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A Small Vacuum Oil Skimming System

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A SMALL VACUUM OIL SKIMMING SYSTEM

by

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Project 15080 FVP

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ABSTRACT

An oil-slick collection system suitable for use on harbor craft is described. This system employs a pneumatic-powered vacuum cleaner to collect oil from the water surface by entrainment in a high-velocity air stream. The components are widely available commercial items.

Tests show the system to be successful in picking up No. 4 fuel and lighter oils. The collection rate depends chiefly on the rate of oil supply to the skimmer.

This report was submitted in partial fulfillment of Project Number 15080 FVP under the partial sponsorship of the Water Quality Office, Environmental Protection Agency.

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CONCLUSIONS

The system described herein, for use by readily available harbor craft to pick up floating oil, has been shown to be effective in picking up No. 4 fuel and lighter oil in tests. No. 6 fuel oil, especially when cold, tends to clog the system. The components are generally available off-the-shelf items. The only power required is compressed air, although in large quantities.

Oil collection rates are limited (on small spills) primarily by the rate of approach of oil to the intake.

By the proper operation of the system, oil leaks can be eliminated. Operating personnel can, therefore, avoid physical contact with oil, and slipping accidents on oily decks can be prevented.

SECTION II

RECOMMENDATIONS

1. The pick-up system described herein was designed originally as auxiliary equipment to enable the clean up of oil and other test substances used in evaluating fire streams and various types of boom as spill control devices. While it works extremely well with the less viscous oils, the aperture and tubing diameters are probably too small to enable the rapid pick-up of the viscous fractions such as bunker "C"; therefore, development of a larger system is suggested.

2. When placed at the apex of a boom corner, with fire streams pushing the oil into the corner, this device proved to be very efficient. The effectiveness of any skimmer depends on the thickness of the oil layer in its vicinity. We, therefore, recommend that any skimmer, whenever possible, be operated as close as possible to the apex of a corner, pocket, or cul-de-sac into which the oil is being herded.

SECTION III

INTRODUCTION

The oil slick collection system described in this report is a vacuum-operated system which entrains oil, water and small debris in a high-velocity air stream for delivery to a vacuum tank separator, from which the oil can be pumped to storage containers and the water discharged. This system was designed to fill a perceived need for a system to pick up harbor oil spills that would be adaptable to fireboats, towboats and other available harbor craft.

The use of harbor craft for rapid initial response is attractive primarily because of their availability. Fireboats, for example, are on 24-hour call in many major ports, and can arrive within 10 - 15 minutes of a call (in New York Harbor). Coast Guard craft also have emergency response capabilities, and towboats are generally available in most ports. Moreover, these craft have other jobs to do; therefore, the cost of maintaining craft exclusively for oil spill control is avoided. This same fact poses complications, however. Equipment cannot be stored on board that would impair these crafts' primary functions, and both the equipment and method of operation should preclude the spillage of oil on personnel or decks. Fireboats, in particular, may have to respond to a fire from an oil spill, and oily decks would pose a substantial safety hazard.

The system described in this report is an application of the air-entrainment pick-up process found in the use of the vacuum-type catch basin cleaners to pick up oil slicks, within the constraints generated by the use of harbor craft. The particular prototype system constructed was designed around the facilities available on the fireboats of the Fire Department of New York; while many variations are possible to meet local conditions and take advantage of locally available components, further development of engineering design criteria is still underway.

