DEVELOPMENT AND EVALUATION OF CONTINUOUSLY-BURNING WICKING DEVICES FOR BURNING OIL SLICKS

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ABSTRACT

This report describes partially completed research concerned with the development and evaluation of continuously-burning wicking devices that can be air deployed onto Arctic oil slicks. It is felt that these devices may have an advantage over in-situ pool combustion.

Oil transport properties and pore sizes were examined for several potential wicking materials. A prototype for the ignition of the burners has been designed and is under construction.

Improvements are to be made on the burners employing a drip-feed mechanism for oil delivery to burners.

1.0 INTRODUCTION

The in-situ combustion of oil on water is never complete and requires a minimum oil thickness for ignition. The use of continuously-burning wicking devices to clean up Arctic oil slicks may be more effective than direct burning techniques.

The operation of these devices is dependent upon the capillary rise (or transport) of oil through the wick and upon the vapourization and combustion of oil by the burner. Either of these processes could serve as the rate-controlling step in the operation of these devices.

Previous research in regards to such burners is limited. Gulf Oil of Canada, Ltd. has developed the "Beehive" burner, which employs porous concrete as the wicking material. Canadian Marine Drilling, Ltd. has tested a burner that employed Terra Fibre pad as the wick. Neither one of them was designed for one-month continuous operation.

Environment Canada. Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 1st. Proceedings. March 15-17, 1978, Edmonton, Alberta, Canada, Environment Canada, Ottawa, Ontario, 164-178 pp, 1978.

The main requirements for these devices are;

(1) to have a minimum oil consumption rate of 0.5 gallons per hour

(2) to be capable of operating without outside assistance for a minimum period of one month

(3) to be self-ignited (either after landing or before deployment) in a safe and simple manner

(4) to be as light and compact as possible to minimize the number of required aircraft missions

(5) to be capable of floating freely above a maximum water height of 10 cm.

2.0 MATERIALS SELECTION

2.1 Properties of Wicking Materials

Ideal wicking materials should have the following properties:

(a) hydrophobic (water-repelling)

(b) oleophillic (oil-absorbing)

(c) flame resistant and non-combustible

(d) contain channels of optimum capillary diameter for oil uptake

(e) amenable to fabrication.

Since crude oil has a lower surface energy value (50 ergs/cm^2) than water (72 ergs/cm^2), solid materials with critical surface energy values between 30 and 72 ergs/cm^2 would be both oleophillic and hydrophobic. Some materials were treated with coatings (silicone, for example) so that their surfaces would satisfy these conditions.

For optimum performance, pore sizes should be different in the upper and lower regions of the wick in order to account for differing viscosity and surface tension values of oil in these regions. The best material would contain continuous channels that converge near the top of the wick. Unfortunately, such materials were not available for this application.

For wicking systems consisting of many small-diameter and interconnecting pores or capillaries, the rate of oil entry (v) can be shown to be directly proportional to the radius, and inversely proportional to the oil viscosity, as shown in equation (1);

$$v = \frac{r\,\gamma_{LV}}{4\,d\eta} \qquad (1)$$

where: r = radius of curvature for the capillary, cm

γ_{LV} = surface tension of the oil, dynes/cm

η = oil viscosity, poises

d = penetration depth, cm.

The actual height (h) to which oil would rise in a vertical capillary is given by equation (2):

$$h = \frac{\gamma_{LV}}{\frac{1}{2}\,r\rho g} \qquad (2)$$

where: ρ = the oil density (g/cm^3)

g = the acceleration due to gravity (980 cms/sec^2)

From these equations an optimum capillary radius (or pore size) can be determined for the most effective uptake of oil.

2.2 Evaluation of Wicking Materials

To date, size materials have been evaluated as wicking materials:

(1) Nomex (nylon felt)

(2) Kevlar-29 (aromatic polyamide felt)

(3) 3M Brand Absorbing Microfibre (polyethylene sheets)

(4) Interwoven polypropylene cord

(5) Tyvek (spun-bonded polypropylene sheets)

(6) Typar (spun-bonded polyethylene sheets).

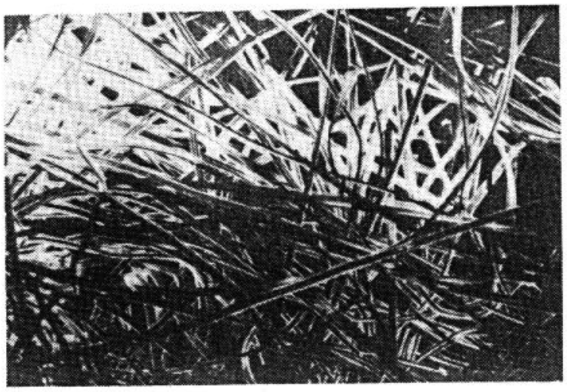
Nomex and Kevlar-29 were chosen because they would not melt or burn easily. 3M Brand Absorbing Microfibre, interwoven polypropylene cord, Tyvek, and Typar were chosen because of their reputation as oil sorbent materials. Capillary tubes would have been considered ideal for the tests, but were not made available in the small diameters required. Other materials (included treated sintered bronze metal) shall be tested in the future.

