure. Water contents in excess of 25% in a stable emulsion generally preclude ignition of the slick. A study of in-situ burning of water-in-oil emulsions formed by weathered Alaska North Slope (ANS) crude oil has recently been completed by Alaska Clean Seas. The study consisted of three phases: laboratory-scale burns in Ottawa in a 0.13 m<sup>2</sup> burn ring; small-scale burns in Prudhoe Bay in 1.2 m<sup>2</sup> and 3.3 m<sup>2</sup> pans; and, meso-scale burns in a 69 m<sup>2</sup> circle of 3M Fire Boom in a water-filled pit at Prudhoe Bay. The laboratory-scale tests showed that conventional gelled fuel igniters could ignite stable, weathered ANS crude emulsions up to a water content of 25%. The combination of adding an oilfield emulsion breaker, Petrolite EXO 0894, and the use of gelled crude oil as an alternative igniter fuel, permitted ignition and efficient combustion of highly weathered ANS emulsions with water contents of 65%, the maximum achievable. The small-scale pan tests conducted in Prudhoe Bay proved the same: that with the application of EXO 0894 one hour prior to ignition, normally unignitable emulsions of weathered ANS crude, up to 65% water content, could be successfully ignited and efficiently burned. These tests were conducted outdoors at 0° to 5°C in winds up to 32 km/hr. Tests with a Heli-torch suspended from a crane showed that a mixture of gelled gasoline and crude oil was the most effective igniter for the emulsions. Attempts were made to ignite emulsion slicks with gelled fuels containing the emulsion breaker, but this technique did not prove as effective as pre-mixing the breaker into the slick. The small-scale tests also indicated that the emulsion burns produced a lighter smoke than water-free crude oil. Three meso-scale experimental burns were carried out: one involved approximately 13 m<sup>3</sup> (80 bbl) of fresh ANS crude as a baseline; one used about 8 m<sup>3</sup> (50 bbl) of a stable 50% water-in-weathered crude emulsion; and, the final burn was done with 17 m<sup>3</sup> (105 bbl) of stable 60% water content emulsion. The oil removal efficiency for the fresh crude oil burn was approximately 98%. The oil removal efficiencies for the 50% and 60% water emulsions were 97% and 96% respectively.

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## **1.0 INTRODUCTION**

In recent years, the use of in-situ burning as an oil spill removal technique has been adapted from ice-infested waters to open-water conditions. This has presented several challenges, including how to quickly and effectively ignite and efficiently burn thin, mobile slicks that are significantly weathered. The development of fire resistant containment booms has resulted in technology to address the problems of oil spreading rapidly on open water to unignitable thicknesses and the collection and concentration of dispersed slicks of oil for efficient removal by burning. The discovery that the Heli-torch, a simple and effective forest firefighting tool, could ignite oil slicks using gelled gasoline permitted the stockpiling of an inexpensive, rapidly deployable, FAA-approved aerial ignition system for responding to open-water spills. Several offshore trials of in-situ burning using booms have demonstrated that the technique can successfully remove high percentages of the contained oil.

Considerable research effort in the lab and in the field has gone into documenting the airborne emissions from in-situ burning and its potential impacts on the water column. Many of these impacts have been quantified and computer models to predict the transport and deposition of combustion gases and soot have been developed.

One key problem that remains with in-situ burning of slicks on water is the formation of emulsions. The formation of highly stable water-in-oil (W/O) emulsions prevents ignition and burning of the oil. The presence of as little as 25% emulsified water in these oil slicks can preclude burning. Even if the W/O emulsion is less than fully stable and thus burnable, the occurrence of water in the oil significantly increases the heat required to ignite it.

The addition of chemical surfactants called emulsion breakers can enhance the burning of emulsions by causing them to break and separate into oil and water. Heat from the ignition source can assist this process.

## **1.1 OBJECTIVE**

The objective of this study was to research the in-situ ignition and burning of emulsions of Alaska North Slope crude using gelled fuel igniters and to prove the efficacy of using chemical emulsion breakers as ignition and burn promoters.

## **1.2 GOALS**

More specifically, this objective was met by carrying out three sequential series of tests: indoor laboratory tests in May 1994; burns in small pans in July 1994; and meso-scale burns in a water-filled pit in September 1994.

The goals of the laboratory test program were to investigate:

- \* the burning on water of Alaska North Slope (ANS) crude oil and emulsions;
- \* the capabilities and limitations of conventional Heli-torch fuels in igniting ANS water-in-oil emulsions;
- \* the effect of adding emulsion breaking chemicals, or demulsifiers, to enhance the ignition of ANS water-in-oil emulsions;
- \* the potential benefits to ignition of using alternative fuels with the Heli-torch; and
- \* the potential advantages and disadvantages of adding emulsion breaking chemicals directly to the Heli-torch fuel.

The goals of the subsequent pan burn tests were to:

- \* test the ability of the Heli-torch to use of alternative gelled fuel mixtures;
- \* determine the maximum ignitable water content of weathered ANS crude oil emulsions outdoors in Arctic summer conditions;
- \* determine the potential of emulsion breaker addition to enhance ANS crude emulsion ignition and burning on water; and
- \* determine the best method of applying the emulsion breaker to the slick for ignition.

And finally, the goals of the meso-scale burn tests were to:

- \* test the effectiveness of alternative igniter fuels, when applied by a Heli-torch carried beneath a helicopter;
- \* examine ignition of and flame spreading over large emulsion slicks treated with emulsion breakers; and
- \* determine the effects of increased scale on emulsion burning processes, rates and efficiencies.

### **1.3 CONCURRENT PROJECTS**

In conjunction with this research, two other projects were carried out concurrently to take advantage of the opportunities afforded by the meso-scale burns. The first was a smoke-plume model ground-truthing program carried out by the National Institute for Standards and Technology (NIST) and involving scientists from the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA). Atmospheric conditions were monitored for each meso-scale burn and smoke particulates were measured both in the plume near-source and at ground stations placed downwind of the burns. These data were used to validate models developed by NIST and NOAA. The NIST model output was recently incorporated into the In-Situ Burning Guidelines adopted by the Alaska Regional Response Team (ARRT). A report on the model ground-truthing program has been produced under separate cover (reference).

The second concurrent project involved the production of a public education video and pamphlet on in-situ burning. The purpose of this project was to disseminate unbiased information on the advantages and disadvantages and capabilities and limitations of in-situ burning as an oil spill response option. Copies of the public education video and written material may be obtained from Alaska Clean Seas.

### **1.4 REPORT CONTENTS**

Chapter 2 of this report presents the background to the study, information on Alaskan oils, a brief introduction to the use of in-situ burning in Alaska and the rationale for the project. Chapter 3 contains a summary of the principles of in-situ burning of oil on water and a review of the current state-of-knowledge on in-situ burning of emulsions.

Chapter 4 documents the equipment and techniques used in each of the three test series (laboratory, small-scale and meso-scale). Descriptions of oil weathering, emulsification, burn test and gelled fuel preparation procedures are included. Chapter 5 presents and discusses the results of each of the three test series. The main body of the report ends with a listing of the conclusions and recommendation arising from the study. Appendices are included that cover the safety aspects of the study, oil properties, raw data and selected equipment specifications.

## **2.0 BACKGROUND**

Emulsion formation in oil slicks on water is a naturally occurring process. Wave action mixes water droplets into the oil slick: if the oil contains a sufficiently high concentration of natural surfactants (primarily the heavy asphaltenes, resins, and waxes) they will stabilize the water droplets and prevent their coalescence and settling out of the slick. These natural surfactants appear to form a skin around the water droplets that prevents them from coalescing when they touch. After some weathering, in which an oil loses its light ends, hence increasing the concentration of the asphaltenes and waxes, most crude oils will reach the point where they can form stable emulsions. The water content of naturally occurring emulsions can be as high as 90%.

The oils produced and transported on the North Slope of Alaska are no exception. The pipeline blend (ANS crude) delivered by the Trans-Alaska Pipeline System will form emulsions after weathering. This oil supplies over 10% of the domestic consumption of the United States and accounts for over 20% of the U.S. domestic crude oil production. It is far and away the crude oil most commonly transported in U.S. waters by tanker and dominates west coast crude oil shipments. Its primary destinations are Washington State, California and the Gulf of Mexico via transshipment through a pipeline paralleling the Panama Canal.

### **2.1 ALASKA NORTH SLOPE CRUDE SPILL EMULSIFICATION**

Recently, a study of the spill-related physical properties of eight Alaskan crudes was completed (S.L. Ross 1994). Two of the crude oils analyzed were samples of Alaska North Slope crude (one from Pump Station 1 in Prudhoe Bay and one from the Valdez terminal at the southern end of the pipeline). The key physical properties of the two are nearly identical, not surprisingly; the properties of the Pump Station 1 sample are reproduced in Table 1. It is a medium-gravity blended crude. The complete data set for this crude may be found in Appendix 1.

Figure 1 shows the measured tendency of the sample to form water-in-oil emulsions in a shaker-type test apparatus and the resulting emulsion's stability as a function of the degree of evaporation of the oil. The tendency of ANS crude to form emulsions at room temperature increases from medium to high as the light ends of the oil evaporate. The stability of the emulsions formed at room temperature in the

Table 1 ANS Crude Oil Properties

**OIL NAME: ALASKA NORTH SLOPE - PUMP STATION #1**

1.0 TYPE: Crude		WEATHERING (VOLUME %)		31.8
		0		20.64
2.0 DENSITY (g/mL):				
1 °C		0.887		0.926
15 °C		0.876		0.914
3.0 VISCOSITY:				
3.1 DYNAMIC VISCOSITY (mPa.s):				
1 °C		38.9		471.3
15 °C		17.6		93.4
3.2 KINEMATIC VISCOSITY (mm <sup>2</sup> /sec):				
1 °C		43.9		509.0
15 °C		20.1		102.2
4.0 INTERFACIAL TENSIONS @ 20°C (mN/m):				
4.1 AIR-OIL:		31.8		34.2
4.2 OIL-SEA WATER:		24.0		27.0
5.0 POUR POINT (°C):		<-13		-13
7.0 FLASH POINT - CLOSED CUP (°C):		<-13		-7
8.0 EMULSION FORMATION TENDENCY AND STABILITY @ ROOM TEMPERATURE (20°C):				
8.1 TENDENCY				
15°C		0.40		0.86
8.2 STABILITY				
15°C		0.00		0.00
9.0 DISTILLATION DATA (°C) :				
		VOLUME PERCENT	LIQUID TEMPERATURE	VAPOR TEMPERATURE
		IBP	77.6	35.5
		2.5	128.2	56.6
		5	147.4	53.7
		7.5	167.7	57.4
		10	181.9	65.2
		12.5	197.6	73.8
		15	213.5	74.9
		17.5	231.8	79.9
		20	248.3	84.5
		22.5	266.3	89.9
		25	284.2	93.9
		27.5	299.9	108
		30	313.6	114.6
		32.5	326.4	123
		35	340.6	121.9

10.0 WEATHERING:

$$F_v = \frac{\ln(1+7164.5 \cdot \exp(6.3 - 3911.5/Tk))}{(7164.5/Tk)}$$

where: Fv is fraction of oil lost by volume

ln is natural log

σ is evaporative exposure

p is exponential base e

Tk is environmental temperature (Kelvin, K = °C + 273)

**OIL NAME: ALASKA NORTH SLOPE - PUMP STATION #1**

1.0 TYPE: Crude		WEATHERING (VOLUME %)		31.8
		0		20.64
2.0 DENSITY (g/mL):				
32 °F		0.887		0.926
60 °F		0.876		0.914
3.0 VISCOSITY:				
3.1 DYNAMIC VISCOSITY (cP):				
32 °F		38.9		471.3
60 °F		17.6		93.4
3.2 KINEMATIC VISCOSITY (cSt):				
32 °F		43.9		509.0
60 °F		20.1		102.2
4.0 INTERFACIAL TENSIONS @ 68°F (dyne/cm):				
4.1 AIR-OIL:		31.8		34.2
4.2 OIL-SEA WATER:		24.0		27.0
5.0 POUR POINT (°F):		<9		9
7.0 FLASH POINT - CLOSED CUP (°F):		<9		19
8.0 EMULSION FORMATION TENDENCY AND STABILITY @ ROOM TEMPERATURE (68°F):				
8.1 TENDENCY				
60°F		0.40		0.86
8.2 STABILITY				
60°F		0.00		0.00
9.0 DISTILLATION DATA (°F) :				
		VOLUME PERCENT	LIQUID TEMPERATURE	VAPOR TEMPERATURE
		IBP	171.68	95.9
		2.5	262.76	133.88
		5	297.32	128.66
		7.5	333.86	135.32
		10	359.42	149.36
		12.5	387.68	164.84
		15	416.3	166.82
		17.5	449.24	175.82
		20	478.94	184.1
		22.5	511.34	193.82
		25	543.56	201.02
		27.5	571.82	226.4
		30	596.48	238.28
		32.5	619.52	253.4
		35	645.08	251.42

10.0 WEATHERING:

$$F_v = \frac{\ln(1+7164.5 \cdot \exp(6.3 - 3911.5/Tk))}{(7164.5/Tk)}$$

where: Fv is fraction of oil lost by volume

ln is natural log

σ is evaporative exposure

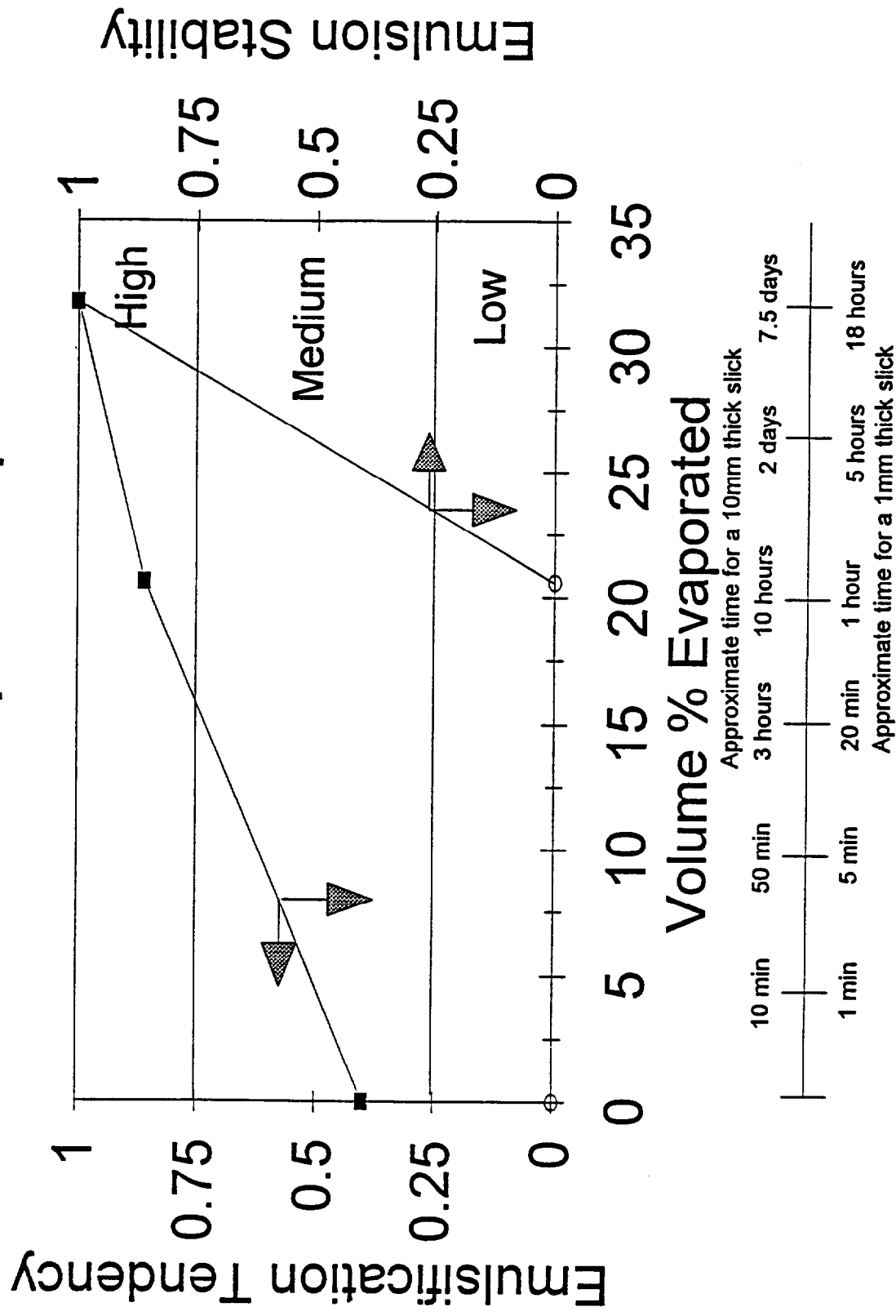
exp is exponential base e

Tk is environmental temperature (Kelvin, K = °C + 273)

Figure 1

# Emulsification Tendency and Stability

## Alaska North Slope Pump Station #1



shaker apparatus remains low until the volume evaporated exceeds 20%. This behavior is consistent with other worker's recent research (Bobra and Callaghan 1990) and observations after the *Exxon Valdez* spill (Allen 1991). The reason for this behavior may be that emulsion breaking chemicals added during production in very low concentrations (10 to 100 ppm, depending on the types of chemicals and their activity) to the individual crudes that constitute ANS crude remain with the oil and delay the onset of stable emulsification. All samples of the individual crudes (some of them blends from fields themselves) that make up ANS crude tested during the aforementioned study showed a high tendency to form stable emulsions when fresh.

Figure 2 shows a computer model (S.L. Ross Oil Spill Model) prediction of the emulsion water content over time of a hypothetical, 160 m<sup>3</sup> (1000 bbl) spill of ANS crude on cold water in a 7.5 m/s (15 knot) wind. The model predicts that the onset of emulsification is delayed for 32 hours; once the oil has evaporated enough to form stable emulsions the process proceeds quickly with the maximum water content (arbitrarily chosen as 75%) being reached in a further 8 hours.

## **2.2 IN-SITU BURNING IN ALASKA**

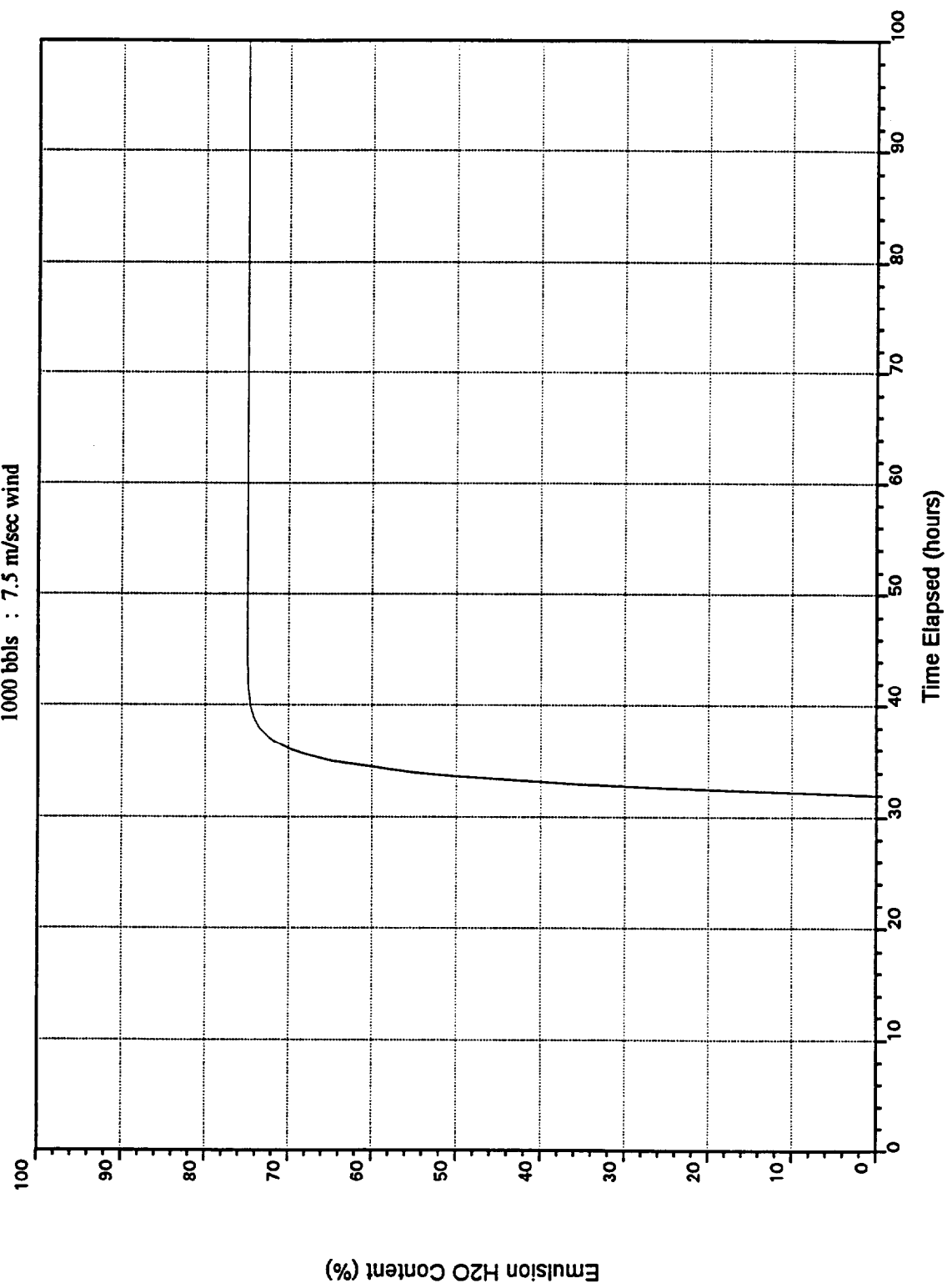
In-situ burning has been an accepted option for spills in ice-infested waters in Alaska for many years (Industry Task Group 1983) and has been actively supported by both industry and government agencies in the State. Alaska was the first state to implement guidelines for the approval of in-situ burning operations; this process has continued and the Alaska RRT is still in the forefront of the in-situ burning pre-approval field. Most recently, the Alaska RRT has incorporated into the burn authorization process the results of the NIST Large Eddy Simulation (LES) computer model used to predict smoke particulate concentrations downwind of in-situ oil fires.

Response organizations in Alaska, including ACS, have responded by supporting the development, testing and stockpiling of large amounts of equipment to support in-situ burning operations in open water, such as Heli-torch systems, other serially-deployable igniters and fire-resistant boom. ACS alone stockpiles 8 Heli-torches, 1500 hand-held igniters and 4200 m (14,000 ft) of fire-resistant boom.

The first ever use of in-situ burning of an oil slick contained in fire resistant boom was conducted during the *Exxon Valdez* spill response in Alaska.



Figure 2 Predicted Emulsification Rate  
Alaska North Slope Crude (PS1)



## **2.3 PROJECT RATIONALE**

With existing technology, there is a "window-of-opportunity" for in-situ burning of ANS crude oil spills on open water of about a day or so, before the oil emulsifies to an unignitable state. Recent work in Norway (Guenette et al. 1994) co-funded by ACS and others, identified two potential methods for enhancing ignition of high water content emulsions: the application of chemical emulsion breakers to the slick prior to ignition (the "pre-mixed" approach) and the addition of chemical emulsion breakers to the gelled fuel mixture for the Heli-torch in an attempt to achieve emulsion separation and ignition in a one-step process (the "enhanced igniter" approach).

The main reason for conducting the work reported here was to evaluate the effectiveness of these "break-and-burn" ideas with Alaska North Slope crude. Another key reason for this study was to test the effectiveness of these concepts at near-full scale, in Arctic open-water environmental conditions, using the equipment that would normally be applied at a real spill.

The meso-scale test portion of the project also provided a unique opportunity to ground-truth the computer model that the Alaskan RRT employs to authorize an in-situ burn. In addition, the meso-scale tests provided an opportunity for representatives of industry, regulatory agencies and local North Slope organizations to observe a large test burn.

### **3.0 CURRENT STATE OF KNOWLEDGE**

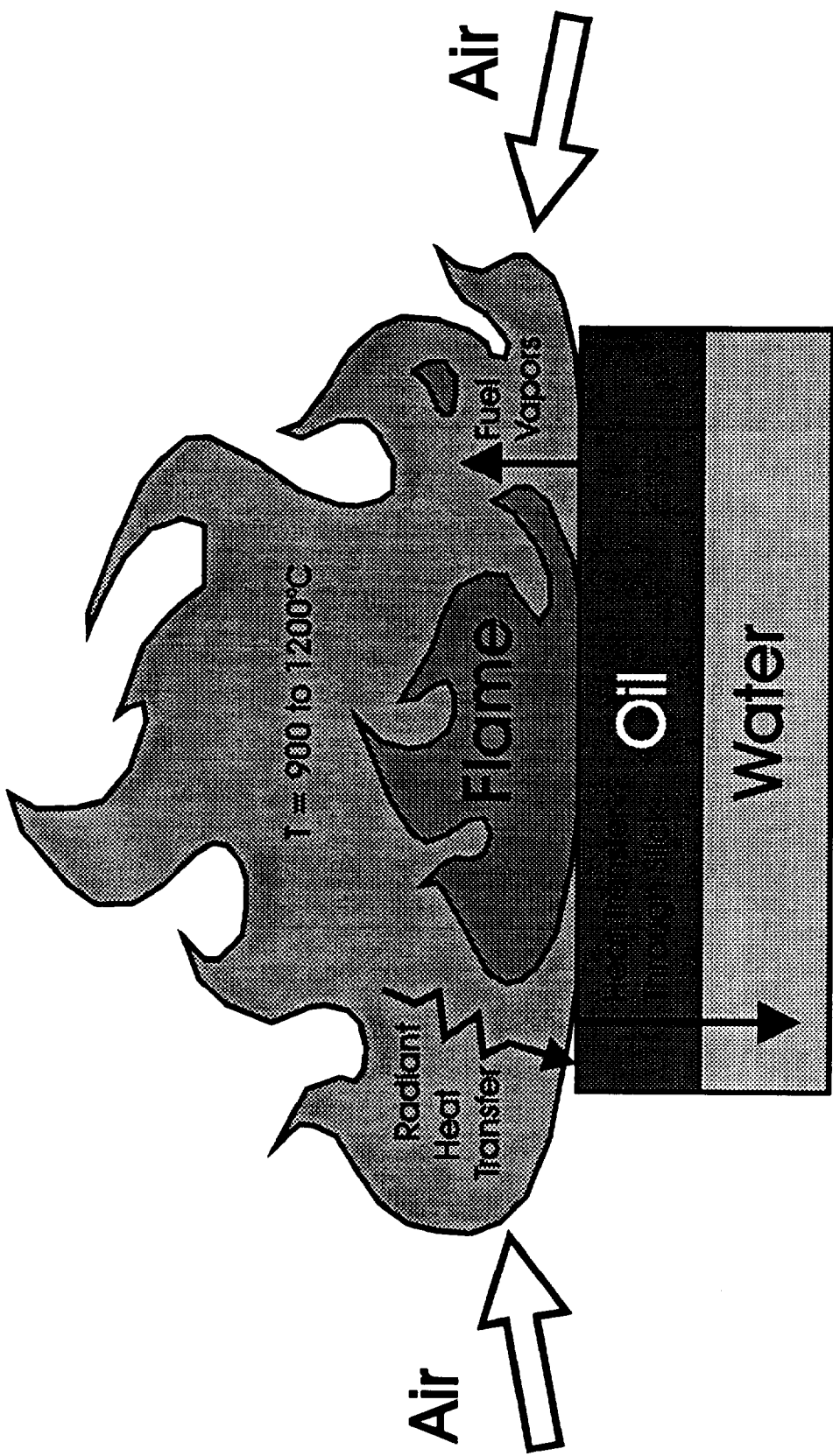
This chapter begins with a very brief overview of the processes involved with in-situ burning of a water-free oil slick and then concludes with a detailed review of the state-of-the-art of burning emulsions in-situ.

#### **3.1 IN-SITU BURNING OF OIL SLICKS**

The three necessary conditions for combustion are: fuel, oxygen (air) and an ignition source. In-situ burning is a vapor phase phenomenon: it is the oil vapors that burn in the air, not the liquid itself. In order to set an oil slick on fire the igniter must heat the oil to a temperature at which it generates enough oil vapors in the air above the slick to support combustion. This critical temperature is called the Fire Point. The minimum oil vapor concentration is termed the Lower Flammability Limit (LFL). Successful ignition requires that the slick be thick enough to insulate itself from the underlying water thus allowing the oil surface to heat up to the fire point. The minimum slick thickness required for igniting various oils are: 1 mm for fresh crude; 3 to 5 mm for evaporated crudes and light diesels; and, up to 10 mm for residual fuel oils. Once one part of the slick is ignited, the flames spread to the rest of the slick by two processes: i) the surrounding oil is heated by the flames of the burning area, warms up and ignites; and, ii) the hot oil under the ignited area physically spreads out over the surrounding cold oil. Wind can both help and hinder flame spreading. It can help by bending the flames over and creating better downwind radiant heating. It hinders flame spreading by diluting oil vapors above the slick to below the LFL.

Once ignited, the heat radiated back to the slick surface from the flames keeps the burning process going by rapidly boiling off (or flashing) the upper surface layer of the oil slick (Figure 3). Only about 3% of the net heat of combustion radiates back to the slick to keep this process going. The burning slick is consumed at a rate of about 3.5 mm/min by this process (for large, thick slicks: slicks > 10 m [30 ft] diameter and > 10 mm thick; smaller or thinner slicks burn more slowly). As the burn progresses, a hot zone develops in the oil slick and moves closer to the oil/water interface.

Once the temperature at the oil/water interface reaches 100°C (212°F), the underlying water begins to boil, quite violently. This causes droplets of oil to be thrown up into the flame where they evaporate and provide additional fuel to the fire. This end portion of in-situ burning is termed the "vigorous burn phase" and is evidenced by an increase in flame height and radiation. In situations where there is a



**Figure 3** Key heat and mass transfer processes in in-situ burning

relative current between the burning oil slick and the water (such as burning in a fire boom under tow), the vigorous burn phase may not occur because the heated water is constantly being replaced by cool water. In all cases, as oil is consumed and the slick thins, the fire eventually goes out as more and more heat is transferred from the oil into the water, resulting in the slick surface cooling down to below the fire point. Normally 1 to 5 mm of residual oil remains after a burn.

### **3.2 IN-SITU BURNING OF WATER-IN-OIL EMULSIONS**

The following has been adapted from Buist et al. (1994).

#### **3.2.1 Past Work**

Experiments on in-situ burning of emulsions have been conducted sporadically over the past 20 years (Maybourn 1971, Energetex 1980, Hossain and Mackay 1981, Energetex 1981, Dome 1982, S.L. Ross 1989). In the last few years, the research has intensified and become more focused (Bech et al. 1992 and 1993, Cabioc'h 1993, Guenette et al. 1994 and NIST 1994).

In-situ burning of water-in-oil emulsions likely involves several different processes as compared to the burning of unemulsified oils. The key differences relate to the heat and mass transfer processes involved.

It has been postulated (Bech et al. 1992 and 1993, Guenette et al. 1994) that in-situ ignition and burning of emulsions involves a two-step process: breaking of the emulsion to form a layer of unemulsified oil laying on top of the emulsion slick; and subsequent combustion of this oil layer. Cabioc'h (1993) confirms this theory. Rate controlling processes for this model of emulsion burning may include: the rate of emulsion breaking; evaporation of emulsion water; and, heat conduction through the emulsion slick. It is clear that emulsion stability at elevated temperatures plays a key role in defining whether or not a particular emulsion slick is burnable.

The rate of oil removal by burning declines with increasing water content. Data from S.L. Ross (1989) indicates that an increase in water content from 0 to 25% by volume reduces oil burn rates by 1/3 to 1/2 for oils that form stable emulsions. Increasing the water content further to 50% by volume further reduces the oil removal rate by a total of 1/2 to 1 (i.e., no burning). A general "rule-of-thumb" appears

to be that the rate of oil (not emulsion) removal by burning is proportional to the fraction of oil in the emulsion. The data of Energetex (1980), Bech et al. (1992), Cabioc'h (1993) and Guenette et al. (1994) support this general trend. The decrease in burning rate with increasing water content is accentuated by evaporation of the oil. It should be noted that the in-situ burning of some oils that form emulsions does not appear to be as greatly affected as noted above. Some researchers believe that perhaps high wax content, low asphaltene content oils fall into this category (Energetex 1980, S.L. Ross 1989, Guenette et al. 1994). The reason that emulsions of these oils are more burnable may relate to their instability at elevated temperatures (below 100°C). It is theorized that although emulsions stable at elevated temperatures can only burn as fast as the emulsified water is evaporated, emulsions that break spontaneously at elevated temperatures can physically release water-free oil for burning, and thus allow burning to proceed at a faster rate.

The results of S.L. Ross (1989), Bech et al. (1992), Bech et al. (1993), Cabioc'h (1993) and Guenette et al. (1994) all show similar trends of:

- little effect on oil removal efficiency (i.e., residue thickness) for water contents up to about 25% by volume;
- a noticeable decreases in burn efficiency with water contents above 25%, the decrease being more pronounced by weathering; and
- unburnable slicks of emulsion having water contents ranging from as low as 20 to 30% for extremely weathered oils forming stable emulsions to as high as 70% for less weathered oils forming less stable emulsions.

The burning of higher water content emulsions in-situ can involve vigorous burning (with its characteristic droplet production and more violent burning) throughout the entire burn as opposed to only just prior to extinction for water-free oil (Energetex 1980, S.L. Ross 1989). This relates to the superheating and boiling of emulsion water from within the slick. The vigorous stage of burning, just prior to extinction, also may be enhanced for emulsions; this possibly relates to enhanced heat transfer through an emulsion slick as opposed to a pure oil slick.

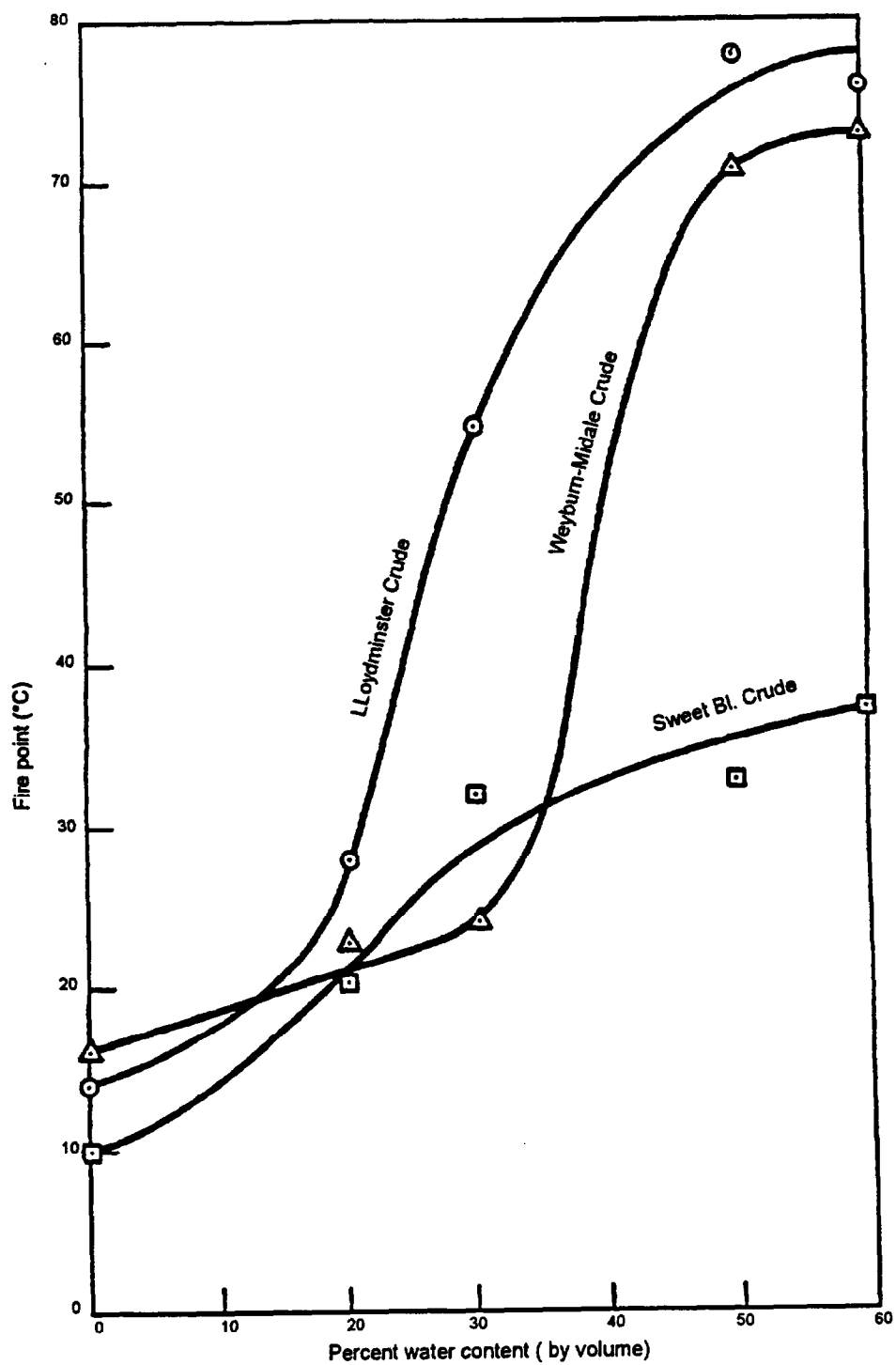
The residue thickness remaining after an emulsion burn generally increases with increasing water content, depending on the stability of the emulsion. The data of Energetex (1980) indicate little change in residue thickness for oils not forming very stable emulsions; however, for oils that did form stable

emulsions the residue was two to three times as thick as unemulsified slicks. The water content of the residue was not reported.

Often, when burning emulsions, extinction is initiated by foaming action of the burning slick (Energetex 1980, S.L. Ross 1989). The foaming is presumably associated with boiling of water, but its origin and contributing factors are unclear. It is not unusual for a burning emulsion slick to foam over one area of its surface while another is still burning; as the foam breaks, the extinguished surface is re-ignited by adjacent flames. This process can result in sudden and rapid flare-ups of flame during an emulsion burn.

Emulsion slick combustion, perhaps because of the more complex and likely delicate heat balance, seems to be more sensitive to environmental conditions than unemulsified slicks. Bech et al. (1993) report that regular wave action resulted in a considerable reduction in burn efficiency (from 80 to 50%) for a weathered, 25% water emulsion. Waves did not have a similar effect on an unemulsified slick of the same oil (removal efficiency = 90%). Energetex (1981) indicates that the burning of stable 50% water emulsions of weathered crude was far more sensitive to wind effects than unemulsified oils.

The ignition of emulsions is more difficult than ignition of unemulsified oil; subsequent flame spreading over emulsion is also slower. Energetex (1980) indicates that the fire point of water-in-oil emulsions increased with increasing water content. Figure 4 shows that the fire point of fresh oils that formed highly stable emulsions rises rapidly above 30% water; oils that form less stable emulsions have less dramatic increases. Smith and Diaz (1980) and Guenette et al. (1994) also observed an increase in fire point with emulsification. Many researchers (Energetex 1980, Hossain and Mackay 1981, Dome 1982, S.L. Ross 1989, Bech et al. 1992, Guenette et al. 1994) have noted that ignition of emulsions in-situ becomes more difficult with increasing water content. Energetex (1980) noted that, for stable emulsions with water contents in excess of 40%, a layer of fresh crude oil spread over the surface of the emulsion was necessary for successful ignition. In essence, the added crude oil was acting as a flame spread promoter. Other experience has shown ignition of emulsion slicks in ice melt pools could not be accomplished with gasoline-soaked sorbents; diesel-soaked sorbents were required, as was priming the slick with diesel (Dome 1982). S.L. Ross (1989) noted that, as water content increased, successively stronger ignition sources were required (5 cm square gasoline-soaked sorbent, then a 10 cm square gasoline-soaked sorbent pad, and finally a 2 mm layer of fresh crude oil).



**Figure 4** *W/O emulsion fire points vs. water content (from Energetex 1980)*



This trend was further explored by Bech et al. (1992) who ranked ignition sources in increasing order of strength as: gelled gasoline, gelled diesel, gelled crude oil. They postulated that the success of the stronger igniters rested with higher flame temperatures (and thus increased radiant heat). Cabioc'h (1993) concluded that gelled diesel was an effective igniter for emulsions. Guenette et al. (1994) concluded that gelled fresh crude was a better igniter for emulsions than gelled gasoline.

The maximum ignitable water content of an emulsion seems to be controlled by three factors:

- the degree of weathering of the parent oil (more evaporated emulsions are more difficult to ignite);
- the stability of the emulsion at temperatures less than 100°C (Cabioc'h 1993 postulates that high asphaltene emulsions are more difficult to ignite); and,
- the strength of the igniter.

The maximum ignitable water content for oils has ranged from 10% to 70% by volume, depending on the above (Energetex 1980, S.L. Ross 1989, Bech et al. 1992, Cabioc'h 1993, Guenette et al. 1994). Guenette et al. (1994) showed that emulsions with water contents as high as 50%, when herded into a contained oil slick fire by current and wind action, would ignite and burn efficiently.

Not only are water-in-oil emulsions difficult to ignite, flame spreading over their surface is much slower. Energetex (1980 and 1981), Hossain and Mackay (1981), Smith and Diaz (1987), S.L. Ross (1989), Allen (1991), Bech et al. (1992) and Guenette et al. (1994) have all noted significant reductions in flame spreading rates with increasing water content. This is likely due to a combination of the following factors:

- increased slick viscosity, slowing interfacial-tension-induced flow and flame spreading;
- increased heat transfer by conduction through the emulsified slick;
- increased flash/fire points of the emulsified slick; and
- delays due to the need to break the emulsion and form a layer of water-free oil for the flame to propagate across.

Bech et al. (1993) have noted that flame spreading over emulsions is very sensitive to wave action; even regular, swell-type waves prevented ignition and flame spreading over heavily weathered, 25%

water emulsions. Energetex (1981) concluded that flame spreading over emulsions is more sensitive to wind influences than unemulsified oils. Bech et al. (1993) and Guenette et al. (1994) give the maximum wind speed for burning emulsions as 36 km/hr (20 knots).

### **3.2.2 A Model for Emulsion Burning**

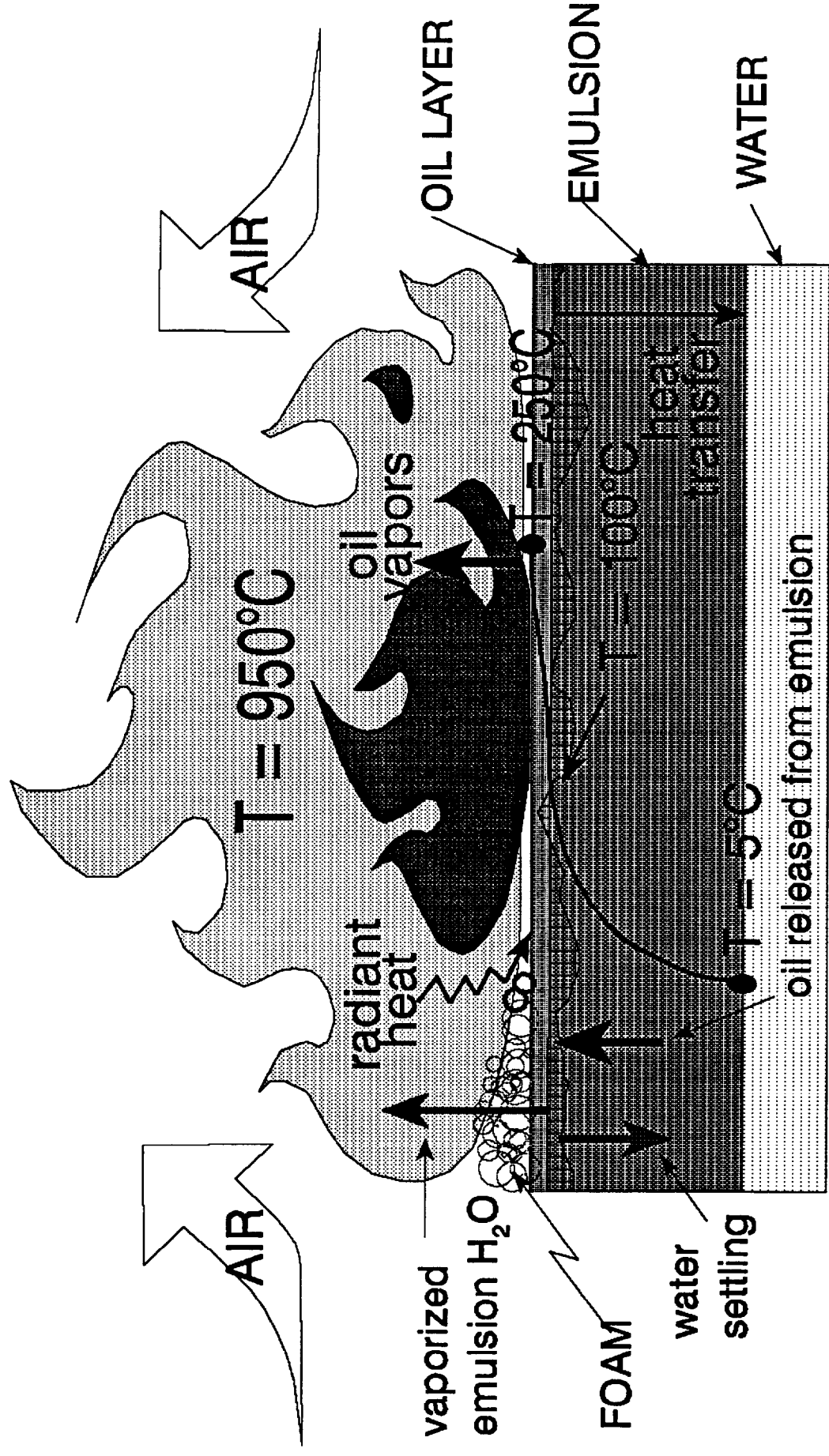
A conceptual model for the processes involved in in-situ burning of emulsions has been developed. The basic premise of this conceptual model of emulsion slick burning is based on that postulated by Bech et al. 1992 and 1993. This is that, it is not the emulsion per se that burns, but rather it is a layer of oil floating on the emulsion that supports the combustion.

This is illustrated in Figure 5. Heat radiated back to the slick from the flame must both: warm and vaporize the surface oil layer; and, provide the energy for the production of an oil layer from the underlying emulsion. The layer of oil can be generated in two ways: by boiling off the water contained within the emulsion or by physically breaking the emulsion by heating. It is possible that both these water removal processes are occurring simultaneously. If an emulsion that is very stable at temperatures up to 100°C (the boiling point of water) is to burn, then boiling of the emulsion water would be the only removal process and would be the rate-limiting process; if the emulsion is unstable and breaks easily at elevated temperatures (less than 100°C) the rate at which oil creams out of the emulsion would be the limiting rate (i.e., the oil cannot vaporize and burn faster than the rate at which an oil layer is produced from the breaking emulsion). Guenette et al. (1994) postulate that, because the viscosity of the underlying slick is high, the water physically separating from the emulsion cannot settle out and they conclude that the major water removal process is vaporization or boiling of the water. Evidence from their laboratory tests, and from the tests in this study, suggests that the separated water may accumulated interstitially within the slick until the bottom interface of the slick is fluid enough to allow the water to pass through. It is the release of the oil to the surface of the slick that is crucial to sustained emulsion burning; the water does not have to exit the slick immediately for this to happen.

Foaming of a burning emulsion may also be related to the water loss mechanism (boiling vs. breaking), the rate of breaking and the presence of film-stabilizing chemical species in the oil. Foam is created by the intense mixing of a gas and liquid. The liquid contains surface acting chemicals that stabilize a thin film of liquid around the gas bubble. In the case of burning emulsions that foam, the gas

Figure 5

# EMULSION BURNING PROCESSES



is likely steam and the liquid is likely oil (it is probably not emulsion since the ambient temperatures would quickly boil any water).

When the foam is generated it extinguishes the fire locally by either smothering, insulating the oil layer or a combination of the two. After the foam breaks, if another area of the slick is still on fire, the affected area can reignite and burn. The foaming process may be one whereby pure oil is delivered to the surface at a faster rate than by slower boiling of the water out of the underlying emulsion.

### **3.2.3 Use of Emulsion Breakers for Burning**

The use of emulsion breakers applied to slicks on water in order to reduce their water content has been suggested in the past (e.g., S.L. Ross 1990, Lunel 1993). Guenette et al. (1994) conducted a large number of small-scale tests and several medium-scale burns to study the use of chemical breakers for water-in-oil emulsion burning. They screened a number of commercial emulsion breakers and selected two, Alcopol 0 70% PG and Breaxit OEB-9 for trials in burn tests. Three crude oils were tested: Statfjord, Avalon and Alaska North Slope. Unfortunately the samples of ANS obtained from a refinery for that study were highly contaminated with a surfactant and would not form emulsions. The other oils were weathered artificially and emulsified with seawater using a paint-mixing attachment for an electric drill (for the laboratory tests) or a large gear pump (for the field tests). The laboratory tests showed that the addition and mixing of an emulsion breaker in the slick prior to ignition allowed the successful ignition of otherwise unburnable emulsions. The results also indicated that the application of a gelled fuel igniter containing the emulsion breaker also promoted the ignition of emulsions. It was noted that this latter technique seemed sensitive to the crude oil type.

Field tests confirmed that the addition of emulsion breaker to gelled igniter fuel enhanced flame spreading rates over weathered Statfjord crude emulsion slicks.

## **4.0 EQUIPMENT AND METHODS**

This section describes the equipment and procedures used to carry out the three experimental phases of this study: laboratory tests, outdoor burn tests in water-filled pans and outdoor burn tests in a large pit filled with water.

## **4.1 LABORATORY-SCALE TESTING**

The laboratory tests were carried out in the S.L. Ross laboratory in Ottawa.

### **4.1.1 Test Oils**

The majority of the tests were conducted using Alaska North Slope crude oil obtained from Pump Station Number 1 on the Trans-Alaska Pipeline System (TAPS). The only physical property test performed was to check the oil/water interfacial tension of the crude to confirm that it had not been highly dosed with surfactants. The measured interfacial tension of 20.2 mN/m confirmed that the sample was relatively clean. The physical properties of a sample of ANS crude obtained from Pump Station Number 1 some six months prior to the sample used for these tests can be found in Appendix 1.

Two laboratory-scale burn tests were conducted with Endicott crude oil emulsions. Endicott crude is one of the constituents of ANS crude. It forms stable emulsions even when it is fresh. Complete physical properties of Endicott crude may also be found in Appendix 1.

### **4.1.2 Oil Weathering**

In order to conduct the tests with oils representative of what must be dealt with at a spill and to determine the effects of evaporation on burning, samples of the ANS crude were artificially weathered in the lab. This involved bubbling compressed air through three 25 L plastic pails each initially containing 19 litres of ANS crude. Periodic measurements of the depth of the oil remaining in the pail were taken to track the evaporative loss. The weathering was stopped in one pail when 10.3 volume % of the ANS crude had been evaporated; the other two pails were sparged until 27.8 and 27.9% of the oil had been evaporated.

The Endicott crude used in the tests was not evaporated.

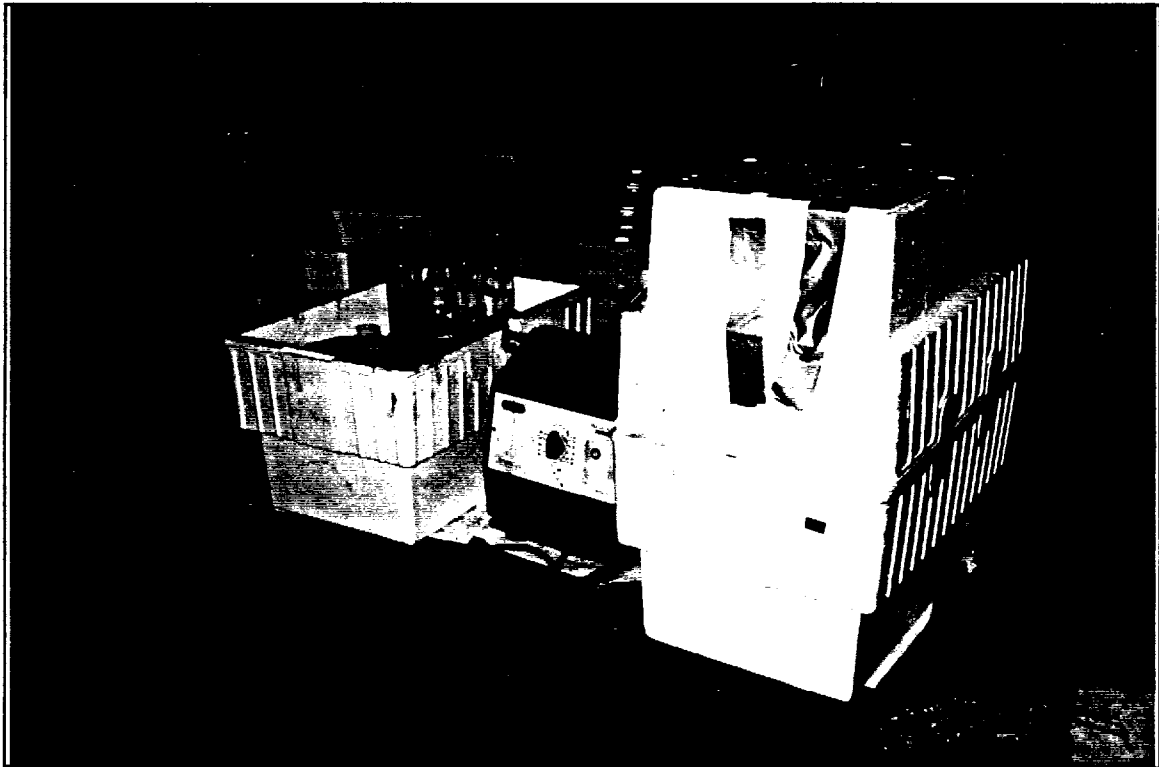
### **4.1.3 Emulsions-Formation and Properties**

#### **4.1.3.1 Tendency and Stability Tests**

A variation of a standardized emulsion formation test (Zagorski and Mackay 1982) was used to determine the tendency of the fresh and weathered ANS crude oil to form emulsions at different temperatures. The test also measured the stability of the resulting emulsion. The tests were performed with fresh, 10.3% and 27.9% weathered ANS crude oil. To simulate cooler Arctic temperatures two different methods were tried: in one, a Burrell wrist-action shaker was placed inside a refrigerator with an ambient temperature range of 10°C to 15°C; the other had the arms of the shaker enclosed in an ice-cooled styrofoam cooler apparatus with ambient temperatures ranging from 5°C to 8°C (Figure 6). The 35 ppt salt water and test oils were pre-cooled in a refrigerator to approximately 5°C. First, 200 mL of cool salt water was poured into three separatory funnels. Then 20 mL of each of the test oils was gently added from a 20 mL syringe into each funnel. To test the oils tendency to form an emulsion, the following procedure was used. The initial oil layer height was recorded and then the shaker turned on. After 30 minutes, the shaker was stopped and the funnels were allowed to settle for 5, 10, 20 and 30 minutes; the height of the oil and emulsion layers was measured after each interval. This data was used to extrapolate back to determine the height of water-free oil immediately after stopping the shaker. This was repeated two more times for a total of three cycles. The oil layer heights at time zero were converted to a fraction of the oil originally in the emulsion by dividing by the initial height of oil added. The fraction of oil in the emulsion at time zero ( $f_0$ ) was then calculated as 1 minus the fraction not in the emulsion. To determine the stability of the emulsion, the height of the oil and emulsion layers were measured after 24 hours of settling. The fraction of the original oil in the emulsion after 24 hours ( $f_{\infty}$ ) was calculated as described above.

#### **4.1.3.2 Preparing Emulsions for Laboratory Burn Tests**

Various mixing techniques were tried in order to create stable emulsions with the three weathered oils in a 25 L bucket. The water used was 35 ppt (parts per thousand) salinity, and had been cooled in a refrigerator to 5°C. The first attempts involved using an electric drill with a paint mixer attached. The salt water was slowly poured into a bucket containing the oil. This method was found to be unacceptable due to the length of time needed to make the emulsion and the small amount of emulsion that could be made (one to two hours for a 1.5 L batch). Moreover, only low water content emulsions could be made



**Figure 6** Cooler apparatus for emulsion tendency and stability tests

and the emulsions made with fresh and 10.3% weathered oil broke after 1 to 2 hours of settling. Next, to help stabilize the emulsions, the 25 L bucket containing the oil was placed in a 100 L plastic pail holding ice water. Even though this helped stabilize the emulsions mixed with the drill, it was only temporary and the emulsions broke or inverted at moderate water contents, approximately 30 to 40%. Finally, a 3/4" rotary gear pump was used to mix the emulsions in the 25 L bucket and ice/water bath (Figure 7). The final procedure was as follows:

- a 25 L bucket of salt water was cooled to approximately 5°C in the refrigerator overnight;
- the required volume of oil was poured into an empty 25 L pail and then placed into a ice/water mixture in a 100 L plastic pail;
- the paint mixer was immersed into the oil and the drill was started to mix the oil;
- the suction and discharge hoses of the gear pump were immersed into the oil and the pump was started;
- the necessary volume of salt water was then slowly poured in, close to the suction hose of the gear pump;
- the mixing was continued until the emulsion appeared homogeneous; this took 5 to 10 minutes for 2 to 5 L batches of emulsion.

The vigorous mixing action and the high shear rate of the gear pump created tiny water droplets, approximately 20 to 40  $\mu\text{m}$  in diameter (estimated with an optical microscope). This technique was not only more efficient than the drill/mixer technique but the emulsions produced were much more stable, even at room temperature. Stable water contents as high as 60 to 65% by volume were achieved in emulsions of both the 10.3% and 27.9% weathered oil. The higher water content emulsions made with the fresh oil were still not fully stable and broke after 1 to 2 hours. It was observed that if water contents exceeded 70% by volume the emulsion inverted, changing from a water-in-oil emulsion, to a multiple emulsion-in-water emulsion.

#### **4.1.4 Emulsion Breaker Selection**

Three commercial emulsion breakers were selected for testing. These were:

- ALCOPOL 0 70% PG, produced by Allied Colloid of Great Britain;
- BREAXIT OEB-9, produced by Exxon Chemical; and





**Figure 7**    Laboratory emulsion mixing apparatus

- EXO 0894, produced by Petrolite Corporation.

The first two are products designed for general oil spill use and were selected for this reason and because they had been tested as ignition promoters in an earlier study (Guenette et al. 1994). The latter product is one used on the North Slope in the production process to treat emulsions from wells. Product specification and safety data sheets for these products may be found in Appendix 2.

#### **4.1.5 Emulsion Breaker Testing**

The effectiveness of the three chemical breakers with stable ANS emulsions was tested. The procedures used were adapted from those proposed by Fingas et al. (1993) for a Burrell-Wrist Action Shaker. In total, seven separatory funnels, each containing 200 mL of 35 ppt salt water, were used. The test involved 20 mL of test emulsion placed in five of the funnels and 10 mL in the other two. The test emulsion was 67% by volume salt water in the 27.9% weathered ANS. The emulsions had been created with the gear pump as previously described in Section 4.1.3. Doses of the demulsifier ranging from 1:165 to 1:3300, demulsifier to oil (d/o), were added to the surface of the emulsion. The funnels were then shaken for three hours in the ice-cooled chamber (see Figure 7) at ambient temperatures of 6°C to 8°C, then allowed to settle for 30 minutes. Visual measurements of the height of the oil/emulsion layer were taken and samples of the oil/emulsion mixture were analyzed for water content. This analysis involved extraction of the oil phase using toluene followed by a spectrophotometric determination of the oil content (and thus, by subtraction the water content) of the emulsion. This analytical method has an error of  $\pm 20$  to 30%.

#### **4.1.6 Emulsion Burn Testing**

The burn tests were performed in a 400 mm diameter test ring, placed in a 1.2 m (4 foot) diameter steel pan containing 320 mm of tap water (Figure 8). There were three sets of thermocouples installed in the pan: one group of three to measure flame temperatures 40, 150 and 290 mm above the middle of the containment ring; a second group of three that were movable and positioned prior to each test just under the slick surface to monitor oil/emulsion temperatures; and, a third group of three with the highest 20 mm below the bottom of the slick to monitor water temperatures. The temperature data was logged by a computer. Two mirrors, illuminated by a 150W floodlight, were placed on the bottom of the steel pan and angled so that the bottom of the slick could be observed.



**Figure 8**    Laboratory burn set-up

To remove the smoke, a 200 m<sup>3</sup>/minute (7000 cfm) fan was used to draw air out of the lab through a 600 mm flexible aluminum duct connected to a fume hood placed 1.45 m (5 feet) above the center of the pan. To prevent a swirling effect induced near the fume hood, an "anti-tornado" device was designed; this consisted of a piece of sheet metal 300 mm high which extended from the outside edge of the containment ring to the outside of the outer steel pan.

Two video cameras recorded each burn. Both the initial mass and volume of the test oils or emulsions were recorded, as well as the test emulsion's water content and the air and the water temperature. The burns were conducted using an initial oil or emulsion volume of 2500 mL (0.66 gallons), equivalent to a 20 mm initial thickness. Subsequent use of an initial volume of 1900 mL (0.5 gallon), or 15 mm initial thickness, became necessary in order to conserve the 28% weathered oil. Results of earlier studies (Guenette et al. 1994, S.L. Ross 1989) show that there are no burn process differences with this amount of thickness reduction other than a decrease in overall burn efficiency and a shorter burn duration. One test, near the end of the series, used only 1500 mL (0.4 gallon) of emulsion.

The test oil or emulsion was poured gently onto the water surface inside the burn ring. The emulsion was then evenly spread out to cover the entire surface of the containment ring. The moveable thermocouples were adjusted, both video cameras were started and the temperature data acquisition program was initiated. Ignition for the baseline burns was then attempted in the following order: first, a 25 cm<sup>2</sup> gas soaked sorbent pad was placed in the centre of the slick and lit with a propane torch; if this failed to ignite the slick, a similar-sized pad soaked with fresh ANS crude oil was placed in the center of the slick and lit with a propane torch. If this also failed to ignite the emulsion, 100 mL of fresh ANS crude oil was spread over the slick surface (creating a layer about 0.8 mm thick) and lit with the torch; if this attempt extinguished after about one minute (which is the approximately time to burn off the 100 mL of crude), then 200 mL of the same fresh crude was spread over the slick surface and ignited with the torch. If this attempt failed to ignite the slick, then this emulsion and all water contents above this were deemed unburnable.

For some tests, various gelled fuels were used as igniters. The fuels used were: gasoline, diesel, fresh ANS crude oil and a 50/50 mixture of gasoline/diesel. The fuels were mixed with Surefire, a commercial gelling agent, at a concentration of 17.5 g/L (8 lbs/55 gallons) by hand-shaking the mixture

in 500 mL glass jars. The desired volume of gelled fuel was weighed, then ladled onto the center of the slick in the containment ring and lit with the propane torch.

As the burns progressed; the preheat time (the time taken for the flames to spread away from the ignition source), the ignition time (the elapsed time for the flames to spread to the edge of the containment ring), the time to intense burn (when the vigorous burn phase began), and the extinction time (the elapsed time to when the last flame extinguished) were recorded. After each burn, the burn residue was collected, weighted and stored.

The baseline burn test matrix consisted of 0%, 10.3% and 28% weathered ANS crude emulsified with 0%, 12.5%, 25%, 40% and 60% by volume salt water. This series provided a reference for the effects of evaporative loss and water content on the ignition and burning of ANS crude oil emulsions.

#### **4.1.7 "Break and Burn" Testing**

The application of emulsion breakers prior to ignition was tested with the 28% evaporated ANS crude emulsions and fresh Endicott crude emulsions. The emulsions had otherwise unburnable water contents. The procedures involved: adding the prescribed dosage of emulsion breaker dropwise to the slick surface from a pipette; gently mixing the emulsion breaker into the slick using a 25 mm wide steel ruler for 2 to 5 minutes; and, then applying the igniter as described in 4.1.6 above.

#### **4.1.8 Enhanced Igniter Testing**

For several test burns, the desired volume of emulsion breaker was added to the gelled fuel igniter mixture. These "enhanced" igniters were then ladled onto the test slick and ignited with the propane torch. If the ignition failed to produce an efficient burn, the residue was mixed gently with a 25 mm wide steel ruler for 5 minutes, then ignited with another gelled fuel igniter that did not contain emulsion breaker.

## **4.2 OUTDOOR TESTING IN PANS**

In July 1994 a series of tests were carried out in Prudhoe Bay, AK to investigate the burning of weathered ANS crude emulsions outdoors. Figure 9 shows the layout of the test site, located beside

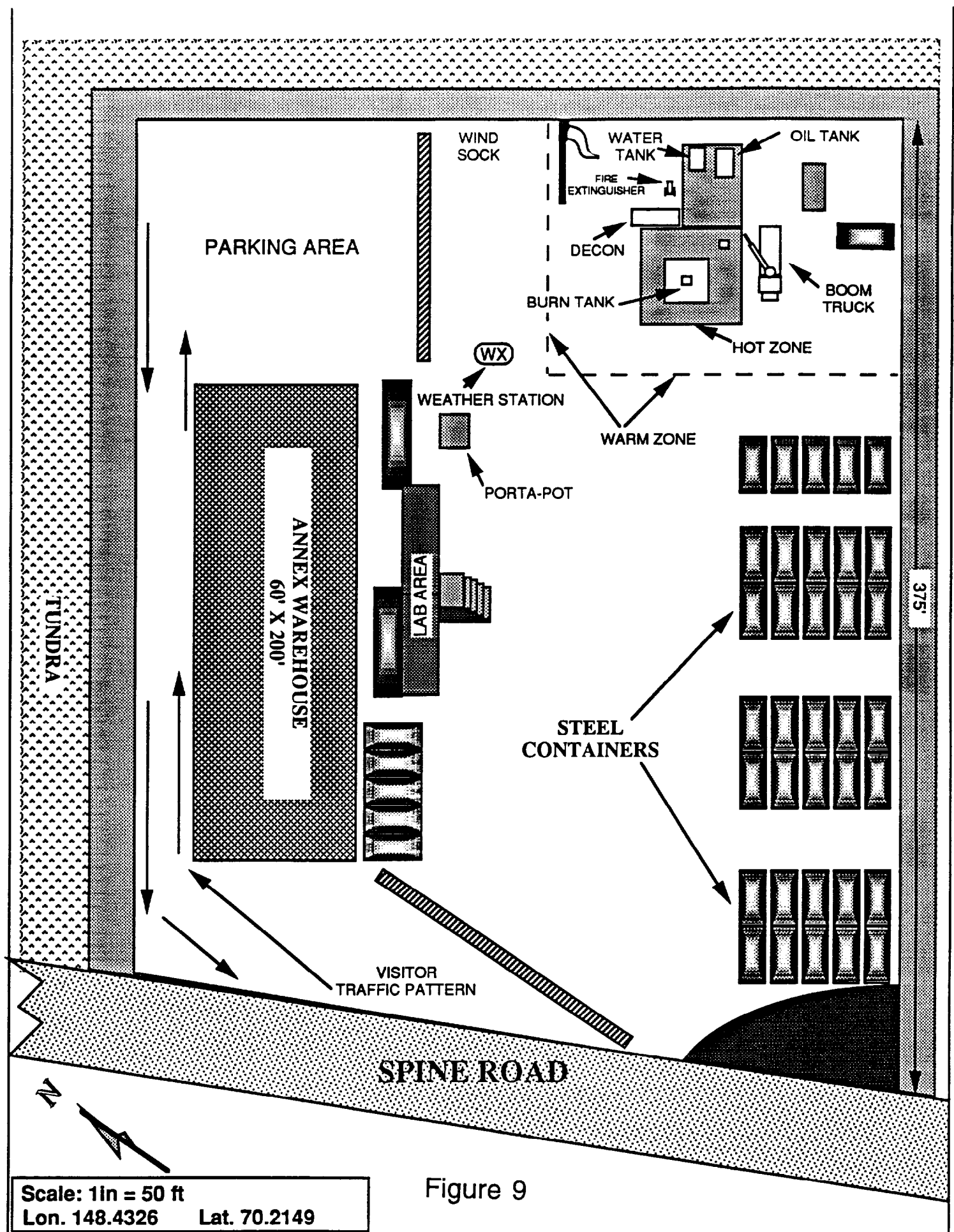


Figure 9

Alaska Clean Seas' Annex warehouse on Spine Road in Prudhoe Bay. The major items of equipment included a laboratory trailer, a burn tank, oil and seawater tanks, a decontamination and cleaning area, a weather station and a boom truck. All of the test equipment was inside a roped-off area to control access. All equipment used with oil was placed in a large plastic-lined berm (Figure 10). All appropriate permits were obtained by Alaska Clean Seas prior to the tests.