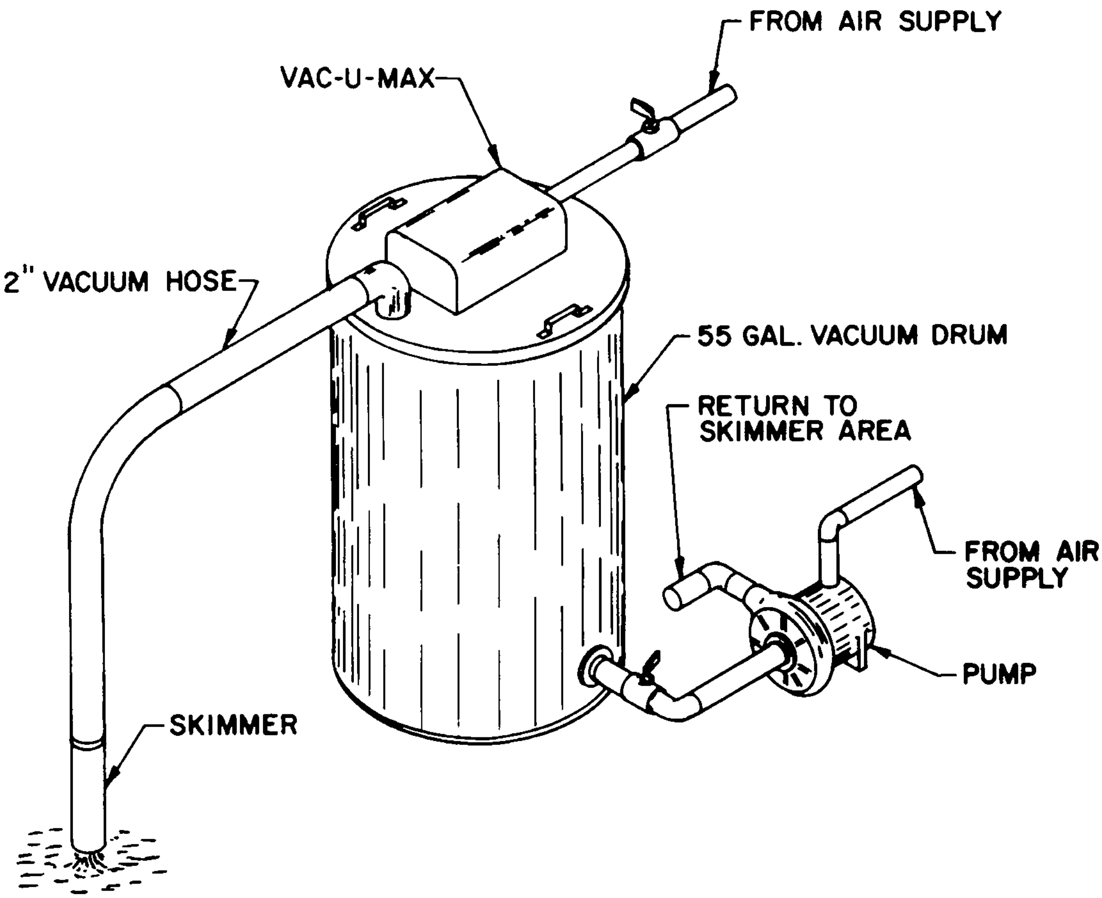

FIGURE I
PICK-UP SYSTEM

SECTION IV

COLLECTION SYSTEM DETAILS

The system can be broken down into the following components: skimmer head, delivery hose, vacuum/separating tank, vacuum pump, water removal pump, plumbing connections, and oil storage containers (Fig. 1). The analysis and construction of each component, and the interaction between components, are detailed below.

Vacuum/Separating Tank

The purpose of the vacuum/separating tank is twofold; first, to separate the oil-water mixture from the air, which then passes out through the vacuum pump; and second, to provide adequate residence time for the oil and water to separate. The air-liquid separation poses no difficulty, especially with the commercial vacuum cleaner head used. (It is designed to match the top of a 55 gal. drum). As the oil-water mixture does not pass through pumps or valves, the formulation of stable emulsions is avoided, and gravity separation occurs within a minute or two. In batch processing (using, say, several 55 gal. drums, and moving the vacuum head with the pickup hose attached from one to the next as each fills), a waiting period of 2 - 5 minutes should be allowed before decanting the water from beneath the layer of collected oil. The drum must be designed to take the maximum vacuum with a closed or clogged inlet without collapse.

