Environmental
Studies
Research
Funds

074

# Removal of Stranded Oil from Remote Beaches by In-Situ Combustion

Canadä

March 1987

Environmental Studies Research Funds

Report No. 074

March 1987

# REMOVAL OF STRANDED OIL FROM REMOTE BEACHES BY IN-SITU COMBUSTION

John A. Bennett
Ian R. McAllister
Lawrence Pertile
Dan McQuillan

Bennett Environmental Consultants Ltd.

Suite 200, 1130 West Pender Street

Vancouver, British Columbia

Canada V6E 4A4

Scientific Adviser: H. Whittaker

The correct citation for this report is:
Bennett, J., I.R. McAllister, L. Pertile, and D. McQuillan. 1987. Removal of stranded oil from remote beaches by in-situ combustion. Environmental Studies Research Funds Report No.074. Ottawa 122p.

Published under the auspices
of the Environmental Studies
Research Funds
ISBN 0-920783-73-2

## TABLE OF CONTENTS

PHASE II: EVALUATION AND FULL-SCALE DESIGN

## LIST OF FIGURES

## LIST OF TABLES

Page

TABLE

## LIST OF PHOTOGRAPHS

Page

PHOTO NO.

PHOTO NO. (continued)

Page

# APPENDICES

# SUMMARY

The first part of this report describes the development and testing of the prototype of a burner which was designed to remove stranded oil from a beach. An impinging flame that vaporizes and ignites the stranded oil is contained within a combustion chamber, which maintains temperature and enhances clean burning. The test results show that even small amounts of oil on coarse gravel beaches, as well as on sand, can be removed at efficiencies of up to 95%. The cost effectiveness of using this technique is shown to be about 36% of the cost of traditional manual clean-up, and greater for mechanical beach-cleaning methods. The use of this technique results in significantly less beach disturbance, thus allowing a quicker return to its natural state.

The second part of this report covers the design of a full-scale Beach Burner. The use of the factory standard Kubota KH-35 Excavator provides a suitable transport vehicle.

The combustion chamber is supported from the side of this light industrial vehicle. There also is an equipment support trailer which is towed by the excavator. All the system components have been selected for their light-weight, making them easily transported by 65% of the helicopters surveyed.

The cost of equipment to convert this unit into a Beach Burner is quoted.

With the completion of the development of the prototype and the design of the full-scale Beach Burner, it is recommended to proceed with its construction.

## RESUME

La première partie de ce rapport décrit la mise au point et à l'essai du prototype d'un brûleur conçu pour enlever le pétrole répandu sur une plage. La flamme qui, entrant en contact avec la plage, carbure le pétrole répandu et y met le feu, est contenue dans une chambre de combustion qui maintient la température et assure une flamme plus efficace. Les résultats des essais indiquent que même de petites quantités de pétrole répandues sur des plages de gros gravier ou sur des plages de sable peuvent être enlevées avec une efficacité allant jusqu'à 95 %. On montre que cette technique est à peu près 36% plus rentable que les méthodes traditionnelles d'épuration manuelle et encore plus rentable que les techniques mécaniques. L'utilisation de cette technique réduit considérablement les perturbations de la plage, lui permettant ainsi de regagner plus rapidement son état naturel.

La deuxième partie de ce rapport est consacré au design d'un "Beach Burner" grandeur naturelle. L'utilisation de l'excavateur Kubota KH-35, qui satisfait aux normes industrielles, fournit un mode de transport convenable.

La chambre de combustion est suspendue au côté de ce véhicule industriel poids léger. En plus, l'excavateur tire une remorque porte-équipement. Tous les organes du système, choisis en fonction de leur poids léger, peuvent être facilement transportés par 65% des hélicoptères considérés.

On spécifie le coût de l'équipement qui sert à convertir cette unité en "Beach Burner".

La mise au point du prototype et le design du brûleur grandeur naturelle ayant été complétés, on recommande de procéder à la construction du "Beach Burner".

## PHASE I: FEASIBILITY AND PROTOTYPE DEVELOPMENT

### INTRODUCTION

REVIEW

To evaluate the effectiveness of combustion insitu in remote locations, using the Bennett Beach Burner,[1] the classification of oils, beach types, biological effects, and beach clean-up methods were reviewed. The costs of two of the methods were compared using the basic information provided by A. Breuel (1981).

Oil classification considers general toxicity, physical state, and changes with time and weathering. Oils can be divided into four categories (see Appendix A):

Class A: Light, volatile oils
Class B: Non-sticky oils
Class C: Heavy, sticky oils
Class D: Non-fluid oils.

Beaches are classified by substrate into: mud, sand, gravel, cobble, boulder, rock, marine, terrace, and wood or concrete. If more than one substrate is present, the predominant one is listed first (see Appendix B).

Estimation to what degree a beach is contaminated by oil depends on type of oil, beach substrate, and the existing tidal and wave conditions.

Usually oil washes ashore in patches and streaks, and only during extremely heavy contamination does it completely cover a beach. Light oils deposit in a narrow windrow along the high-tide line, with occasional streaks in the mid-tide zone.

[1] Patent applied for.

Oil initially contaminating a beach often remains on the surface for several days. Gradually it penetrates the beach or becomes buried by sediments. Class A oils quickly penetrate a beach, whereas Class B, C and D oils remain on the surface until buried.

Thus the amount of oil on a beach cannot be determined from appearance alone. A sand or gravel beach may appear only slightly contaminated after the majority of oil has penetrated the beach or has been buried.

The persistence of oil on a beach is influenced by a combination of physical properties controlling oil deposition, penetration, and removal. Generally:

- the deeper the oil penetrates or is buried, the more likely the oil will persist;
- the lower the beach energy level, the more likely the oil will persist; and
- the colder the air and water temperatures, the more likely the oil will persist.

Five types of biological effects result from existing techniques for the clean-up of oil:

- removal of biota with the substrate or as a consequence of the clean-up efforts;
- extension of toxic effects because of clean-up induced recontamination;
- habitat disruption by equipment, techniques, or clean-up crews;
- crushing of organisms with manual methods or heavy machinery; and
- disturbance of organisms by the noise and commotion associated with either heavy equipment or large numbers of people or both.

The biological effects of beach sand removal are dependent on the depth and area being removed regardless of the technique used or beach type. With the removal of the upper 3 - 10 cm of the beach, shallow-burrowing organisms are likely to be affected. Repopulation is usually rapid owing to migration from other unaffected areas. Removal of 10 - 25 cm of substrate would remove the majority of biological life on the beach. If this removed substrate were artifically replaced, it could take several seasonal cycles for the beach to become stabilized and repopulated because of the low nutrient content of the new material. The removal of 25 - 50 cm of sediment would deplete the beach of almost all its organisms. Recruitment would be slow and both long-term and short-term effects could be significant. Natural cleaning can have the least overall biological effect of the clean-up options. The actual effects are time-dependent and site-specific and cannot be easily predicted.

Twenty-three techniques for beach clean-up have been identified as being in general use (see Appendix C). The most widely used method for dealing with an oil-contaminated beach is the physical removal of the affected material.

Removal of the substrate can involve many hundreds of people using manual removal techniques or heavy equipment when possible.

Once the material has been scraped and collected from the beach substrate, the oiled material is loaded using front-end loaders, and is transported to a final disposal site with dump and tank trucks. The material is transported to an approved dump site by trucks typically having capacities of 8 - 15 m . Truck beds are usually lined with plastic sheeting to prevent leakage.

The material removed from the beach can be stored in an approved dump site and processed, using incineration, to remove the oily contaminants. New or processed substrate would then be returned to the beach area to allow the type of organisms that inhabited the affected areas to migrate back.

The use of a combustion unit insitu, such as the test unit, is not included within the 23 identified methods.

PROBLEM

The major problem of cleaning oil spills from remote beaches is the lack of availability of personnel and equipment in the immediate area to perform the work. This condition is usually made worse by the lack of support facilities to provide adequate accommodation for the personnel if brought in to the site. This latter condition can effectively eliminate the use of a significant amount of manual cleaning.

The simple remoteness of a location usually means that access is limited, with movement to the spill area being restricted to air or water transportation. Thus to minimize the use of people, heavy equipment must be used. Heavy equipment can be moved efficiently and cost effectively by water, but not quickly. Therefore, a quick response is impossible.

The most effective clean-up must involve light-weight equipment transportable by air, preferably by helicopter, that will remove the stranded oil without affecting the beach. In the case of heavy oiling the use of controlled, open burning insitu can be considered. To complete such burning and to remove lighter oiling or spot oiling, similar techniques using controlled combustion schemes should be considered.

CONCEPT

Bennett Environmental Consultants Ltd. has recently designed and tested a road-transportable rotary incinerator. Designed to clean-up to 10 tonnes of oiled sand per hour and gravel containing 5-10% oil and 20% water. Based on this experience, plus staff experience on the combustion of floating oil insitu, McAllister (1983); it was apparent that incineration was the most effective tool for oil spill disposal. The problems of gathering and transporting material as already described, exacerbated by the problems of remote locations, made the concept of the disposal of the beached oil by combustion insitu appear to be appropriate. The applied energy level would of necessity be quite high so that the applied heat would reach the material interstices and would vaporize the oil. The variation in the quantity of residual water would also have a significant effect.

Experience shows that oil can be removed by the application of an impinging flame. Other experiments have demonstrated that thickly oiled beaches can be reduced in oil volume by ignition in controlled sections, Twardus (1980). Such burns are incomplete because they tend to self extinguish at thin oil layers and may be environmentally unacceptable due to smoke and heat problems. However there remain the problems of the residual oils and thinly spilled oils. The use of open flames, even when impinging, is not advised as although the flame is sufficiently hot to cause vaporization of the oil, the surrounding air and beach remains chilled and combustion of the vaporized oil will be incomplete or non-existent. The Bennett Beach Burner is an open-bottomed combustion chamber fitted with skirts to retain the energy of the burner inside the combustion chamber, thereby ensuring that the energy is delivered to the beach target area. The combustion chamber should be of sufficient size for oxidation of the vaporized gases to be complete, thereby minimizing smoke emission.

## PROPOSAL

As a consequence of the high number of unknown values, a three-phase proposal was presented. In Phase I, the question of the feasibility of the concept and prototype development would be addressed. The feasibility was to be tested and the results quantified in a manner that would establish a relative cost of such operations and their efficiency as opposed to heavy equipment operations. These tests were to include different types of beaches oil types, and conditions. It was anticipated that the testing of the prototype equipment would establish the more efficient operating criteria and thereby assist in the establishment of a basis for equipment selection for Phase II - Evaluation and Full Scale Design. Phase III - Production and Testing of a Full Scale Unit was not included as a component of the original proposal.

# METHODOLOGY

The literature was searched for data from actual reports on oil spills to provide some guidance as to the types, amounts, and thicknesses of oil that should be used in the testing. However, after a significant effort, produced minimal written comment and no usable data, the exercise was terminated. Similarly a literature search to review the effect of flame impingement and the results of variation of angle of impingement produced no useful information.

Subsequent to the literature searches a copy of Oil Spill Cleanup and Protection Techniques for Shorelines and Marshlands (Breuel 1981) was obtained and was used extensively as a reference for the background data. However, the question of the thickness of spilled oil on a beach remains unresolved. Thus, it was accepted that the spill tests would be run using an amount of oil that was perceived to be significant from practical experience.

## PROTOTYPE DESIGN

Initially, two assumptions were made: the width of the test strip of oil would be 30.5 cm (the approximate width of an oiled tide line); and the energy input would be 630,000 kJ/h (the capacity of one foot (30.5 cm) of propane-fueled line burner). With this starting point, a theoretical heat balance was developed that examined the effect of oil thickness, percentage of oil, and combustion efficiency (heat recovered from the oil) in relation to the heat requirements (heat losses), combustion air volume, and combustion products. The heat balance was used to establish:

- combustion chamber volume
- theoretical rate of advance.

## Theoretical Calculations

Calculations written in Pascal were run on an IBM personal computer (IBM PC) to provide a full tabulation of values for oil thicknesses from 1.02 mm to 5.08 mm in increments of 1.02 mm, moisture content of 90% to 0% in increments of 10%, and combustion efficiencies of 0% to 50% in increments of 10%.

The tabulated results of the theoretical calculations for burner design were scrutinized to determine the size limits of the combustion chamber. As a result, it was decided not only that the largest size indicated, about 0.45 m , should be built, but also that the size of the combustion chamber could, in some operating conditions, be half the indicated size. Consequently, the combustion chamber was designed with an adjustable top to provide a variable-volume configuration.

The theoretical rate of advance was found to approach 230 m/h.

## Equipment Selection

As conceived, and as described in the proposal, the heat source was to be a 30-cm, propane-gas-fired line burner with an energy output of 630,000 kJ. Detailed investigation uncovered two discouraging aspects of this selection that terminated its acceptability. First, the available line burners were found to have a relatively short (30 cm) flame and secondly, although providing the requisite flame temperatures, were not likely to provide the flame impingement desired nor the ignition source for the vaporized oil. It was contended by two suppliers of gas equipment that the use of gas-fired, radiant-type burners would be more suitable. To verify this a demonstration using a single gas burner firing along the top of a small, shallow, refractory-lined, combustion chamber was arranged. These preliminary tests showed that the radiant heat raised the oil temperature, reduced its viscosity, and resulted in the oil running into the sand before it could vaporize.

With the equipment modified to bring the flame into an impinging position, subsequent tests were run that demonstrated that flame impingement had an ablating effect. Further information indicated that high use rates of bottled propane could provide severe problems of gas supply because of the lack of energy available to vaporize the propane to gas. In colder temperatures this problem of extraction would become worse. When considering the Canadian climatic conditions and the intent to use this equipment in remote locations, were sought.

The obvious fuel to use was oil, preferably diesel fuel, because of its widespread availability and probable compatability with the mechanical support equipment likely to be used during Phase III of the program. A packaged fuel-oil burner capable of running on diesel fuel was found. This unit comes complete with fuel pump, combustion air blower, and a continuous-spark ignition system. Because it uses liquid fuel, flame safety equipment was not required and consequently its requirement for electric power are less rigorous than those of the equivalent gas burner. The quantity of fuel and flame pattern are adjustable by changing the burner's nozzle size. The usage of natural gas in the test locale, the limited availability of literature, and some nozzle sizes inhibited the equipment design, servicing, and, consequently, test results.

To provide combustion air for the spilled oil it was proposed to introduce secondary air at a location considered to be downstream of the flame impingement area. The calculated volumetric requirements were 428 m /min with a discharge pressure of 13 cm of water column. A blower of the central vacuum system type was found to have the necessary characteristics although few technical data were available. Thus, a used industrial model was acquired on a test-and-exchange basis.

Weight was important in the design criteria, so it was proposed to use flexible rather than castable refractory material. The material selected was Cerwool, manufactured by Combustion Engineering, which was secured in place by mechanical fasteners welded to the inside walls of the combustion chamber box.

After investigation Siltemp, manufactured by Metek - Haveg Division, was selected for a skirting material being flexible and light in weight. Other alternative materials were identified.

## Beach Burner Design

With the equipment selected on the basis of the theoretical design calculations, a general arrangement was drawn (Figure 1). From this base, detailed drawings of the structure were prepared, (Figures 2 and 3). At this point, a digression from the design criteria resulted in the combustion chamber being constructed of mild steel, because it was easier to construct and easier to modify in the field. Because transportion of the prototype and its manual movement on site were not weight sensitive, this modification was appropriate.

## Instrumentation

To measure the varying functions of the beach burner a set of instruments was provided. Because of the lack of secure shelter on site the instruments selected were simple and portable. The following were used:

| Measured Value | Description |
| --- | --- |
| Fuel flow - | by a calibrated sight tube mounted on the fuel tank. |
| Air flow - | Burner combustion air and auxiliary combustion air volume by timed flow measurement and area mensuration using an air-flow meter. |
| Temperature - | Combustion chamber, discharge stack, and beach temperature using K-type thermocouples mounted in chrome iron sheaths with the temperature being directly indicated on a Fluke digital millivoltmeter fitted with a Data Tech voltage adapter. Each temperature reading was taken by the change to the appropriate thermocouple plug. |

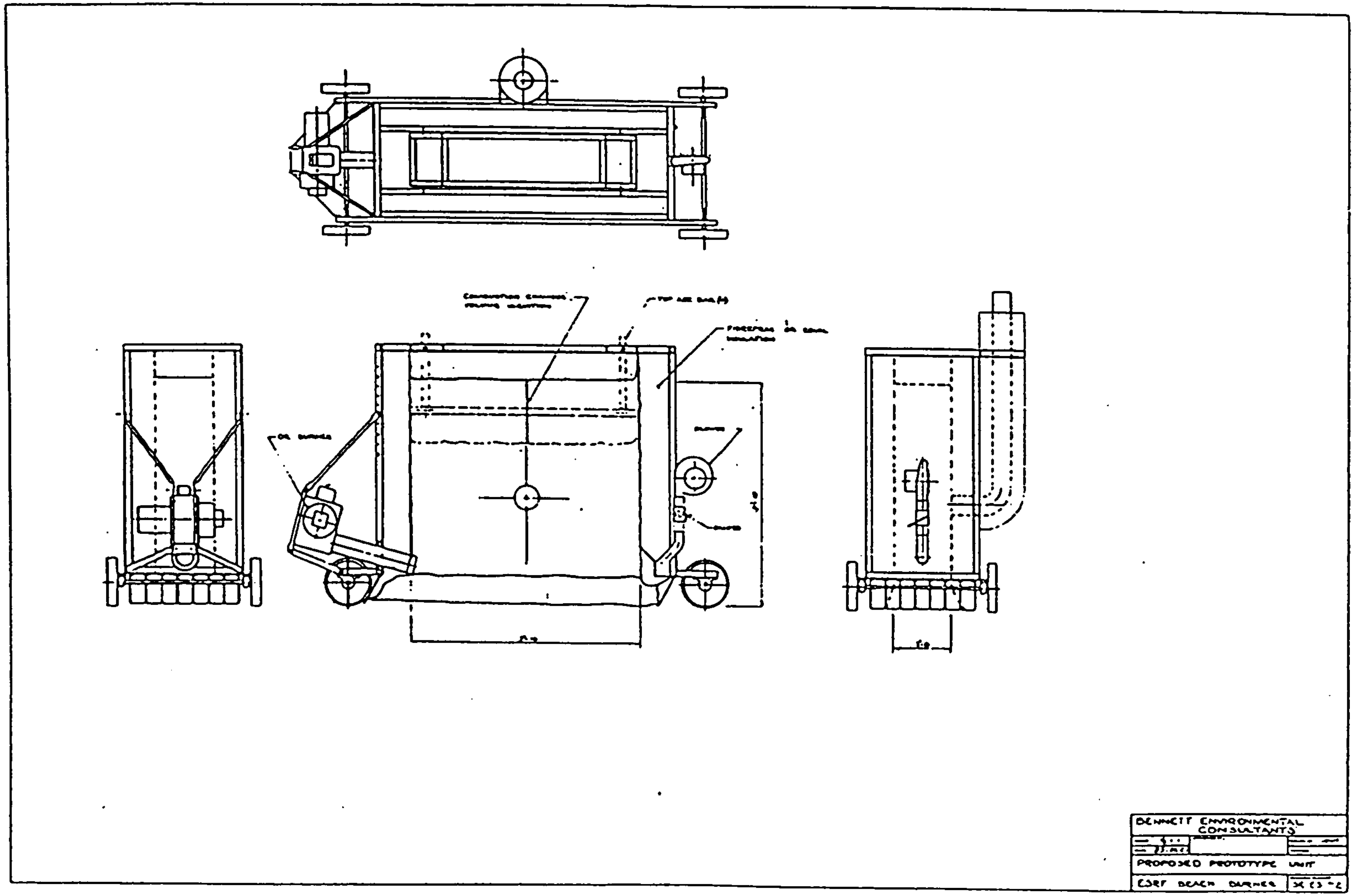



Figure 1. Proposed prototype unit.

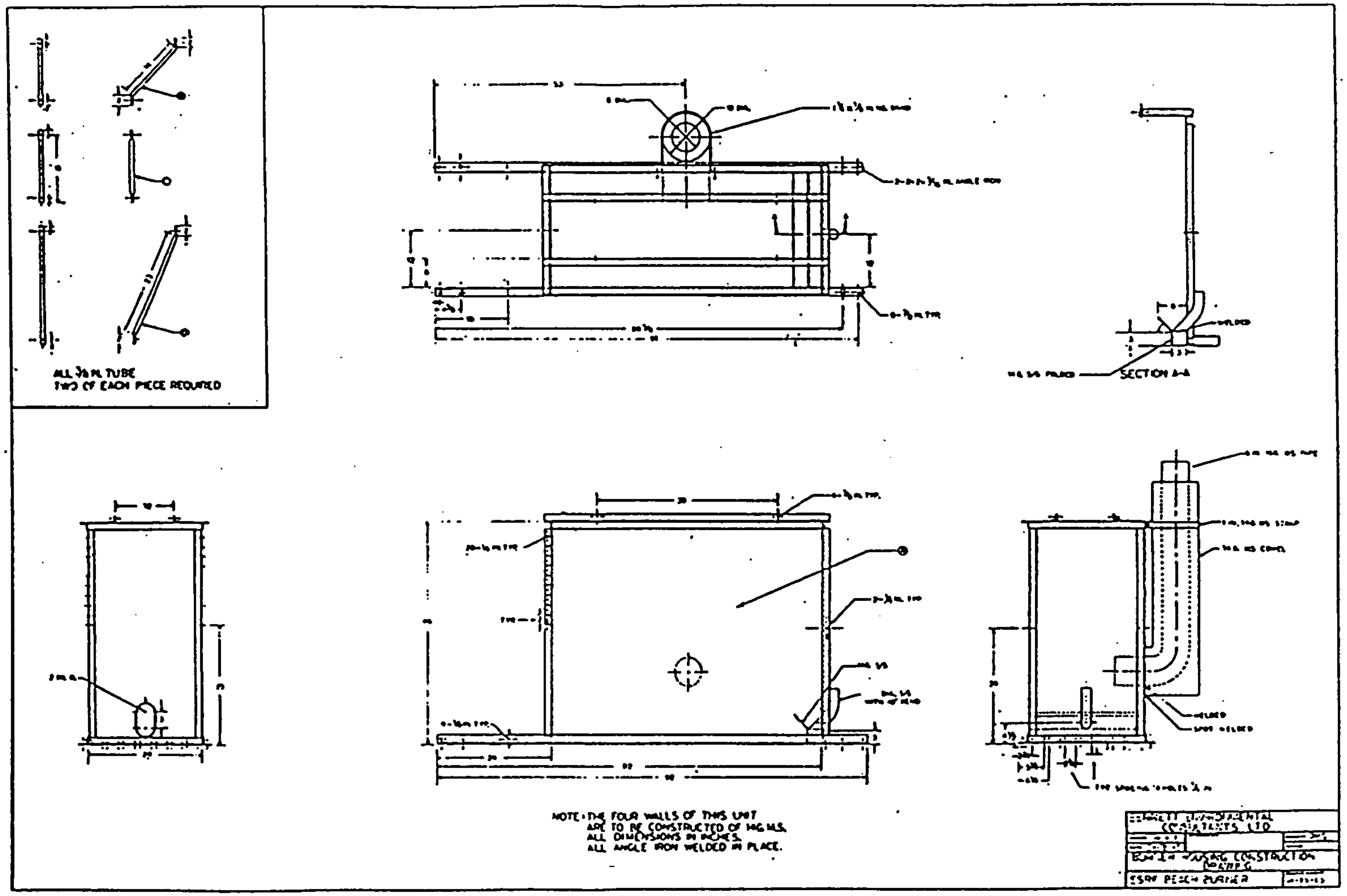



Figure 2 . Burner housing construction drawing.

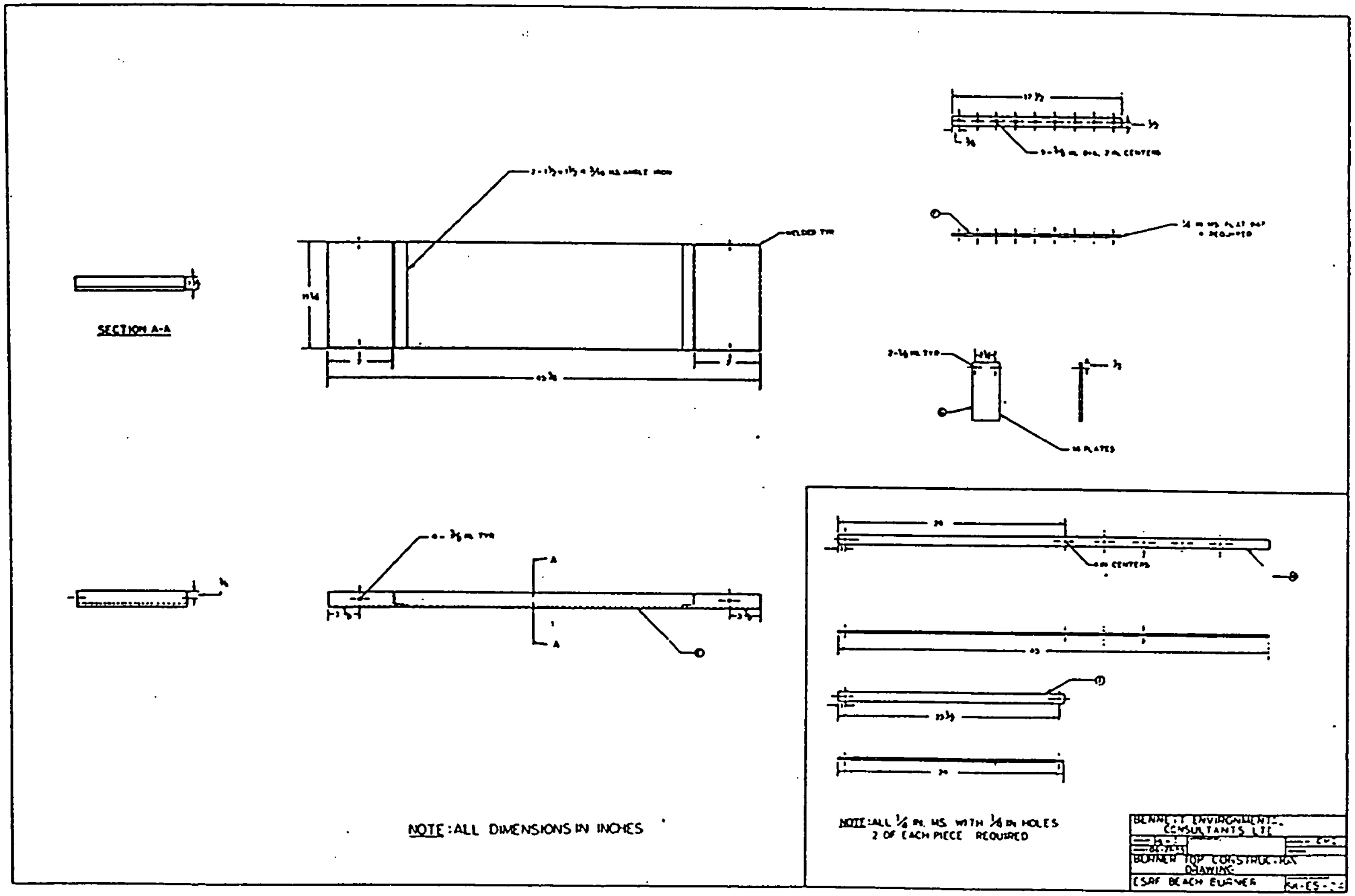



Figure 3 . Burner top construction drawing.

