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A Free Floating Endless Belt Oil Skimmer

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A FREE FLOATING ENDLESS BELT OIL SKIMMER

By

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Contract No. 14-12-908
Project 15080 GBJ

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ABSTRACT

A free floating endless belt oil skimmer was developed as a means of recovering spilled oil from surface waters. The skimmer utilizes a unique high efficiency conveyor wringer to power and wring the belt. The belt is designed to float on the water surface and responds rapidly to the shape of the waves, thereby maximizing oil-sorbent contact time. Evaluation of the skimmer was conducted in a 60 foot diameter annular test tank under the conditions of slightly progressive waves having an amplitude of two feet. One foot wide neoprene backed polyurethane foams were utilized as the sorbent material.

The experimental results indicate that the oil pickup rates will vary with the belt speed, oil slick thickness and belt porosities. Oil pick-up rates of 8.3 and 3.7 gpm per foot of belt width were attained for #2 Fuel Oil and Bunker C Oil respectively at a slick thickness of 0.10 inches. The recovered liquid contained approximately 50-70% oil at 0.10 inch slick thickness.

A conceptual design of a five foot wide boat mounted skimmer capable of harvesting approximately 5 acres per hour of spilled oil is presented.

This report was submitted in fulfillment of Project Number 15080 GBJ, Contract 14-12-908, under the sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

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SECTION I

CONCLUSIONS

The following conclusions can be drawn from information collected during this study.

1. The free floating endless belt concept developed during this study is a feasible concept for oil recovery.

2. The conveyor wringer used in this skimmer is a highly efficient method for wringing and also provides a very effective method for driving the belt.

3. Utilizing neoprene backed polyurethane foams as a sorbent material, the following oil recovery rates can be expected in two foot waves for the one foot wide belt tested in this study.

   a. Light oils - #2 Fuel Oil - 8.3 gpm of oil at 0.10 inch slick thickness. Recovered oil-water mixture contained approximately 50% water.

   b. Heavy oils - #6 Fuel Oil (Bunker C) - 3.7 gpm of oil at 0.10 inch slick thickness. Recovered oil-water mixture contained approximately 28% water.

4. Oil Recovery rate can be expected to vary almost directly with slick thickness and belt speed.

5. Optimum performance was attained with a 1 inch thick 80 ppi belt for light oil (#2 Fuel) and a 3/8 inch thick 45 ppi belt for heavy oils (Bunker C).

6. Endurance testing of the neoprene backed polyurethane belts indicates that a minimum belt life of 1-2 days can be expected even in high debris areas. The belt has a minimum susceptibility to damage from debris because of the free floating configuration.

7. The skimmer is capable of handling almost any sorbent material which can be fabricated into an endless belt configuration.

8. Polyurethane foams have a tendency for high water pickup, particularly in thin slicks.

9. It is technically and economically feasible to construct a five foot wide skimmer for shipboard installation.

SECTION II

RECOMMENDATIONS

Based on observations made during this project, the following recommendations are made.

1. A full scale prototype skimmer should be constructed and mounted on a suitable vessel for use in oil recovery operations. The design of the skimmer and vessel would be according to the conceptual design presented in this report. This skimmer could be evaluated under actual spill conditions and could serve as a working laboratory for the evaluation of new sorbent materials.

2. A relatively significant effort needs to be devoted to the development and evaluation of sorbent materials. It would appear that some very promising sorbents are being shunted aside in laboratories because there is not sufficient market potential to support further work. The EPA and their contractors should be aware of this situation. Perhaps EPA could act as a sorbent materials clearinghouse.

SECTION III

INTRODUCTION

Significant spills of oil and petroleum products in protected and unprotected waters constitute a potential fire hazard and may cause extensive damage to both marine and aquatic flora and faunae. Moreover, such spills seriously degrade water quality with respect to usage, particularly for recreational and consumptive purposes. Property damage resulting from spills near inhabited coastal areas is often substantial.

The increasing number and size of oil tank ships, coupled with accelerated off-shore drilling activities, indicate that the potential for aggravating an already unsatisfactory situation is great. The ideal solution, of course, would be to prevent any oil spills from occurring, but experience shows it is not reasonable to expect that preventive measures will be 100% effective. Defensive measures must be developed for containing and cleaning up floating oil when accidental and uncontrollable spillages occur.

Various measures developed or under development for the control and prevention of major oil spillage have been reviewed in recent literature (1, 2). The technical approaches in these measures can be categorized as: mechanical containment, mechanical removal, physical adsorption, combustion and biological degradation. These methods vary in effectiveness depending upon the type of waters, size of spill and the type of oil. No single combatant method to date is considered sufficiently developed to pursue at the exclusion of other methods.

The proposed approach during this project was to develop a concept for a belt type oil harvesting and recovery skimmer, and to design, build, and test a device large enough to enable the determination of its feasibility for meeting the stated EPA design goals. The process objectives for the device were to recover rapidly, efficiently and without the aid of additives, floating oil from the surface of both protected and unprotected waters. The proposed device should also be capable of being rapidly transported to the oil spill site.

A bench scale model of the proposed prototype was constructed and evaluated in the laboratory. Based on the results of the bench scale model, an experimental prototype oil skimmer system was designed. This report documents the design, construction and evaluation of the experimental prototype performance. In addition, a conceptual design for a full scale, boat-mounted oil belt skimmer is presented.

Initially, a concept was proposed for a belt type skimmer in which a porous belt was mounted either vertically or at a slight angle with respect to the water. The belt would be propelled through the oil-water layer. This concept was later modified to permit the porous belt to float on the oil surface, thus permitting a longer contact period with the oil and a minimum of contact with the water. This procedure significantly improved the skimmer performance and was incorporated into the design of the experimental prototype system.

The prototype skimmer system was tested under the adverse conditions of two foot waves and various types of oil including Bunker C, Oklahoma crude oil and No. 2 fuel oil. Based on the successful evaluation of the experimental prototype, it is proposed that a full scale, boat mounted, oil belt skimmer be constructed and evaluated on an actual oil spill.

SECTION IV

LITERATURE SEARCH

A search of the existing literature was made to determine the characteristics of oil spills, and to obtain pertinent information on oil removal technology.

Characteristics of Oil Spills

Oil spillages, generally speaking, may be classified as "large" or "small" depending upon the amount of oil released in the water. Small spills may vary in volume from less than one hundred barrels to as much as several thousand barrels. Large spills, by contrast, are usually measured in tons of oil released. The highly publicized Torrey Canyon mishap, for example, resulted in the release of about 60,000 tons of crude oil to the sea (3).

Small oil spills usually occur in protected waters such as harbors and estuaries, occur more frequently than large spills, and may or may not be accidental. Because of their proximity to inhabited areas and shallow-water marine life, they often result in as much damage as larger but more remote spillages. Common sources of small spills include those from small vessels, industrial waste discharges, oil transfer operations, pipeline breaks, and vessel cleaning operations. Large spills are nearly always accidental and often uncontrollable. Floundering transport tankers (Torrey Canyon) and off shore well "blowouts" (Santa Barbara incident) are some of the examples of the major oil spills. It has been reported (4) that an estimated 2 million tons of oil enter the ocean from tanker cargoes each year. In 1970 alone there were reported to be 10,000 such spills (4).

The floatable oil from spillages may consist of crude oil, refined products such as gasoline or kerosene, and fish or vegetable oils. The density and viscosity of these oils vary widely, and may significantly affect development of countermeasures employed to contain and clean up spills when they occur. The characteristics of four such oils used by the U.S. Navy, namely, JP-5 Turbine Fuel, distillate fuel, Navy special fuel oil and Bunker C fuel oil (also known as #6 fuel oil) have been discussed in detail in a recent study (5).

The edge of an oil slick can move in two ways - the slick can spread out and cover large areas, and it can move as a unit under the influence of current or wind. The movement of the edge of the slick would equal the algebraic sum of the two components. Actually, very little information is available in the literature on the spreading of large quantities of oil because of strong public objections toward such experimentation. Small scale experiments on the rate of spread of crude oils have been conducted by Berridge et al (6) and Blokker (7). They showed that the tendency for the oil slick to expand is, in part, a function of the difference in the densities of the oil and the water. The spreading rate of a homogeneous oil slick was found to be approximately proportional to the instantaneous mean layer thickness. Other factors influencing the spreading rate were: viscosity, surface tension, interfacial tension between water and oil, chemical composition, pour point of the oil, current, and wind speed. It was concluded that the value of the pour point of any oil may have a profound influence on its spreading characteristics. An oil with a pour point higher than the temperature of the water, as could be the case with Bunker C, can form a semisolid mass that would have very little tendency to spread, particularly if its specific gravity approached that of sea water. Moreover, the influence of viscosity over spreading velocity was considered to be relatively small, especially during the initial stages of the spill. Blokker (7) noted that the time required for spilled oil to spread out to a slick of 2 cm thickness was very short, on the order of one minute for 100 cubic meter of oil spill, with viscosities ranging from 0.8 to 490 CP at 20°C, while Berridge et al (6) found that the thickness of the slick tended to keep reducing, and the area increasing, until the thickness of the slick, for the crude oils with specific gravities ranging from 0.829 to 0.896, reduced to 0.0008 to 0.0012 inch. The time required for a spill of 100 cubic meters of oil to reduce to a slick of that range of thickness was 27.7 hours.

Brockis (9), Smith (9) and Hughes (10) have investigated the effects of winds and currents on the movement of an oil slick. Although there is variation in the results of the different investigators, experimental data coupled with theoretical analysis shows that the speed of movement of an oil slick as a unit, due to the drag force exerted by a wind blowing across its surface, would be in the range of 3 and 4% of the wind speed.

The rate of spreading of an oil slick in protected waters, and its resulting thickness, can be quite different from those in an open sea. In a harbor the water is often contaminated, or becomes contaminated by surface-active substances in the spreading oil. In these cases the thickness of the oil slick will tend to be greater than would be the case on a clean-water surface. In such a case the oil slick may reduce to 0.04 to 0.08 inch in thickness, and the reduction in thickness may stop or continue at a slower rate. At the closed end of a harbor, the wind may cause a considerable increase in the thickness of an oil slick. An 8-knot wind, for example, may keep a layer of oil that is trapped at the end of a harbor at a thickness of one inch (7).

In summary, there are two phases of the spread of an oil slick in a still harbor. The first is the initial rate of spreading, immediately following the failure of an oil container, and can be assumed analogous to the sudden failure of a dam. The potential energy of a thick oil layer is essentially converted into kinetic energy and the effects of viscosity, evaporation, surface tension, and interfacial tension are negligible during this first phase. The spread rate in this phase will take place in accordance with Blokker's findings (7). The slick layer will then continue to decrease according to the Blokker relationships and at the end of a day will tend to approach the values reported by Berridge (6). However, it should be noted here that the effects of harbor currents and winds, the amounts of contaminants in water and the space available for spreading can influence the effects of spreading in the later phase significantly, but none of these can be predicted accurately in advance.

State-Of-The-Art on Oil Removal Devices

Based upon a literature search (1 to 5, 11 to 14) the following technological approaches can be defined for the disposal of an oil spillage: containment, chemical treatment of the oil slick, surface treatment followed by mechanical pickup and/or disposal and the direct mechanical pick-up.

After an oil spill has occurred, the first line of defense is the containment of the spill. The required equipment must deal with the strong forces of nature. Mechanical booms are commercially available and have been successfully demonstrated in protected waters. Efforts are ongoing to develop boom systems for deployment in the open ocean. The boom concept offers potential for all clean up operations and reduces the cost of cleanup by minimizing the area to be treated.

A variety of materials and compounds are available which may be used to absorb, sink, or disperse floating oil in a slick. Three types of absorbents appear to have potential for slick treatment (1, 12):

a. Floating absorbents (straw, sawdust, etc.)
b. Plastics and other polymeric absorbents (polyurethane foam)
c. Gelling agents

Floating absorbents are relatively inexpensive, and the resultant oil/absorbent combination may be disposed of by burning or burial. However, recovery of oil from the absorbent is a difficult task. Plastics and polymeric materials are expensive, but allow the recovery of relatively high percentages of absorbed oil. Gelling agents for solidifying floating oil show promise, and are currently in the development stage.

Biological degradation by natural processes is the ultimate fate of spilled oil not otherwise removed, but it is a relatively slow process. Such natural purification requires the proper species of microbiota in the presence of such appropriate environmental conditions as sufficient oxygen the proper nutrients, and favorable water temperatures. Seeding oil slicks with selected microorganisms to accelerate this process is currently under investigation.

It has been indicated in the literature (1, 2, 13, 14) that mechanical and physical collection of spilled oil should be employed wherever possible. Mechanical devices for collecting spilled oil from the surface of waters include rotating cylinders, moving belts, suction pumps, centrifuges and hydrocyclones. Drum and belt skimming systems generally have relatively lower oil recovery rates but higher oil to water ratios compared to pumps, centrifuges and hydrocyclones. The storage requirement of the later group of devices are therefore generally significantly higher and normally require auxiliary oil/water separation equipment.

Suction devices, in general, are only effective on relatively thick slicks (15). Another operational difficulty encountered is the formation of water-in-oil emulsions because of the passage of the oil and water through a pump impeller. These emulsions are sometimes very stable and difficult to break up.

Numerous devices that employ some configuration of the rotating drum or endless belt are either currently commercially available or are being developed. One of the important requirements of the material utilized for oil pickup is that the material chosen should be wetted easily by the oil. The oil that adheres to the moving surfaces is then either scraped off and/or squeezed out and deposited in a collection vessel. Another type of unit akin to an endless belt system employs long rolls or sorbent materials, such as felt, which retain the oil for subsequent disposal.

An oleophilic belt "oil scrubber" employs a very large loop absorbent material such as polypropylene wool. This device is operated by moving this continuous absorbent belt through an oil slick between two pulleys and squeezing the oil from the belt using wringers mounted on a ship or at a shore facility (13, 14, 15). The results indicate that the maixmum recovery rate of an oleophilic belt oil recovery system is generally limited by the rate at which the oil may be transferred to the belt surface and interior.

A rotating disk oil removal device developed by Lockheed Corporation and called "Clean Sweep" utilizes rotating drums to pick up oil on both sides of a number of closely packed vertical disks half-immersed in the sea (14, 16). The rotation of the drum is fast enough to hold the oil on the disks where the oil is removed by acetal resin-edged aluminum scrapers, directed to a central channel, and pumped to storage bags. The entire drum is mounted on flotation devices, making the whole unit resemble a catamaran. Oil pickup is said to be about 70 to 75% complete (16).

Another rotating disk design for the removal of oil has been made by Atlantic Research Corporation. The disks resemble the circular blade of a power saw, without the serrated edge. Recent modifications include a triangular frame supported at each angle by a globe shaped buoy. Within the frame are two angled rows of disks. Hoses vacuum up the oil scraped from the disks and carry it to a storage barge. The system is claimed to have an oil recovery efficiency of about 80 to 85% (14, 16).

A mechanical skimming device under development employs a free vortex concept (14, 16). A rotating, submerged impeller assembly produces a vortex flow (circular and down, like water draining out of a bath tub) in a subsurface column of water. Axial flow through the impeller produces an inward funneling flow in the overlying water. Under the action of these flow fields, an oil slick will migrate toward the vortex axis, submerge and concentrate in a central pocket. An overhead pump can then remove the oil from the pocket, with relatively little water. Preliminary data indicates oil removal capacities in the range of 100 gal/min.

Another patented skimming system from Ocean Pollution Control Inc. utilizes an adaptation of the shrimp-trawl fishing principle (14). The unit is a tapered, flattened funnel made of flexible sheet material reinforced with netting. The leading edge of the flexible material is held above the water's surface by floats to insure that all oil that passes beneath is channeled into the collecting funnel. A skimmer picks up and pumps the oil and water mixture to gravity tanks or other systems for final separation and storage (16).

A recently developed skimmer is based upon the concept of collecting the oil under the surface of the water, thus reducing the effect of waves (17). As the skimmer moves through the water, or the water moves past the skimmer, the oil is forced to follow the surface of an inclined plane to a collection well underneath the skimmer. Buoyant forces cause the oil to surface in the well, forcing water out the bottom. As the oil collects, it is pumped off to storage tanks. It is claimed (17) that separation occurs automatically and virtually no water is collected. Another modification in this system utilizes a moving inclined plane, rotating into the water. Oil and sorbents are held against the plane by a combination of hydrodynamic, buoyant and cohesive forces. The oil and sorbents are collected in the well and any residual oil is scraped off the belt as it passes through the well volume (17).

From the information published in the literature (2,5, 15) on belt type skimmer devices, it is indicated that:

1. Among the major variables expected to determine the capacity and efficiency of a belt-type skimmer oil recovery device is the belt material. To meet the recovery rate objectives, a belt material with high selective capability to absorb and/or adsorb oil from an oil water mixture is required. Such a material must have at least the following four qualities:

    a. It must be hydrophobic (or conversely oleophilic)

b. It must have a high capacity for ad-or absorbing and retaining oil

c. It must release oil either under pressure or in some other practical way.

d. It must be resistant to the effects of oils and water including sea water

Most polymeric (plastic) materials and natural organic materials meet the first requirement.

2. The capacity of a material to absorb and retain oil is directly related to its surface area. Porous materials having large areas available in internal pores open to the surface (reticulated structure) are expected to have relatively the largest capacity to absorb and/or adsorb and retain oil. The ability to release oil is expected to vary widely with the porosity (pore size) of the material and the viscosity of the oil.

3. The resistance of materials to oils and water varies widely depending on the material and the oil involved.

Based on these requirements it appears that belt material for the pickup of oil should be selected from the following two categories of materials:

1. Plastic or elastomaric foams
2. Felts of natural or synthetic fibers

SECTION V

APPROACH TO THE PROBLEM

The development of a skimmer to recover floating oil from water consistent with the specifications outlined by the Environmental Protection Agency RFP Number WA 70-23 was approached by a number of simultaneous and progressive work phases. These phases are listed in Table 1 in order to provide an understanding of the manner in which the project was undertaken.

The initial work conducted for this project involved laboratory studies and bench scale tests to screen and select suitable sorbent materials and to evaluate the basic skimming concept. The details of these studies are given in Appendix I.

Based on the results of these initial studies, an experimental prototype skimmer and the appropriate support test equipment was designed, fabricated and erected. A detailed description of this equipment will be presented in a subsequent section of this report.

The skimmer was evaluated to determine oil pickup rates at various oil thicknesses and with various sorbent materials. Tests were conducted with two foot high, slightly progressive waves. Approximately 130 tests were conducted under these conditions. Additional tests were conducted to evaluate maximum pickup capacities and wringer efficiencies.

The final phase of the project was devoted to the development of a conceptual design for a full scale boat mounted skimmer.

Table I

MAJOR WORK TASKS ACCOMPLISHED DURING THIS PROJECT

<u>Phase I - Planning, Design, and Fabrication of Experimental Prototype</u>

Task 1 - Preliminary Bench Scale Investigations

Task 2 - Design of Experimental Prototype

Task 3 - Test Plan Design

Task 4 - Fabrication and Erection of Experimental Prototype Skimmer

<u>Phase II - Operation and Evaluation of Experimental Prototype</u>

Task 1 - System Operation and Testing

Task 2 - Data Accumulation and Evaluation

Task 3 - Final Report, Recommendations and Design Criteria for Boat Mounted Skimmer

SECTION VI

DESIGN OF EXPERIMENTAL PROTOTYPE SKIMMER

The experimental prototype skimmer was designed to incorporate those concepts determined essential to effective oil spill pickup by the literature search and subsequent bench scale tests. The most important concept to minimize water pickup is the flotation of the absorbent belt material on the spilled oil. Concomitantly, to prevent oil recycling and low pickup capacity, the concept of high wringing efficiency necessitated development of a long retention time, uniform pressure mechanism to allow a sufficient drainage interval for the viscous oil. In order to test the concepts under anticipated conditions, the design and construction of a unique experimental facility permitted the simulation of two foot waves and up to five knot pickup craft velocities. Schematic diagrams and photographs to illustrate the prototype skimmer and experimental facility are shown in Figure 1 to 11.