The vacuum head is a pneumatically powered commercial unit manufactured by Vac-U-Max, Belleville, New Jersey, model 55-2D, with two venturi jets. Air requirements are approximately 84 SCFM at a minimum of 60 lb/in^2, and it will pull a vacuum up to 13 inches of mercury, or approximately 15 feet of water. It is fitted with a float control which breaks the vacuum when the liquid level nears the top of the drum beneath. The pneumatic powered unit was chosen for the following reasons:

1. Adequate compressed air is available on the fireboats.
2. No sparks, heat or moving parts in the head, minimizing fire hazards and simplifying maintenance.
3. Light weight (about 45 lbs).
4. No hazardous electric extension cords or gasoline required - minor air leaks are of no consequence.

Data on air flow rate vs. vacuum for the unit do not appear readily available, but it was found that with a 2 in. inside diameter hose, water and No. 4 fuel oil were swept directly along, with no visible ponding or accumulation of water in low spots in the hose (transparent plastic), while a section of 3 in. hose connected in the pickup line during the same test showed a substantial amount of ponding. Some rough estimates based on the fall velocity of large drops, and the

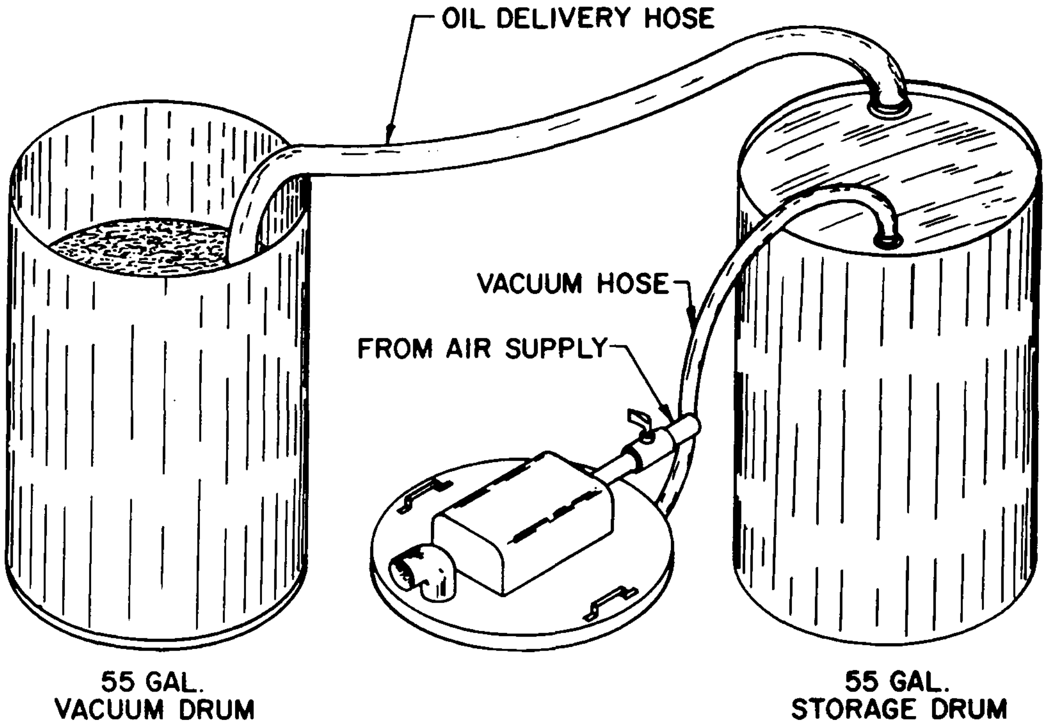

FIGURE 2
OIL REMOVAL FROM DRUM WITH VACUUM HEAD

suction and entrainment at the pickup head suggest that the air velocity in the 2 in. hose was at least 75 - 100 ft/sec, for an air flow rate of at least 90 - 120 cfm. The rated flow at no vacuum is approximately 200 cfm.

Water Removal Pump

Where large amounts of water will be collected with the oil, it is advantageous to have a pump to remove water more or less continuously from the bottom of the drum, through a fitting mounted there. Although oil water separation will take place in the tank while the vacuum head is operating, some simple baffling to enhance this process is recommended, when operating in this way.

The pump selected and obtained for test purposes was a pneumatic double-diaphragm pump, manufactured by Wilden Pump and Engineering Co., Colton, California, Model M-15.