#### **4.2.1 Test Oil Weathering**

Approximately 770 L (4.9 bbls) of fresh ANS crude oil was placed in an open-topped tank for artificial weathering. Two 25 mm (1 inch) diameter pipes with 3 mm holes drilled on 25 mm centers along their length were placed in the bottom of the tank and connected to a 14 m<sup>3</sup>/min (150 cfm) air compressor. The tank was also fitted with a 25 mm (1 inch) air-powered gear pump which recirculated the tank contents through a nozzle. The oil was sprayed against a plastic sheet which directed the oil back into the tank. The open top of the tank was protected from the elements by an A-frame covered with plastic sheet. The open ends of the A-frame were covered with a fabric mesh to prevent access to the oil. Figure 11 shows a view of the oil weathering tank. The oil was simultaneously sparged and sprayed until it had lost the desired volume to evaporation. The depth of oil remaining in the tank was measured periodically to monitor progress.

#### **4.2.2 Emulsion Formation**

Emulsions of the weathered ANS crude and seawater (obtained from the nearby seawater treatment plant that cleans Prudhoe Bay water for oil production injection flooding purposes) were emulsified using the 25 mm (1 inch) gear pump (Figure 12). The required volume of weathered oil was measured into a graduated 38 L (10 gallon) Nalgene container. The necessary volume of seawater was measured into another container. The suction and discharge hoses connected to the gear pump were placed in the bottom of the oil container and the pump was started. The oil recirculation rate was 25 L/min (7 gal/min). Seawater was drawn from its container into the pump through a hose connected to a valved tee on the suction side. The flowrate of seawater was controlled to be less than one sixth the recirculation rate of the pump, as recommended by Gåseidnes 1993. For higher water content emulsions, as the water content approached 50%, the water intake rate was reduced to prevent "water lubrication" or inversion of the emulsion.



**Figure 10** Test Site equipment, including lined area for tests





Figure 11 Oil weathering tank for pan tests



**Figure 12** Emulsifying oil and seawater for pan tests

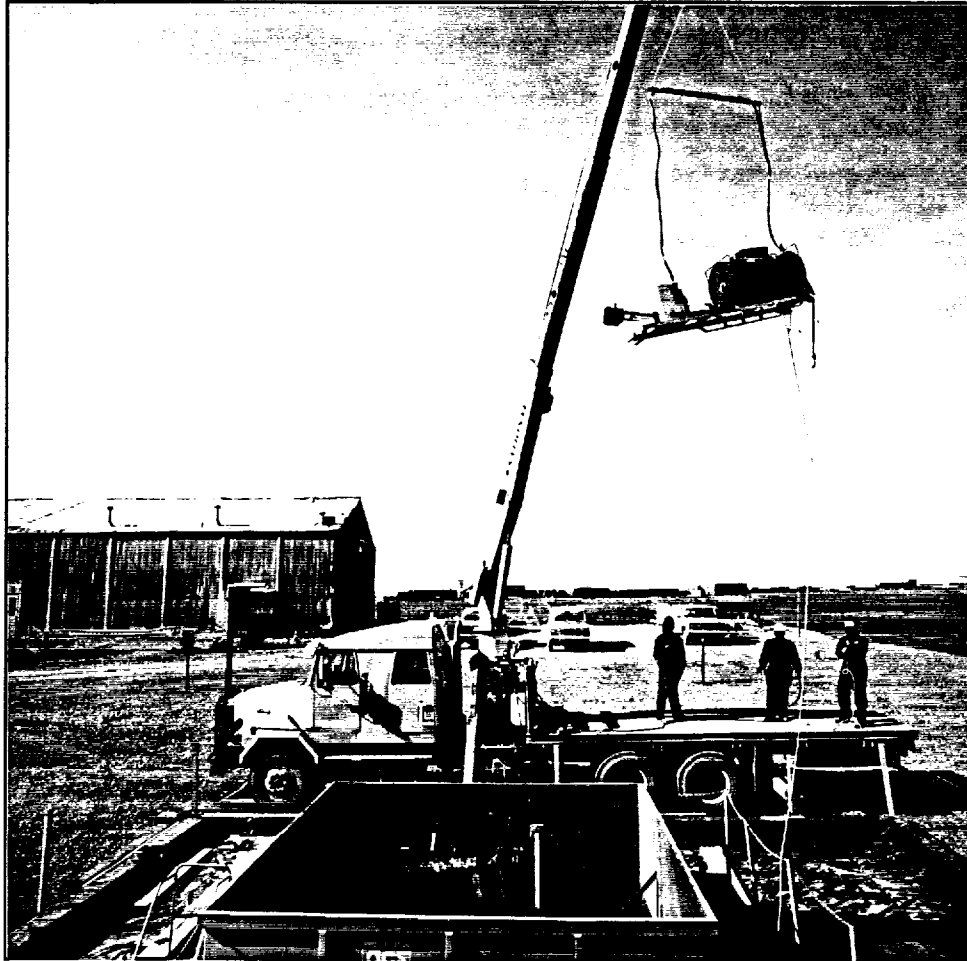
Once the desired water content had been reached the water valve was closed and the mixture recirculated for 10 additional minutes of mixing. After this the lids were put on the containers and they were moved to an electronic balance and weighed - the tare weights of the empty drums had been determined earlier.

Samples of a 50% water content (by volume) emulsion and a 60% water emulsion were taken, placed in 1 L glass bottles and stored. These were checked periodically over 72 hours for signs of emulsion breaking. The samples were then stored in a refrigerator for approximately 60 days and examined again for signs of breaking. Aliquots of these samples were sent to a BP lab on the North Slope and examined under a microscope.

#### **4.2.3 Test Site Equipment**

The major pieces of burn test equipment involved in the study were (see Figures 9 and 10):

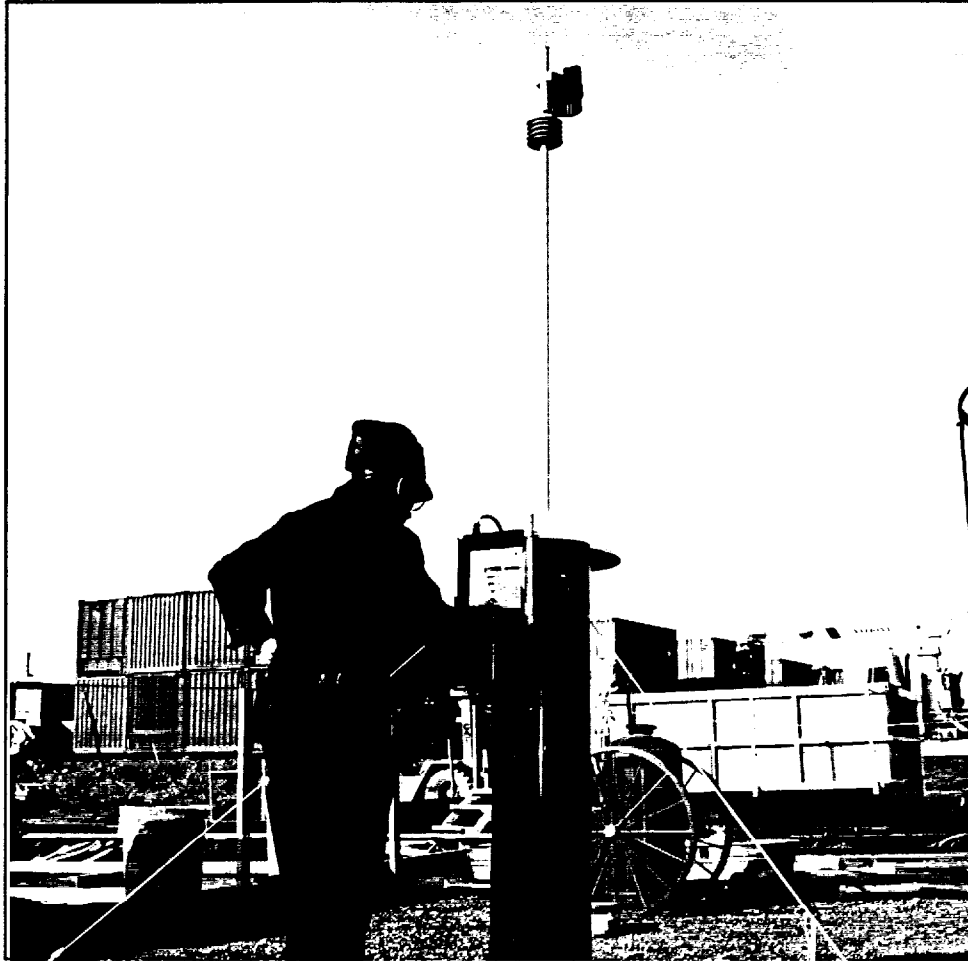
- a 3.6 m x 3.6 m x 1.5 m deep steel tank into which the burn pans were placed -- they sat on a metal frame that held them up near the upper lip of the tank to try to minimize wind eddies;
- a 1.2 x 1.2 m x 145 mm deep steel burn pan with a raised square lip the encompassed a burn area of 1.1 m x 1.1 m (Figure 13);
- a 2.4 m x 2.4 m x 300 mm deep steel burn pan with a raised square lip then encompassed an area of 1.8 m x 1.8 m (Figure 14);
- a supply of fresh water in a Fast tank;
- a portable data logging weather station with the anemometer at a height of 4.6 m (15 feet) above ground level (Figure 15);
- a wind sock;
- a 205 L (55 gallon) Heli-torch;
- a boom truck with crane;
- a forklift with a person-basket for video and photography; and
- a laboratory trailer equipped with electronic balances, mixers, volumetric glassware and plastic-ware and various sizes of sample jars.



**Figure 13** 1.2m<sup>2</sup> burn pan



**Figure 14** 3.3m<sup>2</sup> burn pan



**Figure 15** Portable weather station

#### **4.2.4 Gelled Fuel Preparation**

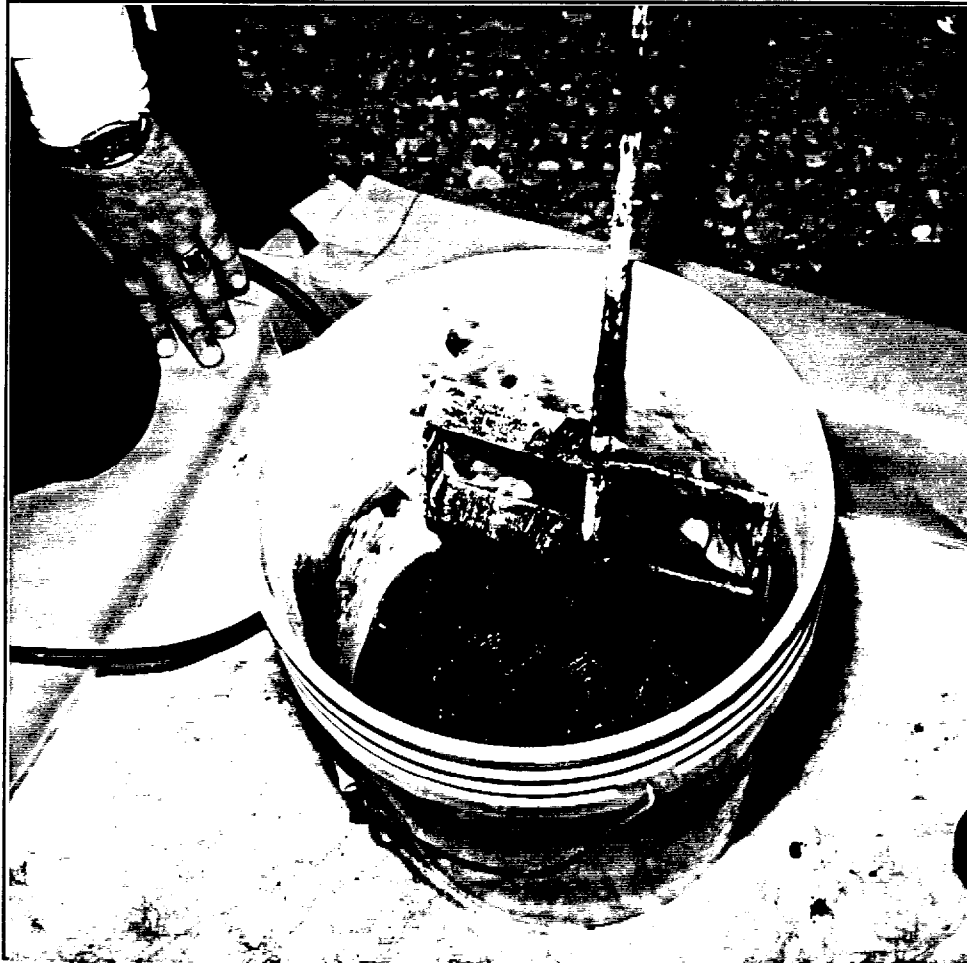
A gelled fuel mixing area was set up inside the warehouse, equipped with porta-berm, plastic pails, screens, stirrers and an air-powered hand drill fitted with a paint-stirrer (Figure 16). Small (8 to 19 L or 2 to 5 gallon) batches of gelled fuel were mixed here for testing purposes. The fuels that were used included:

- gasoline;
- automotive diesel fuel;
- fresh ANS crude oil;
- a 50/50 mix of gasoline and diesel;
- a 50/50 mix of gasoline and crude; and
- a 50/50 mix of diesel and crude.

The procedures followed in mixing the gelled fuels were:

- the required volume of the desired fuel(s) was measured into a plastic pail;
- the desired amount of Surefire gelling agent was weighed into a tared can;
- the gelling agent was poured through a screen (to prevent lumps of gelling agent falling into the fuel) as the fuel was stirred (Figure 17);
- after all the gelling agent had been added, mixing continued until the fuel reached its final consistency;
- then the fuel was poured into a Heli-torch drum (Figure 18) carried out, placed on and connected to the Heli-torch frame.

With many of the new fuel mixtures (i.e., gas/crude) the appropriate dosage of gelling agent was determined by trial and error. This involved adding gelling agent in 110 g (4 oz) increments, mixing and then observing the consistency of the gel. The dosage was deemed to be appropriate when the gelled fuel had a consistency similar to that of gasoline gelled with 3.1 kg of Surefire per drum (6.75 lbs per drum) @ 10°C (50°F), a consistency similar to that of Jello gelatin. Several batches of the alternative fuel mixtures were produced with the emulsion breaker EXO 0894 mixed in.



**Figure 16** Mixer for gelled fuel preparation





**Figure 17** Adding gelling agent to fuel



**Figure 18** Pouring gelled fuel into Heli-torch drum

#### **4.2.5 Heli-torch Static Tests**

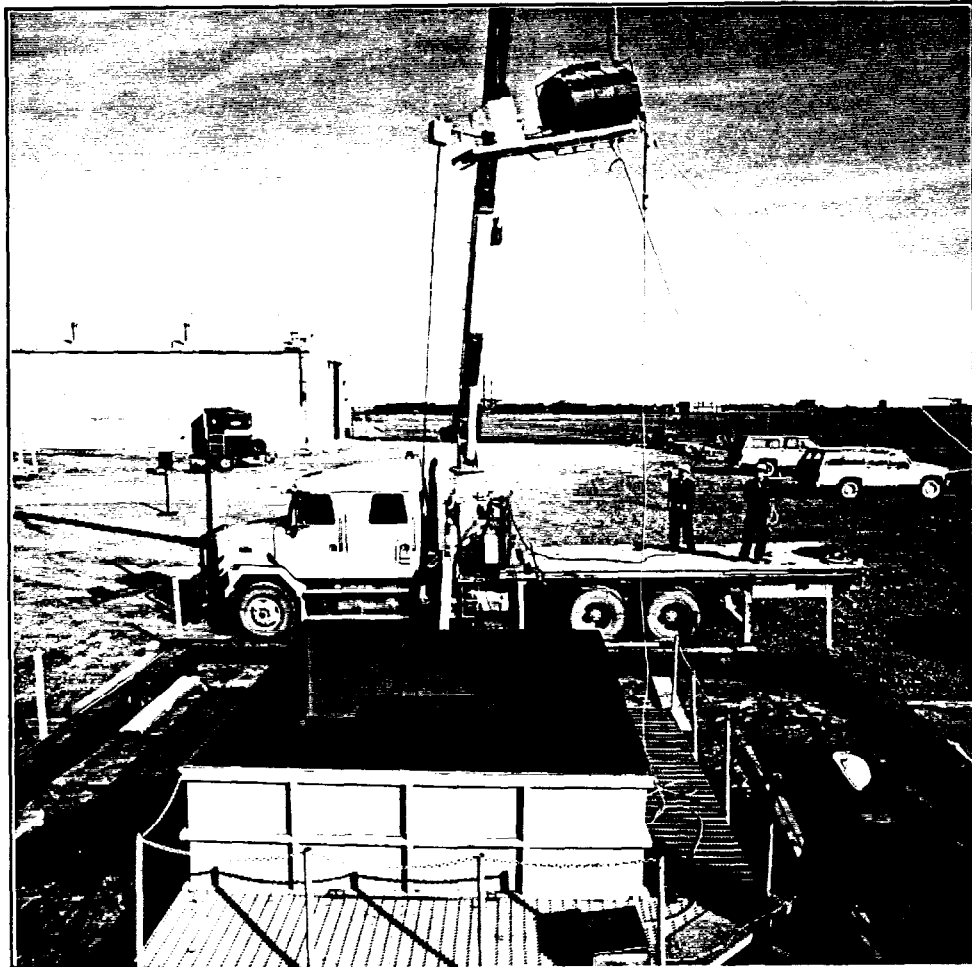
Several tests of the ability of the 205 L Heli-torch to light and deliver the alternate gelled fuels were conducted. The Heli-torch was fitted with the standard 11 mm (7/16") nozzle. These tests involved suspending the Heli-torch, with a crane, about 3 m above the smaller test pan (Figure 19) and operating it from the ground. The burn pan contained only water for these tests. The characteristics of the stream of gelled fuel, its impact with the water, the characteristics of the floating blob, ignition success, wind speed and orientation to the wind were recorded for each test.

#### **4.2.6 Emulsion Burning Tests**

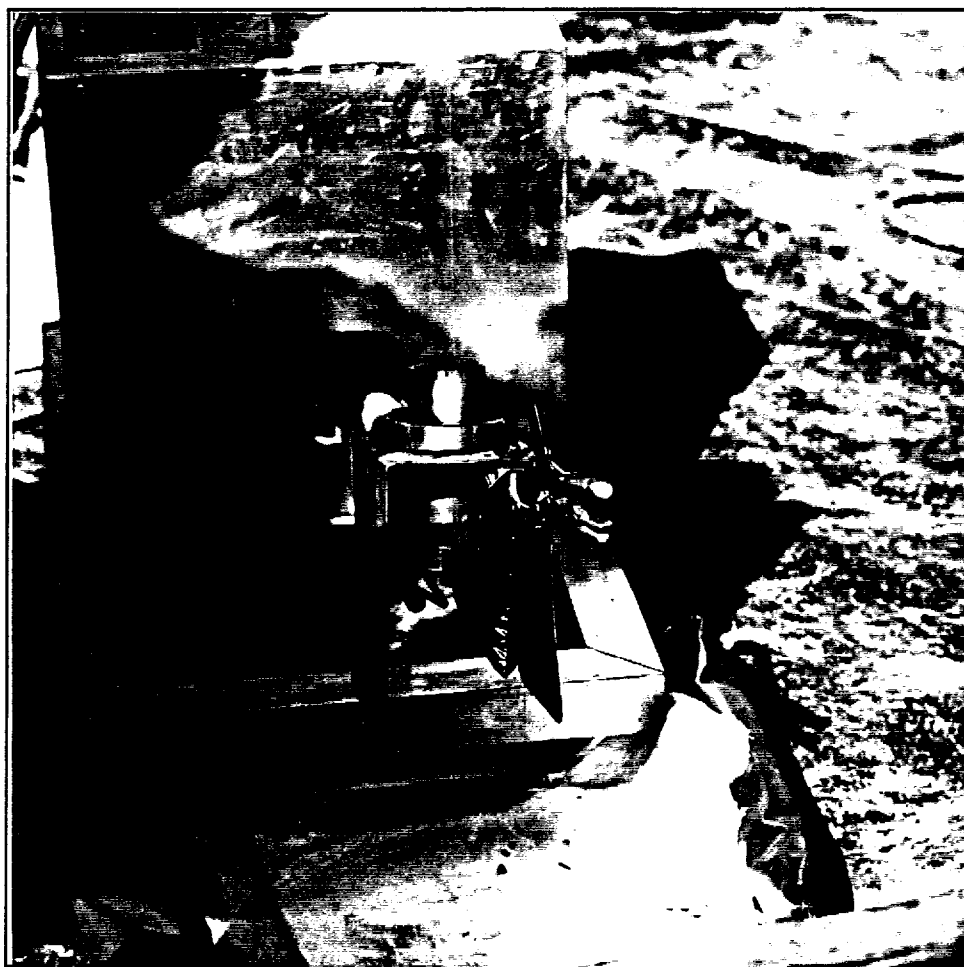
The procedures for each emulsion burn test were as follows:

The emulsion was poured into the water-filled pan over a spill plate that prevented the emulsion from touching and sticking to the bottom of the shallow pan. The volume of oil used for each test was held constant at 13 L (3.5 gallons) for each test in the 1.2 m<sup>2</sup> pan and 66 L (17.5 gallons) in the 3.3 m<sup>2</sup> pan. The volume of emulsion used and the initial thickness of the slick created thus increased with increasing water content. The burn tests started with a 12.5% water emulsion.

After the emulsion had been added to the pan, the wind speed was recorded (for some tests using both a hand-held anemometer and the weather station) and the temperature of the water was recorded. For the first three tests (without emulsion breaker) a baggie containing 500 mL (4 fluid ounces) of gelled fuel was clamped to the wind shroud of the Heli-torch beside the propane lighter (Figure 20). This was done to allow the accurate delivery of a known volume of igniter fuel to the test slick. The Heli-torch was positioned 0.5 to 1 m above the upwind edge of the burn pan. When the propane lighter was fired it melted the baggie and ignited the gelled fuel which fell onto the slick (Figure 21). It became clear that, as the water content of the emulsions increased, additional igniters would be required and the ignition procedure was changed. After the third test burn, a 500 mL ointment jar was used to ladle the gelled fuel onto the surface of the slick (Figure 22). These gelled fuel blobs were then sequentially ignited with a butane torch (Figure 23).



**Figure 19** Heli-torch static tests



**Figure 20** Baggie of gelled fuel clamped inside wind shroud of Heli-torch



**Figure 21** Gelled fuel ignited and released from baggie



**Figure 22** 500 mL gelled fuel igniters added from ointment jar



**Figure 23** Igniting gelled fuel with butane torch



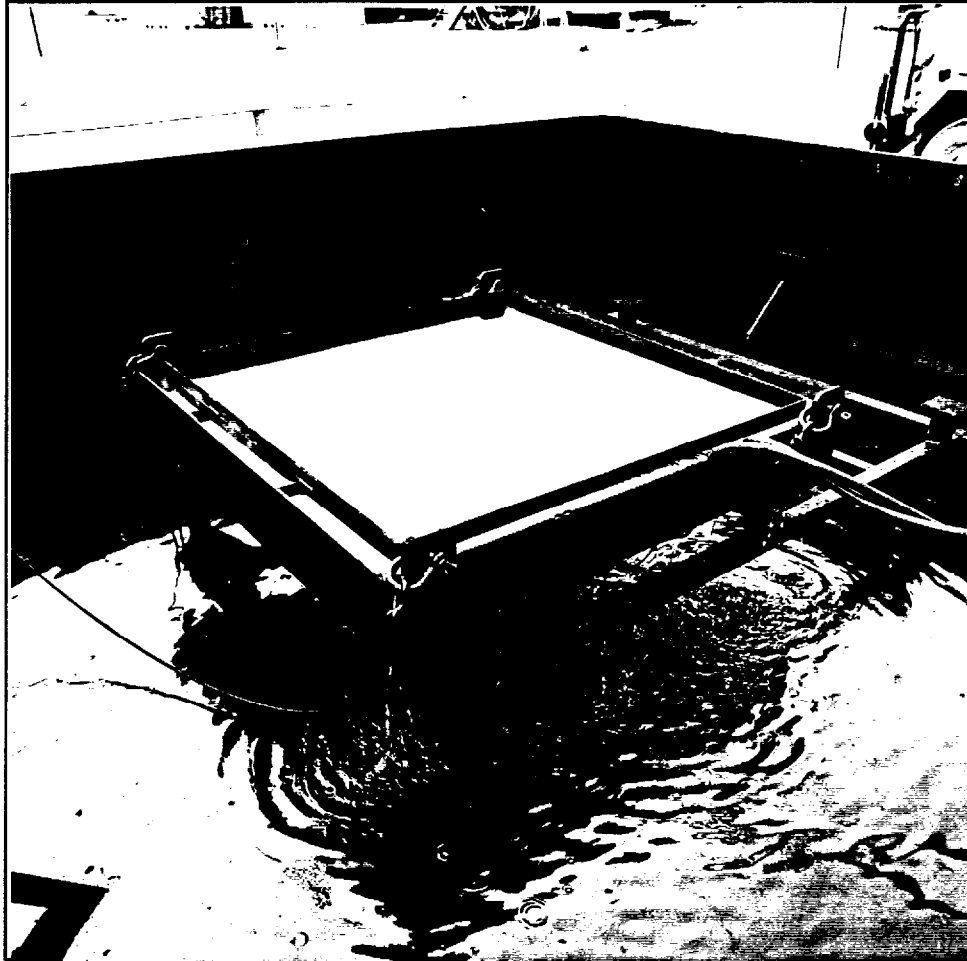
For each burn test the following were recorded:

- preheat time - the time since firing the igniters required for flames to begin to spread away from the burning gelled fuel;
- ignition time - the elapsed time required for the flames to cover the entire pan surface;
- vigorous burn time - the time for the water beneath the slick to boil causing higher flames, greater flame radiation, oil droplets to be sprayed up from the slick and/or a hissing sound;
- extinction time - the time for the flames to completely extinguish.

Each burn was videotaped, photographed from an elevated platform, and observed visually. After each burn the residue was cooled by pumping fresh water into the annulus of the pan between the raised lip and the outer wall (Figure 24). The warm water in the pan emptied over the edge of the pan into the tank and was replaced by cool water. The residue was retained by the raised lip inside the pan.

Once cooled, the residue was collected with a shovel and placed in plastic bags (Figure 25). The residue was then weighed to allow calculations of burn efficiency and rate. The burn efficiency was calculated by comparing the weight of the residue with the weight of oil added initially in the emulsion. The weight of oil added was estimated by multiplying the weight of the emulsion by the oil content of the emulsion, corrected from volume fraction to mass fraction by using the density of the oil (Appendix 1) and that of seawater. The burn rate was calculated by dividing the volume of oil burned by the pan area and the time from full flame coverage (ignition time) to extinction. In some tests the residue was re-ignited after it had extinguished in order to determine the maximum-possible removal efficiency. In these cases a steel "cookie-cutter" (Figure 26) was used to take a small sample of the residue from a known area. The intermediate burn efficiency was estimated by calculating the weight of residue remaining by multiplying the weight of residue collected from inside the cookie cutter by the ratio of the pan and cookie cutter areas.

If emulsion breaker had been used during the test, the pan was emptied completely in order to ensure that the water for each test was surfactant-free.



**Figure 24** Cooling water being added to small pan



**Figure 25** Residue collection



Figure 26 "Cookie-cutter" for residue sampling

#### **4.2.7 Pre-Mixed Emulsion Breaker Testing**

For many of the emulsion burn tests, EXO 0894 emulsion breaker was added to the slick prior to ignition (or after an unsuccessful ignition of an untreated slick). The following procedure was used:

- for the 1.2 m<sup>2</sup> pan tests the desired volume of emulsion breaker (based approximately on a chemical-to-emulsion ratio of 1:475 - the same as used in the laboratory burn tests) was added dropwise by pipette to the slick. The pipette was moved over the slick to evenly distribute the drops of emulsion breaker.
- for the 3.3 m<sup>2</sup> pan tests the EXO 0894 was placed in an empty graduated Windex bottle and weighed. The chemical was sprayed over the surface of the slick until it was estimated that the desired volume had been applied. The exact amount of emulsion breaker added was determined by re-weighing the bottle.
- after the emulsion breaker had been added, it was mixed into the slick with a 25 mm (1 inch) wide stick for 10 to 15 minutes. Care was taken to thoroughly mix the entire surface and depth of the slick.
- the slick was then allowed to sit for one hour prior to the first ignition attempt.

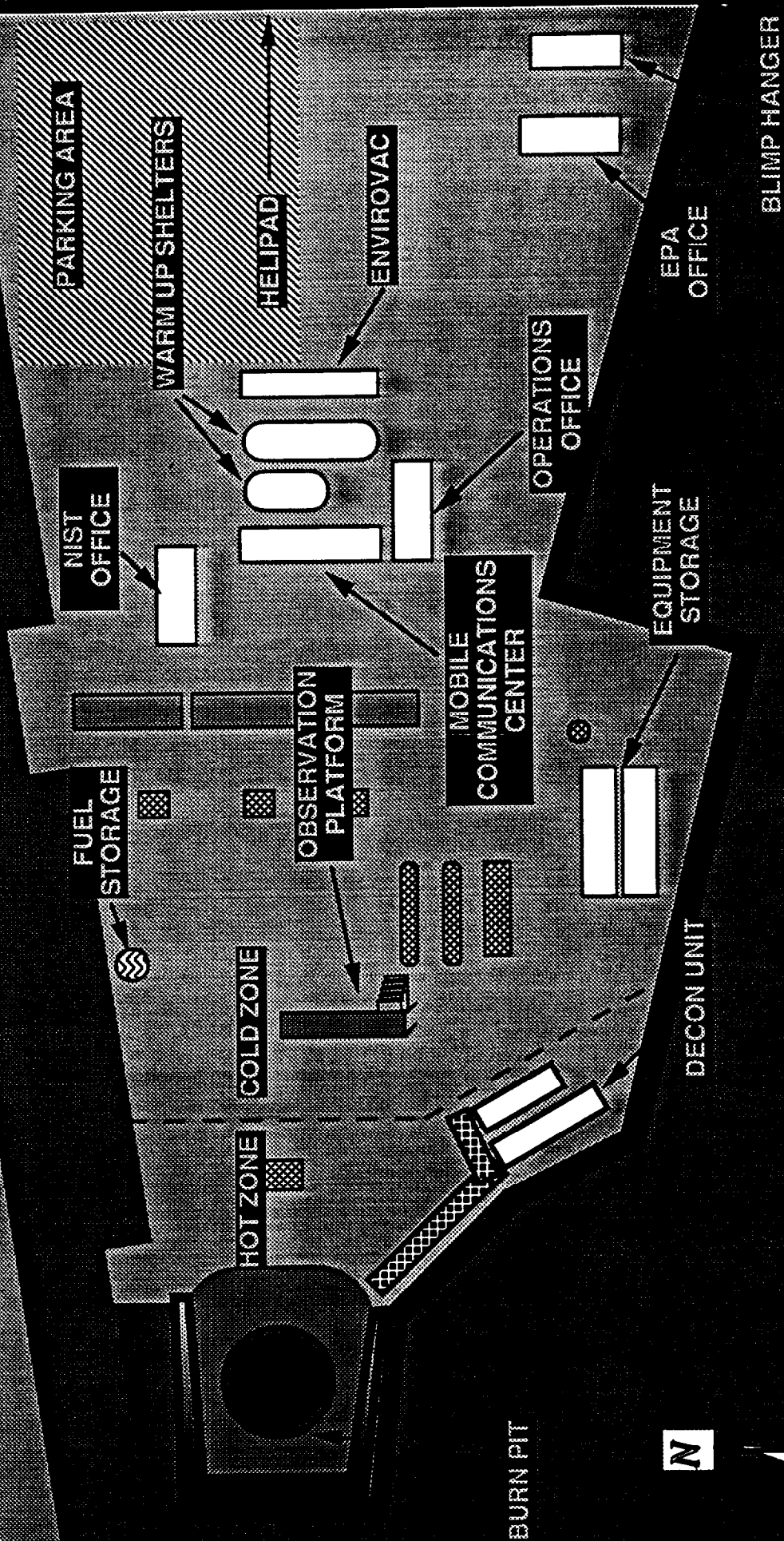
#### **4.2.8 Enhanced Igniter Testing**

In one test, the gelled fuel igniters were prepared with the required dose of EXO 0894 emulsion breaker already mixed in. These were ladled onto the slick and ignited in the usual manner. After extinction of the fire, it was clear that a significant amount of emulsified residue remained. The residue was gently mixed, then allowed to sit for 90 minutes and re-ignited with chemical-free gelled fuel.

### **4.3 MESO-SCALE TESTING**

In September, 1994 another series of burn tests were carried out in Prudhoe Bay, AK. This series of three tests involved significant volumes of emulsions and was carried out in a pit filled with fresh water. This pit was located on Arco Alaska's Fire Training Ground. Figure 27 shows the layout of the site. All appropriate permits were obtained by Alaska Clean Seas.

# MESO-SCALE EMULSIONS BURN TEST ARCO FIRE TRAINING GROUNDS SITE LAYOUT



#### **4.3.1 Test Oil Weathering**

Approximately 13.1 m<sup>3</sup> (83 bbls) of fresh ANS crude oil was placed in the 3.6 m x 3.6 m x 1.5 m deep tank used in the previous tests. Two 3.3 m (11 foot) pipes with 3 mm holes drilled on 25 mm (1 inch) centers were placed 1.8 m (6 feet) apart in the bottom of the tank and connected to a 14 m<sup>3</sup>/min (150 cfm) air compressor. A 25 mm (1 inch) gear pump was used to pump the oil through a nozzle and spray it against a plastic sheet that directed the oil back into the tank. The tank was covered with an "A-frame" of plastic sheeting to protect the oil from the elements (Figure 28). The ends of the "A" were enclosed in a fabric netting to prevent access to the oil. The tank was fitted with steam tracing lines. As the air temperature dropped, steam from a portable generator was used to heat the oil and increase its evaporation rate.

#### **4.3.2 Emulsion Formation and Properties**

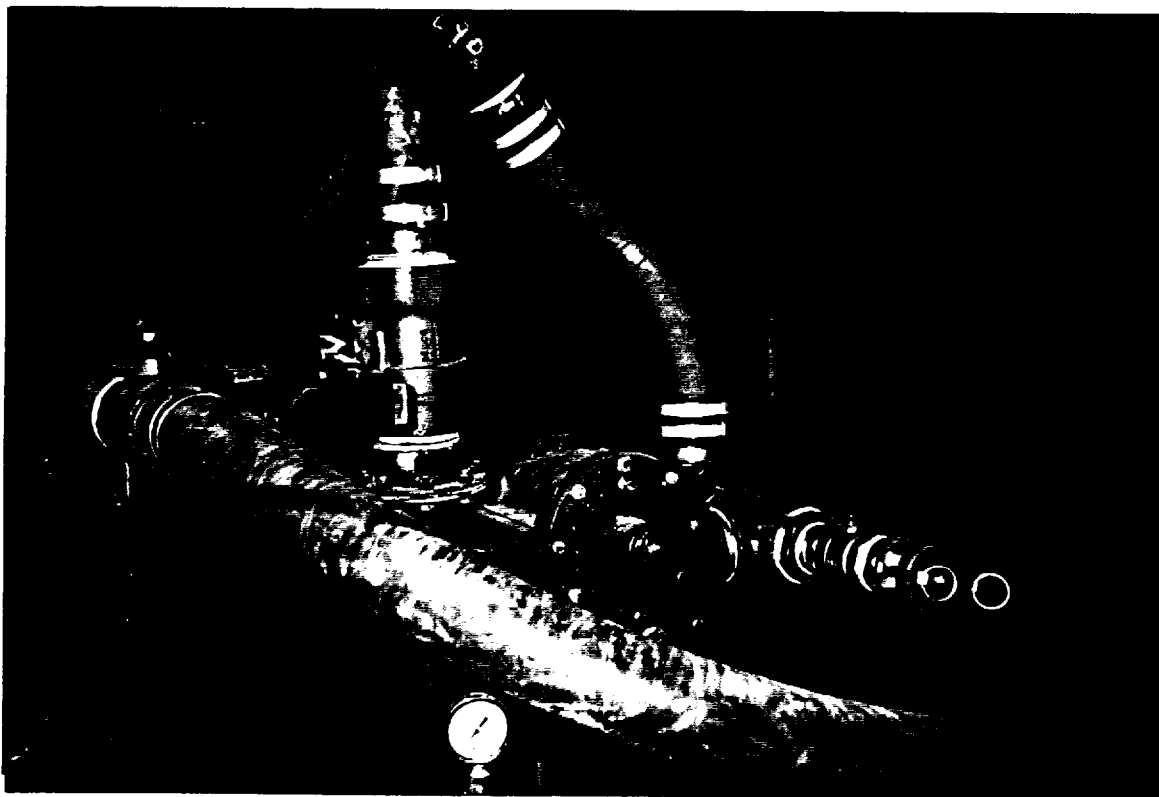
Batches of emulsion were mixed using a vacuum truck with a pump plumbed to draw oil from the bottom of the tank and return it to the top (Figure 29). This was 75 mm (3 inch) gear pump manufactured by Bowie Industries capable of pumping 380 L/min (100 gpm) at 190 rpm and 880 L/min (230 gpm) at 400 rpm. A valved tee in the suction line led to a seawater suction hose. Emulsion mixing was carried out at the ACS Annex Warehouse, remote from the burn pit area. The following procedures were used:

- a 50 m<sup>3</sup> (300 bbl) horizontal cylindrical steel tank was placed beside the weathered oil tank and filled with seawater from the seawater treatment plant;
- the desired volume of weathered crude was sucked into the vacuum truck - the volume taken was determined by measuring the depth of oil remaining in the square tank;
- the oil was recirculated in the vacuum truck with the gear pump;
- seawater was drawn into the pump at a rate less than one sixth the recirculation rate, as specified by Gåseidnes (1993) - the rate was monitored by measuring the rate of fall of water in a sight glass mounted on the end of the tank;
- once the desired volume of seawater had been added, the truck contents were recirculated for an additional two hours;
- just prior to delivery of the emulsion to the test site, the emulsion was recirculated for another two hours;



**Figure 28** Oil weathering system for meso-scale tests





**Figure 29** Gear pump for mixing emulsions in vacuum truck

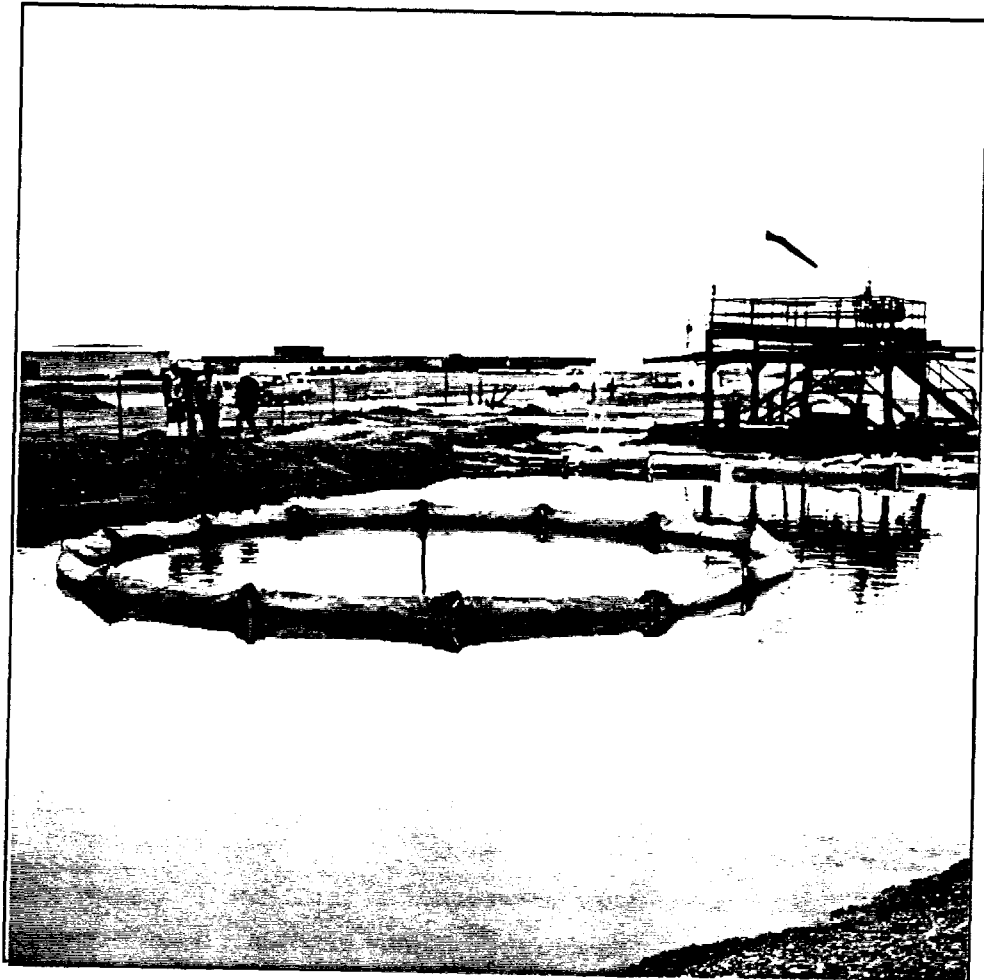
- the truck was driven over a weigh scale on its way to and from the burn pit and the difference in weights was used to determine the amount of emulsion used for each test;
- samples of emulsions used were taken from the hose used to put the emulsion into the burn pit and sent to BP's laboratory for water content determinations.

For the 50% water content test, the emulsion was mixed cold and the vacuum truck was left outside overnight. This resulted in an extremely viscous emulsion that severely taxed the vacuum truck's pump and would not drain quickly inside the tank to the suction of the pump. The oil for the subsequent 60% water content test was warmed to about 25°C (77°F) prior to being sucked into the vacuum truck. The seawater was not heated, but the vacuum truck was parked inside the warehouse overnight. The temperature of this emulsion was 7°C (45°F) after it had been added to the pit.

#### **4.3.3 Test Site and Equipment**

The tests were conducted in a lined, bermed pit at the edge of ARCO's Fire Training Ground. The principal pieces of equipment located at this site were (see Figure 27 previous):

- a 28 m x 20 m x 1 m deep pit filled with fresh water;
- a circle of 3M 18-inch fire boom anchored and floating in the middle of the pit (Figure 30) - the 30 m (100 foot) length of boom encompassed an area of 69.5 m<sup>2</sup> (760 ft<sup>2</sup>) based on two diameter measurements (at right angles) of 10.1 m (33.2 feet) and 8.6 m (28.4 feet);
- command, communications and decontamination trailers;
- warm-up tents for visitors;
- trailers and tents for the smoke plume measurement program equipment and personnel;
- anemometers and a wind sock;
- a gelled fuel mixing area;
- a helicopter landing area; and,
- an MBB 105 helicopter for the Heli-torch and, a 206 L Jet Ranger helicopter and a Twin Otter fixed wing aircraft for the smoke plume monitoring program.



**Figure 30** Fire boom in pit

#### **4.3.4 Gelled Fuel Preparation**

The gelled fuels were mixed in 40 L (10 gallon) Nalgene drums at a site beside the helicopter landing area (Figure 31). Batches of gelled fuel — 19 L (5 gallons) of 50/50 gasoline/crude oil and 75/25 gasoline/crude, and 38 L (10 gallons) of straight gasoline — were made using the following procedures.

- the desired volumes of the fuels were measured into the Nalgene containers;
- the needed amount of Surefire gelling agent was weighed into a tin can;
- the gelling agent was placed into a kitchen flour sifter to prevent adding lumps to the fuel;
- as the gelling agent was sifted into the fuel, the mixture was stirred with a 25 mm (1 inch) wide stick;
- mixing continued after the last of the gelling agent had been added until the fuel had set to the desired consistency (i.e., Jello-like);
- the contents of the Nalgene container were then poured into the 205 L (55 gallon) Heli-torch drum, mounted on the frame and the connections made to the helicopter (it proved necessary to secure the electrical plug with duct tape so it would not pull free when airborne);
- the operation of the pump and propane lighter were checked on the ground, prior to liftoff.

The first batch of gelled gas/crude was mixed in the 205 L (55 gallon) Heli-torch drum using its built-in, hand-cranked mixer. Wind hampered the uniform addition of the gelling agent, and the gel formed was lumpy on top and runny underneath because of poor mixing in the drum.

#### **4.3.5 Heli-torch Aerial Performance Testing**

Prior to the emulsion test burns, the Heli-torch was evaluated for its ability to light and deliver the alternative fuel gels while being flown beneath a helicopter. This involved loading 7.5 L (2 gallon) test batches of 50/50 gas/crude and 75/25 gas/crude into the Heli-torch; flying it over the empty pit; activating the Heli-torch to release and light the alternative fuel; and, visually assessing the performance of the alternative fuel on the water. Several runs were made at different air speeds and orientations to the prevailing winds.

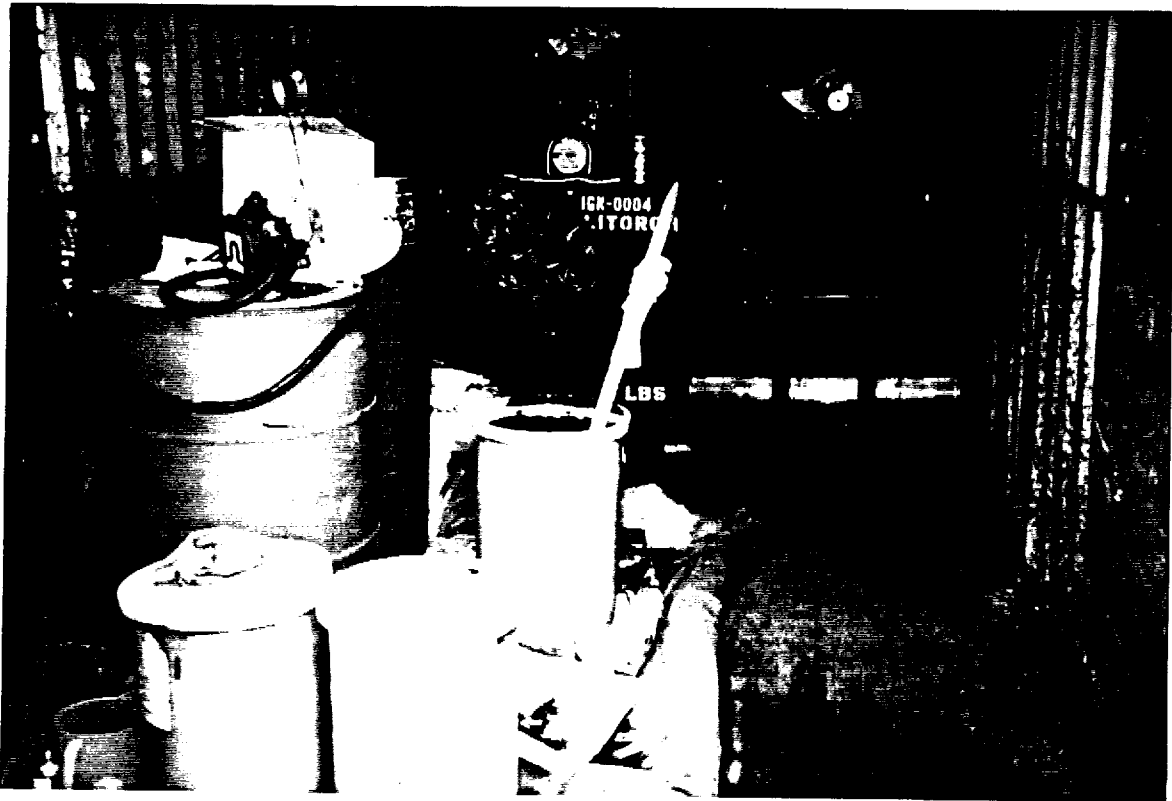


Figure 31 Gelled fuel mixing area

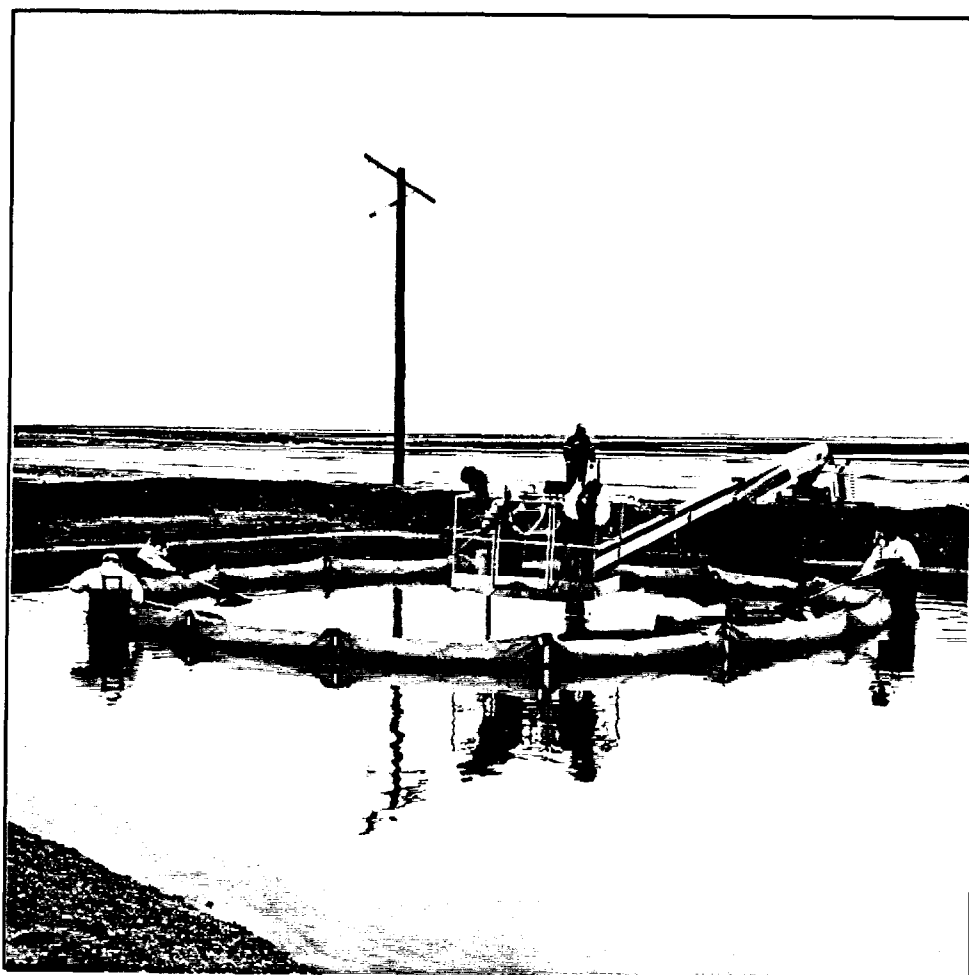
#### 4.3.6 Emulsion Burning Tests

Two emulsions were burned in the pit: 50% water and 60% water emulsions created with weathered ANS crude. One burn of fresh, water-free ANS crude was also undertaken as a baseline for the smoke plume sampling program. The following were the procedures followed:

- once a decision had been made to proceed with a burn, based on appropriate weather conditions, the vacuum truck containing the emulsion (or fresh crude) was backed up to the pit;
- the emulsion (or fresh crude) was pumped into the area contained by the circle of fire boom using a gear pump and 100 mm (4 inch) diameter hose - the end of the hose was placed inside the boomed area and supported there by persons dressed in appropriate protective clothing (Figure 32);
- once the vacuum truck was empty, the hoses were disconnected and an emulsion (or fresh crude) sample was obtained for subsequent analysis;
- the desired volume of EXO 0894 emulsion breaker (27 L - 7 gallons - based on a 1:475 demulsifier:emulsion ratio for 12.7 m<sup>3</sup> - 80 bbls - of emulsion) was sprayed from air-pressurized garden sprayers onto the surface of the emulsion slick by persons on a man-basket (Figure 33). This was moved over the slick to obtain as even a coverage as possible;
- the emulsion breaker was mixed into the emulsion slick using canoe paddles for a period of 30 minutes (longer than for the small-scale pan burns because of the much thicker slicks contained in the pit);
- the emulsion slick was allowed to sit undisturbed for at least one hour;
- for one test - the 60% emulsion burn - the water and slick temperatures were measured;
- once the go-ahead was given, the slick was ignited - in the case of the 50% water emulsion burn and the fresh crude burn this was accomplished using the Heli-torch loaded with 19 L (5 gallons) of a 75/25 gasoline/crude mixture gel and gelled gasoline respectively - Figure 34;



**Figure 32** Pumping emulsion into fire-boomed area



**Figure 33** Spraying EXO 0894 onto emulsion slick





**Figure 34** Ignition with the Heli-torch

- for the 60% emulsion burn, the ceiling and visibility were below VFR (Visual Flight Rules) minimums and the helicopter could not be employed - in this case the gelled 75/25 gasoline crude mix was manually ladled onto the slick, using the man-basket to ensure uniform coverage, and the slick was ignited using Dome hand-held igniters thrown onto the slick from the upwind berm of the pit (Figure 35);
- the subsequent ignition, flame spread and burn were videotaped, photographed and observed from several angles;
- the following times were recorded:
  - preheat time (the time since ignition for flame to begin to spread from the gelled fuel to the surrounding emulsion)
  - ignition times (the times for flames to involve areas of 10%, 25%, 50% and the entire slick area);
  - the elapsed time to failure of the fire-boom;
  - the time to the vigorous burn phase; and
  - the extinction times (the times for the flames to die down to cover less than the full boomed area, 50%, 25% and 10% of the boomed area, and to extinguish completely).

The time of occurrence of other phenomena were also recorded:

- once the fire had extinguished and the water had cooled, the residue was recovered manually and with rakes and shovels and placed in plastic bags (Figure 36) for weighing and samples taken for analysis;
- after the first burn (the 50% emulsion), the fire boom was removed and replaced; after the second burn the fire boom was reused - before it was filled with emulsion for the last test, it was covered with plastic sheeting to restore its oil holding ability.
- the burn efficiency and rate were determined as described in 4.2.6 above. The area used in the burn rate calculation was the area enclosed by the circle of boom multiplied by the time averaged percent of the area on fire from full ignition to the beginning of the final extinction to account for the leaking oil outside the boom that was on fire.



**Figure 35** Hand-held Dome igniters



**Figure 36   Residue Recovery**

## **5.0 RESULTS AND DISCUSSION**

As with the previous section, this chapter is divided into three portions, each of which deals with one of the experimental phases of the study.

### **5.1 LABORATORY TESTING**

#### **5.1.1. Alaska North Slope Oil Weathering**

In order to conduct the laboratory tests with oils and emulsions that might be expected during a real spill event, and to determine the effects of evaporation on ignition and burning, samples of ANS crude were artificially weathered by sparging. The three batches of evaporated oils used for the tests were sparged until they had lost 10.3%, 27.8% and 27.9% of their initial volume. Fresh ANS crude was also used for some tests. In addition, Endicott crude, a major constituent of ANS crude was used in two burn tests: it was not artificially evaporated. The physical properties of fresh and weathered ANS crude and Endicott crude may be found in Appendix 1.

#### **5.1.2 Alaska North Slope Crude Emulsification Tendency and Stability**

It is known that ANS crude must evaporate to greater than about 15% loss by volume in order to form stable emulsions at warm (15°C) temperatures (Bobra and Callaghan 1990, S.L. Ross 1994); at freezing temperatures indications are that even fresh ANS crude will form stable emulsions (Bobra and Callaghan 1990). Standardized emulsion formation tests (Zagorski and Mackay 1982) were conducted with the fresh, 10.3% and 27.9% evaporated ANS crude samples at temperatures of 10°C to 15°C and 5 to 8°C. All tests were conducted with 35 ppt (parts per thousand) saline water. The results are given in Table 2 and Appendix 3. The data clearly illustrate that only the most evaporated oil would form a stable emulsion in the test program.

**Table 2**  
**ANS Crude Oil Emulsion Formation Tendency & Stability Test Results**

Test Temperature (°C)	Evaporative Loss (volume %)	$f_0^*$	$f_\infty^{**}$
10 to 15	0	0	0
10 to 15	10.3	0	0
10 to 15	27.9	1	1
6.4	0	0	0
7.9	10.3	0	0
8.0	27.9	1	1

\* a value of  $F_0$  of 0 indicates no tendency to form an emulsion; a value of 1 indicates a strong tendency

\*\* a value of  $f_\infty$  of 0 indicates a highly unstable emulsion; a value of 1 indicates a highly stable emulsion (after Zagorski and Mackay 1982)

The fresh Endicott crude formed stable emulsions at 15°C during identical tests in a previous study (S.L. Ross 1994 - see Appendix 1).

### **5.1.3 Chemical Emulsion Breaker Screening Tests with Alaska North Slope Crude**

Since the 27.9% weathered oil was the only oil that formed a stable emulsion, it was used for the emulsion breaker screening test. A 67% salt water content emulsion was prepared with this oil.

The results of the emulsion breaker test are given in Table 3 and in Appendix 3. These are best interpreted as a general trend since the accuracy of the test is estimated to be approximately  $\pm 20$  to 30% by Fingas and Fieldhouse 1994. The trend is that all three demulsifiers broke the emulsions equally well in the apparatus. The EXO 0894 may have performed somewhat less effectively in this test than the other two chemicals. All three chemicals were effective at dosages as low as one part chemical to 3300 parts of oil - this dose was equivalent to about 1:1100 demulsifier to emulsion.

**Table 3**  
**Emulsion Breaker Test Results**

Demulsifier	Emulsion: Water Ratio (vol:vol)	Demulsifier:Oil		Average Water* Content (%vol)
		Vol. Demulsifier (μL)	Ratio D:O	
Alcopol	1:10	0	0	66
		40	1:165	0**
		20	1:330	0
		8	1:825	0
		4	1:1650	0
		2	1:3300	0
	1:20	10	1:330	12
		2	1:1650	0
Breaxit	1:10	0	0	73
		40	1:165	11
		20	1:330	0
		8	1:825	0
		4	1:1650	0
		2	1:3300	0
	1:20	10	1:330	0
		2	1:1650	52
EXO 0894	1:10	0	0	71
		40	1:165	31
		20	1:330	13
		8	1:825	25
		4	1:1650	24
		2	1:3300	0
	1:20	10	1:330	0
		2	1:1650	0

\* average of three analysis

\*\* negative values were assumed to be zero

#### 5.1.4 Baseline Ignition and Burning Tests with Alaska North Slope Crude Oil and Emulsions

##### Oil and Emulsions

The results of the baseline burns are given as the first 14 runs on Table 4. A typical burn is shown on Figure 37. Temperature records for each burn may be found in Appendix 4. Ignition times of zero were recorded on Table 4 for the following reasons: 1) the ignition was instantaneous (i.e., the flame flashed over the slick); 2) the slick was unignitable with the sorbent igniters; 3) fresh oil was used to ignite the slick. These burns provided a reference to the natural ignitability and burnability of fresh, 10.3% and 28% weathered ANS emulsions. Both the fresh and 10.3% weathered ANS emulsions were successfully ignited at all water contents tested. The 28% weathered ANS test emulsions proved very difficult to ignite, and if ignited, they burned poorly. At 40% water the 28% weathered ANS would not ignite, even with the addition of 200 mL of fresh crude. Therefore this, and all water contents above this, were deemed to be unburnable for the 28% evaporated crude.

The fresh ANS and 10.3% weathered emulsion burns exhibited a foaming action near the end of the burn. The residue would begin to foam and then the foam would spread over the surface of the emulsion, smothering the flames. Sometimes the flames would nearly extinguish, but the foam would recede and the fire would flare back up again.

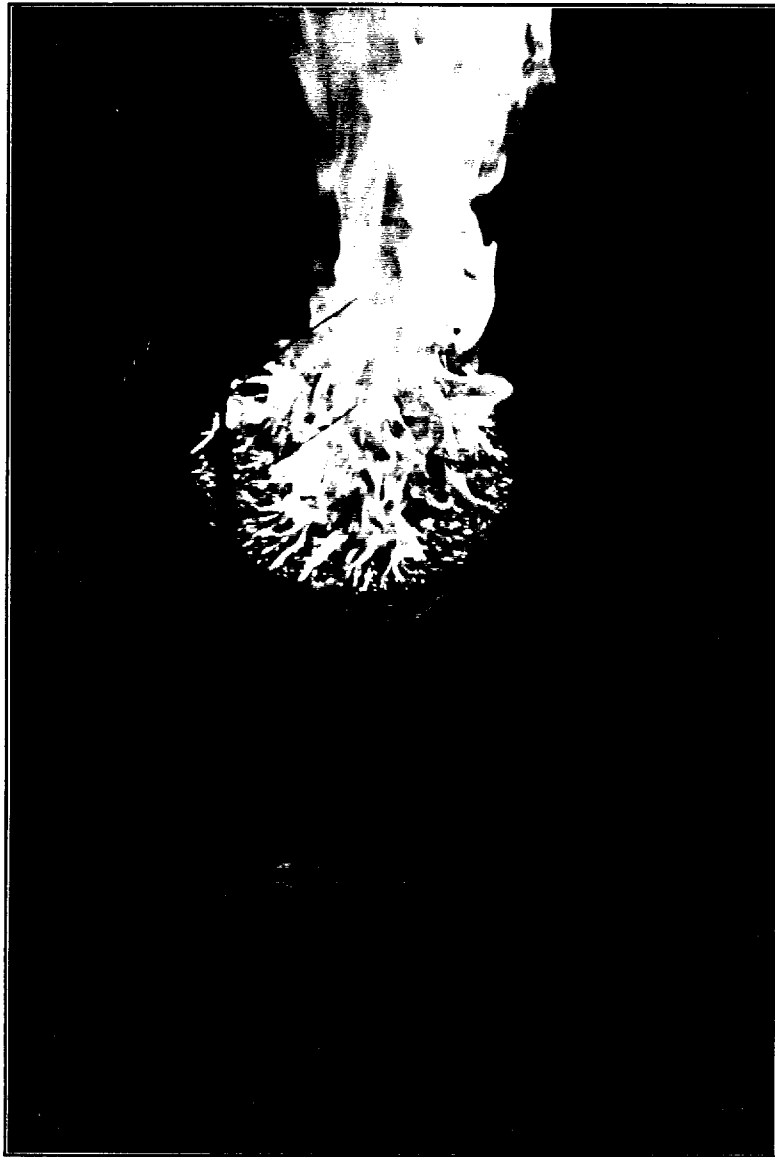
Midway through the burns with 40% and 60% water content emulsions of fresh and 10.3% evaporated ANS crude, balls of salt water could be seen forming at the slick's undersurface, detaching and sinking in the fresh water in the pan. These salt water balls appeared to consist of 10 to 20 mm diameter drops of water surrounded by a skin of oil or emulsion. Their appearance has been noted before (Guenette et al. 1994) and is believed to be an indication of the emulsion breaking mechanism by which the slick loses water (see Section 3.2). The production of these salt water balls from the bottom of a burning emulsion slick may indicate that the emulsion is less than fully stable at elevated temperatures (below 100°C).