Oil transport rates were determined for each material (see Table 1). In general, Nomex and interwoven polypropylene cord materials performed best in the tests. All size of the materials would have to be protected from the flame of a burner, because they are not combustion resistant.

The structure of the materials tested is shown in Figure 1 and 2, TABLE #1*

Wicking Material	Oil Thickness (mm)	Oil Transported After 2 hours (cm^3)	Oil Transport Rate (cm^3 per hour per inch width)	Material Perimeter for 0.5 gal/hr consumption rate (inches)
Nomex	3.0	100	50	45.4
Interwoven Polypropylene cord	3.0	60	30	75.7
Kevlar-29	3.0	13	6.5	
3M-Brand Absorbing Microfibre	3.0	10	5	454.7
Typar	3.0	0	0	N/A
Tyvek	3.0	0	0	N/A

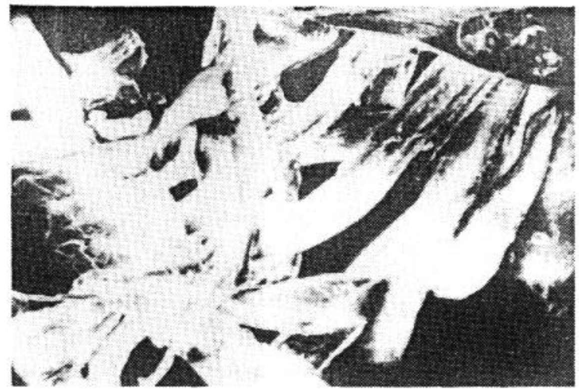
*Tests conducted with Norman Wells crude oil at room temperature.