This unit was selected since it is self-priming, relatively non-clogging, capable of extracting water against the vacuum in the tank, and has a pneumatic power source.

For the batch processing mode of operation, the vacuum cleaner head was modified to allow it to pull a vacuum on the 3/4" vent hole of a standard oil drum. This makes it possible to transfer the oil from the open-ended drum into standard drums for storage. The vacuum hose is connected to the 2" fill hole of the standard drum. (See figure 2)

Hose

The hose used in the prototype system was a 2 in. I.D. clear plastic vacuum hose with spiral stiffening coils, also made by Vac-U-Max. The hose leads directly from the skimmer head to the tank, with no valves in the line, to avoid excessive emulsifying effects on the water-oil mixture.

The clear plastic was chosen to permit observation of flows inside. This worked well except when picking up No. 6 fuel oil, in which case the inside of the hose was coated with an opaque film of oil.

An estimate of the air flow rate required for a given hose diameter can be obtained as follows:

Consider the free-fall velocity of a large drop of water or oil, in air; the upward air velocity must exceed that. For a 1/2 in. diameter spherical drop, the fall velocity is approximately 60 ft/sec.

Skimmer Head-Vertical Pipe

This skimmer head, in its simplest form, consists of a short piece of 2 in. pipe on the end of the vacuum hose. With careful handling, this arrangement minimizes the amount of oil on the outside of the equipment, and thus the amount of oil liable to get on the boat deck after retrieval. This skimmer head is essentially a model of catch basin vacuum cleaner truck pick-up, often used in a variety of ways for oil slick pick-up.

The problem of entraining oil and water in the air stream entering the skimmer and vacuum hose is similar to the problem of selective withdrawal from a density-stratified fluid, except that the density difference is much larger than in the cases usually studied.

The basic entrainment mechanism is based on the pressure drop in the inlet to the vacuum line, equal to the "velocity head" of the air flow in the pipe. When the inlet is near the water surface (say, half a pipe diameter away) the surface responds to this pressure drop by rising towards the inlet, where the liquid is entrained in the air flow. As the inlet moves closer to the water surface, the flow area of the cylindrical surface between the pipe end and the water decreases until it becomes less than the cross-sectional area of the pipe; these two areas are equal when the pipe end is half a pipe radius R away from the water surface. As the pressure drop is governed by the maximum velocity into the pipe, and this velocity increases as the cross-section decreases, the pressure drop will be approximately four times that with the inlet well away from the water surface. Thus, it appears that the end of the inlet should be fixed between 0.5 R and 1.0 R above the water surface, with the air flow rate adequate to give an inlet pressure drop (in, say, feet of water) equal to or greater than the clearance.

Mounting the inlet is subject to these criteria:

1. The clearance between the pipe end and the water surface should, as much as possible, be controlled within the above limits.
2. The mounting system must not obstruct the flow of oil or air to the inlet.

The common way of mounting the intake pipe from a catch basin vacuum truck is to suspend the pipe from the truck over the edge of a dock; depending on the operator's vision, attention, and judgment to maintain the proper clearance. In practice, this has two major drawbacks: operator inattention, and the inability to respond to waves. These systems also have a rather low static lift (typically 36 - 60 inches of water), so that when the end of the pipe goes under the water surface, flow ceases; moreover, the suspension system usually "gives" enough so that the pipe is pulled down, and tends to stay underwater.

The prototype system requires more careful control for effective performance, as the dimensions are smaller; however, the penalty for immersion of the pipe end is much less, as the static lift (approximately 15 feet of water) is generally enough to clear the pipe. Moreover, the unit is small enough so that only relatively small, unobstructive floats are required to control the clearance, allowing occasional immersion with passing "chop", or locally-generated wind waves.