Figure 38 shows the increase in ignition time as a function of water content for the three degrees of evaporation (fresh, 10.3% and 28% loss). It is clear that, once the water content exceeds 25%, the ignition time increases rapidly with water content. All the burns with the 28% evaporated ANS required



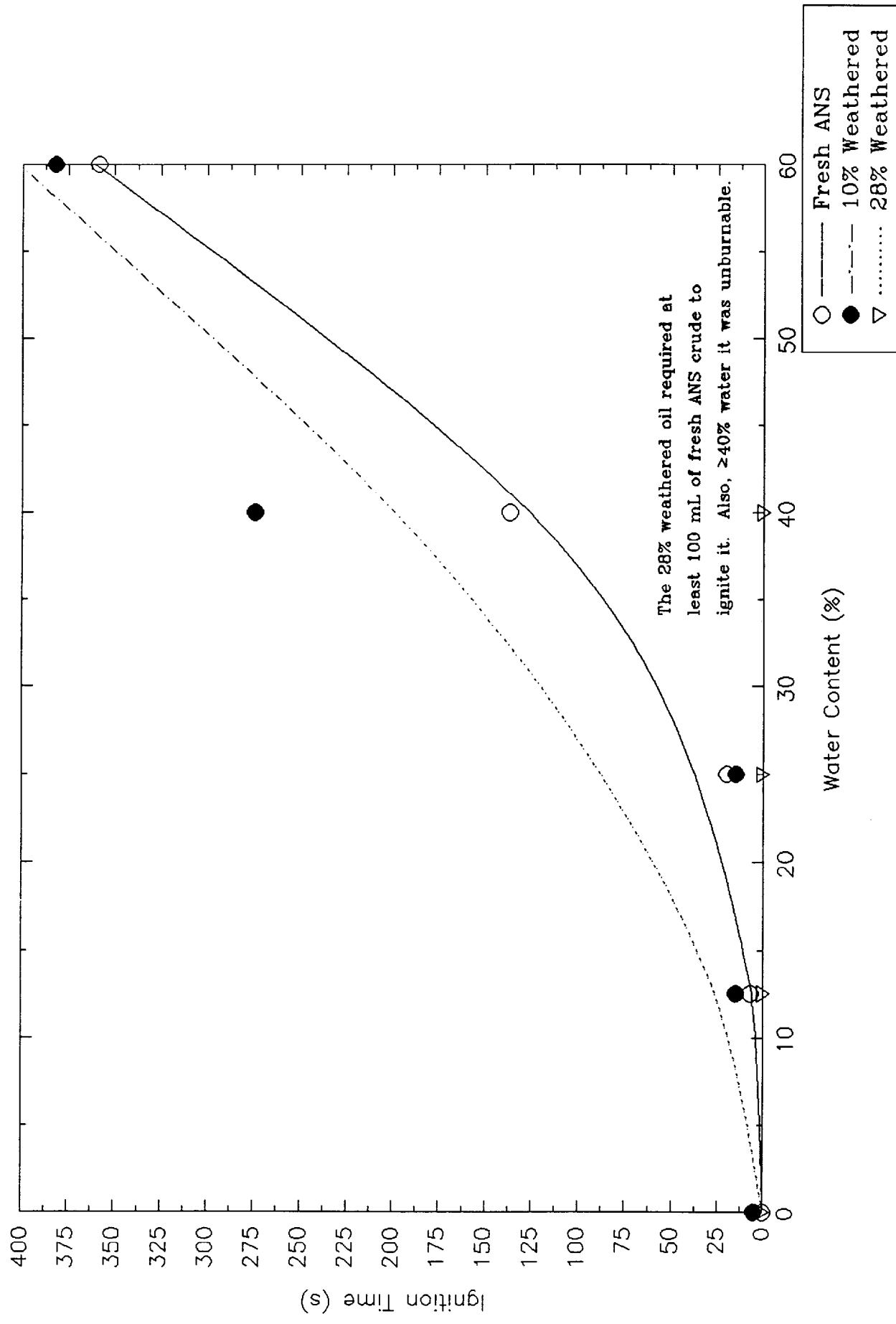
Table 4 - Laboratory-scale Burn Test Results

Exp #	% Evap	% Water	% Emulsion	Oil Mass (g)	Vol (ml)	Residue Mass (g)	Ignition #	Ignition Type	Preheat Time	Ignition Time	Intense Burn Time	Extinction Time	Breaker Type	Breaker Amt	Comments	Mass Oil Burned (g)	Burn Rate (mm oil/min)	Burn Efficiency (%)
1	0	0	2187.5	2500	236.74	1	1	gas pad	00:00:00	00:00:00	00:11:40	00:12:23	none		Emulsion mass estimated	1950.76	1.43	89.18
2	10.3	0	2241.0	2500	137.20	1	1	gas pad	00:00:00	00:00:05	00:15:24	00:17:03	none		Air3 disconnected/cold oil direct from fridge;	2103.80	1.10	93.88
3	28	0	2405.0	2500	598.00	1	1	gas pad	00:00:00	00:00:18			none		foamed out			
						2	2	oil pad	00:00:00	00:00:00			none		foamed out			
						3	3	100 ml oil	00:00:00	00:00:00	00:20:34	00:22:05	none		foamed out	1809.00	0.70	75.22
4	0	12.5	2420.0	2500	579.50	1	1	gas pad	00:00:00	00:00:07	00:11:44	00:12:53	none		foamed out	1538.00	1.10	72.63
5	0	25	2434.4	2500	167.20	1	1	gas pad	00:00:00	00:00:20	00:07:09	00:11:08	none		foamed out, salt water balls	1515.35	1.28	90.06
6	0	40	2432.3	2500	167.20	1	1	gas pad	00:00:00	00:00:20	00:07:09	00:11:08	none		foamed out, salt water balls	1292.18	1.59	88.54
7	0	60	2448.8	2500	175.10	1	1	gas pad	00:01:52	00:05:59	00:10:17	00:11:09	none		foamed out, weak burn; salt water balls	804.42	1.42	82.12
8	10.3	12.5	2270.4	2500	947.80	1	1	gas pad	00:00:00	00:00:15	00:10:30	00:13:30	none		foaming flame dies & flares	1038.80	0.70	52.28
9	10.3	25	2332.1	2500	568.00	1	1	gas pad	00:00:00	00:00:15	00:07:13	00:11:15	none		foamed out; used cookie cutter to estimate residue	1183.06	0.86	67.64
9a	10.3	25	568.0		140.50	2	2	gas pad	00:00:22				none		reignition of residue (assumed to be water free)	425.50	0.59	75.18
						3	3	oil pad	00:00:17				none					
						4	4	100 ml oil	00:00:00	00:00:00	00:04:28	00:06:28	none		Totals	1608.58		91.97
10	10.3	40	2430.1	2500	532.70	1	1	gas pad	00:00:00	00:00:54	00:14:10	00:16:47	none		salt water balls; foamed out	925.36	0.89	63.47
11	10.3	60	2529.0	2500	207.50	1	1	gas pad	00:01:10	00:03:34			none		salt water balls	804.10	1.06	79.49
						2	2	oil pad	00:00:00	00:08:22	00:11:23	00:13:08	none		dies/flares; foaming			
12	28	12.5	1803.8	1800	801.20	1	1	gas pad	00:00:33				none		Extinction time not written down, 12.15 from graph	777.12	0.56	49.24
						2	2	oil pad	00:00:28				none					
						3	3	100 ml oil	00:00:00	00:00:17	00:08:33	00:12:15	none					
13	28	25	1771.6	1800	741.80	1	1	gas pad	00:00:21	00:00:22			none		weak flame; at limit of combustion; not much smoke;			
						2	2	oil pad	00:00:00	00:00:18	00:14:38	00:17:59	none		dies/flares; foamed out			
						3	3	100 ml oil	00:00:00				none		Air3 signal oscillating			
14	28	40	1857.3	1800	622.80	1	1	gas pad	00:00:42				none					
						2	2	oil pad	00:00:00	00:00:29			none					
						3	3	100 ml oil	00:00:00	00:00:11			none					
						4	4	200 ml oil	00:00:00				none					
14a	28	40				5	5	gas pad	00:00:00	00:00:24	00:16:47	00:20:19	none		premixed (breaker dropwise & stirred) for 2 minutes	588.90	0.29	44.17
						6	6	oil pad	00:00:00				none					
						7	7	100 ml oil	00:00:00				none					
15	28	40	1825.7	1800	493.00	1	1	31.4 g Napalm	00:00:00	00:00:00	00:01:17	00:01:17	none		weak flame;	491.48	0.21	44.10
						2	2	28.8 g Napalm	00:00:00	00:00:29	00:10:38	00:10:13	EXO-894 4 ml (pure)		Air3 signal oscillating			
						3	3	100 ml Crude	00:00:00	00:00:29	00:10:38	00:10:13	EXO-894 4 ml (pure)		premixed 2 min	602.42	0.53	54.89
16	28	40	1783.6	1800	317.60	1	1	31 g gelled diesel	00:00:00	00:00:00	00:01:04	00:01:04	Alcopol 4 ml		daily intense burn; minor foaming;			
						2	2	33.8 g gelled diesel	00:00:00	00:00:41	00:03:18	00:03:18	Alcopol 4 ml		Air3 signal oscillating			
						3	3	100 ml crude	00:00:00	00:00:52	00:12:02	00:14:38	EXO-894 4 ml		premixed 5 min	752.58	0.47	70.32
						4	4	100 ml crude	00:00:00				EXO-894 4 ml		weaker flames than exp #15;			
17	28	40	1787.2	1800	238.20	1	1	31.74 g gelled crude	00:00:00	00:00:00	00:00:36	00:00:36	EXO-894 4 ml		cooled 10 min; very intense burn; holes in residue			
						2	2	30.03 g gelled crude	00:00:00	00:00:00	00:00:43	00:00:43	EXO-894 4 ml		premixed 5 min			
						3	3	81.1 g gelled crude	00:00:00	00:00:00	00:01:16	00:01:16	EXO-894 4 ml		foamed out	838.12	0.82	77.97
						4	4	100 ml fresh ANS	00:00:00	00:01:08	00:12:15	00:12:39	EXO-894 4 ml		cooled 10 min; foamed out			
18	28	50	1812.7	1800	187.60	1	1	31 g gelled crude	00:00:00	00:00:31	00:08:35	00:10:13	EXO-894 4 ml		premixed 5 min; pulled Air1			
						2	2	85 g gelled crude	00:00:00	00:01:31	00:08:35	00:10:13	EXO-894 4 ml		foamed out, strong burn; holes in residue	718.75	0.70	79.30
19	28	50	1809.6	1800	140.00	1	1	79.4 g Napalm	00:00:00	00:01:38	00:08:41	00:10:09	EXO-894 4 ml		breaker mixed in Napalm			
						2	2	85.8 g gelled crude	00:00:00	00:01:55	00:08:41	00:10:09	EXO-894 4 ml		sat for 12 min; Air1 failed at end; dies/flares	764.80	0.71	84.53
						3	3	88.64 g gelled crude	00:00:00	00:02:33	00:03:36	00:03:36	EXO-894 4 ml		breaker in igniter			
20	28	50	1808.8	1800	189.90	1	1	100 ml gelled crude	00:00:00	00:00:00	00:08:30	00:09:15	EXO-894 4 ml		sat for 10 min; weak flame			
						2	2	85.6 g gelled crude	00:00:00	00:01:33	00:08:30	00:09:15	EXO-894 4 ml		mixed 3 min; strong flame; dies/flares; holes appear slowly;			
						3	3	90.58 g gelled crude	00:00:00	00:01:08	00:05:45	00:07:27	EXO-894 4 ml		some salt balls	714.50	0.80	79.00
21	28	60	1876.6	1900	194.40	1	1	70 g gelled diesel	00:00:00	00:00:00	00:01:32	00:01:32	EXO-894 4 ml		premixed 5 min; TC's not raised; strong flame holes in residue	536.24	0.73	73.39
22	28	60	1457.0	1500	105.78	2	2	83 g gelled diesel	00:00:45	00:01:07	00:04:45	00:05:50	EXO-894 4 ml		breaker in igniter;	477.02	0.87	81.85
23	28	60	2463.7	2500	133.35	1	1	100 ml Napalm	00:00:13	00:00:08	00:07:05	00:07:49	EXO-894 1:2000 (d.o)		mixed 5 min; strong flame;			
						2	2	81 g Napalm	00:00:08	00:00:36	00:07:05	00:07:49	EXO-894 1:500 (d.o)		premixed 5 min;	852.13	1.02	86.47
						3	3	83.9 g Napalm	00:00:08	00:00:24	00:08:20	00:08:53	EXO-894 4 ml		premixed 5 min; strong flame; salt balls; large holes in residue	862.98	0.90	88.25
24	10.3	60	2444.7	2500	114.90	1	1	100 ml gelled diesel/gas	00:00:24	00:01:03	00:02:16	00:02:16	EXO-894 4 ml		breaker in igniter; strong flame; holes in residue	624.22	0.81	82.08
25	10.3	70	2507.4	2500	128.00	1	1	100 ml Napalm	00:00:00	00:00:53	00:08:13	00:08:58	None		TC's raised late			
						2	2	80 g gelled diesel/gas	00:00:13	00:00:45	00:02:08	00:02:08	EXO-894 4 ml		salt balls; breaker in igniter			
26	0	40	2387.3	2500	350.90	2	2	75.5 g Napalm	00:00:00	00:00:32	00:11:03	00:12:15	EXO-894 2 ml		premixed 5 min; strong flame; dies/flares; holes in residue	1081.48	0.84	75.50
								67.2 g Napalm	00:00:23	00:01:01	00:09:17	00:09:54	EXO-894 4 ml		foamed slowly	831.38	0.85	84.71
27	0	60	2453.7	2500	150.10	1	1	82.5 g gelled diesel/gas	00:00:23	00:01:01	00:09:17	00:09:54	EXO-894 4 ml		breaker in igniter; strong flame; salt balls			



**Figure 37** Typical laboratory burn

Figure 38 Ignition Time vs. Emulsification  
Alaska North Slope Crude



fresh crude as a primer to initiate combustion thus the ignition times for these are all recorded as zero. The data in Figure 38 also show that ignition time increased with increasing degree of evaporation.

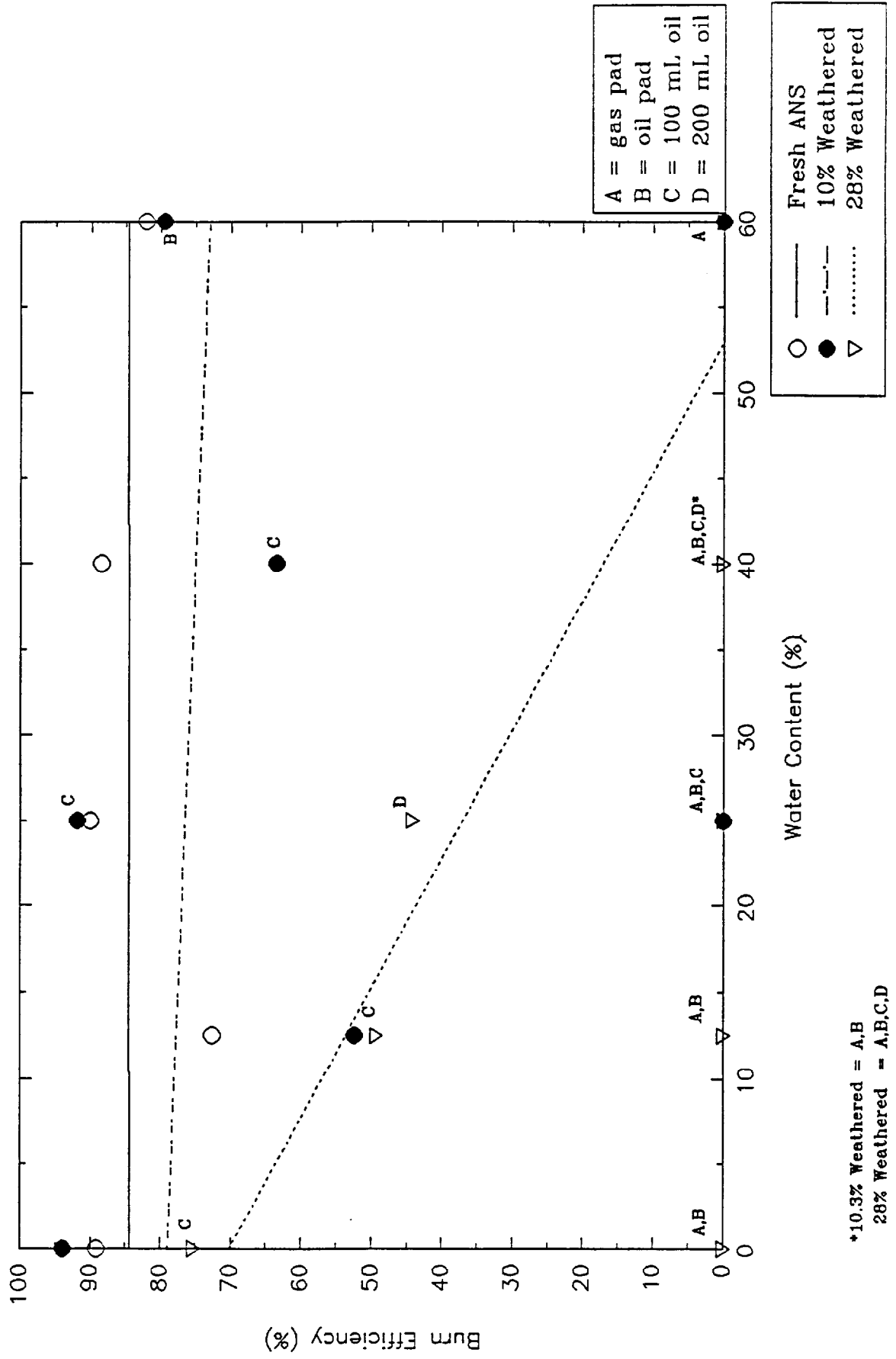
The oil removal efficiencies for the baseline runs are shown on Figure 39. The letters beside some of the symbols indicate the igniters used. For example, the inverted open triangle symbol at 12.5% on the abscissa indicates that neither the gasoline-soaked nor the crude oil-soaked sorbent pad could ignite the 12.5% water emulsion created with the 28% evaporated ANS. The inverted triangle directly above at 50% on the ordinate indicates that a 100 mL primer layer of fresh crude did successfully initiate combustion and that the burn removed 50% of the oil in the emulsion originally placed in the ring. It should be noted that, in all cases of successful burns it was assumed that the residue remaining contained no water. This was based on the visual appearance of the residue as a black, apparently water-free semi-solid or viscous, tarry fluid. The oil removal efficiency was not a strong function of water content for the fresh and 10% evaporated crude. This has been noted in other tests (S.L. Ross 1989, Guenette et al. 1994) and is presumed to be related to the emulsions being less than fully stable at elevated temperatures. The trend for the 28% evaporated emulsions is typical of fully stable emulsions: water contents in excess of 25% prevent burning of the emulsions.

Figures 40a and 40b illustrate that removal efficiency also declined with increasing degree of evaporation for all water contents. Higher water contents appear to accentuate the rate of decline.

Figure 41 shows the calculated baseline burn rate (in mm of oil per minute, excluding water) plotted against water content. The burn rate appears not to be a function of the amount of water in the emulsion for the fresh and 10% evaporated crudes. This has been reported before (Guenette et al. 1994) and is believed to be due to less-than-fully stable emulsions. The decline in burn rate with increasing water content for the 28% evaporated ANS is typical of oils that form fully stable emulsions (S.L. Ross 1989, Guenette et al. 1994).

Figure 42 shows the effect of increased evaporation on burn rate at constant water content. Increasing evaporation reduced the oil burn rate, as noted by Bech et al. (1992); the rate of decline does not appear to be greatly affected by water content.

Figure 39 Burn Efficiency vs. Emulsification  
Alaska North Slope Crude



**Figure 40** Burn Efficiency vs Weathering  
Alaska North Slope Crude

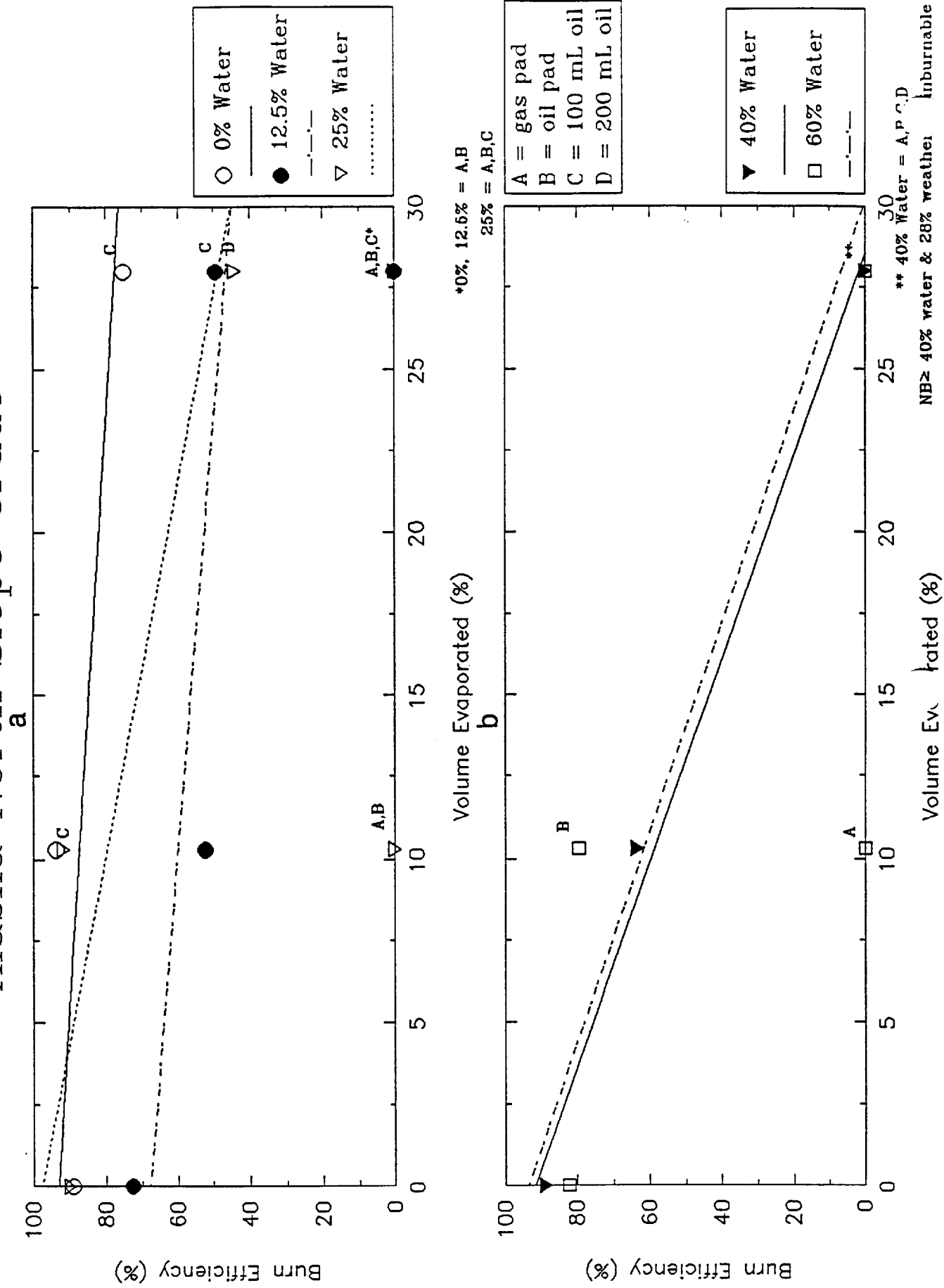
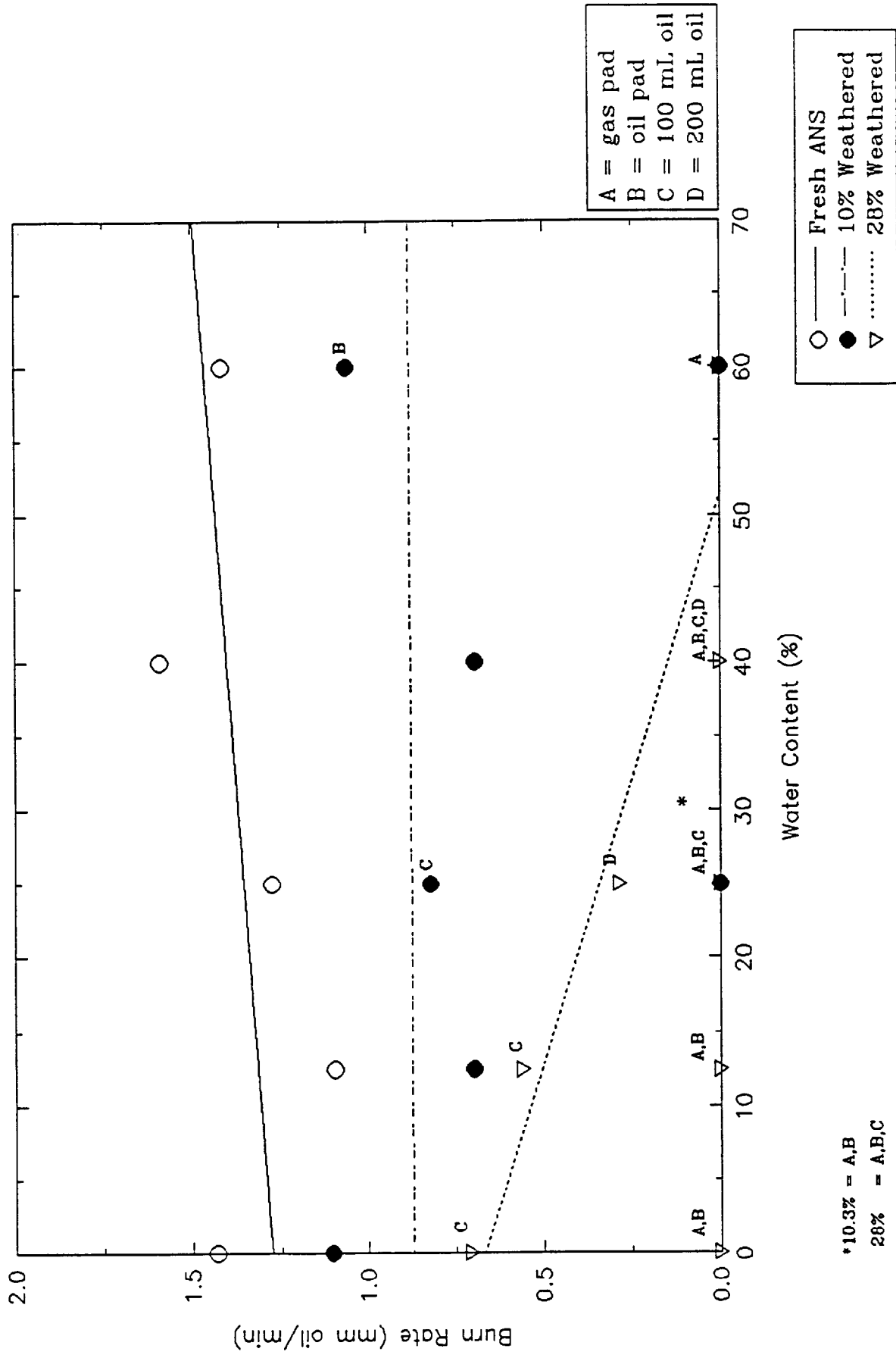


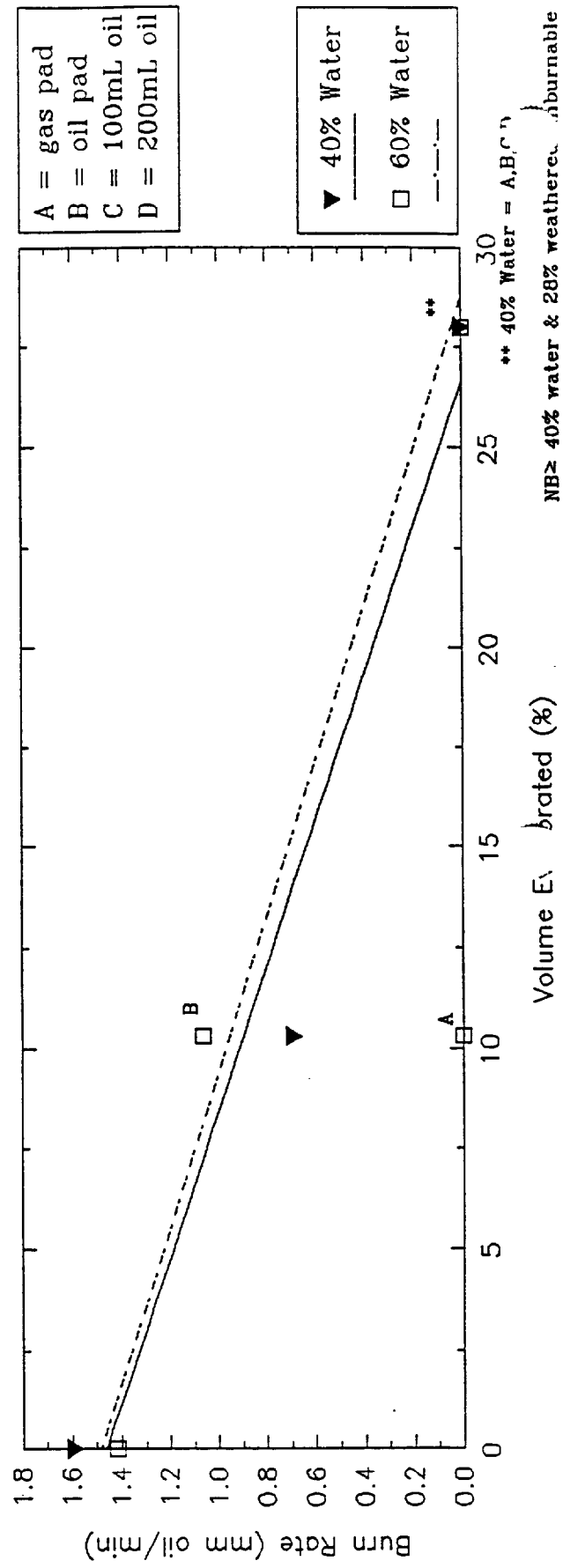
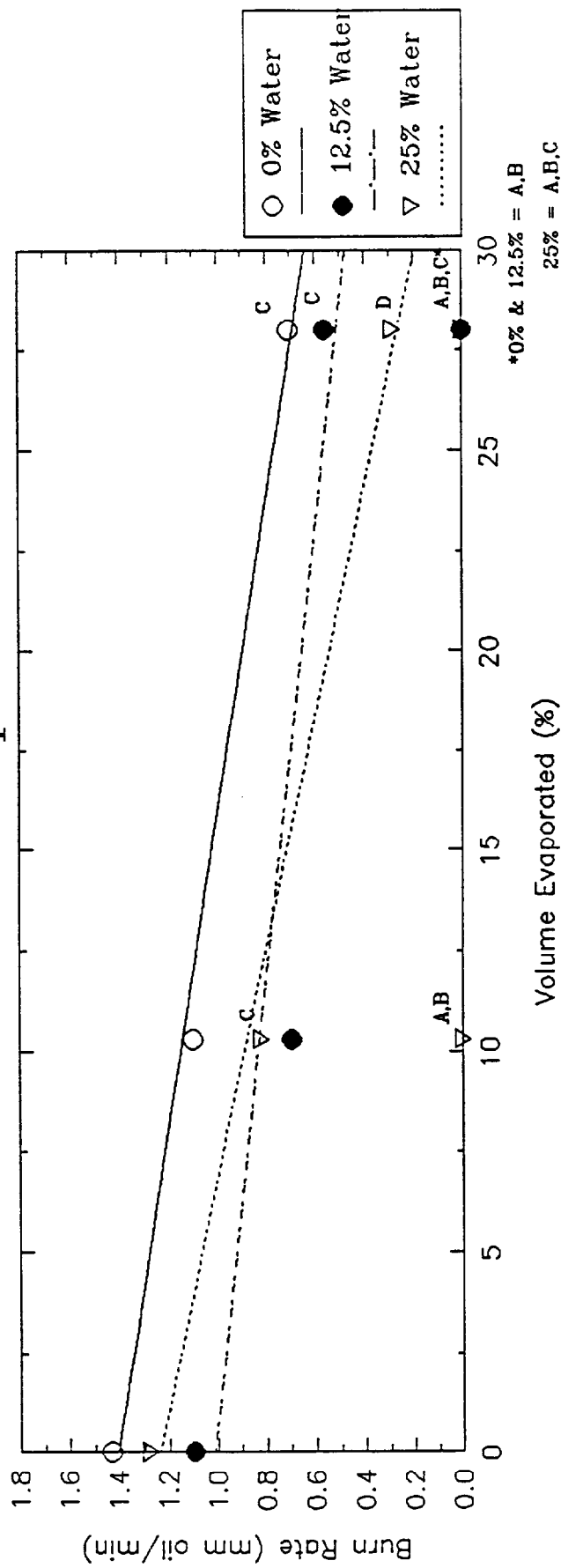
Figure 41 Burn Rate vs. Emulsification  
Alaska North Slope Crude



\*10.3% = A,B

28% = A,B,C

Figure 42 Burn Rate vs. Weathering  
Alaska North Slope Crude





It is apparent from the baseline burns that even at warmer temperatures in the 15°C to 20°C (60°F to 70°F) range that ANS crude will weather to form emulsions that will be unburnable with presently available technology.

#### **5.1.5 Emulsion Breaker Screening Test Burns**

Runs 14a, 15, 16 and 17 in Table 4 involved pre-mixing each of the three emulsion breakers into a slick of 40% water emulsion made with 28% evaporated ANS crude. Each test involved the addition of 4 mL of emulsion breaker (a 1:285 demulsifier:oil ratio or 1:475 demulsifier:emulsion ratio), mixing with a stick, then ignition using the usual sequence.

The emulsion treated with Breaxit OEB-9 (Run 14a) required a primer layer of 100 mL of fresh crude to achieve ignition. The flames were weak, the burn efficiency was low (44%) and the burn rate was low (0.2 mm oil/minute). It was during this first emulsion breaker burn test that interfacial waves and turbulence were observed beneath the slick during the burn. This occurred about 7 minutes into the burn and may be indicative of the action of the emulsion breaker.

The next slick (Run 15) was treated with 4 mL of EXO 0894 and stirred for two minutes. This slick also required priming with a 100 mL layer (about 1 mm) of fresh crude for the combustion to begin. The resulting burn was strong with good flames; some foaming was observed near the end of the burn. The oil removal efficiency was 55% and the burn rate was 0.53 mm/min. Again, interfacial turbulence and waves were observed at the underside of the slick during this test.

The last screening test burn utilized 4 mL of Alcopol 0 70% PG emulsion breaker. In this test the slick was mixed for five minutes after the chemical was applied. One hundred mL of fresh crude as a primer was required to get the slick burning; it burned weakly for slightly more than three minutes, then foamed out. The slick was allowed to cool for 10 minutes then it was re-ignited using 100 mL of fresh crude primer. This time the burn lasted more than 14 minutes. During the second phases of this test, the flames were quite intense. Overall, the oil removal efficiency was 70% - most of which could be attributed to the re-ignition. The overall oil removal rate was 0.47 mm/minute. After the fire extinguished the second time, the residue had circular holes in it exposing clear water. It is likely that this phenomena was caused by the surfactant action of the emulsion breakers herding the oil. It appears that not all of the emulsion breaker was consumed in the fire.

Run 17 was undertaken to confirm the assessment that EXO 0894 was the best candidate for ANS crude emulsions. It involved a repeat of Run 15 with five minutes mixing after dropwise application of the emulsion breaker instead of two minutes. The first successful ignition (with 100 mL of fresh crude as primer) resulted in a burn that lasted 10 minutes and was intense. It was extinguished by foaming. The residue was allowed to cool for 10 minutes then was re-ignited.

The second burn lasted only 3 ¼ minutes. Overall the burn efficiency was 78% with a removal rate of 0.62 mm oil/min.

The emulsion breaker EXO 0894 was selected for the remainder of the tests because it produced the highest burn rates of the three chemicals tested, the highest burn efficiencies, and the strongest flames. This appears to contradict the findings of the emulsion breaker screening tests in the shaker (see Section 5.1.3); however, it may have been the case that EXO 0894 worked best in low-energy emulsion breaker applications whereas the other two worked best in higher-energy situations. The fact that EXO 0894 worked best on ANS crude was not surprising; it was custom-blended to break oilfield emulsions encountered during production on the North Slope.

#### **5.1.6 Pre-Mixed Emulsion Breaker Burn Tests**

Runs 17, 18 and 21 involved testing the pre-mixed application of EXO 0894 to emulsions of 28% evaporated ANS crude with increasing water contents (40%, 50% and 60% respectively). As can be seen in Table 4 above, the emulsion breaker, added dropwise and mixed 5 minutes, proved effective in allowing efficient burning of even the 60% water emulsion. In all cases 100 mL (approximately 85 grams) of crude (gelled for run 18) or gelled diesel fuel was required for ignition; strong flames were generated by each burn. Run 23 involved incrementally increasing the dose of EXO 0894 pre-mixed into the slick. Starting with a 28% evaporated ANS crude, 60% water emulsion the dosage of EXO 0894 was increased stepwise from 1:2000 (demulsifier:oil); each application was followed by 5 minutes of mixing. A 100 mL ball of gelled gasoline was used as an igniter for each run. It was not until the demulsifier dosage reached 1:500 (demulsifier:oil) that a successful burn was achieved - for this water content this was equivalent to a demulsifier:emulsion ratio of 1:1250.

### 5.1.7 Enhanced Igniter Testing

For Runs 19, 20 and 22 the 4 mL of EXO 0894 was added to the gelled igniter fuel, rather than being pre-mixed into the slick. The "enhanced" igniter was ladled onto the slick and lit with the propane torch - no mixing action was provided prior to the first ignition attempt for each run. As can be seen from Table 4 the first ignition attempt for each of the 40%, 50% and 60% water content emulsions of 28% evaporated ANS failed. After the "enhanced" igniter extinguished, the slick was allowed to sit for 10 minutes and a second, untreated igniter was applied. This successfully ignited the 40% water emulsion but failed to ignite the 50% emulsion. Both the 50% and 60% emulsions required that the residue of the "enhanced" igniter be mixed into the slick for several minutes and a second, untreated igniter be applied before a successful burn could be ignited. The phenomenon of the flames dying back then flaring again reappeared during some of the "enhanced" igniter tests: this behavior had not been observed during the pre-mixed emulsion breaker test burns. It is possible that the less-than-perfect mixing of the "enhanced" igniter residue into the remaining emulsion was responsible for this.

In order to see if "enhanced" igniters could promote burning of less stable emulsions, Runs 24 and 25 were conducted. These involved 60% and 70% water content emulsions of the 10.3% evaporated ANS crude. The results (in Table 4) indicate that the burn efficiencies for the emulsions ignited with "enhanced" igniters were slightly higher than for untreated igniter (Run 11) but with slightly lower burn rates.

The effect of adding EXO 0894 to the stable emulsions (28% evaporated) was to virtually eliminate the detrimental effects of emulsification on burning. Table 5 compares the burn efficiencies and rates achieved with EXO 0894 addition (either pre-mixed or added in an enhanced igniter, then mixed) with the burn efficiency and rate for the unemulsified, 28% evaporated ANS crude (Run 3). Within the accuracy of the rate and efficiency determinations, there is little or no difference. This supports the theory that the burning of emulsions can proceed with physical removal of the water (as opposed to only boiling) and that it is a layer of relatively water-free oil floating on top of the breaking emulsion that is burning, not the emulsion itself.

**Table 5**  
**EXO 0894 Burn Rate and Burn Efficiency Comparison**

Evaporative Loss (% Volume)	Water Content (% Volume)	Initial Volume (mm)	Amt. Breaker (mL)	Application Method	Burn Rate (mm oil/min)	Burn Efficiency (% Mass)
28	0	2500	0	n/a	0.7047	75.2
	40	1900	4	pre-mixed 5 min	0.6228	78.0
	50	1900	4	pre-mixed 5 min	0.7027	79.3
	50	1900	4	in igniter, mixed	0.7126	84.5
	50	1900	4	in igniter, mixed	0.7983	79.0
	60	1900	4	pre-mixed 5 min	0.7303	73.4
	60	1500	4	in igniter, mixed	0.8701	81.8
	60	2500	1	pre-mixed 5 min	1.0158	86.5

#### **5.1.8 Endicott Crude Oil Emulsions**

Runs 26 and 27 in Table 4 were conducted with emulsions created with fresh Endicott crude oil (which forms stable emulsions - Appendix 1). The 40% water emulsion was unignitable with a 100 mL gelled gasoline igniter; the addition of 2 mL of EXO 0894 (1:1250 demulsifier:emulsion ratio) permitted a strong burn, although the phenomenon of the flames dying out a flaring up again appear at the end of this run. Pre-mixed addition of 4 mL of EXO 0894 in 2500 mL of 60% water-in-Endicott emulsion resulted in a strong, efficient burn.

#### **5.1.9 Gelled Fuel Igniter Recipe Tests**

In the second set of burns a variety of gelled fuel igniters were created and their ignition capabilities with ANS crude investigated. Four base fuels were used to create the igniters: unleaded gasoline, automotive diesel, a 50/50 (vol/vol) mix of gasoline and diesel and fresh ANS crude.

The normal concentration of "Surefire" gelling agent (from Simplex Mfg., the producer of the Heli-torch) used to produced gelled fuel was 17.5 g/L (8 lb/55 gallons - after Spiltec 1987). This quickly produced an appropriate product when using gasoline; however, the gel time was longer when using 50/50 gasoline/diesel or diesel as the fuel. The viscosity of the resulting product and its viscoelasticity

(a measure of its cohesiveness) appeared to decline as the base refined fuel became heavier. It was not possible to produce a gelled fuel with fresh ANS crude with the normal concentration of "Surefire". Dosages of nearly double the normal (i.e., 30 g/L or 14 lb/55 gallons) produced a somewhat gelled product, but visibly much less viscous than the gelled refined fuels.

The addition of surfactant to the fuel during the gelling process reduced the effectiveness of the "Surefire". The chemical emulsion breaker EXO 0894 was added to the fuel first at the concentration of 40 mL/L (4% = 2.3 gal/55 gallons) then 17.5 g/L of Surefire was added and mixed. The concentration of EXO 0894 in the gelled fuel was based on delivering 4 mL of chemical in a 100 mL blob of gelled fuel. The resultant refined fuel gels took longer to set and appeared to be less viscous and viscoelastic than the untreated gels. The addition of EXO 0894 to fresh ANS crude appeared to render it nearly ungellable even with 35 g/L (16 lb/55 gallons) of "Surefire" gelling agent.

Figures 43 through 46 show the temperatures (flame, igniter and beneath the igniter) measured for gelled gasoline (napalm), 50/50 gas/diesel, diesel and, crude with EXO 0894. The volumes of gelled fuel used were about twice that which would normally be produced as a blob by the Heli-torch (Spiltec 1987); this was necessary in order to fill the burn ring and ensure consistent flame temperature measurements. The 250 mL samples of each fuel were placed on the water surface inside the ring and then lit with a propane torch.

The gasoline igniter (Figure 43), when first ignited, produced a high flame (1.5 m = 5 ft) that declined over about one minute to 0.5 m (1.5 ft). Peak flame temperatures occurred initially and achieved temperatures of 700 to 800°C (1300 to 1475°F). After one minute the flame temperatures had declined and steadied at about 400 to 600°C (750 to 1100°F).

The gelled 50/50 gasoline/diesel igniter (Figure 44) initially produced a flame 1 m high (3.5 ft) which declined to 0.5 m (1.5 ft) after about one minute. The maximum flame temperatures achieved were about the same as for the gelled gasoline (700 to 800°C or 1300 to 1475°F) but these flame temperatures were sustained over a longer period (2 minutes vs. 1 minute for the gelled gasoline).

Figure 43

# ACS Igniter Experiment # 31

## 190 g Napalm

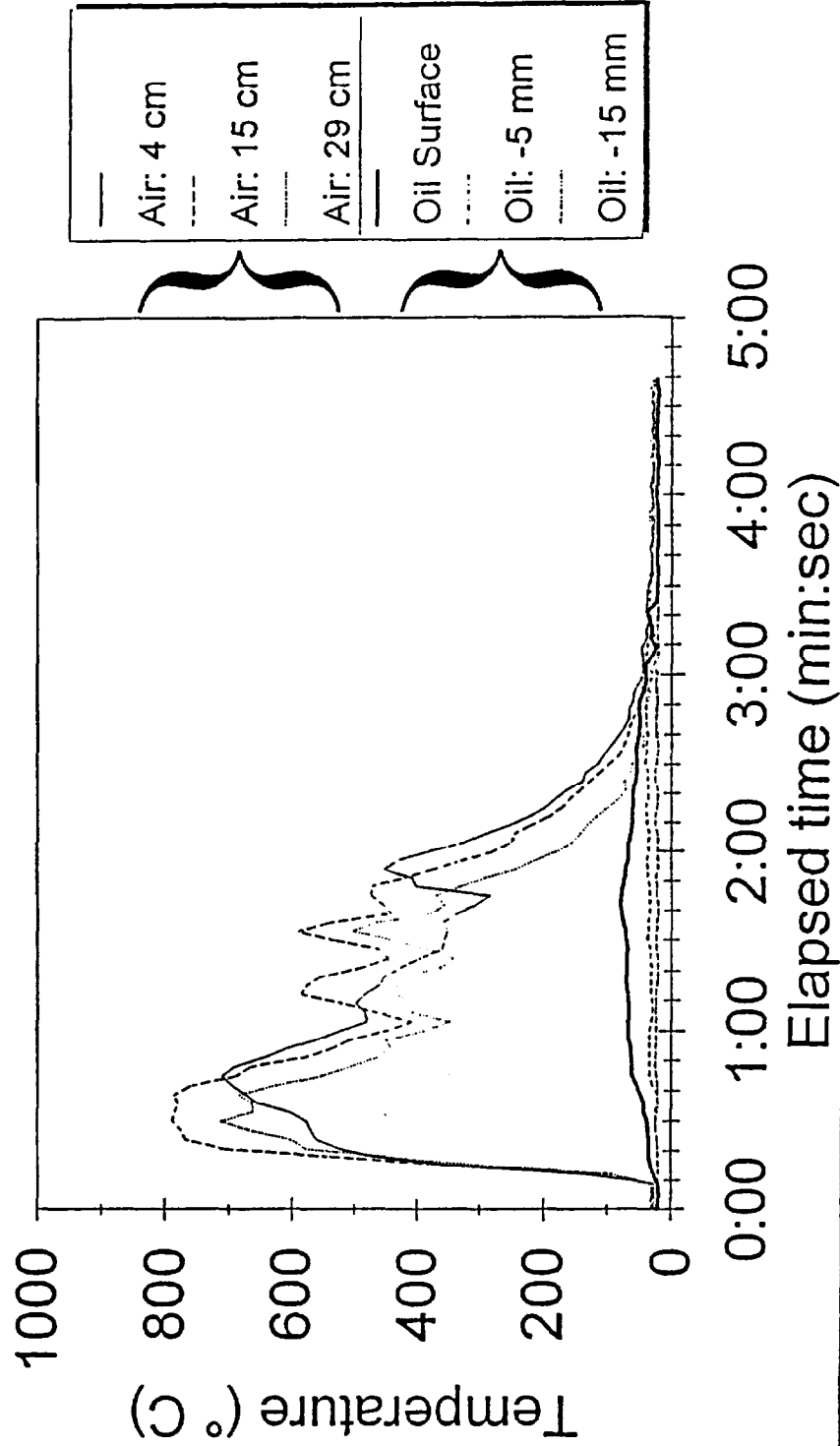


Figure 44

# ACS Igniter Experiment # 32

205 g 50/50 gelled gas/diesel

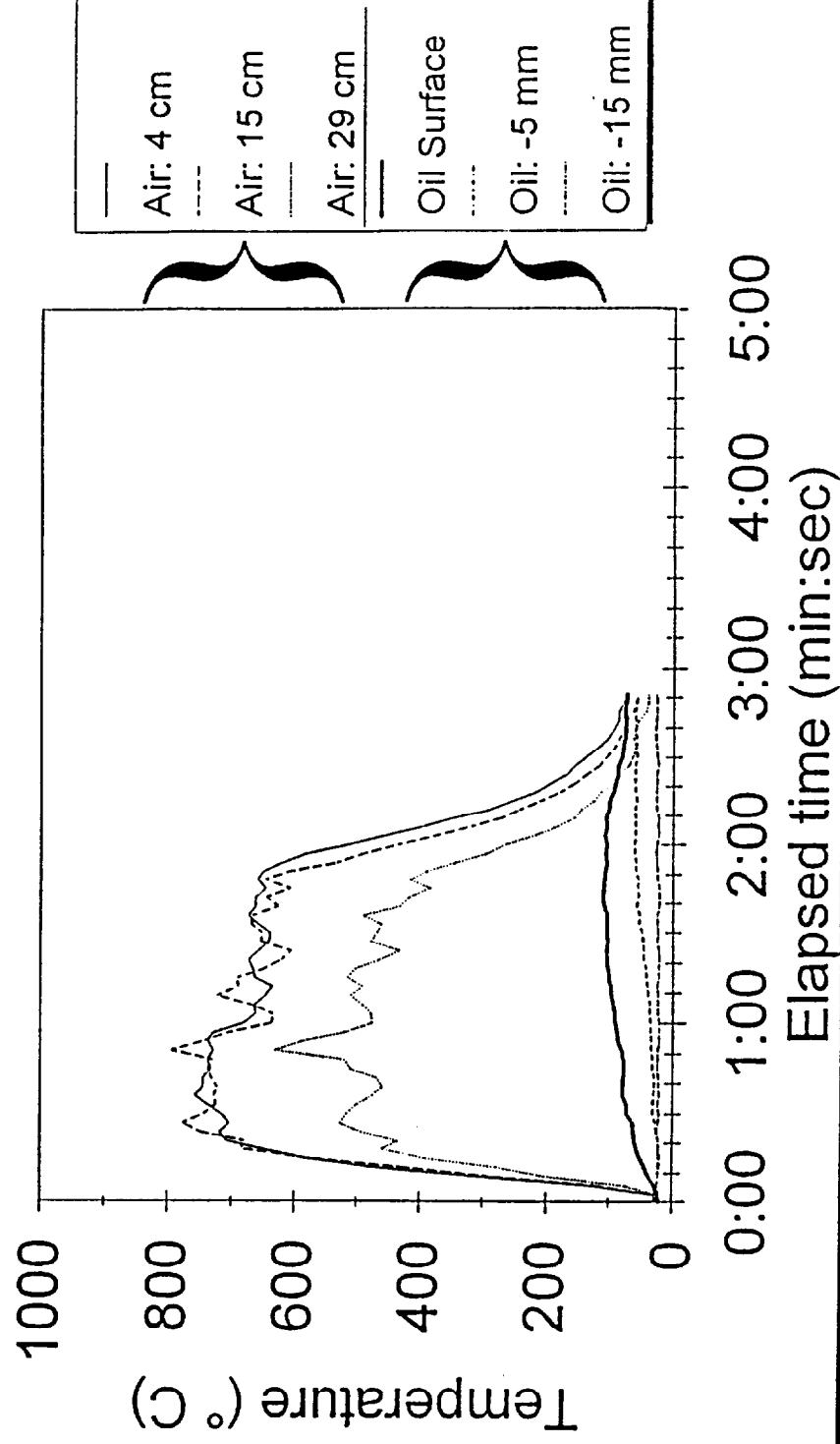


Figure 45

# ACS Igniter Experiment # 33

## 215 g gelled diesel

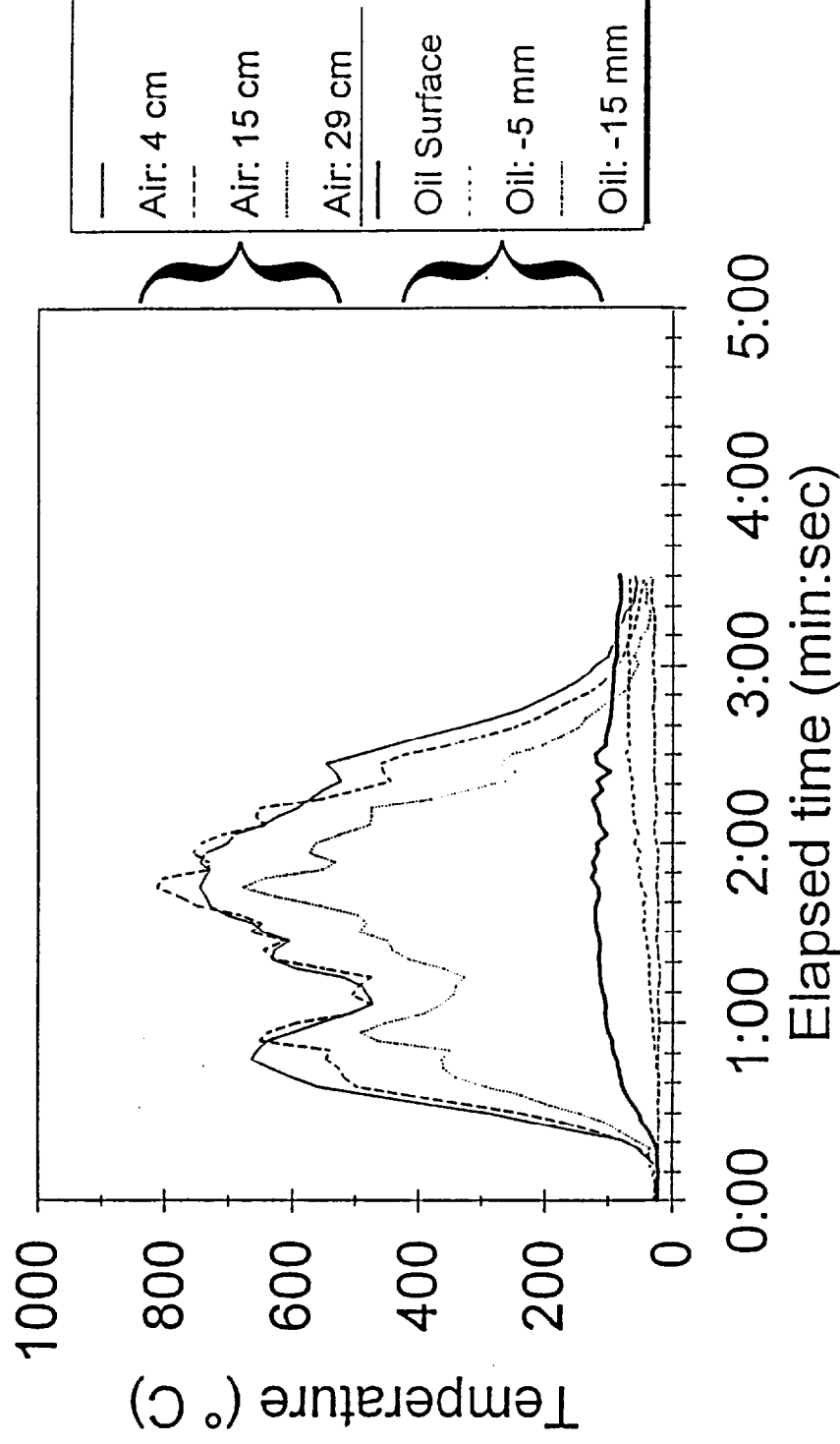
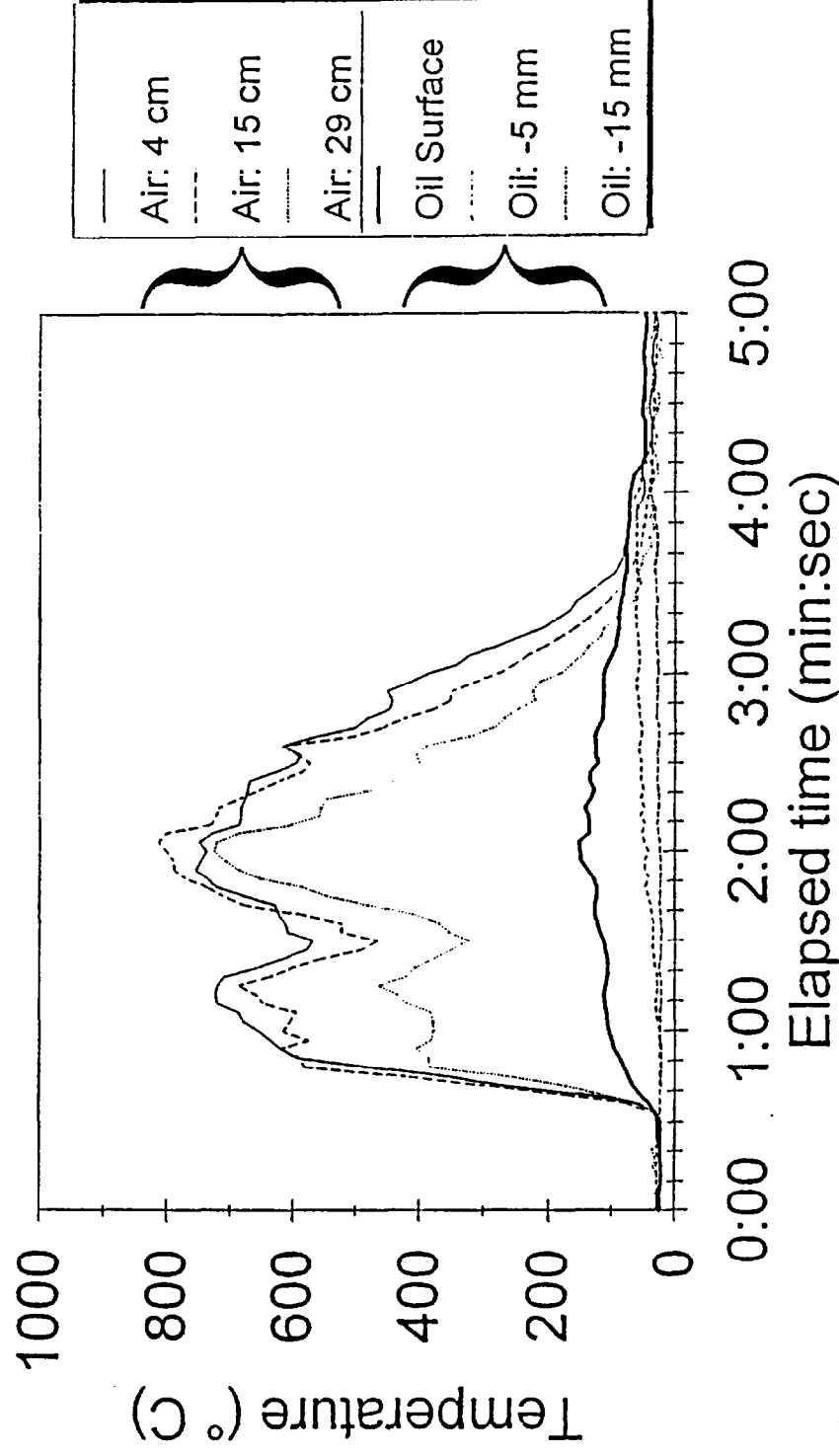




Figure 46

# ACS Igniter Experiment # 34

223 g gelled crude with EXO-894



The gelled diesel igniter (Figure 45) was harder to light with the propane torch than the previous two. Initial flame heights reached only 0.5 m (1.5 ft). Although a maximum flame temperature of almost 800°C (1475°F) was achieved with this igniter, the average flame temperatures were lower than for the previous two.

The treated gelled crude igniter (Figure 46) was easier to light with the propane torch than the gelled diesel. It generated flames of 0.5 to 0.75 m (1.5 to 2 feet) high; a maximum flame temperature of about 800°C (1475°F) was achieved. Near the end of the burn the center of the igniter extinguished but the edges continued to burn.

Table 6 compares the temperatures measured beneath the various igniters and their burn times. These results indicate that the crude oil igniter put the most heat into the water beneath it; however the igniters incorporating gasoline generated higher initial flames (and thus better radiant heating). It appeared that the 50/50 gelled gas/diesel igniter was the best compromise, offering higher initial radiation to its surroundings, a sustained burn of reasonable duration and moderate heat transfer rates to underlying fluids.

**Table 6**  
**Igniter Burn Times and Subsurface Temperatures**

	Gelled Gas	50/50 Gas/Diesel	Diesel	ANS Crude
Initial Avg. Water Temperature (°C)	21	22	23	24
Max. Temperature in Undersurface of Igniter (°C)	72	111	127	152
Max. Temperature 5 mm Below Igniter (°C)	42	62	72	63
Max. Temperature 15 mm Below Igniter (°C)	28	29	34	38
Burn Times (min:sec)				
full ring diameter	0:30	1:10	1:00	2:23
total	2:17	2:24	2:27	2:47

#### **5.1.10 Summary**

The following key results were obtained from the laboratory tests:

- emulsions of fresh and 10% weathered ANS crude, up to the maximum achievable water content of 60+ %, can be ignited and burned because they are not fully stable;
- the maximum burnable water content for stable emulsions of weathered (28% evaporated) ANS crude emulsions is 25%;
- commercial emulsion breakers can effectively promote emulsion breaking and allow burning of emulsions of heavily weathered (28% evaporated) ANS crude containing 60% water;
- the most efficient of three chemicals tested was EXO 0894, a product used for production purposes on the North Slope; the minimum effective dose was 1:500 breaker-to-oil;
- the most efficient chemical application method was pre-mixing the emulsion breaker into the slick; the emulsion breaker could be mixed with the igniter fuel and applied simultaneously but this was not as successful; and
- gelled crude oil and a 50/50 mix of gasoline and diesel proved better in igniting emulsions than gelled gasoline.

### **5.2 OUTDOOR TESTING IN PANS**

#### **5.2.1 Alaska North Slope Crude Weathering**

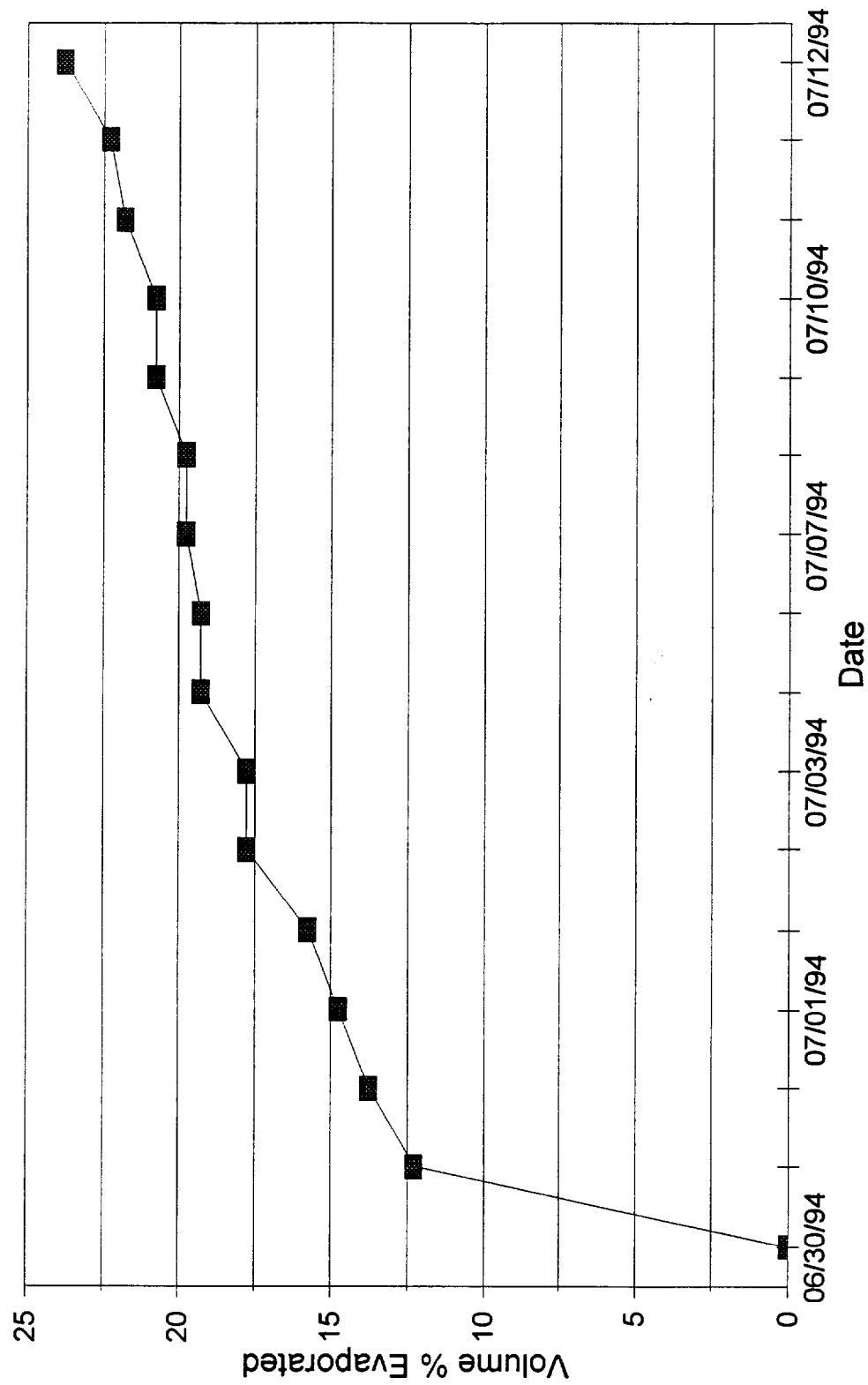
Figure 47 shows the rate of evaporative loss of the 780 L of fresh ANS crude initially placed in the artificial weathering tank. The raw data is contained in Appendix 5. Over a period of 12 days, 23.8% of the original oil was evaporated.

#### **5.2.2 Emulsion Stability and Properties**

Samples of a 60% seawater-in-weathered crude emulsions were taken after 5, 10 and 15 minutes mixing with the gear pump and placed in 1 L jars (Figure 48). After 24 hours at rest at 10°C there was some visible water droplet coalescence in the 5 minute sample, but the 10 and 15 minute samples remained homogeneous and stable. After 72 hours the 10 minute and 15 minute samples were still

Figure 47

## Outdoor Burn Test Oil Weathering Progress Chart





**Figure 48** Sampling emulsion used for pan burns

visually homogeneous and stable. The 10 minute sample (chosen because this was the mixing time selected) was placed in a refrigerator for 60 days and remained stable throughout this time.

A sample of the 60% water emulsion was examined under a microscope. The emulsion was initially packed tightly with water and was difficult to see through at first (Figure 49a), but appeared to consist of a multiple emulsion of water droplets of about 1  $\mu\text{m}$  and less in size enclosed in drops up to 50  $\mu\text{m}$  in size. The heat from the microscope light source encouraged the coalescence of the emulsion on the slide. Figure 49b shows the larger coalesced water droplets: the smaller original drops are more visible on this picture.

### **5.2.3 Heli-torch Static Performance Tests**

Ten tests of the ability of the Heli-torch to light and deliver 7.6 L (2 gallon) batches of various alternative fuels were conducted. The various batches of fuel mixed are shown in Table 7. Each test of the Heli-torch involved first, a short burst of unlit fuel dropped into the water-filled test pan to examine the fuel's shape and consistency; next, the propane lighter was engaged to ignite the gelled fuels as they were emitted.

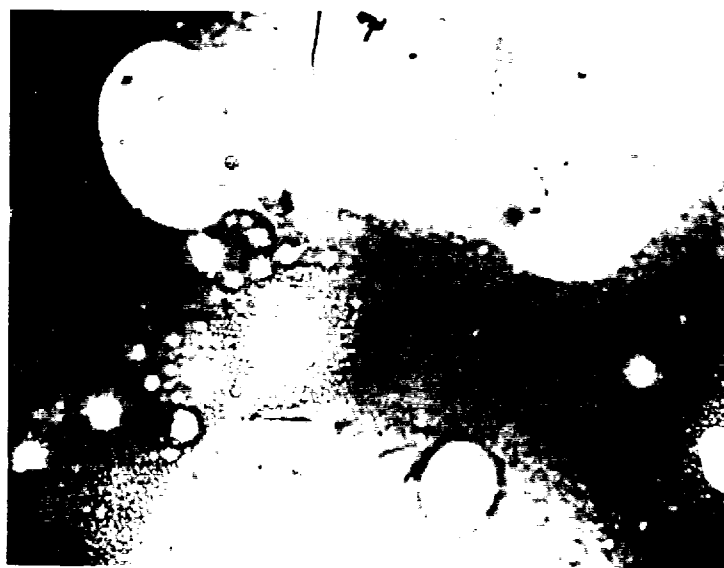
The 50/50 gasoline/diesel mixture gelled with 2.2% wt gelling agent (Batch #1 in Table 7) formed a thin layer on the fresh water that spread to cover the water surface. The Heli-torch produced a solid stream of gelled fuel that lit easily and burned as it fell (Figure 50). The winds were 5 to 10 km/hr.

The gasoline gelled with 2% by weight Surefire (7 lbs/55 gallons) also spread to cover most of the pan with a thin layer of fuel and was visually more viscous than the gasoline/diesel. The Heli-torch successfully fired the gasoline in a 10 km/hr wind producing a solid, burning stream of fuel falling into the pan. The flames produced from the slick of gelled gasoline were much higher than for the gas/diesel mixture.