Figures 1 to 4 illustrate the prototype oil skimmer readied for the oil pickup operation. The front view in Figure 1 shows the mounting of the skimmer mechanism above the water surface. The endless oil pickup belt is fed down onto the oil surface where it floats without submergence and follows closely the motion of the waves. Sufficient length of belt is spread on the oil surface so that the belt is always in contact with the oil, even during the deepest troughs. The oil belt is composed of a thick section of porous and resilient absorbent material bonded to a thin, strong backing of neoprene conveyor belting (Figure 2). The belt lies on the spill surface with the absorbent material facing downward. The mechanism of absorption occurs because of the attraction of the oil to the oleophilic belt material as well as to the upward buoyant pressure which the oil exerts in reaction to the downward force of the belt weight. The variable speed skimmer drive feeds the belt at a rate fast enough to prevent drag turbulence, yet not too fast so that the effective pickup capacity exceeds the available pickup volume of oil in contact with the belt.

An important and practical advantage of the floating belt is its resistance to damage from debris. Because the belt has no rigid guide mechanisms at the water surface, there are no impact points to encourage debris attachment. In its free floating configuration, the belt will slide over the top of floating debris. Attachment of debris to the belt is highly unlikely. Accidental pickup of a piece of debris is not likely to jam the spring-loaded wringer and stop belt feed because of the large pressure contact area (432 square inches) which the conveyor wringer utilizes to pull the belt through.

The path of travel of the belt through the wringer mechanism is shown in Figure 3 and 4. Efficient oil removal is achieved as the belt passes through the wringer with the absorbent material facing downward and is squeezed between the upper and lower sections of a perforated conveyor wringer. Using this type of wringer, a substantially greater

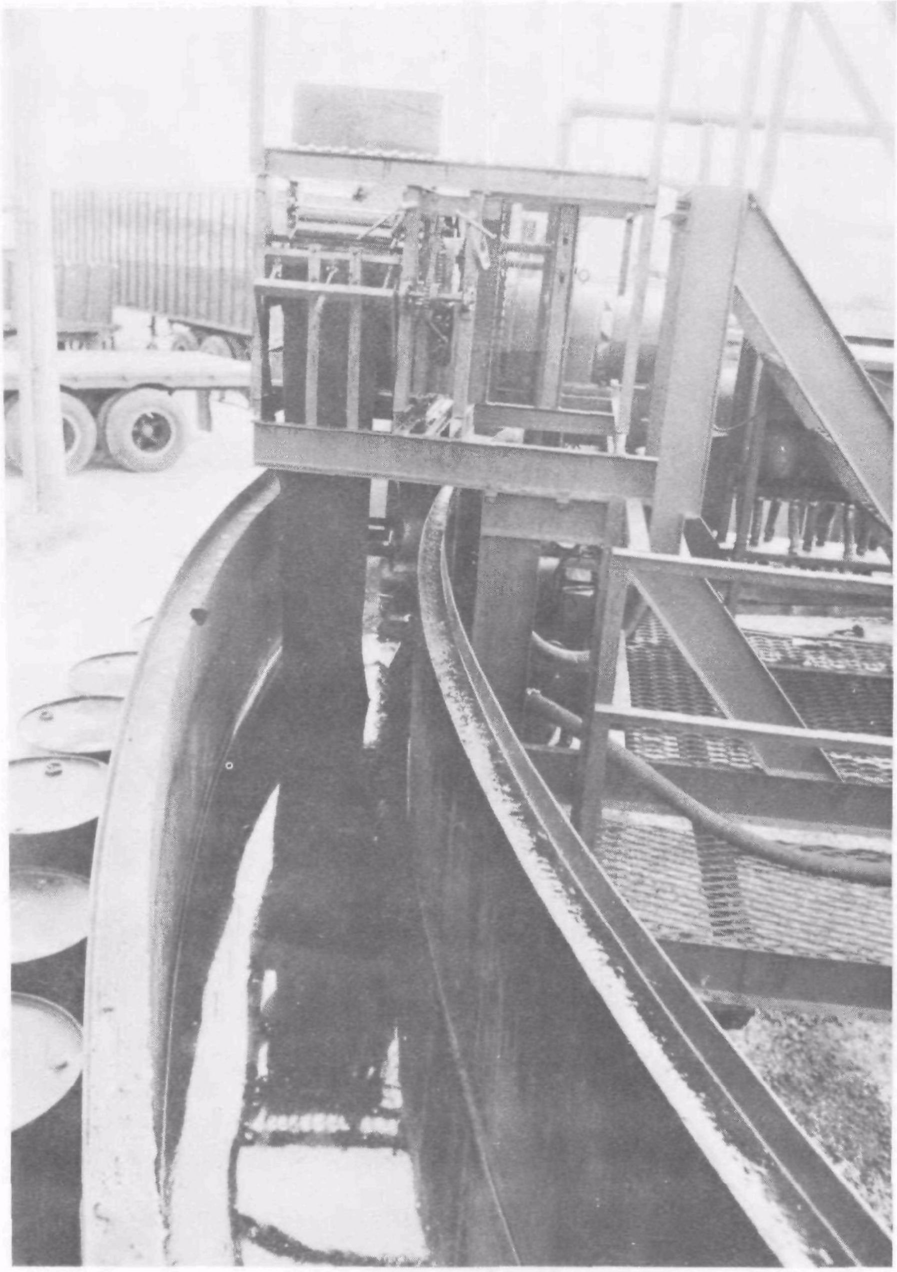


FIGURE 1

ORIENTATION OF FREE FLOATING BELT SKIMMER TO WATER SURFACE

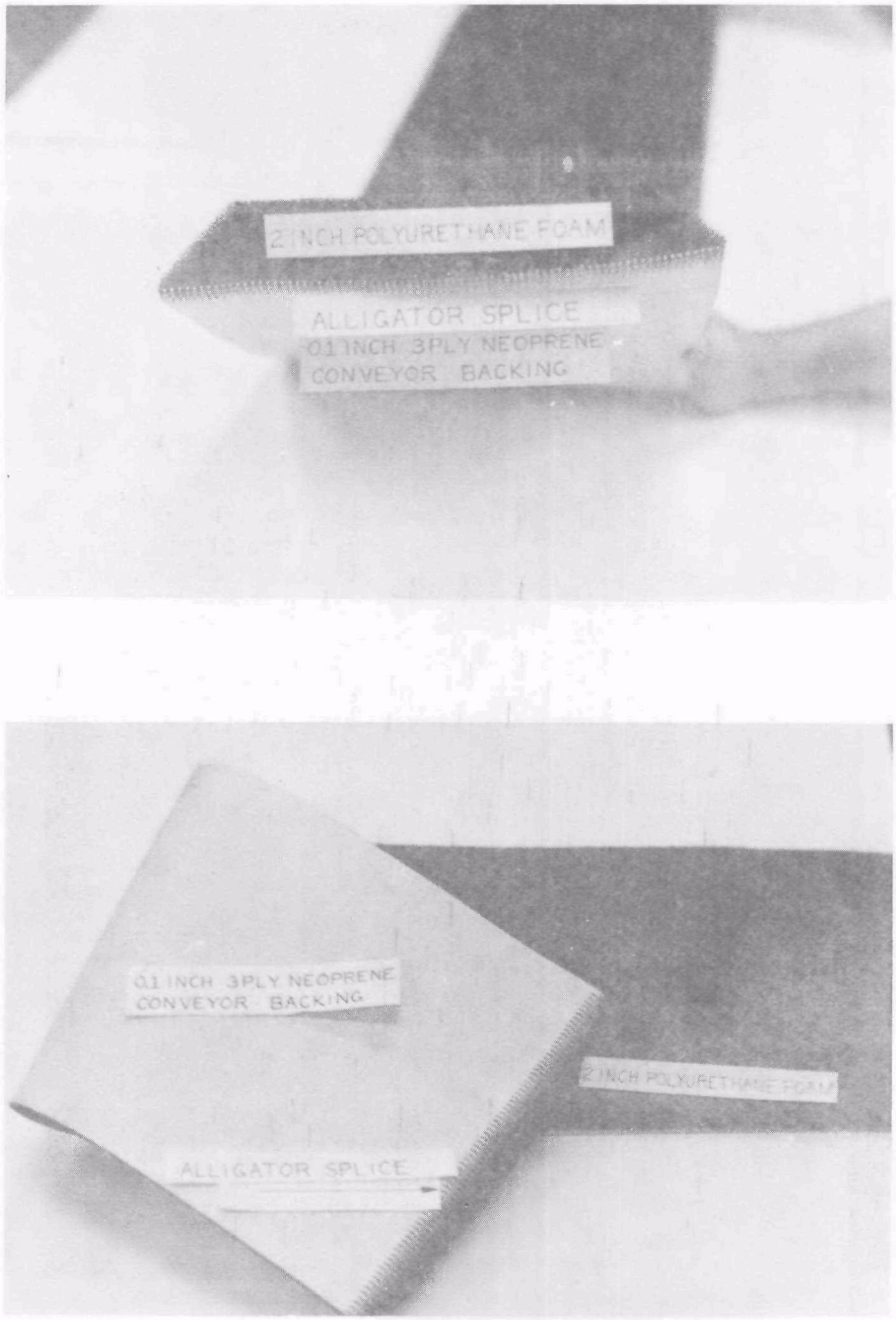


FIGURE 2

POLYURETHANE BELT DETAILS

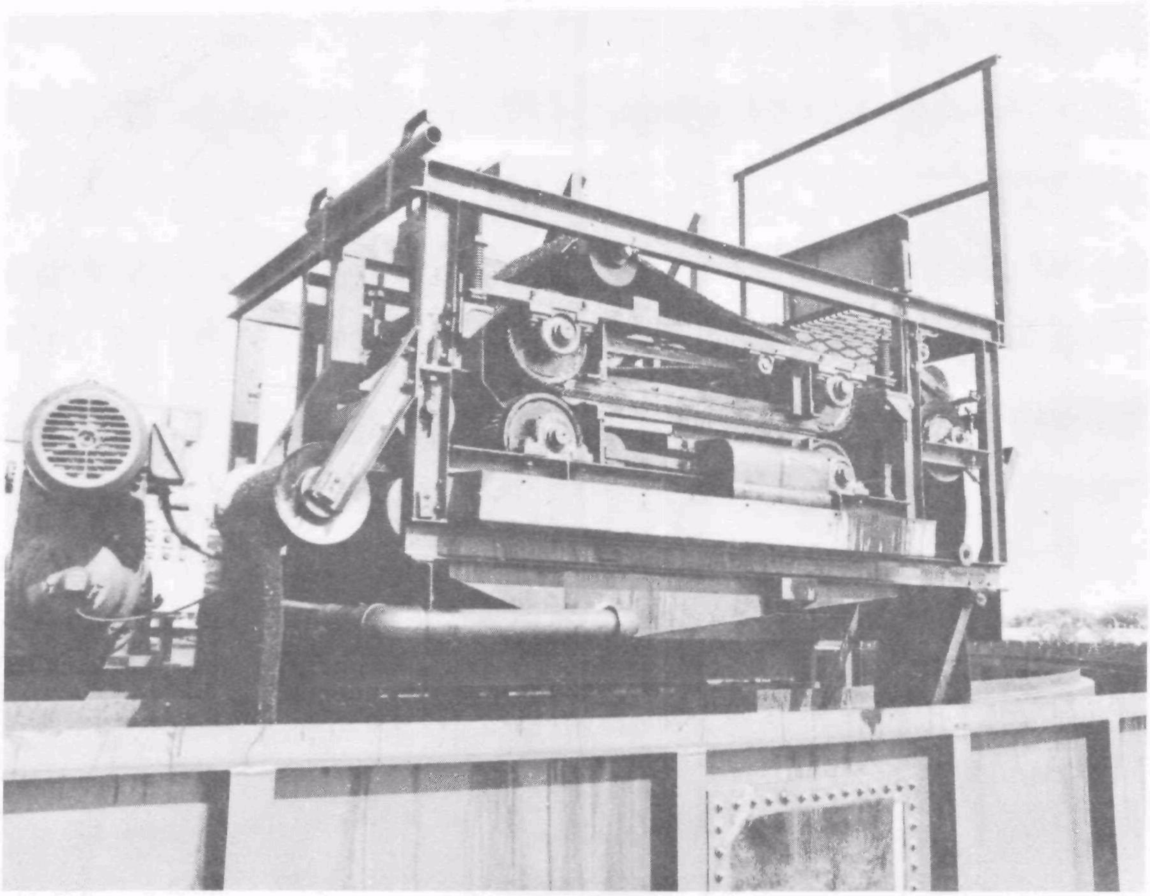


FIGURE 3

CONVEYOR WRINGER ASSEMBLY

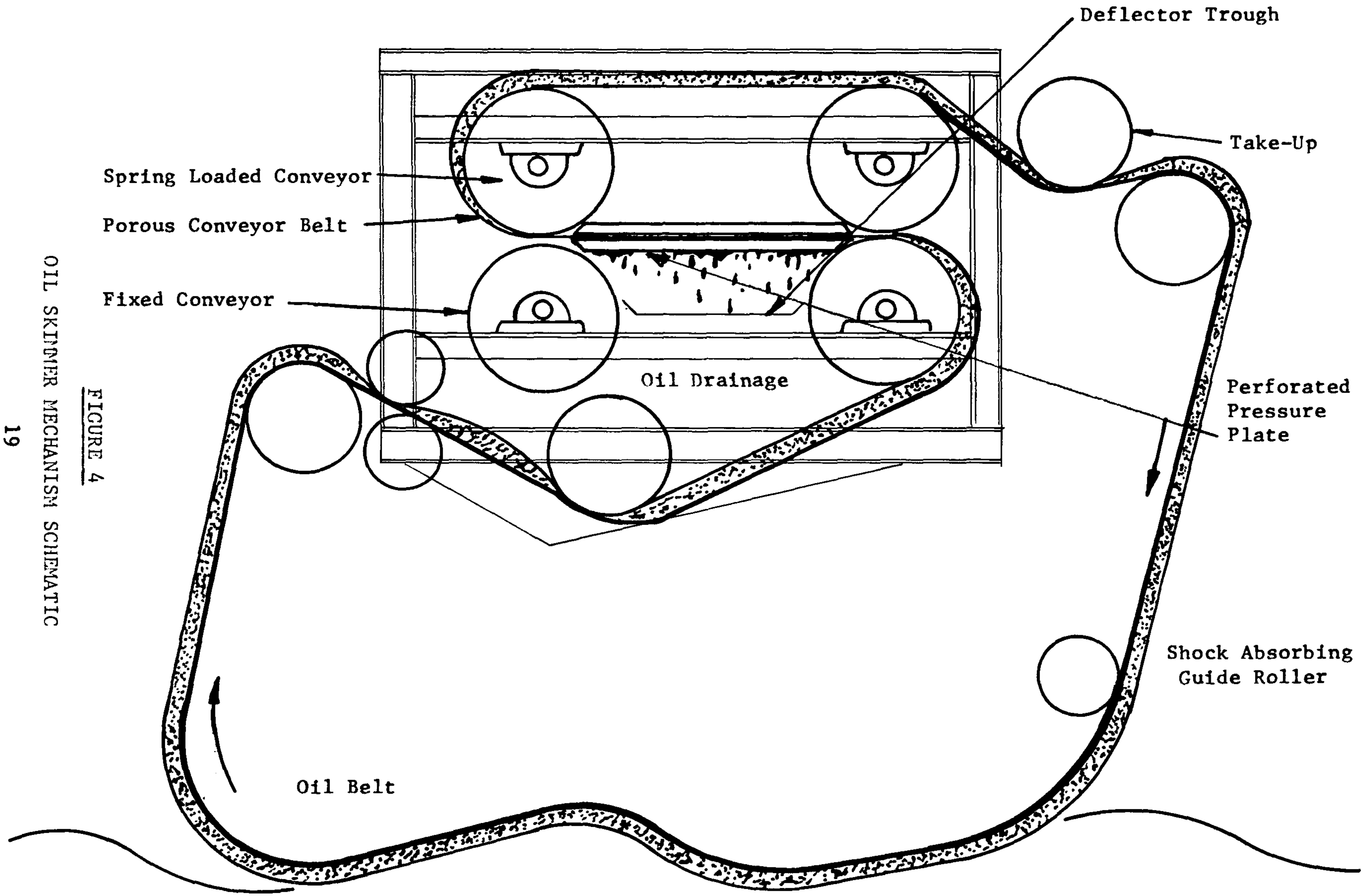


FIGURE 4

OIL SKIMMER MECHANISM SCHEMATIC

portion of the absorbed oil can be removed from the belt than with the conventional "clothes wringer" apparatus consisting of two spring-loaded pressure rollers located one above the other. The conveyor wringer provides the much needed time under pressure which is necessary to remove viscous oil from the absorbent belt material at the required belt feed rates. For the belt feed conditions tested during the prototype study, the wringing time was 1.9 to 9.0 seconds for the conveyor wringer, which corresponds to 0.05 to 0.25 seconds for the roller wringer. Bench scale studies of the roller wringer demonstrated that for these feed rate conditions the pressure roller could not prevent excessive recycle of oil, even at elevated wringer pressures.

Visual as well as quantitative observations indicate that the conveyor wringer consistently provides a much drier and oil free belt than the roller wringer.

The skimmer and floating belt were designed to provide a quick and easy method to change belts. Belt changes on the experimental prototype skimmer could be accomplished by three men in approximately 10 minutes. Two men were assigned to change the belt and the third was required to operate the controls. A belt change was accomplished by stopping the belt when the pin connector was at the top of the skimmer and easily accessible (Figure 5). The connector pin was then pulled and the new belt to be installed was connected to the tail end of the old belt. With the skimmer drive turned on, the new belt was "threaded" through the wringer by the old belt. When the old belt has cleared the entire path of travel, the old and new belts were disconnected and the head and tail ends of the newly installed belt were connected. The skimmer was then ready for operation.

A photograph of the prototype oil skimmer test site is shown in Figure 6. The test tank is 60 feet in diameter with a 2 ft wide by 6 ft high annular water section filled to a 4 ft depth. The oil skimmer is mounted from a frame extending above the annular tank on a pivoted platform which was continuously rotated during the pickup operation at speeds up to 5 knots (Figure 7 and 8). Beneath the center pivot in Figure 7 are stationary, annular supply and collection tanks into and out of which oil could be transferred while the platform was in motion. A uniform layer of oil could be spread on the water surface through the distribution header (Figure 9). During the run another pump was utilized to drain the oil-water mixture from the skimmer trough to the collection tank. Manual diversion valves on the collection line were used for sampling and flow measurement. A multi-partitioned, calibrated sampling chamber was utilized to collect samples at intervals during the test run. Before reuse, the collected oil-water was pumped to a holding tank (Figure 10) for separation.