100μ

NOMEX

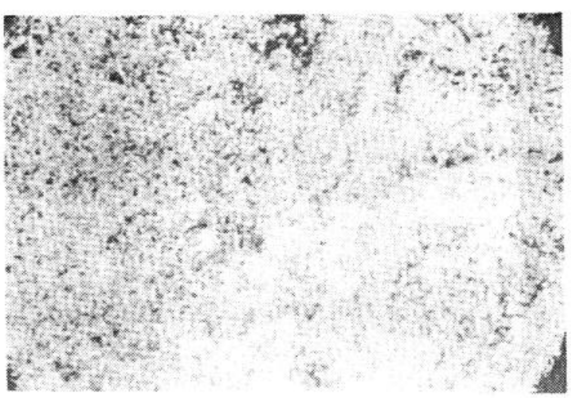
MAGNIFICATION 100X



100μ

CONWEB

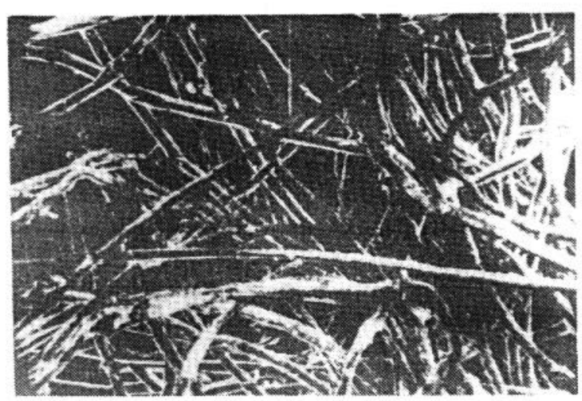
MAGNIFICATION 100X



50μ

TYVEK STYLE 1421F

MAGNIFICATION 200X

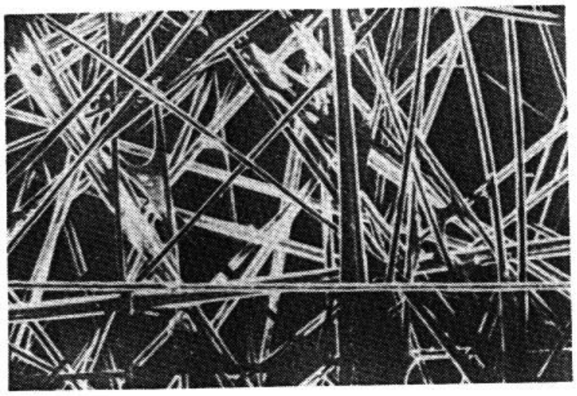


50μ

KEVLAR FELT

MAGNIFICATION 200X

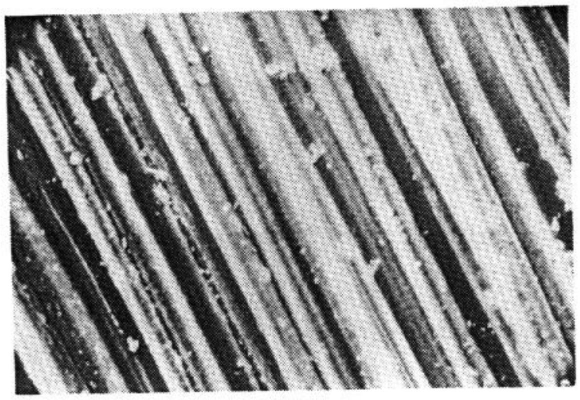
Fig. 1 WICKING MATERIALS



100μ

FIBERGLASS I

MAGNIFICATION 100X



30μ

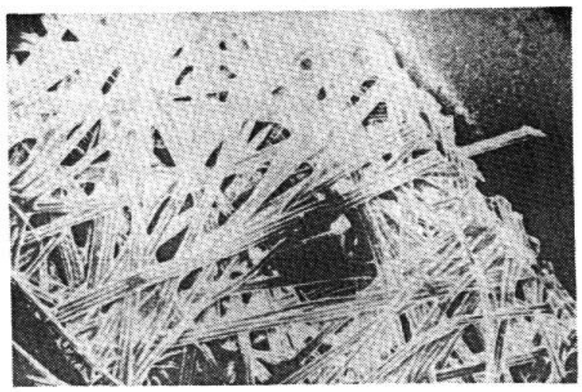
FIBERGLASS II

MAGNIFICATION 350X

400μ

POLYPROPYLENE

MAGNIFICATION 25X



100μ

TYPAR

MAGNIFICATION 100X

Fig. 2 WICKING MATERIALS

where it can be seen that none of the materials tested have the optimum structure for the maximum rate of oil transport.

3.0 BURNER DESIGN

3.1 Linkage and Control of Wicking and Combustion Processes

Burners equipped with drip-feed apparatus were constructed and tested (see Figures 3 and 4). The drip-feeding mechanism was desired since the plugging of the wick pores by carbon deposits would not occur with this design.

In the tests, the burners operated effectively for a maximum period of one hour. After this time, the flames spread over the entire slick, completely destroying the wicking material. Work is in progress to eliminate this problem.

Although considered less practical than drip-feeding mechanisms, oil/wicking storage pads could also be used to dispose of oil slicks.

3.2 Burner Ignition

Three activation techniques were considered for the ignition of burners:

(1) Timing system
(2) Oil slick detection
(3) Radio signals.

The timing system was considered as the most reliable and inexpensive method and a prototype for this system (see Figure 5) was built and tested. The oil detection system was not considered as reliable as the timing system, and shall be used only as an alternative to the timing system. The application of radio signals was considered too expensive for burner ignition.

3.2.1 Burner Ignition By Timing System. The timing system consists of three components:

(1) Timing mechanism
(2) Ignition device (glow plug) and control
(3) Fuel supply (gasoline or propane).

The timing mechanism is identical for both types of fuel injection. However, there are several subtle differences in their operation. The