The third test involved gelled diesel (Batch #4 in Table 7) which, when released unlit, produced a large pancake 500 mm (20 inches) in diameter floating on the water. The propane igniter could not light the gelled fuel stream in the 10 km/hr winds. The next test involved a 50/50 mix of gasoline and crude oil (Batch #2) gelled with 4.9% gelling agent. This higher dosage was required to achieve the desired fuel consistency with the gasoline/crude mixture. The unlit fuel produced a 500 x 750 mm puddle



a) shortly after placement on slide



b) after heat from light had promoted coalescence

Figure 49 Photomicrographs (600 x) of 60% water emulsion

Table 7

## Helitorch Fuel Data Sheet

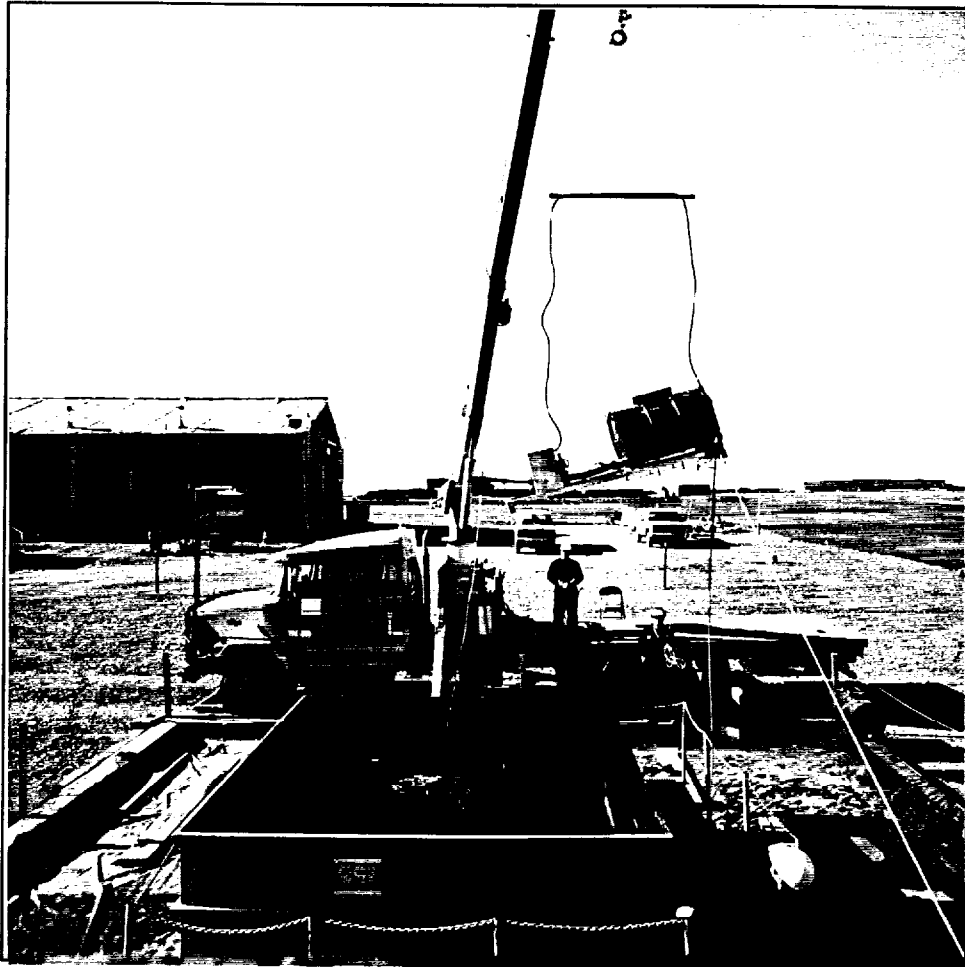
Batch #	Date	Time	Type	Fuel			Surefire Wt. (kg)	Ratio (S/F)	Emulsion Breaker		Comments
				Volume	Wt. (kg)				Volume	Ratio (EB/F)	
1	13-July	1700	gas/diesel	37.85 L 5 ea.	30.54		0.68	2.23%			
2	13-July	1400	gas/crude	22.71 L 3 ea.	18.68		0.91	4.87%			
3	14-July	1455	gas	7.57 L	5.66		0.11	2.01%			
4	14-July	1520	diesel	7.57 L	6.55		0.11	1.73%			
5	14-July	1600	fresh crude	7.57 L	6.79		0.00				
6	14-July	1900	diesel	7.57 L	6.55		0.11	1.73%			
7	14-July	1913	gas	7.57 L	5.66		0.11		300 mL		-fuel sat overnight
	15-July	0845	gas		0.00		0.11				-added additional 0.11 kg
	15-July	1115	gas		0.00		0.11				-added additional 0.11 kg
			#7 Total=	7.57 L	5.66		0.34	6.02%	300 mL	3.91%	
8	14-July	1930	gas/diesel	7.57 L 1 ea.	6.11		0.11		300 mL		-fuel sat overnight
	15-July	0905	gas/diesel		0.00		0.11				-added additional 0.11 kg
	15-July	1130	gas/diesel		0.00		0.11				-added additional 0.11 kg
			#8 Total=	7.57 L 1 ea.	6.11		0.34	5.58%	300 mL	3.91%	
9	14-July	1940	gas/crude	7.57 L 1 ea.	6.23		0.11		300 mL		-fuel sat overnight
	15-July	0925	gas/crude		0.00		0.11				-added additional 0.11 kg
	15-July	1150	gas/crude		0.00		0.11				-added additional 0.11 kg
			#9 Total=	7.57 L 1 ea.	6.23		0.34	5.48%	300 mL	3.91%	
10	15-July	0815	gas	7.57 L	5.66		0.11	2.01%			
11	15-July	0830	diesel/crude	7.57 L 1 ea.	6.67		0.11	1.70%			
12	15-July	1330	gas/diesel	7.57 L 1 ea.	6.67		0.11	1.70%			
13	16-July	1020	gas	7.57 L	1.47		0.11	7.71%			
14	17-July	0830	gas/crude	8.81 L 1 ea.	6.23		0.34	5.48%			
15	18-July	1030	gas/crude	4 L 2 ea.	3.24		0.23	7.01%			
16	18-July	1245	gas/crude	10 L 5 ea.	8.10		0.43	5.26%			

Calculations are based on exact volumes

Assumes the following densities

Gas - 747.57 kg/m<sup>3</sup>Diesel - 865.86 kg/m<sup>3</sup>Crude Oil - 897.3 kg/m<sup>3</sup>





**Figure 50** Heli-torch static test

floating on the water in the pan. The Heli-torch successfully lit this mixture and produced a continuous stream of burning fuel in 11 km/hr winds. The Heli-torch pumped the 7.57 L batch of fuel in a total of 23 seconds giving a flowrate of 20 L/min (5.3 gallons/minute).

The fifth test was a repeat of the third and involved gelled diesel (Batch #6). The wind was calm. Although it took a while, the propane igniter finally lit the fuel as it passed. The sixth test involved gelled crude (Batch #5 in Table 7). The unlit fuel formed a patch 750 mm x 400 mm floating in the pan. The gelled crude proved difficult to ignite with the propane igniter. The next test utilized a 50/50 mixture of gelled crude and diesel (Batch #11). The unlit fuel falling from the Heli-torch formed a patch 750 mm x 750 mm that appeared runny. The mixture proved very difficult to ignite with the propane lighter in the Heli-torch.

The eighth test involved a gas/diesel mix containing 300 mL of EXO 0894. The amount of gelling agent required to gel this mixture initially was 2%; however, the gel broke overnight and this dosage had to be tripled to finally achieve a reasonable consistency. The unlit fuel dropped from the Heli-torch formed a 500 mm x 500 mm patch on the water in the pan. The propane lighter successfully ignited this fuel and produced a continuously burning stream of fuel. The second-last test used employed gasoline containing 300 mL of EXO 0894. Again, the gelled fuel broke overnight and required a triple-dose of gelling agent to achieve a reasonable consistency. It formed a 500 mm x 500 mm patch when dropped unlit and was easy to ignite with the propane igniter. The last igniter fuel was a 50/50 gasoline/crude mixture containing 300 mL of EXO 0894 (Batch #9 on Table 7). It too required a triple dose of gelling agent. It produced a patch 500 mm x 500 mm when discharged unlit and ignited easily in 8 to 10 km/hr winds.

In preparing the gelled fuels for the emulsion burn tests, various recipes were tried (Batches 10 through 15). The best mixture, from the perspectives of ease of production, consistency, delivery and ignition by the Heli-torch and ignition power was felt to be the 50/50 gasoline/crude mixture gelled (at 10°C = 50°F) with 45 g/L (21 lb/55 gallons  $\approx$  5.5% wt) of Surefire. Screening out lumps in the gelling agent during its addition was felt to be crucial to obtaining a good gel.

#### 5.2.4 Baseline and Pre-Mixed Pan Burns

Table 8 gives the results of the burn tests in both the 1.2 m<sup>2</sup> and 3.3 m<sup>2</sup> pans. Only Run 7 involved a test of an enhanced igniter; this is discussed in the next section. The first two burns were undertaken to determine the maximum ignitable water content for the 23.8% evaporated ANS crude. The first test involved 15 L of 12.5% water emulsion with an initial thickness of 12.5 mm. It was successfully ignited in 10 to 13 km/hr winds (measured at a height of 2 m) with gelled gas and burned (Figure 51) to remove 94.7% of the oil. The second test (15 mm of 25% water emulsion) could not be ignited in 10 km/hr winds with a 500 mL batch of either gasoline, gasoline/diesel or gasoline/crude. The latter two igniters nearly succeeded in lighting the slick. The addition of 27 mL of EXO 0894 (1:655 demulsifier:emulsion) followed by 5 minutes of stirring then ignition with a 500 mL gasoline/crude fuel resulted in a successful, efficient burn. The flames died out and flared up near the end of the burn and the characteristic holes in the residue were observed indicating that some surfactant remained (Figure 52). The third test involved 18 mm of 40% water emulsion treated with 27 mL of EXO 0894 (1:820 demulsifier:emulsifier) and mixed for 5 minutes prior to the first ignition attempt. Neither one nor two 500 mL gelled gas/crude igniters could get the emulsion slick burning, although the two igniters came close. Ignition was achieved by priming the slick with 2 L (about 1.7 mm) of fresh crude. This burn did not produce much black smoke near the end and was visually more affected by the 13 to 16 km/hr winds than either of the previous two tests and generated a hissing sound. The characteristic holes in the residue were observed.

The fourth test was a repeat of the third. This time, however, 50 mL of EXO 0894 was pre-mixed into the slick then four baggies, each containing 500 mL of gelled gas/crude, were placed on the oil and ignited with the butane torch. The upper surface of the baggies burned away, but the under-surface remained and retained the gelled fuel in small, thick patches. These burned for over 5 minutes but did not ignite the emulsion. At this point the slick was remixed and allowed to sit for one hour. Four 500 mL gelled gasoline/crude igniters emptied onto the slick resulted in a successful, efficient burn in 14 to 15 km/hr winds.

The fifth test involved a 22 mm thick slick of 50% water emulsion. For the first ignition attempt, 50 mL of EXO 0894 was pre-mixed into the emulsion (1:530) and it was allowed to sit for 30 minutes. The application of four 500 mL gelled gasoline/crude igniters did not ignite the emulsion. The emulsion was left to sit for another 30 minutes, then another four 500 mL igniters were lit on the slick. These succeeded in starting the emulsion burning. Although the wind, at 29 to 34 km/hr, seemed almost strong

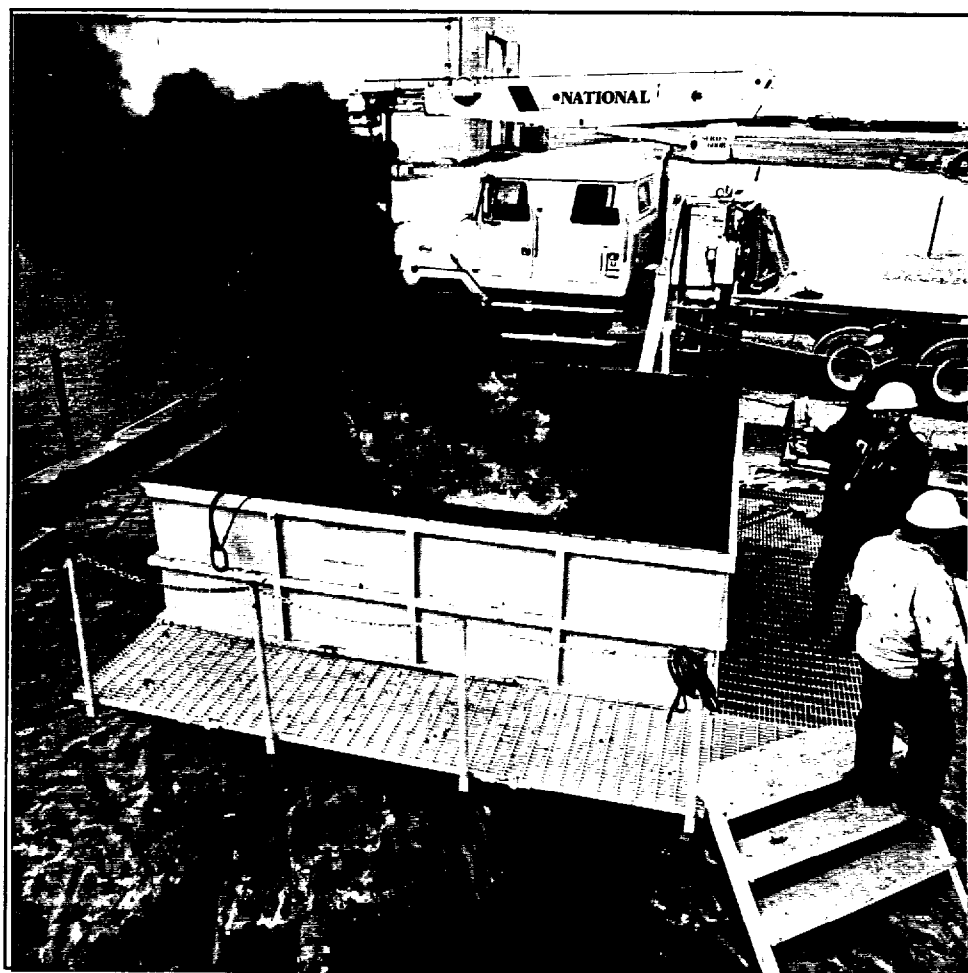
Table 8

## Small-scale Pan Burn Test Results

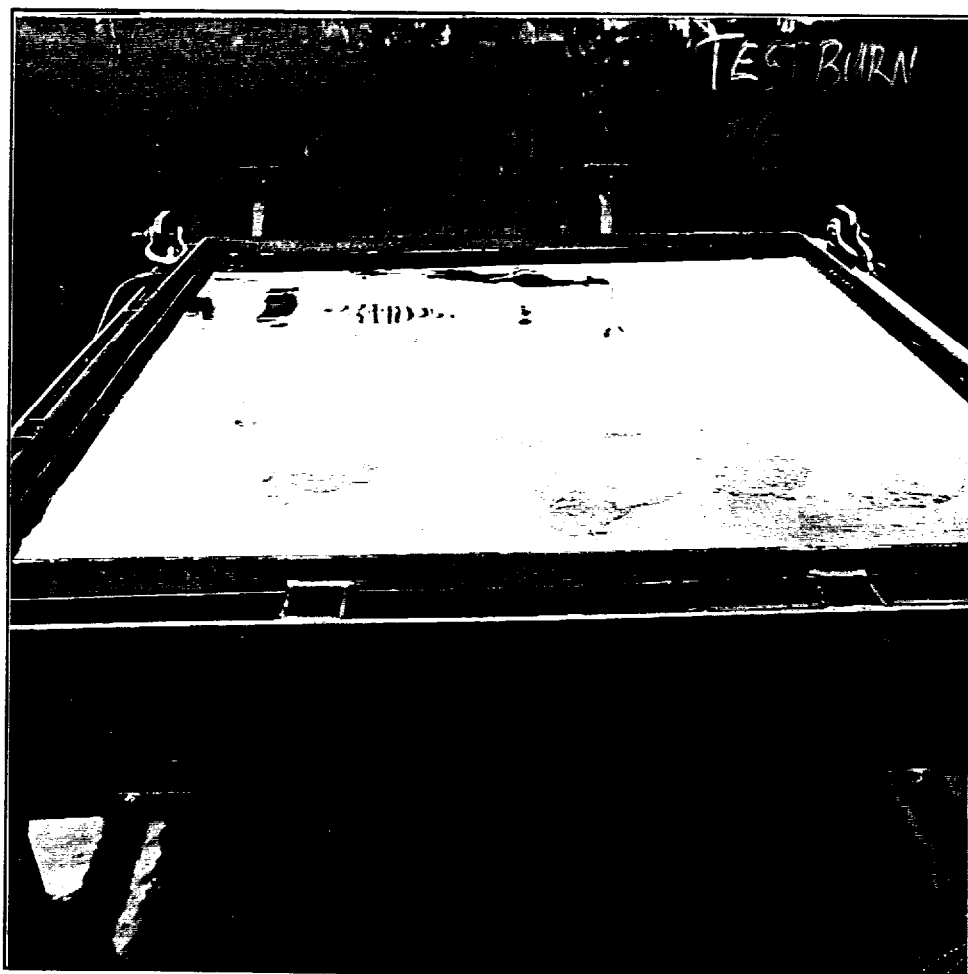
Run #	% Water	Emulsion Volume (L)	Emulsion Mass (kg)	Pan Size (m <sup>2</sup> )	Wind 2 m (km/h)	Fuel #	Ignition #	Preheat	Time (min:sec)	Extraction	Residue Initial (kg)	Residue Final (kg)	Comments	Mass Oil Burned (kg)	Burn Rate (mm oil/min)	Burn Efficiency (%)
1	12.5	15.1	13.6	1.2	10-13	g/c	1	0:15	2:33	6:32	8:39	0.815	-potted gas 12.5% emulsion	11.1	1.74	93.17
2	25	17.7	16.3	1.2	10	g/c g/d g/c g/c	1 2 3 4	0:20 0:30 0:10 0:30	1:30 3:25 3:21 9:36			0.845	-added 27 mL EXO 894 by pipette, stirred for 5 min -dies and flares -holes in residue -added 27 mL EXO 894 by pipette, stirred for 5 min -1000 mL g/c -75% of pan covered by flame after 1 min -2 L of fresh crude as promoter -used diesel soaked sorbent as ignitor	11.5	2.08	94.72
3	40	22.1	20.0	1.2	13-14 13-14 13-16	g/c g/c •	1 2 3	0:45 0:20 0:10	2:07 2:59 6:10	2:07 2:59 8:33		0.455	-holes in residue -added 50 mL EXO 894 by pipette, stirred for 5 min -igniters in baggies -mix residue for 5 min let sit for 1 hour	11.5	1.36	96.20
4	40	22.1	19.1	1.2	13 14-16	g/c 4/500 mL g/c	1 2	0:45 0:10	5:04 6:39	5:04 6:39		0.486	-used jars to apply fuel from here on, pipette -premixed 50 mL EXO and let sit for 30 min -mixed residue for 2 min let sit for 30 min	11.0	1.63	95.76
5	50	26.5	21.8	1.2	16+ 29-34	g/c 4/500 mL g/c 4/500 mL	1 2	0:14 0:20	2:13 5:20	2:13 5:20		0.455		10.4	2.12	95.83
6	60	33.1	31.6	1.2	30-34	g/c 4/500 mL	1	0:15	0:20	7:40	8:02	0.455	-70 mL EXO 894 mix 10 min wait 1 hr	12.2	1.50	96.39
7	40	22.1	20.7	1.2	27 34	g/c 4/500 mL g/c 4/500 mL 16.9 L fuel	1 2 3	0:17	0:50	1:42 3:33	3.24	n/m	-50 mL EXO 894 mixed into igniters -mixed igniter residue and waited 1.5 hrs -no EB in fuel (62)	9.2	1.20	73.98
8	25	66.2	61.8	3.3	30-34 29	g/c 4/500 mL g/c 4/500 mL	1 2	0:22 0:25	1:00	14:28 5:37	14.18	4.28	-165 mL sprayed out of Windex Bottle -fuel on upwind side -upwind side -residue slowly sank	47.2 9.9	1.22 0.66	76.89 69.82
9	40	110.5	103.2	3.3	39-51 35-38 26	g/c g/c 4/500 mL g/c 3 L 50/50 8 L fresh	1 2 3 4	0:15 0:20 0:11 0:00	1:30	3:36 5:49 2:53 12:00			-235 mL EXO 894 sprayed on mix 10 min, wait 1 hr -blown out by wind -emulsion set over light -16-17 min then flared back up	57.1		93.03
10	60	165.8	160.5	3.3	6-10 11	g/c 10/400 mL g/c 16/500 mL	1 2	0:11 0:00	1:38	11:22		1.28	-330 mL EXO 894 sprayed min 10 min, wait 1 hr -mixed residue waited 15 min	47.5 62.9	0.91 1.92	76.77 98.01
11	65	37.9	36.7 (calculated)	1.2	5-8	g/c 4/500 mL	1	0:30	0:30	9:13		0.42	-max achievable stable water content -sprayed 85 mL EXO 894 mixed 10 min, wait 1 hr	12.4	1.22	96.73

## Legend

g/c - gas + crude
g/g - gas + gas
g/d - gas + diesel
4/500 - 4 liters of 500 mL each
n/m - not measured



**Figure 51** Burn of 12.5% water emulsion

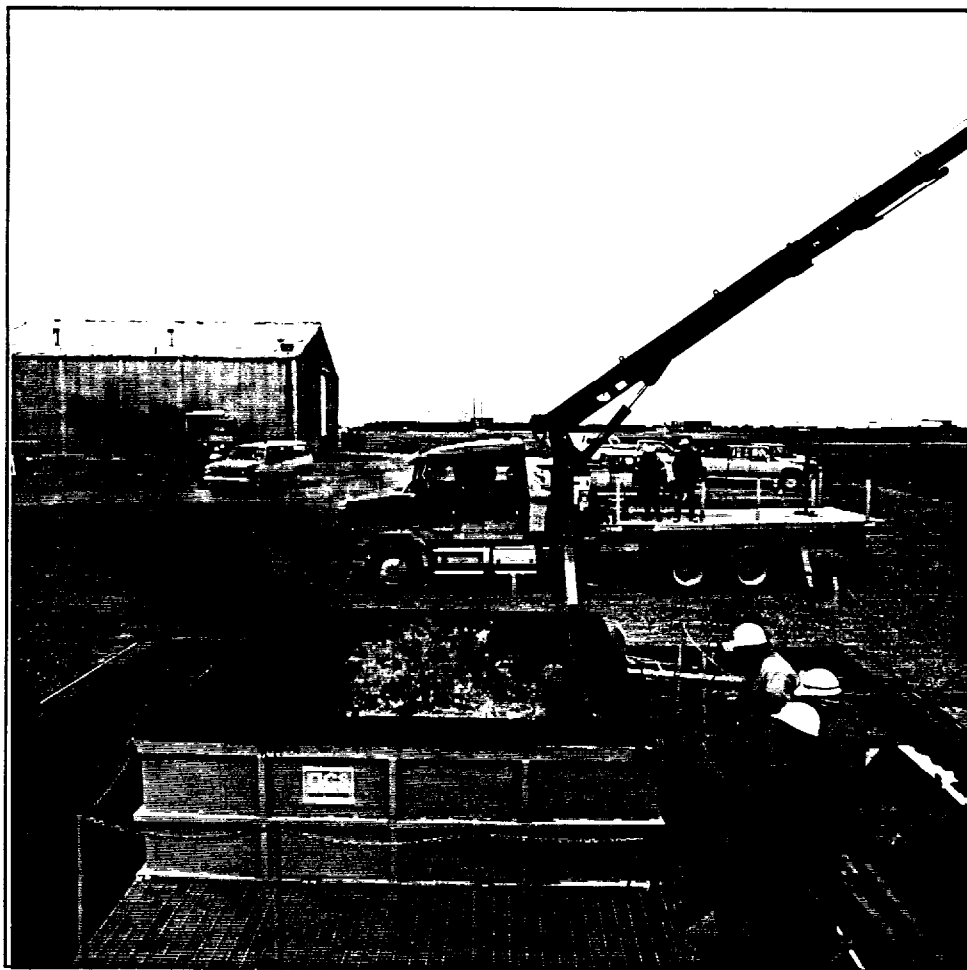


**Figure 52** Reside herded by remaining surfactant after a burn in the 1.2m<sup>2</sup> pan

enough to blow out the fire, an efficient burn results. The sixth burn involved pre-mixing 70 mL of emulsion breaker into a 28 mm thick slick of 60% water emulsion, waiting one hour, then igniting with four 500 mL igniters of gelled gas/crude. A successful burn was started on the first attempt.

Runs 8, 9 and 10 took place in the 3.3 m<sup>2</sup> burn pan. Run 8 involved a 27 mm thick slick of 25% water emulsion. This slick was treated with 185 mL of EXO 0894, mixed for 10 minutes and left to sit for one hour. Despite the high winds (30 to 34 km/hr), four 500 mL gasoline/crude igniters placed in a long along the upwind edge succeeded in initiating a successful burn. The winds buffeted the flames and there seemed to be very little smoke from the fire (Figure 53). The flames died out and flared back up once near the end of the burn. After the fire extinguished no holes were observed in the residue and it appeared quite thick. A "cookie cutter" sample was taken (the first ignition resulted in an estimated 77% removal efficiency) and the residue was re-ignited. The residue was successfully re-ignited with four 500 mL gelled gasoline/crude igniters in a 29 km/hr wind and burned for another 5½ minutes. The residue from this burn slowly sank as it cooled.

Test number 9, involving a 33 mm thickness of 40% water emulsion in the 3.3 m<sup>2</sup> pan extended over two days. In the evening of the first day the slick was treated with 235 mL of EXO 0894, stirred for 10 minutes then left to sit for one hour. At the time of the first two ignition attempts the wind speeds were 39 km/hr gusting to 51 km/hr. The four 500 mL igniters failed to ignite the slick twice in succession. The slick was left overnight in the hopes that the winds would die down. The next morning the slick had gelled into a semi-solid mass in the freezing temperatures and 26 km/hr winds. Three litres of gelled gas/crude mixture were poured onto the slick and ignited but this failed to get the emulsion burning. Finally, eight litres of fresh crude were poured on the slick, to prime it, and ignited (Figure 54). This initiated a burn that lasted 18 minutes. It was noted, once the fresh crude had burned off, that the fire was not generating much smoke and the flames were much lower than when the crude was burning (Figure 55). The flames seemed to dance from one portion of the slick to another and a significant amount of steam was generated. After 13 minutes the flames increased in height and more smoke was generated. The flames died out and then flared back up near the end of the burn. When the fire extinguished the characteristic holes were apparent in the residue. In run 10, a 50 mm thickness of 60% water emulsion was treated with 300 mL of emulsion breaker (1:500) and allowed to sit for one hour. The first ignition attempt involved ten 400 mL gelled gas/crude igniters spread over the upwind half of the slick. These failed to start the slick on fire. The residue of these igniters was mixed into the slick, and 15 minutes later sixteen 500 mL igniters were spread over the entire surface of the slick. This



**Figure 53** 25% water emulsion in 3.3m<sup>2</sup> pan



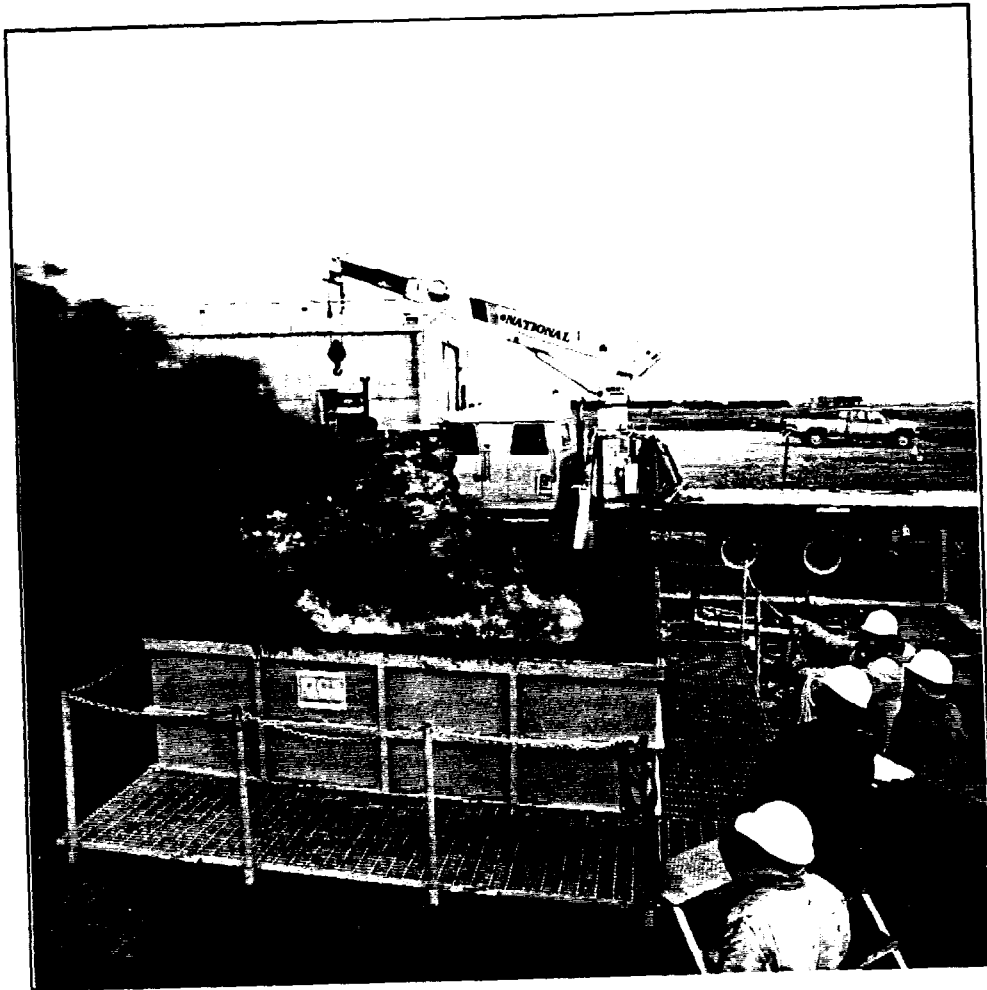
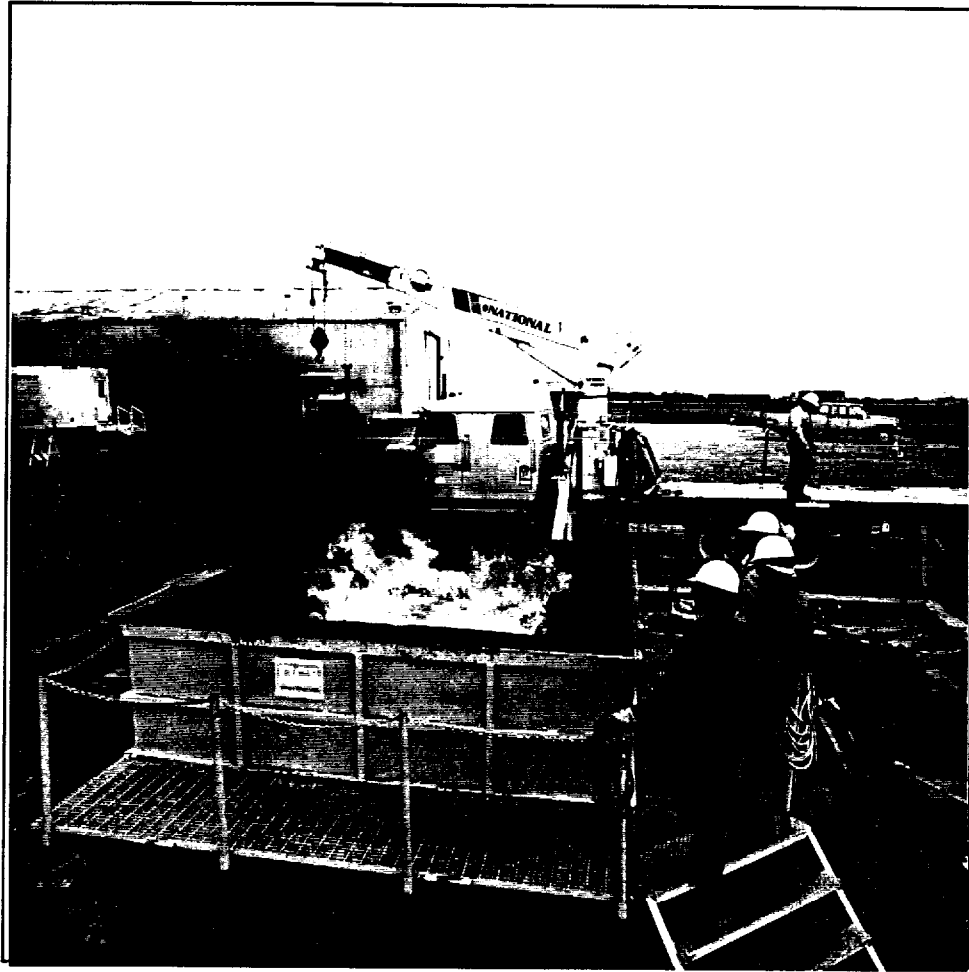


Figure 54 Priming the 40% water emulsion in the 3.3m<sup>2</sup> pan



**Figure 55** Burning the 40% emulsion in the 3.3m<sup>2</sup> pan

resulted in a successful burn. It appears that, at least up to 3.3 m<sup>2</sup> in area, in order to start the higher water content emulsions the entire surface area needed to be covered with igniters. The minimum fire area required for self-sustaining burns of oil slicks is about 1 m<sup>2</sup> (Bech et al. 1993); it appears that the minimum fire area required for emulsions is greater than 3.3 m<sup>2</sup>, at least for ANS crude oil.

Another observation from the 3.3 m<sup>2</sup> pan tests was that the residue from the igniters with higher-than-normal gelling agent concentrations tended to be a solid skin that appeared to block oil vapors from reaching the combustion zone. This appeared to hinder ignition somewhat.

Run 11 was carried out in the 1.2 m<sup>2</sup> pan and involved a 32 mm thick slick of 65% water emulsion, the maximum achievable. This emulsion was successfully burned with the premix application of 85 mL of EXO 0894 (1:445) followed by a one hour wait. The wind speed was 5 to 8 km/hr. Again, the flame was less smoky than a water-free crude oil burn.

Figure 56 shows the pan burn removal efficiency data. Figure 56a compares the Baseline runs in the 1.2 m<sup>2</sup> pan using the 23% evaporated ANS crude with the results from the lab for the 10% and 28% evaporated oil.

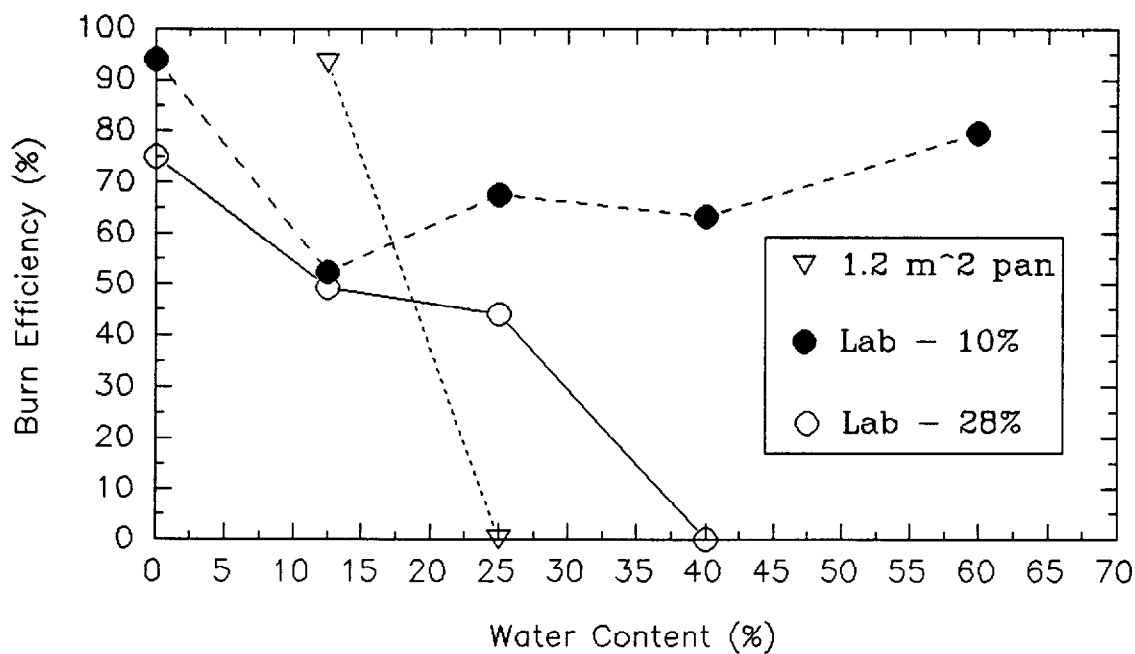
The trends are similar for the two fully stable emulsions (the 23% and the 28%). The fact that the 25% water emulsion of 28% weathered oil was ignited in the lab but the 23% evaporated oil was not ignitable in the pan may relate to winds outdoors, cooler air temperatures or slick thickness differences (20 mm in the lab vs 15 mm in the pan). The higher burn efficiency for the 12.5% emulsion outdoors is likely due to wind herding and scale effects.

Figure 56b shows the effect of water content on the removal efficiency for the pan burns involving emulsion breaker addition. The trends observed in the lab were also apparent in the pan tests: the addition of emulsion breaker virtually eliminated the effect of emulsified water on the burn efficiency. The differences in burn efficiency for the 25% and 40% water content emulsions between the 1.2 m<sup>2</sup> and 3.3 m<sup>2</sup> pans may relate more to wind speed than anything else. The winds during the 1.2 m<sup>2</sup> burns with 25% and 40% water ranged from 10 to 16 km/hr; for the equivalent 3.3 m<sup>2</sup> burns the winds were 26 to 34 km/hr. The wind speed during the burn with a 60% water content emulsion in the 3.3 m<sup>2</sup> pan was 8 to 11 km/hr; the equivalent burn in the 1.2 m<sup>2</sup> pan was conducted in 30 to 34 km/hr winds; however, the smaller pan was more protected from wind effects in the tank, and this may explain the high burn

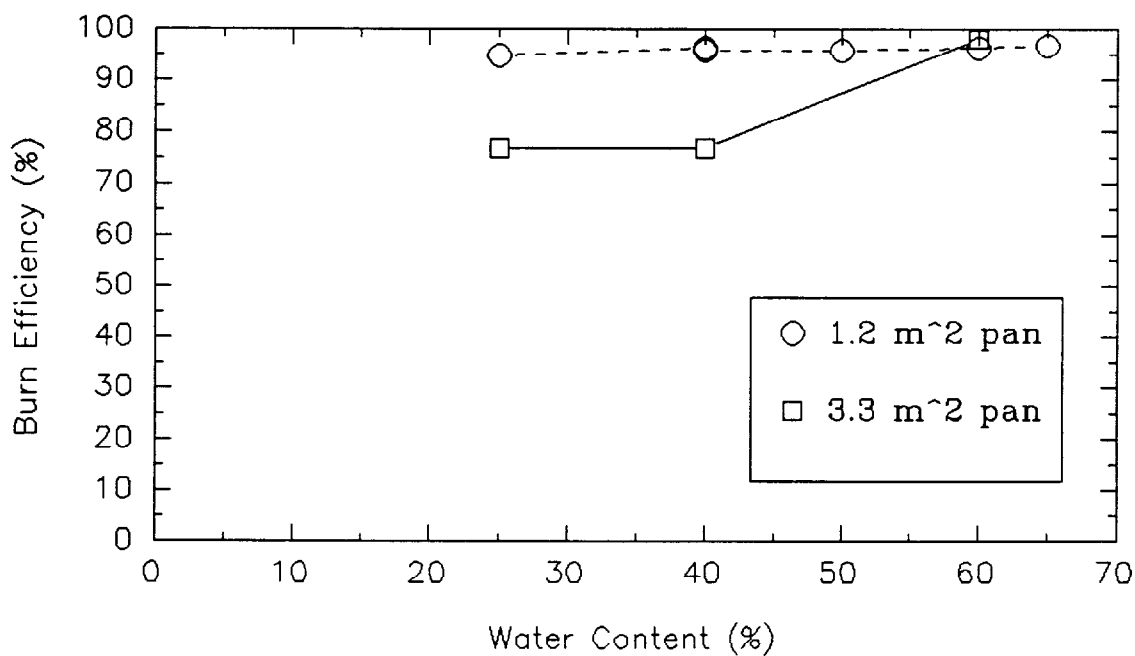
Figure 56

# Burn Efficiency vs. Emulsification

## Baseline Data



## Emulsion Breaker Tests



efficiency for this run. Slick thickness is unlikely to be a factor in the differences between the 1.2 m<sup>2</sup> and 3.3 m<sup>2</sup> tests; the initial slick thickness for the 3.3 m<sup>2</sup> burns was greater than for the 1.2 m<sup>2</sup> burns.

Figure 57 shows the oil removal rate data for the pan burns. Figure 57a compares the untreated emulsion burn rates achieved in the 1.2 m<sup>2</sup> pan with those obtained in the lab with the 10% and 28% evaporated ANS crude. The trends are similar. The higher burn rate in the 1.2 m<sup>2</sup> pan would have been a function of scale (larger fires burn faster); the inability to ignite the 25% emulsion outdoors was likely due to temperature and wind effects.

Figure 57b shows the results for the tests in the two pans when emulsion breaker was added. All other things being equal, the 3.3 m<sup>2</sup> slick should burn faster than the 1.2 m<sup>2</sup> slick; it is clear that the high winds during the 25% and 40% water content burns in the 3.3 m<sup>2</sup> pan affected the burn rate. The lower burn rate would also account for the reduced amount of smoke produced by these burns.

#### **5.2.5 Enhanced Igniter Test**

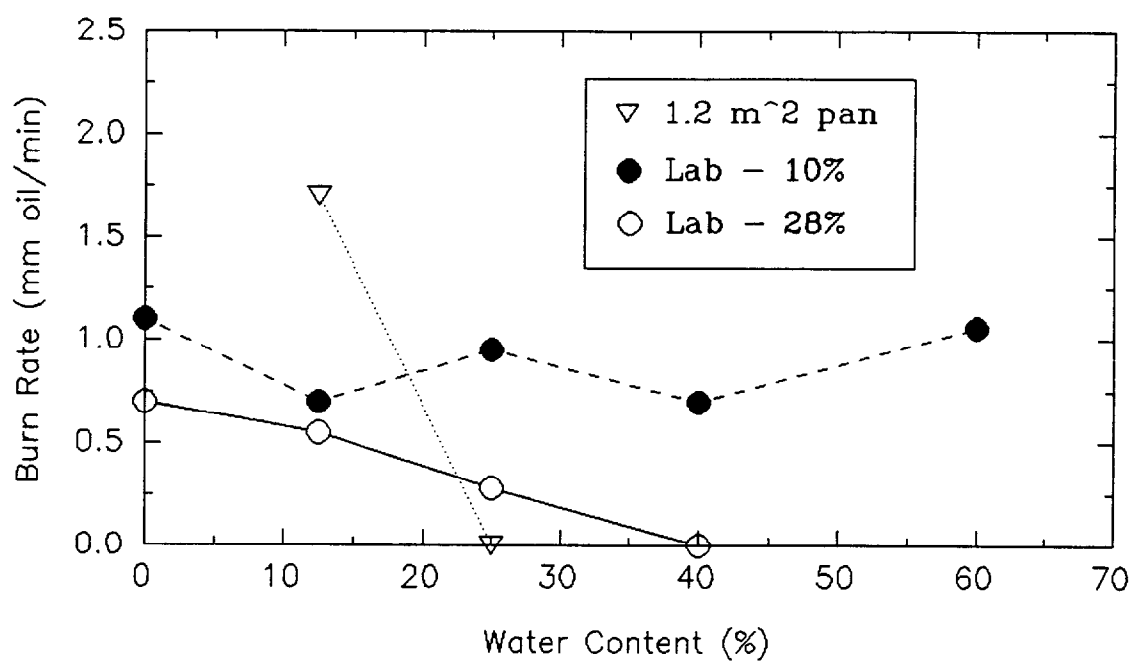
Run 7 (see Table 8 above) involved placing four 500 mL gelled gasoline/crude igniters containing a total of 50 mL of EXO 0894 (1:450 demulsifier:emulsion) on the surface of an 18 mm thick slick of 40% water content emulsion.

After the first ignition attempt failed, the residue remaining from the igniter was mixed into the slick which was then left to sit for 1.5 hours. A second ignition attempt with four untreated 500 mL gelled gasoline/crude igniters resulted in a moderately successful burn that removed an estimated 74% of the oil. Considerable residue remained after this burn; it was successfully re-ignited.

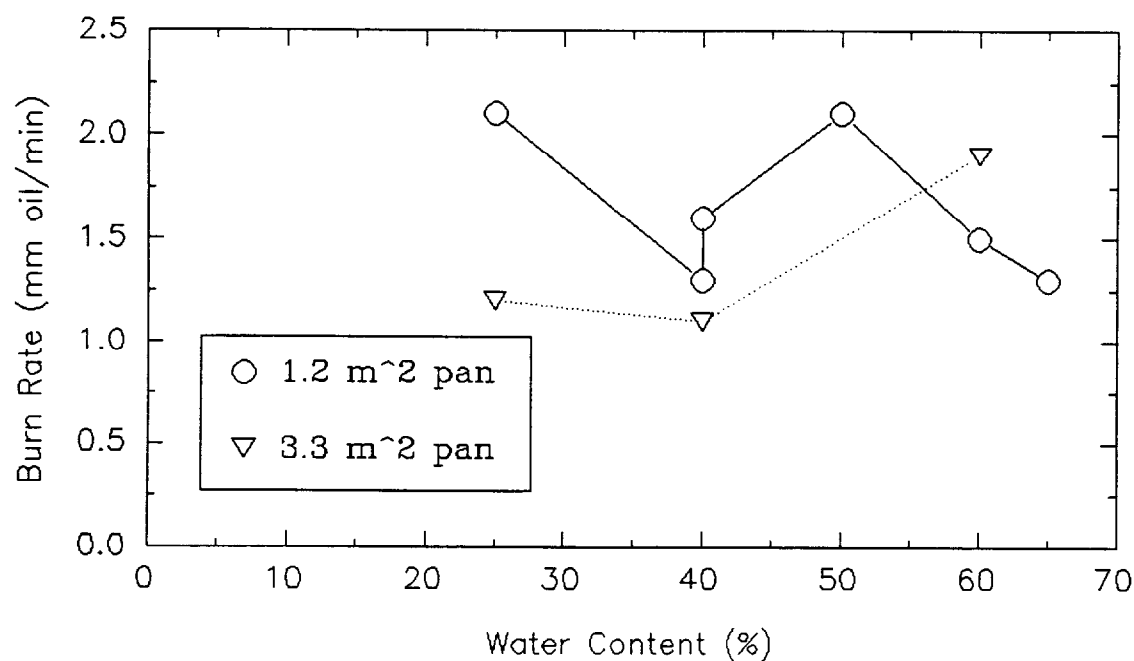
No further tests were conducted on the enhanced igniter concept because, for the combination of EXO 0894 and weathered ANS crude emulsions, it did not seem to offer as large an improvement as the pre-mixed (or break-and-burn) approach. It is possible that different combinations of emulsion breaker and emulsion would offer more promise for this technique. Certainly, the logistics of applying both the emulsion breaker and igniter simultaneously with the same piece of equipment are attractive.

Figure 57  
Burn Rate vs. Emulsification

### Baseline Data



### Emulsion Breaker Tests



### 5.2.6 Summary

The tests conducted outdoors on the North Slope in 1.2 and 3.3 m<sup>2</sup> pans with 23 % evaporated ANS crude showed that:

- a 50/50 mixture of gelled gasoline and fresh crude oil was the most effective Heli-torch fuel for emulsion ignition;
- the maximum ignitable water content for 23%-evaporated ANS emulsion outdoors was less than 25%;
- pre-mixing EXO 0894 with emulsion at a dose rate of 1:475 then letting the surfactant work for 1 hour, allowed ignition and efficient burning of a 65% water-in-oil emulsion of 23%-evaporated ANS crude - the 1 hour wait was crucial to successful ignition;
- compared with pre-mixing the emulsion breaker into the oil slick, adding the breaker to the igniter fuel proved much less effective at igniting and promoting the burn;
- a much stronger ignition source was required to establish burning of emulsion slicks than for oil slicks; the minimum fire size required appears to be greater than 3.3 m<sup>2</sup> for emulsions;
- emulsion ignition and burning was possible at air temperatures as low as 0°C and in winds up to 32 km/hr; winds in excess of 38 km/hr prevented ignition;
- re-ignition of naturally-extinguished burn residue was possible and resulted in higher overall oil removal efficiencies;
- visible smoke emissions seemed much lighter for the emulsion fires than for equivalent oil fires; and
- very high oil removal efficiencies were obtained by treating emulsions with EXO 0894 before burning.

## 5.3 MESO-SCALE TESTING

This section presents and discusses the results of the meso-scale burn tests at Prudhoe Bay in September, 1994.

### **5.3.1 Alaska North Slope Crude Weathering**

Figure 58 shows the progress of the artificial weathering of the 13.17 m<sup>3</sup> (82.8 bbls) of ANS crude used for the emulsion burns. Up to September 4 only air sparging and spraying was used to evaporate the oil; starting on September 4 the tank was heated using steam. The resulting increase in evaporation rate is apparent. The sparging, spraying and heating were stopped on September 6. The apparent increase in evaporation from the 6th to the 7th is due to the tank contents shrinking as they cooled back down to ambient temperature. In future artificial evaporation work, the fluid temperature should be measured when the tank soundings are made.

Overall, 17.4% of the oil's volume was evaporated over a two-week period. The properties of weathered ANS crude may be found in Appendix 1.

### **5.3.2 Emulsion Stability and Properties**

Samples of the test emulsions (nominally 50% and 60% water) were stored in a refrigerator for 72 hours to determine their stability. Neither sample showed any signs of breaking. The samples were then sent to BP's Prudhoe Laboratory for water content analysis. The "50%" water emulsion had actual water contents of 48%, 52% and 50%; the "60%" water emulsion had water contents of 58% and 58%.

The appearance of the 50% water emulsion, as it was pumped into the circle of fire boom prior to the test, was that of an extremely viscous fluid. In contrast, the 60% water emulsion appeared much less viscous and had a dark black color, probably because the oil was warm during mixing and the truck had been kept indoors overnight. Normally, it is expected that emulsion viscosity at a given shear rate increases with increasing water content. Comparison of the predicted viscosity of 20% evaporated ANS crude at 1°C and 15°C (Appendix 1) reveals that it increases from 93 mPas (=cP) at 15°C to 470 mPas (=cP) at 1°C. This would account for the visibly different consistency of the two emulsions.

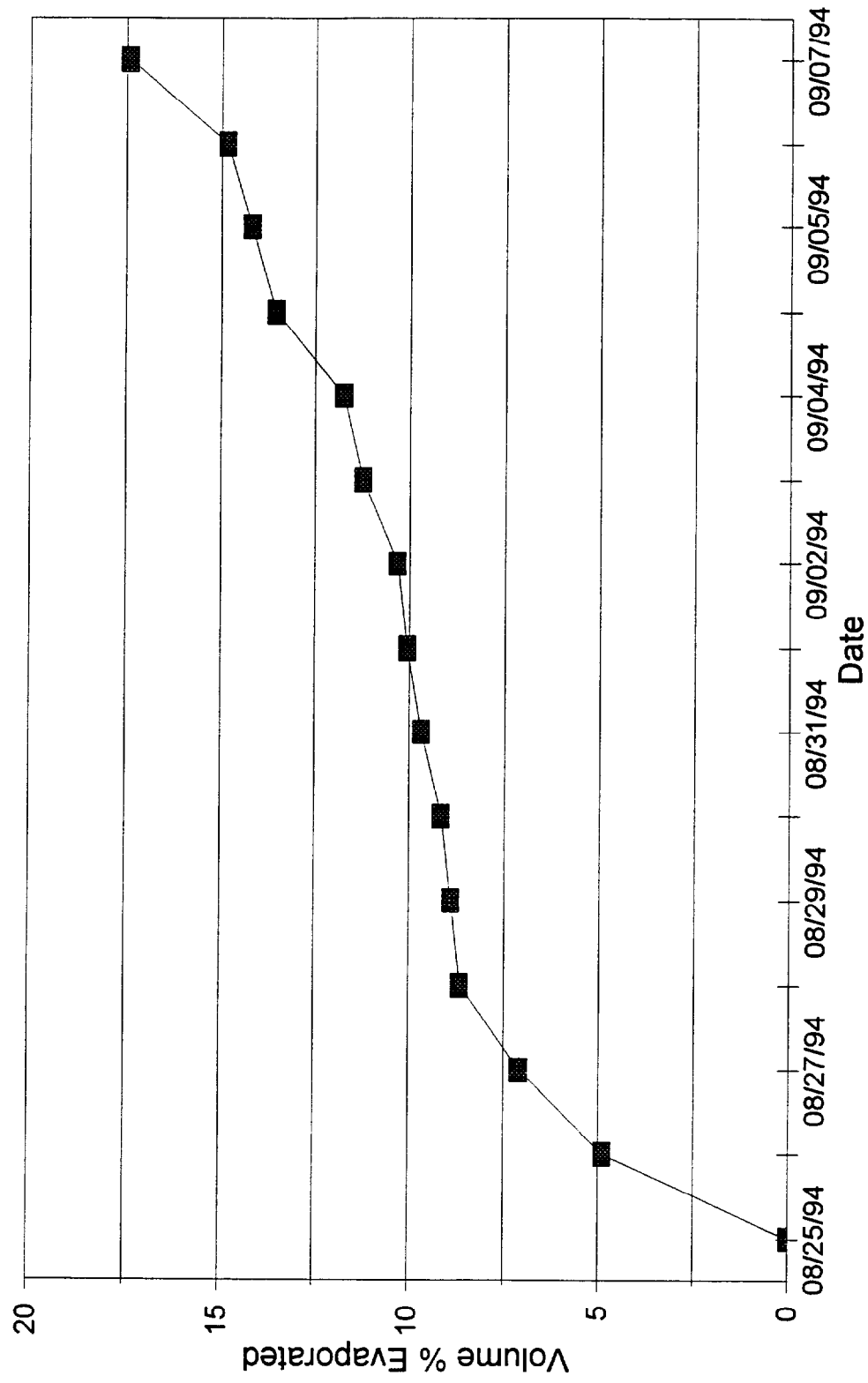
### **5.3.3 Gelled Fuel Igniter Preparation**

Three recipes for gelled fuel igniters were used: a 50/50 gasoline/crude mix; a 75/25 gasoline/crude mix; and straight gasoline. The 50/50 gasoline/crude fuel was mixed and gelled outdoors in the 205 L Heli-torch drum. At the 4°C (40°F) temperatures in 40 to 45 km/hr winds it took a concentration of



Figure 58

# Meso-scale Burn Test Oil Weathering Progress Chart



approximately 62 g/L (28 lbs in 55 gallons) of Surefire to achieve a reasonable gel. Considerable clumping and loss of gelling agent to the wind occurred. The mixing took several hours to complete as the gelling agent was added in incremental amounts. Subsequent gelled fuel mixing was conducted inside an open ISO shipping container for shelter from the wind.

A 38 L (10 gallon) batch of gelled gasoline was produced in one hour with a Surefire dosage of 13.5 g/L (6.2 lbs in 55 gallons). The cool temperatures slowed the gelling process, but did not seem to affect the consistency of the end product, as compared to the batches mixed in July.

Several batches of 75/25 gasoline crude mixture were prepared in the Nalgene containers. The Surefire dosage selected for this blend was 30 g/L (13.75 lbs in 55 gallons). This produced a gel of suitable consistency in 60 to 90 minutes in the cool conditions. All the gels produced did not appear to change consistency over a period of several days.

#### **5.3.4 Heli-torch Testing**

Prior to conducting the emulsion burns the Heli-torch was flown over the empty pit and the viability of the 50/50 gasoline/crude gel was tested. In the 40 to 45 km/hr winds present at the time, the propane igniter would not light the fuel as it exited the Heli-torch, even with the helicopter flying downwind to reduce the relative wind speed. Part of the problem appeared to be that the fully-loaded Heli-torch oriented itself parallel to the line of flight, thus allowing the wind access to the propane igniter. The shroud around the igniter was built to protect the propane igniter when the Heli-torch is flying in its design orientation, perpendicular to the line of flight. Subsequent flights with the Heli-torch only 20% full showed that this lesser weight did permit the Heli-torch to fly as designed. This problem has been noted previously (Spiltec 1987) and an anti-pivot bar has been designed and successfully tested for the Bell 212-series helicopters; a similar bar needs to be developed for other helicopter types that may be used to fly a Heli-torch.

#### **5.3.5 Emulsion Burn Tests**

Table 9 summarizes the results of the three meso-scale burns, including a water-free fresh crude burn.

Table 9  
**Meso-Scale Burn Data Summary**

	<b>Burn 1</b>	<b>Burn 2</b>	<b>Burn 3</b>
Date	9/8/94	9/10/94	9/11/94
Temperature (°C)	3	1	3
Wind Speed (km/h)	26	28	11
Volume of Emulsion (m³)	7.7	12.2	16.6
Volume of Oil (m³)	3.9	12.2	6.7
% Oil	50%	100%	40%
Degree of Oil Evaporation (%Vol)	17.4%	0%	17.4%
Volume of Water (m³)	4	0	10
Volume of EXO 0894 (L)	26.5	0	26.5
Ignition Time	0.5 min	2 min	3 min
Extinguishment Time	55 min 34 s	43 min 42 s	47 min 22 s
Estimated Oil Burn Rate (mm/min)	1	3.8	1.8
Weight of Slick (kg)	7536	10827	16364
Weight of Oil in Slick (kg)	3768	10827	6545
Weight of Burn Residue (kg)	103	170	212
Oil Removal Efficiency	97.3%	98.4%	96.7%

The first burn involved a 100 mm thick slick of 50% salt water emulsion created with the 17.4% evaporated crude. Prior to ignition the 7.7 m<sup>3</sup> (48.5 bbls) of emulsion was sprayed with 26.5 L (7 gallons) of EXO 0894. It proved difficult to pump the cold emulsion breaker through the nozzle tip of the garden sprayers. The solution was to remove the tip and apply a solid stream directly from the end of the wand. This probably reduce the uniformity of coverage of the slick with chemical.

While the emulsion breaker was being added, the slick was gently stirred with canoe paddles. The gentle stirring continued for 20 minutes after the breaker was added.

The slick was ignited approximately one hour after the mixing ceased. Ignition was accomplished with 38 L (10 gallons) of gelled 75/25 gasoline/crude mixture dropped from a Heli-torch beneath the helicopter. The igniter fuel lit easily, burned strongly as it fell and spread out over the surface of the emulsion slick. The helicopter pilot covered nearly the entire slick area by moving the Heli-torch around. The entire 69.5 m<sup>2</sup> surface of the slick was covered with flame 30 seconds after the Heli-torch was emptied - the gelled fuel worked well in igniting the emulsion.

The wind speed at the time of this burn was 26 km/hr (14 knots) and the air temperature was 3°C (38°F). Complete weather records from the nearby Prudhoe Bay airstrip may be found in Appendix 6. The water temperature was near-freezing. Although it was not measured prior to this burn, the water temperature prior to subsequent burns was 3°C (38°F).

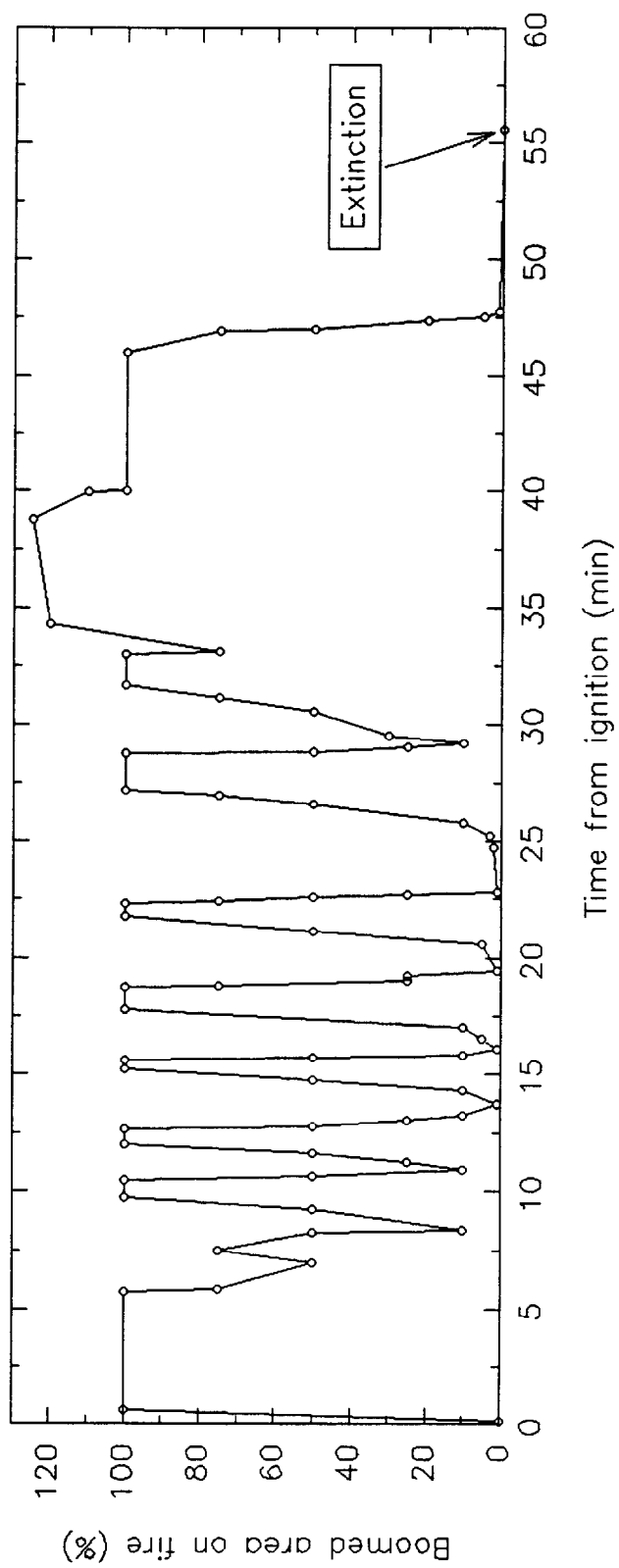
The burn progressed well, with strong flames and full flame coverage (Figure 59). Flame temperatures, measured with an optical pyrometer were 1100 to 1200°C after only 1 minute 30 seconds. Flame heights were visually estimated at one fire diameter, about half what would be expected for a water-free oil fire of equivalent diameter (Buist et al. 1994). After about 6 minutes, the flames began to die down and some of the slick extinguished. After 7 minutes the flames were covering only 50% of the surface. The flames spread out again to cover 75% of the slick but by 8 minutes 15 seconds only the upwind edge of the slick in the lee of the boom was burning. Then the flames began to spread out and, by 9 minutes 45 seconds, the entire slick area was on fire again, burning steadily.

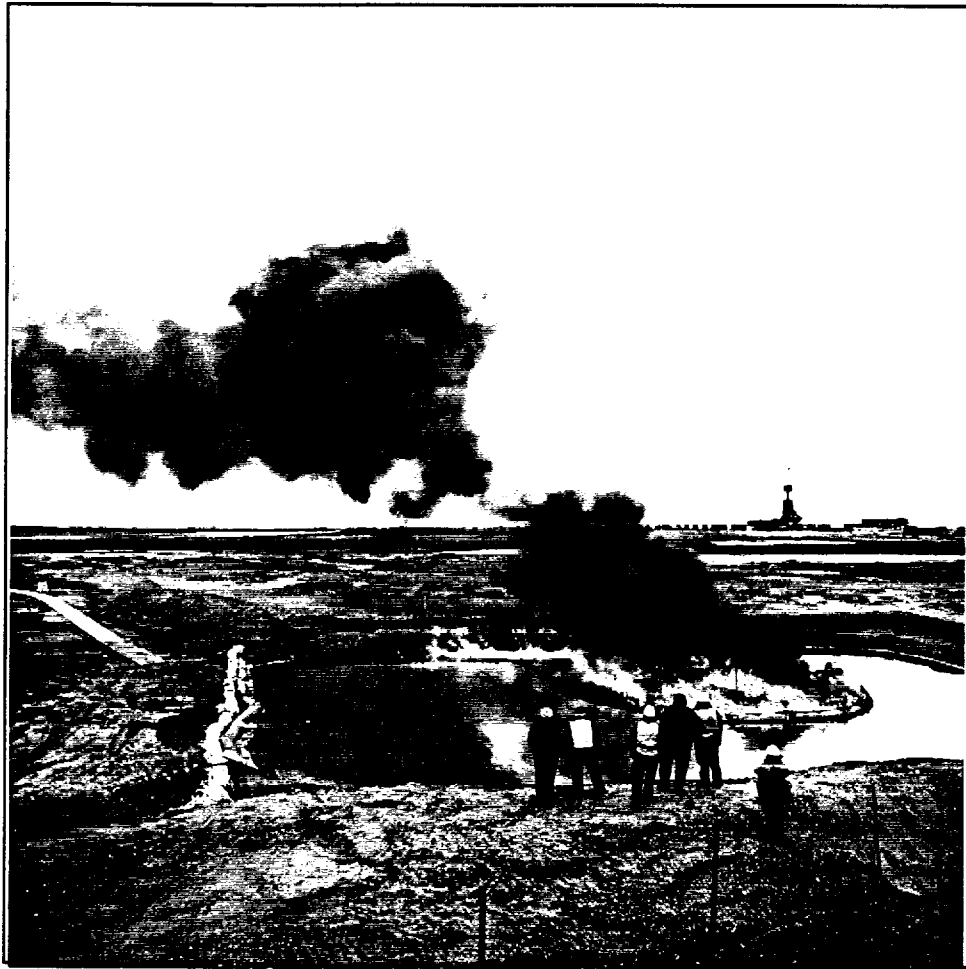
This process repeated itself nine times over the course of the burn. The phenomenon was dubbed "pulsing". Figure 60 shows a graph of the percentage of the contained slick area on fire as a function of time. The pulsing nature of the fire is apparent (see also Figures 61 to 65 for the visual appearance



**Figure 59** 50% water emulsion burn a few minutes after ignition

**Figure 60**  
Pulsing of Meso-scale Burn of 50% Water Emulsion





**Figure 61** 50% water emulsion burn beginning to die out at start of pulsing



**Figure 62** Burn area reduced to 10% during first pulse





**Figure 63** Burn at minimum flame area



**Figure 64** Burn area growing



**Figure 65** Burn area returned to 100% - note oil loss from fire boom

of the phenomenon). The behavior seemed to have a regular frequency during the middle stages of the burn (Figure 60) with a period of approximately 3 minutes. There was no visual evidence of foaming of the slick taking place, although a considerable amount of white vapor (presumably steam) was generated by the unlit portions of the slick.

It is believed that the pulsing phenomenon was related to the balance between the rate at which the fire consumed the oil floating on top of the emulsion and the rate at which the oil creamed out of the emulsion to replenish the layer. When the rate at which oil was burned exceeded the rate at which it creamed out of the emulsion, then, the layer of oil on top of the emulsion got thinner and eventually cooled below its fire point (the underlying emulsion temperature cannot exceed 100°C) and the flames extinguished. Meanwhile, the oil continued to cream out of the emulsion. This, with no flames present, resulted in a growing layer of oil on the surface; once the layer of oil was thick enough it was re-ignited by nearby flames.

It took some time after ignition for this phenomenon to begin. This was likely due to a layer of oil from the emulsion breaking prior to ignition. This layer would have been thick enough (about 20 mm) to burn for 7 minutes before dying back. The phenomenon stopped and a normal, steady burn occurred for the last 15 minutes of the burn likely because the heating of the underlying slick had progressed enough to accelerate the emulsion breaking process to the point where the rate of oil creaming equalled or surpassed the rate of oil consumption by the fire. The last flames disappeared 55 minutes and 34 seconds after ignition.

As the residue cooled, some of it sank. The residue that sank formed a brittle solid that was recovered from the bottom of the pit; the residue that remained afloat was in the form of a semi-solid tar. The total weight of residue recovered was 103 kg. The oil removal efficiency was calculated as 97.3%: the equivalent thickness of residue remaining would have been 1.5 mm. The average burn rate was calculated as 1 mm/min; however, taking into account the pulsing, the burn rate at any given time the slick was fully on fire was probably closer to 2 mm/min. This is still only half what would be expected for this size of fire with water-free oil. Because of the wind herding the residue and its sinking, it was not possible to see any holes in the floating residue that were characteristic of treated burns in the smaller scale tests.

The next burn involved the ignition and burning of 12.2 m<sup>3</sup> (78 bbl) of fresh ANS crude as a baseline for the smoke plume monitoring study. Gelled gasoline dropped from the Heli-torch was used to ignite the 175 mm thick slick. The slick was fully ablaze after 2 minutes. The wind speed was 28 km/hr (15 knots) and the air temperature was 1°C (34°F).

The burn progressed normally with no pulsing (Figure 66) with flame heights of about two to three fire diameter, and much black smoke. Figure 67 shows the percentage of the contained slick area (69.5 m<sup>2</sup>) on fire as a function of time. The area exceeded 100% because, after 5 minutes, the fire boom began to leak oil that caught fire. At the peak of the leakage, the ring of boom was surrounded by a 2 m wide continuous band of burning oil (Figure 68). Some oil also collected against the downwind berm of the pit and burned there. This burn extinguished more slowly than the first, with oil herded against the downwind edge of the boom burning for 10 minutes before extinguishing (Figure 69).

As the residue from this burn cooled it sank. A total of 170 kg of residue was collected, equivalent to a 2.5 mm thick layer. The oil removal efficiency was 98.4%. The overall oil removal rate, based on the area on fire vs. time given in Figure 67, was 3.8 mm/min; almost exactly what would be expected (3.5 mm/min - Buist et al. 1994). The temperature of the surface water in the pit after the burn was 5°C to 7°C (41 to 45°F). At a depth of 0.6 m (2 ft) the temperature was still 3°C.