Ambient air temperatures were recorded at the start of each test using a simple thermometer. Beach and combustion chamber exterior temperatures were monitored using a Wahl Heatspy infra-red thermometer.

TEST SITE

Tests were performed in a heavy-equipment yard belonging to the Municipality of West Vancouver. An area removed from the normally travelled portion of the parking lot was set aside for storage of oil and measuring and mixing equipment. Power was supplied for the equipment by a 2.2-kW, portable, Honda generator. Tarpaulins were provided to cover the beach burner, test oils, and waste materials.

To minimize damage to the test site, at the rear of a large, relatively unused, gravelled parking lot, four trays 50 cm wide, 150 cm long, by 15 cm deep were fabricated of steel and were placed end to end providing a test "beach" 6 m long.

The proposal indicated that the beach burner would have particular application to gravel and cobble beaches, in addition to sand beach. Therefore, a selection of materials were provided that permitted the fabrication of "beach-like" test beds;

- sand: a mixed sand of varying grit-size;
- "Navvy Jack": a mixture of crushed rock and sand. The crushed rock provides a flat-faced "gravel" of about 20 mm or smaller with some random pieces up to 50 mm in one dimension;
- drain rock: a round, beach-type gravel of up to 25 mm in diameter, with "fines" being 10 mm in diameter; and
- cobble: a round, beach cobble varying in size from 25 to 100 mm in size with some sand and other gravels. This material was collected from a West Vancouver ocean beach.

To position the prototype beach burner relative to the elevated beach, two sets of channel iron rails, each 9 m long, were mounted on concrete blocks parallel to the beach. This arrangement provided for accurate positioning of the unit over the beach and the excess length provided a clear elevated area for servicing of the skirts and interior inspection.

To provide control over the rate of advance, a light winch was mounted on a saw horse at the slightly uphill end of the track. A light, 3-mm steel, aircraft cable was used for a tow line (Photo Nos. 1a, 1b).

To increase the level of the water table in the beach, water was added by a fire truck and was topped up from a 20-L container.

## TEST PROGRAM

The tests, made between 8 August and 10 October 1986 are of two types; equipment calibration and performance testing. Appendix D lists all the tests performed.

### Equipment Calibration

<u>Fuel Use</u>. The prototype beach burner was fitted with a 20-L military-type fuel can that was retrofitted with a 12-mm diameter, plastic, sight tube. The direct measurement of the fuel into previously calibrated containers established the relationship between the level change and the volume change. The relationship was 2 cm of height change in the sight tube equaled 1-L of fuel.

<u>Combustion Air</u>. The package burner blower was enclosed using cardboard and duct tape in a manner that permitted the free flow of air to the blower air intake. The square opening, thus formed, was measured and air flow was established using the anemometer and stop-watch. The repeated test provided an air flow of 300 m /h.

Photo No.1a - Test site.

Photo No.1b - Test Site.

Auxiliary Air. The auxiliary air flow was controlled by a ball valve turning through 90 degrees from full open to close. A position-indicating plate divided in 10-degree segments and a pointer were installed prior to flow measurement to provide positional recording. An intake cone was installed to provide a measurable velocity for the anemometer. The velocity was measured using the anemometer and stop-watch technique. During the performance testing auxiliary air flow was determined (see Appendix E).

Secondary Burner Air. After Test # 2 of September 10, the auxiliary air blower was connected directly to the burner unit with the burner blower runner removed. The tests described for the auxiliary air blower were repeated with the supply hose disconnected, connected, and with the burner on. The air flow was found to vary minimally at 570 m /hr.

Performance Testing

To evaluate the performance of the unit, the variable parameters were identified and measured. It was established that only one parameter would be changed at a time if possible, so that the effects of a change be identified. The parameters recorded are listed in Table 1.

One set of measurements taken to quantify the amount of oil removed, inspite of precise recording, were found ultimately to be extremely misleading. To determine the amount of oil removed, two trays 20 x 20 x 5 cm were set into the surface of the beach and were filled with the identical beach material and water table as the beach as a whole. These trays were then weighed to establish a before spill condition; the oil was spilled onto the beach and onto one tray, which was then weighed to measure the oil spilled; and both trays were weighed after the burn was completed. It was conceived that the unoiled tray would act as a control to determine the rate of water loss which could then be subtracted from the loss of the oiled

## TABLE 1

Performance testing parameters

| Observation | Determination | Reason |
|---|---|---|
| **Weight** | | |
| Oiled tray start | | Measured efficiency of oil removal |
| Oiled tray oiled | Oil & water loss | Oil thickness |
| Oiled tray finish | | |
| Control tray start<br>Control tray finish | Water loss | Measured efficiency of oil removal |
| Dispenser tray<br>- Full<br>- Empty | Oil mass spilled | Spill thickness<br>Energy available |
| **Dimension** | | |
| Fuel level - Start<br>- Finish | Fuel used | Energy application rate |
| Spill - Width<br>- Length | Spill Area | Spill thickness<br>Energy available |
| Start point<br>End point | Distance travelled | Rate of advance |
| **Time** | | |
| Burner - On time<br>- Off time | Fuel usage time | Energy application rate |
| Test bed time - On<br>- Off | Travel time | Rate of advance |
| **Visual** | | |
| Smoke emissions | Visual | Combustion efficiency |
| Visual oil removal | Visual assessment | Removal efficiency |
| **Temperature** | | |
| Beach temperature | Thermocouple temp | Heat penetration |
| Stack temperature | Thermocouple temp | Combustion efficiency |
| Box temperature | Thermocouple Temp | Combustion efficiency |

tray. This concept does not work. It appears that the lower vaporization temperature of the water allows a greater loss of water from the control tray, whereas the oil on the oiled tray prevents the water from vaporizing until after the oil is substantially removed. Consequently, the weight loss of the oiled tray at times was less than the control tray. This procedure was abandoned when it was established that it was not accurate.

The accuracy of our oil removal quantification was also affected by the fact that, as the burner passed over the test trays, gravel was heated and fractured. Mass movement resulted either into or out of the scaled test trays. Also the skirts moved gravel either into or out of the trays. These two problems hampered the success of actual oil removal quantification. Because no alternative quantitative measurement system was developed, close visual examination, with photographs, was used to determine the percentage of oil removal and the quality of the burn.

The single largest change in the design concept was initiated as a result of using pure oxygen enrichment in the burner air supply. The oxygen enrichment tests are discussed in the Results section. The effect of the auxiliary air supply as installed caused increased smoke emissions and reduced combustion chamber temperatures. The addition of the oxygen through the oil-burner air-supply tube provided increased combustion chamber temperatures and higher visual removal efficiencies. These improved results indicated that the application of the auxiliary air through the burner might provide a similar improvement. As the burner blower capacity could not be increased it was decided to remove the runner from the burner blower and to deliver the auxiliary air directly to the burner, thus increasing the burner air supply from 305 m /h to 464 m /h.

## TEST PROCEDURE

The test procedure was relatively consistent from test to test. The only significant change in the procedure was made when the use of the test trays was discontinued. At that point, all the operations involving the weight change of the trays were voided because of the inconsistent results. Thereafter steps 2, 3, 6, and 12 were omitted from the procedure and greater attention was paid to evaluating the percentage of visual removal.

Step 1. The test bed was levelled and wetted to simulate a beach surface. At this point a choice of beach surface type was decided upon; sand, gravel, cobble, or combination.

Step 2. Two test trays, 20 cm x 20 cm x 5 cm cake tins, were filled with the beach material and then levelled into the test bed to ensure the consistency of the beach.

Step 3. Both trays were removed from the test bed and weighed on an industrial triple beam balance with results recorded on test data sheets (Figure 4). The mass of each tray was recorded as the pre-spill weight and then replaced in the test bed. Extensive efforts were made to avoid any loss of material from the test trays when moved.

Step 4. A selected quantity and type of oil was weighed in a specially designed oil-spill dispensing container. This container was designed to allow oil to be dispensed in an even manner over the surface of the test bed. The mass of the dispenser was recorded before and after the oil was dispensed to determine the mass of oil spilled.

Step 5. The oil was spread over a pre-determined area of the test bed and over one test tray. The area of the spill was recorded to determine the thickness of the spill.

Step 6. The oiled tray was removed from the test bed and was re-weighed to determine the quantity of oil in the test tray.

Step 7. The ambient, stack, combustion chamber, and beach temperatures were recorded before the generator, burner, and combustion air fan were started.

BEACH BURNER TEST

DATE:________________ WEATHER:______________________________

TEST #:_____ AMBIENT TEMPERATURE:_____ OIL TYPE:________________

BEACH TYPE:____________________________

PURPOSE:________________________________________________________

________________________________________________________________

________________________________________________________________

CHAMBER VOLUME:_________ NOZZLE ANGLE:__________psi

NOZZLE PITCH: _________ NOZZLE SIZE: _____gph______

VOLUME OF SPILL:_______gm______ml AREA OF SPILL:________sq.cm.______

AUXILLARY AIR: Rerouted to supply Burner (30% open at start-up)

| | START | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| | 0 min<br>00 sec | + min<br>sec | + min<br>sec | + min<br>sec | + min<br>sec |
| STACK deg C | | | | | |
| BOX deg C | | | | | |
| BEACH deg C | | | | | |
| CHANGES | | | | | |

| | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|
| | + min<br>sec | + min<br>sec | + min<br>sec | + min<br>sec | + min<br>sec |
| STACK | | | | | |
| BOX | | | | | |
| BEACH | | | | | |
| CHANGES | | | | | |

| | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|
| | + min<br>sec | + min<br>sec | + min<br>sec | + min<br>sec | + min<br>sec |
| STACK | | | | | |
| BOX | | | | | |
| BEACH | | | | | |
| CHANGES | | | | | |

START TIME:_____________________________________________________

FINISH TIME:__________ TIME ELAPSED:__________

| | NO OIL | WITH OIL | AFTER POUR | AFTERBURN | WT. LOSS |
|---|---|---|---|---|---|
| DISPENSER: | ------ | | | --------- | |
| TRAY #1 (oil): | | | ---------- | | |
| TRAY #2 : | | -------- | ---------- | | |

ADVANCE RATE:_________ft/hr TRANSITION TEMP CHANGE:________

FUEL USED:______cm______l FUEL FLOW RATE:________gal/hr ________l/hr

PERCENTAGE OIL REMOVED:________________

COMMENTS:_______________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

Figure 4. Example of beach burner test data sheet.

Step 8. With burner start-up, the timer was started with the temperatures of the chamber, stack, and beach being recorded at one-minute intervals, until the combustion chamber reached a temperature of about 1100 C.

Step 9. From its position short of the test area, the burner was moved to the starting indication mark for the advance rate calculation. The time and temperature were noted and the burner was made to advance across the test area using the hand-operated winch to provide a steady pace. Temperatures continued to be recorded at one-minute intervals, or more frequently if activities allowed.

Step 10. While passing over the spill, subjective notes were made regarding the smoke emissions and the physical conditions of the test bed during, and immediately after, a burn.

Step 11. Upon clearing the test area, the operating time was again recorded, the burner was shut down, and the burner off-time was recorded. The amount of fuel used, as indicated in centimetres on the fuel-tank sight-glass, was recorded.

Step 12. The two test trays were removed from the test bed and were re-weighed. The before and after test weights were used to determine the amount of mass loss per tray. The control tray (non-oiled) was used to determine the water loss from the test bed. This percentage water loss was assumed to be the same from each tray. With this assumption, we calculated the oil loss by removing the water loss from the oiled-tray weight change.

Step 13. Visual observations of the test bed after the burn were noted and the estimated percent of oil removal was used to assess the quality of the burn.

This basic procedure was followed throughout the period of testing, except as noted.

## TEST OILS

To provide an evaluation of the effectiveness of the beach burner on different beach-contaminating oils, the following oils were provided.

| | | |
|---|---|---|
| Class A: | Light volatile oil | - Diesel Oil |
| B: | Non sticky oil | - No. 5 Fuel Oil |
| | | - Alberta Crude Oil |
| C: | Heavy sticky oil | - Bunker C Oil |

No oils that could be described as non-fluid were used, although some of the emulsions developed could be described as such at time of placement on the test beach.

In addition to testing standard oils, it was recognized that emulsified oils could be expected as a beach contaminant. To evaluate the effectiveness of the Beach Burner on oil-water emulsions, a number of tests were performed using both Bunker C and Alberta Crude Oil.

To combine water and oil to form the emulsions, an electrically driven, diesel-fuel, gear pump was used to cycle the mixture.

The oil was placed in a 5-gallon container and mixed with a predetermined quantity of water. The gear pump was set up with both the input and the output end of the pump hoses inserted into the mixing container. This allowed the oil and water mix to circulate from the mixing container through the pump and to return to the container. The pump was operated for about 30 to 45 minutes or until the pump stalled.

This method of emulsifying oil worked well. It was found that the most stable oil to water ratio was 30% oil to 70% water. This emulsion was a mousse for up to one week.

## OXYGEN ENRICHMENT

To improve combustion, it was suggested by a Canadian Liquid Air engineer that we consider the addition of pure oxygen to the combustion chamber. Oxygen enrichment has been used in other applications, including lime kilns, to increase flame temperature and to improve efficiency. Although not part of our original proposal, the concept was considered to have sufficient merit to be worthy of examination.

To modify the burner to allow oxygen injection, the air delivery tube on the oil burner was fitted with a half coupling through which a copper tube, crimped to form a high-velocity injection nozzle was inserted (Figure 5).

The equipment arrangement (Photos No. 3, and 4), show the flow control, metering train, and delivery system respectively. Special installation requirements were required including the washing of all components in perchlorethylene to ensure freedom from oil contamination which could result in spontaneous combustion. This cleaning was carried out on all air-flow passages of the oil burner.

Tests from 27 August (#1) through 10 September (#2) were run using the oxygen enrichment procedure using varying oxygen enrichment flow rates.

## EQUIPMENT REVISION

During the tests a number of equipment revisions were made. Most of these revisions were as a result of the desire to increase the appearance of cleaning the beach. All had a direct relation to the combustion process.

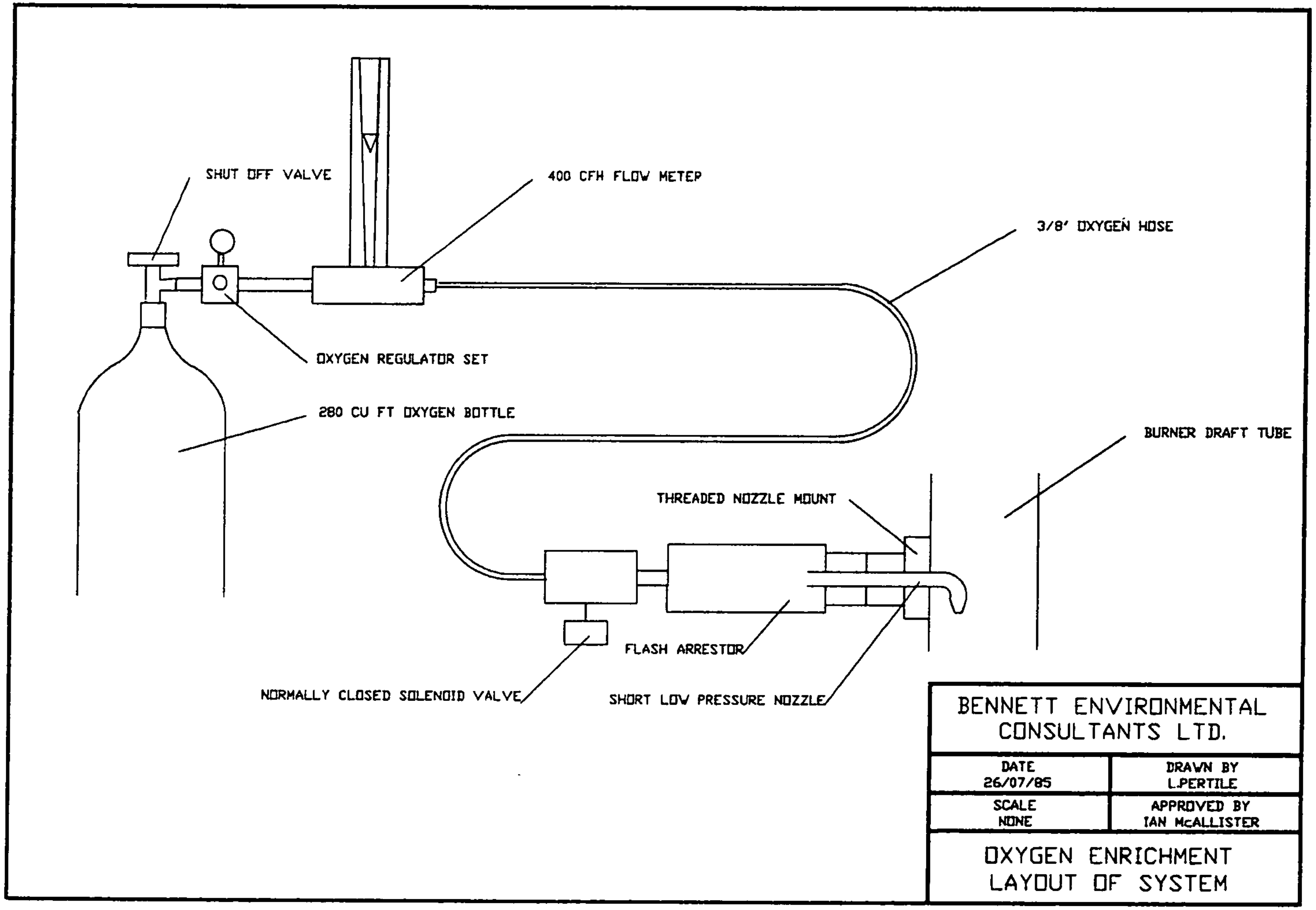



Figure 5 . Layout of oxygen enrichment system.

Photo No.2 - Pressure regulator, flow meter and pressure guage used for the oxygen tests.

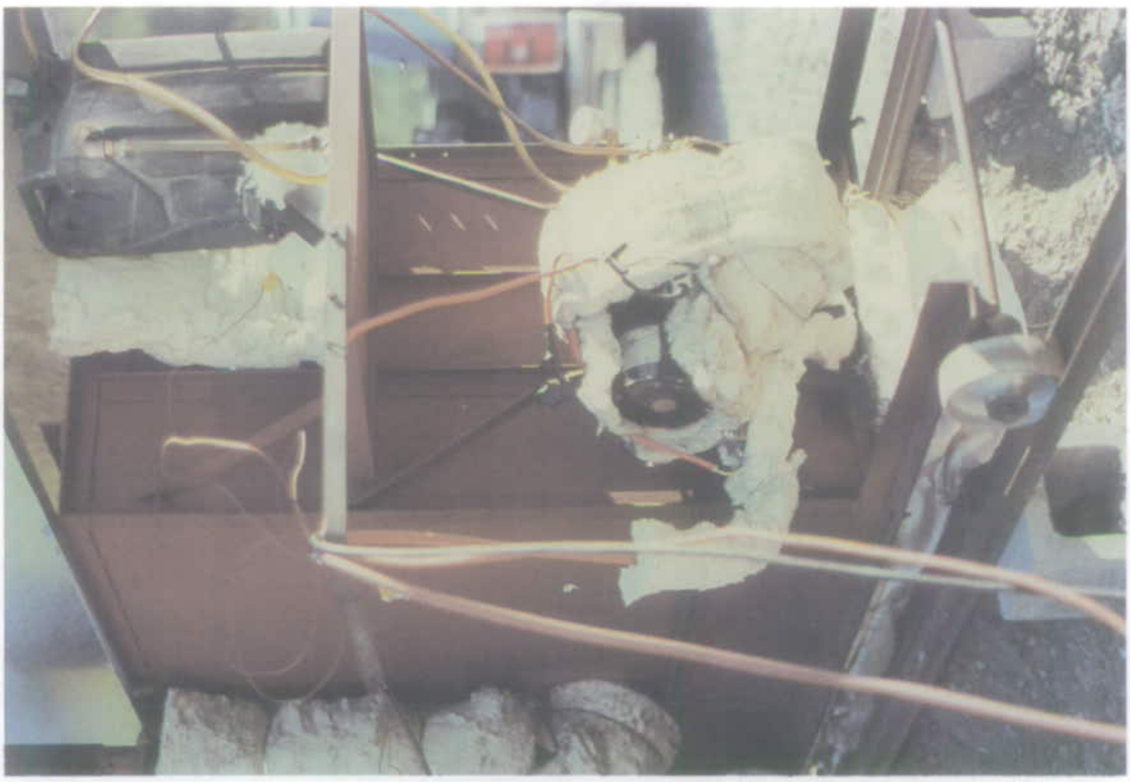


Photo No.3 - The burner end of the combustion box showing the oxygen hose connection.

Photo No.4 - Fitting used to inject the oxygen into the burner nozzle.

## Energy Input

To increase the flow rate of fuel through the burner, two methods were used. A number of different oil-jet nozzles are available for the oil burner. The different nozzles provide different flow rates for the same oil pressure and have different spray patterns. Five different nozzles were used with flow rates of 13 to 19 L/h and spray angles of 30, 45, 60, and 90 degrees. These were changed several times throughout the testing.

The flow rate of a particular nozzle is adjustable by adjusting the oil-return relief-valve setting with a lower pressure resulting in a lower flow through the nozzle.

## Air Supply

As conceived, it was anticipated that the vaporized oil could be induced to burn by the addition of auxiliary air downstream of the vapor source. This air supply could be moderated through the use of ball valve which was previously calibrated to provide an indication of air flow. Temperature measurement and smoke emission levels indicated that the addition of air at the selected point created a cooling affect on the combustion process.

The air supply for the burner blower could be reduced by the reduction in the air-intake opening on the burner. To provide adequate burner air for the larger nozzles used it was necessary to remove sleeve regulating the air flow. consequently, the burner was operated through most of the test at a constant rate of air flow.

The oxygen enrichment trial effectively increased the oxygen flow rate through the burner and resulted in a cleaner beach appearance. From an operational point of view this was regarded as an increase in air flow rate and led to the only major modification to the system.

Because there was no way to increase the air flow of the burner, the runner of the burner was removed and the auxiliary air flow line was re-routed directly into the burner. This change provided a greater air supply directly into the flame path and increased air supply from 306 m /h to 464 m /min. In operation it was necessary to restrict air flow to permit burner ignition from a cold start.

A comparison with earlier results and those tabularized showed a clear indication of improved performance with higher burner flow rates and an increased impingement flame angle. The increase in blower air resulted in a cleaner burn with less carbon deposits present after the burn.

# RESULTS

A total of 98 tests were performed of which 27 were for equipment calibration and 71 were for performance testing. A list of all tests performed, as well as brief statement of the purpose and the results is provided in Appendix D. Tests having obvious errors or omissions in recorded data or that were terminated because of equipment malfunction have not been included in this list. The results of these tests were recorded on test data sheets (see Figure 4).

A method of using two trays to quantify the amount of oil removed by direct measurement was terminated prior to the tests listed in Table 2. The intent of taking tray-weight measurements, one from the spilled oil test area and one as an uncontaminated control, both before and after a test burn, was to determine the relative weight loss, thereby quantify oil removal. With results that varied from negative values to +358% it was apparent that the technique was invalid. The oil with a higher vaporization temperature acts as an insulator to the water thereby reducing the rate of water removal from the oiled tray significantly below that of the control tray. Secondary weight change problems are caused by the explosive fracturing of gravel, thereby becoming removed from the trays and the skirts of the burner which caused movement of gravel off or onto the trays.

## DATA SUMMATION

Tests run after test #4 of 12 September were performed using burner operating conditions that were considered to be the optimum. These tests are listed in chronological order in Table 4. A calculation relating the oil thickness, advance rate, and percentage of removal provided an effective removal rate in litres per hour.

TABLE 2
Oil removal test data sorted in chronological order

| Test Date/no. | Oil Type | Beach Type | Oil Thickness, | Fuel Rate, L/h | Advance Rate, m/h | Visual Removal, % | Removal Rate, L/h | Photo Refer- |
|---|---|---|---|---|---|---|---|---|
| Aug 21/4 | | | | | | | | 18,19,20 |
| Sept 12/4 | AC | G/S W | 0.584 | 16.85 | 75.47 | 80.0 | 10.75 | |
| Sept 12/5 | AC | G20/S80 W | 1.58 | 17.03 | 72.9 | 70,0 | 24.58 | |
| Sept 13/1 | AC | G10/S90 W | 1.04 | 13.8 | 78.64 | 95.0 | 23.68 | |
| Sept 13/2 | AC | G/S W | 0.381 | 16.04 | 70.12 | 96.0 | 7.82 | |
| Sept 13/3 | AC | G10/S90 W | 1.19 | 16.82 | 74.89 | 80.0 | 21.73 | |
| Sept 13/5 | 5 | G10/S90 W | 0.38 | 15.7 | 75.84 | 50.0 | 4.39 | |
| Sept 13/6 | 5 | G10/S90 W | 0.62 | 15.05 | 52.4 | 60.0 | 5.94 | |
| Sept 16/1 | 5 | G/S W | 1.23 | 15.85 | 77.89 | 90.0 | 26.28 | |
| Sept 16/2 | 5 | G/S W | 1.34 | 15.68 | 75.4 | 80.0 | 24.64 | |
| Sept 16/4 | 5 | G10/S90 W | 1.24 | 16.65 | 80.36 | 65.0 | 19.74 | |
| Sept 16/5 | 5 | G/S W | 1.1 | 16.36 | 196.59 | 40.0 | 26.37 | |
| Sept 16/6 | 5 | G10/S90 W | 0.54 | 15.72 | 118.37 | 60.0 | 11.69 | |
| Sept 16/7 | 5 | G/S | 0.84 | 15.42 | 65.53 | 75.0 | 12.58 | |
| Sept 17/2 | AC | G10/S90 W | 0.99 | 15.39 | 70.57 | 90.0 | 19.17 | |
| Sept 17/3 | AC | G10/S90 W | 1.36 | N/A | N/A | 90.0 | N/A | |
| Sept 17/4 | AC | G10/S90 W | 0.68 | N/A | 159.6 | 95.0 | 31.43 | |
| Sept 17/5 | AC | G10/S90 W | 0.7 | 15.0 | 169.37 | 90.0 | 32.52 | |
| Sept 17/6 | AC | G | 1.11 | 15.57 | 111.2 | 50.0 | 18.81 | |
| Sept 18/1 | M C50/W50 | G20/S80 W | 1.01 | 15.36 | 126.54 | 90.0 | 35.06 | |
| Sept 18/2 | M C30/W70 | G20/S80 W | 0.97 | 14.87 | 98.29 | 90.0 | 26.15 | 10,11 |
| Sept 18/3 | M C30/W70 | G | 0.96 | 15.54 | 86 | 50.0 | 12.58 | 15,16,17 |
| Sept 18/5 | M C30/W70 | G | 0.89 | 14.86 | 39.74 | 50.0 | 5.39 | |
| Sept 18/6 | M B30/W70 | GW | 1.02 | 14.84 | 65.92 | 50.0 | 10.25 | |
| Sept 19/1 | REBURN | G | 1.02 | 15.57 | 80.95 | 80.0 | 20.13 | |
| Sept 19/2 | BUNKER | G20/S80 W | 0.6 | 15 | 84.7 | 95.0 | 14.72 | |
| Sept 19/3 | BUNKER | G60/S40 W | 1.04 | 14.8 | 113.5 | 25.0 | 8.99 | |
| Sept 19/4 | M B30/W70 | G60/S40 W | 1.03 | 15.15 | 36.82 | 85.0 | 9.83 | |
| Sept 19/5 | M B30/W70 | G | 1.11 | 15.02 | 62.9 | 50.0 | 10.64 | |
| Sept 19/6 | AC OLD | G60/S40 | 1.07 | 14.4 | 51.38 | 90.0 | 15.08 | 7,8,9 |
| Sept 24/1 | AC | G60/S40 | 0.57 | 14.87 | 71.86 | 96.0 | 11.99 | 4,5,6 |
| Sept 24/2 | M B40/W60 | G50S50 W | 0.74 | 16.4 | 39.4 | 90.0 | 8.0 | |
| Sept 24/3 | AC | GW | 0.73 | 15.89 | 50.15 | 80.0 | 8.93 | 12,13,14 |
| Sept 25/1 | AC | GW | 0.7 | 14.8 | 67.27 | 95.0 | 13.64 | |
| Sept 25/2 | M B40/W60 | S/G | 1.3 | 15.1 | 55.35 | 75.0 | 16.45 | |
| Sept 25/3 | M C40/W60 | S/G | N/A | 14.3 | 65.13 | 95.0 | N/A | |
| Sept 25/4 | AC | G30/S70 | 1.21 | 14.14 | 51.7 | 85.0 | 16.21 | 21,22,23 |
| AVERAGE VALUES | | | 0.94 | 15.41 | 82.08 | 75.75 | 16.65 | |

AC-Alberta Crude Oil;B-Bunker C Oil;5-No. 5 Fuel Oil;M-Mousse;W-Water;Old-Aged.
M B30/W70 = Mousse (30% Bunker/70% Water).
C-Cobble;G-Gravel;S-Sand;W-Wet.
G60/S40 W = 60% Gravel/40% Sand (Wet).