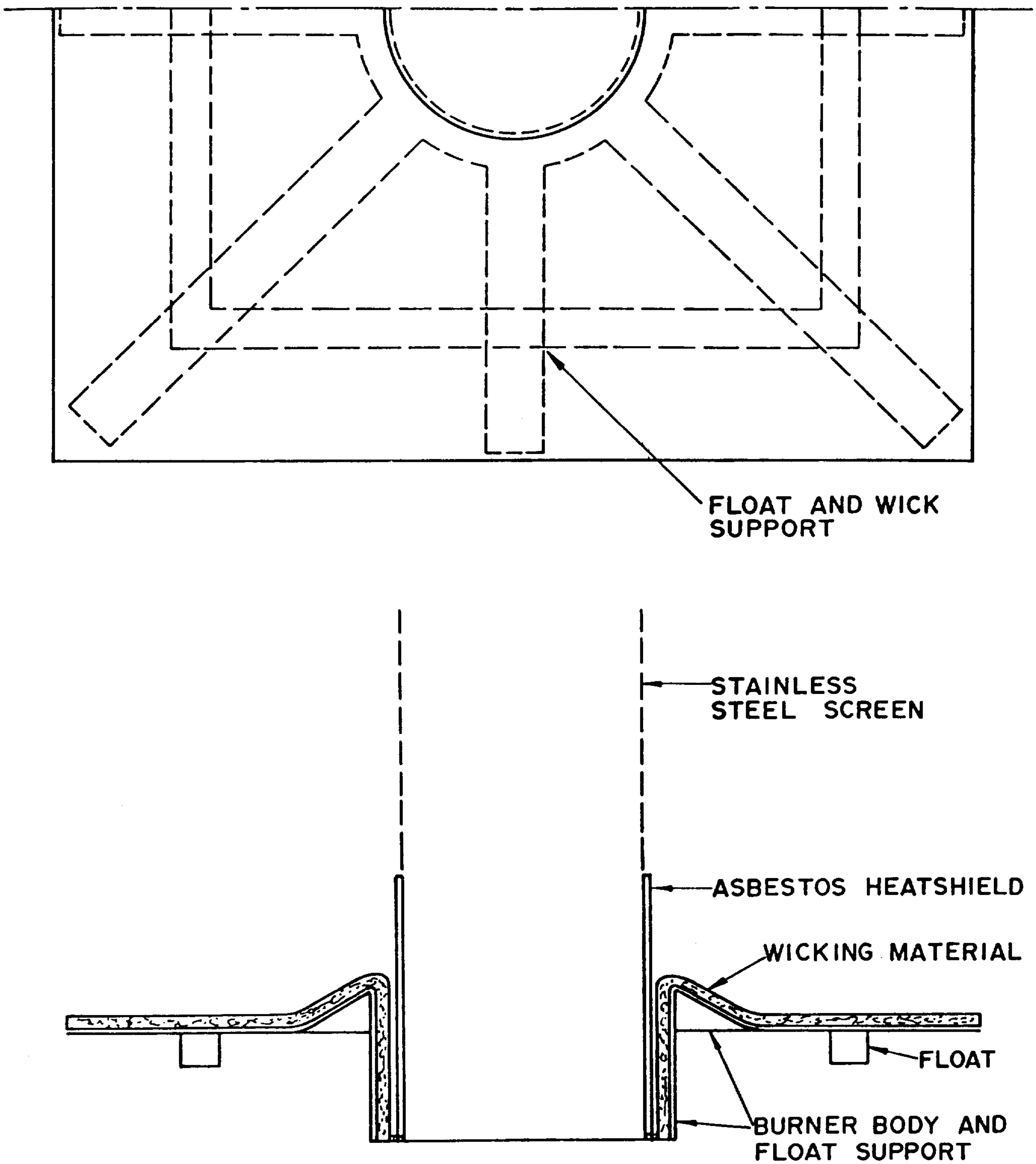


FIG. 3 Nº 1 WICKING BURNER

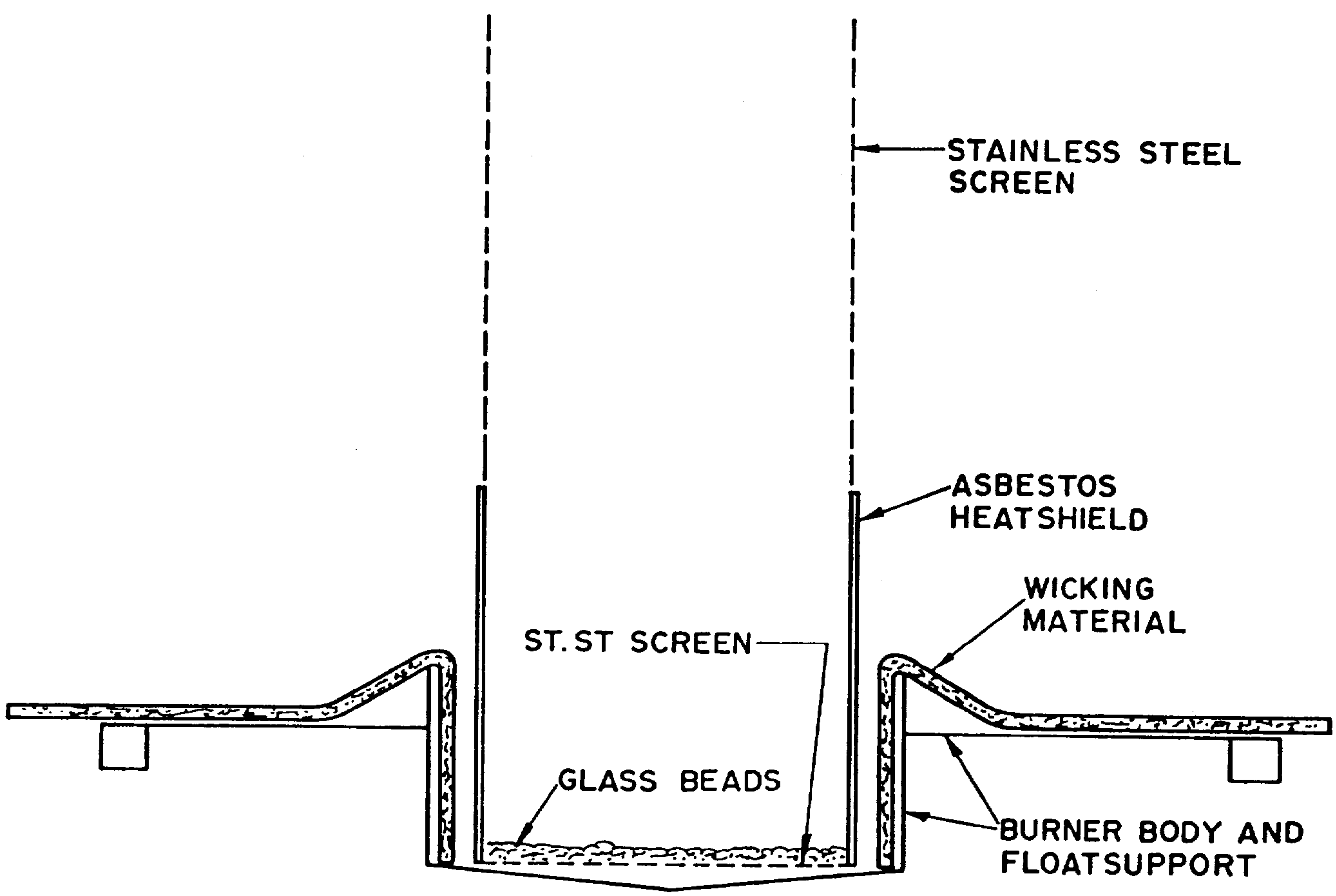


FIG.4 №2 WICKING BURNER

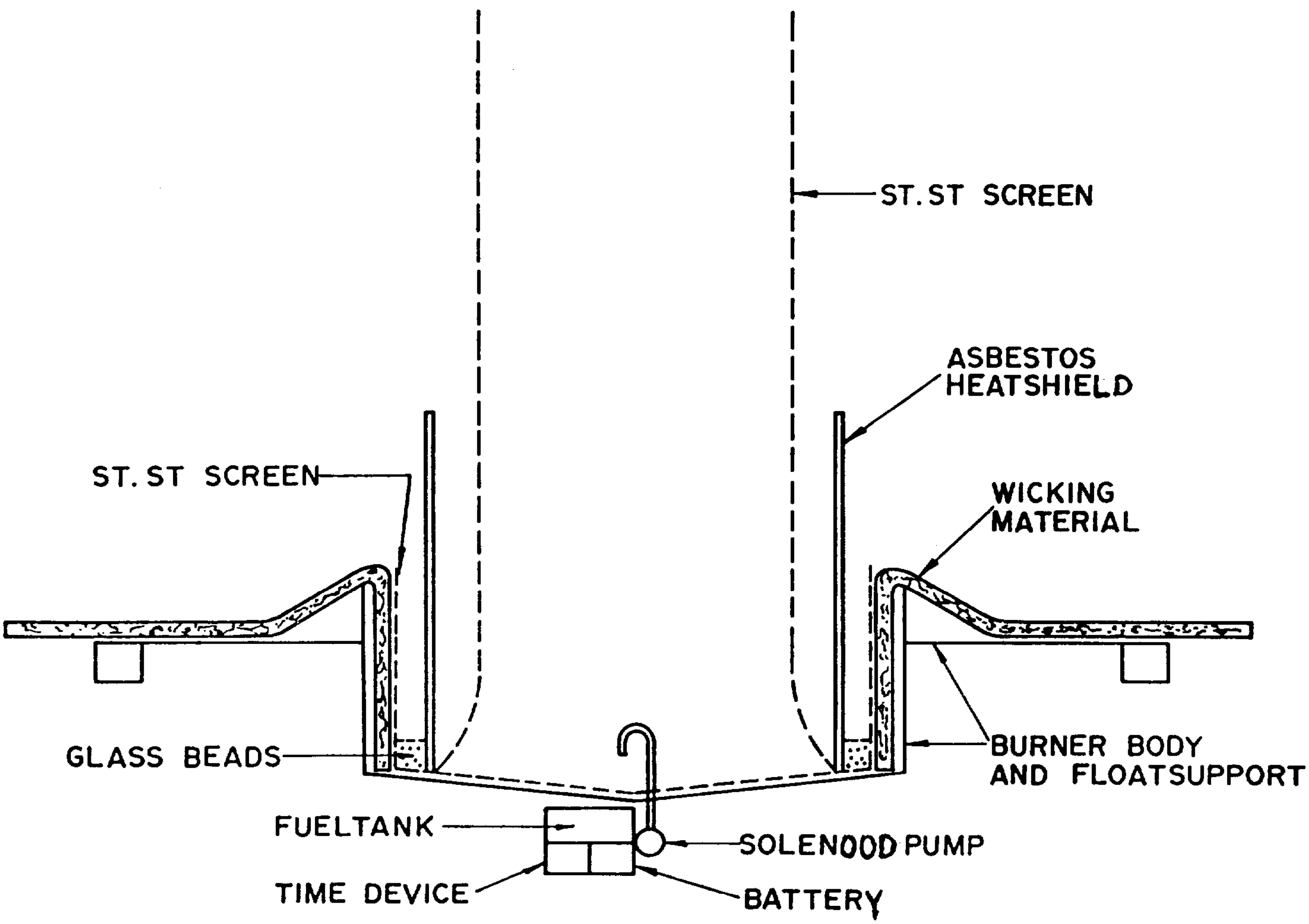


FIG.5 Nº 3 WICKING BURNER

ignition timer is designed to ignite crude oil collected in the burner every 24 hours for a minimum operating period of 30 days. The first ignition cycle is to occur 12 hours after air deployment. Two different fuel injection systems (for gasoline and propane fuels) shall be evaluated for use with the timing device. The time circuits (see Figure 6) are battery-powered, sealed units, which have a shock level of one g.