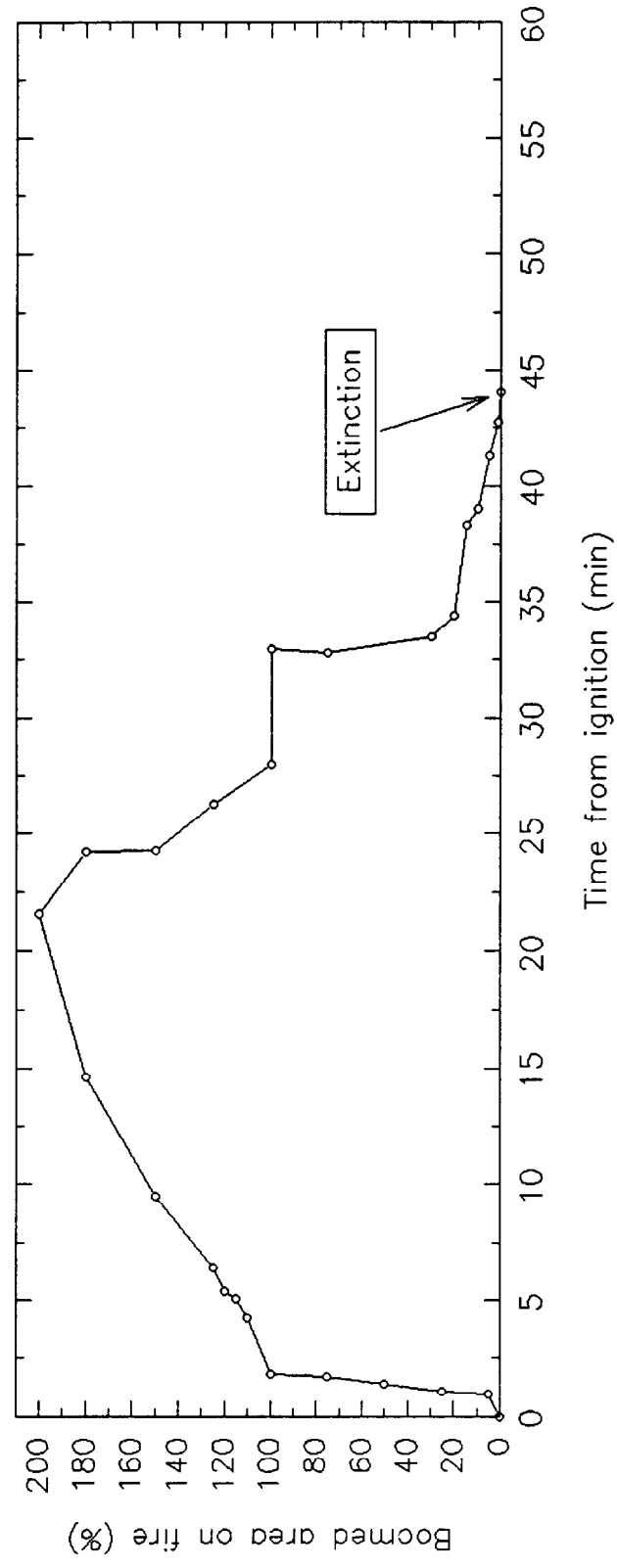
The final test involved 16.6 m<sup>3</sup> (104 bbls) of a 60% water emulsion. The slick was evenly sprayed with 26.5 L (7 gallons) of warmed EXO 0894 which was vigorously stirred (Figure 70) into the slick for 30 minutes. The 240 mm thick slick was ignited by throwing hand-held igniters onto 38 L (10 gallons) of gelled 75/25 gasoline/crude fuel mixture that had been poured on the upwind side of the slick. The temperature of both the air and water prior to the burn was 3°C; the wind speed was near calm at the beginning of the burn, increasing to 11 km/hr (6 knots) by the end.

The flames spread from the approximately 20 m<sup>2</sup> area covered by the gelled fuel to cover the entire slick area in approximately 3 minutes. Initially the flames were low (one fire diameter or less) and relatively luminous (Figure 71) but as the burn progressed the flames became higher and smoke obscured them more (Figure 72). A flame temperature reading of 1200°C was obtained 19 minutes into the burn on the upwind side, just above the boom. Figure 73 shows the area on fire during the course of the burn. Percentages greater than 100 are due to burning oil escaping from the boom.



**Figure 66** Early stages of the crude oil burn

**Figure 67**  
Estimated Burn Area for the 12.2 m<sup>3</sup> Crude Oil Test





**Figure 68** Burning oil leaking from boom

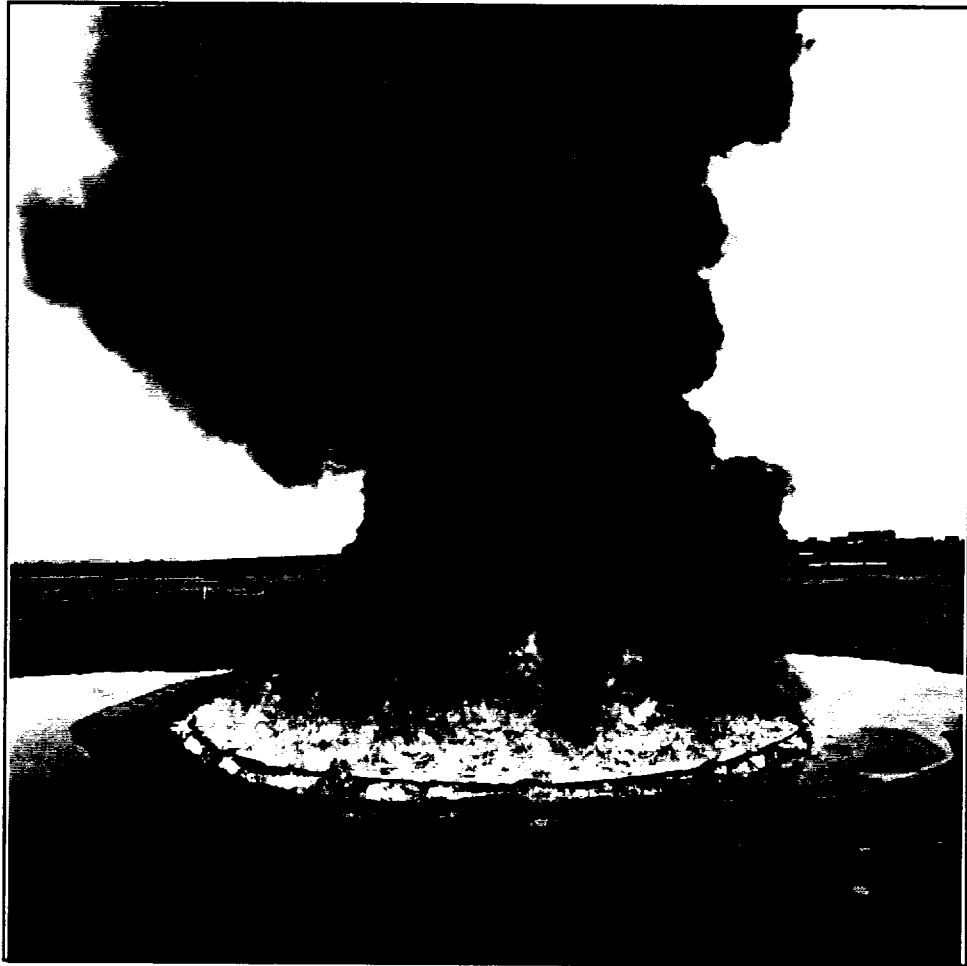




**Figure 69** Oil herded by wind near end of crude oil burn



**Figure 70 Vigorous stirring of 60% water emulsion after EXO 0894 addition**

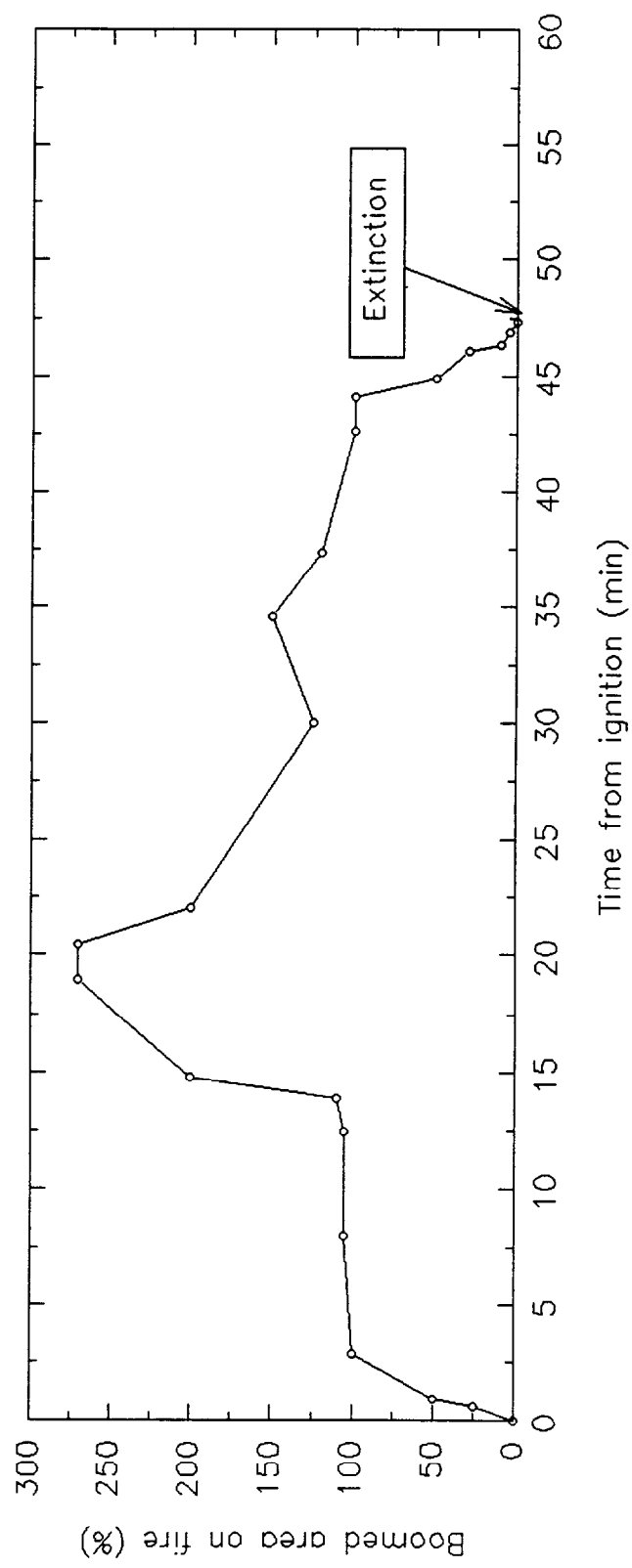


**Figure 71** Appearance of flames and smoke near the beginning of the 60% water emulsion burn



**Figure 72** Appearance of flames and smoke mid-way through the 60% water emulsion burn - note boom completely surrounded by burning oil

**Figure 73**  
Estimated Burn Area for the 16.6 m<sup>3</sup> 60% H<sub>2</sub>O Emulsion Test



After about 45 minutes the flames began to die down as the residue was herded against the downwind edge of the boom (Figure 74). After 47 minutes and 22 seconds the flames extinguished. Holes in the residue were noted similar to those observed after the pan burns. Again, as the residue inside the boom cooled, it sank. In total 212 kg were recovered including the residue from the bottom and surface inside the boom and from along the downwind edge of the pit. This equates to a 96.7% oil removal efficiency. The equivalent thickness of residue in the boom would have been 3 mm.

The burn rate, taking into account the area on fire shown on Figure 73 was 1.8 mm/min.

No pulsing behavior was evident. The reason for this is probably related to the differences between this burn and the 50% burn. The 50% emulsion was colder and more viscous than the 60%; the application and mixing of the emulsion breaker was better for the 60% emulsion; the wind speed was much higher for the 50% emulsion burn; and the 50% emulsion slick was thinner (110 mm vs. 240 mm). The first three are the most likely reasons for the pulsing of the 50% emulsion but not the 60%. Higher temperatures reduce the oil's viscosity which hastens coalescence and settling of water droplets in the emulsion. The poor application and mixing of the emulsion breaker in the 50% water emulsion hindered its ability to promote emulsion breaking. The higher winds could have made the flames over the 50% emulsion slick more fragile and also reduced heat transfer rates into the underlying emulsion.

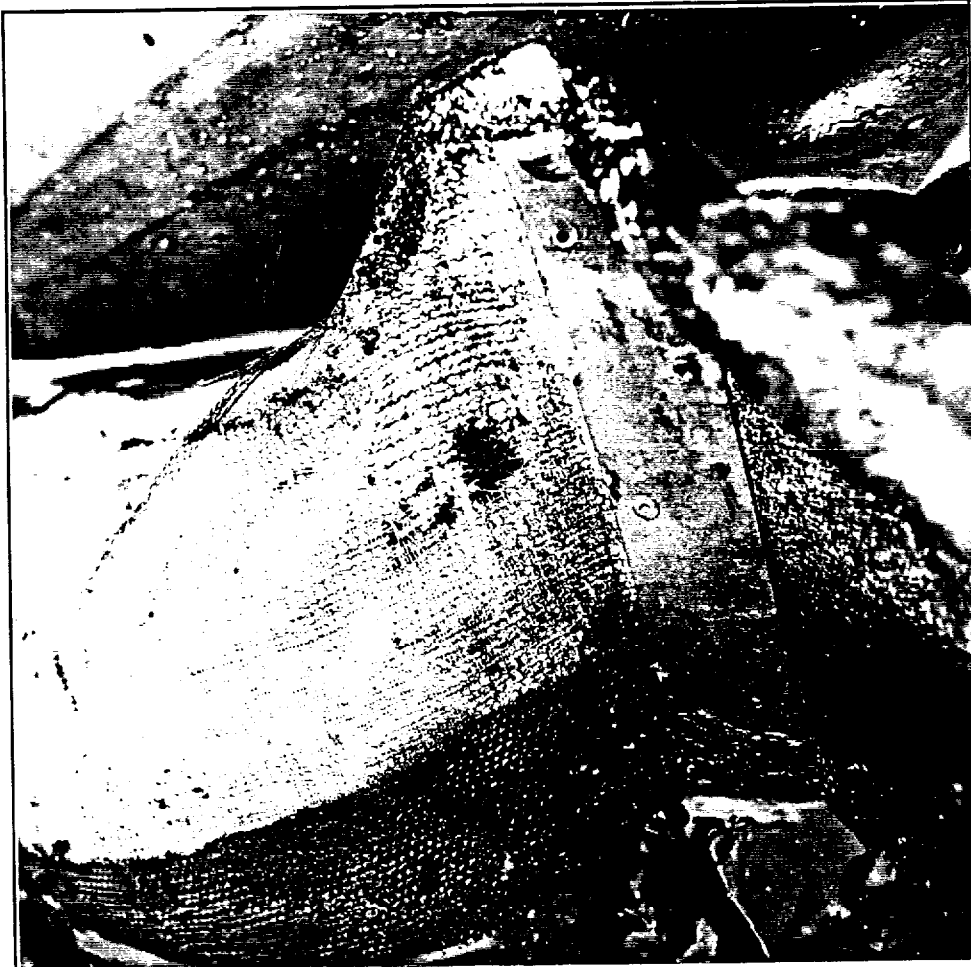
#### **5.3.6 Fire Boom Performance**

This study was neither designed nor intended to evaluate the performance of fire resistant boom materials. The selection of the 3M Fire Boom used during the meso-scale test burns was based on availability and not on performance criteria. Due to the cost associated with possibly destroying the boom, the oldest boom in the ACS inventory was purposely chosen.

During each meso-scale burn test, the oil or emulsion contained within the ring of fire resistant boom began to escape approximately five minutes after ignition. The prime points of leakage were the vertical stiffeners and boom connection points (Figure 75). For the first two burns, new sections of 3M 18 x 24 Fire Boom were anchored in the burn pit to contain the slick. After the second burn the boom was left in place and polyethylene plastic sheeting draped over it to provide an oil proof barrier prior to ignition. This too began to leak five minutes after ignition of the slick.



**Figure 74** 60% water emulsion burn near end



**Figure 75** Vertical metal stabilizer on used fire-boom



This problem of leakage has not been reported before, despite numerous test burns with the 3M Fire Boom (Buist et al. 1994). It is possible that the leakage was not previously identified because of differences in the way the 3M boom was tested. Most of the earlier tests of the boom involved burn times as long or longer than the times here, but they may not have involved thick slicks. Most of the previous tests involved the continuous pumping of oil into the boom as it burned. This maintained a relatively small thickness in the boom at any given time.

The emulsion and crude burn tests in Prudhoe Bay involved slick thicknesses in the hundreds of millimeters. This thickness condition was also achieved at the NOBE offshore burn tests (Fingas et al. 1994) where oil was herded against the back of a boom under tow. Observers onsite for the emulsion burns, who had also been present at the NOBE burns, noted that a similar phenomenon, of oil leaking through and burning on the backside of the boom, occurred at NOBE; however, the cause (leakage, splash-over or entrainment) is uncertain.

The following is offered as a possible explanation for the leakage. A slick thickness of 175 mm of crude oil with a density of  $0.895 \text{ g/cm}^3$  would generate a head (the difference between the height of oil inside the boom and the water level outside the boom) of oil of 18 mm (3/4 of an inch). Once the protective orange cover on the boom burned off this head of oil may have been sufficient to force the oil through the Nextel fire-resistant fabric. Previous tests may not have generated a sufficient head of contained oil to cause the oil to penetrate the boom fabric. This also may explain why the boom stopped leaking near the end of each test; by this time much of the slick had been burned and the head was greatly reduced.

Another piece of evidence supports this theory. Flow through porous media is inversely proportional to the fluid's viscosity. In the meso-scale burn tests, the fresh crude appeared to escape containment faster than either of the emulsions and was notably the least viscous of the fluids tested.

The boom used for this project was not one of the most recent models of 3M Fire Boom. Modifications to the boom have been ongoing based on experience from continued boom testing. Sections of the used boom were removed after the burn and sent to the manufacturer for further evaluation and testing.

### **5.3.7 Summary**

The following conclusions were drawn from the meso-scale tests:

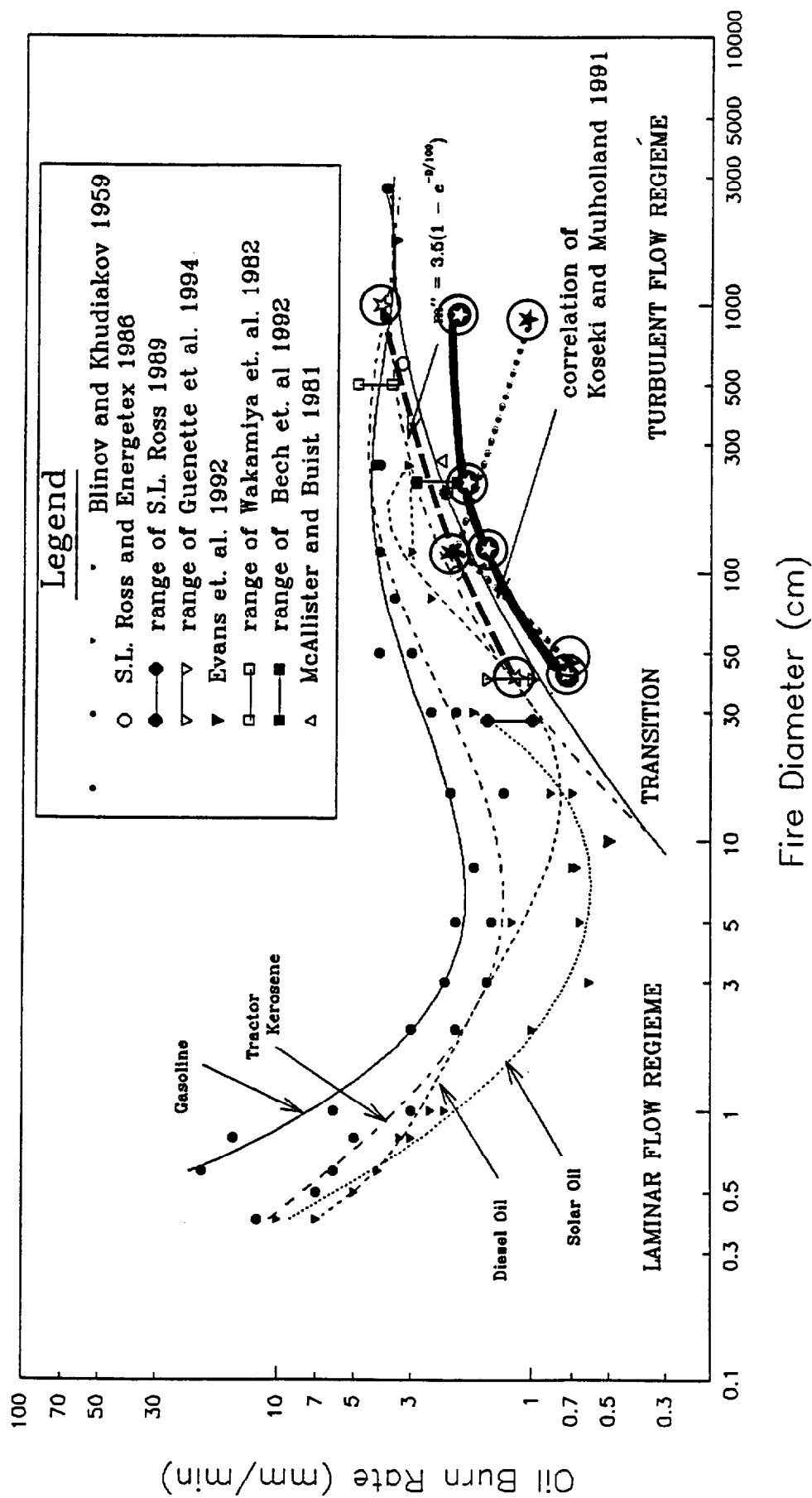
- in order to work from a helicopter in flight, the gasoline content of the gelled igniter fuel had to be increased to 75%;
- this mixture was an effective igniter for both the 50% and 60% emulsions of weathered crude;
- the minimum flame area required for sustained ignition of emulsions was less than about 20 m<sup>2</sup>, the estimated area covered by gelled fuel in the 60% test;
- the addition of EXO 0894 permitted ignition and successful burning of stable water-in-oil emulsions with up to 60% water in cold temperatures;
- an even application of the emulsion breaker, thorough mixing, and an adequate settling time are important to effective emulsion burning;
- the burn residue from thick slicks of ANS crude can sink in fresh water; and
- improvements are needed to the 3M Fire Boom.

## **5.4 SCALING EFFECTS**

In this section the results of the burns at the three different scales (laboratory-, pan- and meso-scale) are compared and also contrasted with other researchers' data.

Figure 76 compares the burn rate data from this study with the work of other researchers. It can be seen that the data for the fresh crude fits the correlations and results of the others quite well. The data for the treated 60% emulsions indicate that its burn rate was consistently less than that of fresh crude. As the scale of the burns increased, the rate at which this emulsion burned increased less than for water-free oil. This may be due to the mixing and action of emulsion breakers becoming less efficient with

Figure 76  
Burning Rate vs. Fire Diameter – A Comparison of Data Sets



larger, thicker slicks. This would result in the emulsion breaking rate limiting the burn process. This seems to be borne out by the data for the 50% emulsion; the meso-scale tests resulted in a lower average oil burning rate than the pan tests did.

The consistently lower emulsion burning rates would also explain the reduced smoke emissions for emulsion burns. With lower oil combustion rates, more air could mix more thoroughly with the fuel.

Table 10 compares the overall oil removal efficiencies achieved for the fresh crude and the treated 50% and 60% emulsions.

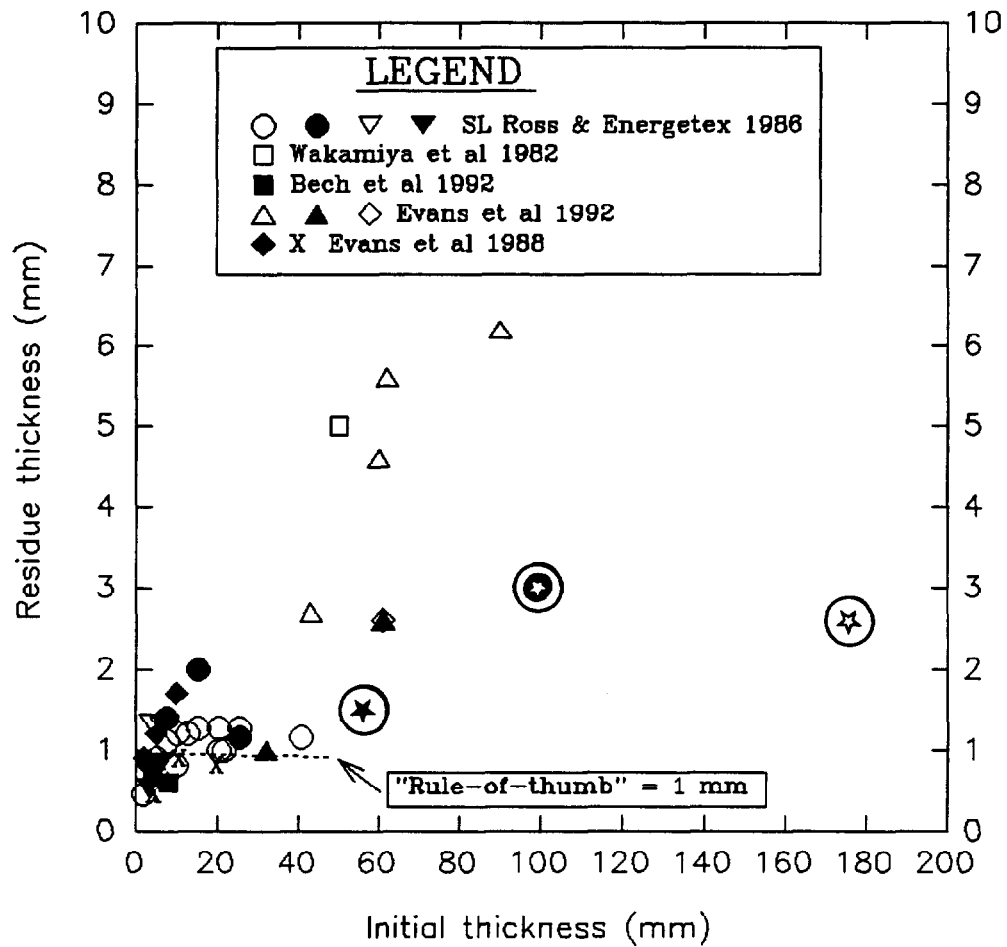
**Table 10**  
**COMPARISON OF OIL REMOVAL EFFICIENCY**

	Laboratory Tests	Pan Tests		Meso-scale Tests
		1.2 m <sup>2</sup>	3.3 m <sup>2</sup>	
fresh crude	89.2	--	--	98.4
50% emulsion of weathered crude	79.3	95.8	--	97.3
60% emulsion of weathered crude	73.4	96.4	98.0	96.7

Although it is not possible to directly compare the results across a row because each test had a different initial thickness, it is clear that the treatment of the emulsion with EXO 0894 resulted in consistently efficient burns.

Another important aspect of in-situ burning is the amount of residue remaining after extinction. Figure 77 compares the equivalent residue thickness remaining after the three meso-scale burns with data from other sources. It is clear that the meso-scale burns, particularly the fresh crude one, resulted in less residue than expected. It is believed that this is due to the effects of wind herding of the residue near the end of the burn; and, for the emulsion burns, the herding action of the chemical emulsion breaker.

**Figure 77**  
**Comparison of Data Sets on**  
**Residue Thickness as a Function of Initial Slick Thickness**



Meso-scale data from this study: (★) = 60% emulsion, (★) = 50% emulsion, (★) = fresh crude

## **6.0 CONCLUSIONS AND RECOMMENDATIONS**

### **6.1 CONCLUSIONS**

The following conclusions were drawn from this study:

- 1/ The maximum ignitable water content for ANS crude oil evaporated to 17% volume loss or more was between 12.5% and 25% emulsified seawater.
- 2/ Commercial emulsion breakers were effective with heavily weathered ANS crude and allowed the successful ignition and efficient burning of emulsions with water contents as high as 65%. The North Slope oilfield emulsion breaker EXO 0894 worked best with ANS crude emulsions.
- 3/ The most effective way of applying EXO 0894 was by pre-mixing it into the emulsion. The dose rate used successfully was 1 part EXO 0894 to 475 parts of emulsion.
- 4/ An even application of the emulsion breaker to the slick, thorough mixing, and a minimum 1 hour settling time were required for effective emulsion burning.
- 5/ A gelled mixture of 75% gasoline and 25% crude oil proved to be an effective Heli-torch fuel for ignition of ANS crude oil emulsions. The dosage of Surefire gelling agent used to obtain adequate gel properties in a reasonable time at near-freezing temperatures was 30 g/L (13.75 lbs/55 gallons).
- 6/ A much stronger, larger ignition source was required for emulsion slicks, compared to oil slicks. The minimum fire area required for sustained burning of weathered ANS crude emulsions was between 3.3 m<sup>2</sup> and 20 m<sup>2</sup> (4 yd<sup>2</sup> and 24 yd<sup>2</sup>).
- 7/ Emulsion ignition was possible with air temperatures as low as 0°C (32°F) and water temperatures as low as 1°C (34°F) in winds up to 32 km/hr (17 knots). Winds of 38 km/hr (20 knots) or greater prevented ignition.

- 8/ Emulsion slicks, both treated and untreated, burned oil at a slower rate than equivalent water-free oil slicks. The rate of oil removal from emulsions by burning declined with increasing water content and increased with fire diameter.
- 9/ Treatment of an ANS crude oil emulsion slick with EXO 0894 prior to its ignition in-situ, resulted in oil removal efficiencies as high as those obtained with equivalent water-free crude oil burns.
- 10/ Re-ignition of naturally-extinguished burn residue was possible and resulted in higher overall oil removal efficiencies. Natural wind herding of residue against a barrier and chemical herding of residue by the remnants of emulsion breaker during the final phases of a burn contributed to high overall oil removal efficiencies.
- 11/ The burn residue from very efficient burns of ANS crude and emulsions can sink in fresh water.
- 12/ The visible smoke emissions from emulsion burns seemed much lighter than from crude oil burns.

## **6.2 RECOMMENDATIONS**

The following recommendations, presented in order of priority, arose from the study:

- 1) The next logical step in assessing whether "break and burn" is a viable spill response tool is to conduct emulsion burning tests in waves. Not only is this important from the perspective of testing the concept under realistic conditions, but it will also indicate whether or not additional mechanical mixing of chemicals into contained emulsion slicks will be necessary for their effective use in the real world. If extra mixing is required, this would involve additional R&D.
- 2) The efficacy of the "break and burn" technique should be assessed in the laboratory with other oils and emulsion breakers. It is known that the efficacy of particular emulsion breakers is oil-dependant. In order to ascertain the most effective chemical for in-situ burning of a specific emulsion, small-scale burn tests will be needed.
- 3) Given that the above recommendations produce encouraging results, regulatory approval for the use of emulsion breakers should be obtained.

- 4) Given that the above three recommended programs are successful, it will be necessary to research and develop systems for the application of emulsion breakers to contained slicks at sea (and perhaps their mixing into the slick as noted in 1 above) and test the effectiveness of the system(s) at sea under realistic conditions.

The following recommendations, though not directly related to the use of emulsion breakers, also arose from the study:

- a) The design of anti-pivot bars for the Heli-torch for various helicopters other than the Bell 212 should be pursued.
- b) The design of fire-resistant booms needs to be revisited. Existing and proposed fire-resistant boom designs need to be tested in an environment that reasonably simulates conditions of actual use.



## 7.0 REFERENCES

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## **APPENDIX 1**

### **ANS and Endicott Crude Oil Properties**



# **OIL NAME: ALASKA NORTH SLOPE - PUMP STATION #1**

1.0 TYPE: Crude		WEATHERING (VOLUME %)	
		0	20.64
2.0 DENSITY (g/mL):			31.8
1 °C		0.887	0.926
15 °C		0.876	0.914
3.0 VISCOSITY:			
3.1 DYNAMIC VISCOSITY (mPa.s):			
1 °C		38.9	471.3
15 °C		17.6	93.4
3.2 KINEMATIC VISCOSITY (mm <sup>2</sup> /sec):			
1 °C		43.9	509.0
15 °C		20.1	102.2
4.0 INTERFACIAL TENSIONS @ 20°C (mN/m):			
4.1 AIR-OIL:		31.8	34.2
4.2 OIL-SEAWATER:		24.0	27.0
5.0 POUR POINT (°C):		<-13	-13
7.0 FLASH POINT - CLOSED CUP (°C):		<-13	-7
8.0 EMULSION FORMATION TENDENCY AND STABILITY @ ROOM TEMPERATURE (20°C):			
8.1 TENDENCY			
15°C		0.40	0.86
8.2 STABILITY			
15°C		0.00	0.00
9.0 DISTILLATION DATA (°C) :			
	VOLUME PERCENT	LIQUID TEMPERATURE	VAPOR TEMPERATURE
	IBP	77.6	35.5
2.5		128.2	56.6
5		147.4	53.7
7.5		167.7	57.4
10		181.9	65.2
12.5		197.6	73.8
15		213.5	74.9
17.5		231.8	79.9
20		248.3	84.5
22.5		266.3	89.9
25		284.2	93.9
27.5		299.9	108
30		313.6	114.6
32.5		326.4	123
35		340.6	121.9

10.0 WEATHERING:	
Fv =	$\ln(1+7164.5 \cdot e^{\exp(6.3 - 3911.5/Tk)/Tk})$ (7164.5/Tk)
where: Fv is fraction of oil lost by volume	
ln is natural log	
e is evaporative exposure	
exp is exponential base e	
Tk is environmental temperature (Kelvin, K = °C + 273)	

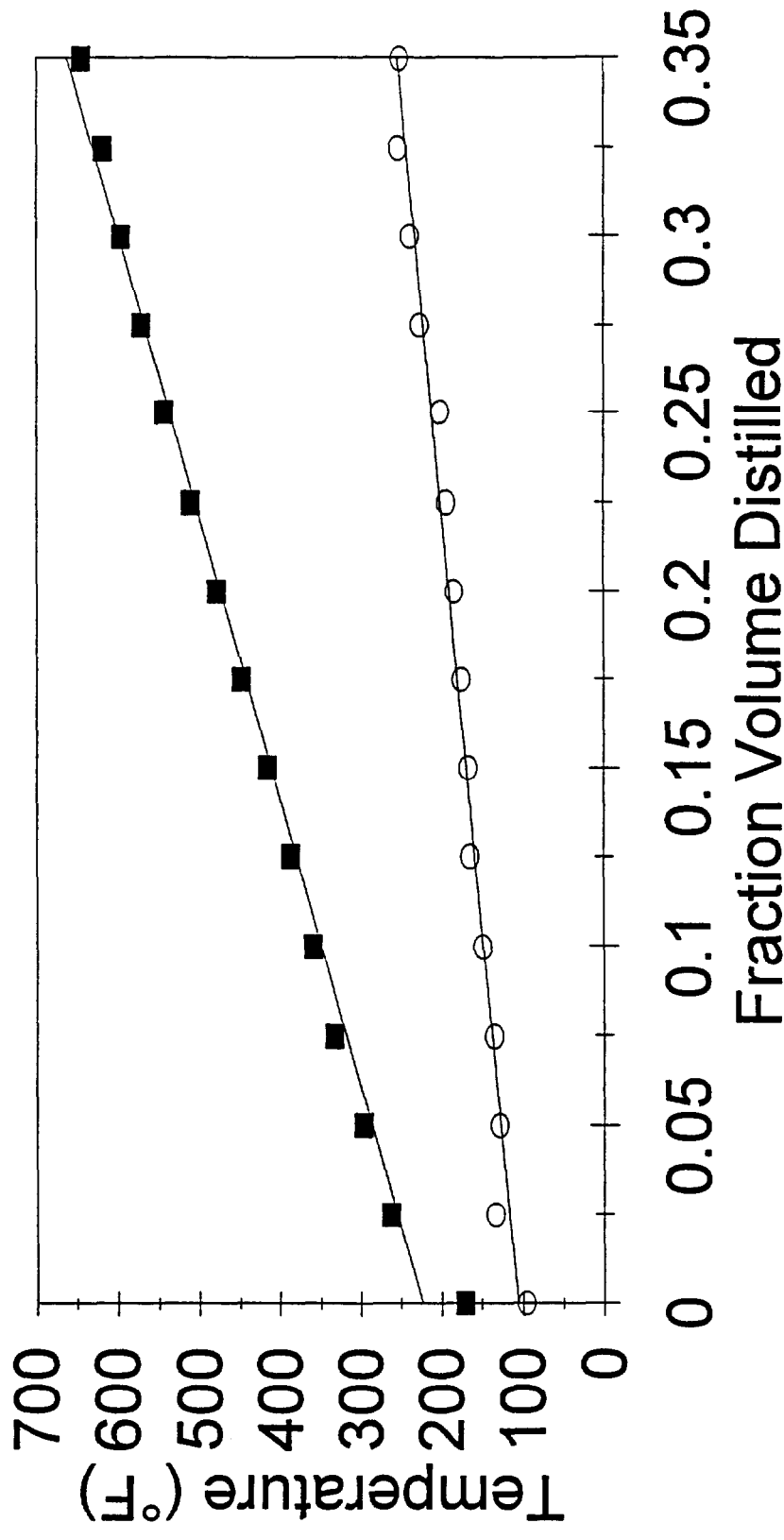
# **OIL NAME: ALASKA NORTH SLOPE - PUMP STATION #1**

1.0 TYPE: Crude		WEATHERING (VOLUME %)	
		0	20.64
2.0 DENSITY (g/mL):			31.8
32 °F		0.887	0.926
60 °F		0.876	0.914
3.0 VISCOSITY:			
3.1 DYNAMIC VISCOSITY (cP):			
32 °F		38.9	471.3
60 °F		17.6	93.4
3.2 KINEMATIC VISCOSITY (cSt):			
32 °F		43.9	509.0
60 °F		20.1	102.2
4.0 INTERFACIAL TENSIONS @ 68°F (dyne/cm):			
4.1 AIR-OIL:		31.8	34.2
4.2 OIL-SEAWATER:		24.0	27.0
5.0 POUR POINT (°F):		<9	9
7.0 FLASH POINT - CLOSED CUP (°F):		<9	19
8.0 EMULSION FORMATION TENDENCY AND STABILITY @ ROOM TEMPERATURE (68°F):			
8.1 TENDENCY			
60°F		0.40	0.86
8.2 STABILITY			
60°F		0.00	0.00
9.0 DISTILLATION DATA (°F) :			
	VOLUME PERCENT	LIQUID TEMPERATURE	VAPOR TEMPERATURE
	IBP	171.68	95.9
2.5		262.76	133.88
5		297.32	128.66
7.5		333.86	135.32
10		359.42	149.36
12.5		387.68	164.84
15		416.3	166.82
17.5		449.24	175.82
20		478.94	184.1
22.5		511.34	193.82
25		543.56	201.02
27.5		571.82	226.4
30		596.48	238.28
32.5		619.32	253.4
35		645.08	251.42

10.0 WEATHERING:	
Fv =	$\ln(1+7164.5 \cdot e^{\exp(6.3 - 3911.5/Tk)/Tk})$ (7164.5/Tk)
where: Fv is fraction of oil lost by volume	
ln is natural log	
e is evaporative exposure	
exp is exponential base e	
Tk is environmental temperature (Kelvin, K = °C + 273)	

# ASTM Distillation

## Alaska North Slope Pump Station #1

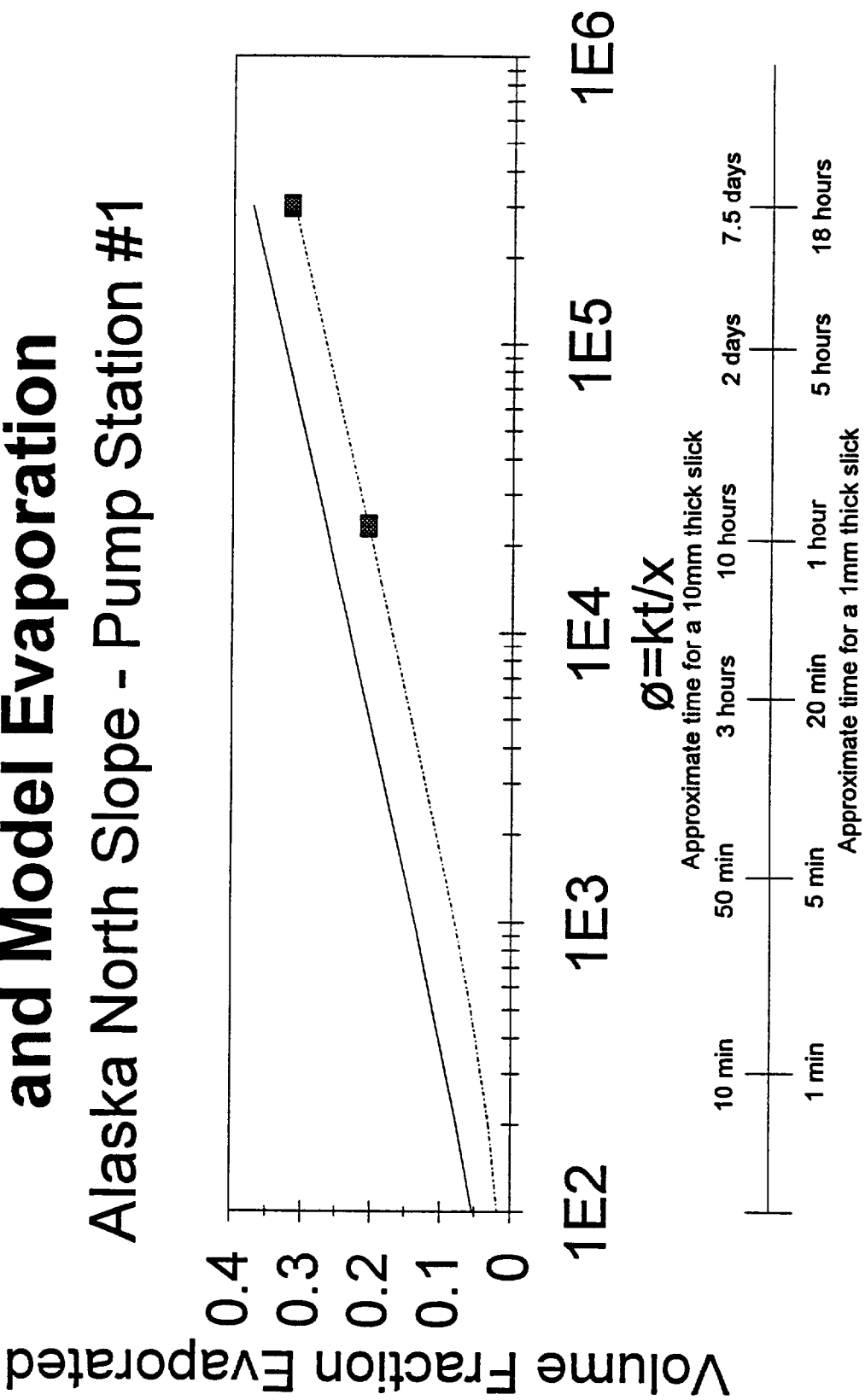


■ Liquid Temperature    ○ Vapor Temperature



# Comparison of Wind Tunnel and Model Evaporation

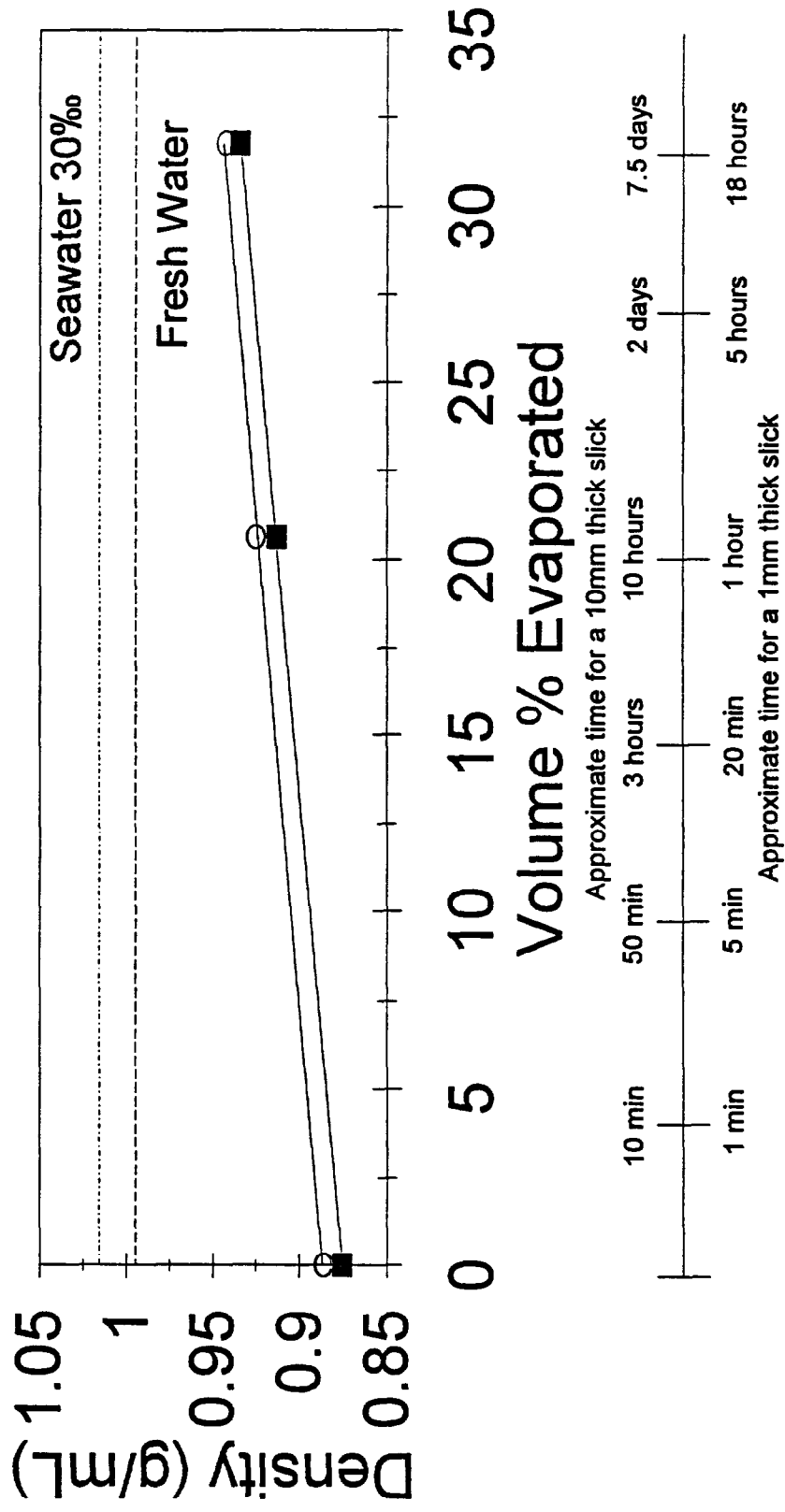
## Alaska North Slope - Pump Station #1



— Standard   ■ Actual   ..... Corrected

# Density

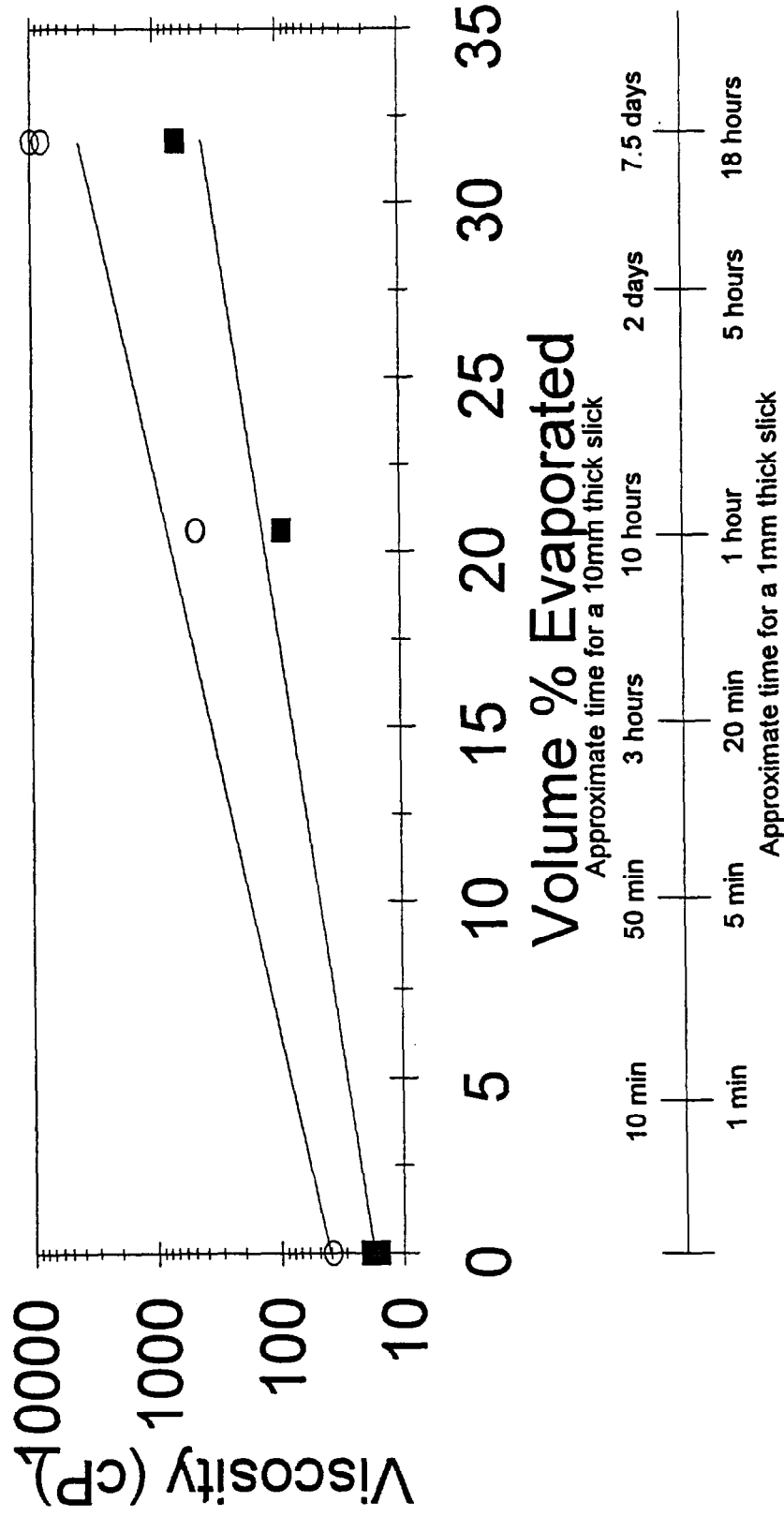
## Alaska North Slope Pump Station #1



■ 60 °F ○ 34 °F

# Viscosity

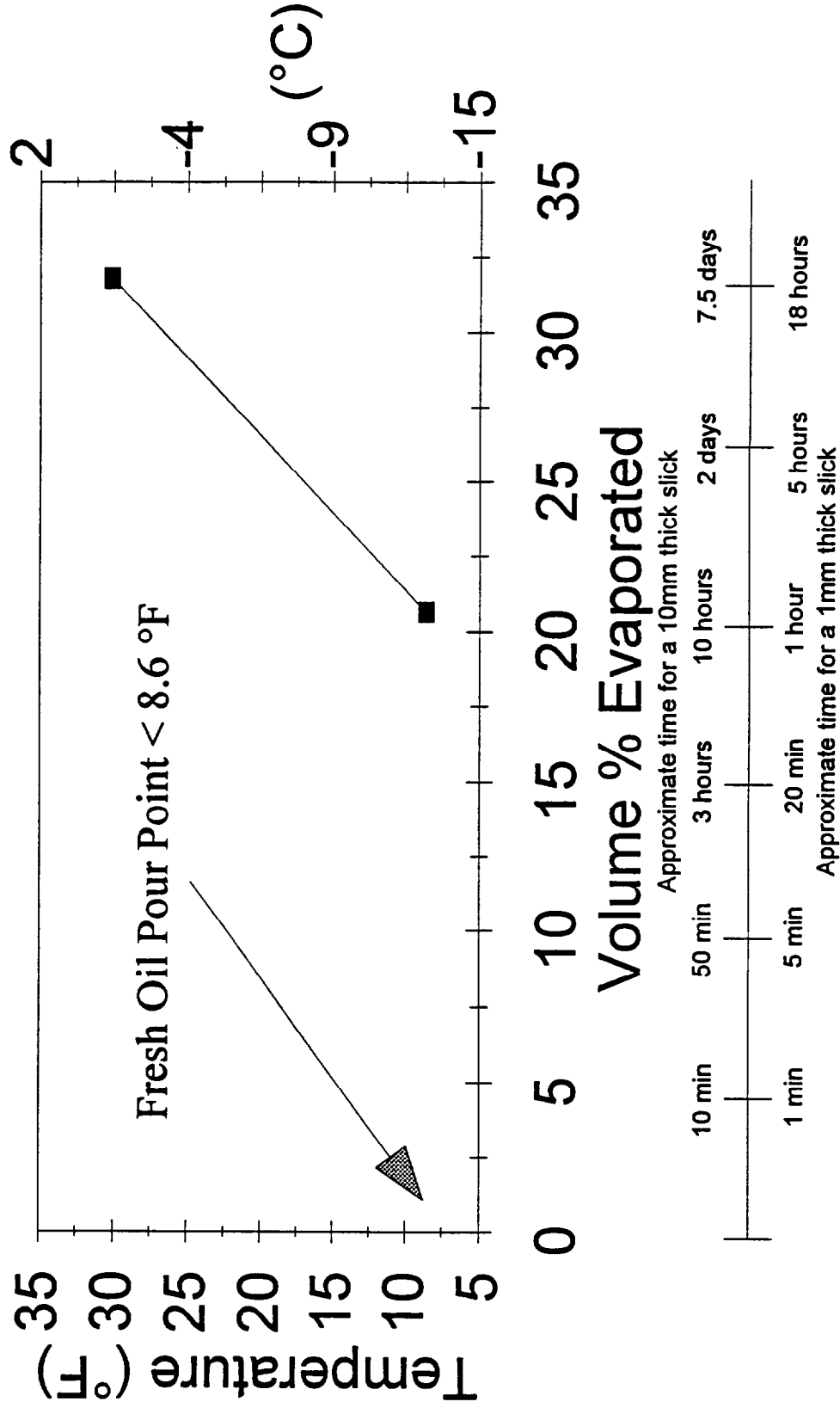
## Alaska North Slope Pump Station #1



■ 60 °F ○ 34 °F

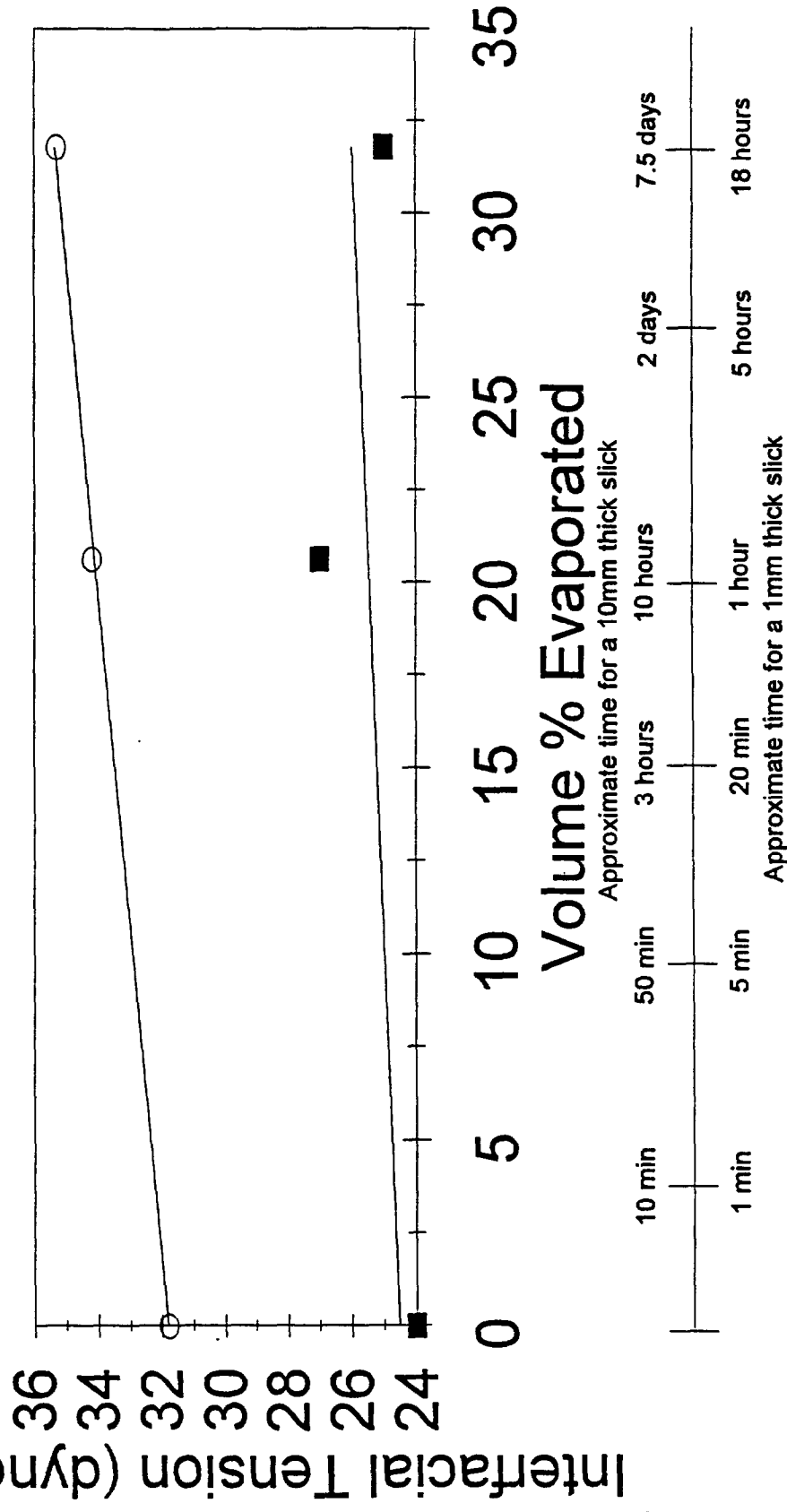
# Pour Point

## Alaska North Slope Pump Station #1



# Interfacial Tension

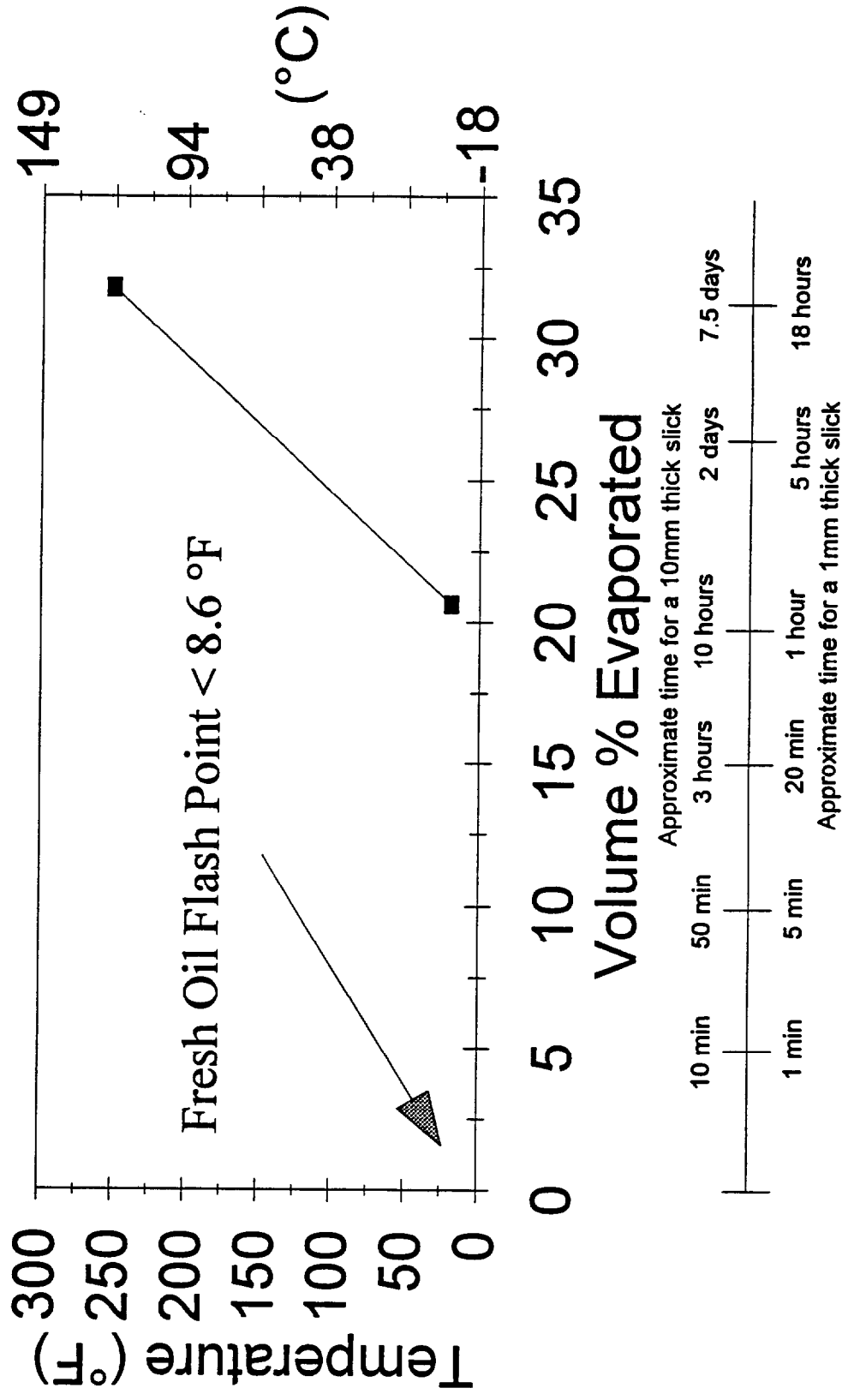
Alaska North Slope Pump Station #1



■ Water/Oil Interface ○ Oil/Air Interface

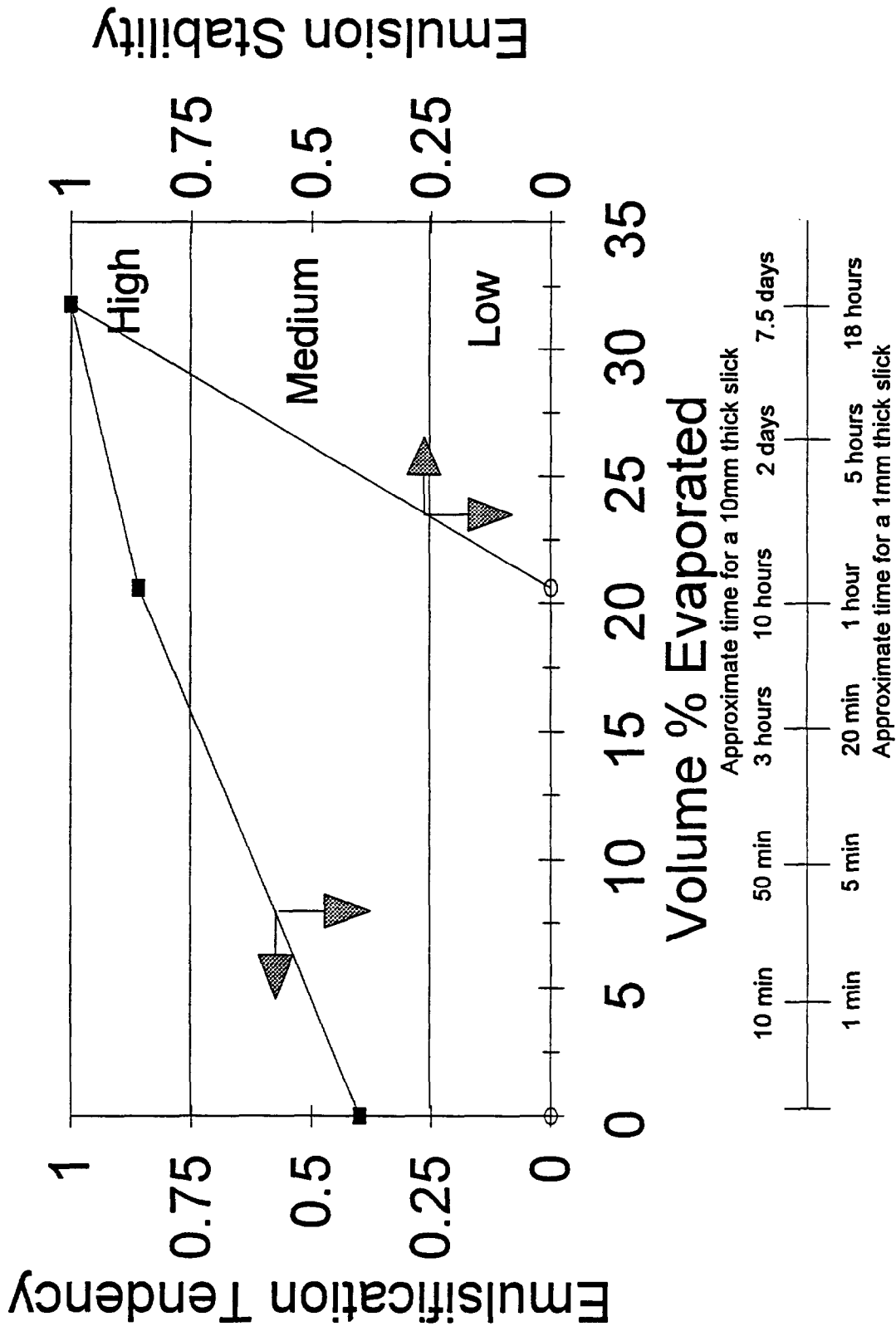
# Flash Point

## Alaska North Slope Pump Station #1



# Emulsification Tendency and Stability

## Alaska North Slope Pump Station #1



## OIL NAME: ENDICOTT

1.0 TYPE: Crude		WEATHERING (VOLUME %)		16.62
		0		8.56
2.0 DENSITY (g/mL):				
1 °C		0.906		0.932
15 °C		0.897		0.924
3.0 VISCOSITY:				
3.1 DYNAMIC VISCOSITY (mPa.s):				
1 °C		313.0		5912.5
15 °C		42.3		628.8
3.2 KINEMATIC VISCOSITY (mm <sup>2</sup> /sec):				
1 °C		345.5		6343.9
15 °C		47.2		680.5
4.0 INTERFACIAL TENSIONS @ 15°C (mN/m):				
4.1 AIR-OIL:		29.2		34.9
4.2 OIL-SEAWATER:		22.1		25.6
5.0 POUR POINT (°C):		-4		13
7.0 FLASH POINT - CLOSED CUP (°C):		-1		30
8.0 EMULSION FORMATION TENDENCY AND STABILITY @ ROOM TEMPERATURE (15°C):				
8.1 TENDENCY				
15°C		1.00		1.00
8.2 STABILITY				
15°C		0.77		1.00
9.0 DISTILLATION DATA (°C) :				
		VOLUME PERCENT	LIQUID TEMPERATURE	VAPOR TEMPERATURE
		IBP	115.5	42.3
		2.5	155	55.5
		5	185	57.8
		7.5	205.5	66.3
		10	227.9	75.0
		12.5	252.7	80.5
		15	279.1	84.5
		17.5	300.3	100.5
		20	319.1	107.9
		22.5	333.7	118.9