To evaluate these results (see Table 2), data were sorted by each of the defined parameters in an attempt to establish a commonality of conditions that would produce the best results. The different sorts are provided in Appendix F, Tables F1-F4..

Data in Order of Visual Removal. Table F-1 provides a clear indication that neither oil type or beach type have a strong influence on the efficiency of the process. However, close examination shows that the removal efficiency improves with a reduction in beach particle size. The different oil types are distributed throughout the range of results.

Data in Order of Oil Thickness. A review of the visual removal percentage provides no reason to believe that the thickness of the spilled oil (see Table F-2) affects the efficiency of the operation.

Data in Order of Removal Rate. The removal rate Table F-3 combines the factors of oil thickness, advance rate, and visual removal efficiency to provide a summation of these factors. It is somewhat dependent on beach types, with sandy beaches being more easily cleaned than gravel. There is an indication that the removal rate for Bunker C oils and mousses is slightly lower than for the lighter oils and that higher removal rates can be achieved on beaches with a high water table.

Further, the removal rate is more influenced by the advance rate than either of the other factors. During testing this characteristic was not particularly noted. In operational use this may permit the use of higher removal rates if a lesser quality of removal can be accepted.

Data in Order of Advance Rate. Table F-4 essentially confirms the observations made regarding Table F-3.

## PHOTOGRAPHIC RECORD

It is apparent from the data gathered that the valuation of the beach burner's effectiveness is more dependent upon a qualitative evaluation than on quantitative values. Consequently, an extensive photographic record was made of the tests. A selection of photographs (Photo Nos. 5-24) detailing different types of beaches, before and after spills and burns, is included for purposes of comparison.

In the photographs it will be noted that some of the gravel is left black, particularly along the outer edges of the test trays. This coating is soft, and is rubbed off easily. It appears to develop along the sides adjacent to the skirts where cooler temperatures prevail and in the oil spill area at higher advance rates or when low oxygen supplies condition exist. It is our supposition that it is a deposit of carbon (coke) formed by incomplete combustion. When submerged in a water bath it does not float off or appear to contaminate the water. It was not analysed for chemical composition. If left on a beach subject to wave action it is surmised that the wave action would remove it rapidly.

Photographs 21, 22, and 23, of test #4, 25 September, provided the equivalent of a typical beach tide line in the Vancouver area by using flotsam collected from a beach and then oiled. Without reducing the rate of advance, much of the material remained after the burn, although charred or burning. The solids appear to protect the oil from the flame and prevent it from vaporizing. A reduced advance rate would consume more of the beach material and thus more oil. In practice, a greater increase in efficiency would be achieved by the spreading of the tide line material manually, thus providing a greater exposure area.

Photo No.5 - Sept. 24 - Test # 1, Sand/gravel test beach prior to oil spill.

Photo No.6 - Sept. 24 - Test # 1, Sand/gravel test beach after oil spill.

Photo No.7 - Sept. 24 - Test #1, Test beach after burn.

Photo No.8 - Sept. 19 - Test # 6, Sand/gravel beach after oil spill.

Photo No.9 - Sept. 19 - Test # 6, Sand/gravel beach after burn.

Photo No.10 - Sept. 19 - Test # 6, Sand/gravel beach after burn and top 70mm of substrate removed.

Photo No.11 - Sept. 18 - Test # 2, Sand/gravel beach after oil spill, prior to burn.

Photo No.12 - Sept. 18 - Test # 2, Sand/gravel beach after the test burn.

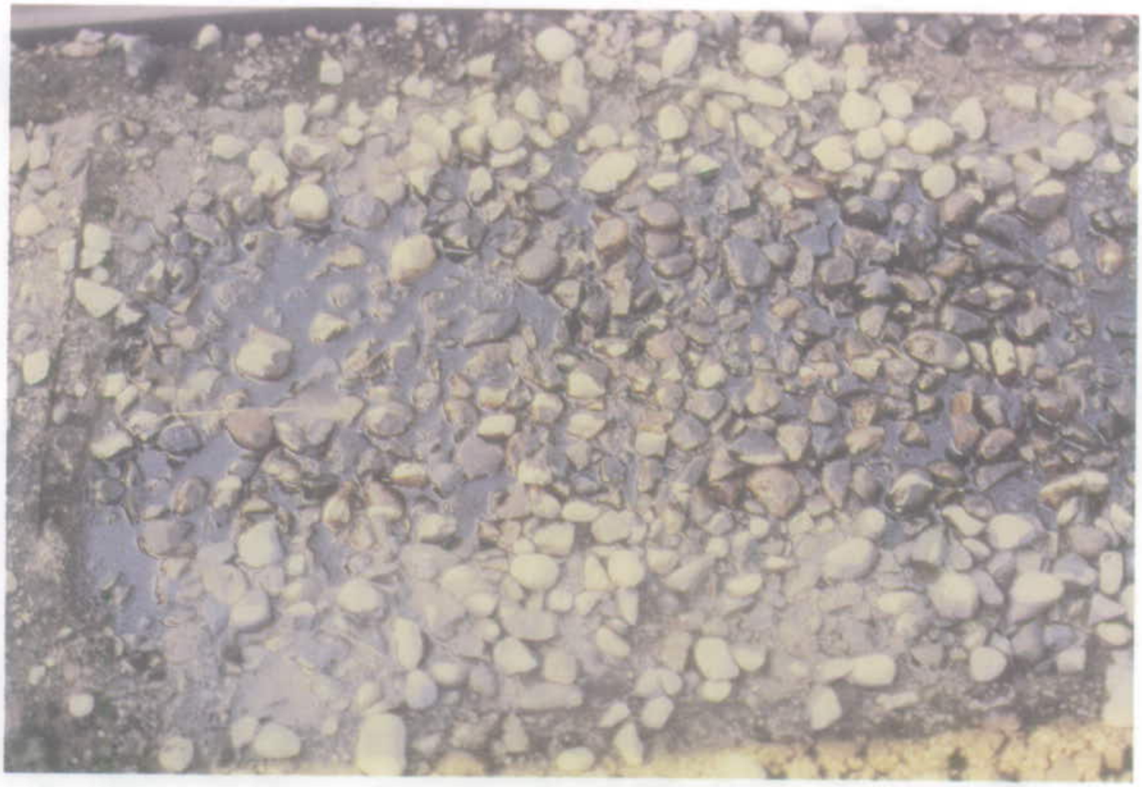
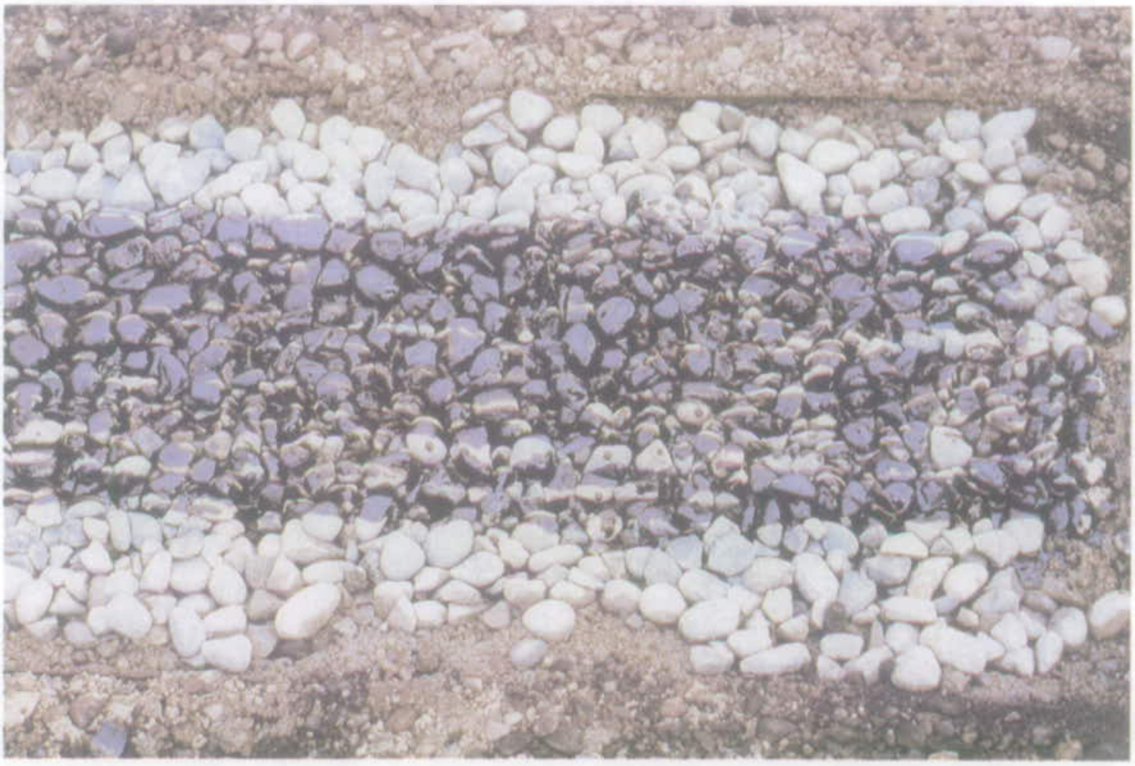


Photo No.13 - Sept. 24 - Test # 3, Gravel beach after the oil spill of Alberta crude.

Photo No.14 - Sept. 24 - Test # 3, Gravel beach after the test burn.

Photo No.15 - Sept. 24 - Test # 3, Gravel beach after the test burn showing the oil remaining between the stones.

<u>Photo No.16</u> - Sept. 18 - Test # 3, beach before the test burn.



<u>Photo No.17</u> - Sept. 18 - Test # 3, Gravel beach after oil spill and before test burn.

Photo No.18 - Sept. 18 - Test # 3, Gravel beach after test burn.

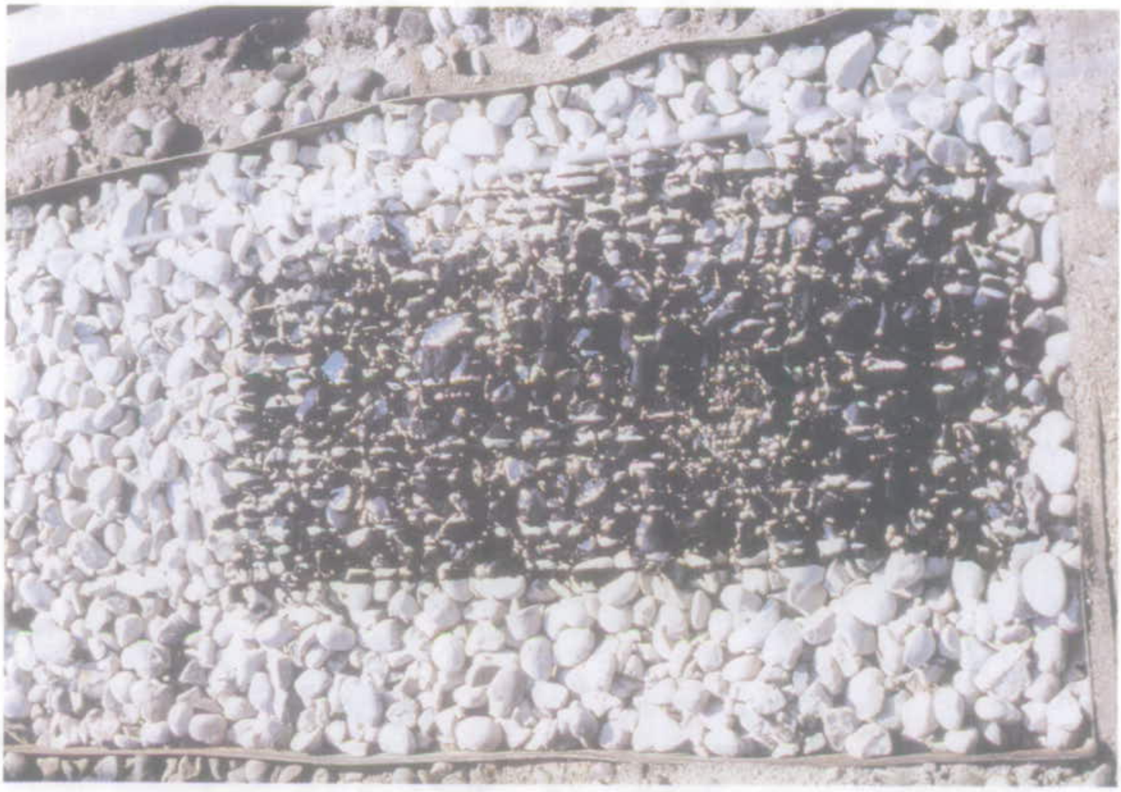


Photo No.19 - Aug. 21 - Test # 4, Coarse gravel beach after oil spill.

Photo No.20 - Aug. 21 - Test # 4, Coarse gravel beach after test burn.

Photo No.21 - Aug. 21 - Test # 4, Coarse gravel beach after test burn. Showing the area between stones.

Photo No.22 - Sept. 25 - Test # 4, Gravel/sand beach with beach debris before oil spill.

Photo No.23 - Sept. 25 - Test # 4, Gravel/sand beach with debris after oil spill.

Photo No.24 - Sept. 25 - Test # 4, Gravel/sand beach with beach debris after test burn.

## OBSERVATIONS

Prior to a test burn it was determined that a period of about 10 minutes should be allowed for the combustion chamber to heat up to a stable temperature (Figure 7).

It was found that the beach burner did not raise the beach temperature significantly during a normal cleaning pass. A thermocouple was initially installed 25 mm below the beach surface to measure the temperature rise. After no temperature rise was measured on either wet or dry beaches the reading of this temperature probe was abandoned.

Readings with the optical pyrometer provided no temperatures in excess of 150$^{\circ}$ C. A bare hand could be held on a sand beach within one minute of completion of a burn. Gravel beaches required longer times for heat dissipation but could normally be touched within 5 to 10 minutes.

Significant smoke emissions were rarely evident. The primary source of smoke emission occurred at the front skirt during the approach of the burner just before entering under the burner proper.

Some pooling of the spilled oil is visible in the photographs. At a constant rate of advance these pools would remain burning for a short period of time which represents an obvious hazard to equipment immediately following the burner. This condition must be considered in the design of a full-scale unit.

Tests run using diesel fuel oil provide a particular problem as once placed, they are virtually invisible and after burning, the depth of contamination is not discernable.

Upon comparing the theoretical considerations with the actual observations a relatively close correlation was found between the two (Table 3).

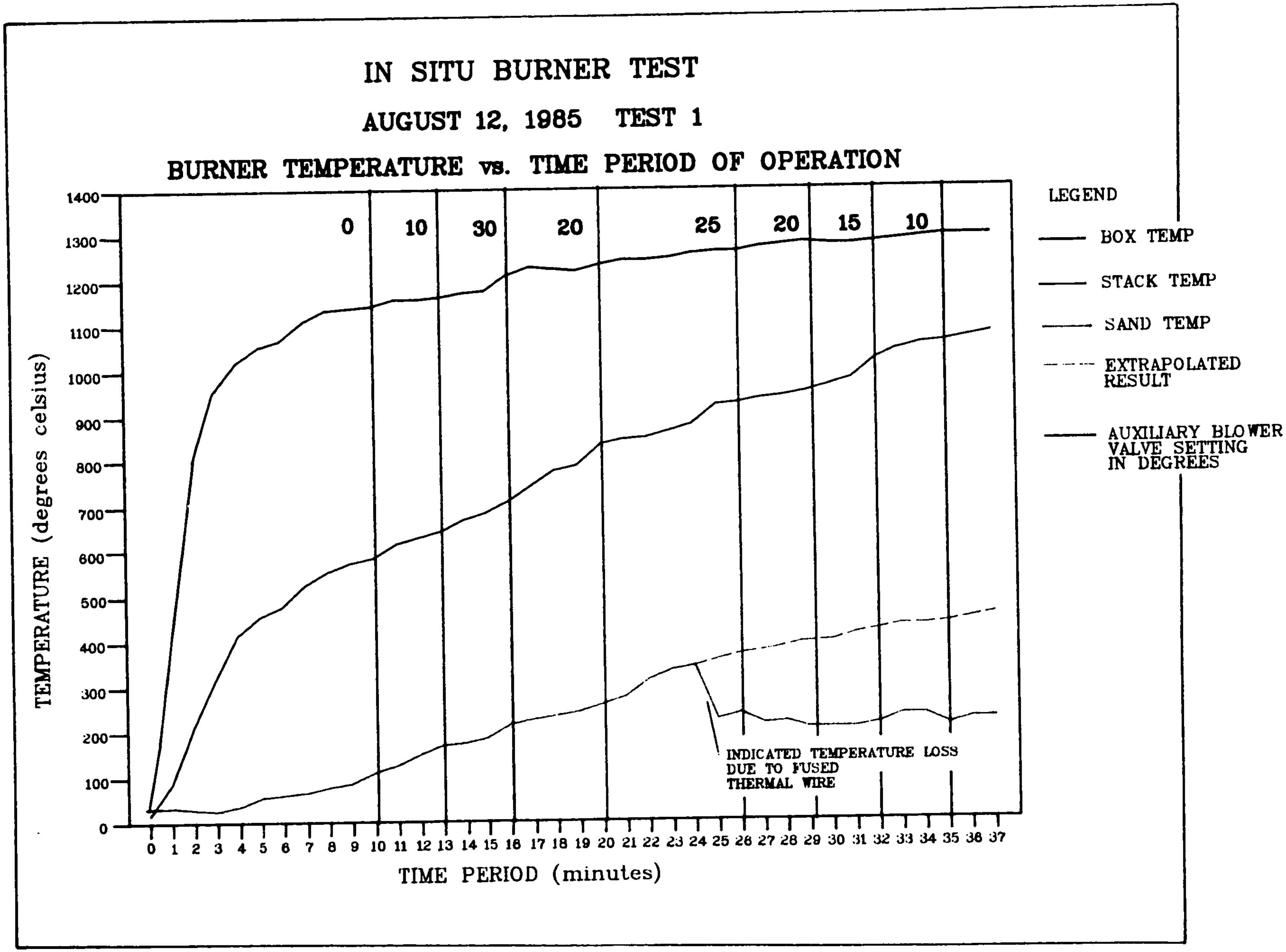



Figure 6. Rate of temperature change over an extended heat-up period.

## TABLE 3

Comparison of theoretical considerations and actual observations

| Considerations | Theoretical | Actual |
|---|---|---|
| Combustion chamber volume | 0.44 m | 0.405 m |
| Combustion chamber temperature | 900 C | 1000 C |
| Burner surface temperature | 200 C | 200 C |
| Oil thickness range | 1-5 mm | .38-1.10 mm |
| Energy supply | 633,000 kJ | 702,300 kJ |
| Velocity of advance range | 21-228 m/h | 50-200 m/h |
| Discharge stack temperature | 900 C | 750 C |

## OXYGEN ENRICHMENT RESULTS

The tests from 27 August through 10 September showed better visual results than prior tests. However, the improvement was not sufficiently dramatic to consider the use of oxygen enrichment as a standard practice on remote beaches. The oxygen provided a shorter heat-up period for both the combustion chamber and the stack (Figure 8). It was expected that the addition of oxygen would result in significantly higher operating temperatures. The tests showed that the slight difference in threshold temperature did not warrant the use of the supplemental oxygen. With the cost of one bottle of compressed oxygen at $30 for 44 $m^3$(about 1 hour's use), the additional cost was not warranted. As oxygen did have a positive effect, the beach burner was modified to provide greater air delivery.

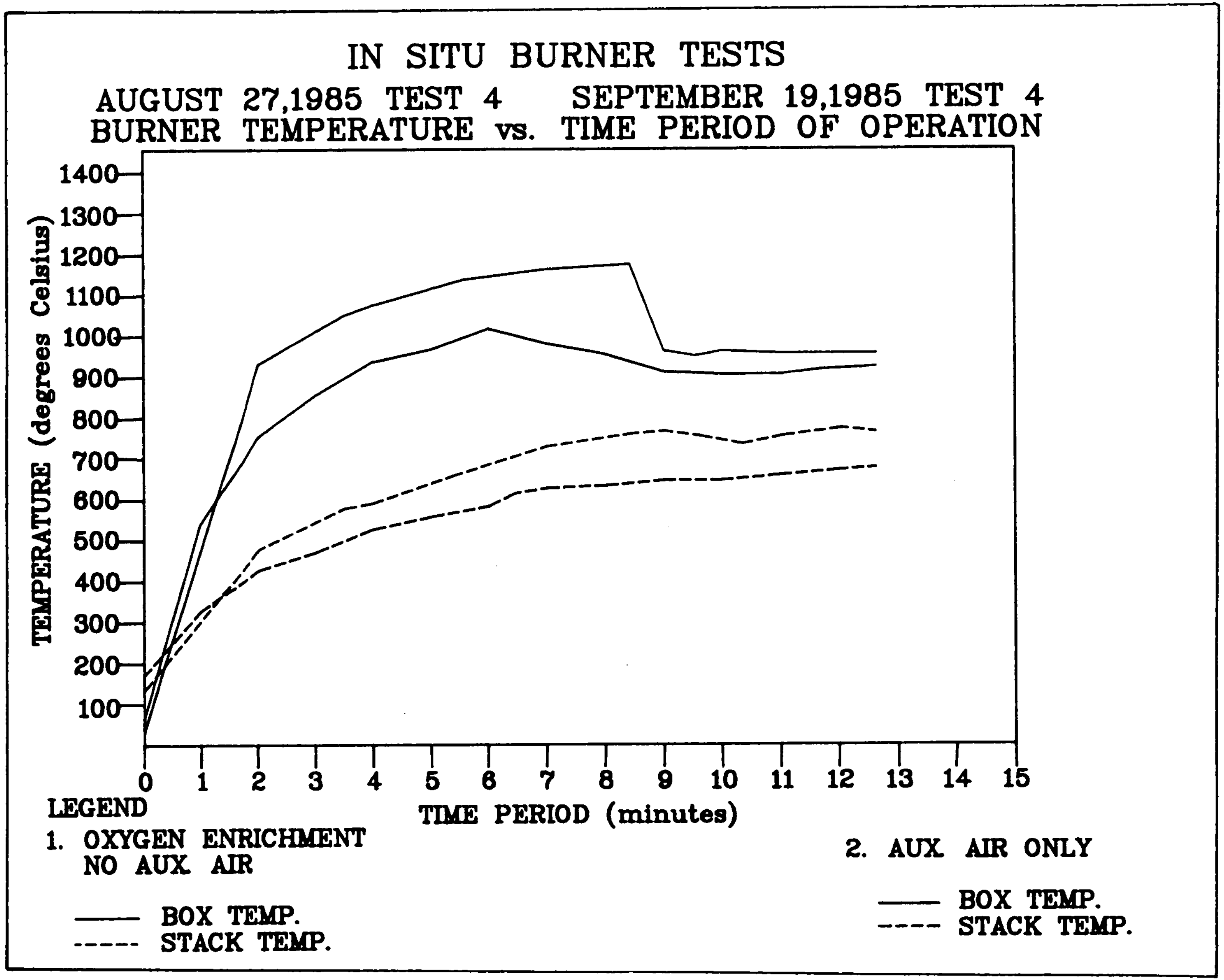



Figure 7. Oxygen enhanced operation vs standard auxiliary air operation.

## COMPARATIVE COST OF BEACH CLEAN-UP OPERATIONS

Two techniques of oil removal from a beach area have been selected for comparative purposes from the list of the 23 techniques (see Appendix C), because they would be the most commonly practised on a remote beach. These techniques are:

- manual removal
- bulldozer/front-end loader

Manual removal was selected for beaches with light contamination, i.e., less than 3 cm of substrate. The second was chosen for heavily oiled beaches with anticipated removal of up to 15 cm of substrate.

The clean-up of a remote beach would require versatile systems unaffected by changes in beach conditions, weather conditions, or the severity of the spill.

The manual removal of a spill would be the most time-consuming, but probably the most effective. A mechanized removal of the spilled oil would be more time-efficient, but could cause long-term damage to the environment.

Most other techniques are limited by the type of beach that is contaminated, the distance at which the spill takes place, and support equipment that is necessary.

All labour and equipment costs and logistical requirements are from the May 1979 survey previously quoted (Breuel 1981). The assumptions and costings calculated are provided in Appendix G. The costs are compared in Table 4.