For the gasoline injection mechanism (see Figure 7), a fixed amount of gasoline is injected into the burner by means of a solenoid-operated piston pump. The minimum required activation time for the solenoid is approximately one second. Since a certain period of time is required for gasoline volatization, the glow plug is to be activated for a minimum period of 2.5 seconds.

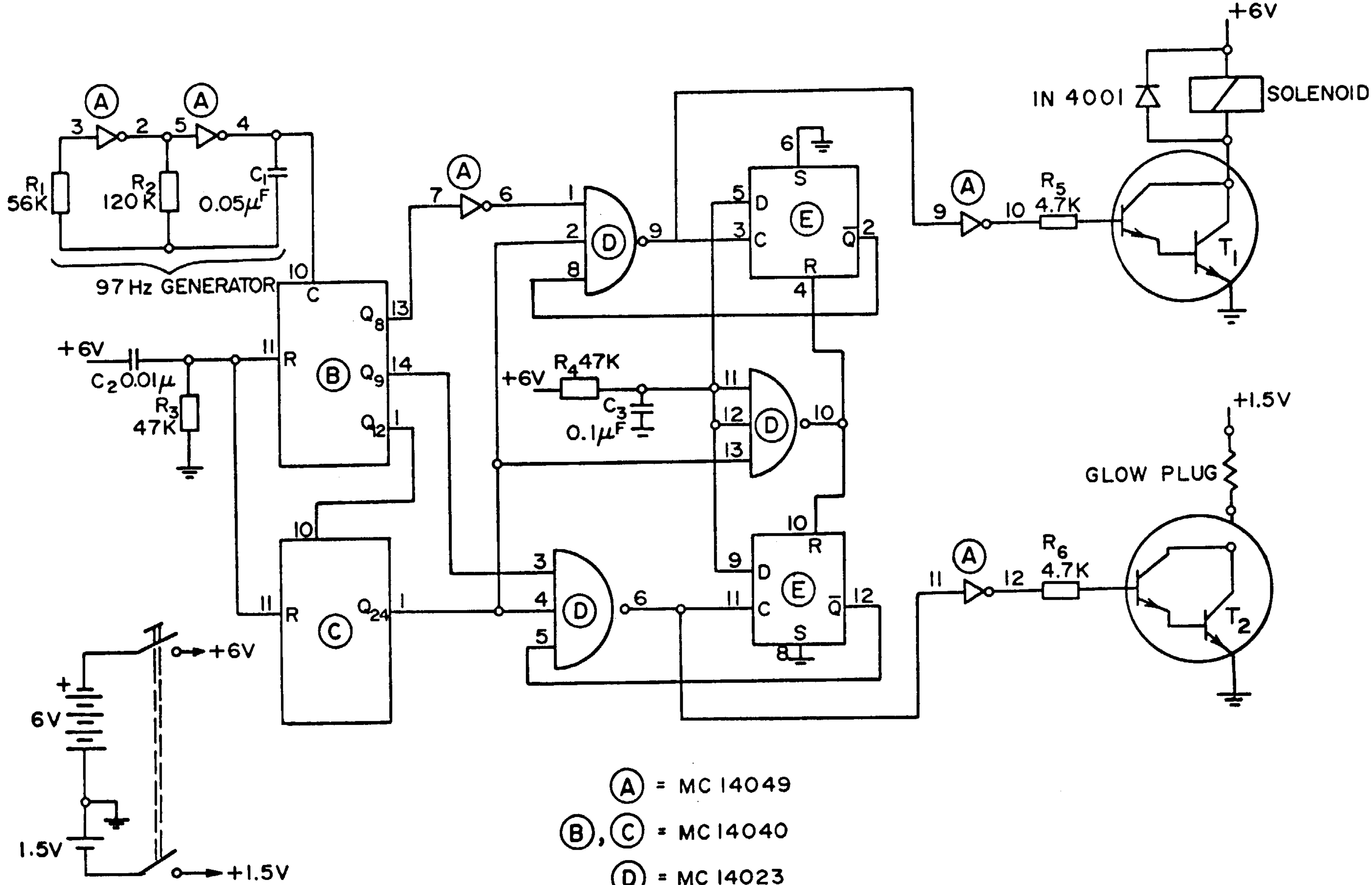
For propane injection (see Figure 8), a solenoid-operated valve shall be opened for approximately 20 seconds. Upon opening of the valve, the glow plug will be simultaneously activated for a period of one second for propane ignition.