## 10.0 WEATHERING:

$$F_v = \frac{\ln(1+9824.6 \cdot e \exp(6.3 - 4153.2/T_k)/T_k)}{(9824.6/T_k)}$$

where: F<sub>v</sub> is fraction of oil lost by volume

ln is natural log

e is evaporative exposure

exp is exponential base e

T<sub>k</sub> is environmental temperature (Kelvin, K = °C + 273)

## OIL NAME: ENDICOTT

1.0 TYPE: Crude		WEATHERING (VOLUME %)		16.62
		0		8.56
2.0 DENSITY (g/mL):				
34 °F		0.906		0.932
60 °F		0.897		0.924
3.0 VISCOSITY:				
3.1 DYNAMIC VISCOSITY (cP):				
34 °F		313.0		5912.5
60 °F		42.3		628.8
3.2 KINEMATIC VISCOSITY (cSt):				
34 °F		345.5		6343.9
60 °F		47.2		680.5
4.0 INTERFACIAL TENSIONS @ 60 °F (dynes/cm):				
4.1 AIR-OIL:		29.2		34.9
4.2 OIL-SEAWATER:		22.1		25.6
5.0 POUR POINT (°F):		25		37
7.0 FLASH POINT - CLOSED CUP (°F):		30		61
8.0 EMULSION FORMATION TENDENCY AND STABILITY @ ROOM TEMPERATURE (60°F):				
8.1 TENDENCY				
60°F		1.00		1.00
8.2 STABILITY				
60°F		0.77		1.00
9.0 DISTILLATION DATA (°F) :				
		VOLUME PERCENT	LIQUID TEMPERATURE	VAPOR TEMPERATURE
		IBP	239.9	108.1
		2.5	311.0	131.9
		5	365.0	136.0
		7.5	401.9	151.3
		10	442.2	167.0
		12.5	486.9	176.9
		15	534.4	184.1
		17.5	572.5	212.9
		20	606.4	226.2
		22.5	632.7	246.0

## 10.0 WEATHERING:

$$F_v = \frac{\ln(1+9824.6 \cdot e \exp(6.3 - 4153.2/T_k)/T_k)}{(9824.6/T_k)}$$

where: F<sub>v</sub> is fraction of oil lost by volume

ln is natural log

e is evaporative exposure

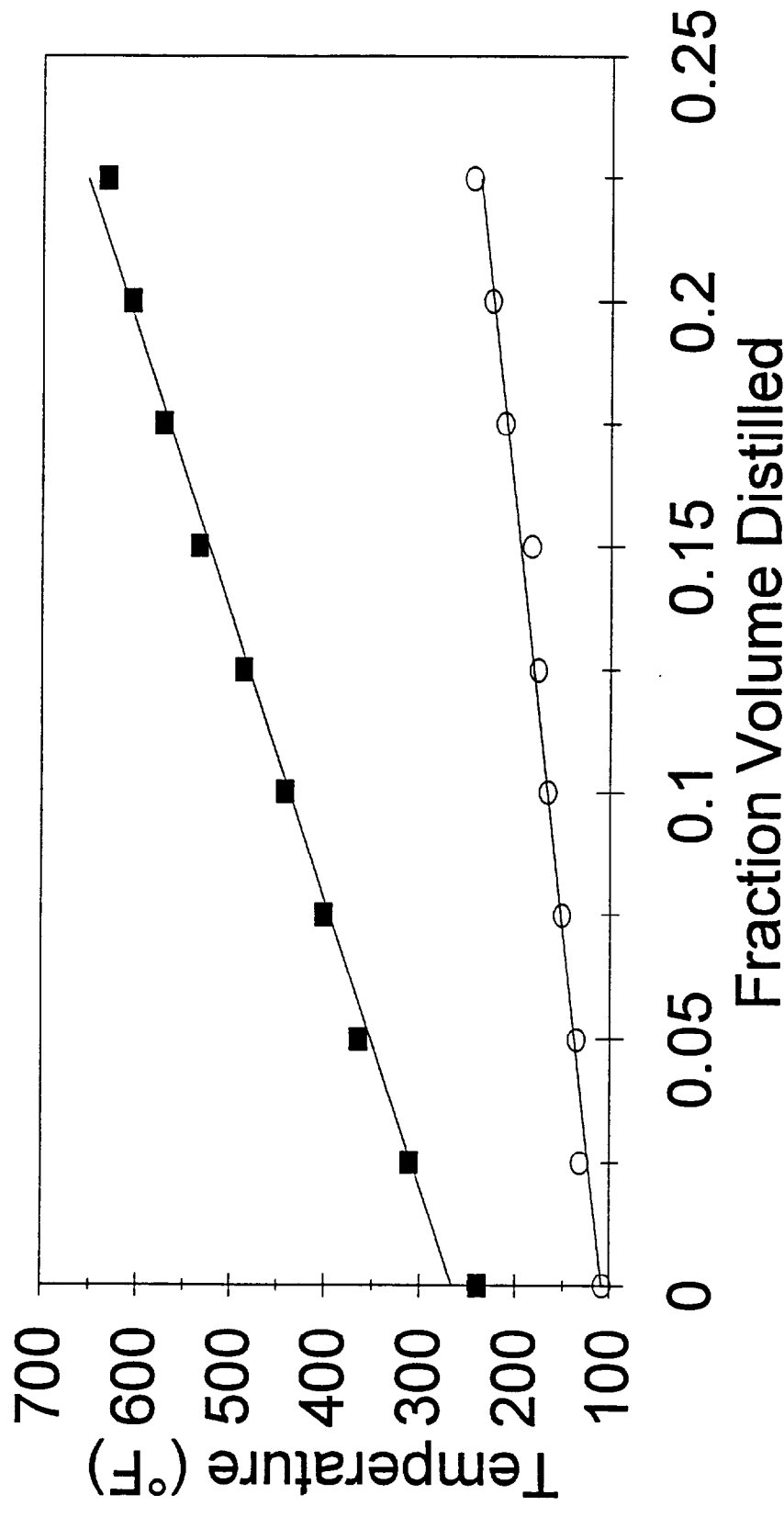
exp is exponential base e

T<sub>k</sub> is environmental temperature (Kelvin, K = °C + 273)



# ASTM Distillation

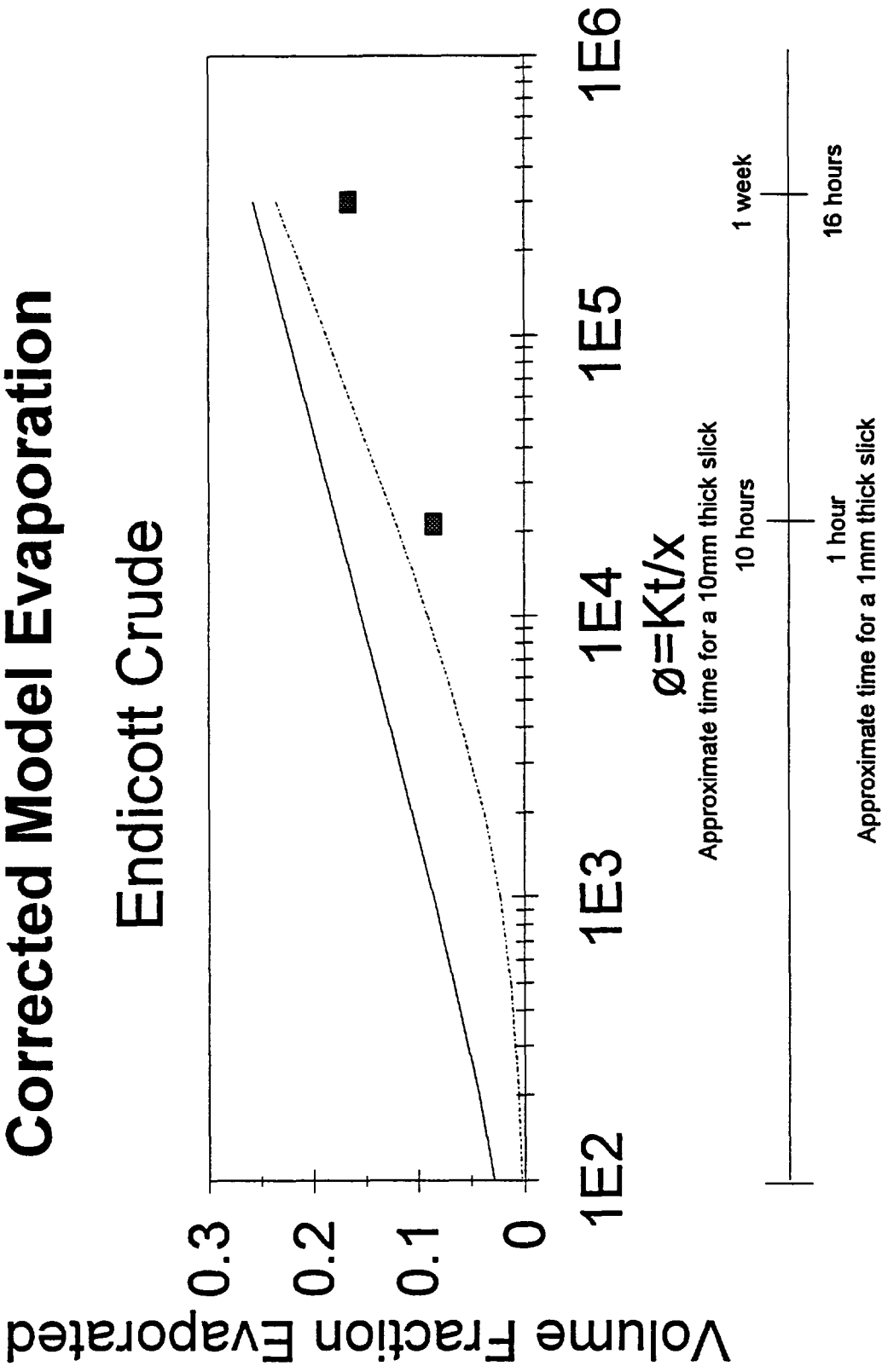
Endicott Crude



■ Liquid Temperature    ○ Vapor Temperature

# Comparison of Wind Tunnel and Corrected Model Evaporation

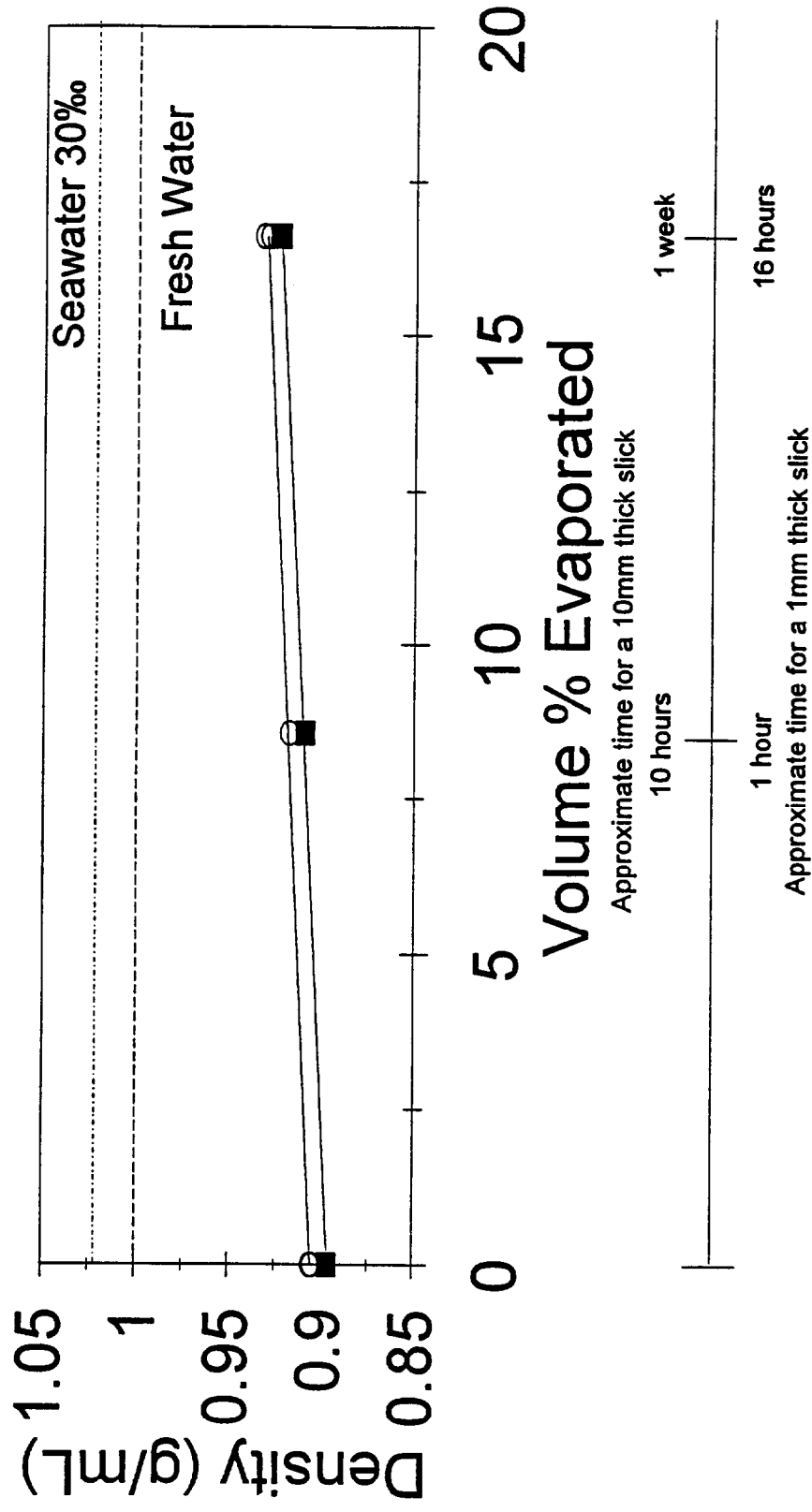
Endicott Crude



Corrected ■ Actual — Standard

# Density

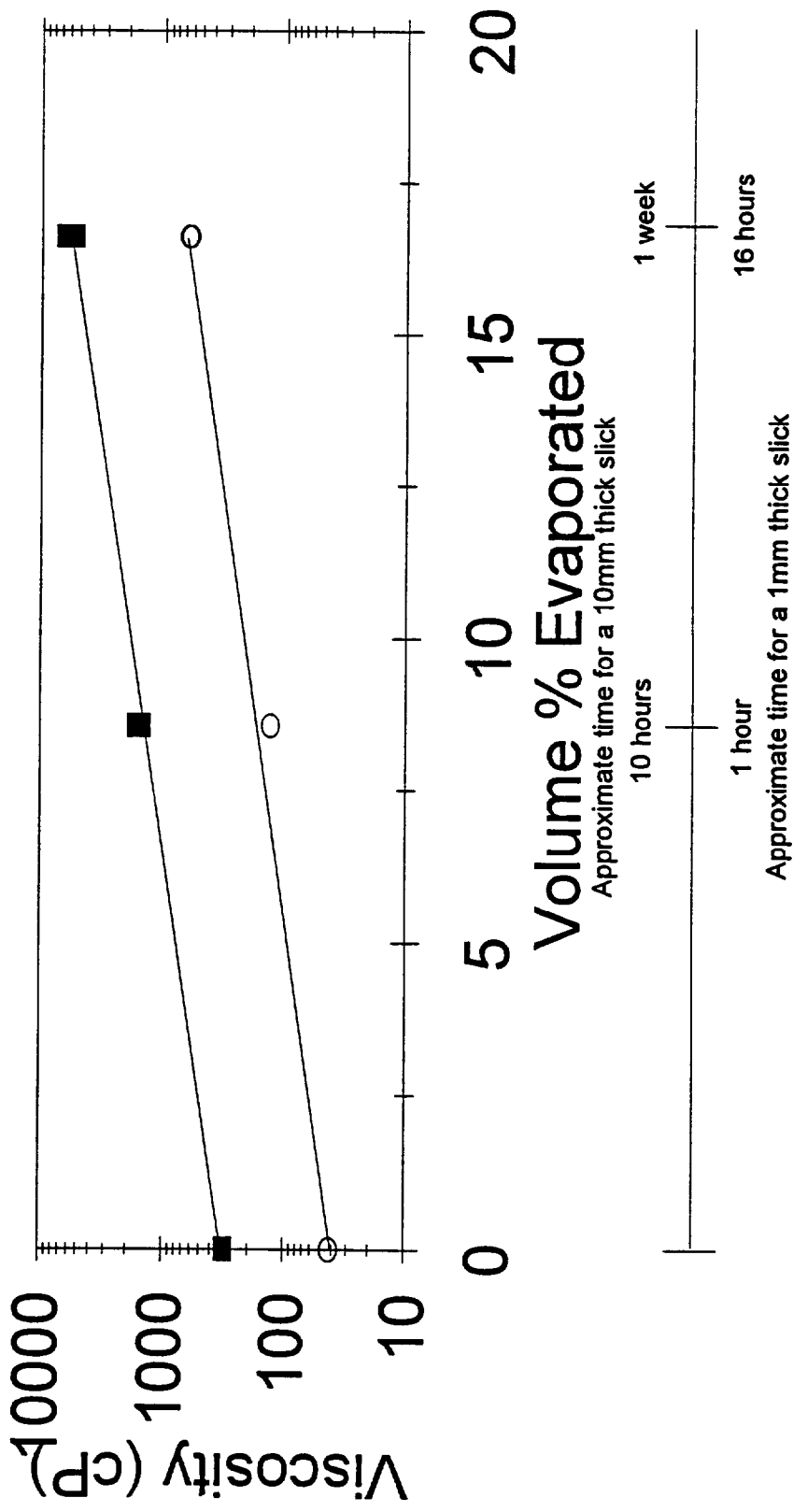
## Endicott Crude



■ 60 °F    ○ 34 °F

# Viscosity

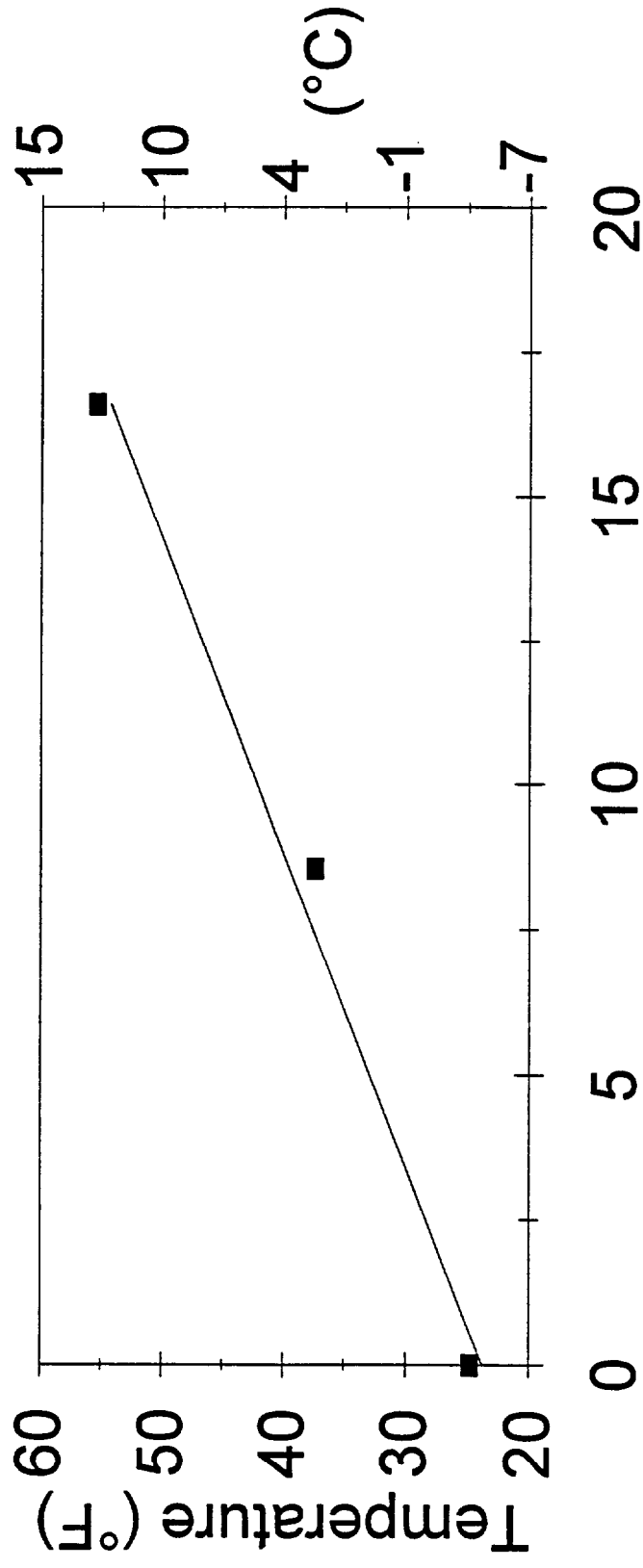
## Endicott Crude



■ 34 °F ○ 60 °F

# Pour Point

## Endicott Crude



Volume % Evaporated

Approximate time for a 10mm thick slick

10 hours

1 week

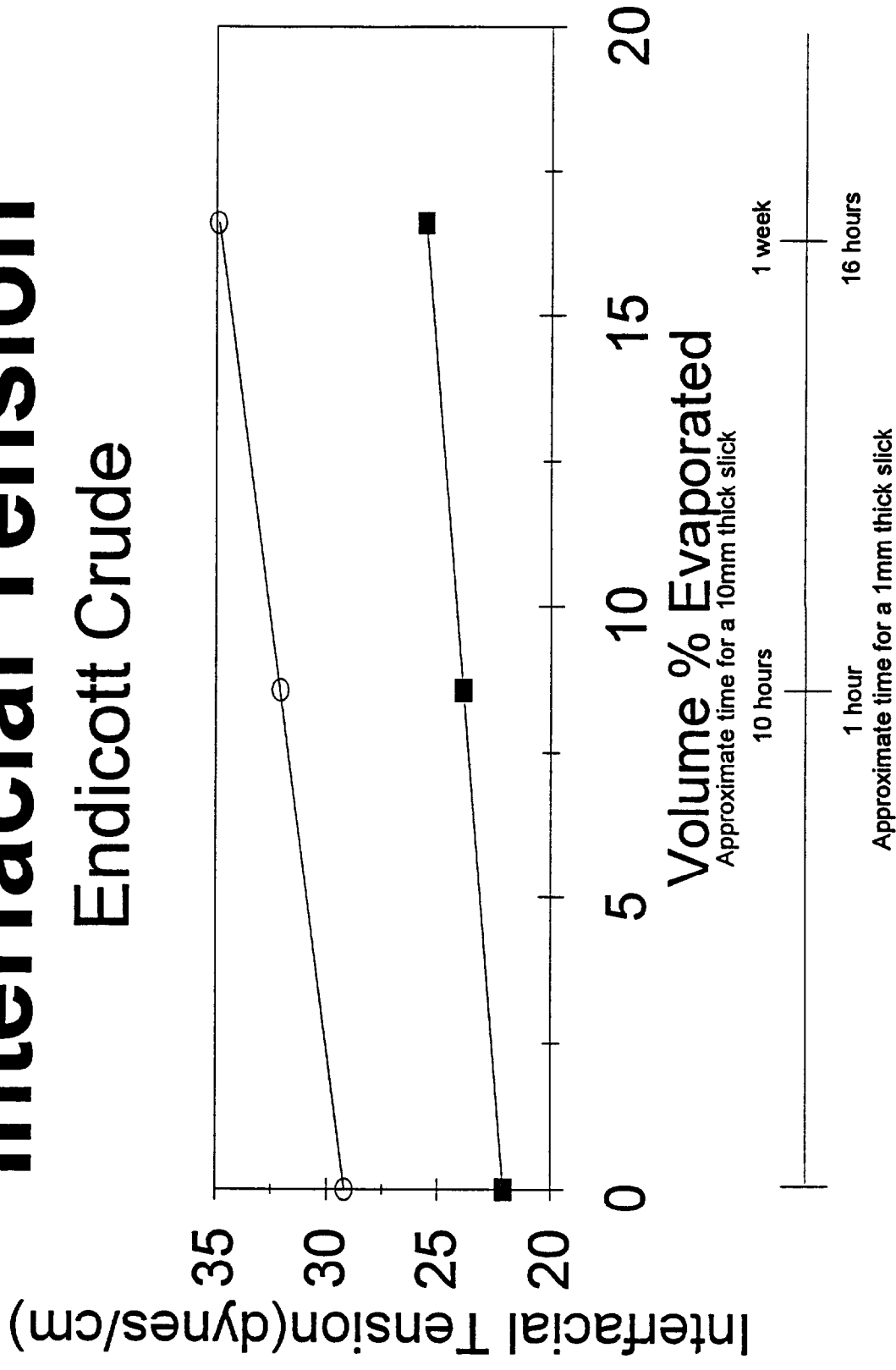
1 hour

16 hours

Approximate time for a 1mm thick slick

# Interfacial Tension

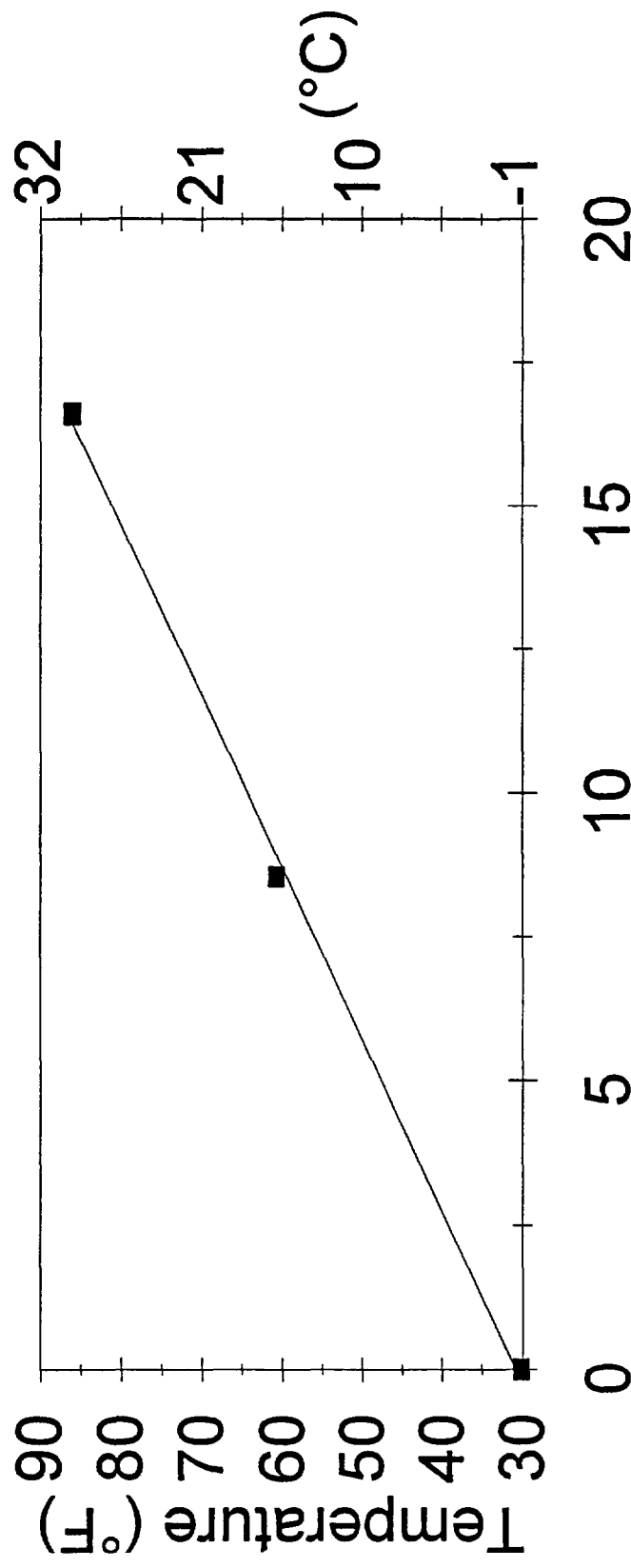
## Endicott Crude



■ Water/Oil Interface    ○ Oil/Air Interface

# Flash Point

## Endicott Crude



Volume % Evaporated

Approximate time for a 10mm thick slick

10 hours

1 week

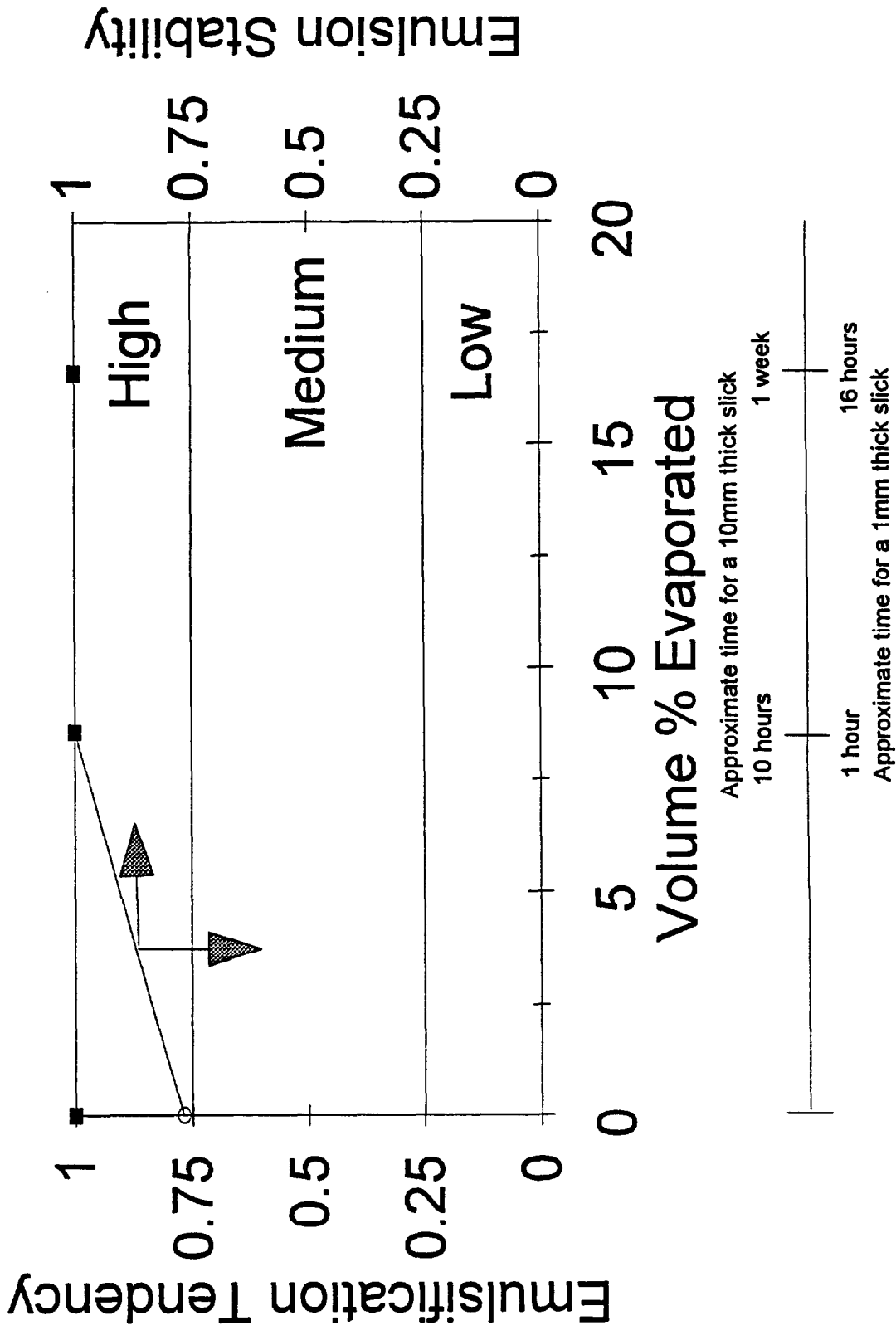
1 hour

16 hours

Approximate time for a 1mm thick slick

# Emulsification Tendency and Stability

## Endicott Crude





## **APPENDIX 2**

### **Emulsion Breaker Data Sheets**



# MATERIAL SAFETY DATA SHEET

PAGE 1

PETROLITE CORPORATION  
369 MARSHALL AVE.  
ST. LOUIS MO 63119 U.S.A

REVISION DATE: 11/30/93  
EMERGENCY PHONE: 1-314-961-3500  
CHEMTREC EMER NO: 1-800-424-9300

\*\*\*\*\*

## SECTION 1 PRODUCT IDENTIFICATION

PRODUCT: EX00894

TRADE NAME: EXP. PROD.

LABEL: 1

(IF HAZARDOUS PER D.O.T. CFR TITLE 49)

SHIPPING NAME: Flammable liquid, n.o.s.

HAZARD CLASS: 3

ID#: UN1993

## CHEMICAL DESCRIPTION

HIGH MOLECULAR WEIGHT POLYALKYLENE OXIDES, OXYALKYLATED  
ALKYLPHENOLIC RESINS, AND POLYOXYALKYLENE GLYCOLS IN  
AROMATIC HYDROCARBONS AND ISOPROPANOL.

\*\*\*\*\*

## SECTION 2 HAZARDOUS INGREDIENTS

CAS NUMBER	MATERIAL	%	EXPOSURE LIMITS
64742-95-6	Light aromatic naphtha	30-60	RECOMMENDED: 25 ppm
00067-63-0	Isopropanol	5-10	ACGIH TLV: 400ppm TWA OSHA PEL: 400ppm TWA ACGIH STEL: 500 ppm
25155-30-0	Sodium aryleulfonate		Not Established

Specific chemical identity of certain hazardous ingredients  
is being withheld for confidential business purposes.

\*\*\*\*\*

## SECTION 3 PHYSICAL DATA

SPECIFIC GRAVITY (H<sub>2</sub>O = 1.0@60 F): 0.936  
VAPOR PRESSURE: Not Established  
VOLATILITY: High  
SOL. IN WATER: Insoluble  
APPEARANCE AND ODOR: Dark amber liquid. Aromatic odor.

\*\*\*\*\*

## SECTION 4 FIRE AND EXPLOSION HAZARD DATA

FLASH POINT: 74 F

FLAMMABLE LIMITS: Not Established

FLASH METHOD:

SFCC ASTM D-3828

\*\*\*CONTINUED ON PAGE: 2\*\*\*

# MATERIAL SAFETY DATA SHEET

PAGE 2

\*\*\*CONTINUATION OF EX00894 \*\*\*

## EXTINGUISHING MEDIA:

Use water spray or fog, alcohol-type foam, dry chemical or CO2.

## FIRE FIGHTING PROCEDURES:

Use a self-contained breathing apparatus with full facepiece operated in pressure-demand or other positive pressure mode. Flammable. Cool fire-exposed containers using water spray.

## UNUSUAL FIRE AND EXPLOSION HAZARDS:

Flammable liquid, vapors of which can form an ignitable mixture with air. Vapors can flow along surfaces to distant ignition sources and flash back.

\*\*\*\*\*

## SECTION 5 HEALTH HAZARD DATA

### EFFECTS OF OVEREXPOSURE:

#### INHALATION:

Chronic effects of repeated exposures to high concentrations may include damage to kidneys and liver. Exposure to elevated vapor concentrations may result in eye, nose and respiratory irritation. Prolonged contact may cause drowsiness, dizziness and, in extreme cases, narcosis.

#### SKIN AND EYE CONTACT:

May cause mild to moderate skin irritation and dermatitis on prolonged and extensive contact. Contact with eyes may cause moderate irritation. Absorption through the skin may exacerbate inhalation exposure leading to narcosis and, in extreme cases, unconsciousness.

#### INGESTION:

May be harmful if swallowed. May cause headache, gastrointestinal disturbances, dizziness and a feeling of intoxication.

## EMERGENCY AND FIRST AID PROCEDURES:

Wash skin thoroughly with soap and water. If rash or irritation develops, consult a physician. Launder clothing before reuse. If in eyes, irrigate with flowing water immediately and continuously for fifteen minutes. Consult a physician promptly. If inhaled, remove to fresh air. Administer oxygen if necessary. Consult a physician if symptoms persist or exposure was severe. If ingested, induce vomiting. Never give anything by mouth to an unconscious person. Consult a physician immediately.

\*\*\*CONTINUED ON PAGE: 3\*\*\*

# MATERIAL SAFETY DATA SHEET

PAGE 3

\*\*\*CONTINUATION OF EX00894 \*\*\*

\*\*\*\*\*

## SECTION 6 REACTIVITY DATA

### STABILITY:

Stable under normal conditions of storage and use.

### INCOMPATIBILITY:

Keep away from strong oxidizing agents, heat and open flames.

### HAZARDOUS DECOMPOSITION PRODUCTS:

None Known.

### HAZARDOUS POLYMERIZATION:

Will not occur.

\*\*\*\*\*

## SECTION 7 SPILL AND LEAK PROCEDURES

### IF MATERIAL IS SPILLED OR RELEASED:

Small spill - Absorb on paper, cloth or other material.

Large spill - Dike to prevent entering any sewer or waterway. Transfer liquid to a holding container. Cover residue with dirt, or suitable chemical adsorbent. Use personal protective equipment as necessary.

### DISPOSAL METHOD:

Place chemical residues and contaminated adsorbent materials into a suitable waste container and take to an approved waste disposal site. Dispose of all residues in accordance with applicable waste management regulations.

### DECONTAMINATION PROCEDURES:

Not appropriate.

\*\*\*\*\*

## SECTION 8 SPECIAL PROTECTION INFORMATION

### RESPIRATORY PROTECTION:

When concentrations exceed the exposure limits specified, use of a NIOSH-approved organic vapor cartridge respirator is recommended. Where the protection factor of the respirator may be exceeded, use of a self-contained breathing unit may be necessary.

### VENTILATION:

General ventilation should be provided to maintain ambient concentrations below nuisance levels. Local ventilation of emission sources may be necessary to maintain ambient concentrations below recommended exposure limits.

\*\*\*CONTINUED ON PAGE: 4\*\*\*

# MATERIAL SAFETY DATA SHEET

PAGE 4

\*\*\*CONTINUATION OF EX00894 \*\*\*

## PROTECTIVE CLOTHING:

Chemical-resistant gloves and chemical goggles should be used to prevent skin and eye contact.

\*\*\*\*\*

## SECTION 9 SPECIAL PRECAUTIONS

Flammable liquid. Avoid heat, sparks and open flames. Avoid breathing of vapors and contact with eyes, skin or clothing. Keep container closed when not in use. Hazardous product residue may remain in emptied container. Do not reuse empty containers without commercial cleaning or reconditioning.

\*\*\*\*\*

Although the information and recommendations set forth herein are believed to be correct as of the date hereof, Petrolite makes no representations to the accuracy of such information and recommendations. It is the user's responsibility to determine the suitability and completeness of such information and recommendation for its own particular use. Petrolite shall not be responsible for any direct, indirect, incidental or consequential damages of whatsoever nature resulting from the publication, use of or reliance upon such information and recommendations.

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# ENVIRONMENTAL DATA SHEET

PAGE 1

PETROLITE CORPORATION  
369 MARSHALL AVE.  
ST. LOUIS MO 63119 U.S.A.

REVISION DATE: 10/11/93  
CHEMTEC EMBR NO: 1-800-424-9300  
INFORMATION PHONE: 1-314-961-3500

PRODUCT: EX00894

The following information is provided for the convenience of Petrolite customers. This Environmental Data Sheet is incorporated into the Material Safety Data Sheet (MSDS) for the Petrolite product named above. When physically attached to the MSDS, this Environmental Data Sheet must not be detached from the MSDS. Any copying or redistribution of the MSDS to which this Environmental Data Sheet is attached must include copying and redistribution of this Environmental Data Sheet as well.

Petrolite makes reasonable efforts to assure the accuracy of this information, but makes no representation or warranty about it. This information is not intended as legal advice nor as a definitive guide to the requirements of applicable laws and regulations.

## NFPA DESIGNATION 704

### PRODUCT LABEL CODES

HEALTH (BLUE) = 1  
FLAMMABILITY (RED) = 2  
REACTIVITY (YELLOW) = 0  
SPECIAL HAZARDS =

### DEGREE OF HAZARD

0 = LEAST  
1 = SLIGHT  
2 = MODERATE  
3 = HIGH  
4 = EXTREME

## TSCA INVENTORY

This product, or its components, if a mixture, are on the Toxic Substance Control Act (TSCA) inventory.

# ENVIRONMENTAL DATA SHEET

PAGE 2

PETROLITE CORPORATION  
369 MARSHALL AVE.  
ST. LOUIS MO 63119 U.S.A.

REVISION DATE: 10/11/93  
CHEMTREC EMER NO: 1-800-424-9300  
INFORMATION PHONE: 1-314-961-3500

PRODUCT: EX00894

## CERCLA HAZARDOUS SUBSTANCES AND REPORTABLE QUANTITIES

This Petrolite product contains the following materials which have been listed as a hazardous substance or substances subject to the release reporting requirements of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and 40 CFR Part 302 and 40 CFR 355.40. The Reportable quantities (RQs) are calculated in gallons of product. Each entry corresponds to the RQ, in pounds, of the listed CERCLA hazardous substance.

CHEMICAL	CAS NUMBER	RQ, #	RQ, GAL
Xylene (mixed)	1330-20-7	1,000	3,100
Naphthalene	91-20-3	100	4,700
Cumene	98-82-8	5,000	52,400
Ethylbenzene	100-41-4	1,000	63,500
Toluene	108-88-3	1,000	159,000
Potassium hydroxide	1310-58-3	1,000	423,000

## SARA TITLE III, EXTREMELY HAZARDOUS SUBSTANCES

This Petrolite product contains the following materials which have been listed as an Extremely Hazardous Substance or Substances subject to the emergency planning provisions of SARA Title III, Section 302 and 40 CFR 355.30, the release reporting requirements of SARA Title III, Section 304 and 40 CFR 355.40, and the hazardous chemical reporting/community right-to-know requirements of SARA Title III, Section 312 and 40 CFR Part 370. The reportable quantities (RQs) and threshold planning quantities (TPQs) are calculated in gallons of product. Each entry corresponds to the RQ or TPQ in pounds, as appropriate, for the listed Extremely Hazardous Substances. No data is given for listed Extremely Hazardous Substances present in concentrations below applicable de minimis levels.

\*\*\* NONE \*\*\*



# ENVIRONMENTAL DATA SHEET

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PETROLITE CORPORATION  
369 MARSHALL AVE.  
ST. LOUIS MO 63119 U.S.A.

REVISION DATE: 10/11/93  
CHEMTREC EMER NO: 1-800-424-9300  
INFORMATION PHONE: 1-314-961-3500

PRODUCT: EX00894

## SARA TITLE III, SECTION 311: HAZARD CATEGORIES

This Petrolite product has been assigned to the following hazard category(ies), as provided by SARA Title III, Section 311 and 40 CFR 370, Subpart A, 370.2:

Acute (immediate) health hazard  
Fire hazard

## SARA TITLE III, SECTION 312 INVENTORY REPORTING INFORMATION

This Petrolite product has the following physical characteristics for any required reporting on the federal Tier Two form or its equivalent:

MIXTURE  
LIQUID

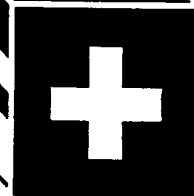
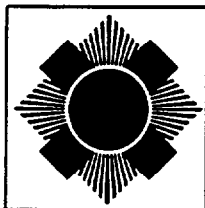
## SARA TITLE III, SECTION 313

This Petrolite product contains the following materials which have been listed as a toxic chemical or chemicals subject to the reporting requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372:

CHEMICAL	CAS NUMBER	WEIGHT PERCENT
Cumene *	98-02-8	1.2 %
1,2,4-Trimethylbenzene *	95-63-6	16.1 %
Xylene (mixed isomers) *	1330-20-7	4.1 %
* solvent component		

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# Allied Colloids Health & Safety Information

HS629

ISSUE DATE: 03/90  
ISSUE No. : 1.0

## ALCOPOL O 70 PG

### 1. CHEMICAL TYPE

SULPHOSUCCINATE DIESTER SOLUTION

### 2. TYPICAL PHYSICAL DATA

FORM	: LIQUID	COLOUR	: COLOURLESS TO STRAW
BOILING POINT	: 188°C	ODOUR	: SLIGHT
VAPOUR PRESSURE (20°C)	: N/K	SOLUBILITY	: MISCIBLE ( IN WATER )
pH VALUE	: 7	VISCOSITY (25°C)	: N/K
DENSITY	: APPROX. 1g/cm <sup>3</sup>	BULK DENSITY	: N/A

### 3. FIRE AND EXPLOSION DATA

FLASH POINT ( closed cup )	: 103 °C	COMBUSTIBILITY ( @ 55°C )	: NOT COMBUSTIBLE
FURTHER INFORMATION	:-		
EXTINGUISHING MEDIA	: CARBON DIOXIDE, DRY CHEMICAL, FOAM OR WATER SPRAY MAY BE USED		

### 4. HEALTH INFORMATION

#### 4.1 NATURE OF HAZARD

SKIN	SKIN IRRITANT
EYES	SEVERE EYE IRRITANT
INHALATION	THE ACTIVE COMPONENT IS NON-VOLATILE.
INGESTION	LOW TOXICITY PRODUCT.

FURTHER INFORMATION :-

#### 4.2 FIRST AID

SKIN CONTACT	WASH CONTAMINATED AREA WITH SOAP AND WATER.
EYE CONTACT	IRRIGATE WITH WATER FOR 15 MINUTES, OBTAIN MEDICAL ADVICE.
INHALATION	REMOVE PATIENT TO FRESH AIR. IF RECOVERY IS DELAYED, SEEK MEDICAL ADVICE.
INGESTION	WATER MAY BE GIVEN TO DRINK OR USED TO WASH OUT THE MOUTH IF, AND ONLY IF, THE PATIENT IS FULLY CONSCIOUS AND NOT CONVULSING. DO NOT GIVE AN EMETIC UNLESS DIRECTED BY A COMPETENT MEDICAL PRACTITIONER. REST AND REASSURE THE PATIENT AND OBTAIN MEDICAL ADVICE IMMEDIATELY.

**5. PRECAUTIONS IN USE AND STORAGE****5.1 USE**

<b>EYE PROTECTION</b>	GOGGLES
<b>HAND PROTECTION</b>	RUBBER / PVC GLOVES
<b>PROTECTIVE CLOTHING</b>	OVERALLS, RUBBER / PVC APRON
<b>RESPIRATORY PROTECTION</b>	NOT REQUIRED UNDER NORMAL CONDITIONS OF USE.
<b>VENTILATION</b>	ADEQUATE VENTILATION REQUIRED
<b>OTHER PRECAUTIONS</b>	DO NOT EAT, DRINK OR SMOKE WHILST HANDLING THE PRODUCT. WASH HANDS AFTER USE. REMOVE CONTAMINATED CLOTHING IMMEDIATELY AND LAUNDRY BEFORE REUSE.

**5.2 STORAGE**

AVOID EXTREMES OF TEMPERATURE, AND WET AND HUMID CONDITIONS.

**6. SPILLAGES**

PREVENT LARGE QUANTITIES GOING TO DRAIN BY CONTAINING WITH AN INERT MATERIAL SUCH AS SAND OR EARTH. SWEEP UP AND REMOVE FOR DISPOSAL. RESIDUES AND SMALL SPILLAGES SHOULD BE HOSED AWAY COMPLETELY WITH WATER

**7. WASTE DISPOSAL**

RESIDUES AND CONTAMINATED PACKAGING MATERIAL SHOULD BE DISPOSED OF IN ACCORDANCE WITH THE 'CONTROL OF POLLUTION ACT' 1974.

**8. OTHER INFORMATION**

SPILLED PRODUCT CREATES A HAZARD BECAUSE OF ITS SLIPPERY NATURE.

**9. SUPPLY AND CONVEYANCE INFORMATION**

( EEC Directives; UK Classification, Packaging and Labelling Regulations, 1984 )

**9.1 DANGEROUS SUBSTANCES IN PRODUCT**

Substance name.	Danger class	Average % wt/wt	Substance Identification No.
DIOCTYL SODIUM SULPHOSUCCINATE	-	-	-

**9.2 PRODUCT CLASSIFICATION****SUPPLY****SKIN AND EYE IRRITANT****SYMBOL****Xi****GENERAL NATURE OF RISK : SKIN AND EYE IRRITANT****RISK PHRASES****R 36/38, 41****SAFETY PHRASES****S 26, 28 ( soap and water )****CONVEYANCE****NOT A DANGEROUS SUBSTANCE****HAZARD WARNING SIGN****N/A****SUBSTANCE IDENTIFICATION No.: N/A****CLASS****N/A****PACKAGING GROUP. N/A**

The information contained in this leaflet is given in good faith. It is accurate to the best of our knowledge and belief and represents the most up to date information. Provided our products are handled and used in accordance with the advice given, they should offer no hazard to health and safety.

**BREAXIT OEB-9****7-9530**PAGE: 1  
DATE PREPARED: NOV 2, 1990  
NO.: 79530000**SECTION 1 PRODUCT IDENTIFICATION & EMERGENCY INFORMATION****PRODUCT NAME:** Breaxit OEB-9 7-9530**CHEMICAL NAME:**

Not applicable: Blend

**CHEMICAL FAMILY:**

Surfactant

**PRODUCT DESCRIPTION:**Clear Yellow Liquid  
Mild Hydrocarbon Odor**EMERGENCY TELEPHONE NUMBERS:** EXXON CHEMICAL AMERICAS 713-870-6000  
CHEMTREC 800-424-9300**SECTION 2 HAZARDOUS INGREDIENT INFORMATION**

The composition of this mixture may be proprietary information. In the event of a medical emergency, compositional information will be provided to a physician or nurse. This product is hazardous as defined in 29 CFR1910.1200, based on the following compositional information:

<u>COMPONENT</u>	<u>OSHA HAZARD</u>
Ethyl Alcohol, Xylene, Polynuclear Aromatic Solvents	Combustible Liquid
Ethyl Alcohol, Xylene, Polynuclear Aromatic Solvents	Eye and Skin Irritant
Ethyl Alcohol, Xylene, Polynuclear Aromatic Solvents	Vapors Irritant to Eyes
Ethyl Alcohol, Xylene, Polynuclear Aromatic Solvents	and Respiratory Tract
Ethyl Alcohol, Xylene	PEL/TLV

For additional information see Section 3.

**SECTION 3 HEALTH INFORMATION & PROTECTION****NATURE OF HAZARD****EYE CONTACT:**

Irritating, but does not injure eye tissue.

**SKIN CONTACT:**

Low order of toxicity.

Occasional brief contact with the liquid will not result in significant irritation unless evaporation is impeded.

Frequent or prolonged contact may irritate and cause dermatitis.

May cause skin sensitization, an allergic reaction which becomes evident on reexposure to this material.

**INHALATION:**

High vapor concentrations are irritating to the eyes and the respiratory tract, may cause headaches and dizziness, are anesthetic and may have other central nervous system effects.



# MATERIAL SAFETY DATA SHEET

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A Division of EXXON CHEMICAL COMPANY, A Division of EXXON CORPORATION

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7-9530

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## INGESTION:

Low order of toxicity.

## FIRST AID

### EYE CONTACT:

Flush eyes with large amounts of water until irritation subsides. If irritation persists, get medical attention.

### SKIN CONTACT:

Flush with large amounts of water; use soap if available.  
Remove grossly contaminated clothing, including shoes, and launder before reuse.  
If irritation persists, seek medical attention.

### INHALATION:

Using proper respiratory protection, immediately remove the affected victim from exposure. Administer artificial respiration if breathing is stopped. Keep at rest. Call for prompt medical attention.

### INGESTION:

First aid is normally not required.

## WORKPLACE EXPOSURE LIMITS

### OSHA REGULATION 29CFR1910.1000 REQUIRES THE FOLLOWING PERMISSIBLE EXPOSURE LIMITS:

A TWA of 100 ppm (435 mg/m<sup>3</sup>) and a STEL of 150 ppm (655 mg/m<sup>3</sup>) for Xylenes.

A TWA of 1000 ppm (1900 mg/m<sup>3</sup>) for Ethyl Alcohol.

### THE ACGIH RECOMMENDS THE FOLLOWING THRESHOLD LIMIT VALUES:

a TWA of 100 ppm (435 mg/m<sup>3</sup>), and a STEL of 150 ppm (655 mg/m<sup>3</sup>) for Xylene.

a TWA of 1000 ppm (1900 mg/m<sup>3</sup>) for Ethyl Alcohol.

### EXXON RECOMMENDS THE FOLLOWING OCCUPATIONAL EXPOSURE LIMITS:

a TWA of 100 ppm total organic vapor based on the Heavy Aromatic Naphtha (HAN) content. This component also contains a significant level of Polynuclear Aromatic Hydrocarbons (PNA's) between 0.4 % and 0.5 %. When aerosols are likely to be generated or when product temperatures exceed 300 deg. C., air samples should be monitored for PNA's.

## PRECAUTIONS

### PERSONAL PROTECTION:

For open systems where contact is likely, wear chemical resistant gloves, rubber boots, a chemical jacket, and a face shield.  
Where contact may occur, wear long sleeves, chemical resistant gloves, and a face shield.

Where concentrations in air may exceed the limits given in this Section and engineering, work practice or other means of exposure reduction are not adequate, NIOSH/MSHA approved respirators may be necessary to prevent overexposure by inhalation.

All contact should be avoided by persons with known hypersensitivity to ALKYL PHENOL SURFACTANT

### VENTILATION:

The use of mechanical dilution ventilation is recommended whenever this product is used in a confined space, is heated above ambient temperatures, or is agitated.



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## SECTION 4 FIRE & EXPLOSION HAZARD

FLASHPOINT: 134 Deg F. METHOD: Seta CC  
FLAMMABLE LIMITS: LEL: 0.8 UEL: 19.0  
AUTOIGNITION TEMPERATURE: NOTE: Not available

### GENERAL HAZARD:

Combustible Liquid, can form combustible mixtures at temperatures at or above the flashpoint.

Toxic gases will form upon combustion.

"Empty" containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT PRESSURIZE, CUT, WELD, BRAZE, SOLDER, DRILL, GRIND, OR EXPOSE SUCH CONTAINERS TO HEAT, FLAME, SPARKS, STATIC ELECTRICITY, OR OTHER SOURCES OF IGNITION; THEY MAY EXPLODE AND CAUSE INJURY OR DEATH.

Empty drums should be completely drained, properly bunged and promptly returned to a drum reconditioner, or properly disposed of.

### FIRE FIGHTING:

Use water spray to cool fire exposed surfaces and to protect personnel.

Isolate "fuel" supply from fire.

Use alcohol type foam, dry chemical or water spray to extinguish fire.

Respiratory and eye protection required for fire fighting personnel.

Avoid spraying water directly into storage containers due to danger of boilover.

### DECOMPOSITION PRODUCTS UNDER FIRE CONDITIONS:

Smoke, Fumes, Carbon Monoxide, Carbon Dioxide, Sulfur Oxides

## SECTION 5 SPILL CONTROL PROCEDURE

### LAND SPILL:

Eliminate sources of ignition. Prevent additional discharge of material, if possible to do so without hazard. For small spills implement cleanup procedures; for large spills implement cleanup procedures and, if in public area, keep public away and advise authorities. Also, if this product is subject to CERCLA reporting (see Section 7) notify the National Response Center.

Vapors/dust can be harmful/fatal. Warn occupants of downwind areas. Prevent liquid from entering sewers, watercourses, or low areas. Contain spilled liquid with sand or earth. Do not use combustible materials such as sawdust.

Recover by pumping (use an explosion proof or hand pump) or with a suitable absorbent.

Consult an expert on disposal of recovered material and ensure conformity to local disposal regulations.



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## WATER SPILL:

Prevent additional discharge of material, if possible to do so without hazard. Advise authorities.  
Eliminate sources of ignition. Vapors/dust can be harmful/fatal. Warn occupants and shipping in downwind areas.  
Consult Health Information and Protection (Section 3) regarding possible hazards.  
Consult an expert on disposal of recovered material and ensure conformity to local disposal regulations.

## SECTION 6 NOTES

### NOTES:

This product may contain trace amounts of ethylene oxide (CAS No. 75-21-8), a condition which creates the potential for accumulation of ethylene oxide in the head space of shipping and storage containers and in enclosed areas where the product is being handled or used. Ethylene oxide is considered by OSHA, IARC, and NTP as a potential carcinogen for humans. Ethylene oxide may also present reproductive, mutagenic, genotoxic, neurologic and sensitization hazards in humans. If this product is handled with adequate ventilation, the presence of these trace amounts is not expected to result in any short or long term hazards.

### HAZARD RATING SYSTEMS:

This information is for people trained in:  
National Paint & Coatings Association's (NPCA)  
Hazardous Materials Identification System (HMIS)  
National Fire Protection Association (NFPA 704)  
Identification of the Fire Hazards of Materials

	NPCA-HMIS	NFPA 704	KEY
HEALTH	2	2	4 = Severe
FLAMMABILITY	2	2	3 = Serious
REACTIVITY	0	0	2 = Moderate
			1 = Slight
			0 = Minimal

## SECTION 7 REGULATORY INFORMATION

### DEPARTMENT OF TRANSPORTATION (DOT):

DOT HAZARD CLASS: Combustible Liquid  
DOT IDENTIFICATION NUMBER: Not Available

### TSCA:

Components of this product are listed on the TSCA Inventory.

### CERCLA:

If the reportable quantity of this product is accidentally spilled, the incident is subject to the provisions of the Comprehensive Response, Compensation and Liability Act (CERCLA) and must be reported to the National Response Center by calling 800-424-8802.



BREAXIT OEB-9

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The reportable spill quantity of this product is 60,600 pounds.  
This product contains:  
Xylene.

**SARA TITLE III:**

Under the provisions of Title III, Sections 311/312 of the Superfund Amendments and Reauthorization Act, this product is classified into the following hazard categories:

Immediate health, Delayed Health, Fire.

This product contains the following Section 313 Reportable Ingredients:

<u>COMPONENT</u>	<u>CAS NO.</u>	<u>MAXIMUM %</u>
Xylene	1330-20-7	2.0

**SECTION 8 TYPICAL PHYSICAL & CHEMICAL PROPERTIES****SPECIFIC GRAVITY:**

1.09 at 60

Density: 9.1 lbs/gal at 60

**SOLUBILITY IN WATER, WT. % AT °F:**

Dispersible

**GRAV. OF VAPOR, at 1 atm (Air=1):**

Greater than 2.00

**EVAPORATION RATE, n-Bu Acetate=1:**

1.5 Greater than; Calculated

**VAPOR PRESSURE, mmHg at °F:**

110 at 100 Calculated

**VISCOSITY OF LIQUID, CST AT °F:**

55 at 100 Cannon-Fenske

21 at 150 Cannon-Fenske

**FREEZING/MELTING POINT, °F:**

-34 Pour Point

**BOILING POINT, °F:**

227 Calculated IBP

**SECTION 9 REACTIVITY DATA****STABILITY:**

Stable

**CONDITIONS TO AVOID INSTABILITY:**

None

**MATERIALS AND CONDITIONS TO AVOID INCOMPATIBILITY:**

Strong Oxidizing Agents

**HAZARDOUS DECOMPOSITION PRODUCTS:**

None

**HAZARDOUS POLYMERIZATION:**

Will not occur

**SECTION 10 STORAGE AND HANDLING****ELECTROSTATIC ACCUMULATION HAZARD:**

Unknown, use proper grounding procedure



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STORAGE TEMPERATURE, °F:

Ambient

STORAGE/TRANSPORT PRESSURE, mmHg:

Atmospheric

LOADING/UNLOADING TEMPERATURE, °F:

Ambient

VISC. AT LOADING/UNLOADING TEMP., cSt:

Not available

## REVISION SUMMARY:

Since APRIL 25, 1990 this MSDS has been revised in Section(s):

6

REFERENCE NUMBER:

HDHA-A-10497

DATE PREPARED:

November 2, 1990

SUPERSEDES ISSUE DATE:

April 25, 1990

FOR ADDITIONAL PRODUCT INFORMATION, CONTACT YOUR TECHNICAL SALES REPRESENTATIVE  
FOR ADDITIONAL HEALTH/SAFETY INFORMATION, CALL 713-870-6885

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### **APPENDIX 3**

#### **Emulsion Formation and Breaker Screening Test Results**



# In-situ Burning: Screening Test Data

## Emulsion Tendancy and Stability Test

Oil Type: ANS-Samples  
 Date: May 27/94  
 Comments: Test performed in fridge @T=8.9°C

Run#1 T test=8.9°C	Fresh-ANS 10.3%-ANS 27.9%-ANS	Ho (cm)		H5 (cm)		H10 (cm)		H20 (cm)		H30 (cm)		H24hrs (cm)	
		H oil	H oil	H oil	H oil	H oil&emls	H oil	H oil	H oil	H oil&emlsn	H oil	H oil	H oil&emlsn
Run#2 T test=10.0°C	Fresh-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	10.3%-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	27.9%-ANS	1.3	0.0	0.0	2.5	2.5	0.0	0.0	0.0	0.0	0.0	-	-
Run#3 T test=10.0°C	Fresh-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	10.3%-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	27.9%-ANS	1.3	0.0	0.0	2.8	2.8	0.0	0.0	0.0	0.0	0.0	-	-
	Fresh-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	10.3%-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	27.9%-ANS	1.3	0.0	0.0	2.7	2.7	0.0	0.0	0.0	0.0	0.0	0.0	2.7

### Fraction of Oil in Emulsion

Run#1 T test=8.9°C	Fresh-ANS 10.3%-ANS 27.9%-ANS	F5 (cm)		F10 (cm)		F20 (cm)		F30 (cm)		F24hrs (cm)	
		F oil	F oil	F oil	F oil	F oil	F oil	F oil	F oil	F oil	F oil
Run#2 T test=10.0°C	Fresh-ANS	0	0	0	0	0	0	0	0	-	-
	10.3%-ANS	0	0	0	0	0	0	0	0	-	-
	27.9%-ANS	1	1	1	1	1	1	1	1	-	-
Run#3 T test=10.0°C	Fresh-ANS	0	0	0	0	0	0	0	0	-	-
	10.3%-ANS	0	0	0	0	0	0	0	0	-	-
	27.9%-ANS	1	1	1	1	1	1	1	1	-	-
	Fresh-ANS	0	0	0	0	0	0	0	0	0	0
	10.3%-ANS	0	0	0	0	0	0	0	0	0	0
	27.9%-ANS	1	1	1	1	1	1	1	1	1	1

NB: The shaker warmed-up the fridge significantly to 15°C in a very short time

# In-situ Burning: Screening Test Data

## Emulsion Tendency and Stability Test

Oil Type: ANS  
 Date: June 7/94  
 Comments: Test performed in Cooler Apparatus

Run#	T test=	H0 (cm)		H5 (cm)		H10 (cm)		H20 (cm)		H30 (cm)		H24hrs (cm)	
		H oil	H oil&emulsn	H oil	H oil&emulsn	H oil	H oil&emulsn	H oil	H oil&emulsn	H oil	H oil&emulsn	H oil	H oil&emulsn
Run#1	Fresh-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	10.3%-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	27.9%-ANS	1.3	0.0	0.0	2.5	0.0	2.5	0.0	2.5	0.0	2.4	-	-
Run#2	Fresh-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	10.3%-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
	27.9%-ANS	1.3	0.0	0.0	2.4	0.0	2.4	0.0	2.3	0.0	2.2	-	-
Run#3	Fresh-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.0	1.3	1.3
	10.3%-ANS	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	27.9%-ANS	1.3	0.0	0.0	2.6	0.0	2.6	0.0	2.5	0.0	2.5	1.3*	1.3

### Fraction of Oil in Emulsion

Run#	T test=	F5 (cm)		F10 (cm)		F20 (cm)		F30 (cm)		F24hrs (cm)	
		F oil	F oil&emulsn	F oil	F oil&emulsn	F oil	F oil&emulsn	F oil	F oil&emulsn	F oil	F oil&emulsn
Run#1	Fresh-ANS	0	0	0	0	0	0	0	0	-	-
	10.3%-ANS	0	0	0	0	0	0	0	0	-	-
	27.9%-ANS	1	1	1	1	1	1	1	1	-	-
Run#2	Fresh-ANS	0	0	0	0	0	0	0	0	-	-
	10.3%-ANS	0	0	0	0	0	0	0	0	-	-
	27.9%-ANS	1	1	1	1	1	1	1	1	-	-
Run#3	Fresh-ANS	0	0	0	0	0	0	0	0	0	0
	10.3%-ANS	0	0	0	0	0	0	0	0	0	0
	27.9%-ANS	1	1	1	1	1	1	1	1	0*	0*

\* NB - This value is inconsistent with all other data for 27.9% weathered oil.  
 Other data shows that this emulsion should be stable.