## TABLE 4
## Cost Comparison Summary *

| Activity | Manual Removal | Bulldozer/Loader | Beachburner |
|---|---|---|---|
| Clean-up | $15,074.00 | $7,541.00 | $8,855.00 |
| Cost/100 $m^2$ | $150.74 | $75.41 | $88.55 |
| Treatment (Incineration) | $7,946.00 | $39,733.00 | --- |
| Material Replacement | $1,206.00 | $4,440.00 | --- |
| Total Cost | $24,226.00 | $51,714.00 | $8,855.00 |
| Cost/100 $m^2$ | $242.00 | $517.14 | $88.55 |

* Note: Does not include costs of transport to and from site or cost of crew maintenance at a remote site.

## DISCUSSION

From the results, it is apparent that the Bennett Beach Burner can significantly reduce the amount of oil left on a beach. The percentage of oil removed is related to the beach type, with an increase in removal rate occurring with a reduction in particle size. Sand was cleaned more completely than gravel, which in turn, was cleaned more completely than cobble. A beach with a high water table is more effectively cleaned than one that is well drained.

The efficiency of the burner is virtually unaffected by the type or condition of the oil to which it is exposed. However, with high-viscosity oils, the speed needs to be reduced to allow a greater period of time in which vaporization can take place.

The equipment operator can visually ascertain the most suitable rate of advance.

With an average rate of removal of 76% on thinly coated beach material (about 1 mm in diameter) the amount of oil remaining is minimal. This remaining oil is below the beach surface. Under some operating conditions the beach will be left with a thin black soot (presumably coke) coating the beach surface, which is loosely adhered to the beach material and would presumably be dispersed in a few tidal cycles.

The depth of heat penetration into the beach is minimal in a normal operating pass, and the beach can be touched by hand within a few minutes.

In the results we have extrapolated the average results obtained from the prototype beach burner to determine the cost of cleaning one hectare of beach. These results indicate a cost of $8,855/hectare. The costs of providing manual cleaning or mechanical equipment have been calculated for comparative purposes. These costs of $24,226/hectare and $51,714/hectare respectively are significantly higher. Both of these latter figures include a charge for the incineration of the contaminated material.

An examination of the effects of the beach burner on beach organisms has not been undertaken. Although surface organisms will be obliterated, subsurface survival rates should be greatly enhanced because of the low level of heat penetration into the beach and the greatly reduced level of oil contaminantes. With appropriate low pressure contact vehicles, the alteration of the beach surface will be significantly less than for other clean-up techniques.

As a result of these tests, the basic data exists for the design of a full-size model. The structural temperatures encountered do not preclude the use of aluminum for construction of a lighter unit.

There is some indication that higher energy input could be achieved with the addition of a higher-volume air supply which in turn would result in greater rates of advance.

Thus, the use of a combustion unit insitu, using the concepts examined in this trial, appears to be an operable, cost-effective means of removing stranded oil from beaches. The system can be lightly constructed to be transportable by helicopter, and requires the minimum in support personnel. Such a unit would be appropriate for use in remote locations.

# PHASE II: EVALUATION AND FULL-SCALE DESIGN

## INTRODUCTION

The purpose for complete study was to devise a cost-effective way to remove oil from remote beaches. In developing the prototype (Phase I) we determined that combustion of oil insitu was the most cost-effective way of cleaning a remote, contaminated beach. Having shown the feasibility of such a device, we then proceeded with the design of a full-scale beach burner.

One of the prime concerns about a beach burner system is the weight of the equipment. Much emphasis was placed on creating a system that would be cost-effective, efficient, and transportable by helicopter. Therefore, not only was the weight of the combustion chamber a concern, but also that of the support vehicle and of the associated equipment.

# METHODOLOGY

## SUPPORT VEHICLE SELECTION CRITERIA

Upon review of the information gathered during the design and testing of the original beach burner prototype, it was determined that the burner would have to meet the following criteria.

1) Maximum weight should not exceed 3,182 kg, with optimum weight being less than 1,364 kg.

2) Operation should be possible down to a travel rate approaching 0 k/h.

3) Track or tire system should be suitable for wet sand, gravel, or cobble (80 mm minus).

4) Vehicle should use diesel fuel.

5) Cab should be enclosed for operator protection from the elements and from products of combustion.

6) Support assembly (side arm) is required to carry the burner chamber.

7) Storage should be provided on board for one or two drums (200 L) of diesel fuel.

8) Supply of 10-15 kW (13-20 hp) is required for auxiliary power.

The following paragraphs elaborate on these selection criteria.

1) The maximum weight was chosen to be less than 3,182 kg because this is the maximum tolerable payload of any of the helicopters surveyed. However, because only 33% of helicopters surveyed could lift more than 1,364 kgs, it was preferable to design the burner so that it could be transported by more types of helicopter. An optimum weight of 1,364 kg was chosen because this weight could be air-lifted by 10 of 15 helicopters surveyed.

2) Because a slow rate of travel was an important factor in the effectiveness of the beach burner, a vehicle was sought with a hydrostatic transmission as opposed to a standard gear transmission. The hydrostatic transmission allows the operator to slow the advance rate to less than 5 k/h which provides flame impingement for a longer period of time, which results in a more effective burn. With the standard gear transmission, speed control is lost below 5 k/h. Thus, the hydrostatic transmission was an important factor in the beach burner operation.

3) The type of track or tire selected had to be suitable for wet sand, gravel, and cobble (80 mm minus). Under saturated beach conditions - recent high tide - the track or tire must be able to get traction without disturbing the beach substrate too extensively. Another consideration was the susceptability of the track or tire to thermal destruction. Depending on the weather conditions and the vehicle advance rate, the temperature of the beach surface after a pass could be up to 100 C. Thus, the track or tire should withstand surface temperatures up to that temperature.

4) The most common type of fuel for support vehicles in remote locations is diesel fuel, which is readily available and is less hazardous to store and transport than other fuels. Further, selection of suitable oil burner components would allow diesel fuel oil use as a burner fuel.

5) To protect the operator from the weather and from combustion products that may be generated by the beach burner, an enclosed pressurized heated cab was recommended for the burner transport vehicle.

6) The vehicle, with a net weight of less than 1,364 kg, should be capable of manipulating the combustion chamber at 1.5 to 3 meter lever arm from the support vehicle while still maintaining control of the forward motion. Cantilevering the combustion chamber to the side of the support vehicle would eliminate the transport vehicle being subjected to heat and flames produced by the burner. It is only on the second pass that the support vehicle would travel on the heated beach, but by the time the second pass is made the beach will have cooled to below 100 C. An added benefit to using a side-arm support structure would be the ability to position the combustion chamber for vertical burning, which would allow the removal of oil from sea walls.

7) Because of the relatively high volume of fuel used, the support vehicle needs to transport fuel for at least two hours, minimizing the number of refueling stops. The ability to carry two drums (200 L) of diesel fuel would allow two hours of burner operation.

8) Auxiliary power would be required for the burner ignition source, fuel solenoids, fuel pump and combustion air blower. The total power requirement is 10-15 kW (13-20 hp). If adequate auxiliary hydraulic power is available from the support vehicle, the electric power requirement could be reduced.

## SUPPORT VEHICLE SELECTION

As proposed, both dedicated vehicles and vehicles of opportunity were assessed. Originally we intended to use an All Terrain Vehicle (ATV) to carry the combustion chamber. Unfortunately an appropriate ATV could not be found, as explained later, to suit the set-up shown in Figure 9.

Thus, a cost estimate to construct a dedicated custom built ATV was investigated. A construction cost estimate of $50,000 minimum was received using the design shown in Figure 10. After careful consideration of this cost and the machine's versatility, we determined that this design was too costly for the development of each burner system.

Because the purpose of this study was to find a cost effective way of removing oil from remote beaches, we chose to seek a vehicle of opportunity to minimize the capital cost of the system.

A range of industrial equipment was examined (Table 5). One of the limiting factors was the vehicle weight (Table 6). Most of the industrial equipment, such as loaders and bulldozers, were too heavy to be transportable by helicopter. Thus, standard industrial equipment was eliminated from the choices.

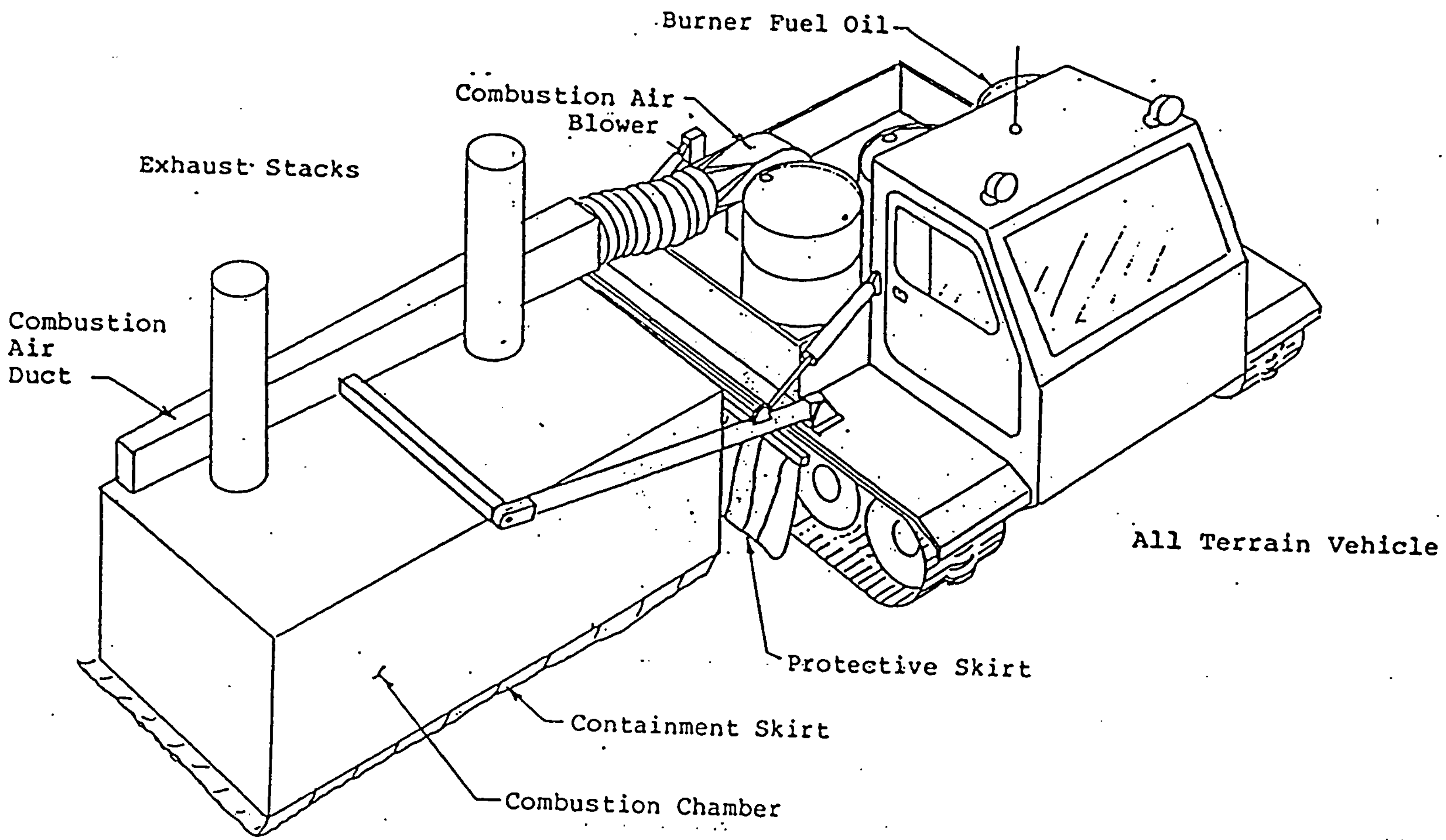



Figure 8. Conceptual sketch of the "In-Situ" Beach Burner.

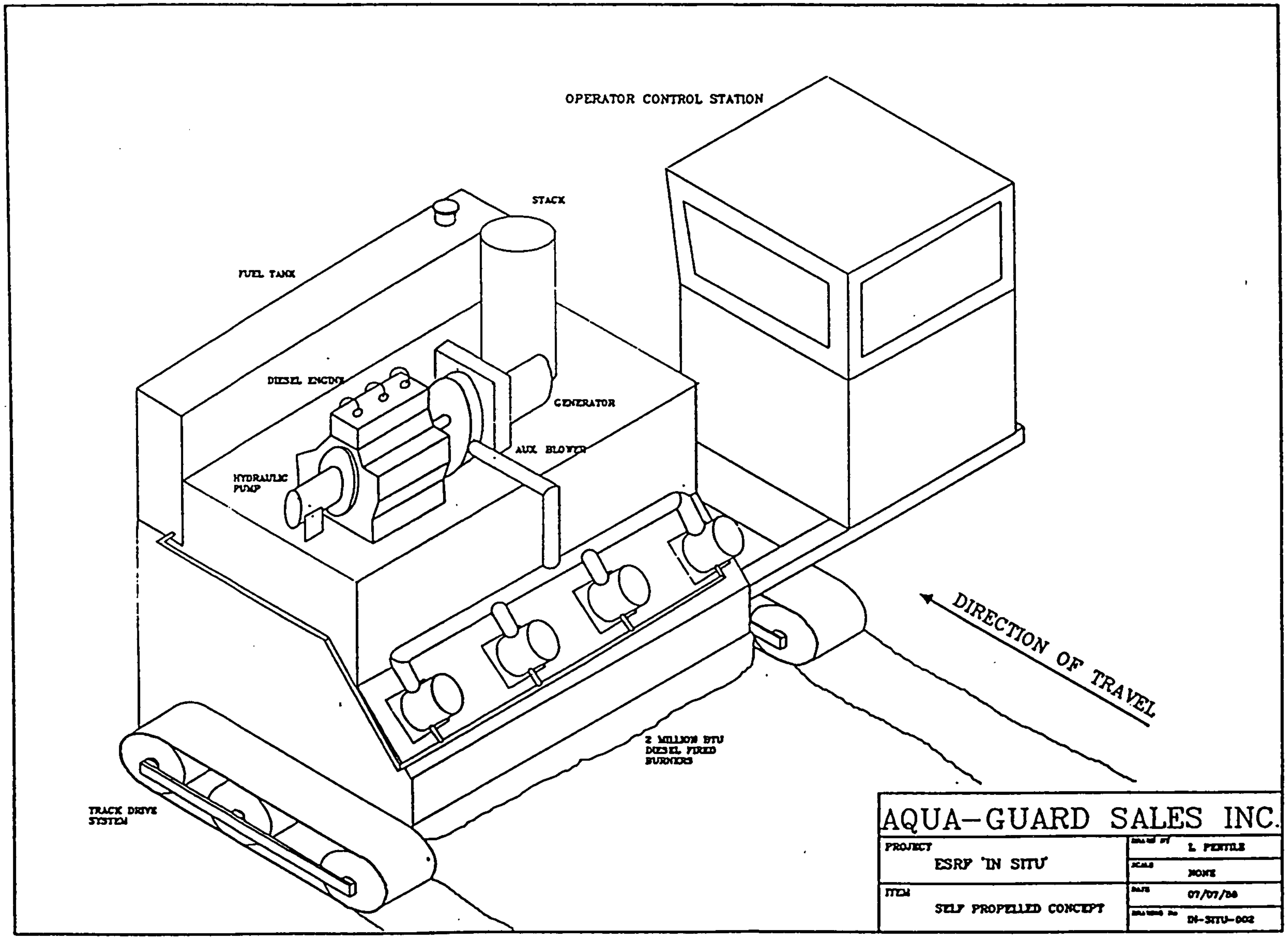



Figure 9. All Terrain Vehicle with integrated combustion system.

## TABLE 5

Support vehicle specifications

| Name/Model number | Engine, hp/rpm | Weight, kg | Drive, type | Wheel drive | Hydraulic pump, L | Length, mm | Width, mm | Height, mm | Wheel Base, mm | Ground clearance, mm |
|---|---|---|---|---|---|---|---|---|---|---|
| LMC 1200 | 124 | 2809 | auto | track | N/A | 3785 | 2527 | 2134 | 1850 | 317 |
| LMC 1500 | 120 | 1955 | auto | track | N/A | 3531 | 2057 | 2108 | 1422 | 279 |
| Ford 1310 | 19/2800 | 1026 | F12 R4 | 4WD | 23.7 | 2775 | 1259 | 2106 | 1600 | N/A |
| Ford 1510 | 22/2800 | 1101 | F12 R4 | 4WD | 25.2 | 2785 | 1278 | 2131 | 1600 | N/A |
| Ford 1710 | 26/2700 | 1161 | F12 R4 | 4WD | 29.7 | 2985 | 1390 | 2154 | 1600 | N/A |
| Ford 1910 | 32/2500 | 1462 | F12 R4 | 4WD | 32.5 | 3115 | 1487 | 2210 | 1700 | N/A |
| Yanmar YM 276D | 27/2600 | 1035 | F12 R4 | 4WD | N/A | 2986 | 1432 | 1870 | 1625 | 309 |
| Yanmar YM 186D | 18/2600 | 698 | F3 R1 | 4WD | N/A | 2496 | 1080 | 1289 | 1350 | 359 |
| Canterra Bulldog | 52 | 1247 | F5 | 4WD | N/A | 4597 | 2130 | N/A | 2290 | 356 |
| Yanmar YM 165YD | 16/2700 | 550 | F6 R2 | 4WD | N/A | 2420 | 956 | 1295 | 1240 | 265 |
| Kubota L4150D | 50/2600 | 1850 | F8 R8 | 4WD | 35.1 | 3485 | 1720 | 1580 | 1940 | 420 |
| Mitsubishi MT 250D | 25/2700 | 925 | F9 R3 | 4WD | 17.4 | 2620 | 1275 | 1380 | 1525 | 286 |
| Yanmar YM 226 D | 22/2600 | 890 | F9 R3 | 4WD | N/A | 2740 | 1231 | 1356 | 1550 | 312 |
| Canterra CT 207 | 80 | 4590 | HST | 4WD | N/A | N/A | 2490 | N/A | 2743 | N/A |
| Ford 1110 | 13/2700 | 633 | HST | 4WD | 16.2 | 2573 | 1100 | 2020 | 1400 | N/A |
| Ford 1210 | 16/2700 | 653 | HST | 4WD | 16.2 | 2573 | 1100 | 2020 | 1400 | N/A |
| Kubota B7200 HST | 17/2500 | 610 | HST | 4WD | 15.0 | 2590 | 1240 | 1805 | 1470 | 215 |
| Kubota B8200 HST-D | 19/2600 | 770 | HST | 4WD | 24.5 | 2710 | 1365 | 1900 | 1535 | 230 |
| Kubota KH-35 | 16/2200 | 1350 | HST | Track | 24.2 | 3330 | 980 | 2115 | 750 | 150 |
| Mitsubishi MT 180 HD | 19/2700 | 625 | HST | 4WD | 12.9 | 2225 | 970 | 1185 | 1300 | N/A |
| Pac-Trac PT 4000 | 45 | 1386 | HST | Track | N/A | 2692 | 1753 | 2001 | N/A | N/A |
| Grizzly SV1186 | 18 | 614 | V-Belt | 16 WD | N/A | 2667 | 1359 | 1251 | 1159 | 152 |

## TABLE 6

Hydrostatically driven support vehicles sorted in order of weight

| Name/Model number | Engine, hp/rmp | Weight, kg | Wheel drive | Auxiliary hydraulic pump | Length, mm | Width, mm | Height, mm | Wheel base, mm | Ground Clearance, mm |
|---|---|---|---|---|---|---|---|---|---|
| Kubota B7200 HST | 17/2500 | 610 | 4WD | 15 | 2590 | 1240 | 1805 | 1470 | 215 |
| Mitsubishi MT180HD | 19/2700 | 625 | 4WD | 12.9 | 2225 | 970 | 1185 | 1300 | N/A |
| Ford 1110 | 13/2700 | 633 | 4WD | 16.2 | 2573 | 1100 | 2020 | 1400 | N/A |
| Ford 1210 | 16/2700 | 653 | 4WD | 16.2 | 2573 | 1100 | 2020 | 1400 | N/A |
| Kubota B 8200HST-D | 19/2600 | 770 | 4WD | 24.5 | 2710 | 1365 | 1900 | 1535 | 230 |
| Kubota KH-35 | 16/2200 | 1350 | Track | 24.2 | 3330 | 980 | 2115 | 750 | 150 |
| Pac-Trac Pt-4000 | 45 | 1386 | Track | N/A | 2692 | 1753 | 2001 | N/A | N/A |
| Canterra CT207 | 80 | 4590 | 4WD | N/A | N/A | 2490 | N/A | 2743 | N/A |

Our attention was then directed towards light industrial equipment and farm vehicles. Small tractors were examined because they met the weight criteria. Our intentions were to try to use as many "off-the-shelf" products as possible. We approached local farm equipment dealers and found that a side mounted mower arm existed for various models. The arm was mounted below the center or at the rear of the tractor (Figure 11). However, the problem that we encountered was that the mower arms capable of supporting the combustion chamber were too large to be mounted on the smaller, helicopter transportable, tractors. The articulating mower arm allowed extensive movement of the mower head, but was inappropriate for our application.

We also gathered information about All Terrain Vehicles (ATVs) such as "Muskeg Crawlers" used in winter environments in snow and wet weather conditions. Our findings showed that most of these vehicles exceeded our maximum weight criteria. Those ATVs that were within the weight specifications did not facilitate the mounting of the side support arm because of problems inherent in their design. For us to support the chamber about 1.5 m from the side of the support vehicle a large counter-weight would be required. Due to the light suspension and structure of the ATVs, they were eliminated from our survey.

Using the idea of the articulating side arm, we looked for a light industrial backhoe or bulldozer. After review of the different types of light industrial equipment we were still faced with the same problem; that equipment capable of supporting the combustion chamber was too heavy to be transported by helicopter. Thus, a single, air-transportable unit could not be designed, so we decided to break the unit into multiple pieces that could be easily assembled at the site of the oil spill. The beach burner could be transported in three separate shipments to remain below the maximum weight of 1,364 kg per payload.

In our survey of the light industial equipment we came upon a small excavator manufactured by Kubota. Kubota has an extensive line of farm and light industrial tractors. The Kubota KH-35 Excavator is small, and easily transportable, with all the features of a large excavator but at a much smaller scale.

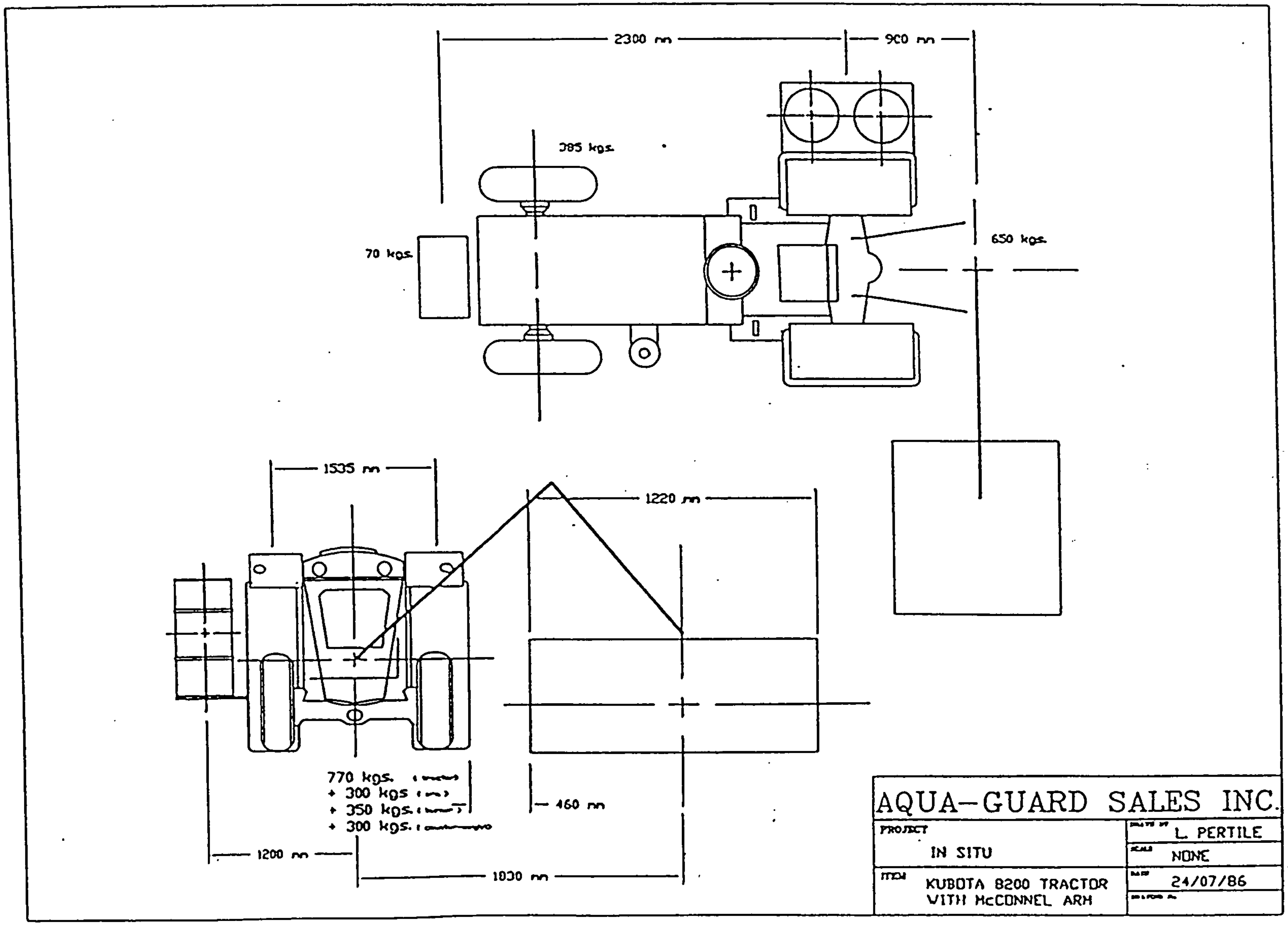



Figure 11. Light industrial farm tractor with support arm.

# RESULTS

## DESCRIPTION OF SELECTED SUPPORT VEHICLE

The Kubota KH-35 Excavator was selected because it was the only light industrial vehicle which could meet the requirements (see Appendix H) as outlined in the following summary.

1) The total weight with the enclosed cab is 1350 kg (1235 kg with the canopy). This falls within our previously determined maximum of 1368 kg. Also, according to local suppliers, the KH-35 has been transported by helicopter during previous applications with the mining industry.

2) Hydrostatic drive transmission is a standard feature. This allows slow transition speeds from 0 to 1900 m/h (metres per hour), thus satisfying our design criteria of operating speeds between 50 and 150 m/h. The slow speeds are required for the effective removal of spilled oil. Transition speeds depend on the type of oil, type of beach, and the weather conditions.

3) There are two choices for the type of tracking; rubber tracks or standard metal tracks. The metal tracks have been chosen because of their greater resistance to heat and improved traction on oily surfaces over the rubber tracks.

4) This vehicle operates on diesel fuel which is the same as the burners. Diesel fuel is more available in remote areas and is safer to transport.