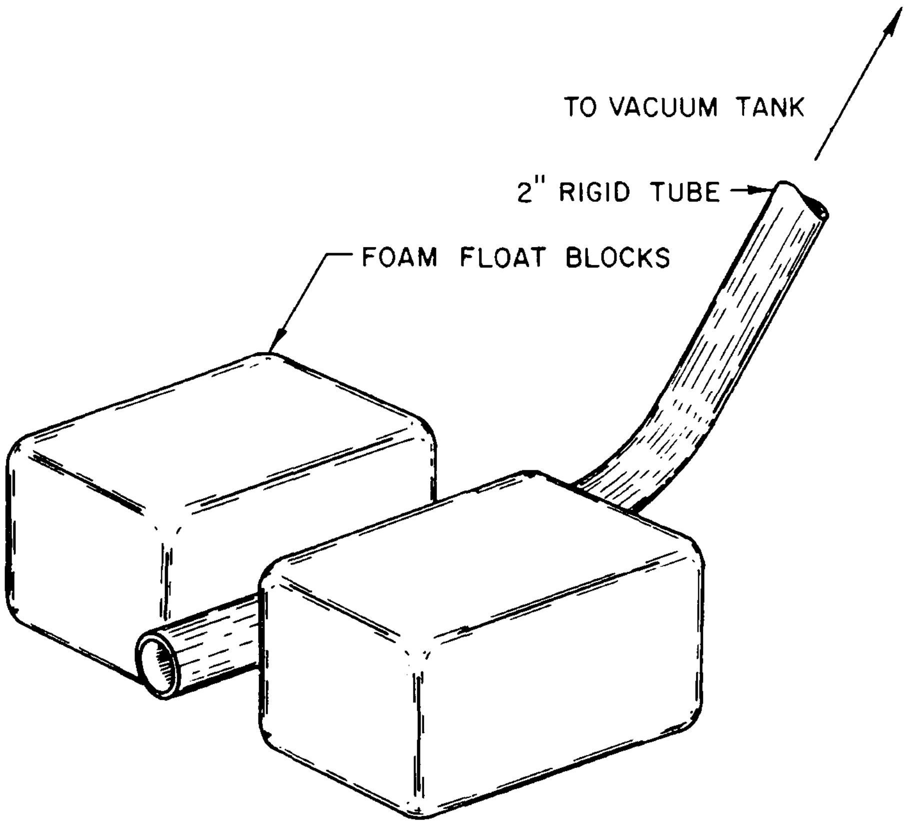

FIGURE 3
HORIZONTAL SKIMMER HEAD

Skimmer Head - Horizontal Pipe

Basically this skimmer consists of the open end of a short, horizontal section of 2 in. pipe at the water surface, vacuum tubing, and flotation (Fig. 3). Since part of the opening is below the surface, fluid will continue to flow through it so long as the water levels on either side are unequal. The suction hose, by constantly drawing off the fluid, maintains the flow of fluid into the pipe. In this respect, the horizontal suction head behaves like a miniature weir type skimmer. However, the suction has an additional important function. It creates in the immediate neighborhood of the orifice, a rather high velocity air flow which strongly augments the inward flow of fluid. The flotation is needed to keep the orifice at the air/water interface.

For maximum effectiveness any pick-up device must be in the vicinity of the highest oil concentration. Yet, such a device tends to reduce the thickness of oil around it, and, if left to itself, it becomes increasingly inefficient as it thins out the oil layer near it. If the area is large enough and the oil thin enough, it will eventually cease to draw any oil at all, and pick up only water. There must be either a means of moving oil to the pick-up device (e.g., fire streams or a chemical herder at the edge of the oil slick) or a means of moving the pick-up device to the highest oil concentration. Ideally, both should be available.

The main effort in the development of this type of head has been directed towards improving its controlability. In this respect it has some advantage over an orifice which remains suspended above the water, because the flotation automatically assures proper vertical positioning, and only the horizontal position need be controlled. However, the bobbing of the device in waves tends to force oil away from it.

In practice, this type of head has usually been affixed to the end of a long aluminum or rigid plastic tube (a part of the suction tubing) by which it can be moved as needed from the deck of a boat or from a pier or dock. Also it can be fitted to the apex of the floating boom corner which is described in the next section.