In order to simulate actual pickup conditions in protected waters, 2 ft wave conditions were created for the oil skimming tests by a wave generator using the submerged piston technique. This device was designed under the direction of a project consultant, Dr. Clifford Mortimer,

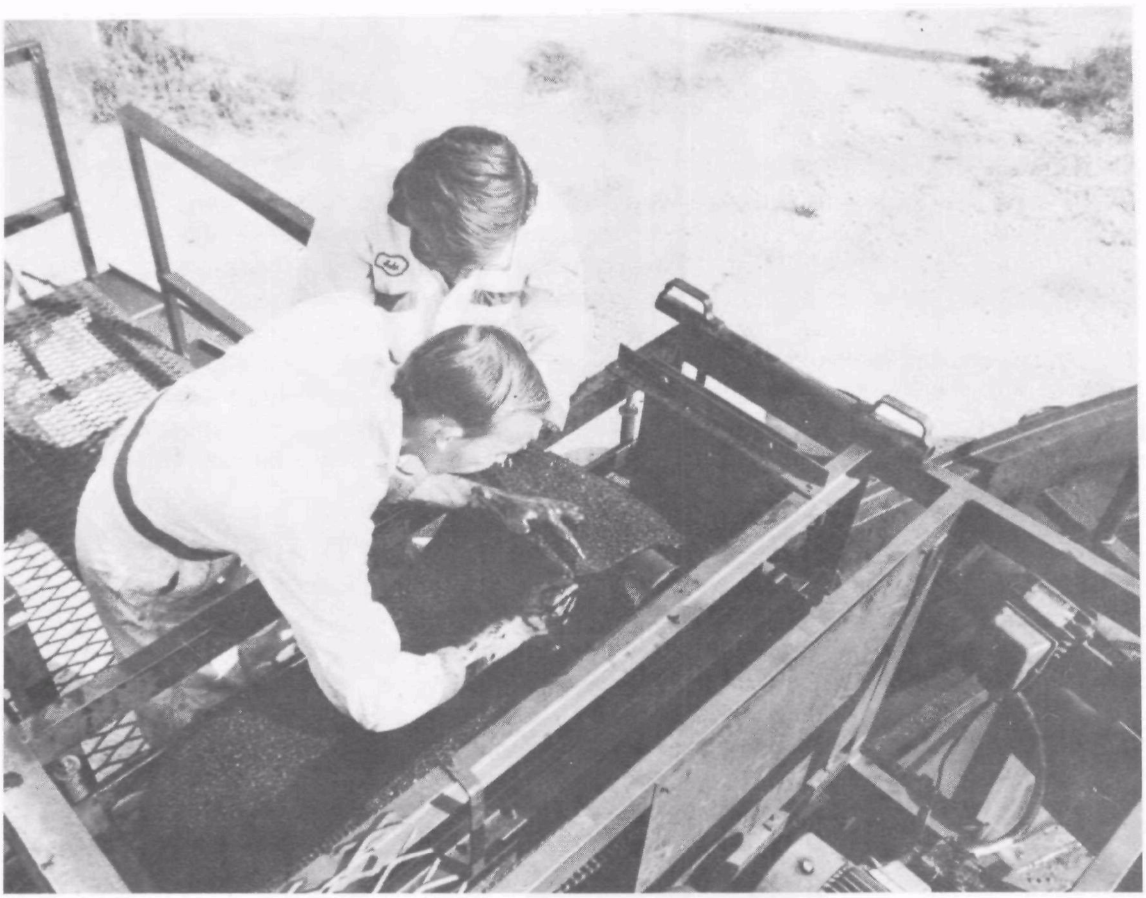


FIGURE 5

REMOVAL OF THE PIN CONNECTOR TO CHANGE A BELT

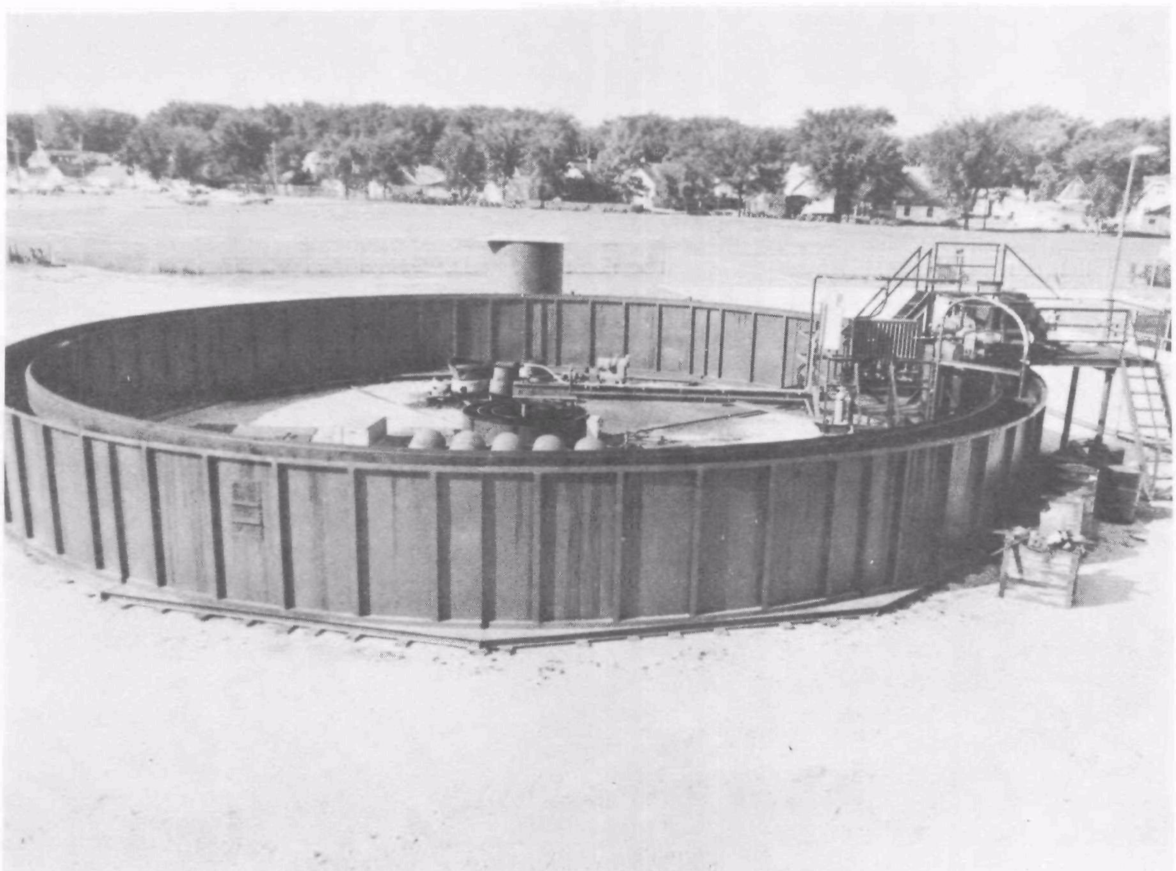


FIGURE 6

EXPERIMENTAL PROTOTYPE TEST SITE

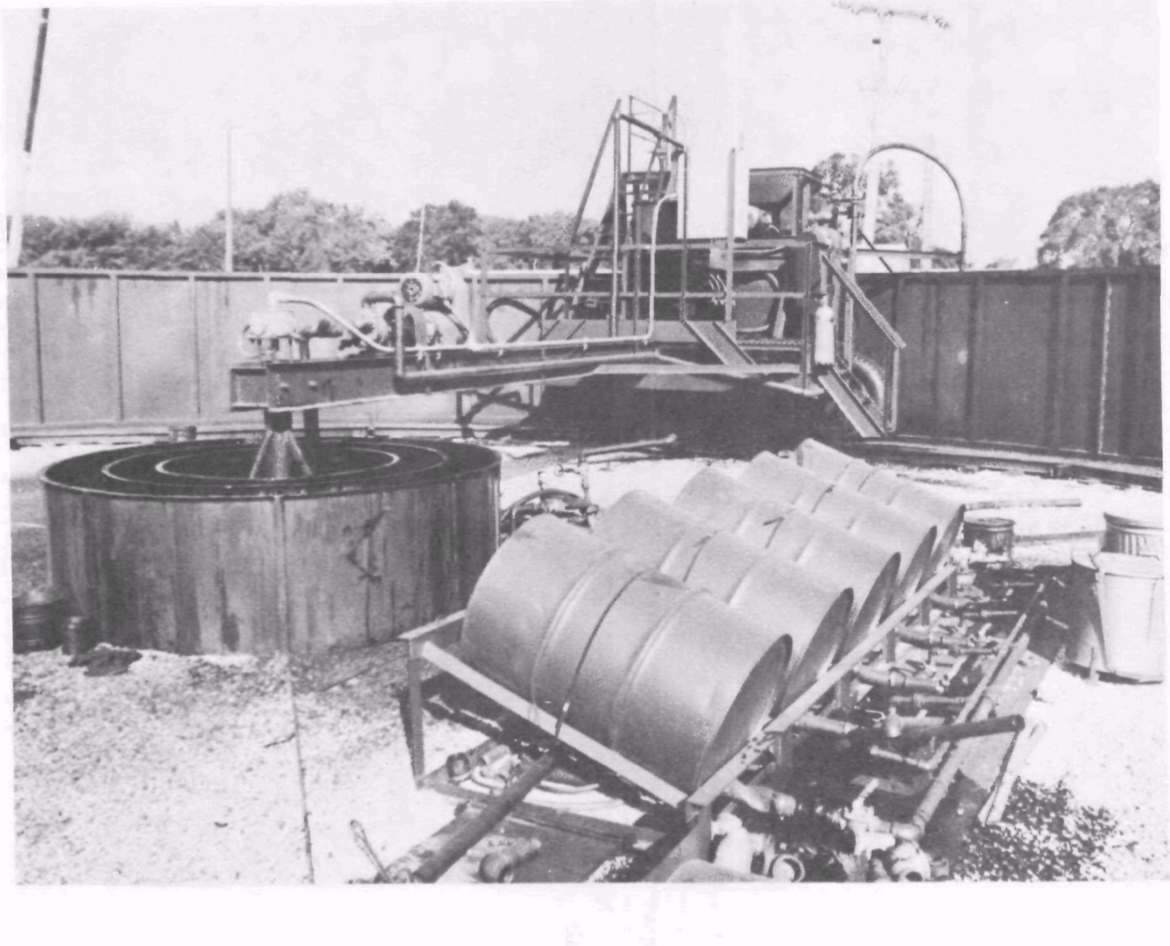


FIGURE 7

ANNULAR COLLECTION AND SUPPLY TANKS

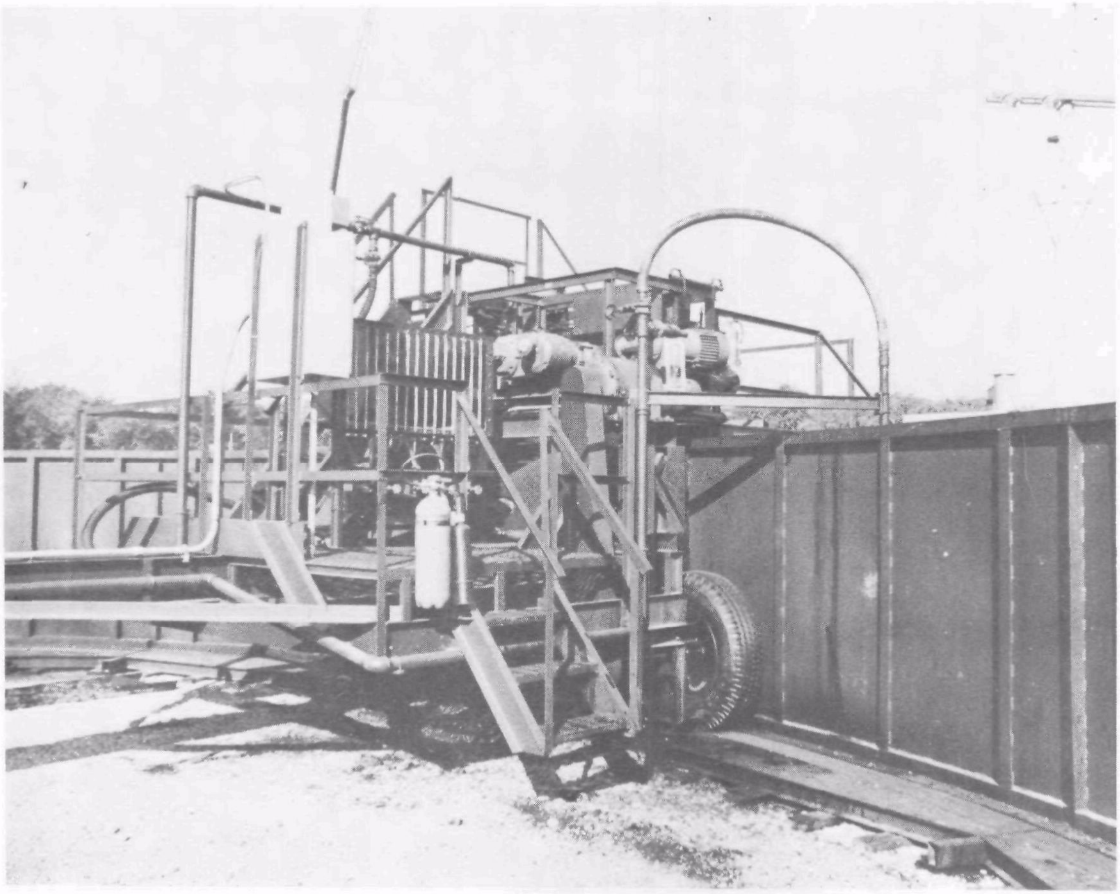


FIGURE 8

ROTATING PLATFORM ASSEMBLY

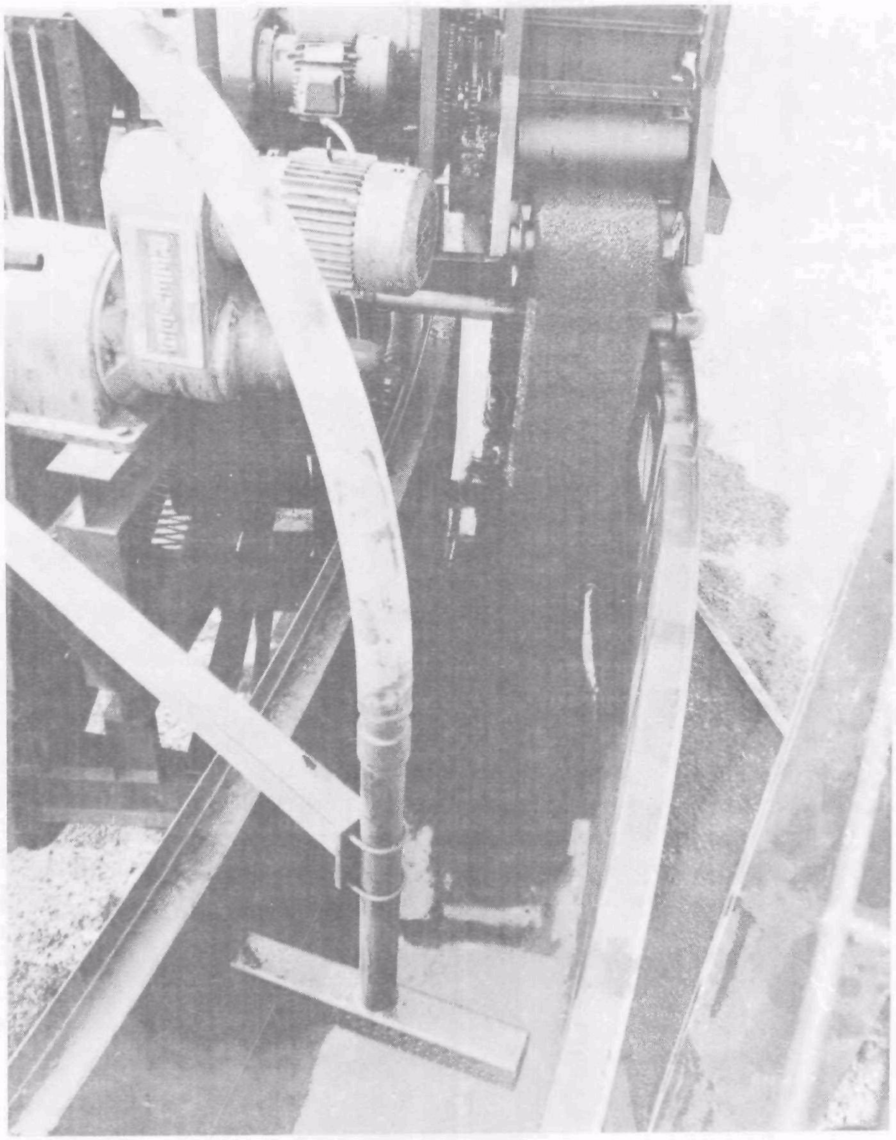


FIGURE 9

OIL DISTRIBUTION HEADER AND OIL SATURATED POLYURETHANE BELT

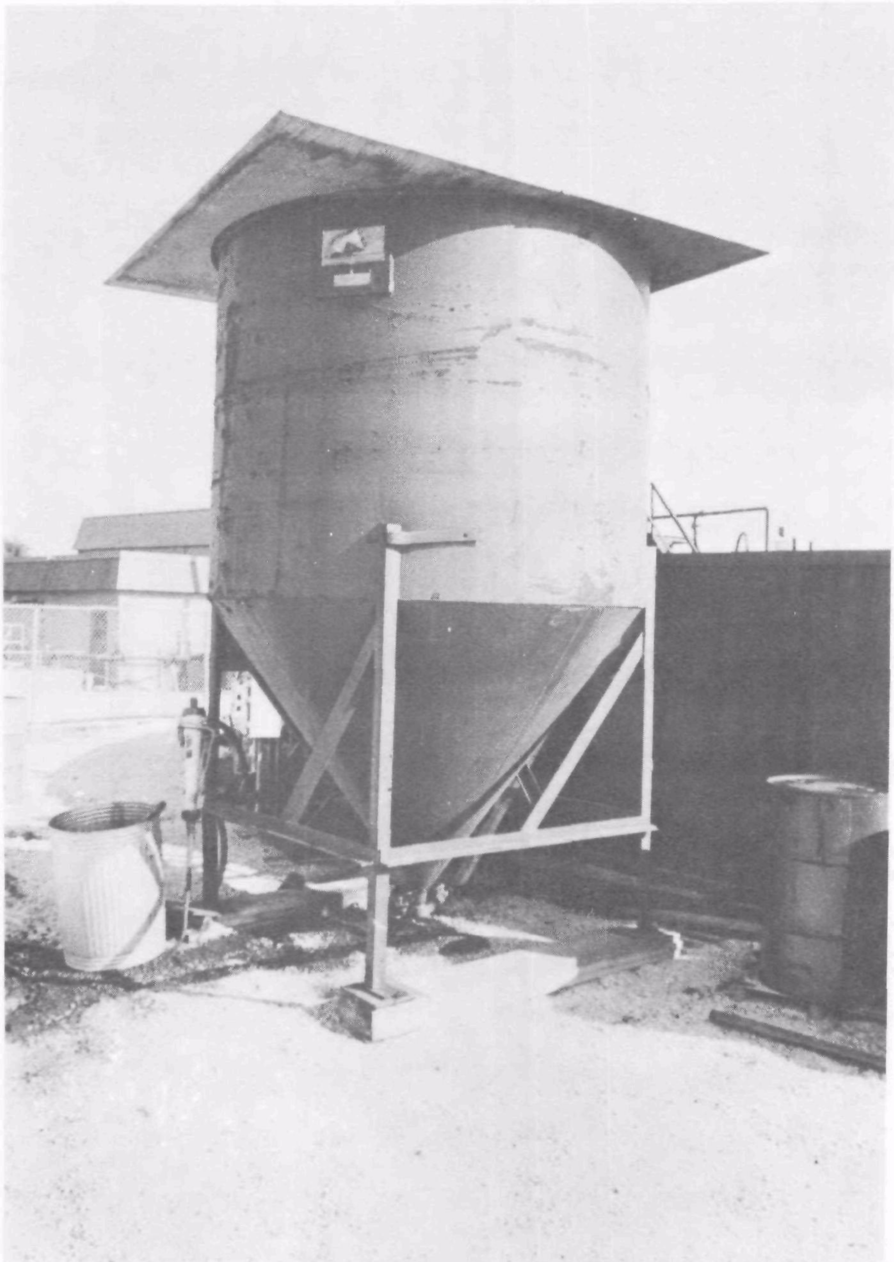


FIGURE 10

OIL SEPARATION TANK

Director of the Center for Great Lakes Studies, University of Wisconsin-Milwaukee. In all ways but one, the problem of wave generation in channels has been extensively studied. The unknown area involved the efficient refraction of waves to make them travel around a circular annual tank. The underwater piston technique, driven by a motorized cable transmission system (Figure 11) produced a very uniform wave of approximately 17 ft. wave length and comparable to the short waves found in harbors and protected waters.