5) The enclosed cab is an option which is available and is required. It adds weight to the support vehicle but still allows it to remain below the maximum helicopter-transportable weight of 1368 kg. With the cab the weight is 1350 kg; with the canopy the weight is 1235 kg. The enclosed cab is recommended for the protection of the operator. The cab can be heated for wet and cold weather conditions, and also pressurized to keep combustion products away from the operator.

6) The sturdy, articulating support arm is designed as an integrated part of the excavator operation, as a backhoe, making it very reliable. This is much stronger than any of the tractor-mower arms surveyed. A load of about 250 kg can be applied to the end of this arm.

7) To displace the weight from the support vehicle and the combustion chamber, a support trailer is to be towed by the support vehicle. The burner fuel stored in two, 200 L drums will be carried on this trailer.

8) Auxiliary hydraulic power is available from the KH-35 up to 9 hp. This hydraulic energy can be applied to a hydraulic motor to power the burner fuel pump and the combustion air blower, both located on the auxiliary support trailer. Also a 2.2 kw, portable, 110 V generator will be carried on the trailer to power the ignition transformers and the fuel oil solenoids.

The KH-35 Excavator is supplied with a backhoe bucket and a dozer blade. This facility makes the excavator much more versatile than any tractor or ATV. The excavator could be used to move beach material or support equipment, thus enhancing the excavator's operation for beach clean-up.

The KH-35 also has the advantage that no customizing is required to support the combustion chamber and the auxiliary support trailer. This means that any KH-35 excavator can be used to support the chamber and trailer. This allows the operator the option of leasing or purchasing the support vehicle.

## COMBUSTION CHAMBER MATERIAL SELECTION AND DESIGN

Through evaluation of all the support equipment available, it has been determined that the most cost-effective and practical means of constructing and operating the unit would be as described in the following paragraphs and (Figures 12 to 15).

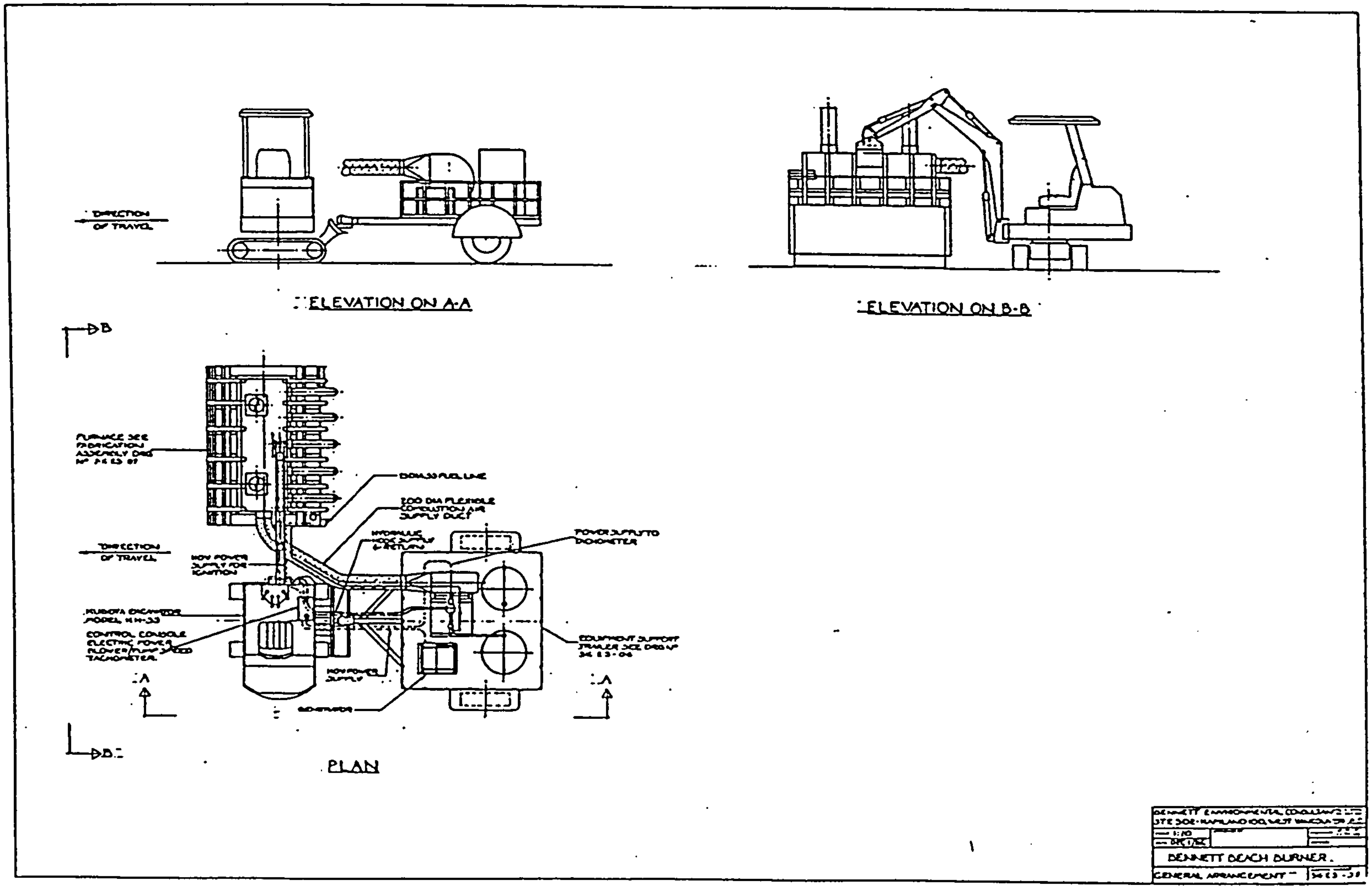



Figure 12. Beach Burner general arrangement.

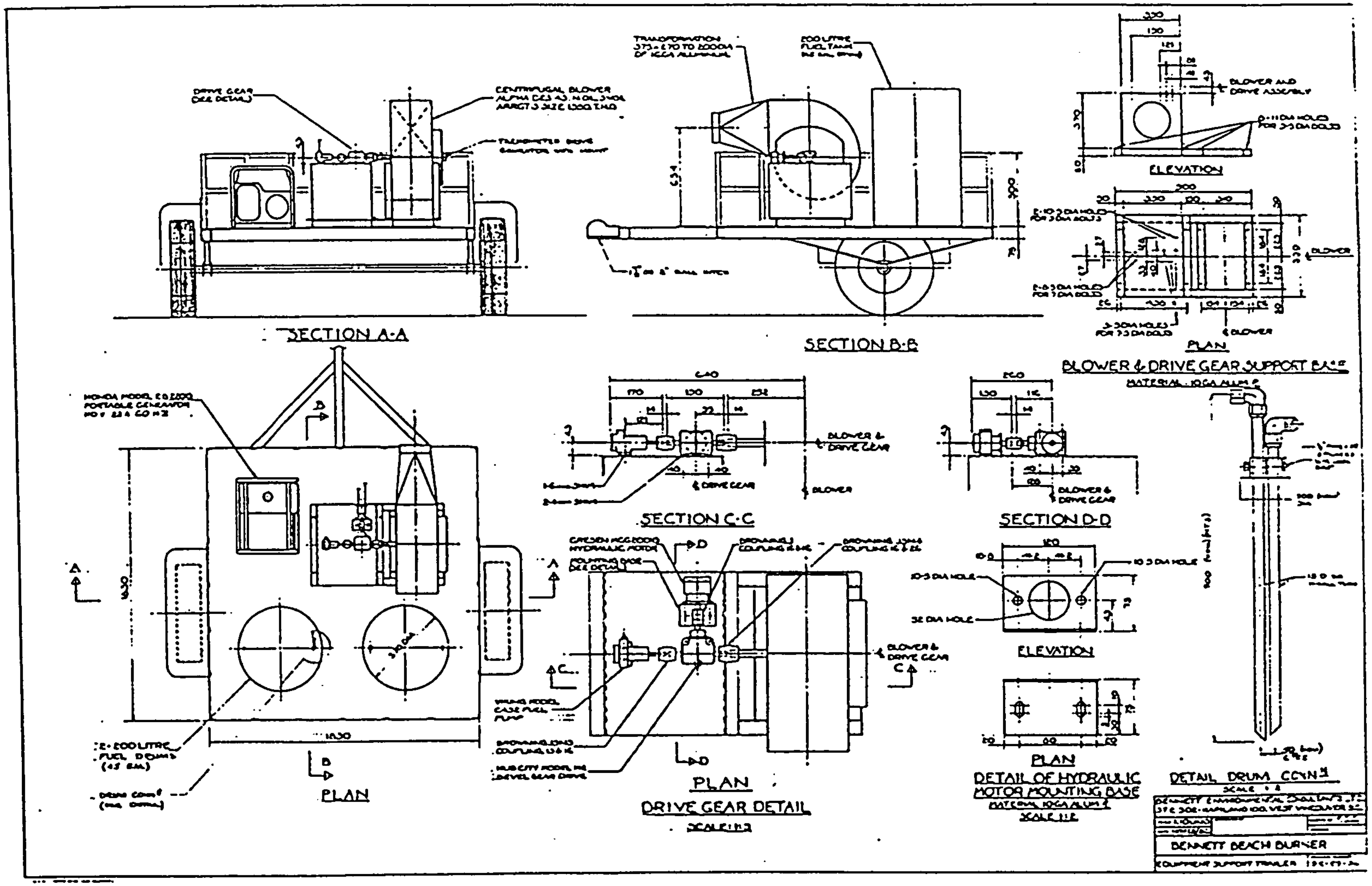



Figure 13. Beach Burner equipment support trailer.

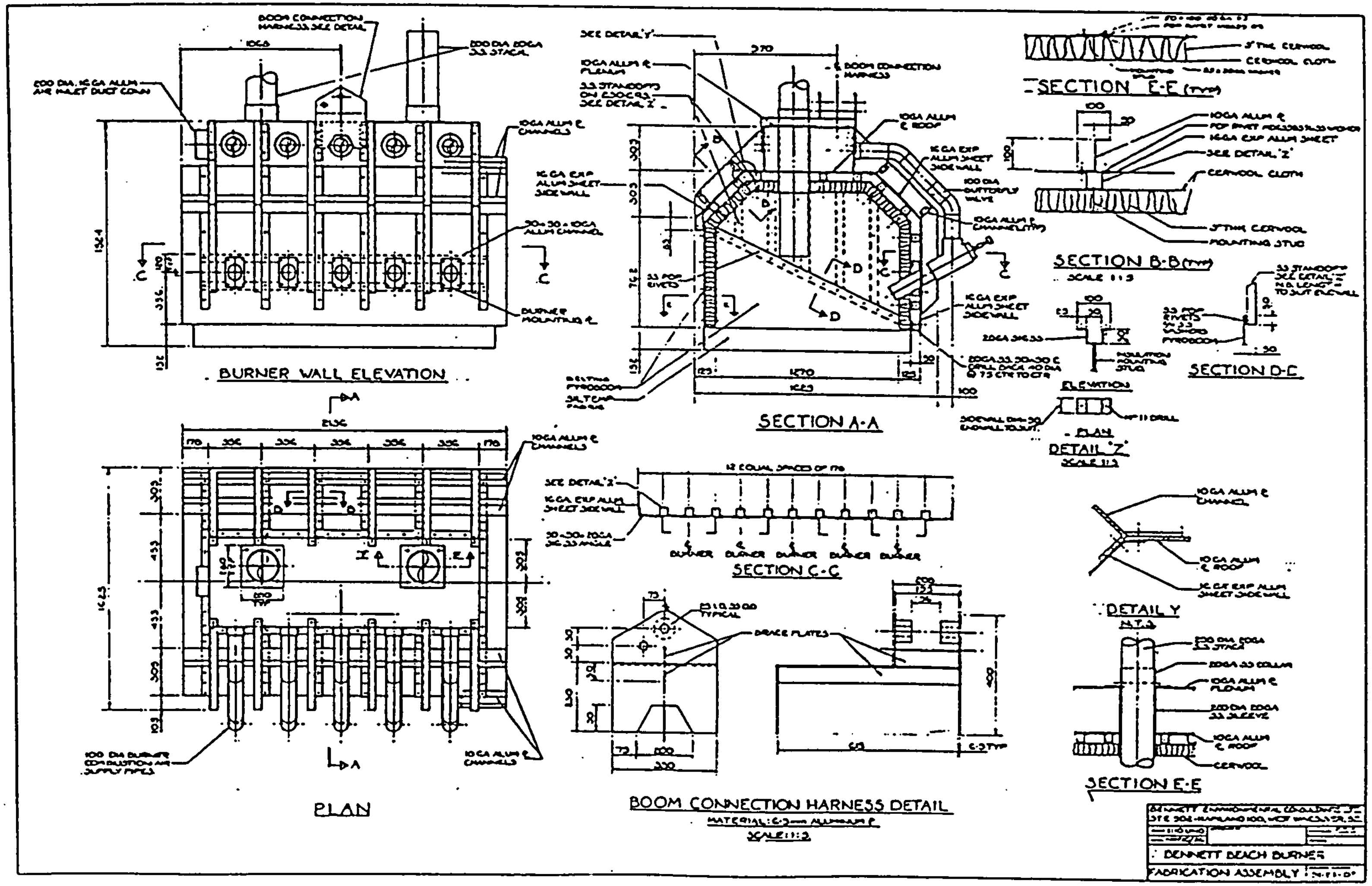



Figure 14. Combustion chamber fabrication assembly.

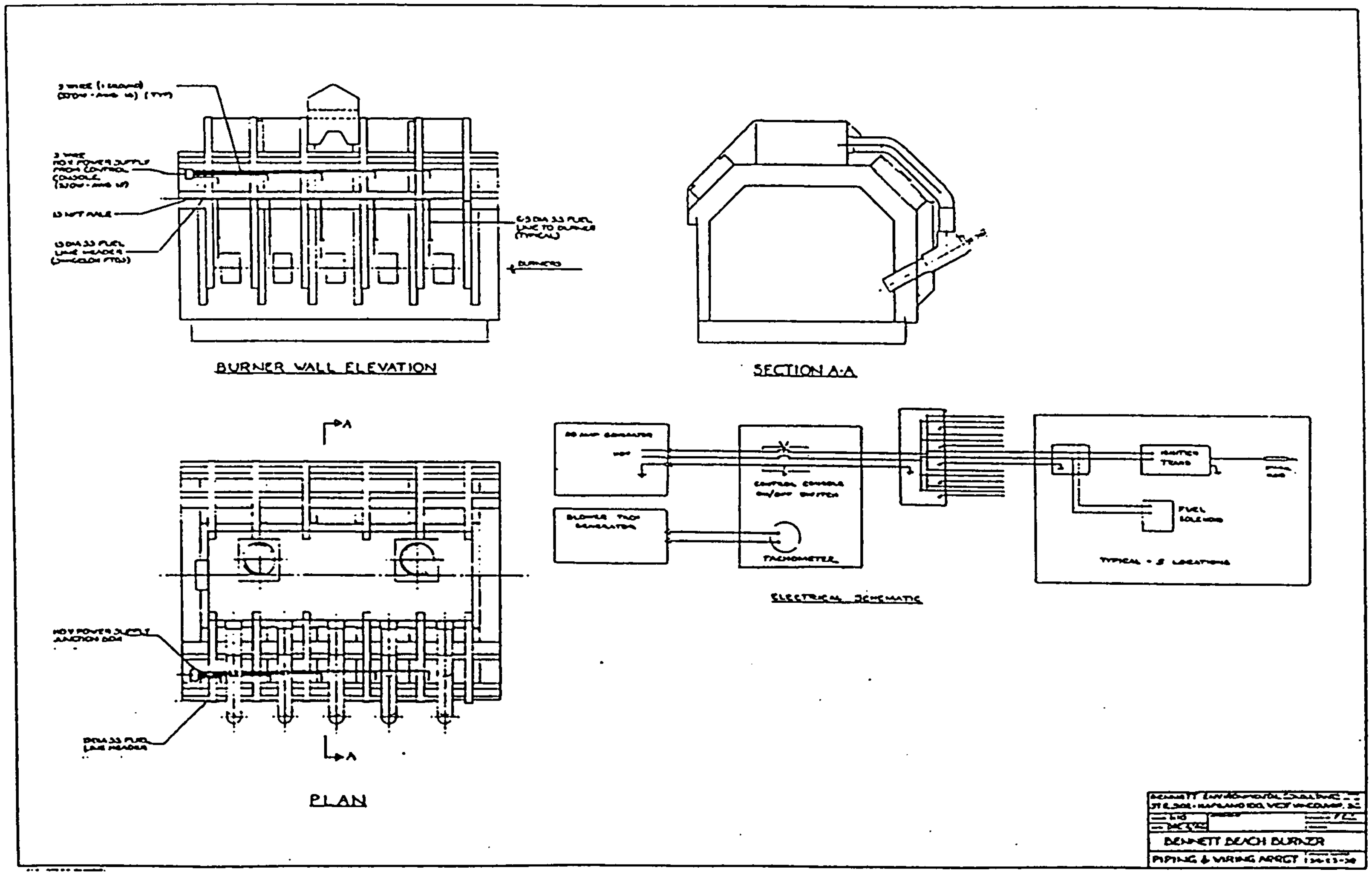



Figure 15. Beach burner piping and wiring arrangement.

The Kubota KH-35 Excavator will be the main support auxiliary vehicle. It will support the combustion furnace from its boom in place of the bucket assembly. Using the boom arm, it will be capable of manoeuvering the unit for operation in either a horizontal or vertical mode, or any position in between. Because of limitations in total weight that the excavator can carry, a support trailer will be provided and towed behind. This support trailer will carry 400 L of fuel, the combustion air blower, and fuel pump. Umbilical connections between the furnace KH-35 and trailer will be made via flexible hoses and tubes. A built-in hydraulic pumping system will provide power to drive the burner blower and oil pump assembly.

A control console mounted on the excavator will give the operator full control of the combustion process.

## Furnace Outer Structure and Frame

The design criteria called for a light-weight structure as the box would be supported by an arm of a small support vehicle. To do this and to maximize the size-to-weight ratio, it was felt that an outer structure of thin aluminum section was required.

The furnace chamber structure incorporates 16-gauge expanded aluminum plate on all walls supported by vertical "Rib" sections of 20-gauge thickness. A plenum chamber located on top of the structure acts as a manifold supplying combustion air to the burner units.

All these aluminum sections are connected into the structure using stainless-steel pop rivets to allow for thermal expansion and to reduce the total amount of heat dissipated.

The two exhaust tubes pass through the plenum chamber to allow for preheating of the combustion air prior to combustion. The stacks are manufactured from 20-gauge stainless steel and are uninsulated. These stacks are removable for transport.

The front and part of the side walls are constructed of Pyro-boom, a conveyor-belting type of material resistant to open flame and high heat. This allows for deflection of these walls in the event of encountering obstacles such as large stones or wood on the beach to be cleaned.

The area between the bottom of the chamber and the beach level is skirted using Siltemp refractory material. This material was used on the prototype unit in Phase I, and was felt to be the best material at present available for this application.

A boom connection harness is located on the top of the furnace, midway along the plenum chamber. It allows for the coupling of the chamber to the excavator boom arm, in place of the excavator bucket. The two connector pins are so positioned as to allow for the operation of the furnace from the horizontal to the vertical plane.

Stainless-steel standoffs line the inside of the structure to provide extra rigidity and to allow for the attachment of the inner Cerwool lining while reducing direct heat transfer to the aluminum skin.

### Thermal Insulation

Cerwool has been used in the form of a blanket to insulate the furnace. The lining consists of a 75-mm layer of "4 pound" Cerwool blanket sandwiched between two layers of Cerwool cloth. The outside surface of the insulation sandwich is covered with aluminum foil to reduce the porosity of the blanket and aid in containing the pressurized gases produced during combustion. This lining is affixed to the structure using 100-mm stainless-steel anchor pins spaced at 175-mm centres.

### Burners

The burners selected have been especially designed for this application. They are No. 2 fuel oil (diesel) fired each producing 700,000 BTU. Ignition is provided for each burner from transformers located on the burner box. All burners are independently operated except for a common fuel supply and pump. Consumption of each burner is about 15 L/h. depending on fuel rate. The draft tubes for each nozzle has been angled at 30 degrees from the horizontal as determined in Phase I.

The combustion air blower and fuel pump are located on the support trailer and connected to the burners via flexible ducting and hose.

## COST ESTIMATE

This estimate was prepared using formal quotes from suppliers and estimates in the event that no quotation was available. Costs do not include transportation or taxes. The complete quotation is listed in Appendix I.

A) Support Vehicle. Price includes:

- Kubota KH 35 Excavator
- Closed cab with air-conditioning unit
- Control console including Tachometer and auxiliary hydraulic control valve
- Fabricated trailer hitch for towing of support trailer
- Boom connection harness connector pins
- Lifting eyes for helicopter transport
- Analog temperature meter

SUB-TOTAL $ 28,795

B) Combustion Furnace. Price includes:

- Burner structure
- "Cerwool" lining
- "Siltemp" refractory skirting
- Burner air-supply tubes
- "Pyroboom" flexible wall
- Electrical wiring for burner
- Fuel lines for burners
- Oil-burner assemblies
- Two K-type thermocouple head/probe assemblies
- 8 m WK-20 thermocouple wire

SUB-TOTAL $ 15,106

C) <u>Support Trailer</u>. Price includes:

- 2.2-kW 110 V Honda generator
- Fuel drum connection
- Radial blower
- Fuel pump and filters
- Bevel gear drive
- Hydraulic motor
- Drive couplings and mountings
- Tachometer pick-up sender
- Combustion air-supply duct
- Fuel lines tank/furnace
- Burner, transformers
- "Turf" type tires

| | |
|---|---|
| SUB-TOTAL | $ 4,119 |
| TOTAL PRICE | $ 48,019 |

This quotation is for the cost of constructing one unit. Profits, overheads, and taxes have not been included. A reduction in fabrication costs could be expected if more than one unit were purchased.

Overhead and profit are estimated to be 15%; contingency is calculated at 10%.

| | |
|---|---|
| TOTAL COST PRICE | $ 48,019 |
| Overhead and Profit | 4,612 |
| Contingency | 3,075 |
| EXTENDED PRICE | $ 55,706 |

It is suggested that this quotation be subject to a complete review prior to a fixed budget being set for its construction.

## DISCUSSION OF PROCEDURES

The beach burner was designed as a tool to remove spilled oil from remote beaches. The burner applies an impinging flame to the beach surface causing ignition of the spilled oil. The quantity of heat applied to the beach is an important factor in the quality of the burn. With the fuel pressure set, the amount of heat applied to the beach depends on the rate of travel and the amount of combustion air supplied. Both these variables are manipulated by the operator to maintain an efficient rate of removal. Because the actual system is not yet constructed a detailed operation manual could not be compiled. Thus, a general discussion showing the ease of set-up and operation follows.

### EQUIPMENT CHECKLIST

1) Kubota KH-35 Excavator with closed cab
   Trailer ball hitch

2) Support trailer
   Fuel-supply drums
   2.2-kW, 110 V portable generator
   Combustion air blower. fuel pump, and drive assembly
   Hydraulic hoses
   Ignition control and pump and blower control console
   Flexible combustion-air hose
   Blower tachometer wiring
   Fuel line from tank to pump
   Fuel storage-tank piping assembly

3) Main combustion chamber
   Support-arm securing pins
   Fuel line for burners from trailer to manifolds

There will be three separate packages, but for helicopter transport two payloads should be considered. First, the excavator will be transported to the spill site with the operator to allow preliminary removal of obstructive rocks or logs. Secondly, the support trailer and burner box load will be transported.

Once all the equipment is on-site the beach burner system can be assembled. First, the combustion and support trailer should be removed from the transport slings and placed in easily accessible positions on the beach. The excavator can be used to load the support trailer prior to the connection to the combustion chamber.

SET-UP PROCEDURES

To set up the beach burner:

1) Using the excavator, remove the main combustion chamber and the support trailer from the transport container. Be sure to position both the combustion chamber and the support trailer in an easily accessible location.

2) With the assistance of the excavator, load the support trailer with the associated equipment and fuel supply.

3) Hookup the support trailer to the ball hitch fastened to the dozer blade at the rear of the excavator.

4) Remove the excavator bucket and position the support arm in the mounting bracket located on the top side of the burner chamber. Note that the burners should be facing in the direction of vehicle advancement with the trailer in tow.

5) Connect the hydraulic drive hoses to the auxiliary hydraulic connections located at the front of the excavator.

6) Mount the control console on the tank on the right hand side of the driver's position.

7) Connect the blower tachometer wire to the tachometer located in the control console at the front of the excavator.

8) Attach a 110 V power line from the control console to the portable generator located on the support trailer.

9) Secure the clamps on the flexible combustion air supply duct at the combustion air manifold and at the blower exhaust on the support trailer.

10) Connect the ignition tranformer wire from the combustion chamber to the control console on the excavator.

11) Fasten the burner fuel supply line from the burner feed manifold to the fuel pump on the support trailer.

12) Lift the combustion chamber to a position where the skirt at the bottom makes a seal with the beach.

OPERATION PROCEDURES

1) Ensure that all hoses, wires, and ducting are securely fastened.

2) Check all fuels and regular lubrication points. (Refer to the Kutoba KH-35 owner's manual.)

3) Check trailer-hitch connection and combustion chamber support-arm connection to ensure firm connections.

4) Start up excavator and allow at least a five-minute warm-up period.

5) Position combustion chamber to the right side of the excavator, perpendicular to the direction of advance of the excavator and trailer.

6) Position the chamber, on uncontaminated beach in the direction of travel, with lower skirt touching the beach surface.

7) Start the portable generator. Switch on the power.

8) From the control console, switch on the ignition.

9) Ensure that the burner control at the control console is set at a minimum. Turn on the burner using the

burner on/off switch. While observing the combustion chamber, slowly throttle the burner control up to about the 3/4 full-throttle point. Keep a close watch on the stack emissions, if emission becomes black, adjust the throttle accordingly.

10) With close attention to the chamber emissions and the trailing edge of the burner, start to advance the excavator slowly. Also watch the leading edge of the chamber to ensure that should large rocks or logs get in the burn path, the chamber can be elevated.

11) The chamber can be angled for many different beach surfaces, even sea walls. By elevating the chamber to the vertical position, impinging flames can be applied to sea walls.

12) It is important to start cleaning at a slow speed and to increase the speed gradually as long as a clean burn is resulting. To reduce smoke emissions increase the burner control and slow the rate of advance, if necessary.

13) The burner fuel from each diesel storage drum will last about 1 h with the burner operating at full throttle. Thus, at lesser flow rates, fuel will last longer.

## SHUTDOWN PROCEDURES

1) Throttle down burner control valve to a minimum. Shut off the burner on/off switch.

2) Switch off the burner ignitor control switch.

3) Ensure that the chamber is supported off the ground before the excavator is shut-down.

4) Turn off all equipment including the portable generator.

## DISASSEMBLY PROCEDURES

1) Disconnect all support hoses and wires noted in the set-up procedures.

2) Place the combustion chamber assembly in the transport container. Disconnect support arm from the chamber mounting bracket.