Date: June 14/84  
Emulsion Breaker: Trebolite - EIO-884  
Emulsion Spec: 67% H<sub>2</sub>O  
33% of 27.9% water

[illegible]

**Date:** June 14/94  
**Emulsion Breaker:** Alcopol  
**Emulsion Spec's:** 97% H<sub>2</sub>O  
13% of 27.9% w/w solids

Emulsion Breaker Test Results													
Date: June 14/94													
Emulsion Breaker: Brestat													
Emulsion Spec: 67% H <sub>2</sub> O													
33% or 27.5% weight/and AHS													
Sample	Vol. Emulsion	Vol. Demulsifier (10 <sup>-3</sup> mL)	Qing Oil (mL)	Mass H <sub>2</sub> O 25 ml sol. (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)	Mass H <sub>2</sub> O 1 ml sample (g)
1	20	0	131.32	153.58	153.4	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06
2	20	40	131.74	153.29	153.4	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06
3	20	40	131.74	153.29	153.4	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06
4	20	40	131.74	153.29	153.4	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06
5	20	40	131.74	153.29	153.4	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06
6	20	40	131.74	153.29	153.4	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06
7	20	40	131.74	153.29	153.4	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06
8	10	10	38.77	81.51	81.78	113.99	119.2	117.24	118.2	113.81	117.41	117.54	118.2
9	10	2	122.64	143.83	144.24	115.09	110.32	112.39	116.42	115.89	117.17	115.74	116.06

Date: June 14/84  
Emulsion Brazing:  
Emulsion Spec's:  
Breakout  
67% H<sub>2</sub>O  
33% of 27 g/l washcoat





## **APPENDIX 4**

### **Laboratory Burn Data**

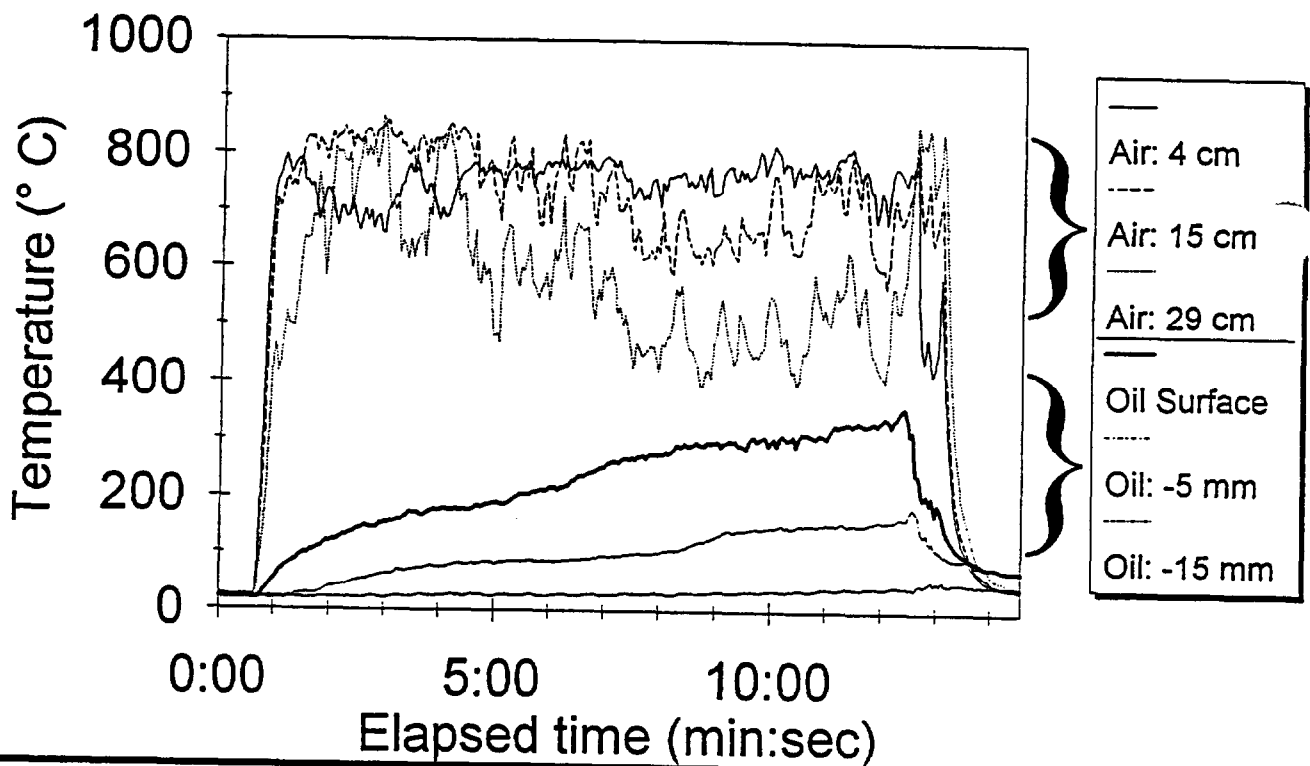


### Table 3 Burn Results

[illegible]

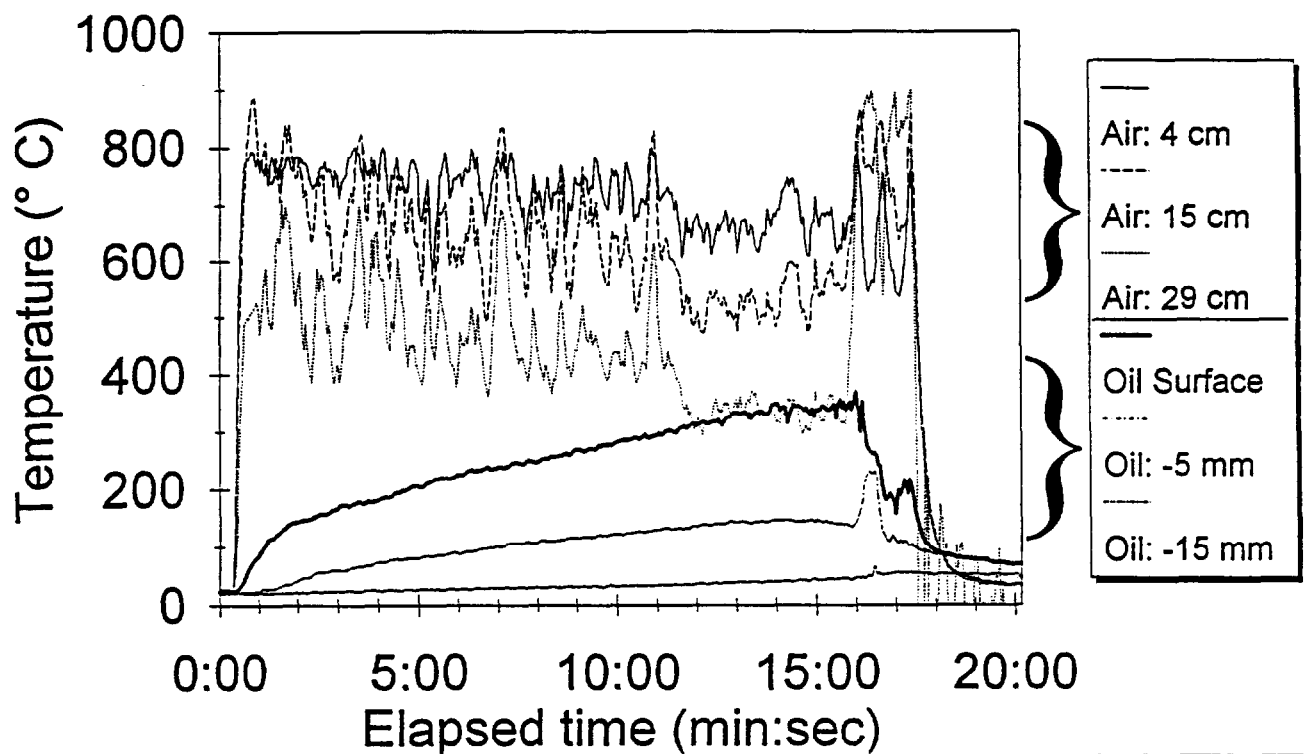
# ACS Burn Experiment # 01

Fresh ANS; No water; 20 mm thick



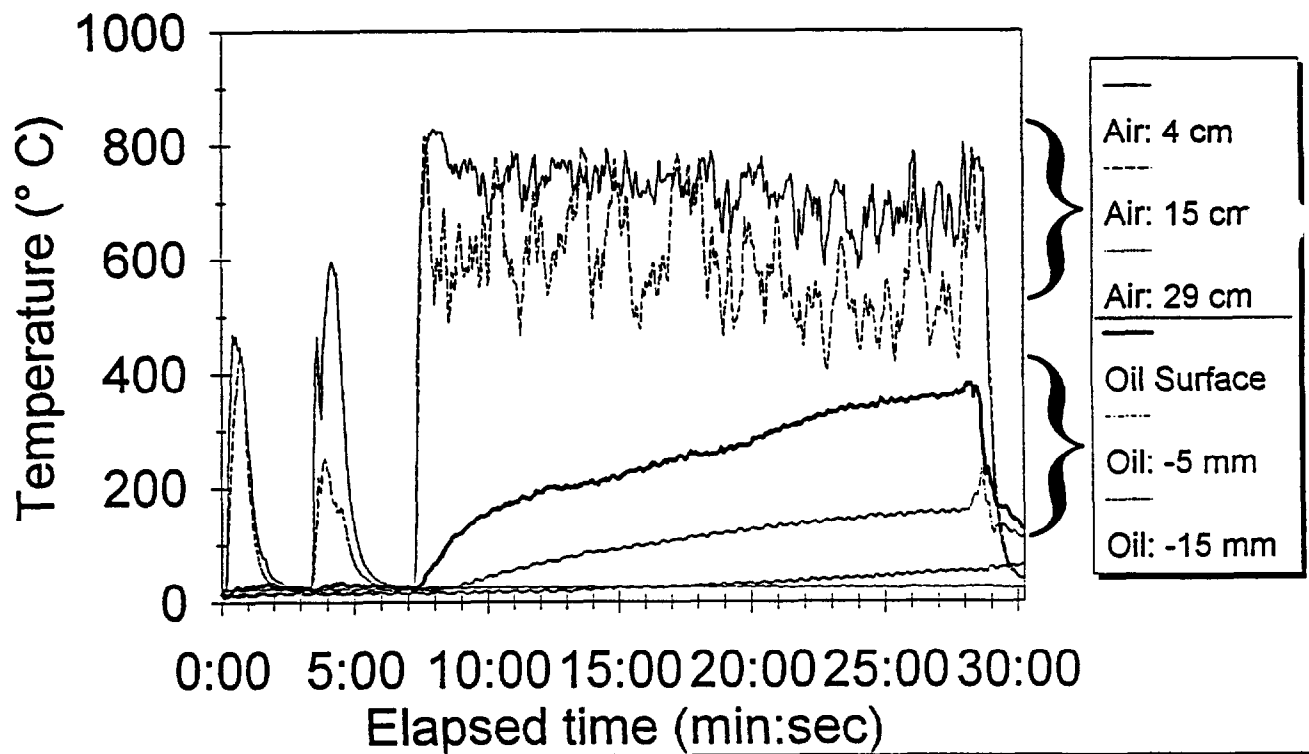
# ACS Burn Experiment # 02

10% ANS; No water; 20 mm thick



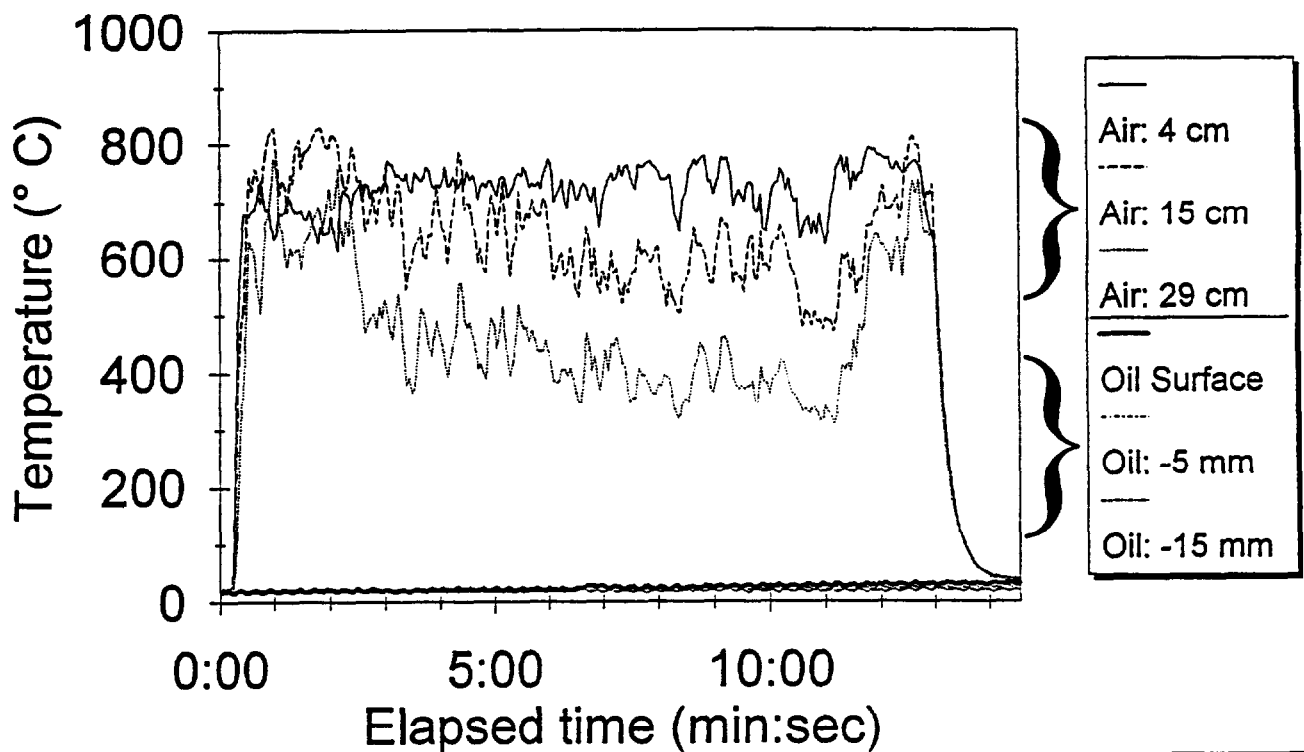
# ACS Burn Experiment # 03

28% ANS; No water; 20 mm thick



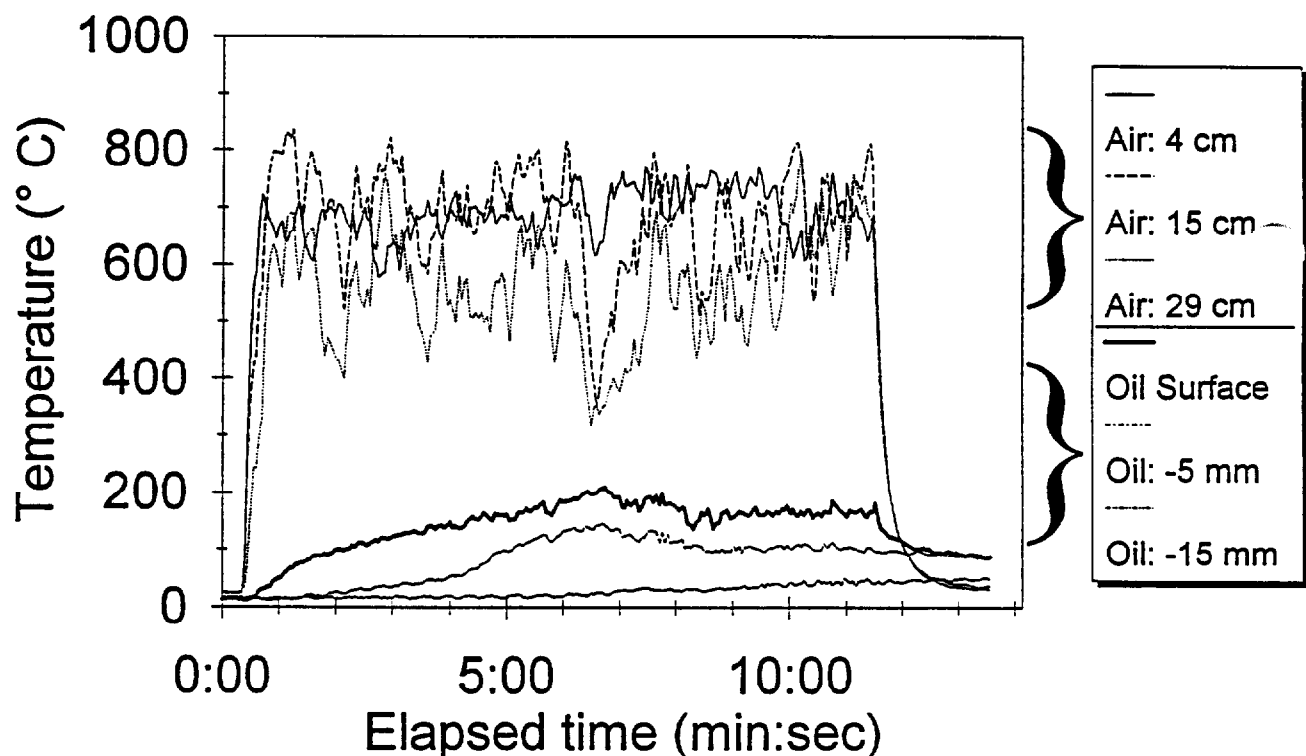
# ACS Burn Experiment # 04

Fresh ANS; 12.5% water; 20 mm thick



# ACS Burn Experiment # 05

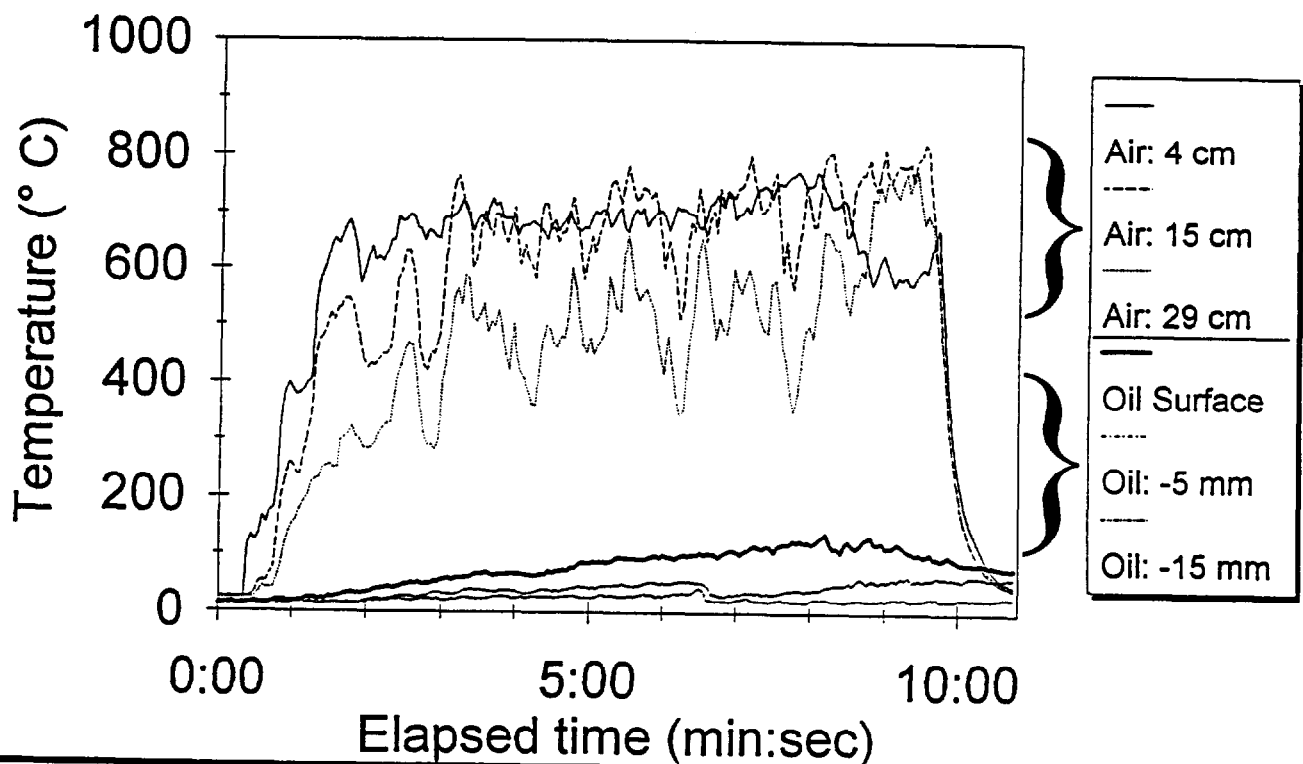
Fresh ANS; 25% water; 20 mm thick





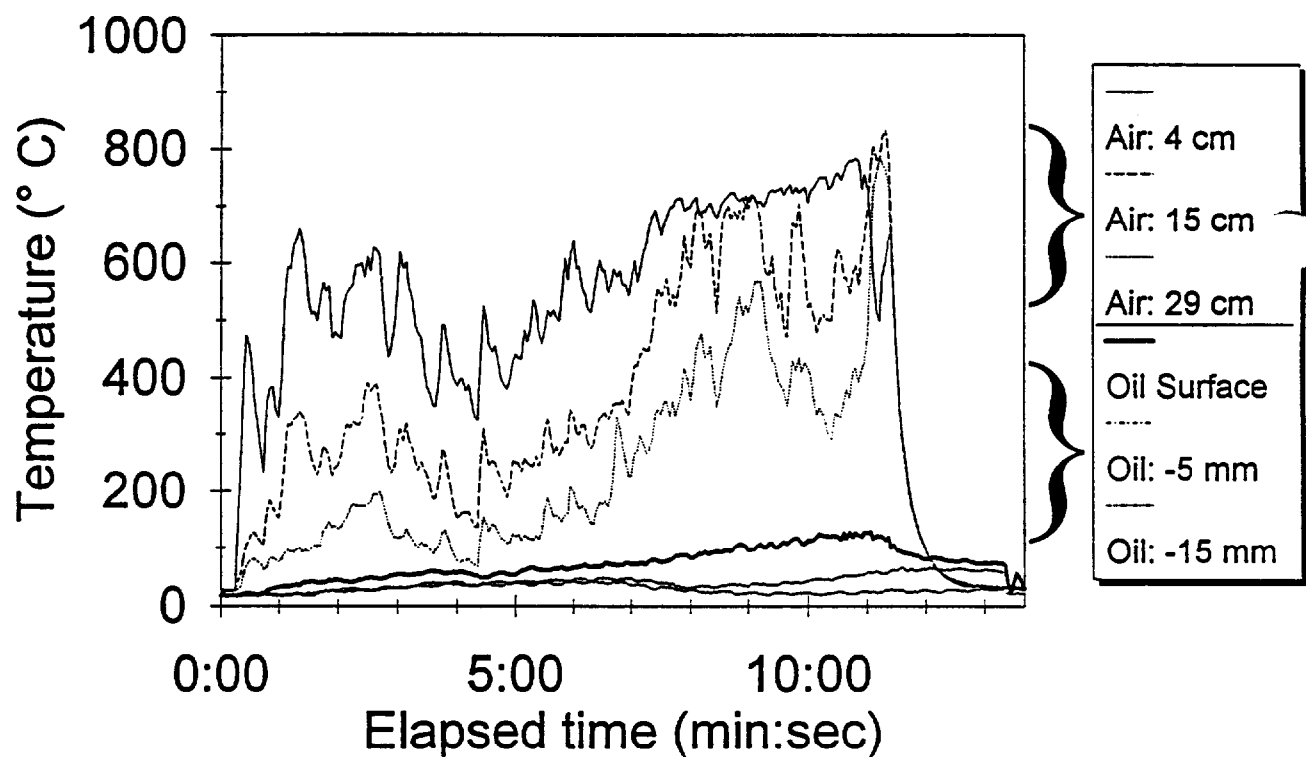
# ACS Burn Experiment # 06

Fresh ANS; 40% water; 20 mm thick



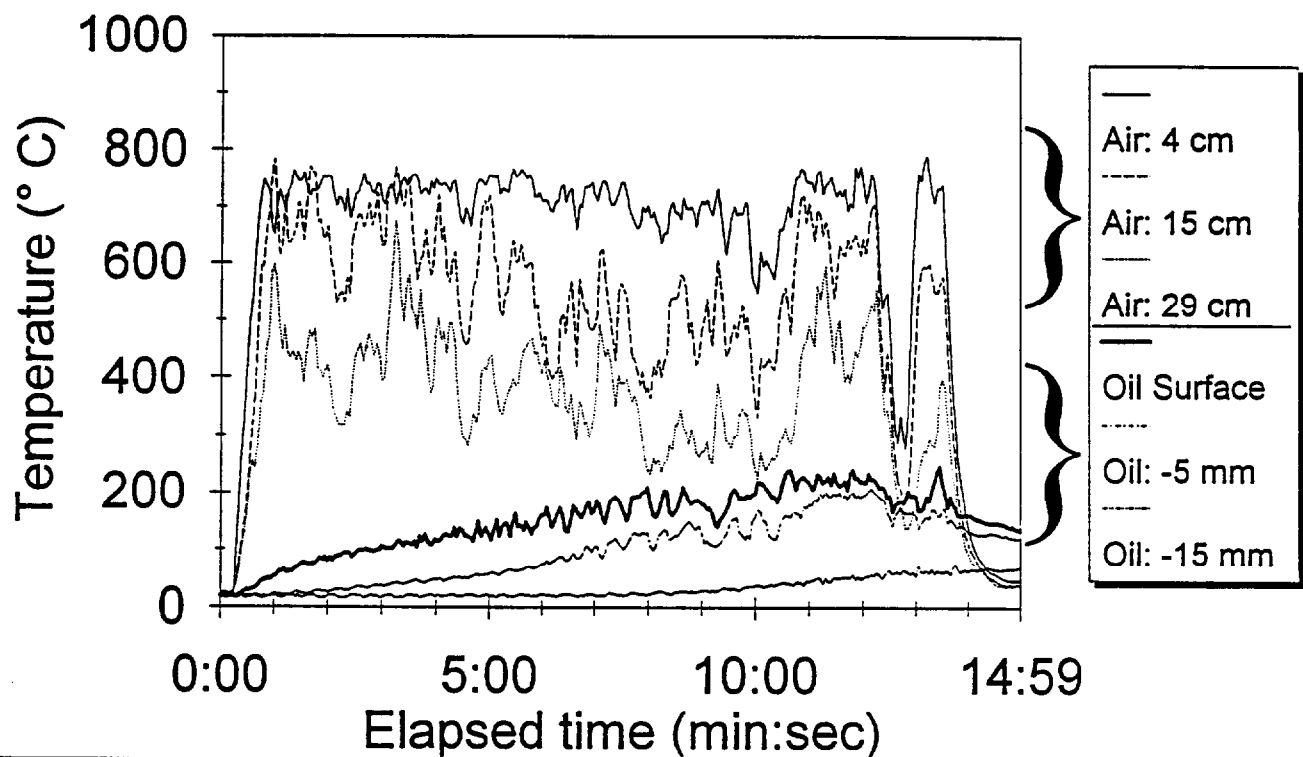
# ACS Burn Experiment # 07

Fresh ANS; 60% water; 20 mm thick



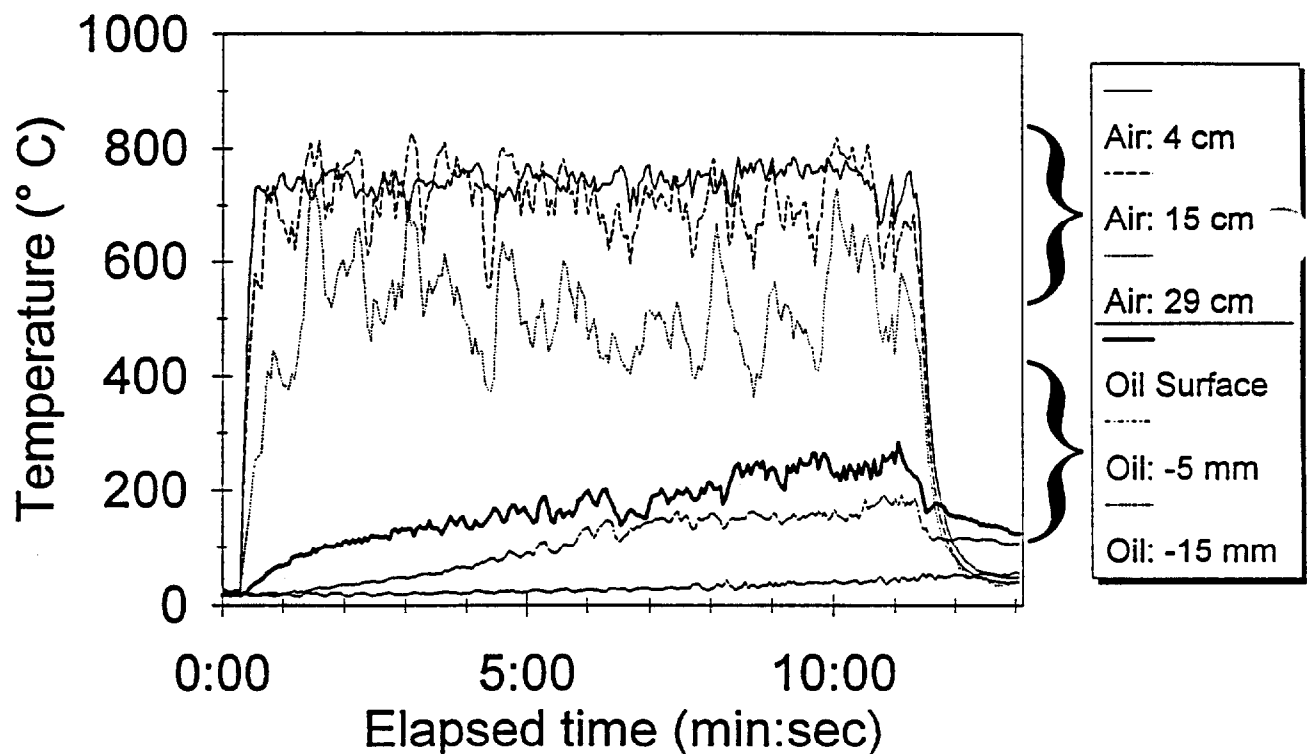
# ACS Burn Experiment # 08

10% ANS; 12.5% water; 20 mm thick



# ACS Burn Experiment # 09

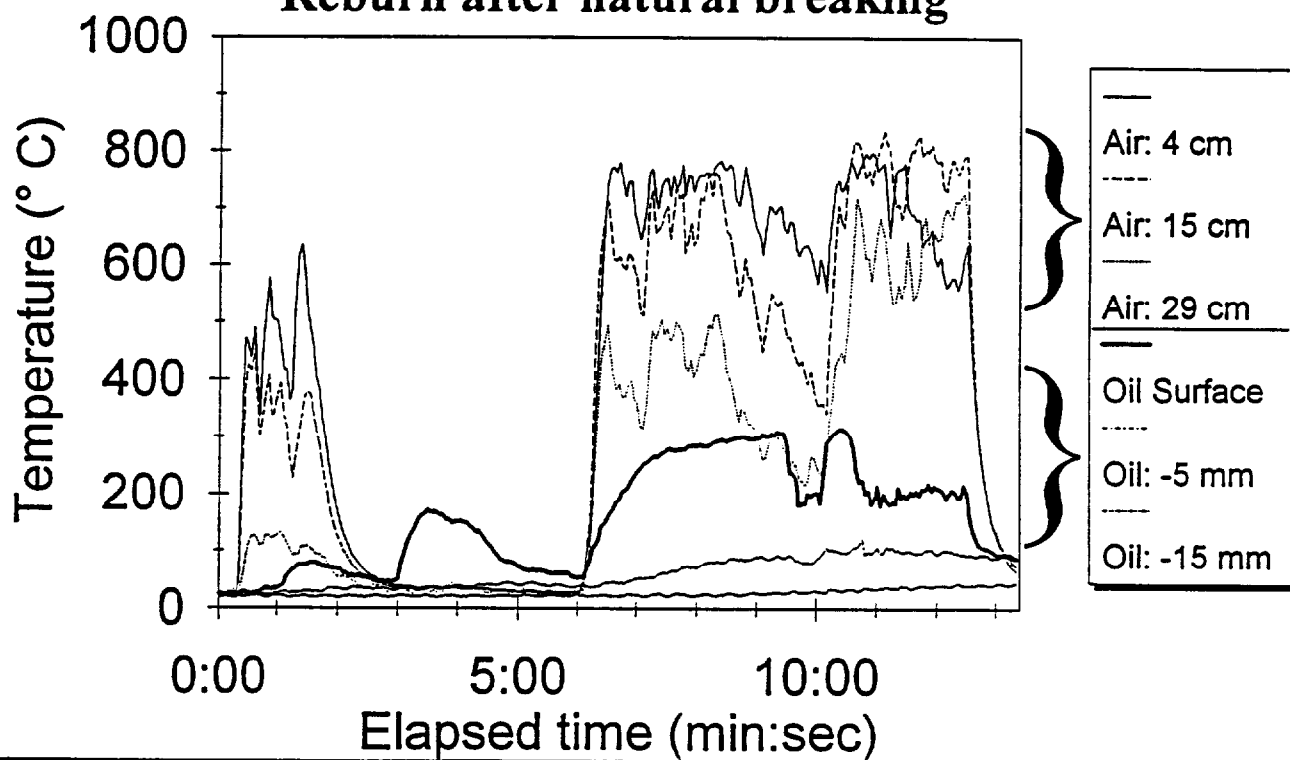
10% ANS; 25% water; 20 mm thick



# ACS Burn Experiment # 09a

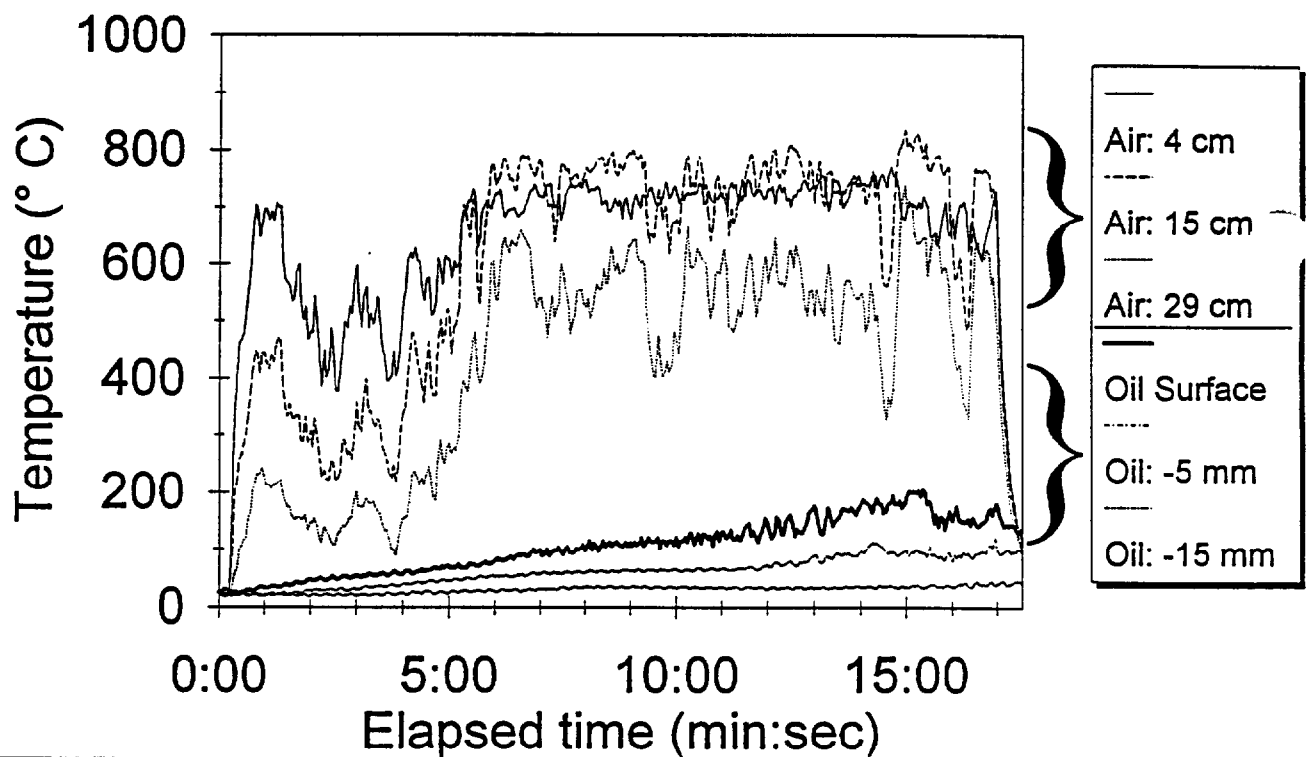
10% ANS; 25% water; 20 mm thick

Reburn after natural breaking



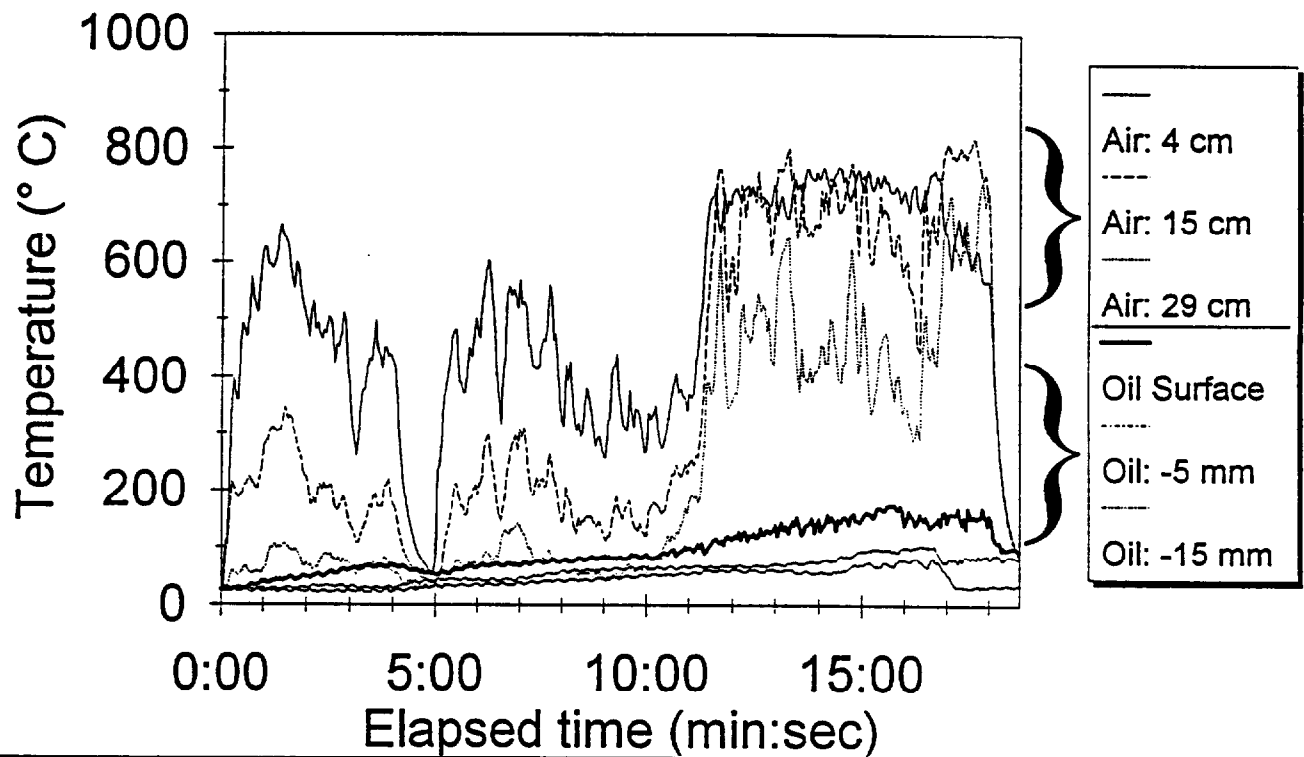
# ACS Burn Experiment # 10

10% ANS; 40% water; 20 mm thick



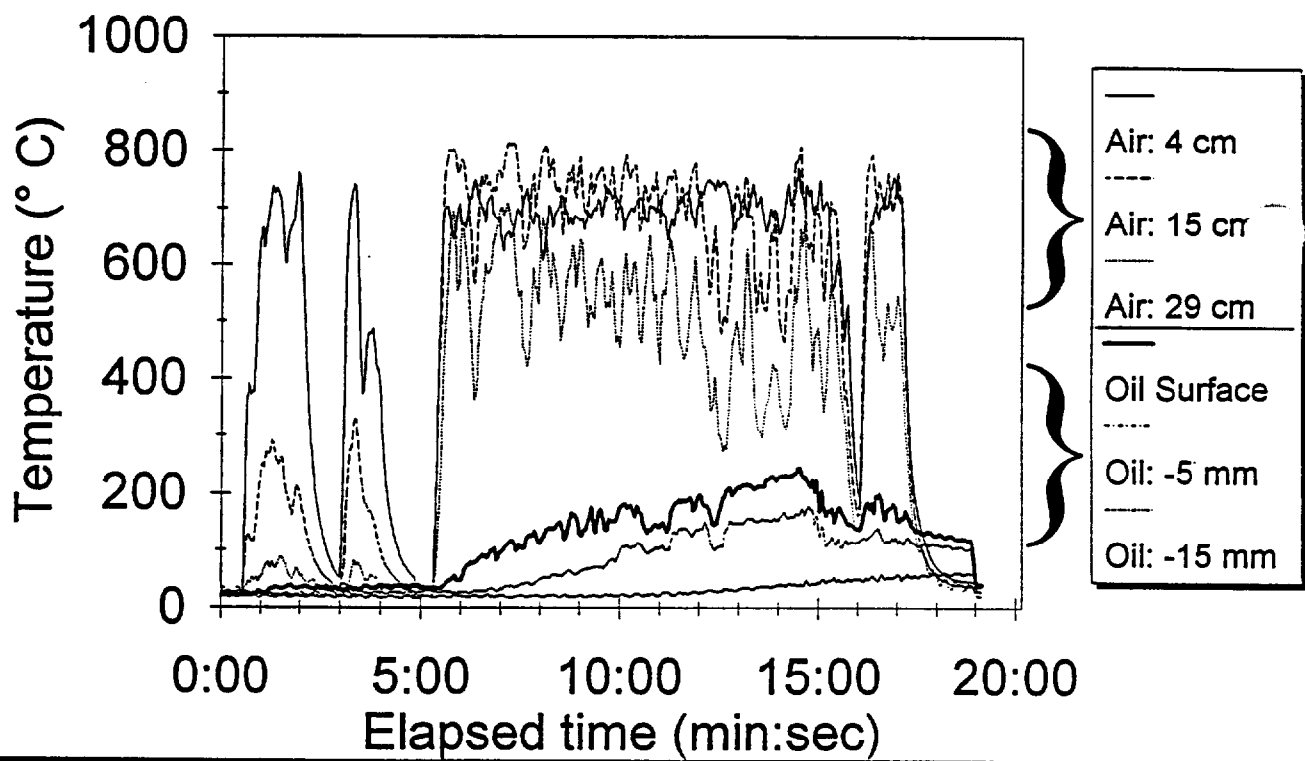
# ACS Burn Experiment # 11

10% ANS; 60% water; 20 mm thick



# ACS Burn Experiment # 12

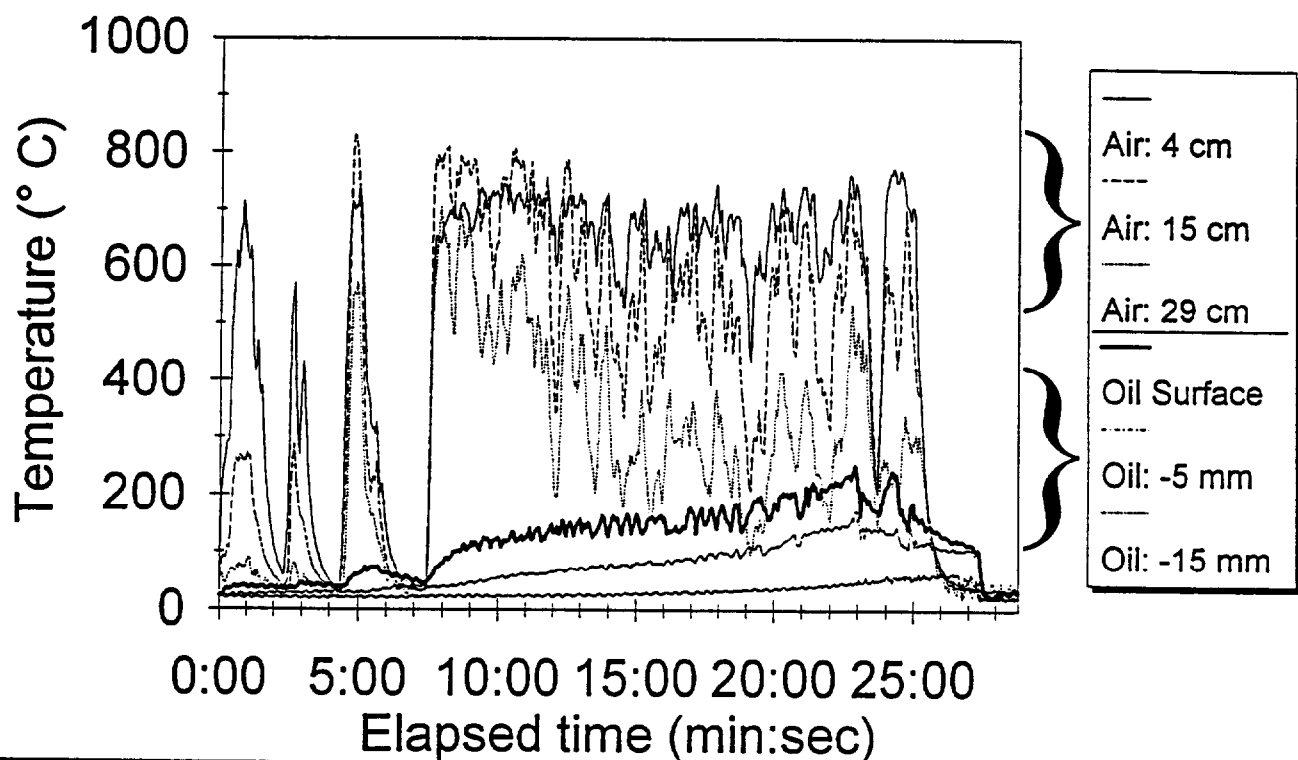
28% ANS; 12.5% water; 15 mm thick





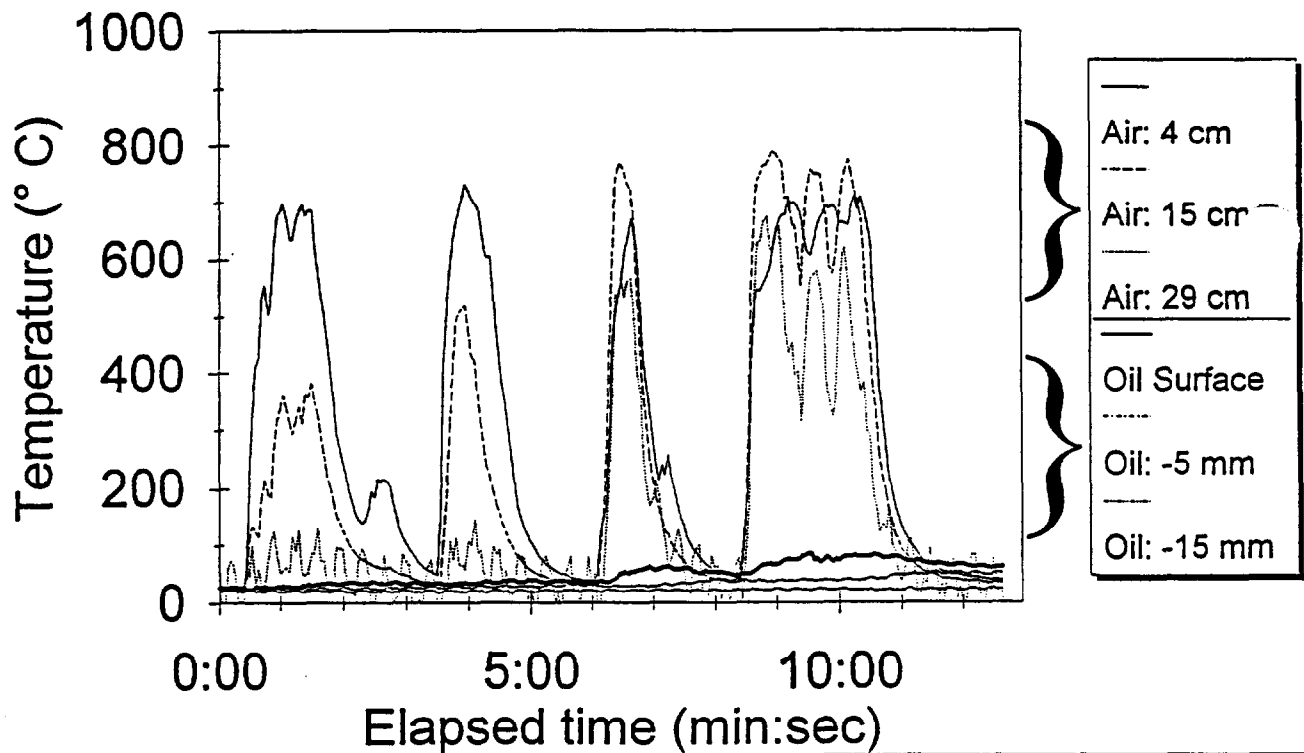
# ACS Burn Experiment # 13

28% ANS; 25% water; 15 mm thick



# ACS Burn Experiment # 14

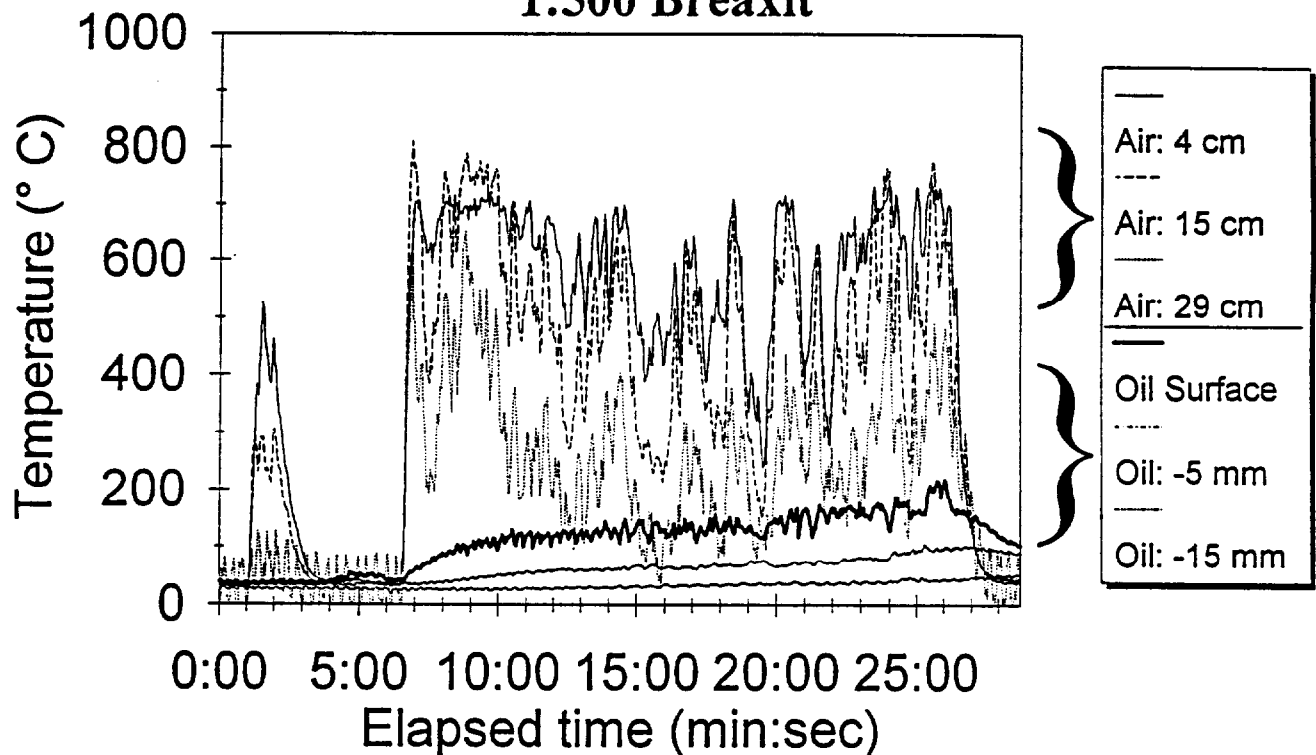
28% ANS; 40% water; 15 mm thick



# ACS Burn Experiment # 14a

28% ANS; 40% water; 15 mm thick

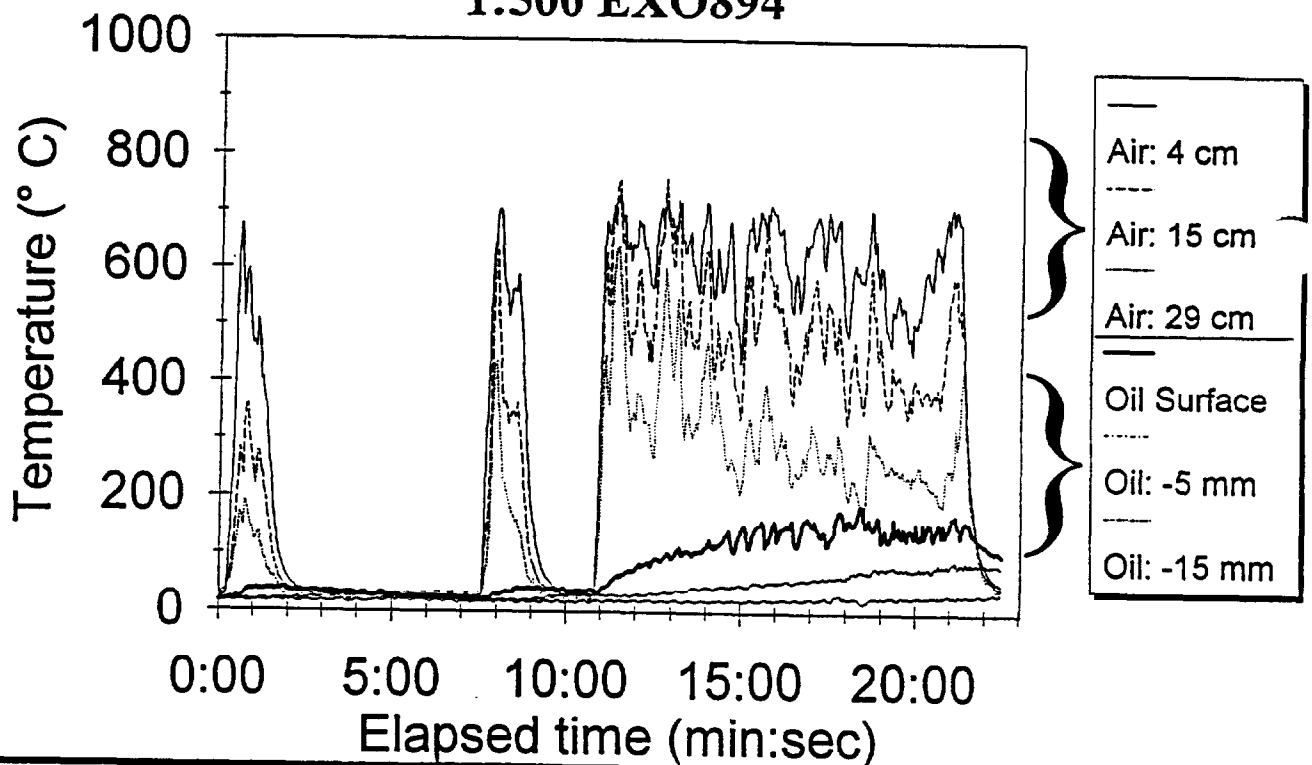
1:500 Breaxit



# ACS Burn Experiment # 15

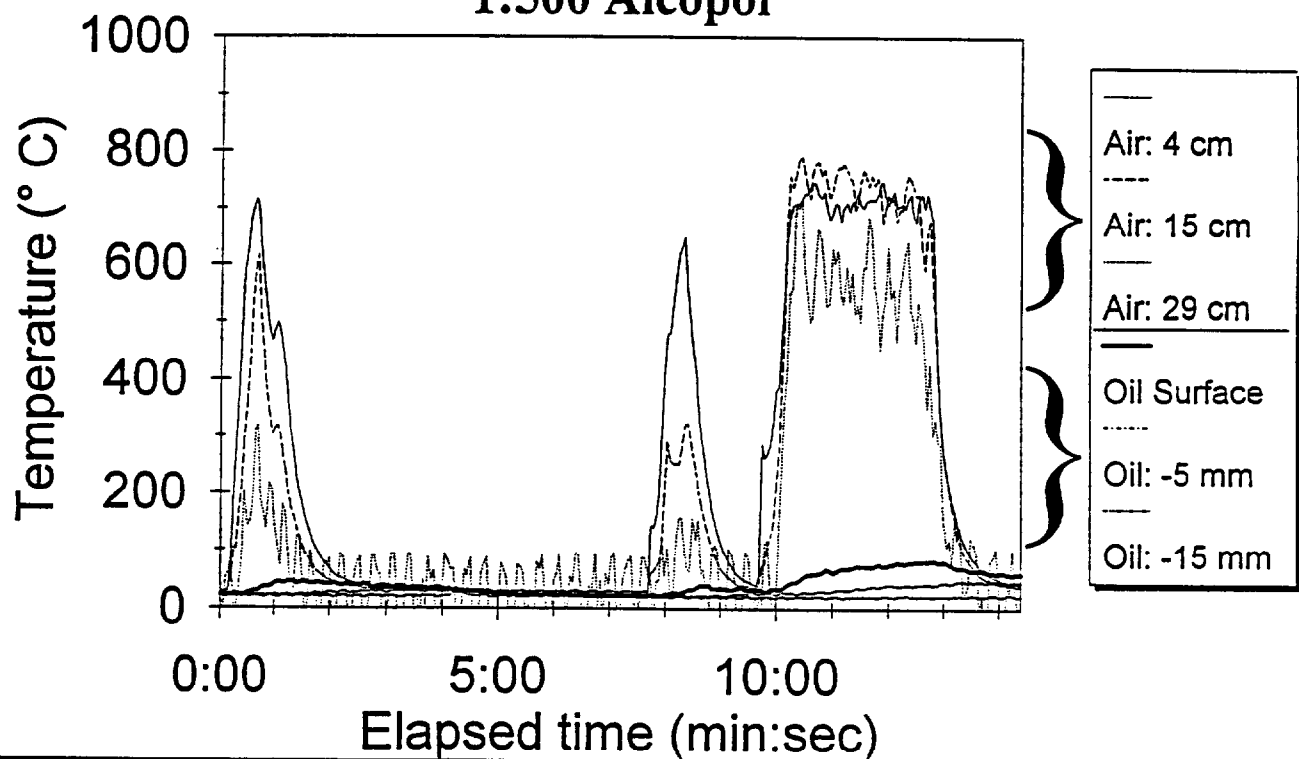
28% ANS; 40% water; 15 mm thick

1:500 EXO894



# ACS Burn Experiment # 16

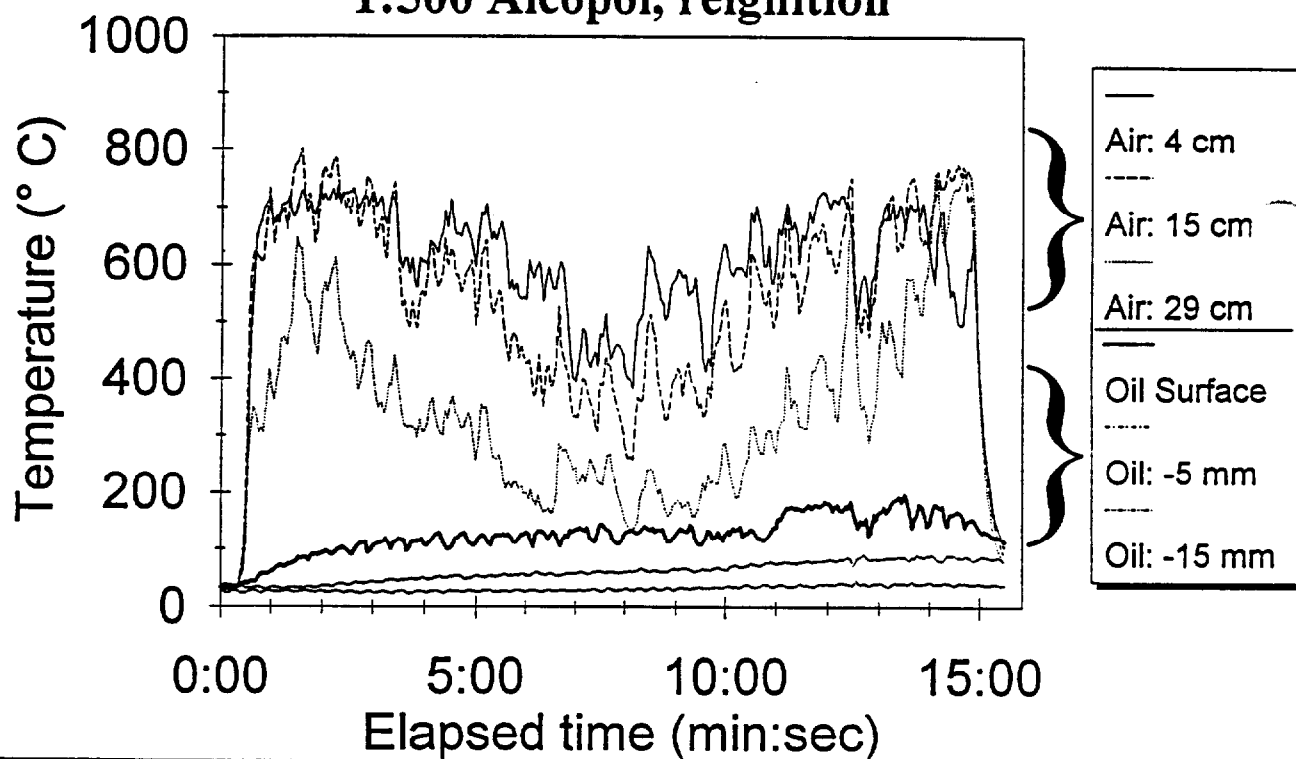
28% ANS; 40% water; 15 mm thick  
1:500 Alcopol



# ACS Burn Experiment # 16a

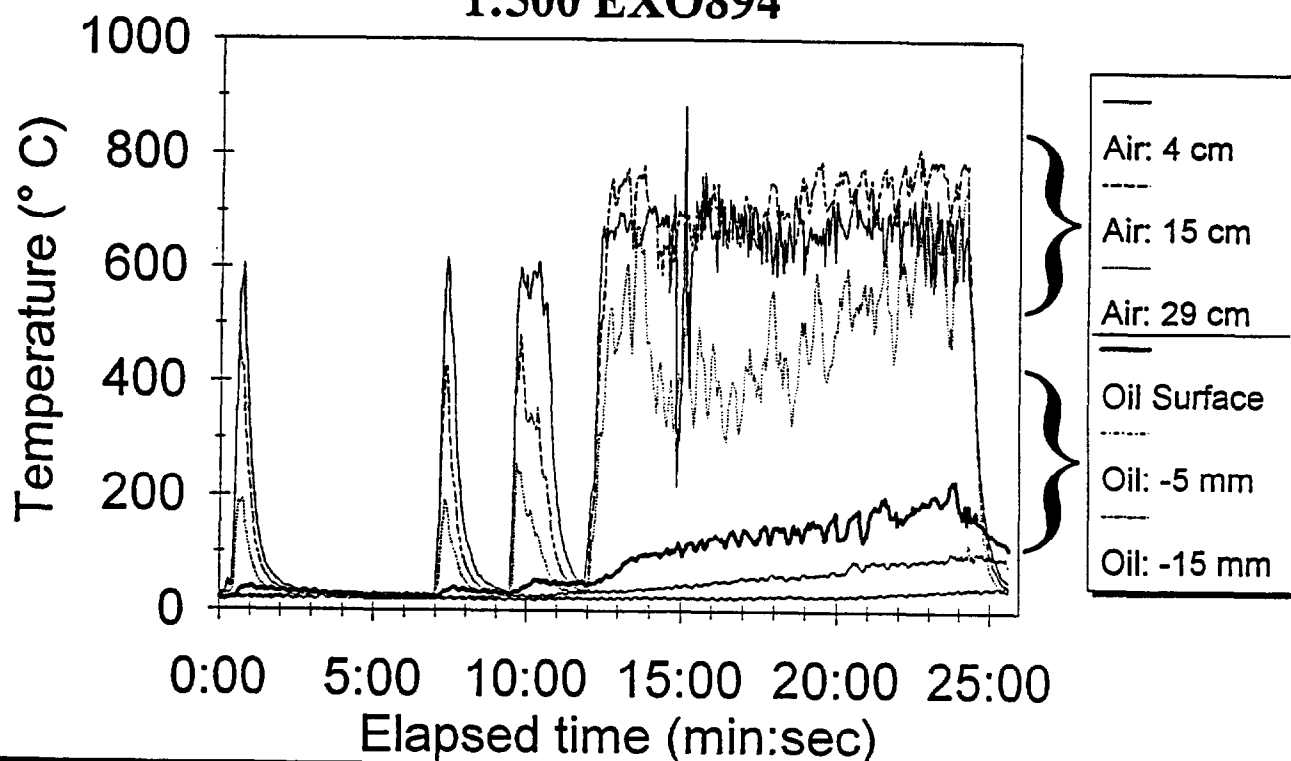
28% ANS; 40% water; 15 mm thick

1:500 Alcopol, reignition



# ACS Burn Experiment # 17

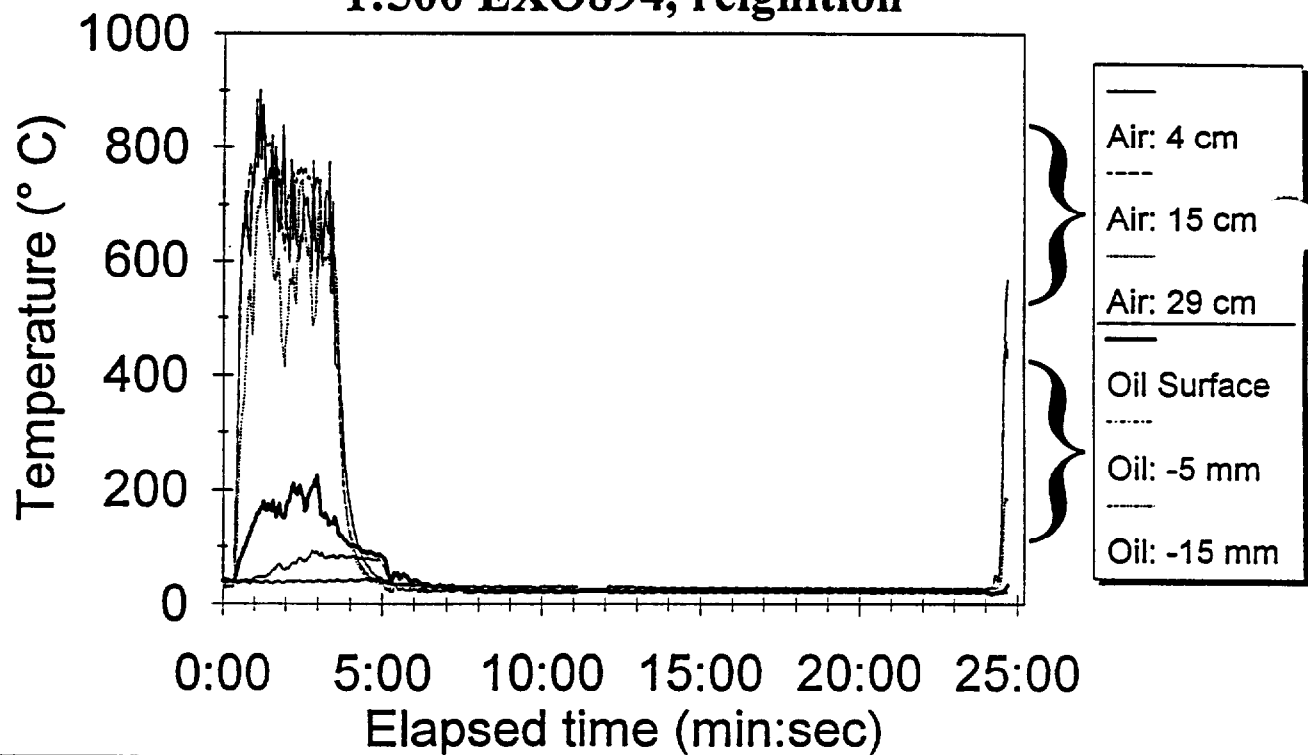
28% ANS; 40% water; 15 mm thick  
1:500 EXO894