Some slight advantage can be realized by flattening the orifice. This will cause the lower lip to be nearer the surface and tend to improve the oil/water ratio a little. But elaborate flattened heads which provide an orifice area substantially larger than the cross sectional area of the vacuum tubing are counter-productive because the air velocity into the orifice is so reduced that it provides no significant assistance to the oil flowing in, and the entire apparatus becomes a rather inefficient weir type skimmer. While it is true that low vacuum at the orifice tends to cause less mixing, eventually the oil and water must enter tubing where the air velocity is much greater (especially if a substantial lift is required) and the two fluids will thoroughly mix there. Furthermore, as mentioned elsewhere in this report, stable emulsions are not formed in the high vacuum hoses, and decanting is only a minor problem.

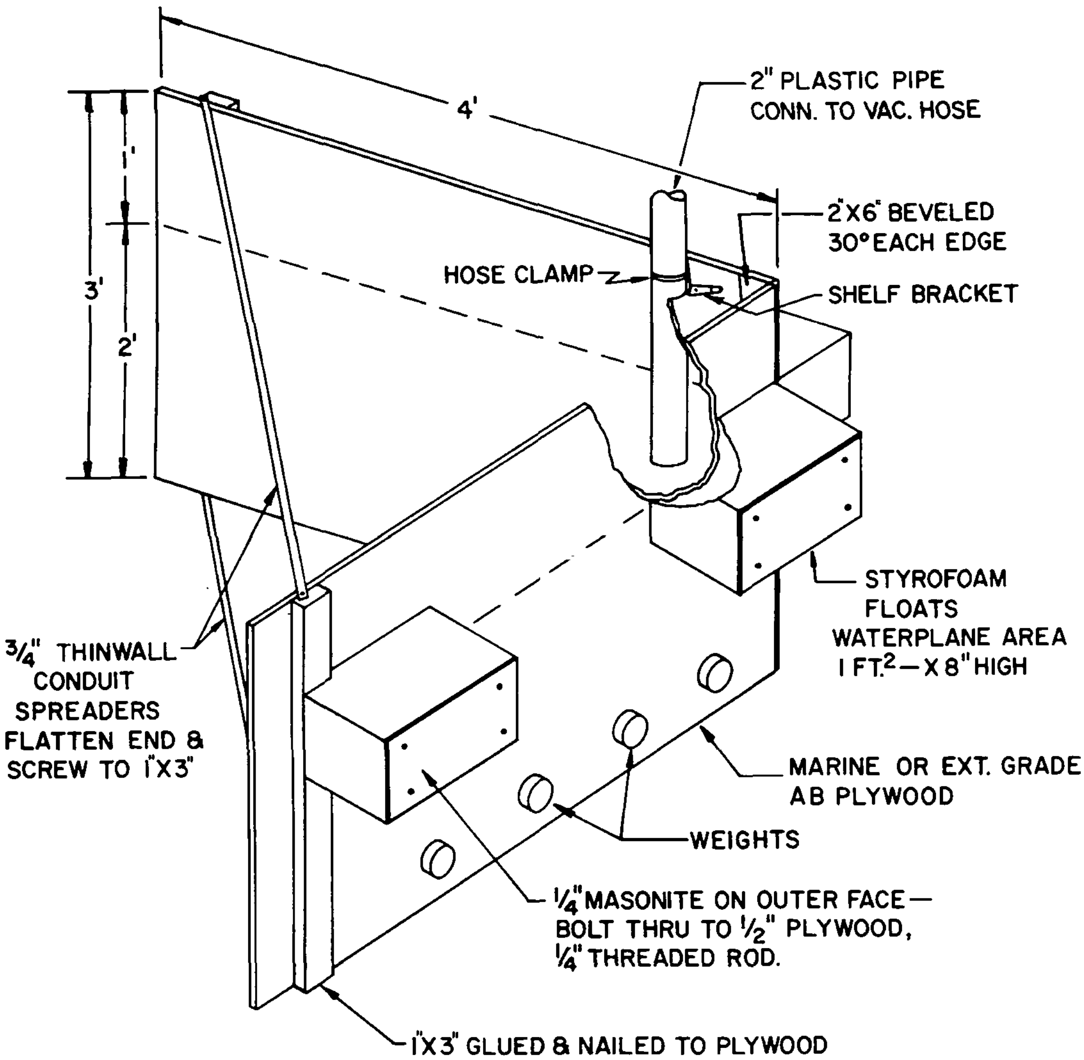

FIGURE 4

BOOM CORNER SKIMMER SUPPORT UNIT ASSEMBLY

SECTION V

APPLICATION

The above concepts and prototype system can be applied in several ways: hand-held, from a small boat or pier near the water level; fitted, with appropriate mounts, into a moored boom system; and as part of a moving skimmer to be mounted on a boat.