3) Unload the support trailer using the support arm.

4) Replace the support trailer and the support equipment in the transport container.

5) Prepare the excavator for helicopter transport.

## CONCLUSIONS

In Phase I of this study the proposed method of removing oil from a beach was shown to be feasible, efficient, and cost-effective. A combustion chamber, with its own ignition source, was passed over a beach test bed containing spilled oil on sand, gravel, and cobble. Up to 95% of the oil was removed. The effect of the burn depended on the rate of box travel, the volume of combustion air supplied, and the state of the spilled oil (i.e., oil thickness, type of substrate, level of substrate water saturation). The first two variables are operator controllable, whereas the spilled oil conditions are not.

Burning insitu on saturated beaches proved to be more effective than on dry cobble. With chamber temperatures between 900 and 1000$^{o}$ C, 80-95% of the original oil thickness (1 mm) was removed. With the cost of $8,855/ha, in-situ combustion of stranded oils appears to be a cost-effective way to remove oil from remote shorelines.

During Phase II of the study much emphasis was placed on the selection of support equipment and on combustion chamber design. Some 22 All Terrain Vehicles and light industrial vehicles were assessed of which one was chosen. The Kutoba KH-35 Excavator was selected as a support vehicle because of its extensive manoeuverability, air transportable weight, and its versatility in operation. This excavator was chosen also because it has been used in other helicopter-transportable applications and more than 180 are now being used in Canada.

The combustion chamber was designed with weight reduction in mind. The weight of the box is limited by the lifting capacity of the support vehicles side arm. This is the reasoning for aluminum construction. An auxiliary for support trailer equipment was also designed to transport the combustion air blower, burner fuel, and the ignition transformer power source.

All three units are made to be easily detached allowing for rapid transport by helicopter.

With the completion of Phase II, we recommend the completion of this project with the the construction and testing of the full-scale "in-situ" Beach Burner in Phase III.

# APPENDICES

# APPENDIX A

## Description of Oil Characteristics and Behaviour

Class A: Light, volatile oils. This class includes diesel oils and light crude oils. These oils do not tend to adhere to surfaces. The tendency to penetrate porous surfaces is very high, and in the case of contaminated substrate, the oil may be persistent. When, fresh they can be considered very toxic.

Class B: Non-sticky oils. This class includes medium to heavy paraffin-based oils. Their tendency to penetrate permeable substrates is variable, and increases as temperature rises. Their toxicity is variable.

Class C: Heavy, sticky oils. This class includes heavy fuel oils and heavier asphaltic mixed-base crude oils in the fluid state.

After natural light ends evaporate, it's toxicity tends to be lower. Biological effects are generally due to smothering. Typically, the ability to penetrate substrate is low. Class C oils will weather to a tar or asphalt like consistency. Emulsions formed tend to be very stable.

Class D: Nonfluid oils. This class includes residual oils, heavy crude oils, and weathered oils that are non-fluid at spill temperatures. They are essentially non-toxic.

## APPENDIX B

### Beach Classification

| Substrate Type | Grain Size (mm) | General Descriptive Features |
|---|---|---|
| Mud | - 0.06 | . Less than 1 degree beach slope<br>. Develop in areas where there is a source of fine material<br>. Incised by a complex network of creeks and channels despite the generally flat surface<br>. Saturated with water; even at low tide, the mud deposits are usually covered with a thin film of water that cannot drain through the closely packed sediments<br>. Low bearing capacities frequently incapable of supporting the weight of a person |
| Sand | 0.06-2.0 | . 1 - 40 degree beach slope<br>. Subjected to seasonal erosion and deposition cycles as a consequence of the varying levels of incoming wave energy and to a lesser extent, ebb and flood tidal action<br>. Closely packed substrate with a low water infiltration rate |
| Gravel | 2.0 - 50 | . Narrower and steeper beach slope than sand beaches<br>. Storm ridges often present to the landward side of the berm |
| Cobble | 50 - 256 | . Narrower and steeper beach-face than gravel beaches<br>. Rock fragments are somewhat rounded or modified by abrasion<br>. Storm ridge usually present to the landward side of the berm |

## APPENDIX C

### Oil Spill Clean-up Techniques

| Clean-up Techniques | Description | Primary Use Of Clean-up Technique | Biological Effect of Use |
|---|---|---|---|
| 1. Motor grader/ elevating scraper | Motor grader forms windrows for pickup by elevating scraper. | Used primarily on sand and gravel beaches where oil penetration is 0 to 3 cm, and trafficability of beach is good. Can also be used on mud-flats. Removes only 3 cm of beach. | Removes shallow burrowing polychaetes, bivalves, and amphipods. Recolonization likely to rapidly follow natural replenishment of the substrate. |
| 2. Elevating scraper | Elevating scraper picks up contaminated material directly off beach. | Used on sand and gravel beaches where oil penetration is 0 to 3 cm. Can also be used on mudflats. Also used to remove tar balls or flat patties from the surface of a beach. Removes upper 3 to 10 cm of beach. Minor reduction of beach stability. Erosion and beach retreat. | Removes shallow and deeper burrowing polychaetes, bivalves, and amphipods. Restabilization of substrate probably slow; recolonization likely to follow natural replentishment of substrate; re-establishment of long-lived indigenous fauna may take several years. |
| 3. Motor grader/ front-end loader | Motor grader forms windrows for pickup by front-end loader. | Used on gravel and sand beaches where oil penetration is less than 2 to 3 cm. This method is slower than using a motor grader and elevating scraper but can be used when elevating scrapers are not available. Can also be used on mudflats. Removes only 3 cm of beach. | Removes shallow burrowing polychaetes, bivalves, and amphipods. Recolinization likely to rapidly follow natural replenishment of the substrate. |
| 4. Front-end loader - rubber-tired or tracked | Front-end loader picks up material directly off beach and hauls | Used on mud, sand, or gravel beaches when oil penetration is moderate and oil contamination is light to moderate. Rubber-tired front end loaders are preferred because they are faster and minimize the disturbance of the surface Front-end loaders are the preferred choice for removing cobble sediments. If rubber-tired loader cannot operate tracked loaders are the next choice. Can also be used to remove extensively oil contaminated vegetation. Remove 10 to 25 cm of beach. Reduction of beach stability. Erosion and beach retreat | Removes almost all shallow and deep burrowing organisms. Restabilization of the physical environment slow; new faunal community could develop. |

| Clean-up Techniques | Description | Primary Use Of Clean-up Technique | Biological Effect of Use |
|---|---|---|---|
| 5. Bulldozer/ rubber-tired front-end loader | Bulldozer pushes contaminated substrate into piles for pickup by front-end loader. | Used on coarse sand, gravel, or cobble beaches where oil penetration is deep, oil contamination extensive and trafficability of the beach poor. Can also be used to remove heavily oil-contaminated vegetation. Removes 15 to 50 cm of beach. Loss of stability. Severe erosion and cliff or beach retreat. Inundation of backshores. | Removes all organisms. Restabilization of substrate and repopulation of indigenous fauna is extremely slow; new faunal community could develop in the interim. |
| 6. Backhoe | Operates from top of a bank or beach to remove contaminated sediments and loads into truck. | Used to remove oil contaminated sediment (primarily mud or silt) on steep banks. Removes 25 to 50 cm of beach or bank. Severe reduction of beach stability and beach retreat. | Removes all organisms. Restabilization of substrate and repopulation of organisms is extremely slow; new faunal community could develop in the interim. |
| 7. Dragline or clamshell | Operates from top of contamimated area to remove oiled sediments. | Used on sand, gravel, or cobble beaches where trafficability is very poor (ie., tracked equipment cannot operate) and oil contamination is extensive. Removes 25 to 50 cm of beach stability. Erosion and beach retreat. | Removes all organisms. Restabilization of substrate and repopulation of indigenous fauna is extremely slow; new faunal community could develop in the interim. |
| 8. High pressure flushing (hydroblasting) | High pressure water streams remove oil from substrate where it is channeled to recovery area. | Used to remove oil coatings from boulders, rock, and man-made structures; preferred method of removing oil from these surfaces. Can disturb surface of substrate. | Removes some organisms and shells from the substrate, damage to remaining organisms variable. Oil not recovered can be toxic to organisms downslope of cleanup activities. |
| 9. Steam cleaning | Steam removes oil from substrate where it is channeled to recovery area. | Used to remove oil coatings from boulders, rock, and man-made structures. Adds heat (100 C) to surface. | Removes some organisms from substrate but mortality due to the heat is more likely. Empty shells remaining may enhance repopulation. Oil not recovered can be toxic to organisms downslope of cleanup activities. |

Appendix C - continued

| Clean-up Techniques | Description | Primary Use Of Clean-up Technique | Biological Effect of Use |
|---|---|---|---|
| 10. Sandblasting | Sand moving at high velocity removes oil from substrate. | Used to remove thin accumulations of oil residue from man-made structures. Adds material to the environment. Potential recontamination, erosion, and deeper penetration into substrate. | Removes all organisms and shells from the substrate. Oil not recovered can be toxic to organisms down-slope of cleanup activities |
| 11. Manual scraping | Oil is scraped from substrate manually using hand tools. | Used to remove oil from lightly contaminated boulders, rock, and man-made structures or heavy oil accumulation when other techniques are not allowed. Selective removal of material. Labor-intensive activity can disturb sediments. | Removes some organisms from substrate, crushes others. Oil not removed or recovered can be toxic to organisms repopulating the rocky substrate or inhabiting sediment downslope of clean up activities. |
| 12. Sump and pump/ vacuum | Oil collects in sump as it moves down the beach and is removed by pump or vacuum truck. | Used on firm sand or mud beaches in the event of continuing oil contamination where sufficient longshore currents exist, and on streams and rivers in conjunction with diversion booming. Requires excavation of sump 60 to 20 cm deep on shoreline. Some oil will probably remain on beach. | Removes organisms at sump location. Potentially toxic effects from oil left on the shoreline. Recovery depends on persistence of oil at the sump. |
| 13.Manual removal of oiled materials | Oiled sediments and debris are removed by hand, shovels, rakes, wheelbarrows, etc. | Used on mud, sand, gravel, and cobble beaches when oil contamination is light or sporadic and oil penetration is slight or on beaches where access for heavy equipment is not available. Removes 3 cm or less of beach. Selective. Sediment disturbance and erosion potential. | Remove sand disturbs shallow burrowing organisms. Rapid recovery. |
| 14. Low-pressure flushing | Low pressure water spray flushes oil from substrate where it is channeled to recovery points. | Used to flush light oils that are not sticky from lightly contaminated mud substrates, cobbles, boulders, rocks, man-made structures, and vegetation. Does not disturb surface to any great extent. Potential for recontamination. | Leaves most organisms alive and in place. Oil not recovered can be toxic to organisms down slope of cleanup. |

Appendix C - continued

| Clean-up Techniques | Description | Primary Use Of Clean-up Technique | Biological Effect of Use |
|---|---|---|---|
| 15. Beach cleaner | Pulled by tractor or self-propelled across beach, picking up tar | Used on sand or gravel beaches, lightly contaminated with oil in the form of hard patties or tar balls. Disturbs upper 5 to 10 cm of beaches. | Disturbs shallow burrowing organisms. |
| 16. Manual sorbent application | Sorbents are applied manually to contaminated areas to soak up oil. | Used to remove pools of light, nonsticky oil from mud, boulders, rock, and man-made structures. Selective removal of material. Labor intensive activity can disturb sediments. | Foot traffic may crush organisms. Possible ingestion of sorbents by birds and small mammals. |
| 17. Manual cutting | Oiled vegetation is cut by hand, collected, and stuffed into bags or containers for disposal. | Used on oil contaminated vegetation Disturbes sediments because of extensive use of labor; can cause erosion. | Removes and crushes some organisms. Rapid recovery. Heavy foot traffic can cause root damage and subsequent slow recovery. |
| 18. Burning | Upwind end of contaminated area is ignited and allowed to burn to downwind end. | Used on any substrate or vegetation where sufficient oil has collected to sustain ignition; if oil is a type that will support ignition, and air pollution regulations so allow. Causes heavy air pollution; adds heat to substrate, can cause erosion if root systems due damaged. | Kills surface organisms caught in burn area. Residual matter may be somewhat toxic (heavy metals). |
| 19. Vacuum trucks | Truck is backed up to oil pool or recovery site where oil is picked up via vacuum hose. | Used to pick up oil on shorelines where pools of oil have formed in natural depressions, or in the absence of skimming equipment to recover floating oil from the water surface. Some oil may be left on shoreline or in water. | Removes some organisms. Potential for longer-term toxic effects associated with oil left on the shoreline. Recovery depends on persistence of oil left in the pools. |

Appendix C - continued

| Clean-up Techniques | Description | Primary Use Of Clean-up Technique | Biological Effect of Use |
|---|---|---|---|
| 20. Push contaminated substrate into surf | Bulldozer pushes contaminated substrate into surf zone to accelerate natural cleaning. | Used on contaminated cobble and light contaminated gravel beaches where removal of sediments may cause erosion of the beach or backshore area. Disruption of top layer of substrate; leaves some oil in intertidal area. Potential recontamination. | Kills most of the organisms inhabiting the uncontaminated substrate. Recovery of organisms usually more rapid than with removing substrate. |
| 21. Breaking up pavement | Tractor fitted with a ripper is operated up and down beach. | Used on low amenity cobble, gravel, or sand beaches or beaches where substrate removal will cause erosion where thick layers of oil have created a pavement on the beach surface. Disruption of sediments. Leaves oil on beach. | Disturbs shallow and deep burrowing organisms. |
| 22. Disc into substrate | Tractor pulls discing equipment along contaminated area. | Used on nonrecreational sand or gravel beaches that are lightly contaminated. Leaves oil buried in sand. Disrupts surface layer of substrate. | Disturbs shallow burrowing organisms. Possible toxicity effects from buried oil. |
| 23. Natural recovery | No action taken. Oil left to degrade naturally. | Used for oil contamination on high energy beaches (primarily cobble, boulder, and rock) where wave action will remove most oil contamination in a short period of time. Some oil may remain on beach and could contaminate clean areas. | Potential toxicity effects and smothering by the oil. Potential incorporation of oil into the food web. Potential elimination of habitat if organisms will not settle on residual oil. |

## APPENDIX D

### Directory of Tests Performed

| Date/Test no. | Purpose | Results |
|---|---|---|
| Aug 8/1 | Maximize burner temperature | Test terminated, poor flame. |
| Aug 8/2 | Optimize burner temperature | New nozzle 5 gal/30 degree (5/30) better flame. |
| Aug 8/2A | Optimize burner temperature | Ran 10 minutes, achieved 1160°C. |
| Aug 8/3 | Optimize temperature and fuel consumption. | Use Rate 19.5 L/h. Temperature 920°C. |
| Aug 8/4 | Prelimary test burn of No. 5 Fuel Oil on sand. | Sand temperature 596°C. |
| Aug 8/5 | Prelimary test burn of No. 5 Fuel Oil on sand. | Operated 10 minutes, no recorded rates. |
| Aug 9/1 | Measure auxiliary air flow | Maximum flow - 464 cu m/h. |
| Aug 9/2 | Measure blower air flow. | Maximum flow - 298 cu m/h. |
| Aug 12/1 | Maximize & achieve steady state temperature. | Temperature 1170°C at 634 kPa fuel pressure. |
| Aug 12/2 | Achieve steady state over cold sand. | Thermocouple failure. Achieved 1300°C. |
| Aug 14/1 | First test using test trays to calculate percentile of burn. | 83% oil removed. Two trays used. One tray as base. |
| Aug 14/2 | To calculate oil removed. | 62% oil removed, water volume removed is subtracted from total. |
| Aug 14/3 | Calculate percentile of burn with high water content. | Appears results are invalid. 4.34% removed. Procedure error suspected. |
| Aug 15/2 | To attempt running pass at 1 m/min. | 4% oil removed. Procedure error suspected. |

Appendix D - continued

| Date/Test no. | Purpose | Results |
| --- | --- | --- |
| Aug 16/1 | First test using No. 5 oil and new skirting, wet compact sand. | Oil puddled on test bed. Missing test data to calculate oil loss. |
| Aug 16/2 | Calculate the oil removed. | Oil removed 70.8% advance rate at 58 m/h. Good burn. |
| Aug 16/3 | Test combustability of oil left on wet sand over 60 hours, No. 5 Fuel Oil. | Oil totally absorbed in sand after 5 minutes. Test not completed. |
| Aug 19/1 | Attempt to remove weathered oil on sand. | Oil dried significantly. Sand moisture dried out. Poor burn. |
| Aug 20/1 | Remove oil from gravel beach. | Approximate gravel size 25 mm. Oil enters and seeps between rocks. Incomplete test. |
| Aug 20/2 | Reburn of Test # 1 the 20th. | Advance rate is 33.9 m/h. |
| Aug 20/3 | Adjust burner setting to most efficient burn level (monitor fuel pump pressure). | Carbon deposits on gravel improved. Fuel pressure 586 kPa from 654 kPa. |
| Aug 20/4 | Adjust burner setting to efficient level to reduce carbon deposits on rocks. roduce new probe holes for monitoring box temperatures. | Fuel pressure at 517 kPa, less carbon deposits evident. New temperature probe locations show that heat inside box is relatively uniform. |
| Aug 20/5 | Adjust burner setting for most efficient burn on dry gravel with fuel at 517 kPa. | Slower to initially heat. 125 mm path of deposit. Similar deposit as when fuel pressure was 586 kPa. |
| Aug 20/6 | To check fuel consumption at 469 kPa for 5 minutes. | 14.4 L/h. good rate of temperature rise in warm-up. |
| Aug 20/7 | To check fuel consumption at 551 kpa for 5 minutes. | 14 L/hr. Better burn. No smoking at skirts. Nozzle has stable through-put between 469 and 551 kPa |

Note: Dry gravel beach was composed of approximately 25 mm depth of drain rock with a saturated sand bed.

Appendix D - continued

| Date/Test no. | Purpose | Results |
| --- | --- | --- |
| Aug 20/8 | Calibrate burner output with respect to pump pressure. | At 620 kPa, box appeared to heat at the best rate. |
| Aug 20/9 | Observe carbon deposits on gravel at 551 kPa. | Minimal deposit on gravel. Some whitening of gravel and also pooled oil left behind. |
| Aug 21/1 | Vary angle of burner impingment to find most effective position for oil consumption. Pump pressure 551 kPa. | Smoke through stack minimal. Oil does not penetrate sand. Tar residue left behind. Light ends tend to penetrate sand more easily. Burner at 45 degrees to beach. |
| Aug 21/2 | Slow oil transition time to burn oil more effectively. Burner angle at 45 degrees. Fuel pump pressure at 551 kPa. | Slow heating time due to torn skirt. Stack smoked. Not much carbon deposit. Oil does not penetrate sand due to saturated beach. |
| Aug 21/3 | Change the burner angle of impingement. (Burner Position @ 27 degrees) | Fuel pump 551 kPa. Motor breakdown. Burner breakdown from excess heat. |
| Aug 21/4 | As previous (Test #2) Burner position impingement @ 27 degrees. | Auxiliary air left relatively heavy deposits on gravel. Upper level gravel black and dry. Most effective burn to date. |
| Aug 21/5 | Examine gravel from previous test and observe oil floatability. | Virtually no oil floated off. Oil present seemed to be a thick pitch. |
| Aug 22/1 | With burner at steepest angle calculate amount of oil removed. Dry gravel. | Breakdown of auxiliary air blower. Half of gravel bed had carbon deposits. |
| Aug 23/1 | Observe results of compressing the combustion chamber. Watch for carbon deposits. Dry gravel. | Clean stack emissions, stack temperature rising faster. Less carbon deposits. |
| Aug 23/2 | Observe efficiency of the burn with oil on damp loosely packed gravel. | Noticeable difference in stack temperature (190$^{o}$C). No smoke. Surface rocks cleaned of oil. No carbon deposits. |

Appendix D - continued

| Date/Test no. | Purpose | Results |
|---|---|---|
| Aug 27/1 | First oxygen run. Achieve maximum temperature with smallest chamber. Dry gravel. | Chamber smallest volume. Temperature maximum 1248°C. |
| Aug 27/2 | To remove oil from beach gravel, with smallest volume. Dry gravel. | Temperature reached 1290°C. Oil remained at bottom of test tray. 56% oil removal. |
| Aug 27/3 | To remove oil from beach. Smallest chamber. Oxygen used. | Temperature reached was 1290° C. Smoking at skirts. Maximum oxygen flow of about 476 cu m/h. |
| Aug 27/4 | Observe oil burn, 100% Oxygen at 276 kPa and steep burner angle. | Little smoke, carbon deposit remaining after burn is from poor thermal insulation. Good test, all surface oil removed. |
| Sept 6/1 | To observe oil removal with 413 kPa @ 100% volume. | Deep penetration of poured oil to water line before heat. After-burn, oil driven down about 25 mm below surface |
| Sept 6/2 | Oil comsumption check. | 19.9 L/h. |
| Sept 6/3 | Oil consumption check. | Found a kink in fuel return line. Produced a large fuel consumption, corrected, 16.2 L/h. |
| Sept 6/4 | To observe oil removal at at 56 kPa Oxygen pressure at 100% flow volume. Dry gravel. | Good burn on oxygen side only. Other had carbon deposit. |
| Sept 9/1 | Try a new nozzle to use pressure of 689 kPa for best atomization of fuel. New nozzle is 3.5/45. | Trial # 1 @ 689 kPa 13.99 L/h.<br># 2 @ 861 kPa 14.5 L/h. |
| Sept 9/2 | To observe the rate of temperature rise with new nozzle and effect of higher pressure and angle. Dry gravel. | Slight carbon deposit approximately 100 mm on side of bed, same side as the smoking skirt. |
| Sept 9/3 | To observe carboning with new nozzle @ 861 kPa and oxygen @ 92% 138 kPa. Dry gravel. | No smoke at skirt. Fuel temperature is 38.5 C with ambient at 22 degrees C. Used 3.44 MPa oxygen from bottle. |

Appendix D - continued

| Date/Test no. | Purpose | Results |
|---|---|---|
| Sept 10/1 | To observe the effect of the burner nozzle changed to 3.5/45. | Used same bed as the Sept 9 test. Attained 1027 °C in box. |
| Sept 10/2 | Same test as Sept 10/1 with oxygen. Dry gravel. | Not as clean, but with less over-all carbon deposits. |
| Sept 11/1 | Test of new burner configuration nozzle at 5/30 and auxiliary air injected into the blower chamber. Dry gravel. | Smallest volume of chamber used. Some light smoke. Some soot on gravel. |
| Sept 11/2 | Test of new burner nozzle 5/30 at angle of 45 degrees. Dry gravel. | Smallest chamber volume, results not recorded. |
| Sept 11/3 | Test of new burner arrangment. Nozzle at 5/30. Burner position @ 27 degrees. | Very little smoke, very clean down center of burn path. Appears starved of air. Smallest chamber volume. |
| Sept 11/4 | To observe burner response to air addition to combustion chamber. | Total air into burner 569 cu m/h |
| Sept 11/5 | To observe smoke emissions the chamber volume increased to its maximum. | Better burn was achieved with 4.5/30 nozzle, cleaner exhaust Skirt heavily carboned. |
| Sept 11/6 | To observe efficiency of the burn with the burner at 5/30 @ 689 kPa. Burner at steepest angle. Chamber setting largest. Dry gravel. | Slight smoking, stack slow to heat up. Gravel smoking after the burn, some oil is still being removed after the burn. |
| Sept 12/1 | To check the repeatability of our burn holding all variables constant. Fuel pressure 689 kPa. Dry gravel. | Skirts lifted to 45 degrees due to winds. Bed smoking after burn. Humidity level seems to have effect on quality of burn. Apears better with low humidity. |
| Sept 12/2 | Repeat of Test # 1 Dry gravel. | Very good burn. Carbon deposits medium on edges of bed due to holes in skirting. Virtually no oil residue. |

Appendix D - continued

| Date/Test no. | Purpose | Results |
|---|---|---|
| Sept 12/3 | To observe oil removal from sand/gravel mix in trays to see better oil removal. | Oil penetrated sand. Sand burning after burner passes. Appears that burner removes oil best from wet sand/gravel. |
| Sept 12/4 | To observe if more oil can be removed from wet or dry sand. | After pour, oil remained near surface on wet sand. Very good burn. Very little oil residue. |
| Sept 12/5 | To check repeatability of the previous test where 80% oil was removed. Wet sand/gravel. | Temperature climbing rapidly. Very little penetration of oil into sand. Flame out front of burner. |
| Sept 13/1 | To check the repeatability of oil removal from Sept. 12/4 & /5. Wet sand/gravel. | Sand surface totally clean after burn. Slight darkening where oil pooled. No oil penetration of sand. |
| Sept 13/2 | To observe the repeatability of previous test (#1) 689 kPa. | Bed has black residue after burn. Dry with minimal oil content. Removed valve in auxiliary air line. Improved air flow. |
| Sept 13/3 | Check repeatability of Test 2. | Sand not totally saturated with oil. |
| Sept 13/4 | Observe burner operation on No. 5 Fuel Oil. | Incomplete test due to test tray hooking on burner. Test stopped. |
| Sept 13/5 | Repeat previous test. | Not much oil burned. 3 mm layer of pitch left. Tacky surface. |
| Sept 13/6 | To re-run the previous test at a slower rate of travel. Wet sand/gravel. | Rocks popping. Better burn than previous test. Oil penetrated approximately 12 mm. Dry rock on top surface. |
| Sept 16/1 | Observe oil removal over a 1.5 m test bed. Wet sand/gravel. | Very good burn occurred with wet beach. Visually 95% of oil removed. Minimal residue. |
| Sept 16/2 | Observe repeatability of test #1 (previous test). Wet sand/gravel. | 80% oil removed. Top surface dry Oil penetrated 6 mm. |

Note: Sand/gravel (approximately 90% sand/10% gravel)

Appendix D - continued

| Date/Test no. | Purpose | Results |
|---|---|---|
| Sept 16/3 | Try a reburn on the previous test bed to remove more oil. Wet sand/gravel. | Sand remained darkened and hardened. Resulted in drying out of the oil. Removed an additional 5%. Formed a hard crust. |
| Sept 16/4 | To examine the effects of not pre-heating the burner chamber. Wet sand/gravel. | Tacky damp spots where oil pooled and left afterburn. |
| Sept 16/5 | To redo the previous test No pre-heat. New oil. Wet sand/gravel. | Appears light ends removed leaving Heavy ends forming tar like pools. |
| Sept 16/6 | Do reburn of previous test. Observe changes, will heat box to 1000 C before burn. Wet sand/gravel. | Oil penetrated sand. Box should be pre-heated in succeeding tests. Better than previous burn. |
| Sept 16/7 | Observe the efficiency of burn on an oil spill thickness of 0.8 mm. Damp sand/gravel, not saturated. | Oil penetrated sand 6 mm. After burn, a tar surface. Hard and crusty. Good burn. |
| Sept 17/1 | Observe oil removal difference between AC and No.5 on a 1.5 m bed. Wet sand/gravel. | Problems with burner ignition. Repaired burner for next test. |
| Sept 17/2 | Repeat previous test but now oil has been on beach for 30 minutes. Partial penetration of sand. Wet sand/gravel. | Appears that 90% oil removed. Appears crude oil easier to remove then No.5 Fuel Oil. Minimal crust after burn. Good burn. |
| Sept 17/3 | Observe quality of burn. Increase thickness of oil. Wet sand/gravel. | 90% oil removal. Still problems with ignition. Burning of oily beach ahead of burner. |
| Sept 17/4 | Observe oil removal at a higher rate of advance. Saturated sand/gravel. | Good burn, 95% removal. Works well on water saturated beach. Did not heat or dry out beach. |
| Sept17/4a | Reburn same area as Test # 4. | 100% oil removal. Some drying of the sand. |