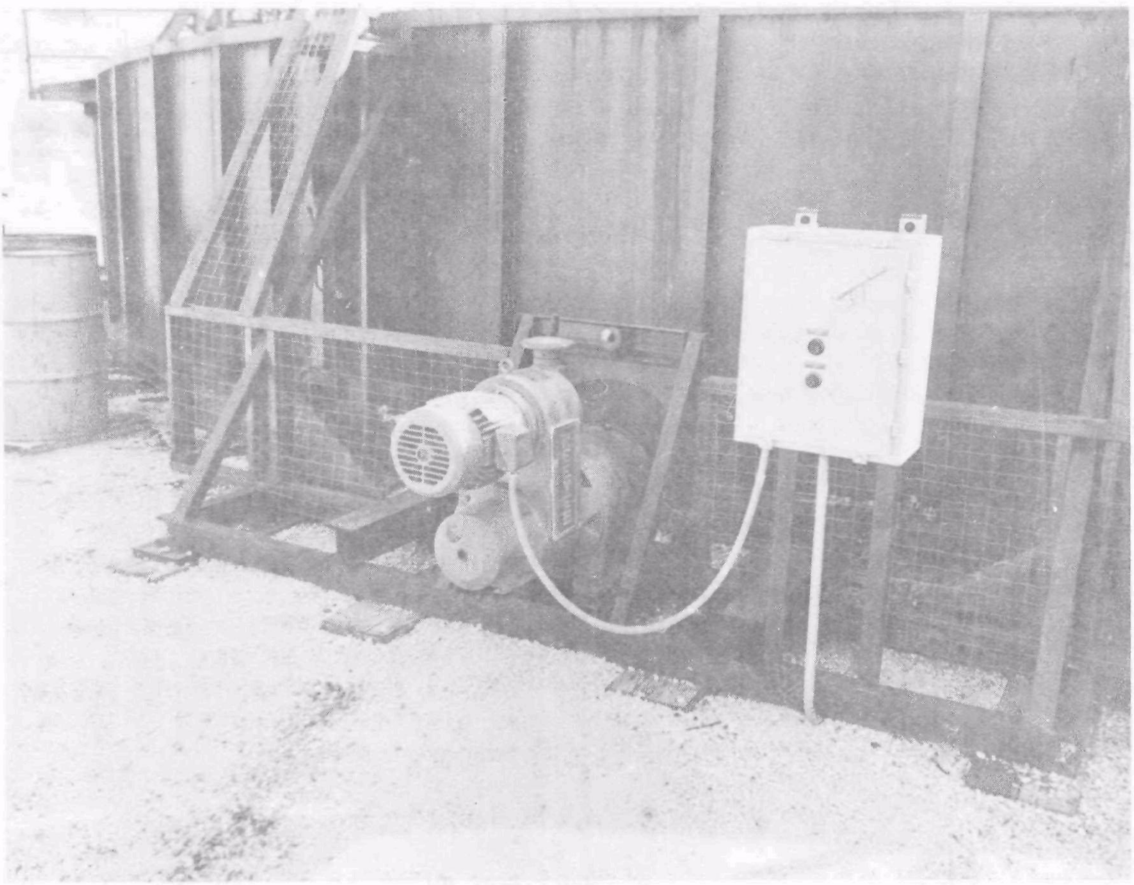


FIGURE 11

WAVE GENERATOR DRIVE

SECTION VII

EXPERIMENTAL PROCEDURES

The experimental prototype skimmer and test tank were located outside and adjacent to the Rex Chainbelt Technical Center. The test tank was filled to a four foot depth with City of Milwaukee tap water from a nearby fire hydrant. Each tankful of water was used for approximately 30 tests before it was drained and refilled.

The recovery of three types of oils (Oklahoma Crude, #2 Fuel Oil, and Bunker C) was evaluated during the test program. These oils were stored outside the test tanks in 55 gallon shipment drums until they were needed for tests. They were then pumped to the oil supply tank located in the center of the annular test tank (Figure 7).

Prior to the initiation of an experiment, the particular belt which was to be evaluated was installed according to the procedure outlined in the Design of Experimental Prototype Section.

With the exception of two groups of tests, the maximum oil pickup tests and the wringer efficiency tests, all experiments were conducted using the standard procedure outlined below. Hereafter, all experiments using these procedures will be referred to as standard procedure tests (SPT).

1. A calculated amount of oil to provide the desired initial oil-layer thickness was spread uniformly over the entire water surface of the test tank. The amount of oil spread was monitored by means of a calibrated speedometer on the pump drive. In addition, the change in oil level in the supply tank was measured during each experiment. The change in oil level was determined to more accurately reflect the amount of oil spread and was therefore used in all calculations. No oil was added to the tank surface during cleanup experiments.

2. The wringer was adjusted to the desired pressure.

3. The wave generator was started and adjusted to provide two foot waves. The time required to attain the desired wave condition was approximately 5 minutes.

4. The rotating platform was started and adjusted to the desired forward velocity.

5. The skimmer was turned on and adjusted to the proper speed. In general, Steps 4 and 5 were accomplished in less than 1/4 of a tank revolution.

6. Samples of the oil-water mixture were obtained by diverting the entire flow from the oil collection pump to the 5-gallon

sample containers at various time intervals during the test run. Initially, samples were taken at very close time intervals (on the order of 30 seconds). The time interval between samples was gradually increased as the amount of oil left on the surface diminished with time. The volumetric rate of flow was determined by measuring the time required to collect each sample. Flow which was not collected in the sample containers was pumped to the collection tank in the center of the annular tank.

7. The skimming was continued until, by operator's judgment, a substantial portion of the spilled oil had been collected.

8. The volume of oil-water mixture in the center collection tank as well as in each sample container was measured and recorded.

9. The oil-water mixture in the sample tanks was allowed to separate for one hour and the volume of oil and water was then recorded. During the tests using Oklahoma Crude it was necessary to add 3000-4000 ppm of Nalco 7713 to break the emulsion which had formed.

10. The oil-water mixture in the collection tank was then transferred to the oil separation tank. The oil in the separation tank was pumped back to the supply tank for reuse and the water was returned to the annular test tank.

11. Prior to the initiation of a new experiment the water surface was visually checked for residual oil. If any substantial amount of oil (≈ 2 gallons or more) was present additional skimming was conducted prior to spreading more oil.

Collection and Analysis of Standard Procedure Experiment Data

As explained in the previous pages, periodic samples of the oil-water mixture were collected and recorded during the duration of an experiment. A sample data sheet from Experiment No. 35 is shown in Table 2 to illustrate the means by which the data was collected and results were determined.

A computer program (PETSKI) was developed to calculate the various parameters of interest. These parameters included:

1. Percent oil in the recovered oil-water mixture
2. Oil-water mixture pickup rate (gpm).
3. Oil pickup rate (gpm)
4. Cumulative oil volume collected
5. Cumulative percentage of oil recovered
6. Equivalent oil slick thickness remaining at the time of the sample.

TABLE 2

OIL BELT SKIMMER DATA SHEET

Operated by: MS, TR, MG Experiment No. 35 Date: 7/13/71 Duration of Experiment 12 min 39 sec.

Oil Type & Viscosity #2 Fuel Test Plan Code # ______ Oil Temperature: 88^oF

Belt Code No. 3/8" x 45 ppi Oil Thickness 0.125 in. Wringer Pressure 4.0 psi

Wringer Setting ______ % Oil at Surface -- Platform Velocity 2.5 knot

Platform Setting ______ Skimmer Velocity 55 fpm Skimmer Setting 27

Oil Supply Tank Level Start 1.772 End 1.600 Oil Collection Tank Level Start 0.616 End 0.962

Amount of Oil Spread ≃28 gallons Oil Supply Pump Setting 51 Oil Supply Rate 14 gpm

Time of Oil Spread -- Platform Velocity ______ Platform Setting 32

No. of Revolutions --

Sampling Time Min	Sampling Time Sec	Sample Collection Time sec.	Sample Volume gal.	Settling Time hrs.	Volume of oil in Sample gal.
0	15	29.9	4.25	1 hr.	1.74
1	10	24.9	4.47	1 hr.	2.35
2	0	25.0	4.29	1 hr.	2.20
2	50	25.8	4.32	1 hr.	1.90
3	45	26.3	4.40	1 hr.	1.35
5	0	30.1	4.45	1 hr.	1.07
6	45	30.0	4.10	1 hr.	0.65
8	0	29.4	4.0	1 hr.	0.30
10	0	27.9	4.24	1 hr.	0.20
12	0	29.8	4.23	1 hr.	0.16

TABLE 3

OUTPUT FROM COMPUTER ANALYSIS OF EXPERIMENT NO. 35

RUN NUMBER 35
AMOUNT OF OIL SPREAD 27.04 GAL INITIAL OIL DEPTH .1190 INCHES

TIME INTO RUN (MIN)	VOLUME OF SAMPLE (GAL)	VOLUME OF OIL (GAL)	PERCENT OIL (PCT)	COLLECTION RATE MIX (GPM)	COLLECTION RATE OIL (GPM)	SAMPLE MIDPOINT (MIN)	CUMULATIVE OIL VOL (GAL)	CUMULATIVE PCT REC (PCT)	EQUIV OIL DEPTH (IN)
.3	4.25	1.74	40.94	8.53	3.49	.5	.9	3.2	.115
1.2	4.47	2.35	52.57	10.77	5.66	1.4	4.9	18.0	.098
2.0	4.29	2.20	51.28	10.30	5.28	2.2	9.4	34.9	.077
2.8	4.32	1.90	43.98	10.05	4.42	3.0	13.5	50.0	.060
3.8	4.40	1.35	30.68	10.04	3.08	4.0	17.0	62.7	.044
5.0	4.45	1.07	24.04	8.87	2.13	5.3	20.3	75.1	.030
6.8	4.10	.65	15.85	8.20	1.30	7.0	23.3	86.2	.016
8.0	4.00	.30	7.50	8.16	.61	8.2	24.5	90.6	.011
10.0	4.24	.20	4.72	9.28	.44	10.2	25.5	94.5	.007
12.0	4.23	.16	3.78	9.13	.35	12.2	26.3	97.4	.003

TOTAL MIXTURE COLLECTED 109.6 GAL

PERCENT OIL IN THE MIXTURE 24.02 PERCENT

AVERAGE COLLECTION RATES: MIXTURE 8.66 GPM
OIL 2.08 GPM

The computer program was run on a General Electric Co. timesharing computer with input and output being handled through a teletype terminal. A program listing for PETSKI together with definitions of the variables is presented in Appendix B.

The computer output from experiment No. 35 is shown in Table 3. Output information from the computer program was used to evaluate the skimmer performance under the various operating conditions.

The results of these calculations permitted observation of a number of effects. For example, instantaneous oil pickup rates and oil percentages could be determined for various equivalent oil slick thicknesses. It was also possible to obtain average collection rates and oil percentages during an entire slick pickup operation. For experiment No. 35, the average oil pickup rate was 2.08 gpm during the time when the slick thickness varied from 0.119 inches to 0.003 inches. Also, the total oil-water mixture collected during this experiment contained 24.0 percent oil.

To facilitate interpretation and analysis of the data, the results of each experiment were plotted in a manner similar to that shown in Figure 12.

Maximum Oil Pickup Rate Tests

A series of experiments were conducted to evaluate the maximum low viscosity oil pickup capacity of the skimmer with 1 and 2 inch thick polyurethane belts. The tests were conducted in quiescent water with approximately a 6 inch layer of Oklahoma crude oil. The rotating platform was maintained in a fixed position (zero forward velocity).

The tests were conducted at four skimmer (belt) speeds, 20, 55, 90 and 140 feet per minute for each of the 6 belts listed below in Table 4.

TABLE 4
MAXIMUM OIL PICKUP RATE TEST CONDITIONS

Belt No.	Belt Thickness, inches	Pores/Lineal inch (ppi)
1	1	20
2	1	45
3	1	80
4	2	10
5	2	20
6	2	45

Oil pickup rate as a function of belt speed is shown in Figure 13 for the various belts tested. The general trend is for an increase in pickup rate with an increase in belt speed up to a maximum level.

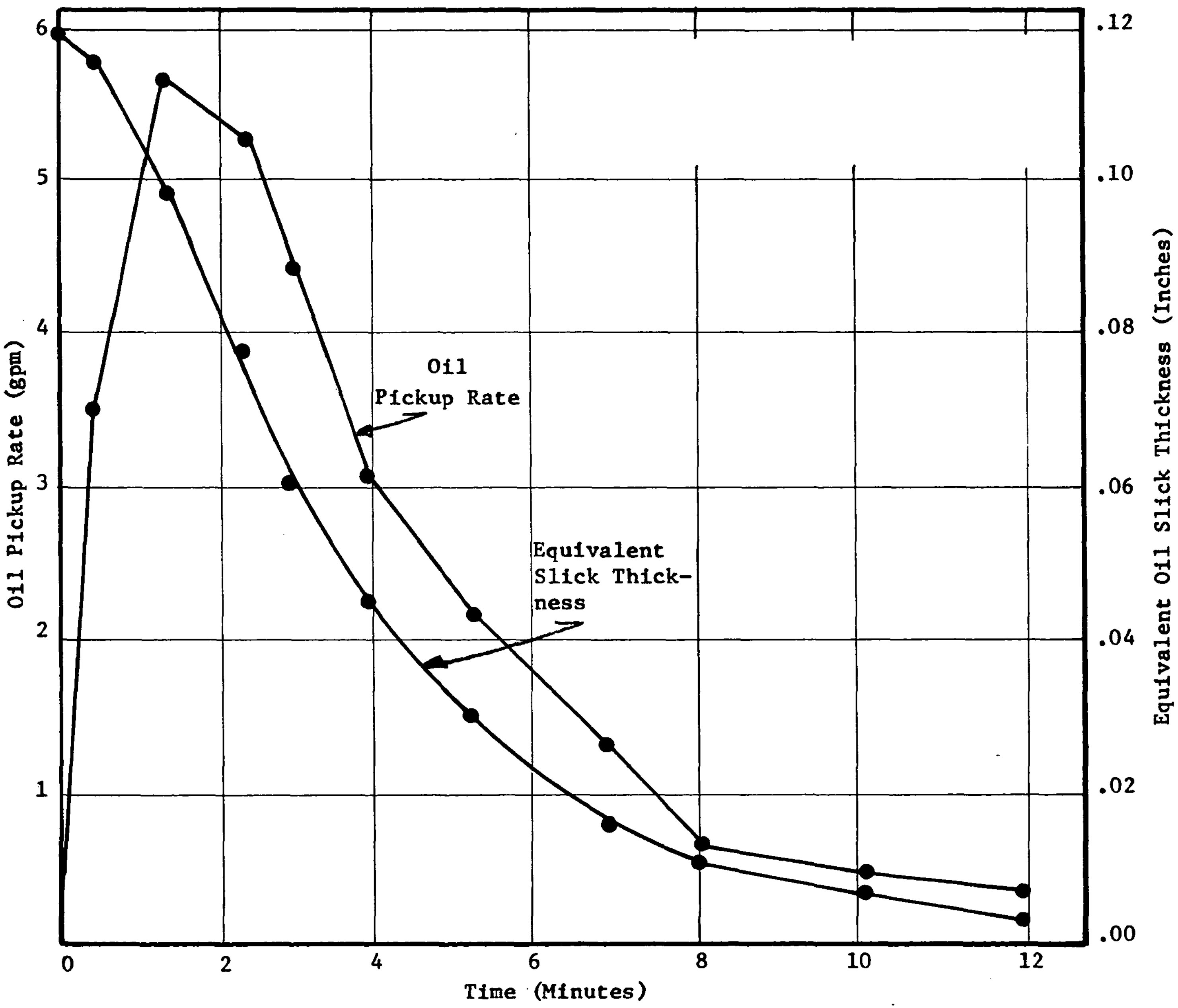


FIGURE 12

OIL PICKUP RATE AND EQUIVALENT SLICK THICKNESS VS. TIME

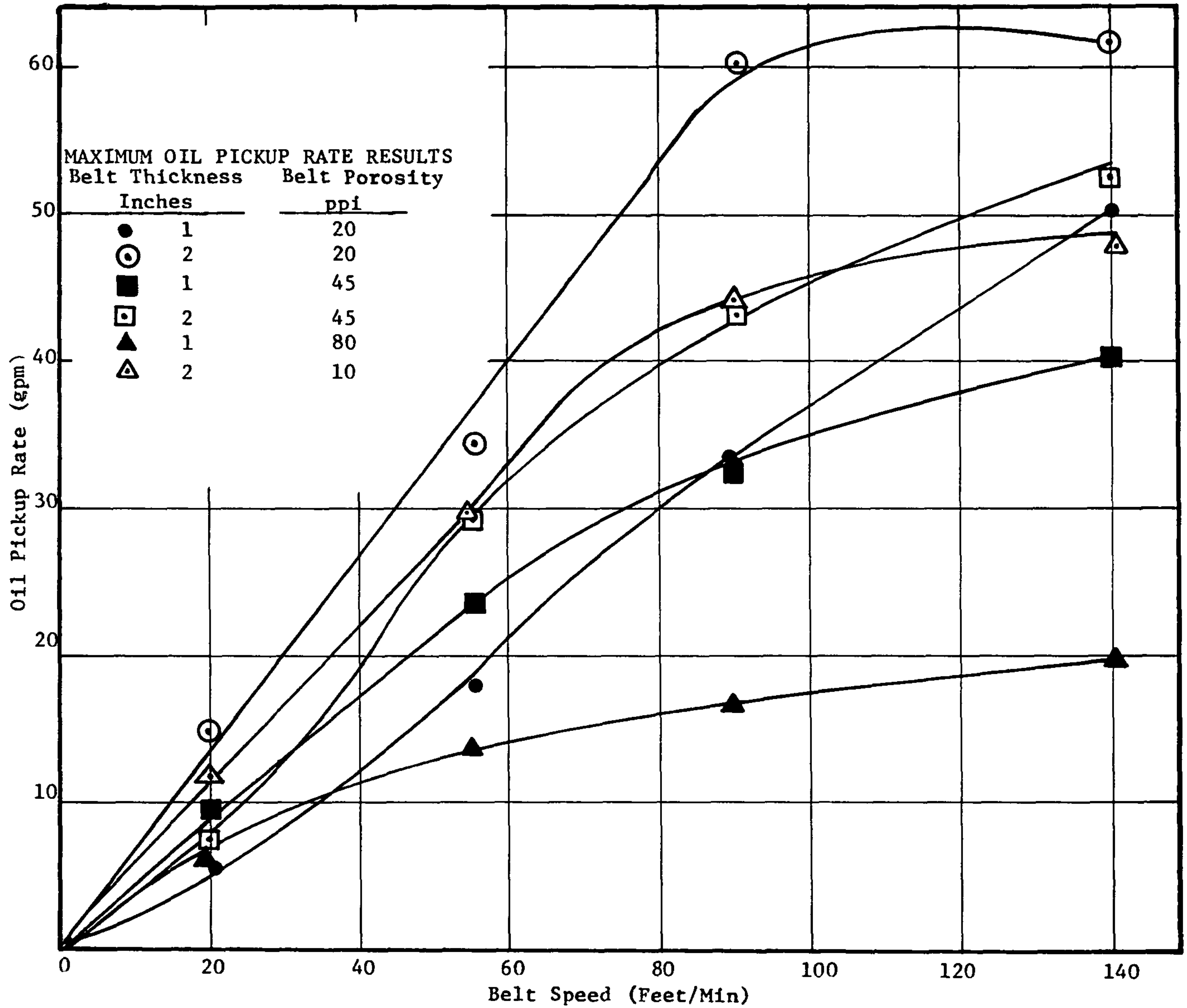


FIGURE 13

OIL PICKUP RATE VS. BELT SPEED

Two inch thick belts of 10 and 20 pores per lineal inch showed the highest pickup rates. This observation is consistent with theory since these belts presented the maximum amount of sorbtion volume and had an open surface which permitted the oil to penetrate into the foam.