# ACS Burn Experiment # 17a

28% ANS; 40% water; 15 mm thick

1:500 EXO894, reignition

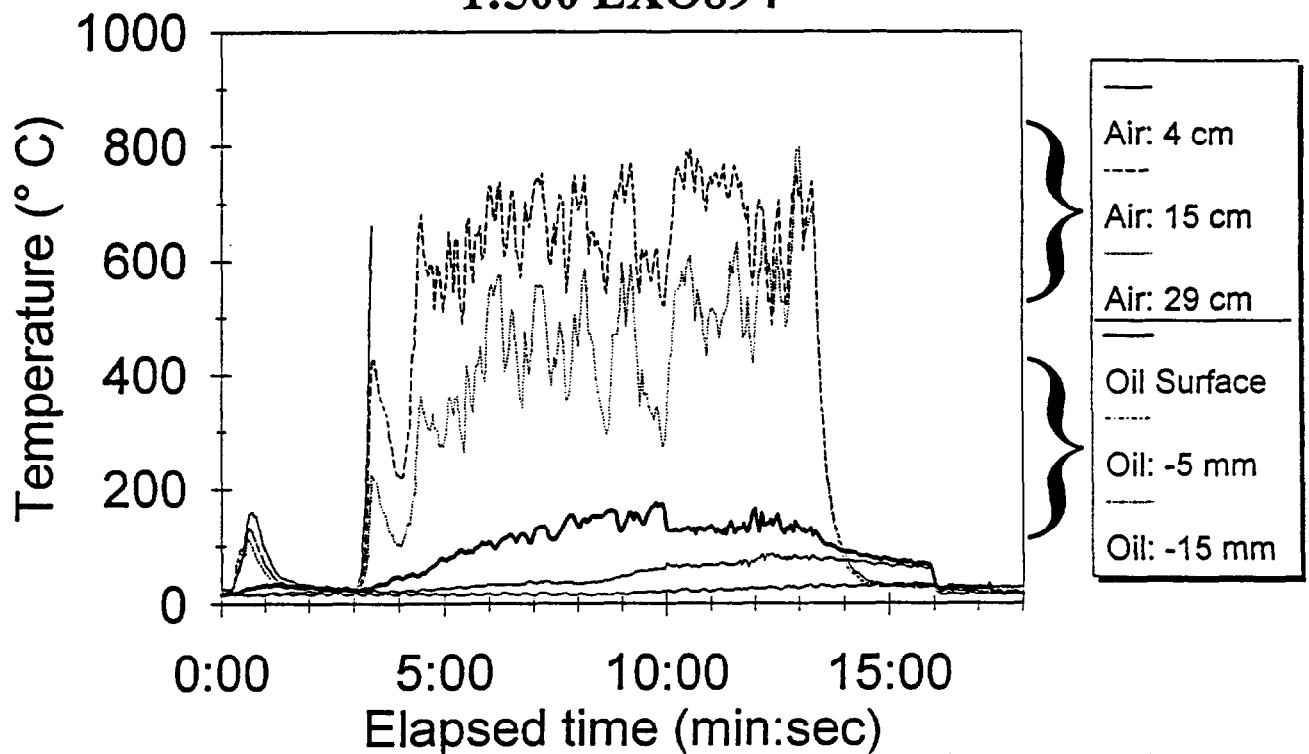




# ACS Burn Experiment # 18

28% ANS; 50% water; 15 mm thick

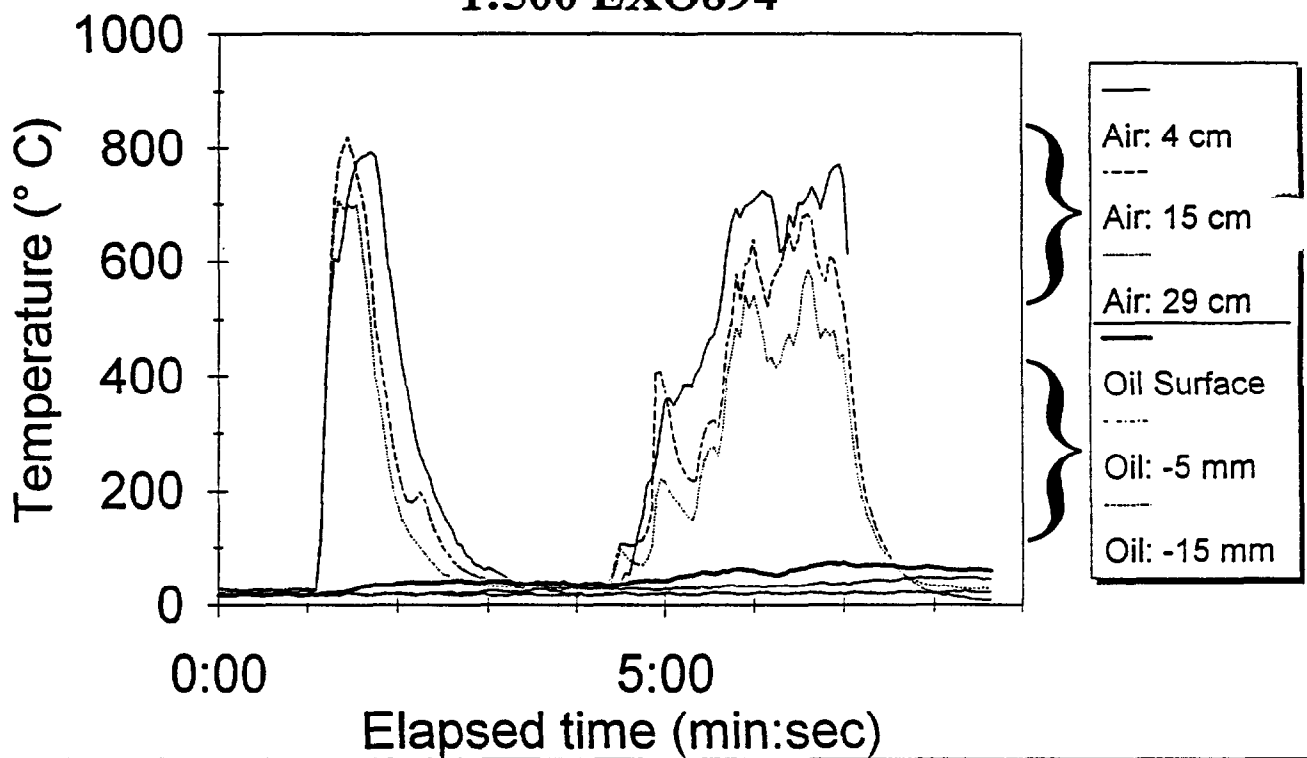
1:500 EXO894



# ACS Burn Experiment # 19

28% ANS; 50% water; 15 mm thick

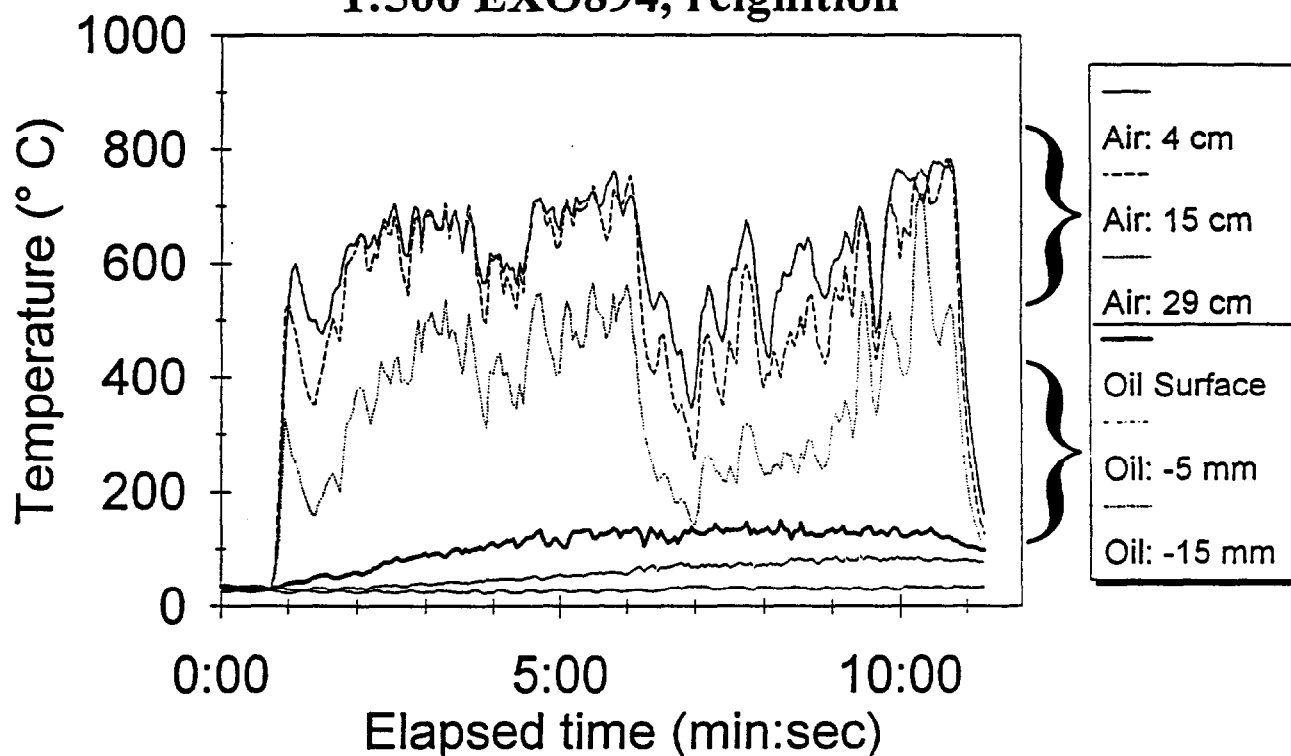
1:500 EXO894



# ACS Burn Experiment # 19a

28% ANS; 50% water; 15 mm thick

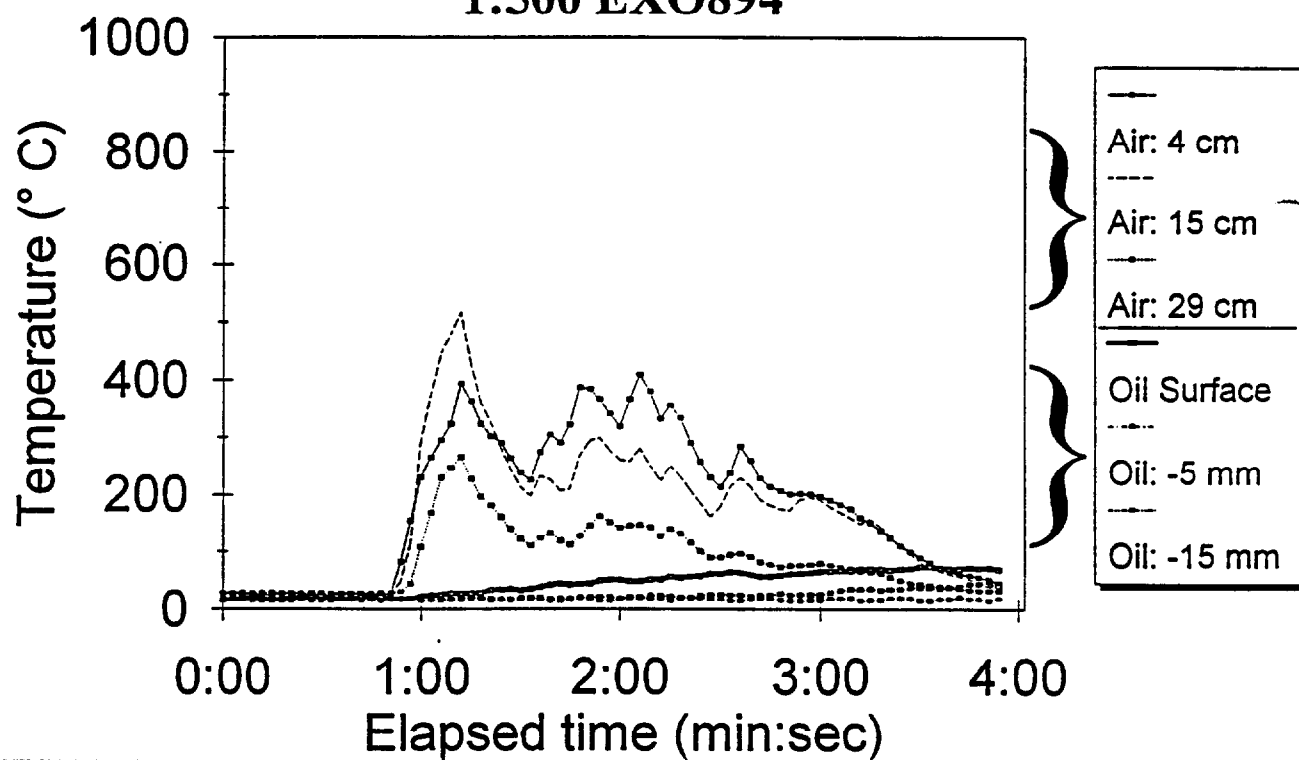
1:500 EXO894, reignition



# ACS Burn Experiment # 20

28% ANS; 50% water; 15 mm thick

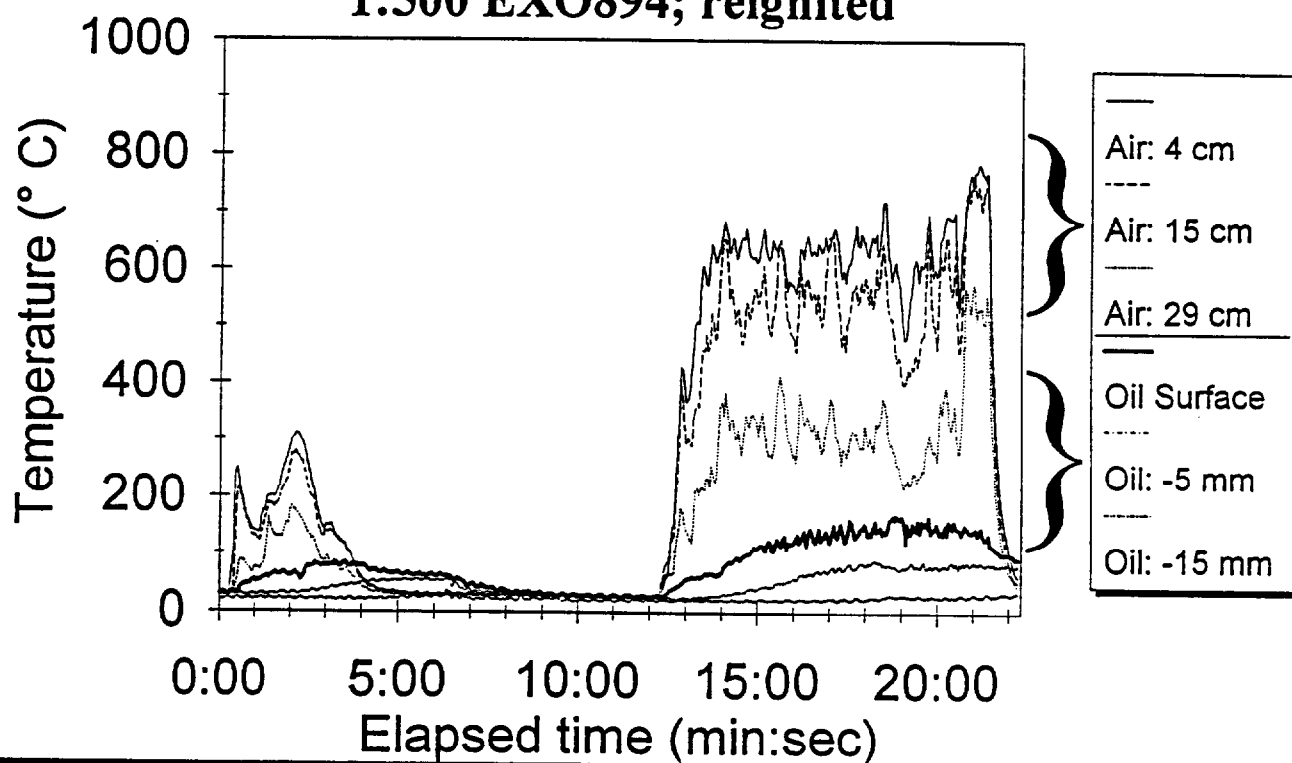
1:500 EXO894



# ACS Burn Experiment # 20a

28% ANS; 50% water; 15 mm thick

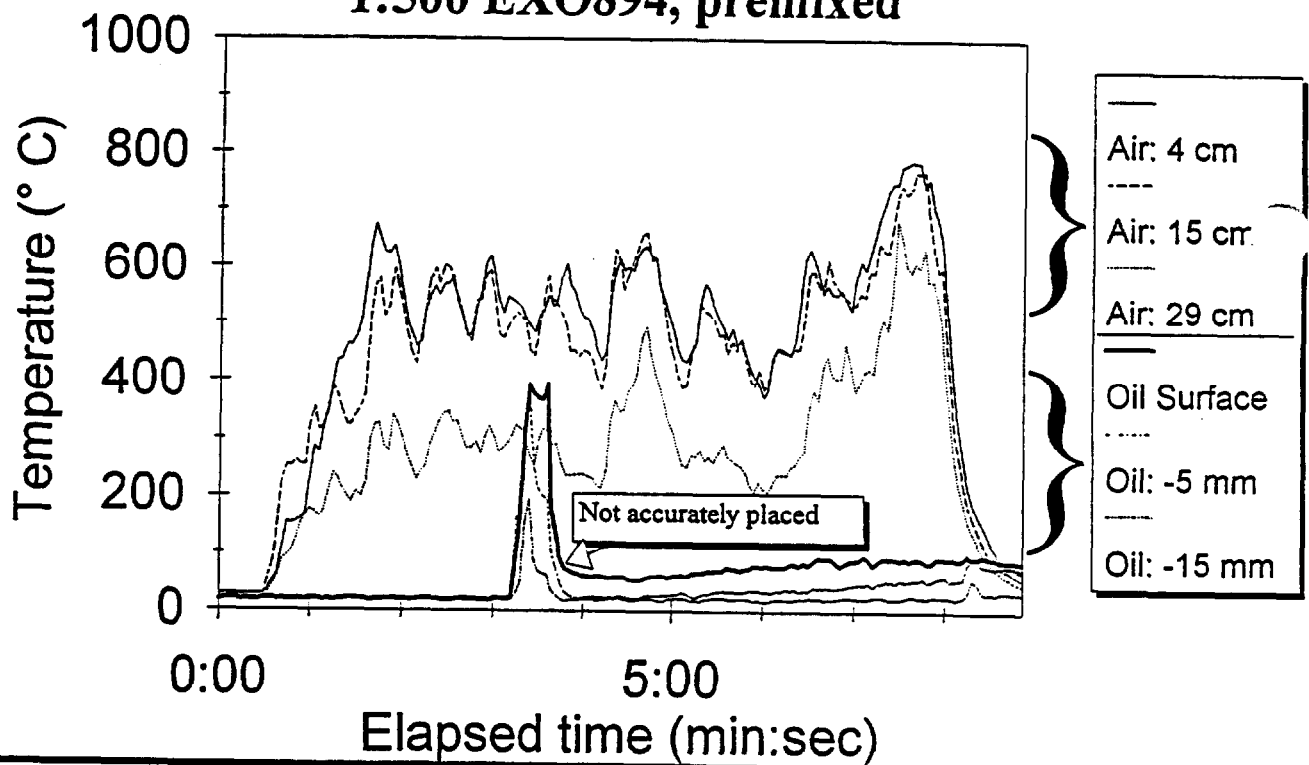
1:500 EXO894; reignited



# ACS Burn Experiment # 21

28% ANS; 60% water; 15 mm thick

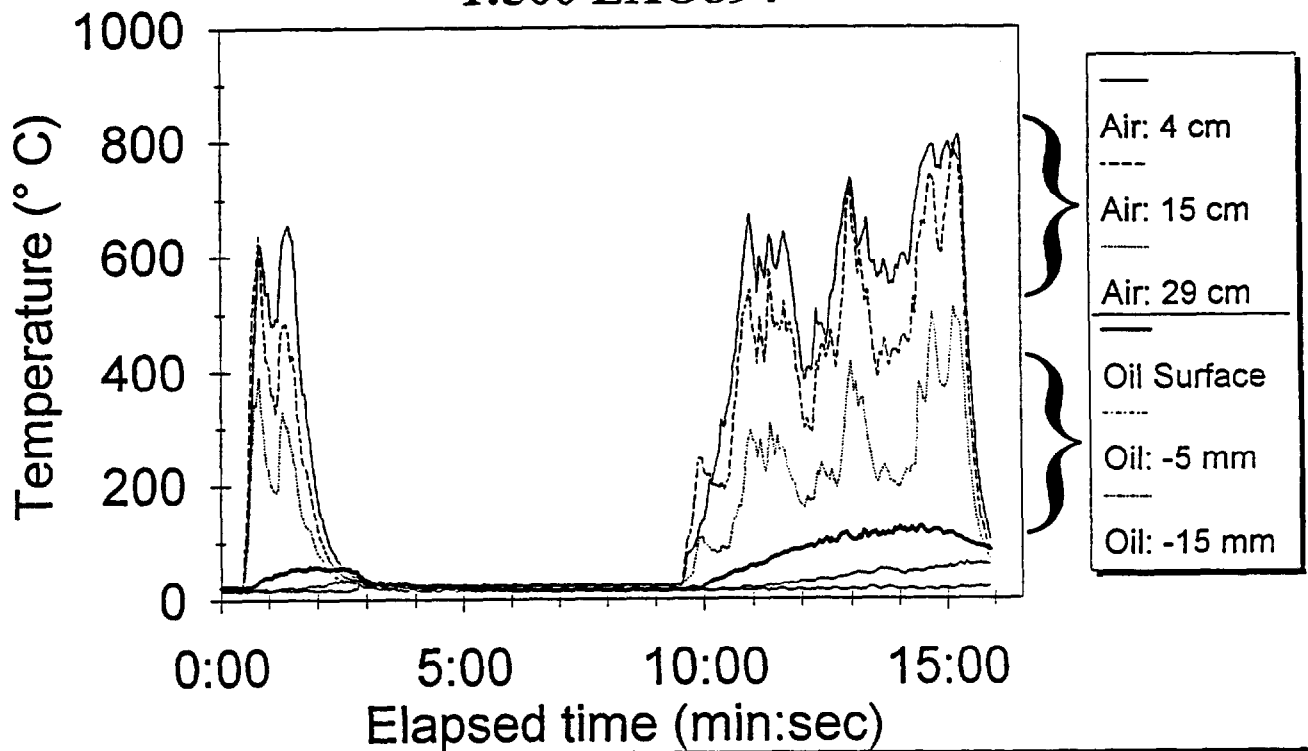
1:500 EXO894, premixed



# ACS Burn Experiment # 22

28% ANS; 60% water; 12 mm thick

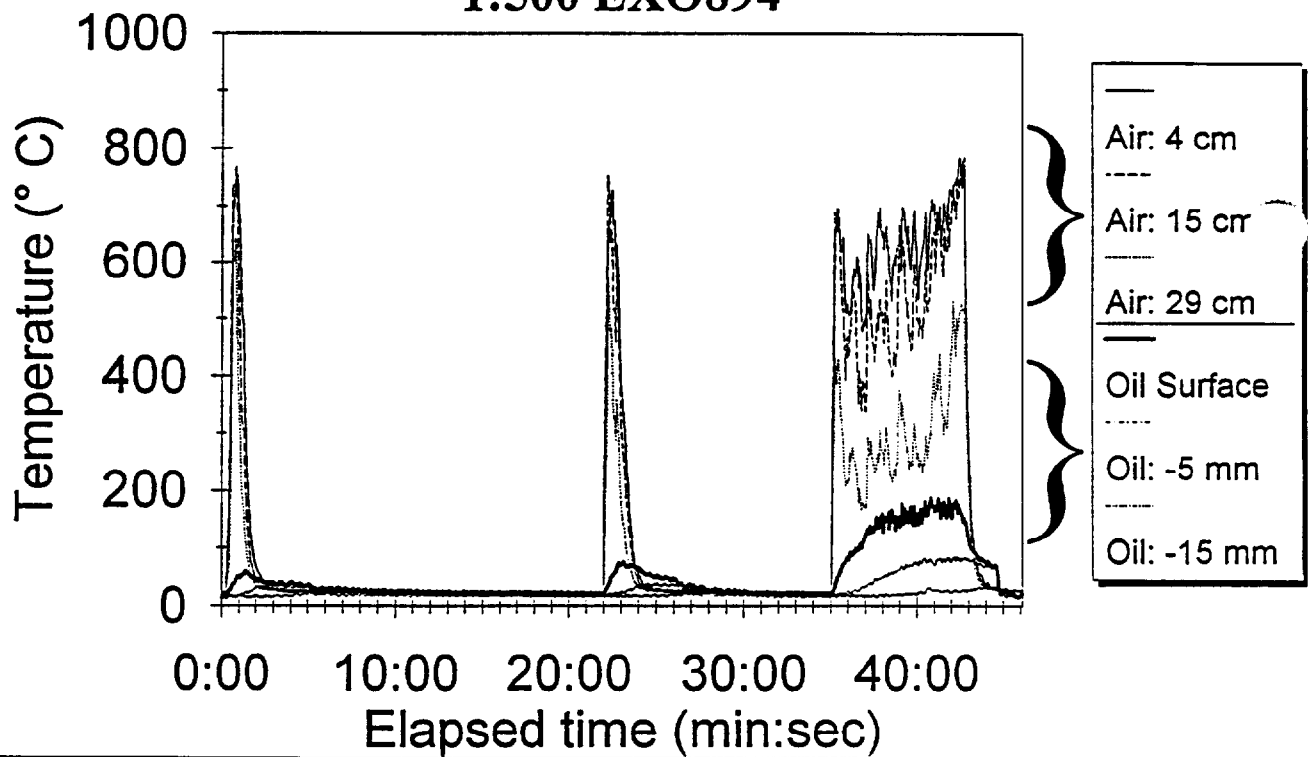
1:500 EXO894



# ACS Burn Experiment # 23

28% ANS; 60% water; 20mm thick

1:500 EXO894

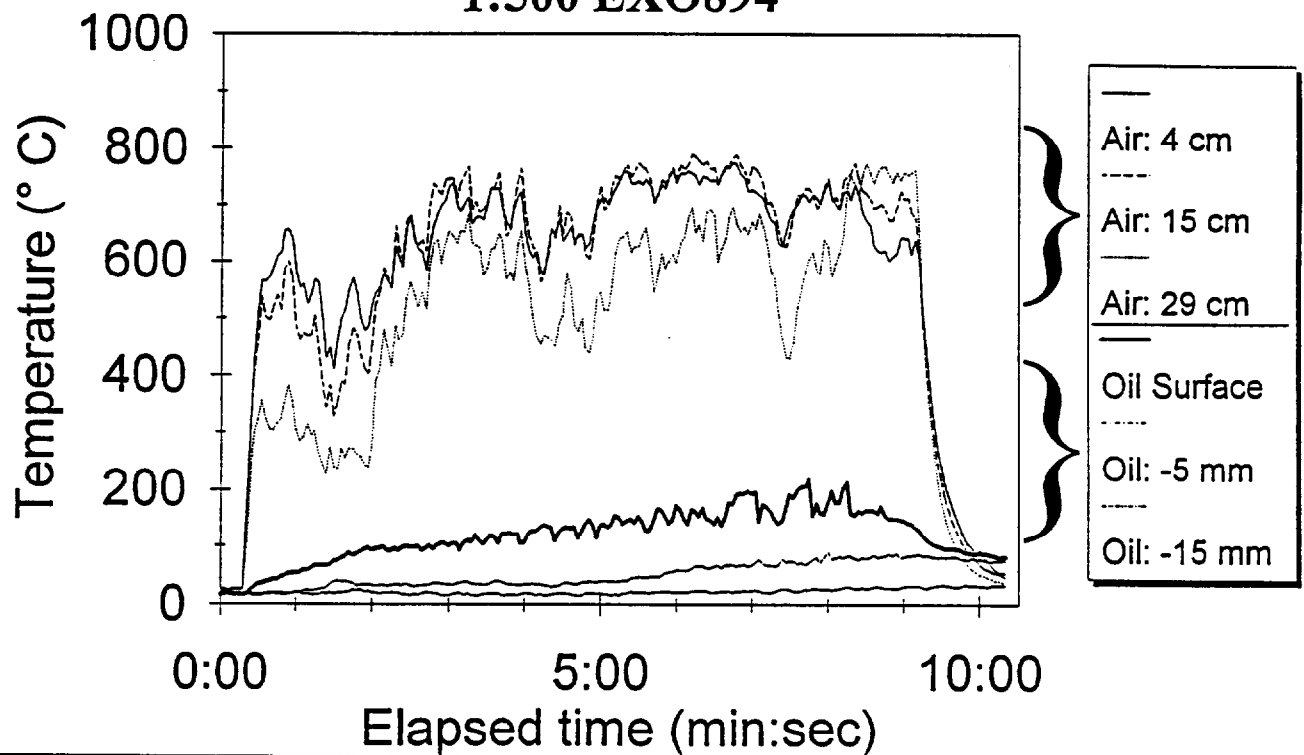




# ACS Burn Experiment # 24

10% ANS; 60% water; 20 mm thick

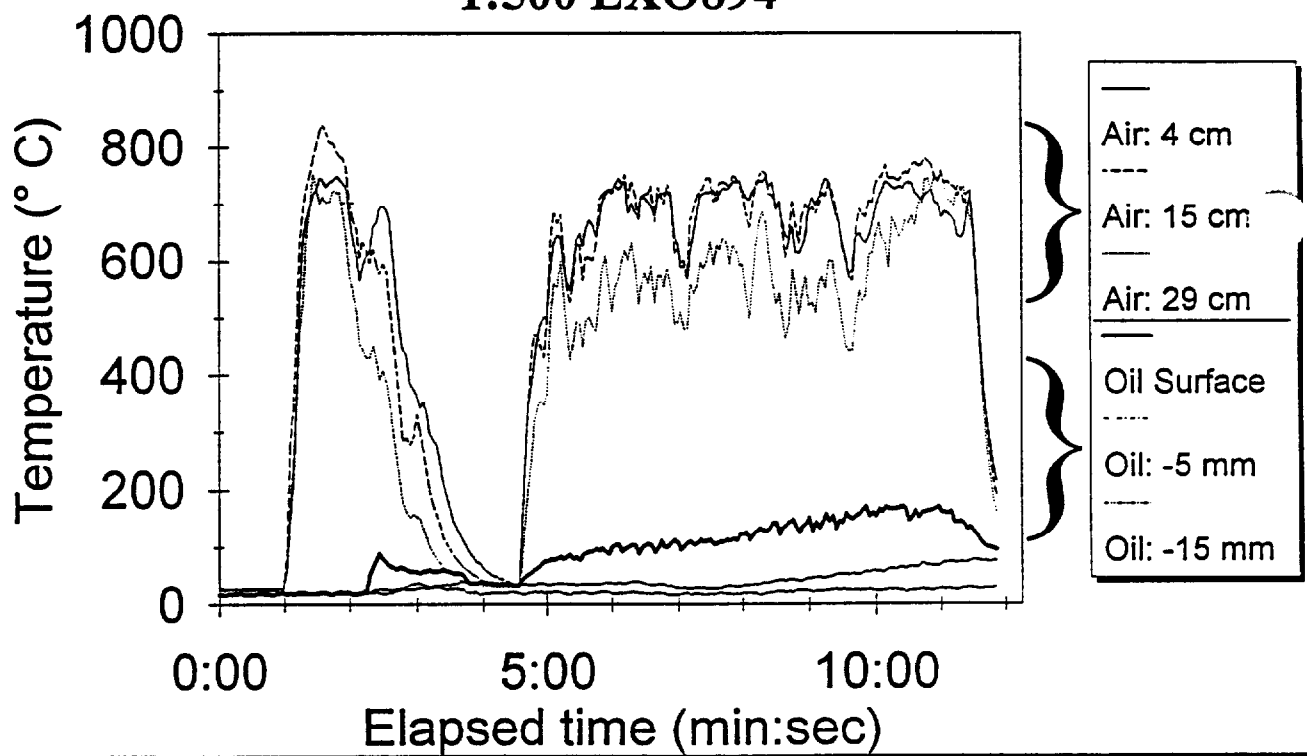
1:500 EXO894



# ACS Burn Experiment # 25

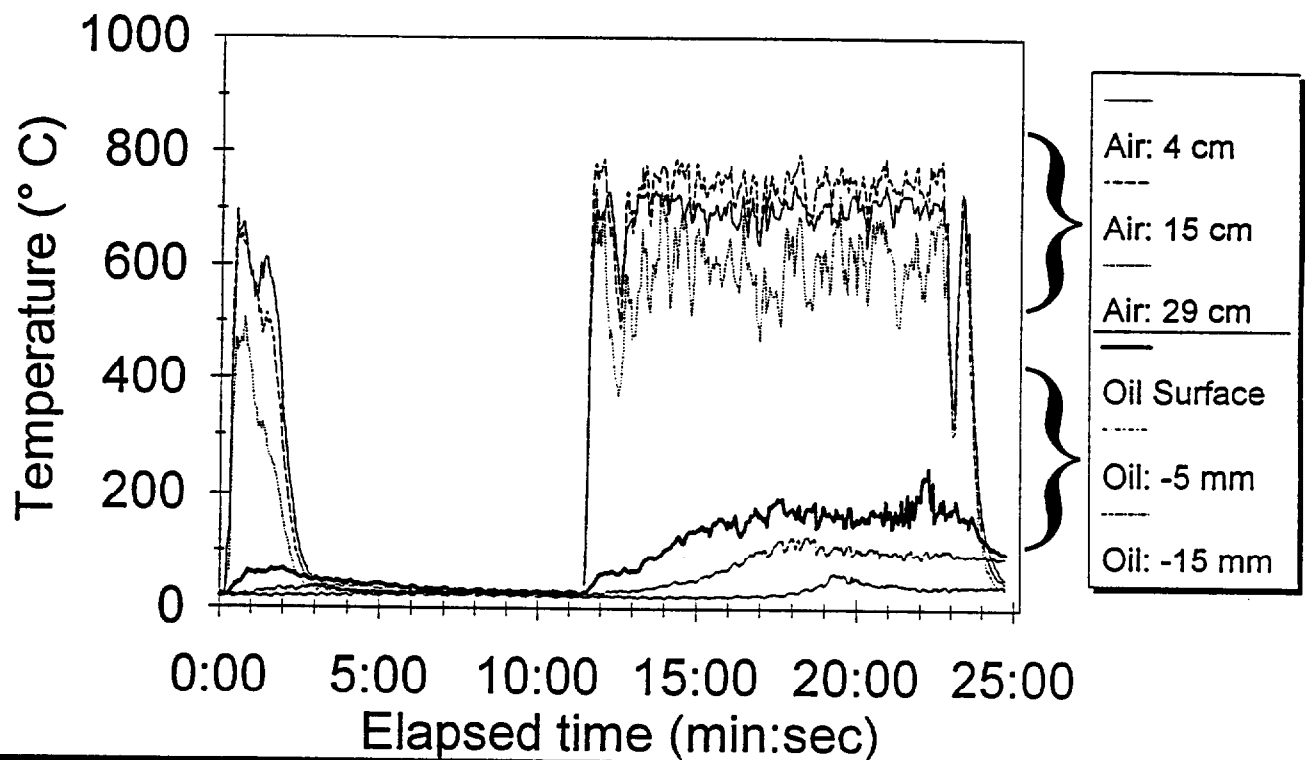
10% ANS; 70% water; 20 mm thick

1:500 EXO894



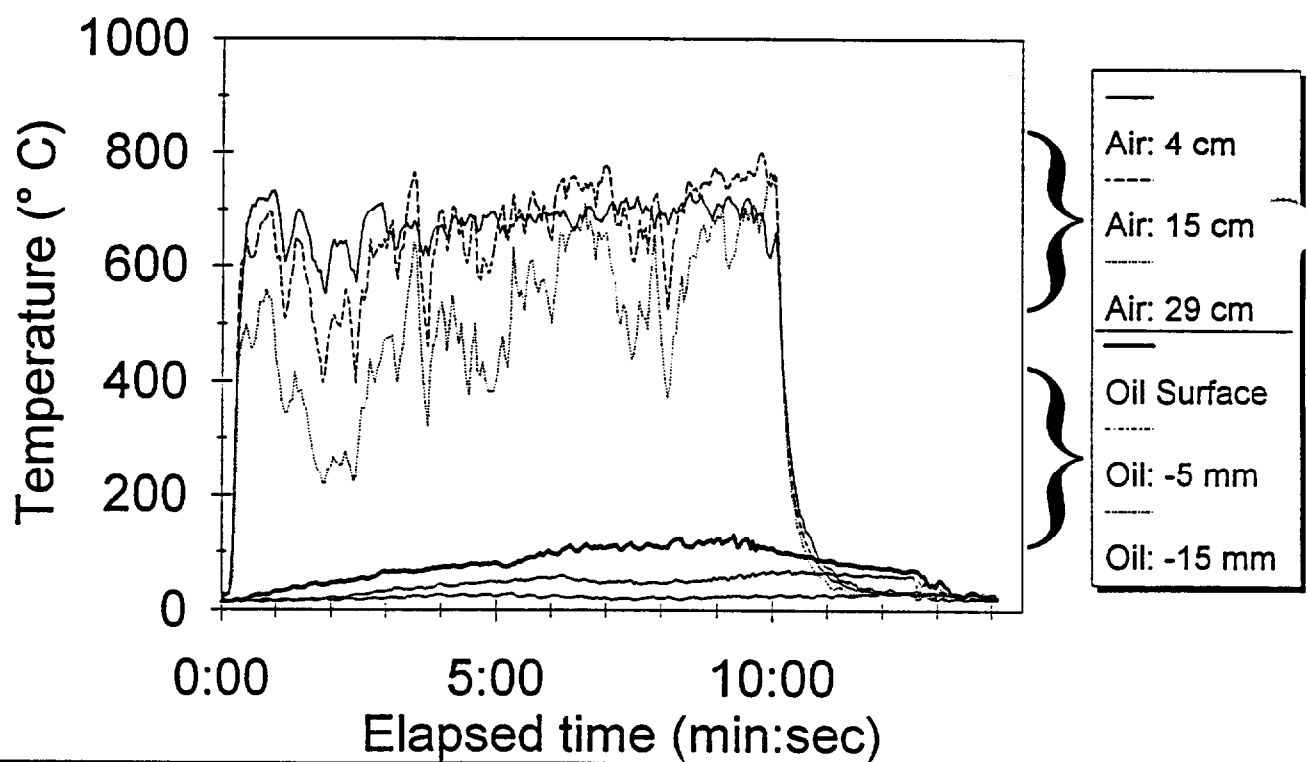
# ACS Burn Experiment # 26

Fresh Endicott; 40% water; 20 mm thick



# ACS Burn Experiment # 27

Fresh Endicott; 60% water; 20 mm thick



## **APPENDIX 5**

### **Outdoor Pan Burn Data**



Weath. log sheet

DATE/ time	HEIGHT (in)	vol (ft^3)	% WTHD	BBLS	GAL	COMMENTS
6/30/94 15:30	12	27.52	0.00%	4.89	205.37	start of process
6/30/94 18:30	10 7/16	24.14	12.29%	4.29	180.13	Shut down, left uncovered for the night
7/1/94 9:00	10 1/4	23.73	13.78%	4.22	177.07	started circulating, air sparger.
7/1/94 14:00	10 1/8	23.45	14.77%	4.17	175.03	left system running
7/2/94 8:00	10	23.18	15.77%	4.12	172.98	
7/2/94 18:30	9 3/4	22.63	17.77%	4.02	168.88	shut system down
7/3/94 7:00	9 3/4	22.63	17.77%	4.02	168.88	started system
7/3/94 11:00	9 9/16	22.22	19.27%	3.95	165.80	shut down and sealed system
7/7/94 9:30	9 9/16	22.22	19.27%	3.95	165.80	restarted to take it to 25%
7/7/94 18:00	9 1/2	22.08	19.77%	3.92	164.77	stop
7/9/94 8:00	9 1/2	22.08	19.77%	3.92	164.77	start
7/9/94 16:30	9 3/8	21.80	20.77%	3.87	162.71	stop
7/10/94 14:30	9 3/8	21.80	20.77%	3.87	162.71	start
7/11/94 7:30	9 1/4	21.53	21.78%	3.82	160.65	ran all night
7/11/94 18:00	9 1/5	21.39	22.28%	3.80	159.61	
7/12/94 9:00	9	20.97	23.79%	3.73	156.51	





























# MESO-SCALE BURN TEST WEATHERING PROGRESS CHART

DATE	TIME	COLUMN MEASUREMENT	COLUMN UNITS	CALCULATED VOLUME	VOLUME UNITS	% WEATHERING	MEASURED BY
8/25/94	7:30	38.75	Inches	3,478.44	Gallons	0.00%	M. Hummel
8/26/94	9:00 AM	36.85	Inches	3,307.89	Gallons	4.90%	M. Hummel
8/27/94	8:00AM	36	Inches	3,231.58	Gallons	7.10%	C. Newnam
8/28/94	7:15AM	35.4	Inches	3,177.72	Gallons	8.65%	C. Newnam
8/29/94	10:00AM	35.3	Inches	3,168.75	Gallons	8.90%	M. Hummel
8/30/94	8:00AM	35.2	Inches	3,159.77	Gallons	9.16%	J. Hanover
8/31/94	7:30AM	35	Inches	3,141.82	Gallons	9.68%	J. Hanover
9/1/94	7:30AM	34.85	Inches	3,128.35	Gallons	10.06%	J. Hanover
9/2/94	10:15AM	34.75	Inches	3,119.38	Gallons	10.32%	J. Hanover
9/3/94	7:30AM	34.4	Inches	3,087.96	Gallons	11.23%	J. Hanover
9/4/94*	7:00AM	34.2	Inches	3,070.01	Gallons	11.74%	J. Hanover
9/5/94	6:30AM	33.5	Inches	3,007.17	Gallons	13.55%	J. Hanover
9/5/94	5:15PM	33.25	Inches	2,984.73	Gallons	14.19%	N. Glover
9/6/94	6:00 AM	33	Inches	2,962.29	Gallons	14.84%	J. Hanover
9/7/94	3:00 PM	32	Inches	2,872.52	Gallons	17.42%	N. Glover

*oil cooling*

\* Heat was added on this date through the steam tracing built into the tank. No fluid temperatures were recorded.

Standards: • The test tank measures 12'0" x 12'0"

- % weathering by volume calculated by the decrease in oil column height in the test tank
- Gallon measurement is US gallons
- 231 cu. in. per gallon

Lab No: see below

**Source: Bruce McKenzie**

[illegible]

**Comment:** -0493 sent to Huffman Laboratories for analysis. The sample was centrifuged to remove most of the water. Karl Fisher % water = 1.18%

**Distribution:** Bruce McKenzie(ACS fax-907-345-2435  
lab file

**Analyst: BW**

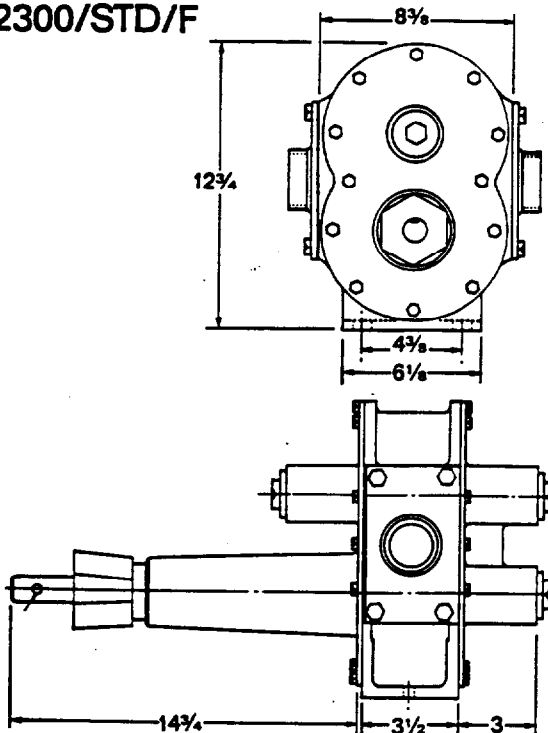
**Date:** 11/3/94

# APPLICATION DATA

Bowie Series 300 Pumps are designed for General Purpose use and are widely used for transfer of fluids. Used extensively on oil tank trucks, transports.

Rotation in either direction. Furnished in 2" or 3" sizes. Pumps straight through. Pumps high viscosity fluids. Designed for trouble-free operation under a wide range of temperature conditions.

2300/STD/F

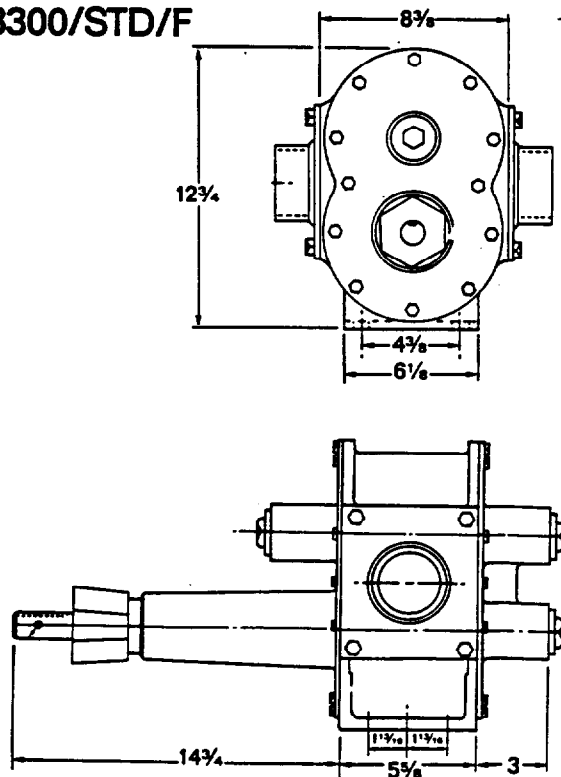


## SERIES 300 SIZE: 2 INCH

### BOWIE PUMP RATINGS FOR 2" PUMP SIZES FLUID KEROSENE

Pump RPM	Temperature of Fluid °F	Discharge Pressure	Capacity GPM	Brake Horsepower
190	147	6	68.5	.83
190	147	10	67.0	1.0
190	147	30	60.0	1.9
190	147	50	55.8	2.7
190	146	70	53.0	3.6
190	146	100	50.0	4.7
280	146	10	99.0	1.8
280	146	30	95.0	3.1
280	146	50	89.0	4.3
280	146	70	86.0	5.6
280	146	100	83.0	7.5
420	146	20	147.0	4.3
420	146	40	144.0	3.9
420	147	60	139.0	8.4
420	147	80	136.0	10.3
420	147	100	133.0	12.2

3300/STD/F



## SERIES 300 SIZE: 3 INCH

### BOWIE PUMP RATINGS FOR 3" PUMP SIZES FLUID KEROSENE

Pump RPM	Discharge Pressure	Capacity GPM	Brake Horsepower
190	6	101	1.1
190	10	99	1.3
190	30	89	2.5
190	50	83	3.6
190	70	78	4.8
190	100	74	6.3
280	10	147	2.4
280	30	141	4.1
280	50	132	5.7
280	70	127	7.5
280	100	123	9.9
400	10	233	5.2
400	20	218	5.7
400	40	213	8.6
400	60	206	11.2
400	80	201	13.7
400	100	197	16.2

**BOWIE INDUSTRIES, INC.**

1004 E. WISE • P.O. BOX 931 • BOWIE, TEXAS 76230

Telephone: 1-800-433-0934 • In Texas: 1-817-872-1106







## **APPENDIX 6**

### **Meso-Scale Burn Data**



## Crude Used

Test #	Date	Volume Crude Used In Ignititors (gal)	Weathered Crude Used (gal)	Total Volume Crude Used (gal)
IGN #1	14/7/94	0.000	0.000	0.000
IGN #2	14/7/94	0.000	0.000	0.000
IGN #3	14/7/94	0.000	0.000	0.000
IGN #4	14/7/94	1.000	0.000	1.000
IGN #5	15/7/94	0.000	0.000	0.000
IGN #6	15/7/94	2.000	0.000	2.000
IGN #7	15/7/94	1.000	0.000	1.000
IGN #8	15/7/94	0.000	0.000	0.000
IGN #9	15/7/94	0.000	0.000	0.000
IGN #10	15/7/94	1.000	0.000	1.000
BURN #1	15/7/94	0.066	3.500	3.566
BURN #2	15/7/94	0.132	3.500	3.632
BURN #3	15/7/94	0.730	3.500	4.230
BURN #4	16/7/94	0.260	3.500	3.760
BURN #5	16/7/94	0.260	3.500	3.760
BURN #6	16/7/94	0.130	3.500	3.630
BURN #7	16/7/94	0.260	3.500	3.760
BURN #8	17/7/94	0.260	17.500	17.760
BURN #9	17/7/94	3.120	17.500	20.620
BURN #10	18/7/94	3.120	17.500	20.620
BURN #11	18/7/94	0.260	3.500	3.760
Total		13.598	80.500	94.098

## Crude Used

Test #	Date	Volume Crude Used In Ignititors (L)	Weathered Crude Used (L)	Total Volume Crude Used (L)
IGN #1	14/7/94	0.000	0.000	0.000
IGN #2	14/7/94	0.000	0.000	0.000
IGN #3	14/7/94	0.000	0.000	0.000
IGN #4	14/7/94	3.785	0.000	3.785
IGN #5	15/7/94	0.000	0.000	0.000
IGN #6	15/7/94	7.570	0.000	7.570
IGN #7	15/7/94	3.785	0.000	3.785
IGN #8	15/7/94	0.000	0.000	0.000
IGN #9	15/7/94	0.000	0.000	0.000
IGN #10	15/7/94	3.785	0.000	3.785
BURN #1	15/7/94	0.250	13.248	13.497
BURN #2	15/7/94	0.500	13.248	13.747
BURN #3	15/7/94	2.763	13.248	16.011
BURN #4	16/7/94	0.984	13.248	14.232
BURN #5	16/7/94	0.984	13.248	14.232
BURN #6	16/7/94	0.492	13.248	13.740
BURN #7	16/7/94	0.984	13.248	14.232
BURN #8	17/7/94	0.984	66.238	67.222
BURN #9	17/7/94	11.809	66.238	78.047
BURN #10	18/7/94	11.809	66.238	78.047
BURN #11	18/7/94	0.984	13.248	14.232
Total		51.468	304.693	356.161

# Burn Control Sheet

Run #	Date	Time	Volume (L)	Water (L)	Ratio	Evaporation	Water Temp (°C)	Wind (km/h)	Wind (km/h)	Post-Burn	MP Temp (°C)	Wind (km/h)	Wind (km/h)	Residue Weight (g)	Comments
1	15-Jun	1405	1.85	13.25	12.5	0.75	13.84	18.72	8.5-12.8	8.5	21.11	8.5-12.8	8.5	0.115	collected per 12.5% emission
2	15-Jun		4.43	13.25	25	75	18.27	21.85	8.5						
3	15-Jun	1500	8.82	13.25	40	60	18.85	18.81	12.8-14.4					0.445	added 27 ml EXO B4 by pipette, stirred for 5 min
4	15-Jun	1600	8.82	13.25	40	60	19.06	12.89	12.8					0.458	added 27 ml EXO B4 by pipette, stirred for 5 min
5	15-Jun	1600	13.25	13.25	50	50	21.80	17.39	16+					0.455	added 27 ml EXO B4 by pipette, stirred for 5 min
6	15-Jun	1630	18.87	13.25	60	40	31.85	15.72	30.4-33.6					0.455	added 27 ml EXO B4 by pipette, stirred for 5 min
7	15-Jun		8.82	13.25	40	60	20.74	15.00	27.2					0.455	added 27 ml EXO B4 by pipette, stirred for 5 min
8	17-Jun	1245	22.07	66.24	25	75	31.82	8.28	30.4-33.6					14.18	added 27 ml EXO B4 by pipette, stirred for 5 min
9	17-Jun		23.81	66.24	40	60	110.52	10.56	38.4-51.2					4.26	added 27 ml EXO B4 by pipette, stirred for 5 min
10	18-Jun		66.54	66.24	60	40	165.78	8.89	25.8					1.28	added 27 ml EXO B4 by pipette, stirred for 5 min
11	18-Jun	1422	24.86	13.25	65	35	37.85		4.4-4					42	added 27 ml EXO B4 by pipette, stirred for 5 min

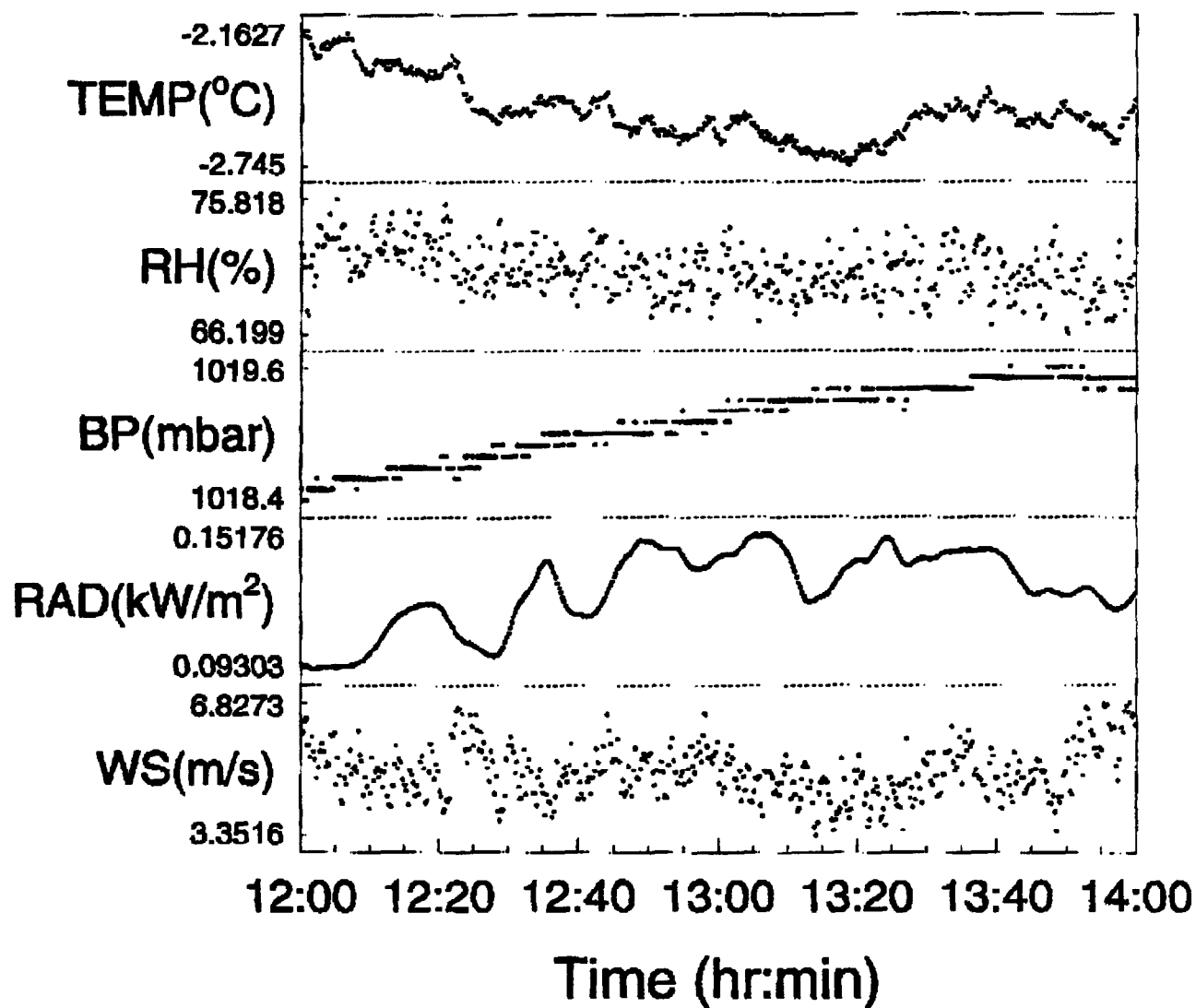
Legend  
 PC - gas + crude  
 PC - gas + gas  
 PC - gas + diesel  
 LHM - not measured



U.S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NATIONAL WEATHER SERVICE										STATION <b>PRUDHOE BAY, ALASKA</b>	
SURFACE WEATHER OBSERVATIONS (Abridged for use at designated Civil Stations)										DATE <b>July 18, 1994</b>	
MF 1-10C 10.001 10.002 10.003 10.004 10.005 10.006 10.007 10.008 10.009 10.010 10.011 10.012 10.013 10.014 10.015 10.016 10.017 10.018 10.019 10.020 10.021 10.022 10.023 10.024 10.025 10.026 10.027 10.028 10.029 10.030 10.031 10.032 10.033 10.034 10.035 10.036 10.037 10.038 10.039 10.040 10.041 10.042 10.043 10.044 10.045 10.046 10.047 10.048 10.049 10.050 10.051 10.052 10.053 10.054 10.055 10.056 10.057 10.058 10.059 10.060 10.061 10.062 10.063 10.064 10.065 10.066 10.067 10.068 10.069 10.070 10.071 10.072 10.073 10.074 10.075 10.076 10.077 10.078 10.079 10.080 10.081 10.082 10.083 10.084 10.085 10.086 10.087 10.088 10.089 10.090 10.091 10.092 10.093 10.094 10.095 10.096 10.097 10.098 10.099 10.100 10.101 10.102 10.103 10.104 10.105 10.106 10.107 10.108 10.109 10.110 10.111 10.112 10.113 10.114 10.115 10.116 10.117 10.118 10.119 10.120 10.121 10.122 10.123 10.124 10.125 10.126 10.127 10.128 10.129 10.130 10.131 10.132 10.133 10.134 10.135 10.136 10.137 10.138 10.139 10.140 10.141 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10.571 10.572 10.573 10.574 10.575 10.576 10.577 10.578 10.579 10.580 10.581 10.582 10.583 10.584 10.585 10.586 10.587 10.588 10.589 10.590 10.591 10.592 10.593 10.594 10.595 10.596 10.597 10.598 10.599 10.600 10.601 10.602 10.603 10.604 10.605 10.606 10.607 10.608 10.609 10.610 10.611 10.612 10.613 10.614 10.615 10.616 10.617 10.618 10.619 10.620 10.621 10.622 10.623 10.624 10.625 10.626 10.627 10.628 10.629 10.630 10.631 10.632 10.633 10.634 10.635 10.636 10.637 10.638 10.639 10.640 10.641 10.642 10.643 10.644 10.645 10.646 10.647 10.648 10.649 10.650 10.651 10.652 10.653 10.654 10.655 10.656 10.657 10.658 10.659 10.660 10.661 10.662 10.663 10.664 10.665 10.666 10.667 10.668 10.669 10.670 10.671 10.672 10.673 10.674 10.675 10.676 10.677 10.678 10.679 10.680 10.681 10.682 10.683 10.684 10.685 10.686 10.687 10.688 10.689 10.690 10.691 10.692 10.693 10.694 10.695 10.696 10.697 10.698 10.699 10.700 10.701 10.702 10.703 10.704 10.705 10.706 10.707 10.708 10.709 10.710 10.711 10.712 10.713 10.714 10.715 10.716 10.717 10.718 10.719 10.720 10.721 10.722 10.723 10.724 10.725 10.726 10.727 10.728 10.729 10.730 10.731 10.732 10.733 10.734 10.735 10.736 10.737 10.738 10.739 10.740 10.741 10.742 10.743 10.744 10.745 10.746 10.747 10.748 10.749 10.750 10.751 10.752 10.753 10.754 10.755 10.756 10.757 10.758 10.759 10.760 10.761 10.762 10.763 10.764 10.765 10.766 10.767 10.768 10.769 10.770 10.771 10.772 10.773 10.774 10.775 10.776 10.777 10.778 10.779 10.780 10.781 10.782 10.783 10.784 10.785 10.786 10.787 10.788 10.789 10.790 10.791 10.792 10.793 10.794 10.795 10.796 10.797 10.798 10.799 10.800 10.801 10.802 10.803 10.804 10.805 10.806 10.807 10.808 10.809 10.810 10.811 10.812 10.813 10.814 10.815 10.816 10.817 10.818 10.819 10.820 10.821 10.822 10.823 10.824 10.825 10.826 10.827 10.828 10.829 10.830 10.831 10.832 10.833 10.834 10.835 10.836 10.837 10.838 10.839 10.840 10.841 10.842 10.843 10.844 10.845 10.846 10.847 10.848 10.849 10.850 10.851 10.852 10.853 10.854 10.855 10.856 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11.000 11.001 11.002 11.003 11.004 11.005 11.006 11.007 11.008 11.009 11.010 11.011 11.012 11.013 11.014 11.015 11.016 11.017 11.018 11.019 11.020 11.021 11.022 11.023 11.024 11.025 11.026 11.027 11.028 11.029 11.030 11.031 11.032 11.033 11.034 11.035 11.036 11.037 11.038 11.039 11.040 11.041 11.042 11.043 11.044 11.045 11.046 11.047 11.048 11.049 11.050 11.051 11.052 11.053 11.054 11.055 11.056 11.057 11.058 11.059 11.060 11.061 11.062 11.063 11.064 11.065 11.066 11.067 11.068 11.069 11.070 11.071 11.072 11.073 11.074 11.075 11.076 11.077 11.078 11.079 11.080 11.081 11.082 11.083 11.084 11.085 11.086 11.087 11.088 11.089 11.090 11.091 11.092 11.093 11.094 11.095 11.096 11.097 11.098 11.099 11.100 11.101 11.102 11.103 11.104 11.105 11.106 11.107 11.108 11.109 11.110 11.111 11.112 11.113 11.114 11.115 11.116 11.117 11.118 11.119 11.120 11.121 11.122 11.123 11.124 11.125 11.126 11.127 11.128 11.129 11.130 11.131 11.132 11.133 11.134 11.135 11.136 11.137 11.138 11.139 11.140 11.141 11.142 11.143 11.144 11.145 11.146 11.147 11.148 11.149 11.150 11.151 11.152 11.153 11.154 11.155 11.156 11.157 11.158 11.159 11.160 11.161 11.162 11.163 11.164 11.165 11.166 11.167 11.168 11.169 11.170 11.171 11.172 11.173 11.174 11.175 11.176 11.177 11.178 11.179 11.180 11.181 11.182 11.183 11.184 11.185 11.186 11.187 11.188 11.189 11.190 11.191 11.192 11.193 11.194 11.195 11.196 11.197 11.198 11.199 11.200 11.201 11.202 11.203 11.204 11.205 11.206 11.207 11.208 11.209 11.210 11.211 11.212 11.213 11.214 11.215 11.216 11.217 11.218 11.219 11.220 11.221 11.222 11.223 11.224 11.225 11.226 11.227 11.228 11.229 11.230 11.231 11.232 11.233 11.234 11.235 11.236 11.237 11.238 11.239 11.240 11.241 11.242 11.243 11.244 11.245 11.246 11.247 11.248 11.249 11.250 11.251 11.252 11.253 11.254 11.255 11.256 11.257 11.258 11.259 11.260 11.261 11.262 11.263 11.264 11.265 11.266 11.267 11.268 11.269 11.270 11.271 11.272 11.273 11.274 11.275 11.276 11.277 11.278 11.279 11.280 11.281 11.282 11.283 11.284 11.285 11.286 11.287 11.288 11.289 11.290 11.291 11.292 11.293 11.294 11.295 11.296 11.297 11.298 11.299 11.300 11.301 11.302 11.303 11.304 11.305 11.306 11.307 11.308 11.309 11.310 11.311 11.312 11.313 11.314 11.315 11.316 11.317 11.318 11.319 11.320 11.321 11.322 11.323 11.324 11.325 11.326 11.327 11.328 11.329 11.330 11.331 11.332 11.333 11.334 11.335 11.336 11.337 11.338 11.339 11.340 11.341 11.342 11.343 11.344 11.345 11.346 11.347 11.348 11.349 11.350 11.351 11.352 11.353 11.354 11.355 11.356 11.357 11.358 11.359 11.360 11.361 11.362 11.363 11.364 11.365 11.366 11.367 11.368 11.369 11.370 11.371 11.372 11.373 11.374 11.375 11.376 11.377 11.378 11.379 11.380 11.381 11.382 11.383 11.384 11.385 11.386 11.387 11.388 11.389 11.390 11.391 11.392 11.393 11.394 11.395 11.396 11.397 11.398 11.399 11.400 11.401 11.402 11.403 11.404 11.405 11.406 11.407 11.408 11.409 11.410 11.411 11.412 11.413 11.414 11.415 11.416 11.417 11.418 11.419 11.420 11.421 11.422 11.423 11.424 11.425 11.426 11.427 11.428 11.429 11.430 11.431 11.432 11.433 11.434 11.435 11.436 11.437 11.438 11.439 11.440 11.441 11.442 11.443 11.444 11.445 11.446 11.447 11.448 11.449 11.450 11.451 11.452 11.453 11.454 11.455 11.456 11.457 11.458 11.459 11.460 11.461 11.462 11.463 11.464 11.465 11.466 11.467 11.468 11.469 11.470 11.471 11.472 11.473 11.474 11.475 11.476 11.477 11.478 11.479 11.480 11.481 11.482 11.483 11.484 11.485 11.486 11.487 11.488 11.489 11.490 11.491 11.492 11.493 11.494 11.495 11.496 11.497 11.498 11.499 11.500 11.501 11.502 11.503 11.504 11.505 11.506 11.507 11.508 11.509 11.510 11.511 11.512 11.513 11.514 11.515 11.516 11.517 11.518 11.519 11.520 11.521 11.522 11.523 11.524 11.5											

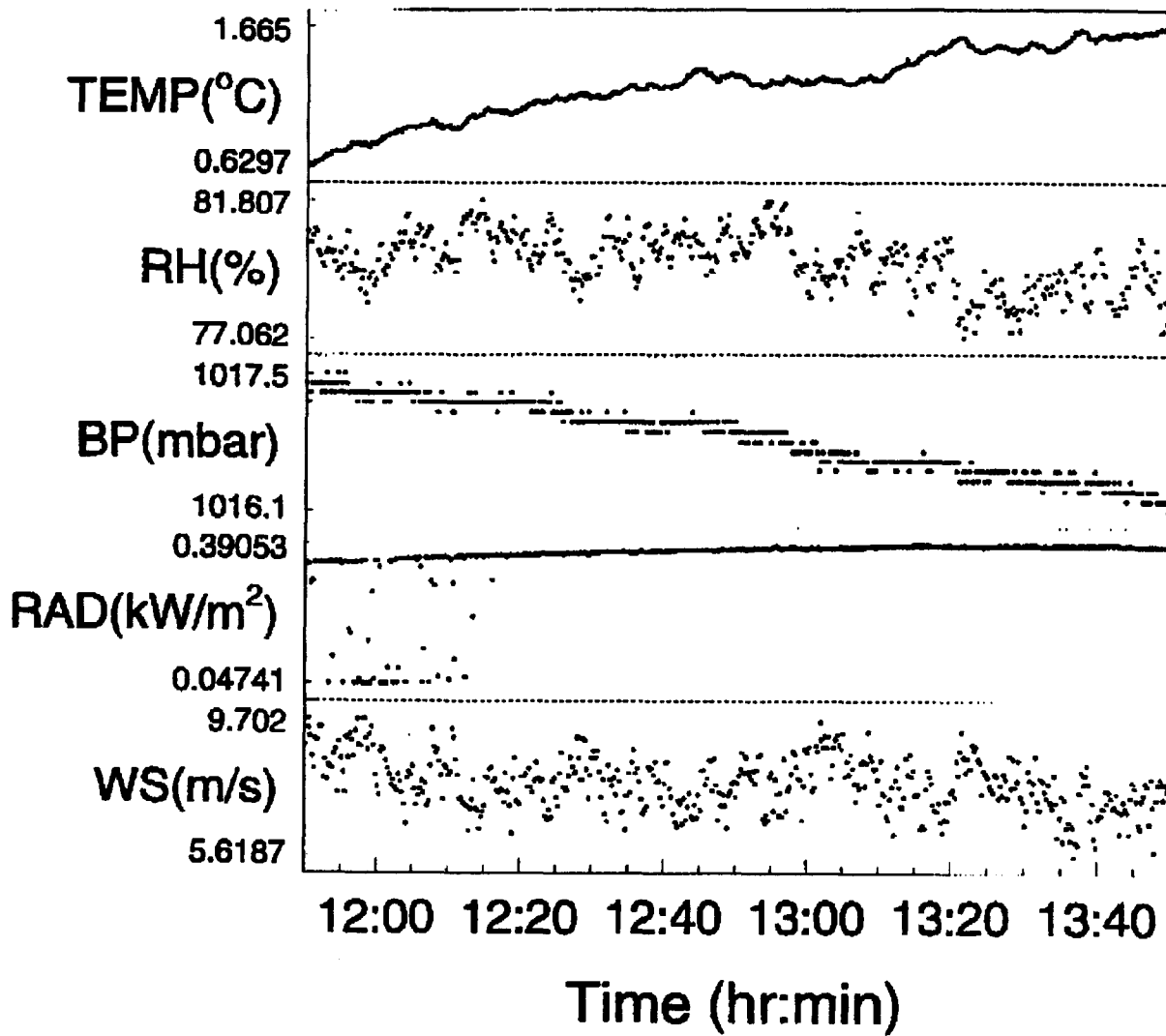


## Weather Station 9/8/94





## Weather Station 9/10/94



## Weather Station 9/11/94