Appendix D - continued

| Date/Test no. | Purpose | Results |
|---|---|---|
| Sept 17/5 | Check repeatability of previous test (# 4). Wet sand/gravel. | Good burn. Surface gravel remained wet after burn. Sand clean with no visual oil. No carbon deposits. |
| Sept 17/6 | To observe oil removal at 60 to 90 m/h. Dry gravel. | 50% oil removal. Top gravel clean but oil driven down in gravel. 20% more oil removed on 2nd pass. |
| Sept 18/2 | Examine the oil removal rate of a mousse of 30% oil and 70% water. | Minimal smoke. 90% oil removed. Dried sand and gravel. |
| Sept 18/3 | Observe oil removal in mousse state on a gravel surface. | 40% oil removed. Remainder driven down. Top rocks clean with no carbon. Oil descended to water table. |
| Sept 18/4 | Attempt to remove more oil from the gravel sub-surface (second burn on oil from Test # 3). | Removed another 50% of oil. Slower rate of travel appears more effective. |
| Sept 18/5 | To advance at a slower rate and observe the burn. | About 50% oil removed. Surface rocks cleaned. |
| Sept 18/6 | To operate the system in reverse and observe the burn. | Same type of burn. Machine can be operated in forward or reverse. |
| Sept 19/1 | Observe whether we can remove more oil from gravel by floating oil out after burn and re-burning. | A further 30% oil removed. Total of 80%. Again some oil is drive down to water table. |
| Sept 19/2 | To examine oil removal of a heavy oil - Bunker C. | Minimal smoke out stack. A sealed chamber is important. |
| Sept 19/3 | Observe quality of burn with 40% sand/60% gravel (damp). Bunker C oil used. | Asphalt like surface of 6 mm. Remaining after burn. |
| Sept 19/4 | Examine oil removal of crude mousse on a gravel/sand surface. | Badly torn skirt. Advance rate 1/3 of previous test. Black surface but dry. Mousse penetration 3 mm. |

Appendix D - continued

| Date/Test no. | Purpose | Results |
|---|---|---|
| Sept 19/5 | Examine oil removal of a thick mousse. | No smoke. Top surface dry and blackened, 50% of oil is driven down to sand/water table. |
| Sept 19/6 | Observe temperature change over 3 m bed to see if the temperature will actually stabilize. | Appears if oil penetrates sand, it will be black after burn. With a water saturated bed, sand strip clean. Temperature stabilized between 910 and 950$^{o}$C. |
| Sept 24/1 | Examine quality of burn using Alberta crude. Wet 60% gravel/40% gravel. | Good burn. Virtually a clean bed except for some carbon on some rocks. |
| Sept 24/2 | Observe quality of burn using mousse. Wet gravel /sand. | Fins on the nozzle redirected to straighten air flow. Smoking stack. |
| Sept 24/3 | Observe the quality of burn of Alberta Crude. Wet sand/gravel. | Popping of rocks below burner. Oil continued to burn after burner passed over. |
| Sept 25/1 | Demonstration for official observers (ESRF, EPS, Indonesian, Thai.) Wet sand/gravel. | Good burn could have advanced faster. Top surface of sand is dry. |
| Sept 25/2 | Exhibit the operation of the prototype beach burner. Damp sand/ gravel. | Oil penetrated sand 6 mm. Dried out surface. |
| Sept 25/3 | Repeat of Test (1&2) Wet sand/dry gravel. | Smoking stack. Beach burning after pass. Blackening of sand. |
| Sept 25/4 | Observe the burn of ocean debris covered with oil. | The majority of debris is combusted leaving only ashes with some oil. |
| Oct 1/1 | To run test for producing video presentation. | As seen on video. |

# APPENDIX E

## Air Flow Calculations

### A - Burner Blower

Air Flow Meter Cross-Section Area = 11.227 sq cm

Width = (19.368+19.685)/2 = 19.527 cm
Height = (38.74+39.37)/2 = 39.055 cm
Face Area = Width X Height = 762.627 cm

Net Area = 762.627-11.227 = 751.400 sq cm

| | |
|---|---|
| Velocities Recorded | 68.63 m/min |
| | 67.10 m/min |
| Average | 67.86 m/min |

Volume = Net Area x Average Velocity
= 5.10 cu m/min
= 305.94 cu m/h

### B - Auxiliary Combustion Air

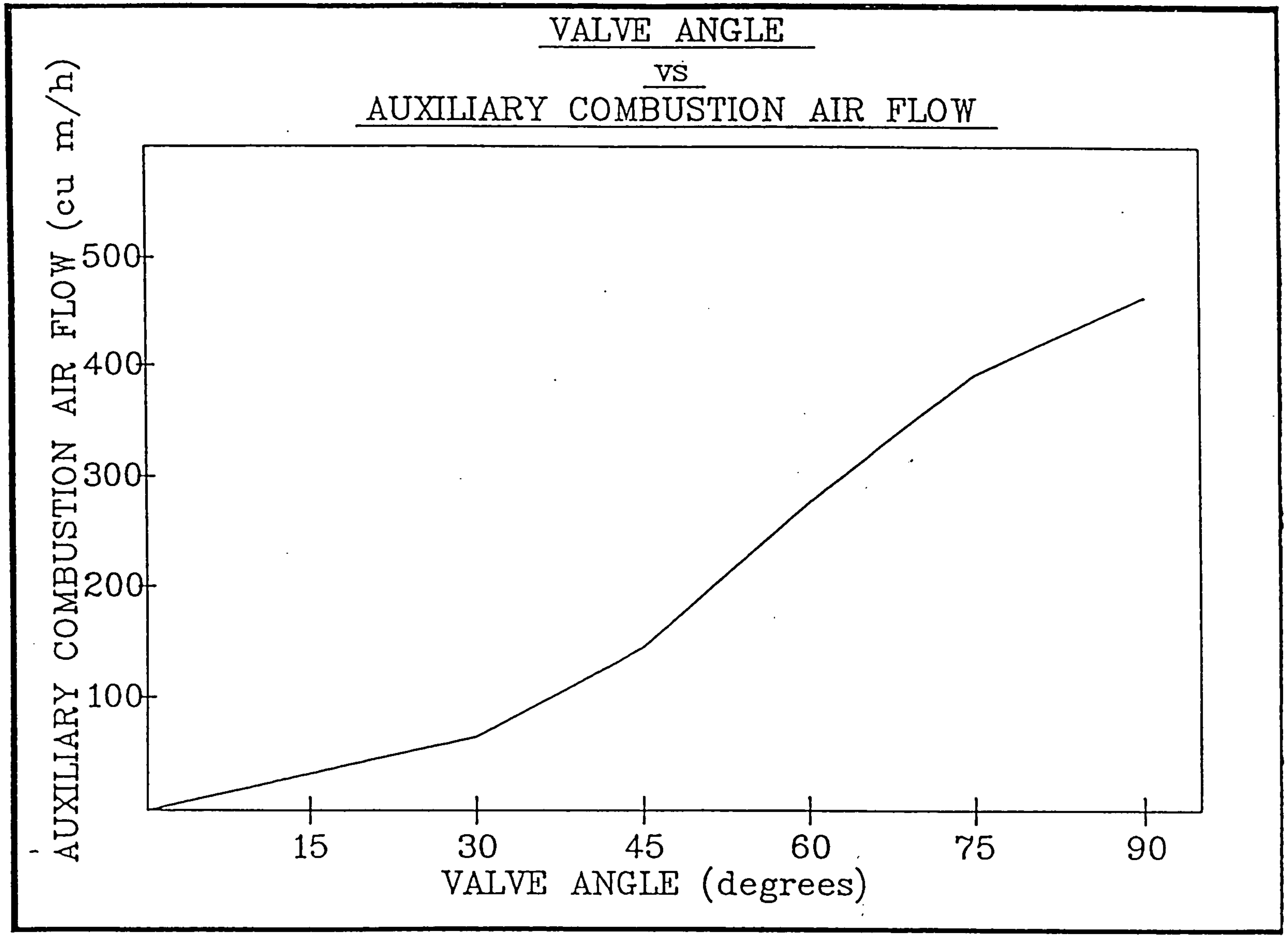
Average Diameter = (32.39+29.85+33.00+29.85)/4 = 31.27 cm

Face Area = 3.142x (Avg. Dia./2) = 98.24 sq cm

Net Area = 98.24-11.23 = 87.01 sq cm

### Velocities Recorded

| Valve Angle | Velocities m/min | | | | | Average Velocity m/min | Air Flow cu m/h |
|---|---|---|---|---|---|---|---|
| 90 | 110 | 99 | 101 | 109 | | 105 | 464 |
| 75 | 98 | 93 | 82 | 86 | 84 | 89 | 393 |
| 60 | 73 | 52 | 59 | | | 61 | 271 |
| 45 | 33 | 31 | 36 | | | 33 | 147 |
| 30 | 14 | | | | | 14 | 60 |
| 15 | 7.6 | | | | | 7.6 | 34 |




Calibration curve of the auxilary combustion air control valve.

APPENDIX F

Table F-1

Sorted test data: Visual removal

| TEST DATE | OIL TYPE | BEACH TYPE | OIL THICKNESS mm | FUEL RATE L/h | ADVANCE RATE m/h | VISUAL REMOVAL % | REMOVAL RATE L/h |
|---|---|---|---|---|---|---|---|
| SEPT 13/ 2 | AC | G/S W | 0.381 | 16.04 | 70.12 | 96.0 | 7.82 |
| SEPT 24/ 1 | AC | G60/S40 | 0.57 | 14.87 | 71.86 | 96.0 | 11.99 |
| SEPT 25/ 1 | AC | G W | 0.7 | 14.8 | 67.27 | 95.0 | 13.64 |
| SEPT 25/ 3 | M C40/W60 | S/G | N/A | 14.3 | 65.13 | 95.0 | N/A |
| SEPT 17/ 4 | AC | G10S90 W | 0.68 | N/A | 159.6 | 95.0 | 31.43 |
| SEPT 13/ 1 | AC | G10/S90 W | 1.04 | 13.8 | 78.64 | 95.0 | 23.68 |
| SEPT 19/ 2 | BUNKER | G20/S80 W | 0.6 | 15 | 84.7 | 95.0 | 14.72 |
| SEPT 18/ 1 | M C50/W50 | G20/S80 W | 1.01 | 15.36 | 126.54 | 90.0 | 35.06 |
| SEPT 17/ 2 | AC | G10/S90 W | 0.99 | 15.39 | 70.57 | 90.0 | 19.17 |
| SEPT 19/ 6 | AC OLD | G60/S40 | 1.07 | 14.4 | 51.38 | 90.0 | 15.08 |
| SEPT 17/ 3 | AC | G10/S90 W | 1.36 | N/A | N/A | 90.0 | N/A |
| SEPT 24/ 2 | M B40/W60 | G50S50 W | 0.74 | 16.4 | 39.4 | 90.0 | 8.00 |
| SEPT 18/ 2 | M C30/W70 | G20/S80 W | 0.97 | 14.87 | 98.29 | 90.0 | 26.15 |
| SEPT 16/ 1 | 5 | G/S W | 1.23 | 15.85 | 77.89 | 90.0 | 26.28 |
| SEPT 17/ 5 | AC | G10/S90 W | 0.7 | 15 | 169.37 | 90.0 | 32.52 |
| SEPT 25/ 4 | AC | G30/S70 | 1.21 | 14.14 | 51.7 | 85.0 | 16.21 |
| SEPT 19/ 4 | M B30/W70 | G60/S40 W | 1.03 | 15.15 | 36.82 | 85.0 | 9.83 |
| SEPT 12/ 4 | AC | G/S W | 0.584 | 16.85 | 75.47 | 80.0 | 10.75 |
| SEPT 19/ 1 | REBURN | G | 1.02 | 15.57 | 80.95 | 80.0 | 20.13 |
| SEPT 16/ 2 | 5 | G/S W | 1.34 | 15.68 | 75.4 | 80.0 | 24.64 |
| SEPT 24/ 3 | AC | G W | 0.73 | 15.89 | 50.15 | 80.0 | 8.93 |
| SEPT 13/ 3 | AC | G10/S90 W | 1.19 | 16.82 | 74.89 | 80.0 | 21.73 |
| SEPT 16/ 7 | 5 | G/S | 0.84 | 15.42 | 65.53 | 75.0 | 12.58 |
| SEPT 25/ 2 | M B40/W60 | S/G | 1.3 | 15.1 | 55.35 | 75.0 | 16.45 |
| SEPT 12/ 5 | AC | G20/S80 W | 1.58 | 17.03 | 72.9 | 70.0 | 24.58 |
| SEPT 16/ 4 | 5 | G10/S90 W | 1.24 | 16.65 | 80.36 | 65.0 | 19.74 |
| SEPT 13/ 6 | 5 | G10/S90 W | 0.62 | 15.05 | 52.4 | 60.0 | 5.94 |
| SEPT 16/ 6 | 5 | G10/S90 W | 0.54 | 15.72 | 118.37 | 60.0 | 11.69 |
| SEPT 18/ 6 | M B30/W70 | G W | 1.02 | 14.84 | 65.92 | 50.0 | 10.25 |
| SEPT 18/ 5 | M C30/W70 | G | 0.89 | 14.86 | 39.74 | 50.0 | 5.39 |
| SEPT 18/ 3 | M C30/W70 | G | 0.96 | 15.54 | 86 | 50.0 | 12.58 |
| SEPT 19/ 5 | M B30/W70 | G | 1.11 | 15.02 | 62.9 | 50.0 | 10.64 |
| SEPT 13/ 5 | 5 | G10/S90 W | 0.38 | 15.7 | 75.84 | 50.0 | 4.39 |
| SEPT 17/ 6 | AC | G | 1.11 | 15.57 | 111.2 | 50.0 | 18.81 |
| SEPT 16/ 5 | 5 | G/S W | 1.1 | 16.36 | 196.59 | 40.0 | 26.37 |
| SEPT 19/ 3 | BUNKER | G60/S40 W | 1.04 | 14.8 | 113.5 | 25.0 | 8.99 |
| | AVERAGE VALUES | | 0.94 | 15.41 | 82.08 | 75.75 | 16.65 |

AC-Alberta Crude Oil;B-Bunker C Oil;5-No. 5 Fuel Oil;M-Mousse;W-Water;Old-Aged.
M B30/W70 = Mousse (30% Bunker/70% Water).
C-Cobble;G-Gravel;S-Sand;W-Wet.
G60/S40 W = 60% Gravel/40% Sand (Wet).

Table F-2
Sorted test data: Oil thickness

| TEST DATE | OIL TYPE | BEACH TYPE | OIL THICKNESS mm | FUEL RATE L/h | ADVANCE RATE m/h | VISUAL REMOVAL % | REMOVAL RATE L/h |
|---|---|---|---|---|---|---|---|
| SEPT 12/ 5 | AC | G20/S80 W | 1.58 | 17.03 | 72.9 | 70.0 | 24.58 |
| SEPT 17/ 3 | AC | G10/S90 W | 1.36 | N/A | N/A | 90.0 | N/A |
| SEPT 16/ 2 | 5 | G/S W | 1.34 | 15.68 | 75.4 | 80.0 | 24.64 |
| SEPT 25/ 2 | M B40/W60 | S/G | 1.3 | 15.1 | 55.35 | 75.0 | 16.45 |
| SEPT 16/ 4 | 5 | G10/S90 W | 1.24 | 16.65 | 80.36 | 65.0 | 19.74 |
| SEPT 16/ 1 | 5 | G/S W | 1.23 | 15.85 | 77.89 | 90.0 | 26.28 |
| SEPT 25/ 4 | AC | G30/S70 | 1.21 | 14.14 | 51.7 | 85.0 | 16.21 |
| SEPT 13/ 3 | AC | G10/S90 W | 1.19 | 16.82 | 74.89 | 80.0 | 21.73 |
| SEPT 17/ 6 | AC | G | 1.11 | 15.57 | 111.2 | 50.0 | 18.81 |
| SEPT 19/ 5 | M B30/W70 | G | 1.11 | 15.02 | 62.9 | 50.0 | 10.64 |
| SEPT 16/ 5 | 5 | G/S W | 1.1 | 16.36 | 196.59 | 40.0 | 26.37 |
| SEPT 19/ 6 | AC OLD | G60/S40 | 1.07 | 14.4 | 51.38 | 90.0 | 15.08 |
| SEPT 13/ 1 | AC | G10/S90 W | 1.04 | 13.8 | 78.64 | 95.0 | 23.68 |
| SEPT 19/ 3 | BUNKER | G60/S40 W | 1.04 | 14.8 | 113.5 | 25.0 | 8.99 |
| SEPT 19/ 4 | M B30/W70 | G60/S40 W | 1.03 | 15.15 | 36.82 | 85.0 | 9.83 |
| SEPT 19/ 1 | REBURN | G | 1.02 | 15.57 | 80.95 | 80.0 | 20.13 |
| SEPT 18/ 6 | M B30/W70 | G W | 1.02 | 14.84 | 65.92 | 50.0 | 10.25 |
| SEPT 18/ 1 | M C50/W50 | G20/S80 W | 1.01 | 15.36 | 126.54 | 90.0 | 35.06 |
| SEPT 17/ 2 | AC | G10/S90 W | 0.99 | 15.39 | 70.57 | 90.0 | 19.17 |
| SEPT 18/ 2 | M C30/W70 | G20/S80 W | 0.97 | 14.87 | 98.29 | 90.0 | 26.15 |
| SEPT 18/ 3 | M C30/W70 | G | 0.96 | 15.54 | 86 | 50.0 | 12.58 |
| SEPT 18/ 5 | M C30/W70 | G | 0.89 | 14.86 | 39.74 | 50.0 | 5.39 |
| SEPT 16/ 7 | 5 | G/S | 0.84 | 15.42 | 65.53 | 75.0 | 12.58 |
| SEPT 24/ 2 | M B40/W60 | G50S50 W | 0.74 | 16.4 | 39.4 | 90.0 | 8.00 |
| SEPT 24/ 3 | AC | G W | 0.73 | 15.89 | 50.15 | 80.0 | 8.93 |
| SEPT 17/ 5 | AC | G10/S90 W | 0.7 | 15 | 169.37 | 90.0 | 32.52 |
| SEPT 25/ 1 | AC | G W | 0.7 | 14.8 | 67.27 | 95.0 | 13.64 |
| SEPT 17/ 4 | AC | G10S90 W | 0.68 | N/A | 159.6 | 95.0 | 31.43 |
| SEPT 13/ 6 | 5 | G10/S90 W | 0.62 | 15.05 | 52.4 | 60.0 | 5.94 |
| SEPT 19/ 2 | BUNKER | G20/S80 W | 0.6 | 15 | 84.7 | 95.0 | 14.72 |
| SEPT 12/ 4 | AC | G/S W | 0.584 | 16.85 | 75.47 | 80.0 | 10.75 |
| SEPT 24/ 1 | AC | G60/S40 | 0.57 | 14.87 | 71.86 | 96.0 | 11.99 |
| SEPT 16/ 6 | 5 | G10/S90 W | 0.54 | 15.72 | 118.37 | 60.0 | 11.69 |
| SEPT 13/ 2 | AC | G/S W | 0.381 | 16.04 | 70.12 | 96.0 | 7.82 |
| SEPT 13/ 5 | 5 | G10/S90 W | 0.38 | 15.7 | 75.84 | 50.0 | 4.39 |
| SEPT 25/ 3 | M C40/W60 | S/G | N/A | 14.3 | 65.13 | 95.0 | N/A |
| | AVERAGE VALUES | | 0.94 | 15.41 | 82.08 | 75.75 | 16.65 |

AC-Alberta Crude Oil;B-Bunker C Oil;5-No. 5 Fuel Oil;M-Mousse;W-Water;Old-Aged.
M B30/W70 = Mousse (30% Bunker/70% Water).
C-Cobble;G-Gravel;S-Sand;W-Wet.
G60/S40 W = 60% Gravel/40% Sand (Wet).

Table F-3

Sorted test data: Removal rate

| TEST DATE | OIL TYPE | BEACH TYPE | OIL THICKNESS mm | FUEL RATE L/h | ADVANCE RATE m/h | VISUAL REMOVAL % | REMOVAL RATE L/h |
|---|---|---|---|---|---|---|---|
| SEPT 18/ 1 | M C50/W50 | G20/S80 W | 1.01 | 15.36 | 126.54 | 90.0 | 35.06 |
| SEPT 17/ 5 | AC | G10/S90 W | 0.7 | 15 | 169.37 | 90.0 | 32.52 |
| SEPT 17/ 4 | AC | G10S90 W | 0.68 | N/A | 159.6 | 95.0 | 31.43 |
| SEPT 16/ 5 | 5 | G/S W | 1.1 | 16.36 | 196.59 | 40.0 | 26.37 |
| SEPT 16/ 1 | 5 | G/S W | 1.23 | 15.85 | 77.89 | 90.0 | 26.28 |
| SEPT 18/ 2 | M C30/W70 | G20/S80 W | 0.97 | 14.87 | 98.29 | 90.0 | 26.15 |
| SEPT 16/ 2 | 5 | G/S W | 1.34 | 15.68 | 75.4 | 80.0 | 24.64 |
| SEPT 12/ 5 | AC | G20/S80 W | 1.58 | 17.03 | 72.9 | 70.0 | 24.58 |
| SEPT 13/ 1 | AC | G10/S90 W | 1.04 | 13.8 | 78.64 | 95.0 | 23.68 |
| SEPT 13/ 3 | AC | G10/S90 W | 1.19 | 16.82 | 74.89 | 80.0 | 21.73 |
| SEPT 19/ 1 | REBURN | G | 1.02 | 15.57 | 80.95 | 80.0 | 20.13 |
| SEPT 16/ 4 | 5 | G10/S90 W | 1.24 | 16.65 | 80.36 | 65.0 | 19.74 |
| SEPT 17/ 2 | AC | G10/S90 W | 0.99 | 15.39 | 70.57 | 90.0 | 19.17 |
| SEPT 17/ 6 | AC | G | 1.11 | 15.57 | 111.2 | 50.0 | 18.81 |
| SEPT 25/ 2 | M B40/W60 | S/G | 1.3 | 15.1 | 55.35 | 75.0 | 16.45 |
| SEPT 25/ 4 | AC | G30/S70 | 1.21 | 14.14 | 51.7 | 85.0 | 16.21 |
| SEPT 19/ 6 | AC OLD | G60/S40 | 1.07 | 14.4 | 51.38 | 90.0 | 15.08 |
| SEPT 19/ 2 | BUNKER | G20/S80 W | 0.6 | 15 | 84.7 | 95.0 | 14.72 |
| SEPT 25/ 1 | AC | G W | 0.7 | 14.8 | 67.27 | 95.0 | 13.64 |
| SEPT 16/ 7 | 5 | G/S | 0.84 | 15.42 | 65.53 | 75.0 | 12.58 |
| SEPT 18/ 3 | M C30/W70 | G | 0.96 | 15.54 | 86 | 50.0 | 12.58 |
| SEPT 24/ 1 | AC | G60/S40 | 0.57 | 14.87 | 71.86 | 96.0 | 11.99 |
| SEPT 16/ 6 | 5 | G10/S90 W | 0.54 | 15.72 | 118.37 | 60.0 | 11.69 |
| SEPT 12/ 4 | AC | G/S W | 0.584 | 16.85 | 75.47 | 80.0 | 10.75 |
| SEPT 19/ 5 | M B30/W70 | G | 1.11 | 15.02 | 62.9 | 50.0 | 10.64 |
| SEPT 18/ 6 | M B30/W70 | G W | 1.02 | 14.84 | 65.92 | 50.0 | 10.25 |
| SEPT 19/ 4 | M B30/W70 | G60/S40 W | 1.03 | 15.15 | 36.82 | 85.0 | 9.83 |
| SEPT 19/ 3 | BUNKER | G60/S40 W | 1.04 | 14.8 | 113.5 | 25.0 | 8.99 |
| SEPT 24/ 3 | AC | G W | 0.73 | 15.89 | 50.15 | 80.0 | 8.93 |
| SEPT 24/ 2 | M C40/W60 | G50S50 W | 0.74 | 16.4 | 39.4 | 90.0 | 8.00 |
| SEPT 13/ 2 | AC | G/S W | 0.381 | 16.04 | 70.12 | 96.0 | 7.82 |
| SEPT 13/ 6 | 5 | G10/S90 W | 0.62 | 15.05 | 52.4 | 60.0 | 5.94 |
| SEPT 18/ 5 | M C30/W70 | G | 0.89 | 14.86 | 39.74 | 50.0 | 5.39 |
| SEPT 13/ 5 | 5 | G10/S90 W | 0.38 | 15.7 | 75.84 | 50.0 | 4.39 |
| SEPT 25/ 3 | M C40/W60 | S/G | N/A | 14.3 | 65.13 | 95.0 | N/A |
| SEPT 17/ 3 | AC | G10/S90 W | 1.36 | N/A | N/A | 90.0 | N/A |
| | AVERAGE VALUES | | 0.94 | 15.41 | 82.08 | 75.75 | 16.65 |

AC-Alberta Crude Oil;B-Bunker C Oil;5-No. 5 Fuel Oil;M-Mousse;W-Water;Old-Aged.
M B30/W70 = Mousse (30% Bunker/70% Water).
C-Cobble;G-Gravel;S-Sand;W-Wet.
G60/S40 W = 60% Gravel/40% Sand (Wet).