In order to compare these results with those of Schatzberg and Nagy (18), the oil pickup rate was converted to pounds of oil per pound of sorbent and plotted versus belt speed (Figures 14 and 15). Although there is significant variation in sorption capacity with belt porosity the maximum pickup capacity was observed to be 22 pounds of oil per pound of sorbent. Schatzberg reported 30.6 pounds of oil/pound of sorbent for a light crude oil. Although there are a number of possible reasons for this discrepancy in results, it is felt that the primary reason is one of sorption contact time. All of the data, with the exception of the 1" thick 20 ppi belt indicates a decreasing unit pickup rate with increasing belt speed (decreasing belt contact time). Schatzberg' data was collected in a series of laboratory tests utilizing 15 minutes oil-sorbent contact time.

This information is significant and indicates that maximum sorbtion efficiency can probably not be obtained with a continuous belt concept, due to the difficulty encountered in obtaining adequate contact time.

Wringer Efficiency

Utilization of an endless belt oil skimming concept requires a highly efficient wringer in order to be able to return a clean belt to the oil/water interface. Throughout the design phase, significant effort was devoted to the development of a high efficiency wringer. The wringer used in the experimental prototype skimmer has proven to meet these needs.

During skimming operations it was possible to wipe your hand across the surface of a wrung belt and detect only a very minimal amount of oil. Initial tests indicated that no significant improvement in wringer efficiency at pressures over 4 psi. Accordingly it was decided to conduct all tests at a wringer pressure of 4.0 psi.

A series of tests were conducted to quantitatively determine the efficiency of the wringer. Twenty inch long sections of oil saturated belt (polyurethane foam and neoprene rubber backing) were put through the wringer and weighed to determine the amount of oil removed from the belt by the wringer. These tests indicate that approximately 91% of #2 fuel oil and 80% of Bunker C could be removed from 3/8 and 1 inch thick polyurethane belts by the wringer. For the purpose of comparison, tests conducted with the bench scale roller wringer indicated wringer efficiencies of approximately 40-60% depending on belt and oil type.

It is felt that a substantial portion of the oil remaining on and in the belts is being reabsorbed from the perforated conveyor belts. This oil could be removed by applying a vacuum to the final section of the wringer to assist in removing oil from the conveyor belts. Although

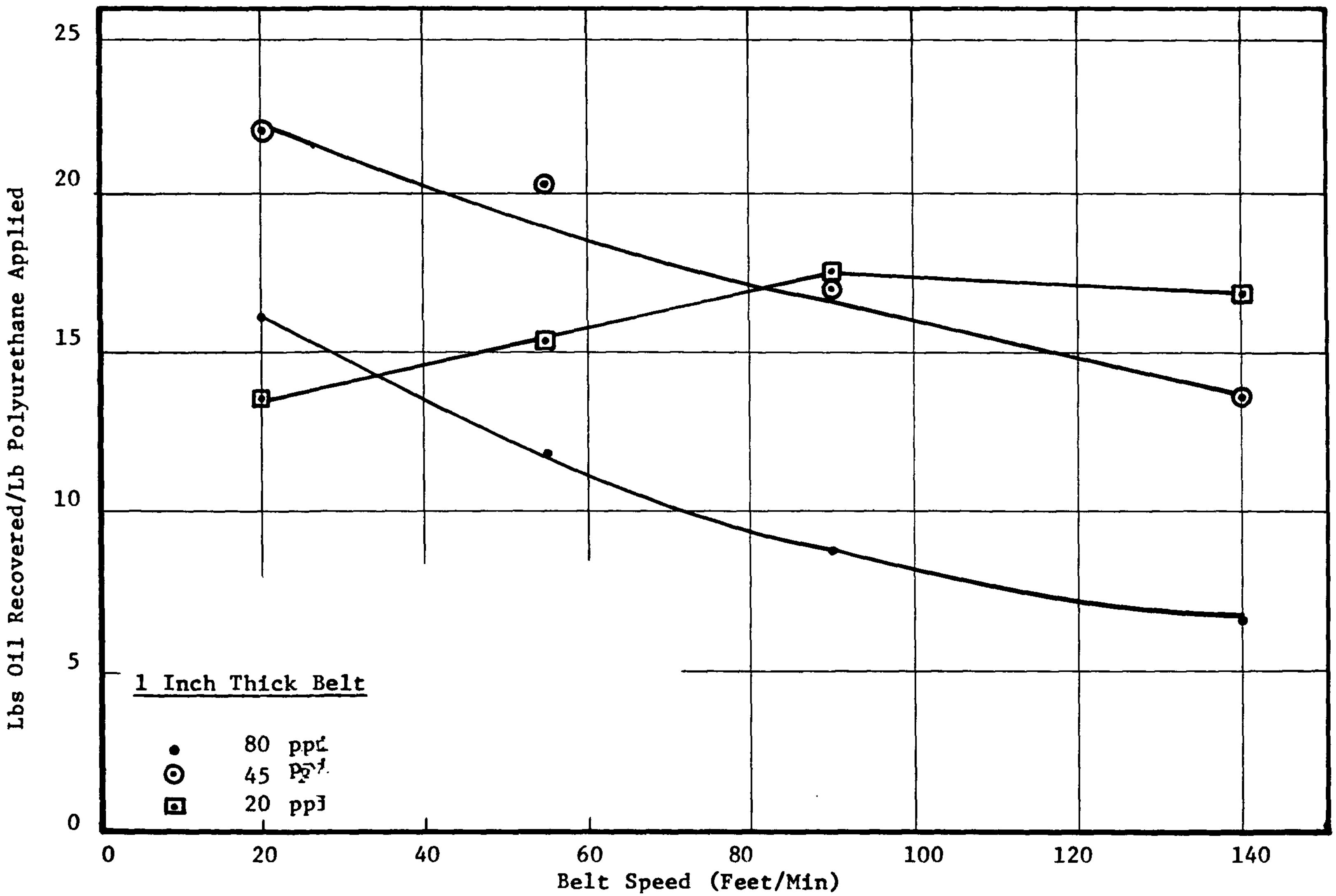


FIGURE 14

LBS OIL RECOVERED/LB POLYURETHANE APPLIED VS. BELT SPEED

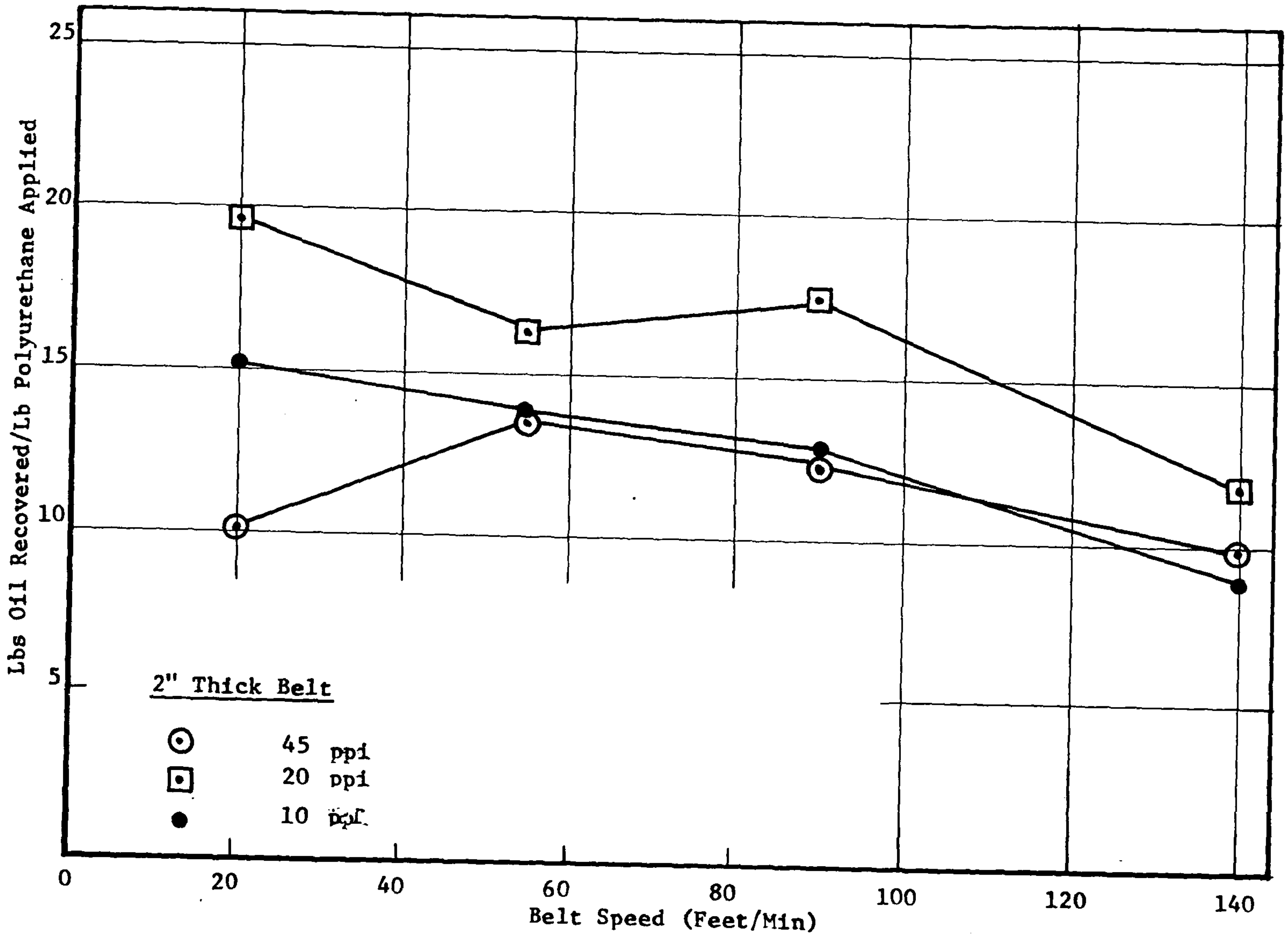


FIGURE 15

LBS OIL RECOVERED/LB POLYURETHANE APPLIED VS. BELT SPEED the experimental prototype skimmer was designed to utilize vacuum in the final one foot of the wringer, a vacuum pump was not purchased because initial tests indicated a high efficiency in the wringer.

A vacuum section should probably be included in any future wringers, especially if recovery of very thin oil layers (sheens) are to be attempted.

Results of Standard Procedure Tests

The standard procedure tests (SPT) were conducted according to the methods outlined in a previous section. The objective of these tests was to determine the oil pickup rate and percentage of water in the oil-water mixture for various polyurethane belt types (thickness and pore size), belt speeds and forward skimmer velocities. As previously mentioned, all tests were conducted under the condition of a slightly progressive wave with an amplitude of two feet.

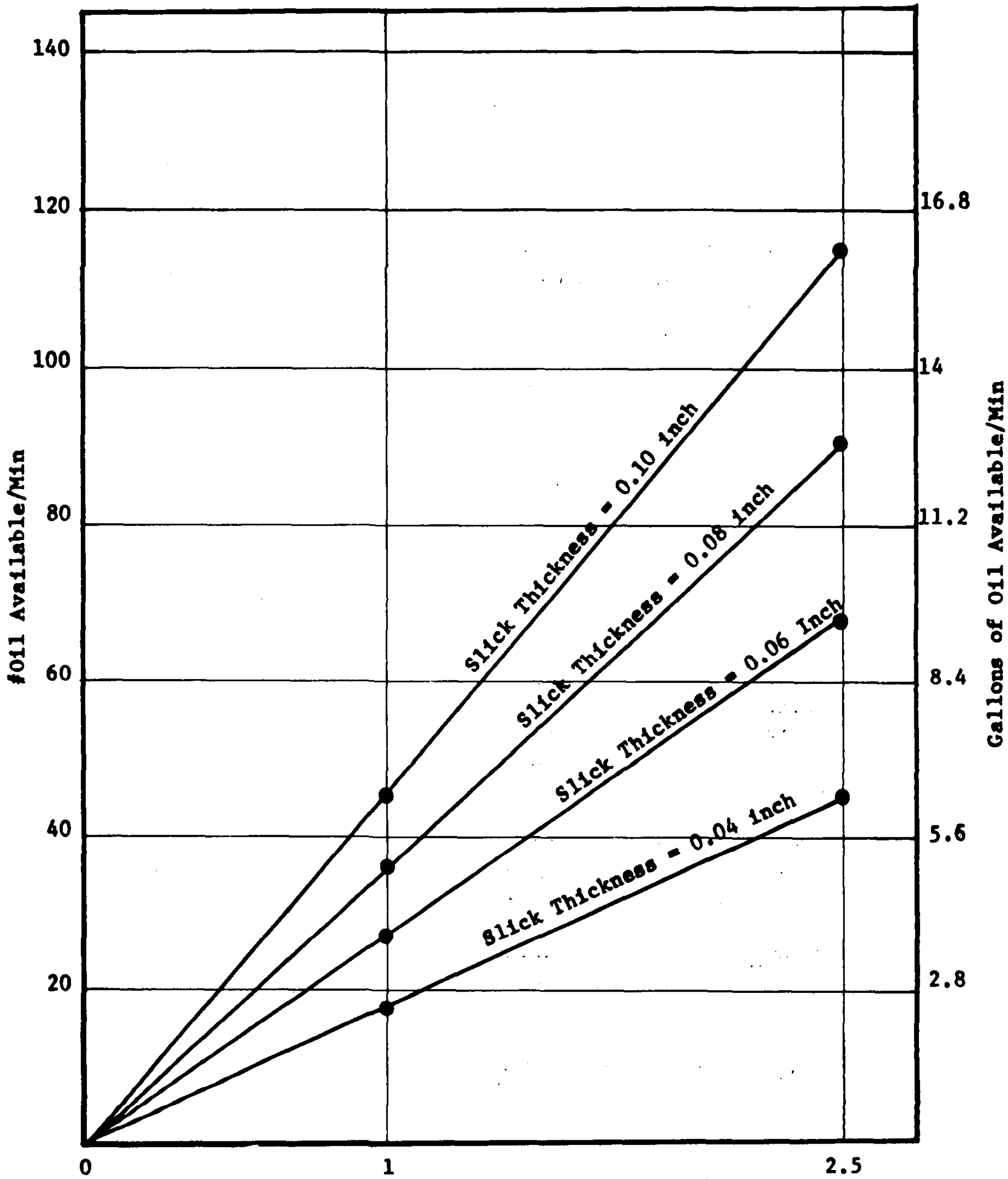
Nearly all oil skimmers presently in service make use of deflector booms attached to the front of the recovery vessel to sweep a wide area ahead of the boat and funnel the oil to the skimming device. This technique has significant advantages in that it permits a vessel to cover a somewhat wider area with a single pass as well as presenting a thicker oil layer to the skimmer than exists on the water surface ahead of the vessel. Attempts were made to utilize a deflector boom concept of the experimental prototype skimmer. However, due to the geometry of the test tank, it was found that oil recovery rates were decreased when the deflector boom was installed. This effect was attributed to the tangential wave action in the tank, and the subsequent "pumping" of water through the boom entrance. Consequently this technique was abandoned. It is therefore important to realize that the data presented in this report reflect the actual equivalent oil slick thickness and that no thickening in the approach area to the skimmer was accomplished. Further implications of this fact will be discussed later.

The amount of oil to be encountered by an oil slimmer and consequently available for recovery is a function of the oil slick thickness, the skimmer width and the forward velocity of the skimmer. Figure 16 shows the amount of oil available to the experimental prototype skimmer tested in this project for various forward velocities and slick thickness. This figure therefore indicates the maximum oil pickup rates which could be attained under the specific conditions of a particular test.

The oil pickup capacity of the polyurethane belts can be defined by the following equation;

$$Q_B = K \times V_B \times A \times 7.48$$

where: Q_B = belt pickup capacity in gpm



Forward Velocity (Knots)

FIGURE 16
OIL AVAILABLE FOR SKIMMING VS. FORWARD VELOCITY-
EXPERIMENTAL PROTOTYPE SKIMMER

V_B = Belt velocity in feet/minute

A = cross sectional area of belt in square feet

7.48 = conversion from cubic feet to gallons

K = Dimensionless sorption coefficient

Based on the results of the maximum pickup rate tests it would appear that K and V_B are related, in that sorption is a function of contact time at least over the range of belt speeds (contact times) studied. It should be noted that this equation is applicable only for oils which are readily absorbed into the foam material. The equation should not, for example, be used with Bunker C oil for which absorbtion is minimal due to its viscous nature. It can, however, be said that in general, the oil pickup rate for low viscosity oils can be increased by increasing either the belt speed and/or the cross sectional area of the belt.

Tests with #2 Fuel Oil

Thirty-six SPT tests were conducted with #2 Fuel Oil. The results were processed using the time sharing computer program PETSKI and subjected to an analysis of variance to define the significant variables affecting oil pickup rate and percentage of oil in the oil-water mixture which was recovered.

Based on the results of the analysis of variance, it was determined that the forward platform velocity did not affect either the oil pickup rate or the percentage of oil in the recovered mixture at the 95% level. Consequently all of the data which follows has been calculated on the average of the results obtained at 1 and 2.5 knots forward velocity.

Variables which significantly influence oil pickup rate and the percent of oil in the recovered mixture include belt speed, belt thickness, pore size of the polyurethane and slick thickness.

For a given thickness of belt material, the volume of sorbent material presented to the oil surface can be increased by increasing the speed of the belt. Figures 17 and 18 show the oil pickup rate as a function of belt speed for the 20, 45 and 80 ppi belts at both 3/8 and 1 inch belt thicknesses. Maximum oil pickup rates were obtained at a belt speed of 90 feet per minute.

Oil pickup rate is also influenced by the porosity of the belts. For the three porosities tested, the maximum oil pickup rates were observed to exist with 80 ppi belts. It is felt that for low viscosity oils, 80 and even 100 ppi belts should be used since they present more resistance to outflow or drainback of oil than the higher porosity belts as well as being less susceptible to water pickup.

The oil recovery rates for the belts investigated are shown at various slick thicknesses up to 0.10 inches in Figures 19 and 20.