3.2.2 Burner Ignition By Oil Slick Detection. This system consists of three components:

(1) Oil detector
(2) Ignition device (glow plug and control)
(3) Fuel supply (gasoline and butane).

The detector consists of a float, two identical thermistors (one located just below the float and the other deeper into the water) and an electronic control device. Equal current is supplied to both thermistors and the power dissipation is such that the thermistors will heat up to a temperature above that of their environment. When both thermistors are submerged in water, the temperature of the thermistors is equal and the differential voltage between thermistors is kept at zero.

If an oil layer of sufficient thickness is present, the upper thermistor is immersed in oil, and consequently becomes hotter (due to the difference in heat transfer coefficients betweeen oil and water) than the lower thermistor. Assuming that the thermistors have negative heat transfer coefficients, there shall be a voltage drop over the upper thermistor. The electronic control device shall then detect the differential voltage between



Ⓐ = MC 14049

Ⓑ, Ⓒ = MC 14040

Ⓓ = MC 14023

Ⓔ = MC 14013

T_1, T_2 = DARLINGTON TRANSISTOR

FIG. 6 TIMING CIRCUIT DIAGRAM FOR GASOLINE IGNITION

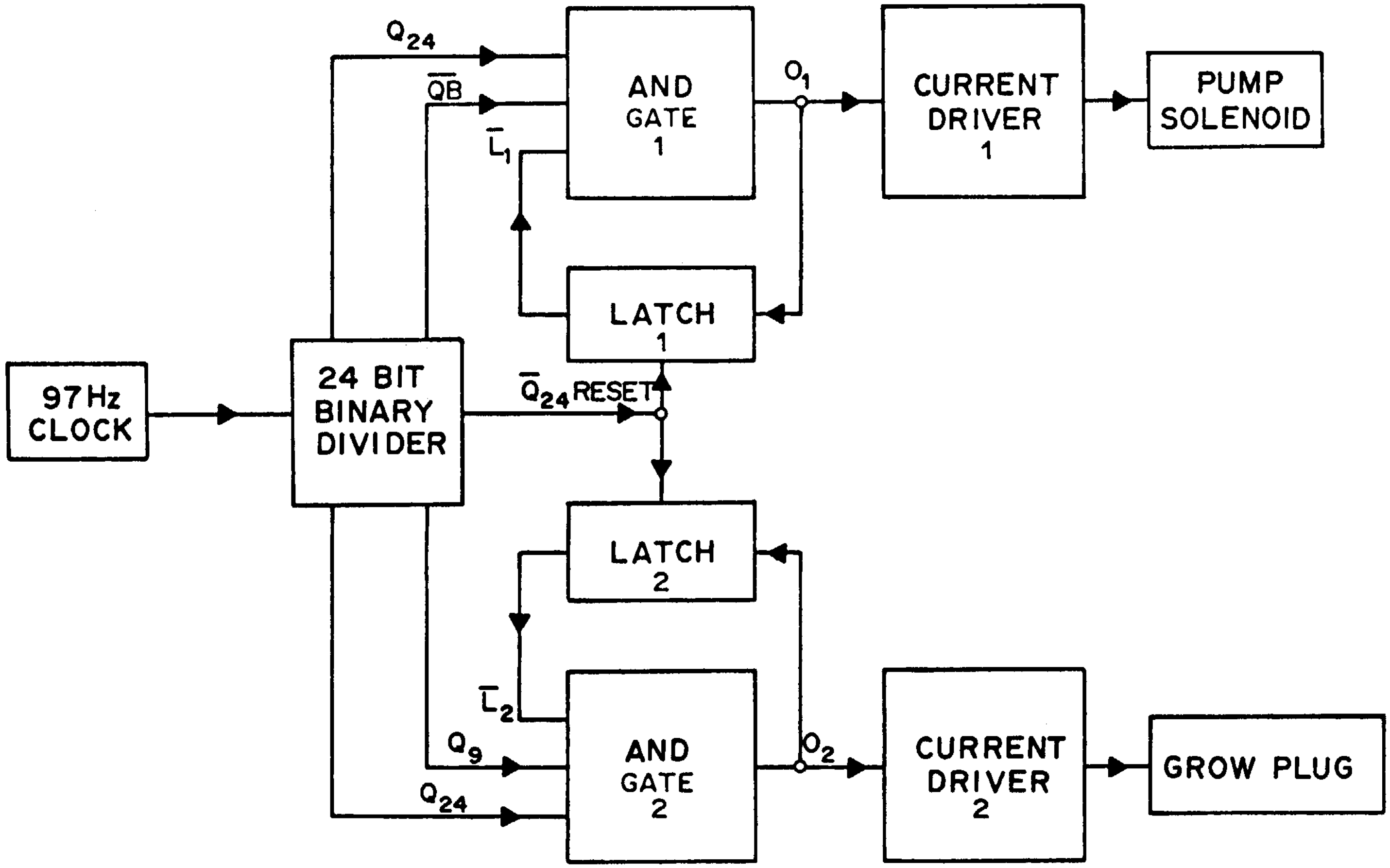


FIG. 7 FUNCTIONAL DIAGRAM OF TIMING CIRCUIT FOR GASOLINE IGNITION

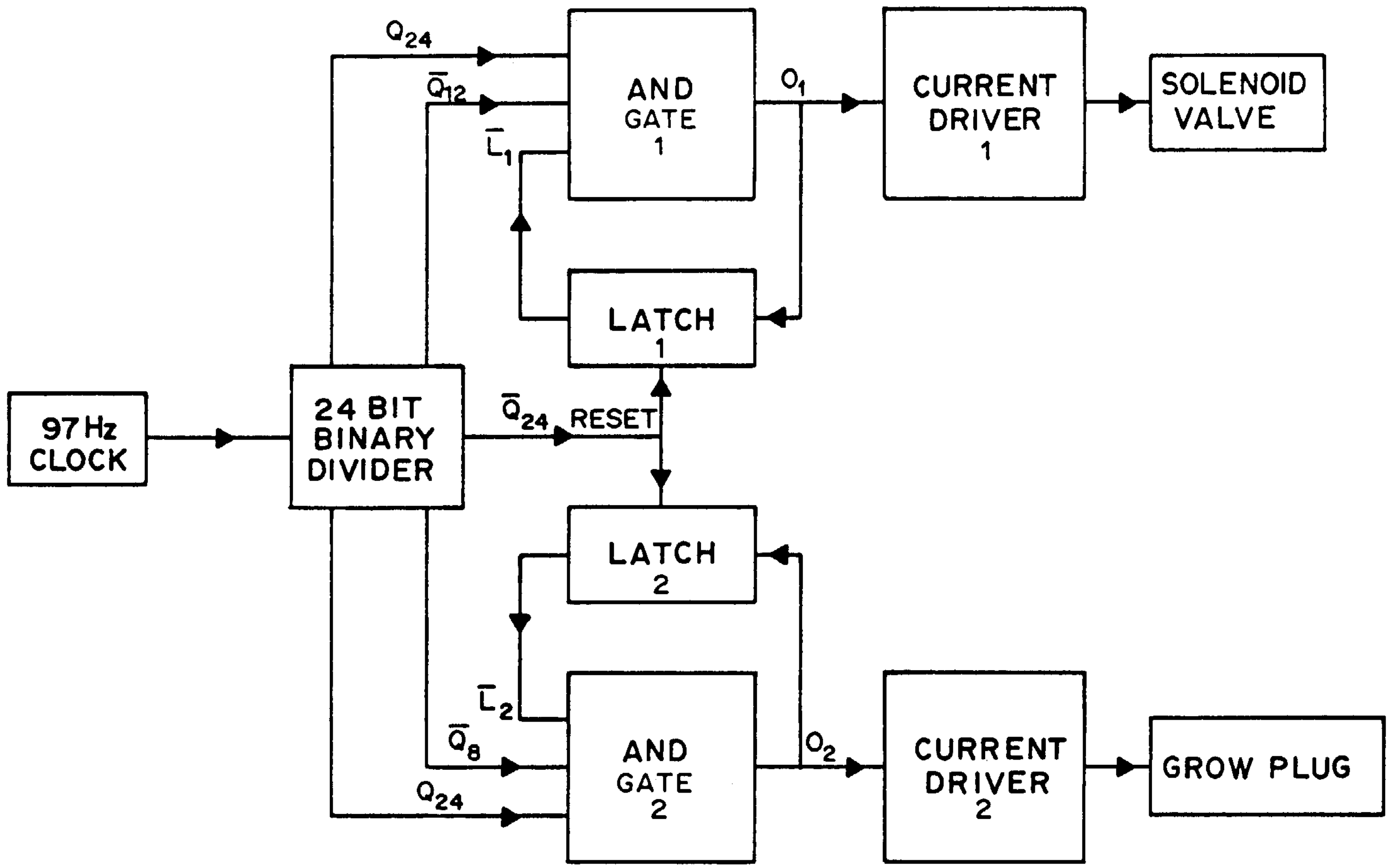


FIG. 8 FUNCTIONAL DIAGRAM OF TIMING CIRCUIT FOR PROPAVE IGNITION

the thermistors, and then activates a power supply, which heats the glow plug and releases fuel into the burner. Fuel release and glow plug activation are discussed in the previous section.

3.3 Summary

1. Burners equipped with drip-feed wicking devices have been proven partially successful.

2. The timing mechanism was the preferred method for burner ignition. A prototype was built and evaluated.

3. To date, Nomex felt is considered the most suitable wicking material out of six materials tested, and would require a wick perimiter of 46 inches to supply 0.5 gallons of crude oil per hour to the burner.