Table F-4

Sorted test data: Advance rate

| TEST DATE | OIL TYPE | BEACH TYPE | OIL THICKNESS mm | FUEL RATE L/h | ADVANCE RATE m/h | VISUAL REMOVAL % | REMOVAL RATE L/h |
|---|---|---|---|---|---|---|---|
| SEPT 16/ 5 | 5 | G/S W | 1.1 | 16.36 | 196.59 | 40.0 | 26.37 |
| SEPT 17/ 5 | AC | G10/S90 W | 0.7 | 15 | 169.37 | 90.0 | 32.52 |
| SEPT 17/ 4 | AC | G10S90 W | 0.68 | N/A | 159.6 | 95.0 | 31.43 |
| SEPT 18/ 1 | M C50/W50 | G20/S80 W | 1.01 | 15.36 | 126.54 | 90.0 | 35.06 |
| SEPT 16/ 6 | 5 | G10/S90 W | 0.54 | 15.72 | 118.37 | 60.0 | 11.69 |
| SEPT 19/ 3 | BUNKER | G60/S40 W | 1.04 | 14.8 | 113.5 | 25.0 | 8.99 |
| SEPT 17/ 6 | AC | G | 1.11 | 15.57 | 111.2 | 50.0 | 18.81 |
| SEPT 18/ 2 | M C30/W70 | G20/S80 W | 0.97 | 14.87 | 98.29 | 90.0 | 26.15 |
| SEPT 18/ 3 | M C30/W70 | G | 0.96 | 15.54 | 86 | 50.0 | 12.58 |
| SEPT 19/ 2 | BUNKER | G20/S80 W | 0.6 | 15 | 84.7 | 95.0 | 14.72 |
| SEPT 19/ 1 | REBURN | G | 1.02 | 15.57 | 80.95 | 80.0 | 20.13 |
| SEPT 16/ 4 | 5 | G10/S90 W | 1.24 | 16.65 | 80.36 | 65.0 | 19.74 |
| SEPT 13/ 1 | AC | G10/S90 W | 1.04 | 13.8 | 78.64 | 95.0 | 23.68 |
| SEPT 16/ 1 | 5 | G/S W | 1.23 | 15.85 | 77.89 | 90.0 | 26.28 |
| SEPT 13/ 5 | 5 | G10/S90 W | 0.38 | 15.7 | 75.84 | 50.0 | 4.39 |
| SEPT 12/ 4 | AC | G/S W | 0.584 | 16.85 | 75.47 | 80.0 | 10.75 |
| SEPT 16/ 2 | 5 | G/S W | 1.34 | 15.68 | 75.4 | 80.0 | 24.64 |
| SEPT 13/ 3 | AC | G10/S90 W | 1.19 | 16.82 | 74.89 | 80.0 | 21.73 |
| SEPT 12/ 5 | AC | G20/S80 W | 1.58 | 17.03 | 72.9 | 70.0 | 24.58 |
| SEPT 24/ 1 | AC | G60/S40 | 0.57 | 14.87 | 71.86 | 96.0 | 11.99 |
| SEPT 17/ 2 | AC | G10/S90 W | 0.99 | 15.39 | 70.57 | 90.0 | 19.17 |
| SEPT 13/ 2 | AC | G/S W | 0.381 | 16.04 | 70.12 | 96.0 | 7.82 |
| SEPT 25/ 1 | AC | G W | 0.7 | 14.8 | 67.27 | 95.0 | 13.64 |
| SEPT 18/ 6 | M B30/W70 | G W | 1.02 | 14.84 | 65.92 | 50.0 | 10.25 |
| SEPT 16/ 7 | 5 | G/S | 0.84 | 15.42 | 65.53 | 75.0 | 12.58 |
| SEPT 25/ 3 | M C40/W60 | S/G | N/A | 14.3 | 65.13 | 95.0 | N/A |
| SEPT 19/ 5 | M B30/W70 | G | 1.11 | 15.02 | 62.9 | 50.0 | 10.64 |
| SEPT 25/ 2 | M B40/W60 | S/G | 1.3 | 15.1 | 55.35 | 75.0 | 16.45 |
| SEPT 13/ 6 | 5 | G10/S90 W | 0.62 | 15.05 | 52.4 | 60.0 | 5.94 |
| SEPT 25/ 4 | AC | G30/S70 | 1.21 | 14.14 | 51.7 | 85.0 | 16.21 |
| SEPT 19/ 6 | AC OLD | G60/S40 | 1.07 | 14.4 | 51.38 | 90.0 | 15.08 |
| SEPT 24/ 3 | AC | G W | 0.73 | 15.89 | 50.15 | 80.0 | 8.93 |
| SEPT 18/ 5 | M C30/W70 | G | 0.89 | 14.86 | 39.74 | 50.0 | 5.39 |
| SEPT 24/ 2 | M B40/W60 | G50S50 W | 0.74 | 16.4 | 39.4 | 90.0 | 8.00 |
| SEPT 19/ 4 | M B30/W70 | G60/S40 W | 1.03 | 15.15 | 36.82 | 85.0 | 9.83 |
| SEPT 17/ 3 | AC | G10/S90 W | 1.36 | N/A | N/A | 90.0 | N/A |
| | AVERAGE VALUES | | 0.94 | 15.41 | 82.08 | 75.75 | 16.65 |

AC-Alberta Crude Oil;B-Bunker C Oil;5-No. 5 Fuel Oil;M-Mousse;W-Water;Old-Aged.
M B30/W70 = Mousse (30% Bunker/70% Water).
C-Cobble;G-Gravel;S-Sand;W-Wet.
G60/S40 W = 60% Gravel/40% Sand (Wet).

## APPENDIX G

### Assumptions

Beach Length 2 km
Contamination Width 5 m
Total Area 1 hectare
Effect of tides on working time not considered.

Incinerator is owned, thus there are no costs for operation other than fuel/loader cost. Fuel cost based on experience with a rotary incinerator with fuel consumption of 90 - 180 L/h.

### Manual Removal

Manual Pick-up, helicopter transportation of debris boxes to barge or truck, truck transport to receiving area.

Material to be processed

30 mm x 10,000 sq m = 300 cu m
Time = 2 days @ 8 hours/day

### Equipment Removal

Bulldozer to scrape and windrow.
Front End-loaders to load trucks
Truck to Transport to dump sites; not more than 150 m haul.

Material to be processed
150 mm x 10,000 sq m = 1,500 cu m
(Wet sand density = 2019 kg/cu m)
= 3,029 tonnes
Time = 13 hours

### Beach Burner Removal

Beach burner to make two passes at 3 m wide each at an advance rate of 82 m/h

Beach burner transported by front-end loader.

Time = 48.7 hours

1) Manual Removal

Assuming a two day at 8 hr/day operation to clean 2 km of beach, or one hectare, and 3 cm depth of substrate removal. (See Appendix G for clean-up costs).

REMOVAL

| Equipment | Units | Costs |
|---|---|---|
| . Debris Box @ $90/day | 3 | $ 540.00 |
| . Helicopter @ $575/day | 1 | 1,150.00 |
| . Barge @ $400/day | 1 | 800.00 |
| . Truck @ $320/day | 2 | 1,280.00 |
| **Personnel** | | |
| . Workers @ $13.19/h | 50 | 10,552.00 |
| . Supervisors @ $23.50/h | 2 | 752.00 |
| | | $15,074.00 |

Material to be Processed

30 mm x 10,000 sq. meters = 300 cu m
= 606 tonnes
(Wet sand density = 2019 kg/cu m)
@ 16 hours operation = 38 tonnes/h

INCINERATION

At a processing rate of 10 tonnes/h, it would require 60.6 hours of operation.

| Equipment | Units | Costs |
|---|---|---|
| . Front End Loader @ $55.00/h | 1 | $ 3,333.00 |
| **Personnel** | | |
| . Operators @ $15.60/h | 3 | 2,836.00 |
| **Fuel** | | |
| . Propane @ $0.27/L | 4587 L | 1,238.96 |
| . Diesel @ $0.47/L | 1147 L | 539.00 |
| Total incineration cost | | $ 7,946.00 |

Appendix G - continued

REPLACEMENT

| Equipment | Units | | Costs |
|---|---|---|---|
| . Front-end Loader @ $55/h | 1 | $ | 220.00 |
| . Bulldozer @ $55/h | 1 | | 220.00 |
| . Dump Trucks @ $40/h | 2 | | 160.00 |
| **Personnel** | | | |
| . Operators @ $15.60/h | 4 | $ | 250.00 |
| **Support** | | | |
| . Fuel @ $0.46/L | 333 L | $ | 156.00 |
| . Barge @ $50/h | 1 | | 200.00 |

Assume replacement time is 4 hours based on 12 - 7.6 cu m truck loads per hour. (Appendix G)

| | |
|---|---|
| Total Replacement Cost | $1,206.00 |
| Total for Manual Clean-Up | $24,226.00 |
| To process one hectare of contaminated beach substrate to a depth of 3 cm with 95% efficiency | $24,226.00 |
| | or $242/100 sq m |

Appendix G - continued

2) Bulldozer/Front-End Loader Removal

Based on 150 m haul distance and 13 hours per hectare clean-up time.

REMOVAL

| Equipment | Units | Costs |
|---|---|---|
| . Bulldozer @ $55/h | 1 | $ 715.00 |
| . Front-End Loader @ $55/h | 4 | 2,860.00 |
| . Dump Trucks @ $40/h | 2 | 1,040.00 |
| **Personnel** | | |
| . Operator @ $15.60/h | 7 | $1,420.00 |
| **Support** | | |
| . Fuel @ $0.47/L | 1821 L | $ 856.00 |
| . Barge @ $50/h | | 650.00 |
| | Total Removal Cost | $7,541.00 |

Material to be Processed

| | | |
|---|---|---|
| 150 cm x 10,000 sq. meters | = | 1,500 cu m |
| (wet sand 2019 kg/cu m) | = | 3,029 tonnes |
| @ 13 hours operation | = | 233 tonnes/h |

INCINERATION

It will require 303 hours of operation. Incineration rate is 10 tonnes/h.

| Equipment | | |
|---|---|---|
| . Front-end Loader @ $55/h | 1 | $ 16,665.00 |
| **Personnel** | | |
| . Operator @ $15.60/h | 3 | 14,180.00 |
| **Fuel** | | |
| . Propane @ $0.27/L | 22,937 L | 6,193.00 |
| . Diesel @ $0.47/L | 5,734 L | 2,695.00 |
| | Total incineration cost | $ 39,733.00 |

Appendix G - continued

REPLACEMENT

| Equipment | Units | Costs |
|---|---|---|
| . Front-end Loader @ $55/h | 1 | $ 715.00 |
| . Bulldozer @ $55/h | 1 | 715.00 |
| . Dump Truck @ $40/h | 2 | 1,040.00 |
| **Personnel** | | |
| . Operators @ $15.60/h | 4 | 811.00 |
| **Support** | | |
| . Fuel @ $0.47/L | 1,083 L | 509.00 |
| . Barge @ $50/h | 1 | 650.00 |

Assume replacement time is 13 hours based on 23 - 7.6 cu m truck loads per hour. (Appendix G)

Total Replacement Costs $ 4,440.00

Total Clean-up Operation $ 51,714.00

To process one hectare of contaminated beach substrate to a depth of 22.8 cm, with 90% efficiency $ 51,714.00

or $517/100 sq m

Appendix G - continued

3) Beach Burner

REMOVAL

These costs assume a production model has a width of 3 meters with up to 10 fuel oil burners.

To clean 2 km of beach = 1 hectare:

Two passes of the machine are required to cover a beach width of 5 meters.

Therefore 4000 m @ 82 m/h = 48.7 hours

* Assume an oil removal on the average of 75%.

| Equipment | Units | Costs |
|---|---|---|
| . Loader @ $55/h | 1 | $2,679.00 |
| **Personnel** | | |
| . Operator @ $15.60/h | 2 | $1,599.00 |
| . Supervisor @ $23.50/h | 1 | 1,144.00 |
| **Support** | | |
| . Diesel @ $0.47/L | 7305 L | $3,433.00 |
| Total Cost for Clean-up Operation | | $8,855.00 |
| | | or $89/100 sq m |

## APPENDIX G

### Table G-1: Oil Spill Clean-up Costs

I. Labour Rates (dollars per hour)

| | Straight Time | | Overtime | | Double Time | |
|---|---|---|---|---|---|---|
| | range | average | range | average | range | average |
| Workman | $8.00-$21.25 | $13.19 | $10.80-$34.50 | $19.94 | $13.60-$40.00 | $22.57 |
| Equipment Operator | $9.00-$26.00 | $15.60 | $12.15-$48.00 | $23.05 | $15.30-$52.00 | $25.29 |
| Foreman | $13.00-$30.00 | $18.08 | $16.00-$45.50 | $26.32 | $19.00-$50.00 | $28.61 |
| Supervisor | $15.00-$35.00 | $23.50 | $20.00-$54.50 | $30.54 | $22.50-$60.00 | $33.61 |

II. Equipment Rental Rates (cost ranges)

| | | Cost per day (or hour, if indicated) |
|---|---|---|
| Compressors: | (based on flow capacity) | |
| | 85 - 200 CFM | $42.00 - $220.00 |
| | 201 - 600 CFM | $66.00 - $308.00 |
| | > 600 CFM | $96.00 - $330.00 |
| Generators: | (based on current capacity) | |
| | up to 4 KW | $ 16.00 - $ 60.00 |
| | 5 - 15 KW | $ 65.00 - $125.00 |
| | 50 - 150 KW | $550.00 - $750.00 |
| Heavy-Duty Equipment: | (based on size) | |
| | Backhoe | $ 96.00 - $480.00 |
| | Front end loader | $240.00 - $440.00 |
| | Tractor | $ 60.00 - $144.00 |

Table G-1 - continued

Mobilization Equipment:

| | |
|---|---|
| Helicopter, | |
| up to 3 hours | $165.00 - $310.00 per hour |
| more than 3 hours | $400.00 - $575.00 per day |
| | $ 75.00 - $ 95.00 per flight hour |
| Plane | $100.00 - $320.00 per hour |
| Commander trailer | $ 50.00 - $100.00 |
| Tank storage trailer (275-8000 gallons) | $ 7.00 - $ 50.00 |
| 4-wheel-drive truck | $ 34.00 - $160.00 |
| Tank storage truck (2000-9000 gallons) | $160.00 - $372.00 |
| Utility truck | $ 27.50 - $ 60.00 |
| 12-14 ft work boat (without outboard) | $ 40.00 - $ 60.00 |
| Boston Whaler work boat (without outboard) | $148.00 - $300.00 |
| 12-20 ft work boat (without outboard) | $ 56.00 - $240.00 |
| 30 - 40 ft work boat (diesel-powered) | $280.00 - $450.00 |
| Work barge | $ 38.00 - $ 50.00 |
| Vacuum pumping barge | $360.00 - $600.00 |

Pumps: (based on type and size)

| | |
|---|---|
| Centrifugal (1 - 3 inch) | $ 15.00 - $ 40.00 |
| Single Diaphragm (2-3 inch) | $ 28.00 - $ 50.00 |
| Double Diaphragm (2-3 inch) | $ 28.00 - $ 50.00 |
| High pressure | $ 48.00 - $ 75.00 |
| Moyno solids | $ 75.00 |
| Submersible (1-1/2-8 inch) | $ 24.00 - $280.00 |
| Dual Pass Strainer (2-6 inch) | $ 15.00 - $ 25.00 |

Table G-1 - continued

Skimmers:
(based on size and capacity)

| | |
|---|---|
| Disc or roll type | $100.00 - $760.00 |
| Single overflow Weir type | $ 30.00 - $480.00 |
| Adjustable overflow Weir type | $ 45.00 - $480.00 |
| Double advancing Weir type | $400.00 |
| Rotating porous belt type | $ 96.00 - $450.00 |

Support Equipment:

| | |
|---|---|
| Coppus air blower | $ 26.50 - $ 45.00 |
| Breathing equipment | $100.00 - $175.00 |
| Chemical cleaning unit | $380.00 |
| Communication equipment | $ 20.00 - $125.00 |
| Boom lights | $ 10.00 |
| Flood lights | $ 15.00 - $ 25.00 |
| 150-watt pneumatic lights | $ 12.00 |
| 500-watt mercury vapor lights | $ 14.50 |
| Sparkproof lights | $ 8.00 |
| High-pressure steam unit | $ 65.00 - $600.00 |
| High-pressure water washer (100 psi - 10,000 psi) | $ 25.00 - $520.00 |
| Hand dip nets | $ 1.00 - $ 10.00 each per day |
| Rakes, pitchforks, shovels | $ 1.00 - $ 10.00 each per day |
| Chain saws | $ 20.00 - $ 40.00 |
| Non-sparking tools | $100.00 - $125.00 |

Vacuum Equipment:
(based on storage capacity)

| | |
|---|---|
| Vacuum truck (<2000 gallons) | $268.00 - $360.00 |
| Vacuum truck (2000 - 4000 gallons) | $280.00 - $640.00 |
| Vacuum truck (>4000 gallons) | $448.00 - $800.00 |
| Vacuum pumping barge | $360.00 - $600.00 |

Table G-1 - continued

III. Materials and Supplies

Boom rental rates (dollars per foot per day):

| | 1st Day | | 2nd - 7th days | | 8th. - 15th days | | more than 15 days | |
|---|---|---|---|---|---|---|---|---|
| | range | average | range | average | range | average | range | average |
| Class I | $.50-$142. | $1.01 | $.50-$1.35 | $.85 | $.50-$1.35 | $.85 | $.50-$1.35 | $.85 |
| Class II | $.30-$1.50 | $ .94 | $.30-$1.25 | $.79 | $.24-$1.25 | $.68 | $.24-$1.25 | $.59 |
| Class III | $.35-$3.00 | $1.52 | $.35-$1.50 | $1.22 | $.25-$1.25 | $1.01 | $.28-$1.50 | $1.01 |

| | |
|---|---|
| Boom cleaning charges | $.25 - $1.50 per foot |
| Hose rental rates: | |
| Air hose (3/4 - 2 inch) | $.08 - $ .55 per foot |
| Fire hose (2-1/2 inch) | $.20 - $ .24 per foot |
| Discharge hose (1-1/2 - 6 inch) | $.16 - $ .76 |
| Suction hose (3-6 inch) | $.24 - $1.00 |
| Piston Film or Herder Chemical Costs: | |
| Oil Herder | $13.00 per gallon |
| Sorbent Costs: | |
| Particulate | $ 2.92 per pound |
| Perlite | $ 6.75 per bag |
| Polypropylene mop | $35.00 each |
| Polyurethane | $ 1.38 per cubic foot |
| Soda ash | $ .15 per pound |
| Sorbent blanket (35 inch x 200 ft) | $96.00 each |
| Sorbent fiber material | $ .28 - $ .40 per pound |
| Sorbent pads, | |
| 24 x 32 inch | $ 1.00 - $1.45 each |
| 17-1/2 x 17-1/2 inch | $ .52 each |
| Sorbent pillars, | |
| 14 x 25 inch | $7.40 - $8.00 each |
| 10 x 14 inch | $2.95 each |
| Sorbent rolls (150 ft) | $79.00 - $102.00 each |
| Sorbent sheets, | |
| 18 x 18 inch | $ .55 each |
| 36 x 36 inch | $2.10 each |
| Sorbent sweeps (100 ft) | $69.00 per bale |
| Sorbent strips (3 x 26") | $ .16 each |
| Straw | $5.00 per bale |
| Urethane foam sheets (54 x 36 inch) | $6.00 per pound |

## APPENDIX G

### Table G-2

### Logistic Requirements

The logistical requirements for using the bulldozer/front-end loader combination will vary with the haul distance between the pickup point and truck-loading area; as the haul distance increases more front-end loaders will be needed to maintain a reasonable cleaning rate. Table 805-6 gives logistical requirements for a 2-km (1.2 mi) length of beach.

LOGISTICAL REQUIREMENTS FOR BULLDOZER/FRONT-END LOADER(1) (Rubber-Tired) COMBINATION

| Item | 30 m (100-ft) Haul Distance | 150 m (500-ft) Haul Distance | Combined Cleaning Rate (hr/hectare) |
|---|---|---|---|
| Equipment | | | |
| . Bulldozer | 1 | 1 | |
| . Front-end loader (rubber-tired) | 2 | 4 | 12 1/2-13 |

| | No. of 10 cu yd Truck-Loads/hr. | No. of 20 cu yd Truck-Loads/hr. |
|---|---|---|
| . Dump Trucks | 23* | 12* |

Personnel - 1 operator for each piece of equipment

| Support | Diesel Fuel Requirements (gal/hr) | Bucket Capacity (cu yd) |
|---|---|---|
| . Front-end loader | 5 - 5.1 | 2 |
| (rubber-tired) | 13.5 - 14.5 | 5 |
| . Bulldozer | 4 - 14 | |
| . Dump truck | 6 - 12 | |

Access requirements - heavy equipment, barge, or landing craft

Note: Cleaning rates based on bucket capacity of 3 cu yd 2/3 full.

* Based on a cleaning rate of 13 hr/hectare (5.26 hr/acre) and 1500 cu m/hectare (794 cu yd/acre) of material removed.

(1) Oil Spill Clean-up Protection Techniques for Shorelines and Marshlands, A. Breuel, 1981.

## APPENDIX G

### Table G-3

### Logistical Requirements for Manual Removal of Oiled Material

| Item | For Light or Sporadically Oiled Shoreline | For Heavily Oiled Shoreline |
|---|---|---|
| **Equipment** | | |
| . Debris box | 2 | 3 - 4 |
| . Helicopter (if used) | 1 | 1 - 2 |
| . Boat or barge (if used) | 1 | 2 - 3 |
| . Truck (if used) | 1 | 2 - 3 |
| **Personnel** | | |
| . Workers | 10 - 20 | 50 - 100 |
| . Supervisors | 1 | 2 - 3 |

Access requirements - light vehicular, shallow craft, or helicopter.

## APPENDIX H

### Kubota KH-35 Excavator Specifications

**Machine Weight**

Operating weight incl. boom, 740 mm arm, 400 mm bucket, steel crawler, lubricant, coolant and full fuel tank.

| | |
|---|---|
| Canopy Type | 1235 kg |
| Cabin Type | 1350 kg |

**Engine**

Type --- 4 cycle, water-cooled, overhead valve diesel engine.

| | |
|---|---|
| Maximum Torque | 4.8 kg-m @ 1600 rpm |
| No. of cylinders | 3 |
| Displacement | 855 cc |

**Hydraulics**

Capacity (discharge flow) @ engine 2200 rpm:
12,100 cc x 2 @ 195 kg/sq cm
7,800 cc x 1 @ 195 kg/sq cm

Relief valve settings:

| | |
|---|---|
| Implement circuits | 195 kg/sq cm |
| Travel circuits | 195 kg/sq cm |
| Swivel circuits | 170 kg/sq cm |

Hydraulic motors:
Travel - Axial piston motor with counterbalance valve (2 units)
Swing - Axial piston motor with brake valve

**Steering**

Minimum tail turning radius - 1080 mm

**Drives**

Maximum travel speed - 1.95 km/h (1.2 rpm)

## Swing System

| | |
|---|---|
| Swing Speed - | 9.1 rpm |
| Boom Swing angle (left/right) | 100 (50/50 ) degrees |

## Undercarriage

| | |
|---|---|
| Shoe width | 230 mm |
| Ground pressure (canopy type) | 0.24 kg/sq cm |
| (cabin type) | 0.26 kg/sq cm |

## Coolout & Lubricant Capacity

| | |
|---|---|
| Fuel tank | 19 L |
| Coolant | 4.2 L |
| Engine | 2.1 L |
| Final drive (each side) | 1.6 L |
| Swing drive | 0.6 L |
| Hydraulic tank | 24 L |

## General Specifications

| | |
|---|---|
| Maximum digging force @ bucket teeth | 860 kg |
| Maximum digging depth | 2245 mm |
| Maximum digging height | 3140 mm |
| Maximum dumping height | 2155 mm |
| Maximum digging radius | 3715 mm |
| Minimum boom swing radius | 1440 mm |
| Grade ability | 58% (30 degrees) |

## APPENDIX I

### Equipment Price Quote

| ITEM DESCRIPTION | BOX | TRACTOR | TRAILER |
|---|---|---|---|
| Burner Structure (Frame) | 6,780.00 | | |
| Cerwool Lining | 2,550.00 | | |
| Refractory Skirting (Siltemp) | 223.70 | | |
| Burner Housing and Nozzle | 3,980.00 | | |
| Burner Air Supply Tube | 280.00 | | |
| Flexible Burner Wall (Pyroboom) | 908.00 | | |
| Kabota KH-35 Excavator | | 22,000.00 | |
| Burner Electrical on Box | 96.00 | | |
| Burner Fuel Lines on Box | 103.00 | | |
| Tachometer | | 229.00 | |
| Two K-type Thermocouple Head/ Probe Assemblies | 160.00 | | |
| 8 m WK-20 Thermocouple Wire | 25.00 | | |
| Analog Temperature Meter | | 300.00 | |
| 2.2 kw 110V 15 AMP Generator | | | 990.00 |
| Support Trailer | | | 900.00 |
| Drum Connection | | | 200.00 |
| Axial Blower | | | 751.00 |
| Fuel Pump with Filter | | | 172.00 |
| Bevel Gear Drive | | | 195.71 |
| Hydraulic Motor | | | 201.06 |
| Blower Drive Shafts and Couplings | | | 85.00 |
| Blower and Drive Gear Support | | | 80.00 |
| Power Supply to Tachometer | | | 60.00 |
| Hydraulic Hoses Kabota - Trailer | | | 58.00 |
| 110V Electrical Connection Kabota - Trailer | | | 30.00 |
| 110V Electrical Connection Kabota - Box | | | 30.00 |
| Combustion Air Supply Duct | | | 132.00 |
| Fuel Line Tank - Pump | | | 28.00 |
| Fuel Line Pump - Box | | | 36.00 |
| Control Console including Valve | | 300.00 | |
| Kubota Trailer Hitch | | 220.00 | |
| Excavator Arm Connector Pins | | 166.00 | |
| Closed Cab for Kabota | | 5,580.00 | |
| Trailer Tires | | | 170.00 |
| | 15,105.70 | 28,795.00 | 4,118.77 |

TOTAL FOR COMPLETE SYSTEM $ 48,019.47

Not including taxes, overhead
and profits.

REFERENCES

## REFERENCES

Breuel, A. (Editor). Oil Spill Cleanup and Protection Techniques for Shorelines and Marshlands. Noyes Data Corporation, Park Ridge, New Jersey, 1981.

Environment Canada, P.E.I. Coastal environments and the clean-up of oil spills, Technical Review Report EPS-3-EC-79-5. p. 122-140.

Regional Program Report 79-28, E.P.S., December 1979.

Fussell, D.R. Inland oil spill clean-up manual. Report No. 7/81 Concawe, June 1981.

International Maritime Organization. Manual on Oil Pollution Section IV. Practical information on means of dealing with oil spillages. London 1980. p. 100-103.

International Tanker Owners Pollution Federation Limited. Measures to Combat Oil Pollution. Graham and Trotman Limited, 1980.

1977 Proceedings, Oil Spill Conference. Library of Congress Catalog No. 75-4161. p. 39-44.

Twardus, E. 1980. Proceedings of the Third Arctic Marine Oilspill Program Technical Seminar, Edmonton, Alberta. p. 385-401.

McAllister, I.R. 1983. The development and testing of a fireproof boom. In: Proceedings, Oil Spill Conference, Library of Congress Catalog No. 75-4161. p. 43-53.

1985 Proceedings, Oil Spill Conference, Library of Congress No. 75-4161.

Oudenhoven, J.A.C.M. Van. Disposal Techniques for Spilt Oil. Report No. 9/80, Concawe, 1980. p. 13-46.

Pertile, L., 1986. Proceedings of the Ninth Arctic Marine Oilspill Program Technical Seminar, Edmonton, Alberta. p. 237-244.

Twardus, E., 1980 Insitu combustion: an oil spill countermeasure for Arctic shorelines. In: Proceedings of the Third Arctic Marine Oilspill Program Technical Seminar, 1980.