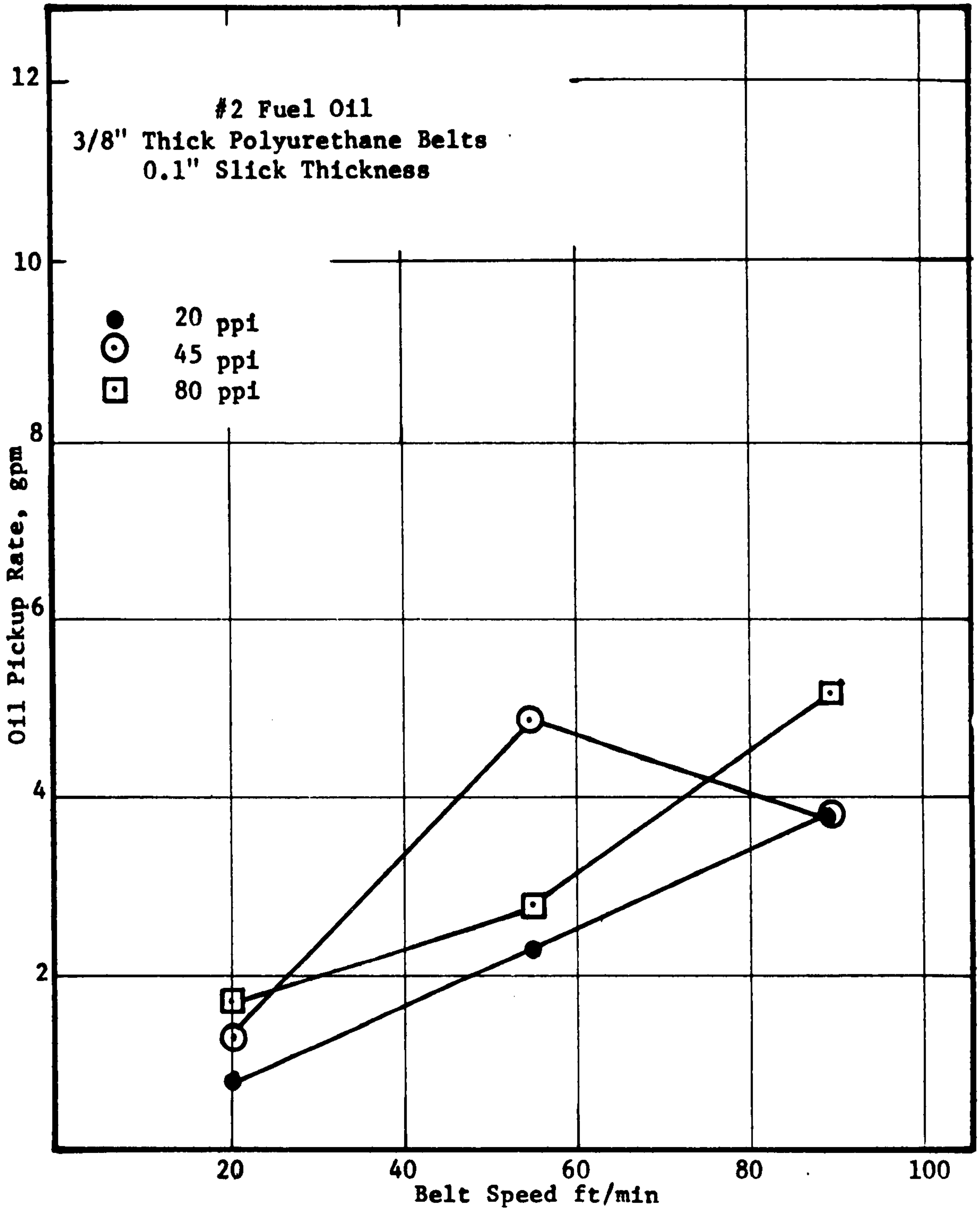


FIGURE 17
OIL PICKUP RATE VS. BELT SPEED

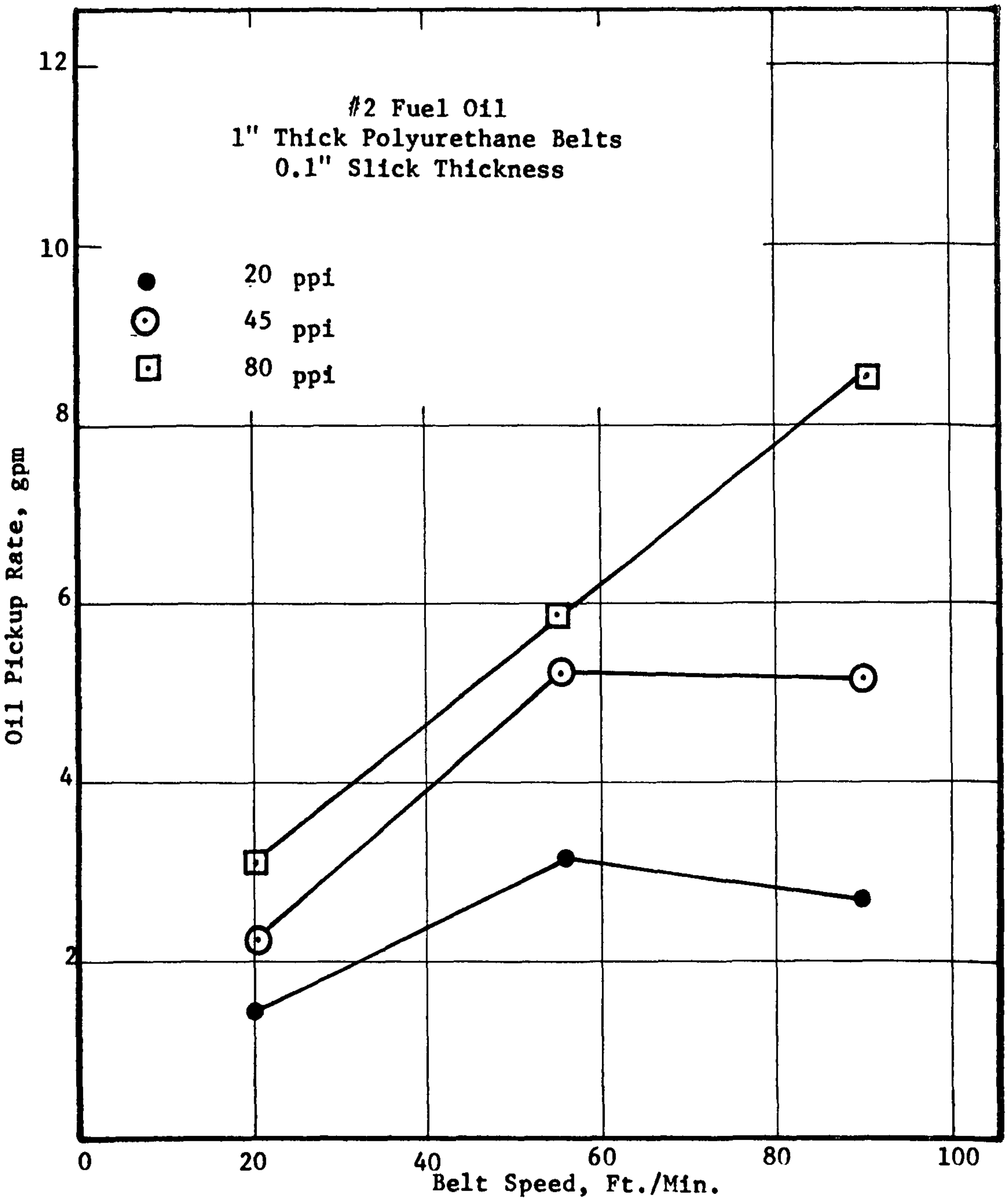


FIGURE 18

OIL PICKUP RATE VS. BELT SPEED

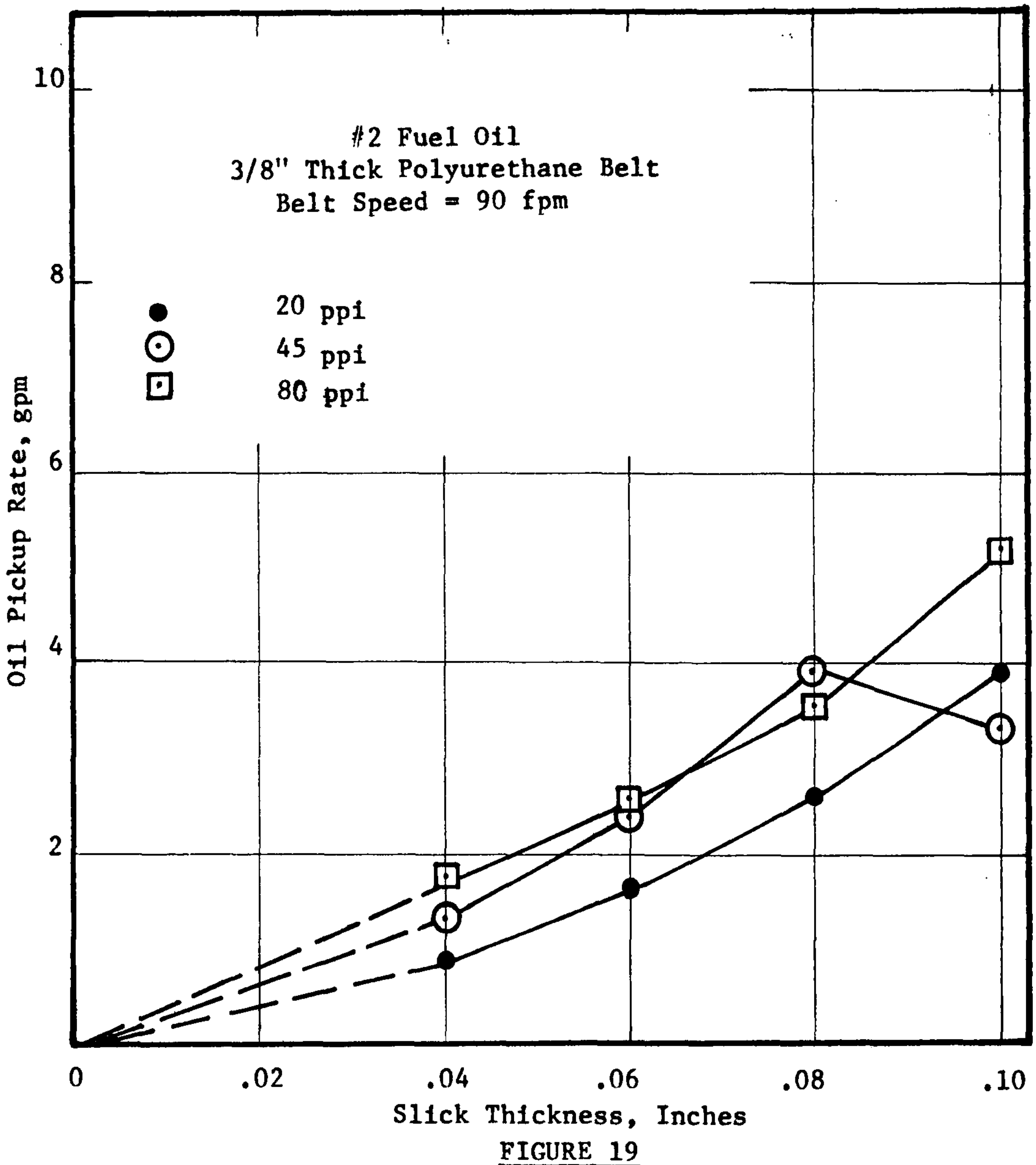


FIGURE 19

OIL PICKUP RATE VS. SLICK THICKNESS

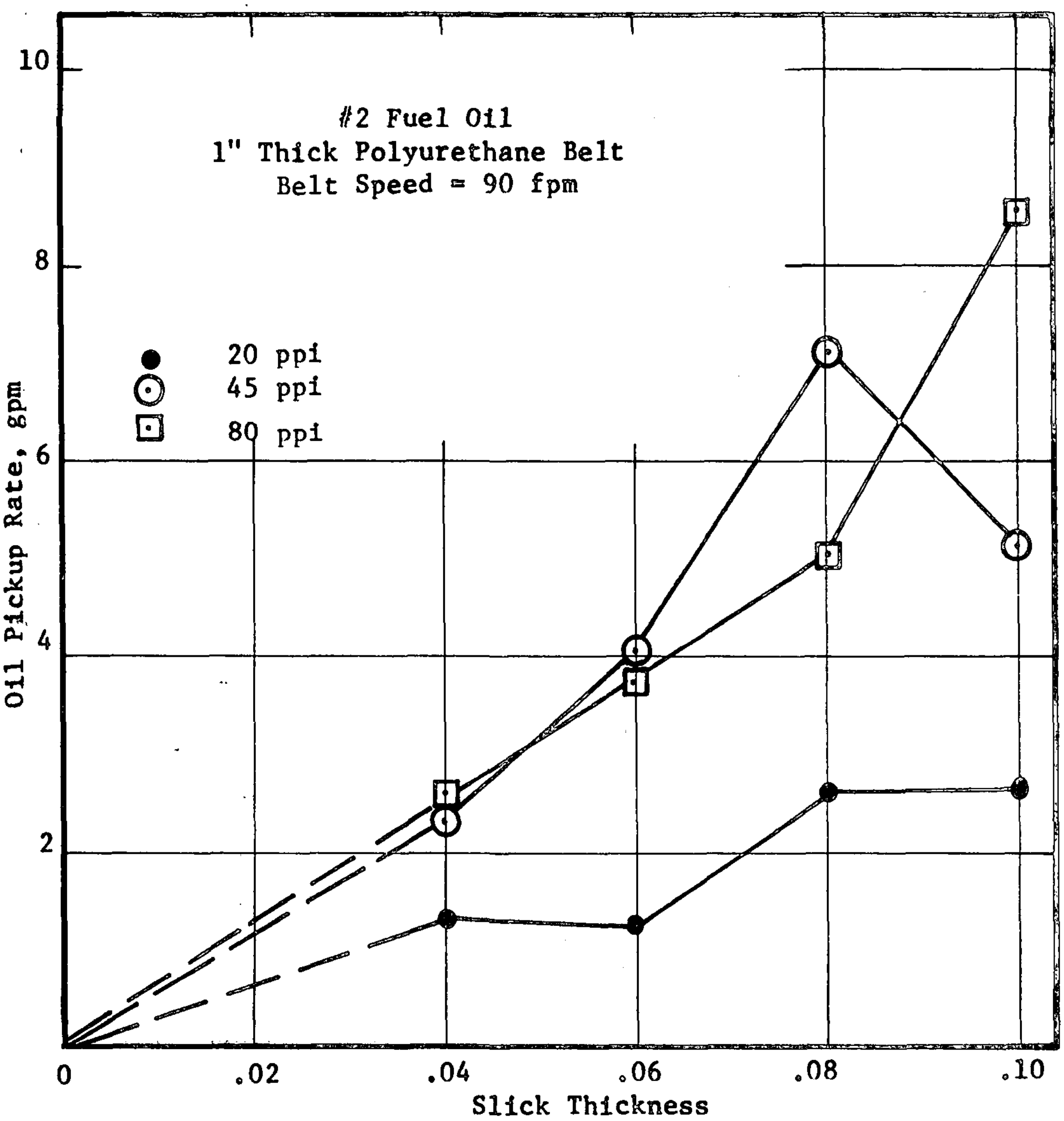


FIGURE 20
OIL PICKUP RATE VS. SLICK THICKNESS

Although there is significant variation among the various porosities and belt thicknesses, an approximately four fold decrease in pickup rate was observed for the 1" 80 ppi belt as the slick thickness decreased from 0.10 to 0.04 inches. This information confirms early comments regarding slick thickness and indicates the need for immediate response to oil spills as well as the use of deflector booms to thicken the oil immediately in front of the skimmer.

The percentage of oil associated with the recovered oil-water mixture was determined for each experiment which was conducted. These data are presented in Figure 21 through 26 and indicate how the oil content varied with slick thickness, belt velocity and belt porosity. The highest percentage of oil was obtained with the 80 ppi belts at a slick thickness of 0.10 inches. Although belt speed exerts some influence on oil content of the recovered oil-water mixture, the effect is minor compared to belt porosity and slick thickness. Based on these data, it can be concluded that for #2 Fuel Oil the maximum percentage of oil which can be obtained with this skimmer at slick thicknesses of 0.10 inches and less is about 50%.

An apparent discrepancy exists for the optimum foam as determined for the Maximum Oil Pickup Rate tests (Figure 13) and the #2 Fuel Oil tests. Maximum oil pickup rate was observed in thick oil layers (5-6 inches) with a 20 ppi belt. However, when the SPT tests were conducted on thin layers (0.125 inches and less) the 80 ppi belt was optimum. There is little doubt that the open pore 20 ppi belt has the greatest oil pickup capacity. However, in thin slicks, the resistance of a belt to water becomes at least as important as the pickup capacity of the belt. The affinity of the 20 ppi belts for water appears to impede the pickup of oil and hence for thin slicks an 80 ppi belt which has less liquid recovery capacity but more resistance to water pickup was found to be optimum.

The optimum operating conditions and results observed during these tests when skimming #2 Fuel Oil are summarized in Table 5. It is felt that operation of the skimmer under these conditions will yield the best overall results.

TABLE 5

OPTIMUM OPERATING CONDITIONS AND RESULTS FOR #2 FUEL OIL

Wringer Pressure	4.0 psi
Belt Speed	90 fpm
Belt Thickness	1.0 inches
Belt Porosity	80 pores/lineal inch
Forward Skimmer Velocity	1 - 2.5 knots