Hand-Held

For hand use, the operator must have a fairly stable platform just above the water line, as from a small boat alongside the harbor craft. Experience has shown that adequate control cannot be achieved manually from a deck several feet above the water with the vertical head system.

Moored

A floating "boom corner" mount has been designed and constructed for the system, as shown in Fig. 4. The V-shape is intended to be fitted between sections of boom, so the oil can be herded conveniently to the skimmer head with fire streams, currents, etc. Each 1/2" plywood panel is 3 ft high by 4 ft long, and designed to float with a draft of two feet. The styrofoam float blocks are 8 in. high with a water plane area of 1 ft^2 each, and are through-bolted with a 1/4 in. masonite cover plate to the plywood. The spreaders are 3/4 in. thin wall conduit, flattened on the ends for fastening. For preliminary trials, the boom (Kane boom, 36" high) fabric was screwed to the panels and backing blocks with wood screws and fender washers. The components shown in Fig. 4 were selected for availability, so that the boom corner could be rapidly assembled in the field from locally available materials. Construction time was a few hours (with one man) for the corner, with spray painting.

In operation, with fire streams herding the oil towards the "boom corner" and with the suction head operating at its apex, this system proved to be extremely efficient.

SECTION VI

FIELD EXPERIENCE AND DATA

Horizontal Head

The horizontal head proved effective in picking up No. 4 fuel oil in calm water. Attempts at picking up patches of No. 6 fuel oil, however, were thwarted by clogging of the vacuum line with a mixture of debris and the extremely viscous oil, and by difficulties in maneuvering the fireboat. The mobility of the skimmer was found to be a definite asset; however, the oil-soaked floats and pipe end were messy when retrieved.

Vertical Head

Field experience with vertical-pipe vacuum skimmers is limited to observations of catch-basin vacuum trucks and to operational tests of the boom corner skimmer. The most significant observation is that the oil collection rate in either case is limited by the rate at which oil is brought to the skimmer.

Catch-basin trucks do pick up oil, with or without sorbents. Examination of films taken of the intake end show entrainment when the clearance between the pipe end is less than approximately six inches, half the diameter of the pipe. Since the advertised air velocity is nearly 300 ft/sec, corresponding to an inlet pressure drop of 20 in. of water, it is clear that this proximity is required for entrainment and collection.

The boom corner skimmer was mounted in one corner of a closed boom moored in a triangular shape. Clearance was adjusted to 1/2 - 3/4 in. Pickup trials were run by dumping 2 gals. of No. 4 fuel oil inside the boom. The wind blew the oil into the corner, except for some trapped in the lee of the upwind boom section. As fast as oil would run into the corner, within an inch or two of the pipe, it would be picked up. Waves occasionally submerged the pipe end, resulting in water being pumped. The vacuum system was then operated for about two additional hours, with the 54 cu ft vacuum box ending up about two-thirds full of water, with essentially all the oil floating on top.

SECTION VII

ACKNOWLEDGMENTS

Practical tests of the system at actual spills and at numerous test exercises were conducted with the aid of the officers, men and equipment of the Marine Division of the New York Fire Department.

The guidance of Mr. Howard Lamp'l, EPA Project Officer, and the cooperation of the City of New York and the U. S. Navy in providing the test basin at Wallabout Creek, Brooklyn, New York, is gratefully acknowledged.

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17a. Descriptors

*Oil Spills, *Skimming, *Oil-Water interfaces, *Entrainment, *Harbors

17b. Identifiers

*Vacuum Skimming Unit, *Compressed Air, *Floating Corner Skimmer
*Fire Department, *Emergency Service, Oil-Water Separation
Herding

17c. COWRR Field & Group 05D

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