Expected Operating Results at 0.10 in. Slick Thickness

Oil Pickup Rate	8.3 gal/min
% Oil in Recovered Oil-Water Mixture	49

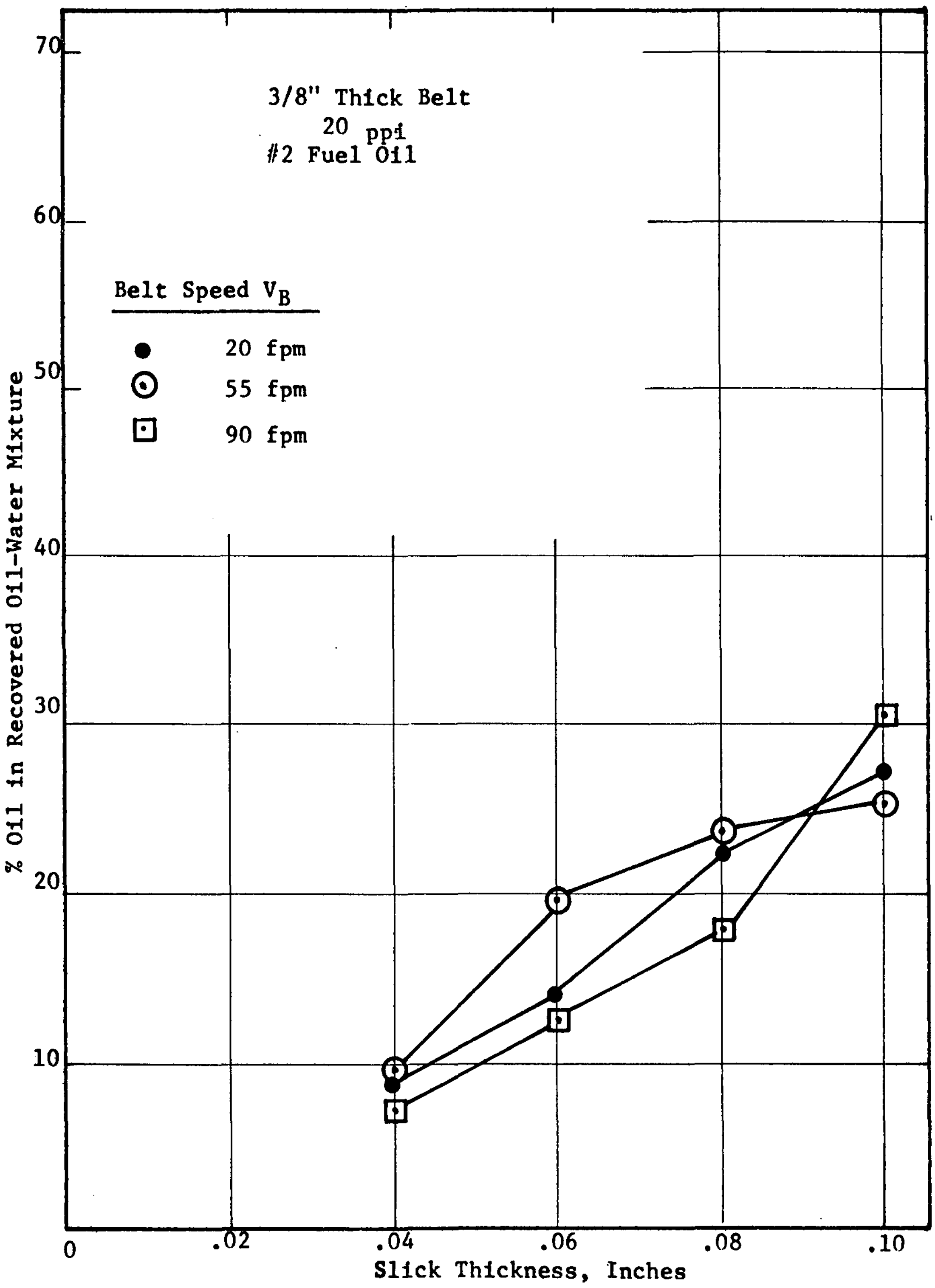


FIGURE 21

PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

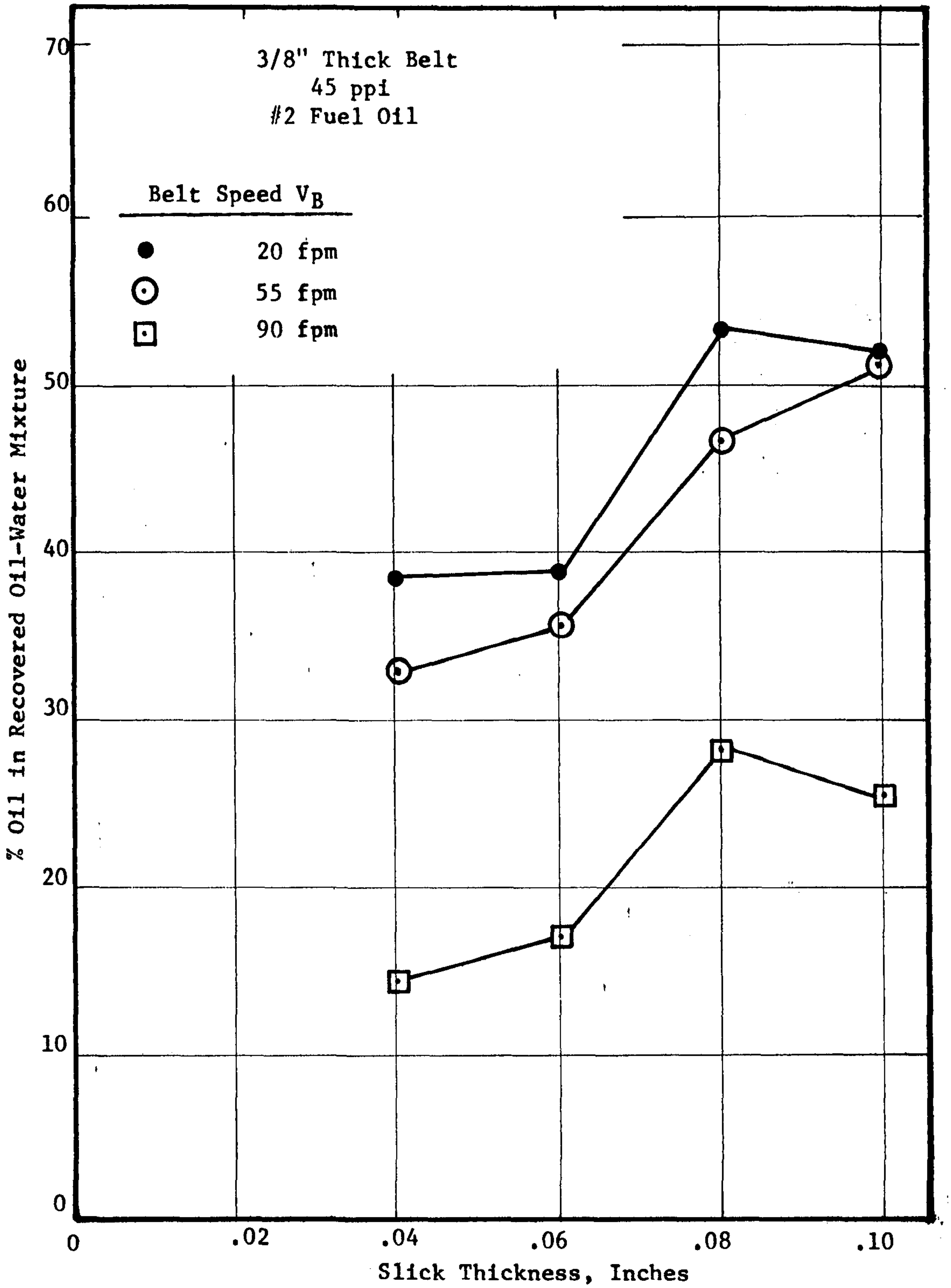


FIGURE 22
PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

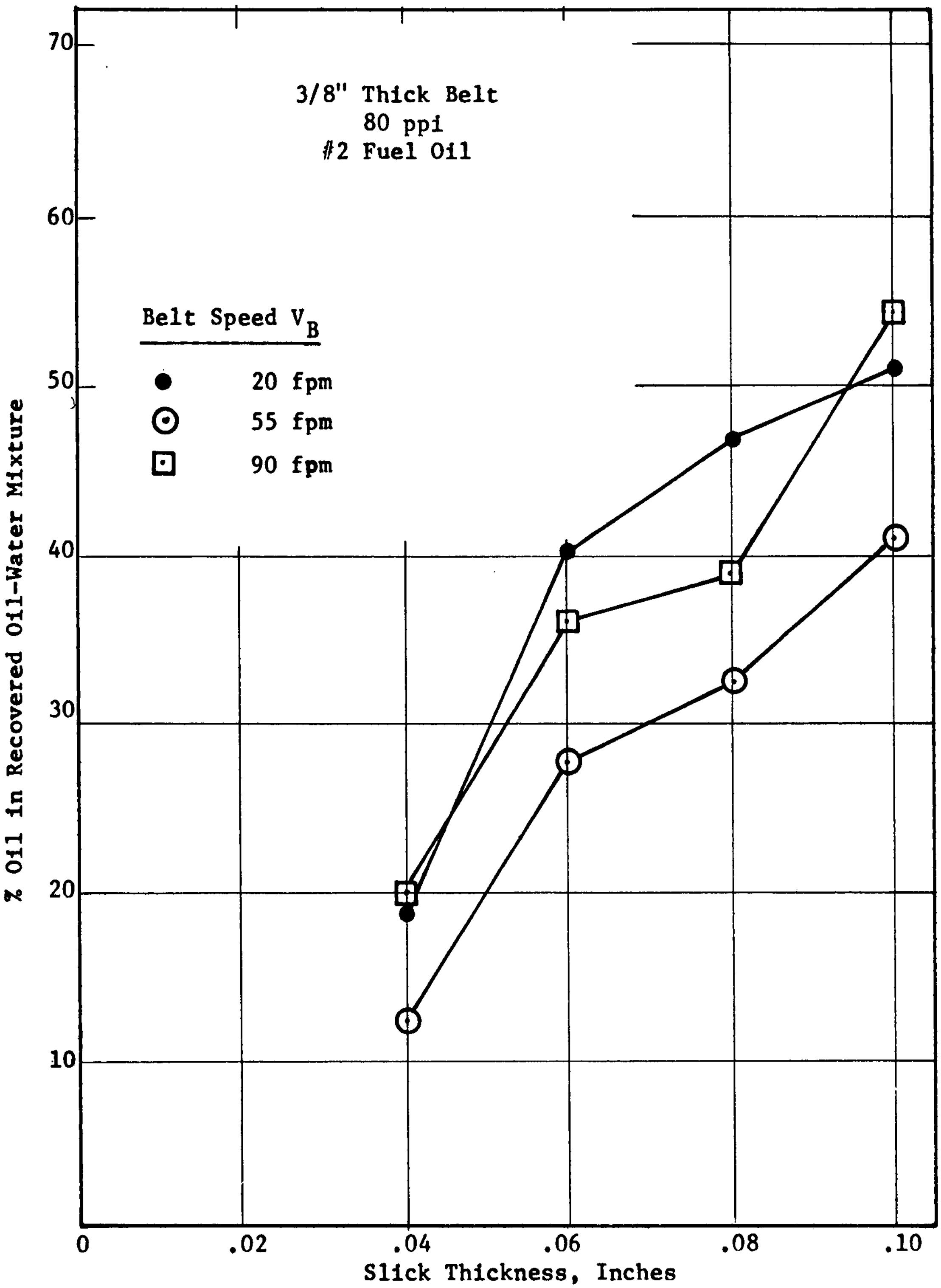


FIGURE 23
PERCENT OIL IN RECOVERED MIXTURE VS SLICK THICKNESS

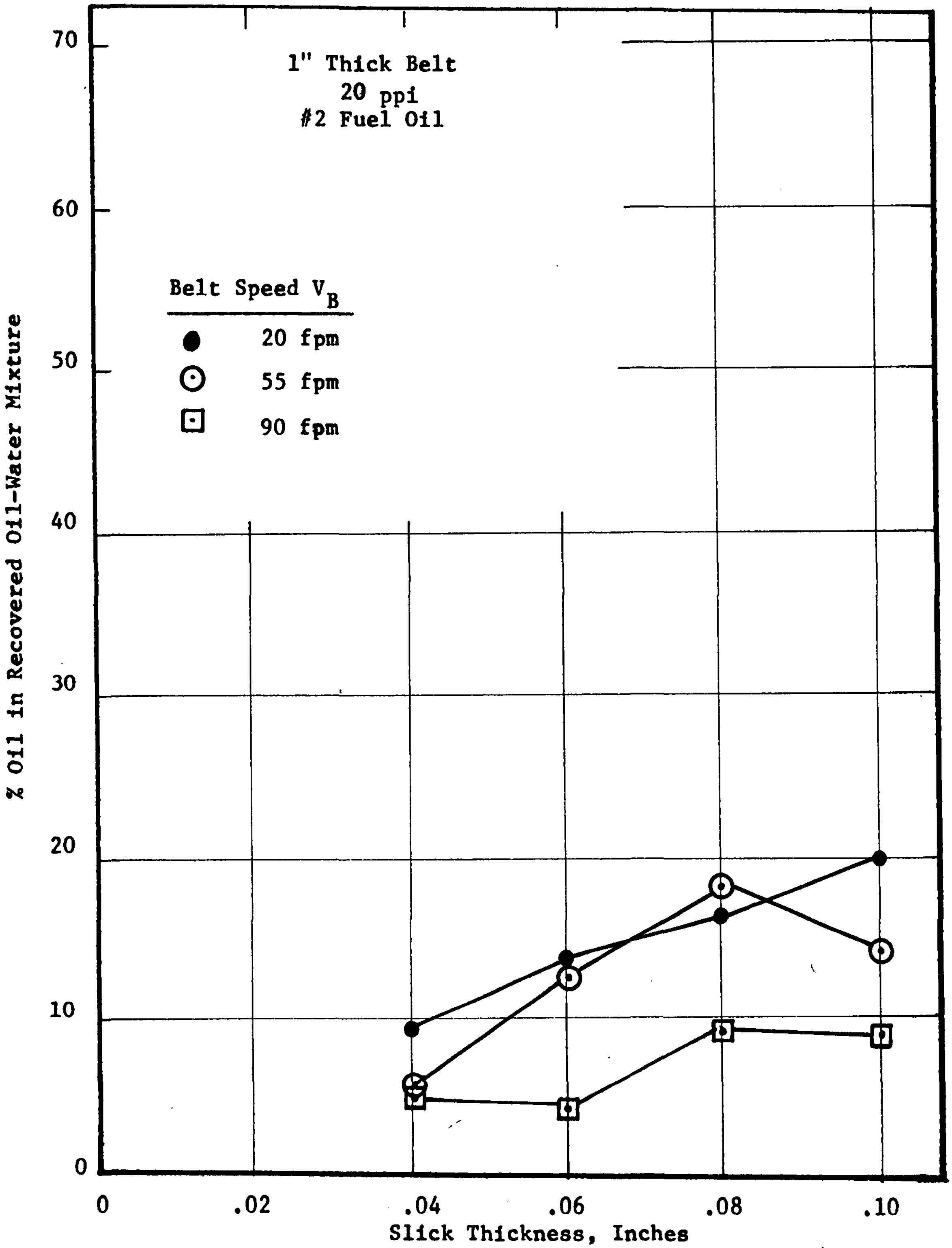


FIGURE 24

PERCENT OIL IN RECOVERED MIXTURE VS SLICK THICKNESS

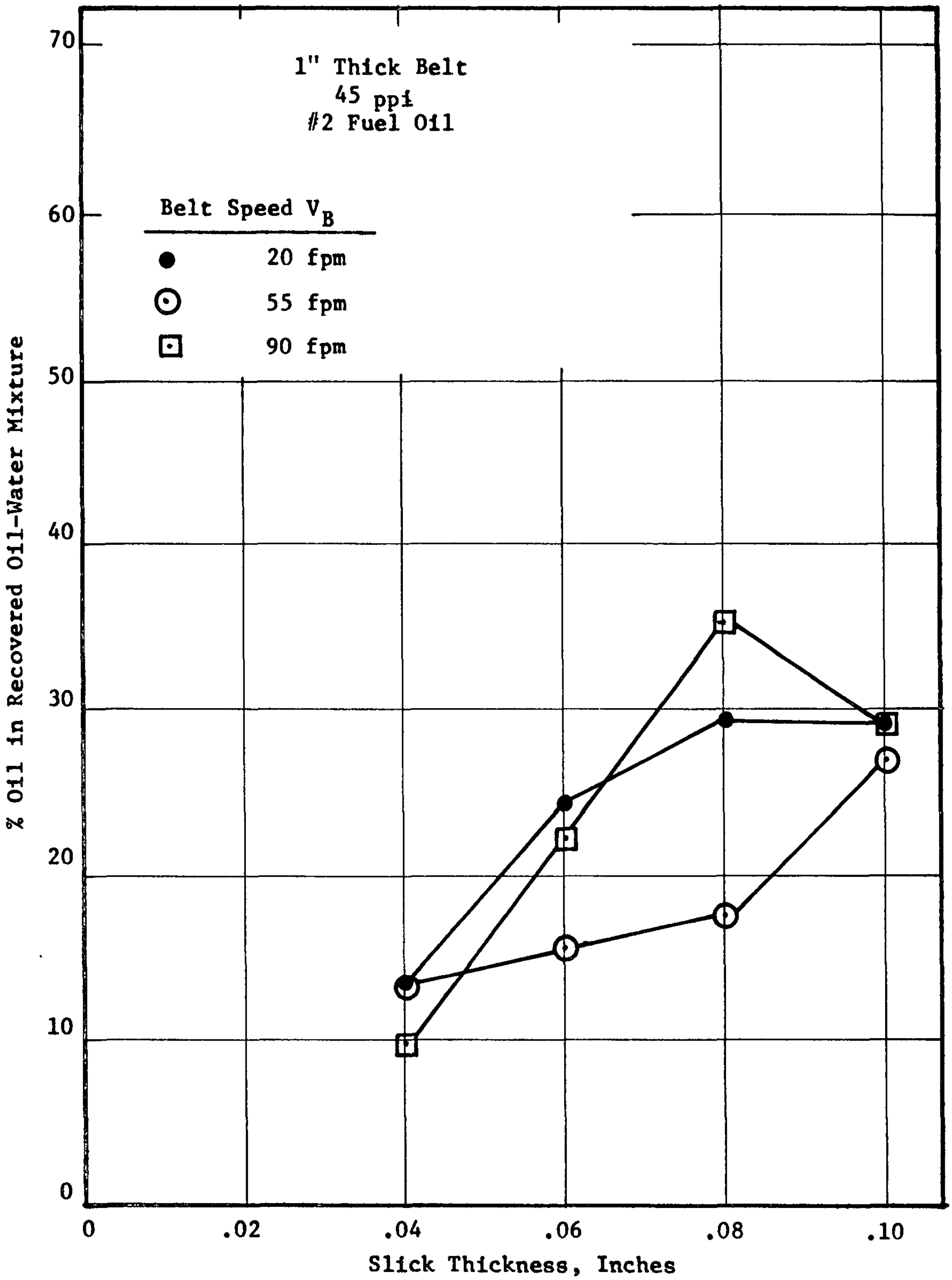


FIGURE 25
PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

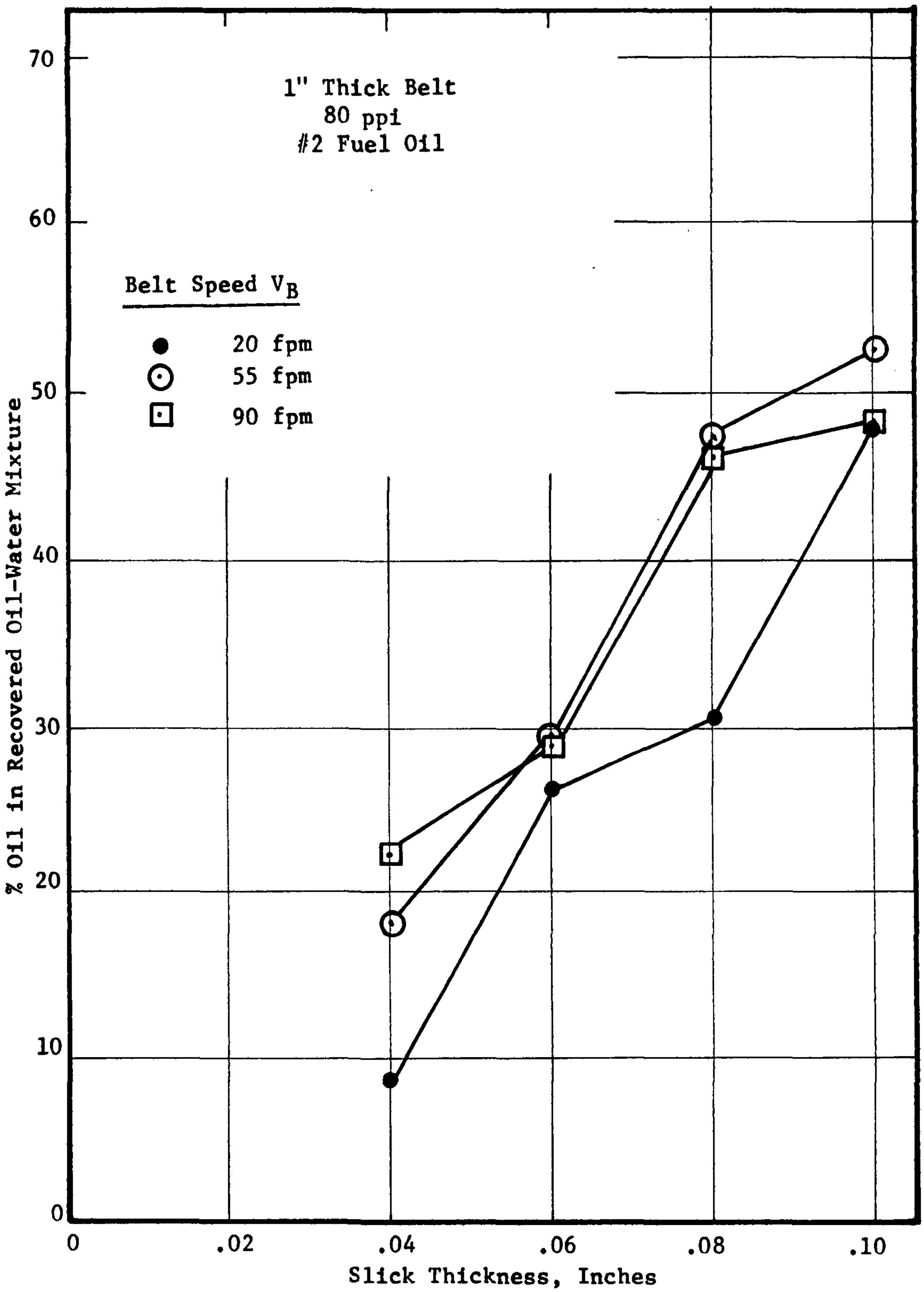


FIGURE 26

PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

TABLE 5 (CONT.)

Operating Results at 0.04 Inch Slick Thickness

Oil Pickup Rate	2.6 gal/min
% Oil in Recovered Oil-Water Mixture	22

Tests with #6 Oil (Bunker C)

Twenty-two separate tests were conducted using Bunker C oil to evaluate the oil recovery rate and oil content in the recovered mixture. The tests were conducted and analyzed in the same manner as was reported for the #2 Fuel Oil tests.

Because of the highly viscous nature of this oil certain difficulties were experienced with these tests which were not encountered in the #2 Fuel Oil tests. These difficulties are enumerated below.

1. Because of its physical properties, Bunker C did not spread uniformly over the water surface. The general tendency was for the formation of oil patches and non-uniform slicks at various locations in the tank. As a result of the physical constraints of the test system it was not possible to move directly into an oil slick as would normally be done on an open water oil spill. The data are therefore somewhat less sensitive to the slick thickness than was observed in #2 Fuel Oil tests.

2. A significant amount of oil was alternately deposited and washed from the side walls of the annular tank as a result of wave action. This oil was unavailable for skimming while it was on the tank wall and therefore reduced both the percentage of oil recovered and the oil pickup rates.

3. On cold days the Bunker C tended to form large oil balls due to the wave action in the tank. The skimmer was unable to remove these balls some of which were estimated to weigh in excess of 50 pounds. An oil ball of this size is equivalent to approximately 25% of the oil which was spread for a particular test.

For these reasons a less extensive test program was conducted with Bunker C than with the #2 Fuel Oil.

The oil pickup rates for the various belt speeds studied are shown in Figures 27 and 28. The maximum pickup rates at 0.1" equivalent slick thickness are 3.7 gpm for a 45 ppi 3/8" thick belt and 4.2 gpm for a 20 ppi 1" thick belt. Figures 29 and 30 illustrate how these pickup rates change with slick thickness. It can be noted that the change in pickup rate is not as significant as was observed in the #2 Fuel Oil tests. It is felt that this is a result of the viscous nature of

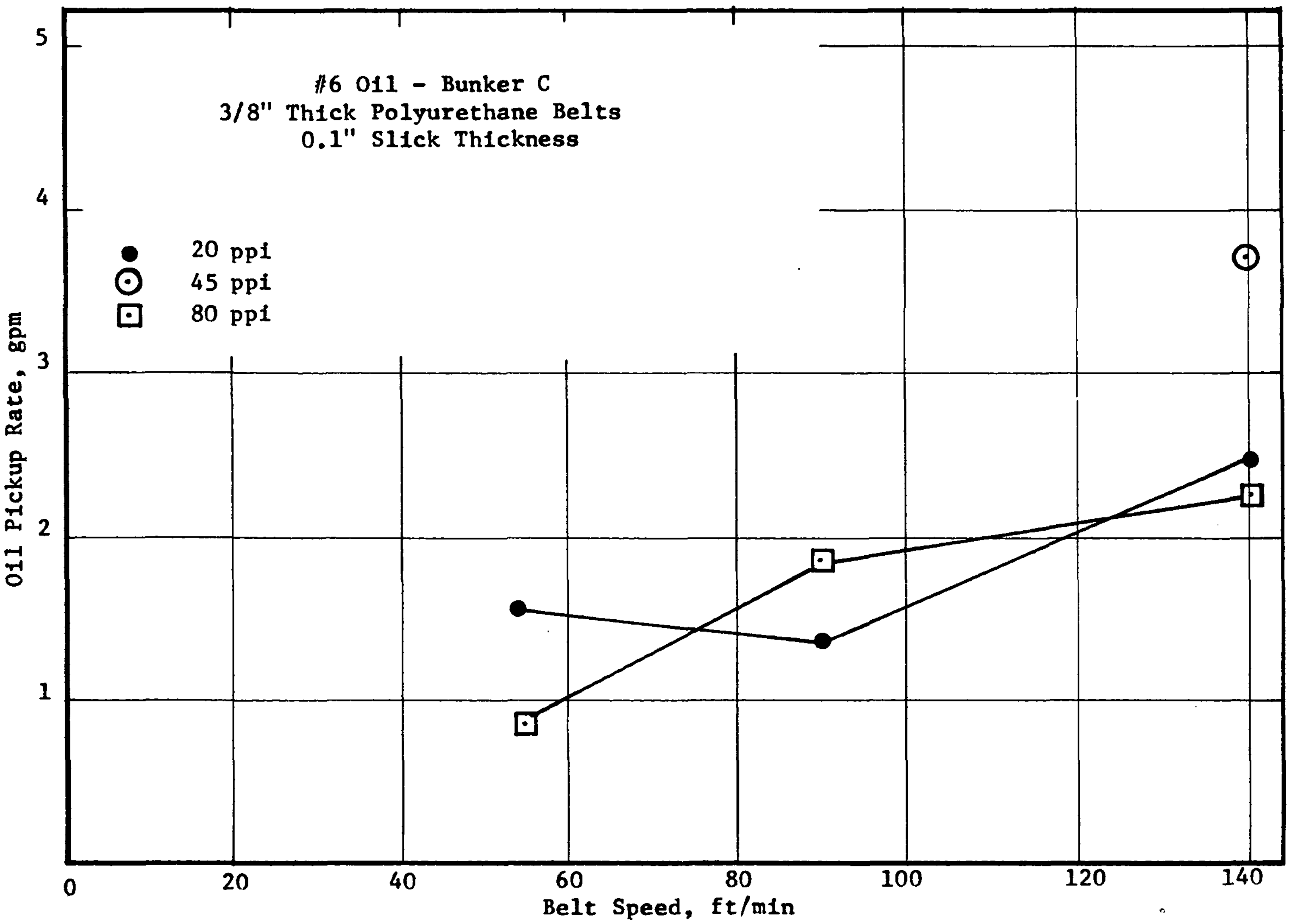


FIGURE 27

OIL PICKUP RATE VS. BELT SPEED

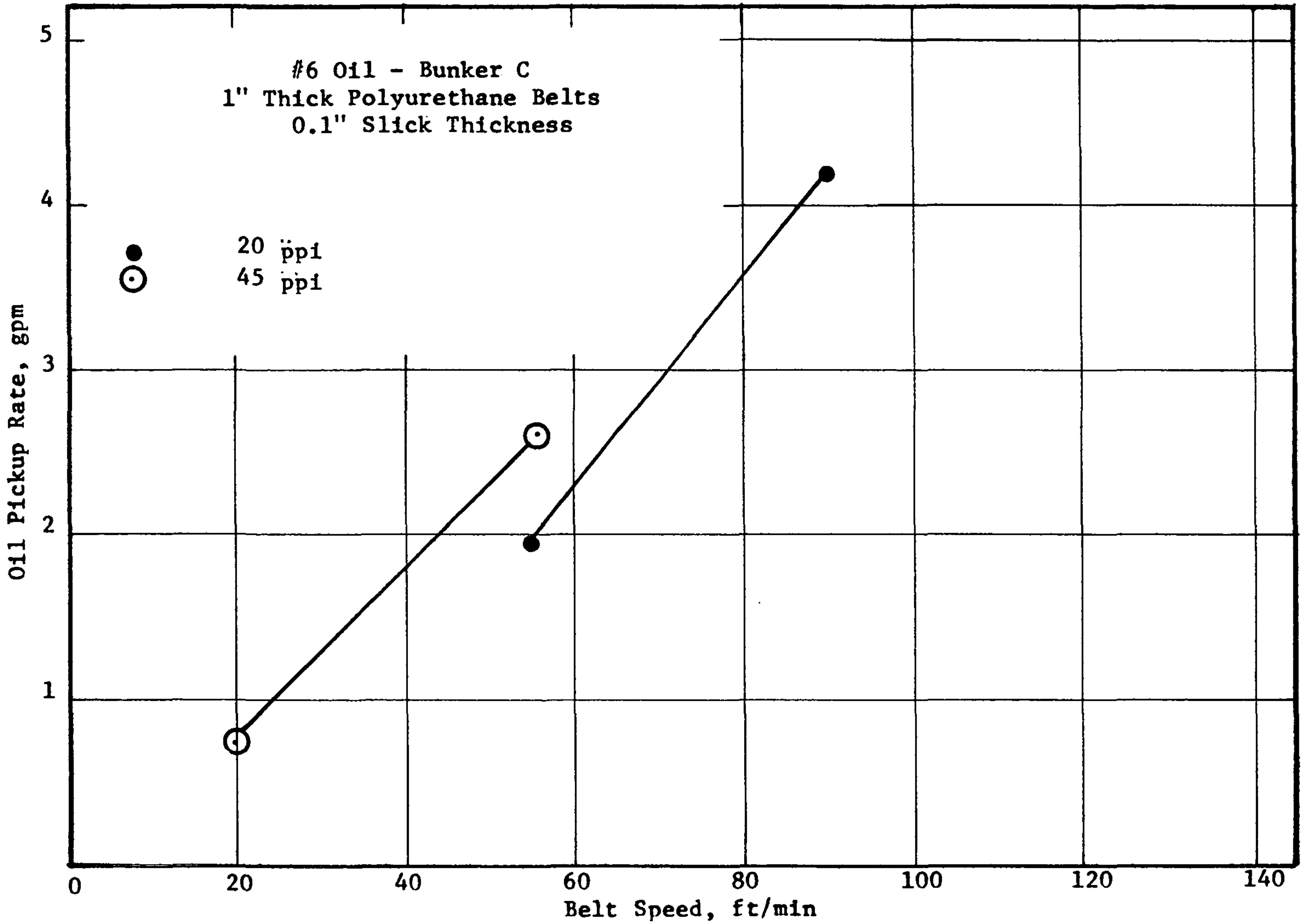


FIGURE 28

OIL PICKUP RATE VS. BELT SPEED

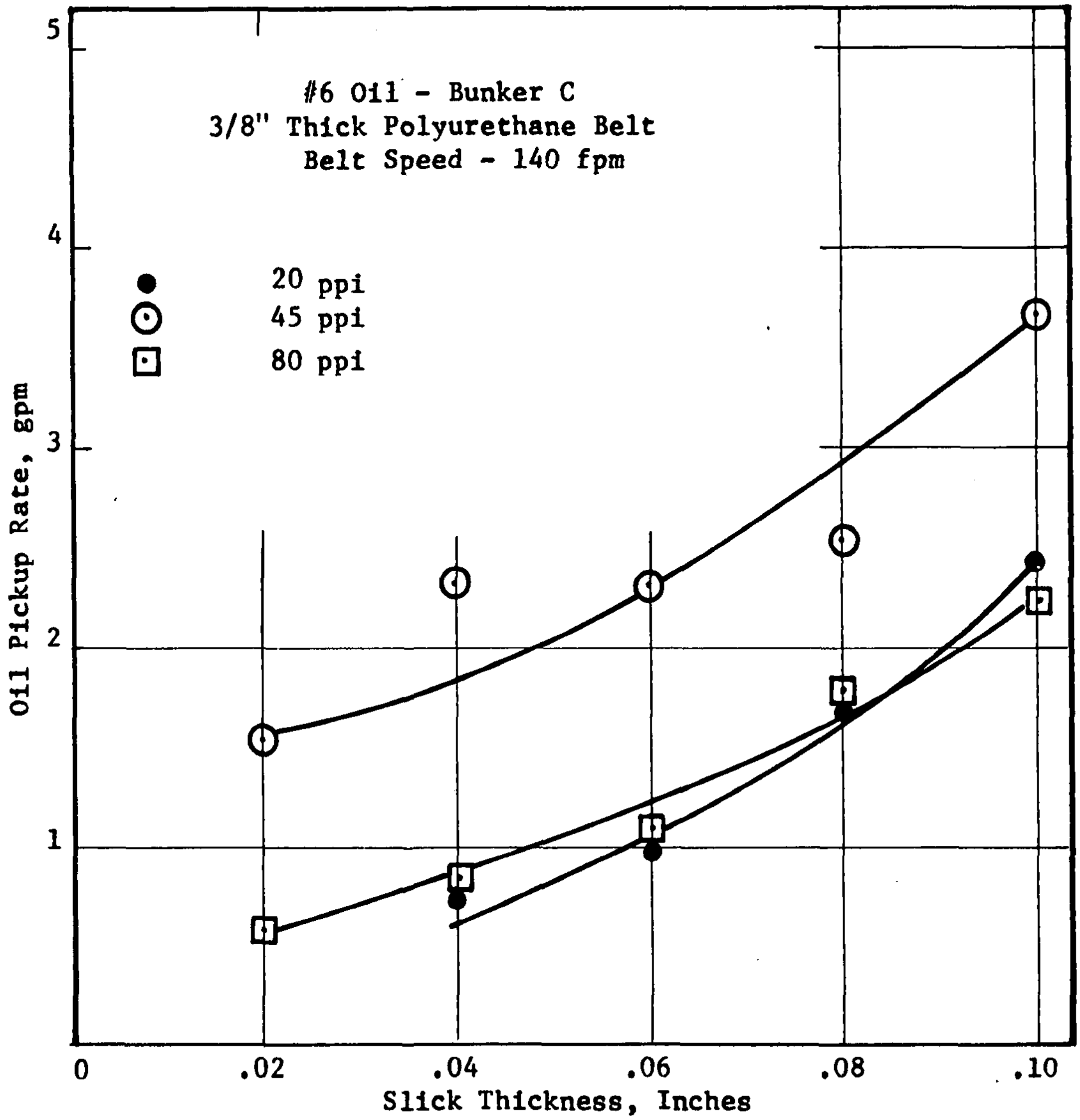


FIGURE 29

OIL PICKUP RATE VS. SLICK THICKNESS

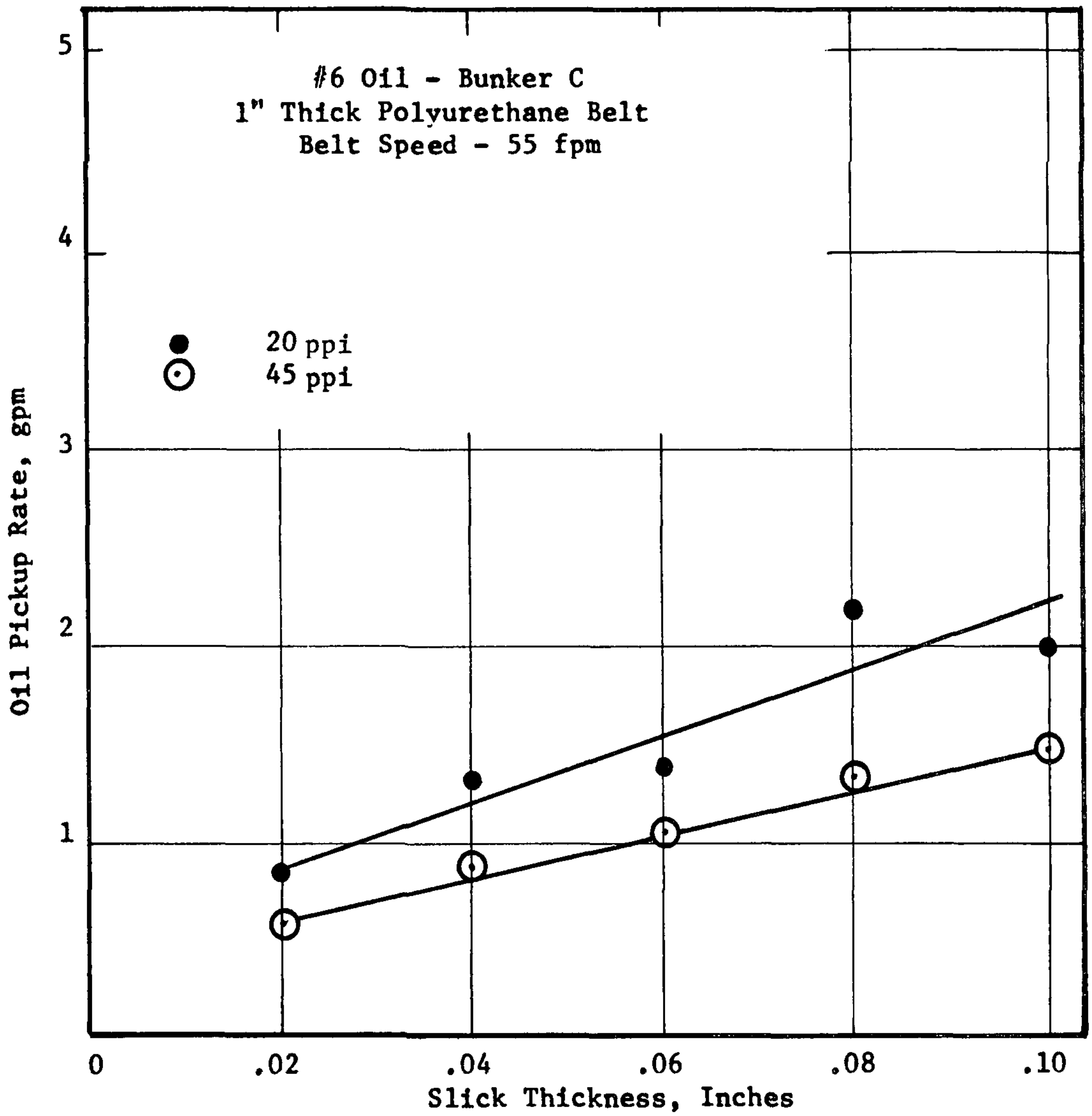


FIGURE 30

OIL PICKUP RATE VS. SLICK THICKNESS

Bunker C and reflects a tendency for belt surface pickup rather than absorption into the polyurethane foam.

The change in percentage of oil in the recovered oil-water mixture as a function of slick thickness is shown in Figures 31 through 35. The highest oil percentages over the entire range of slick thickness was attained with a 3/8" thick 45 ppi polyurethane belt.

Based on the results of the Bunker C tests it is recommended that the skimmer be operated under the conditions shown in Table 6 to obtain best results in a Bunker C recovery operation.

TABLE 6

RECOMMENDED OPERATING CONDITIONS FOR RECOVERY OF BUNKER C

Wringer Pressure	4.0
Belt Speed	140 ft./min
Belt Thickness	3/8" polyurethane
Belt Porosity	45 ppi
Forward Skimmer Velocity	1 - 2.5 knots

Expected Operating Results

At 0.10 inch slick thickness

Oil Pickup Rate	3.7 gpm
% Oil in Recovered Oil-Water Mixture	72

At 0.04 inch slick thickness

Oil Pickup Rate	1.9 gpm
% Oil in Recovered Oil-Water Mixture	35

Oklahoma Crude Oil Tests

The initial testing of the experimental prototype oil skimmer was performed using an Oklahoma crude oil which was selected as being representative of low viscosity oils. This oil had the characteristics shown in Table 7.

TABLE 7
CHARACTERISTICS OF OKLAHOMA CRUDE OIL

Density	0.83 gms/cm^3
Temperature	26.7°C
Viscosity @ 100°F	2.9 centipoise (Ostwald)

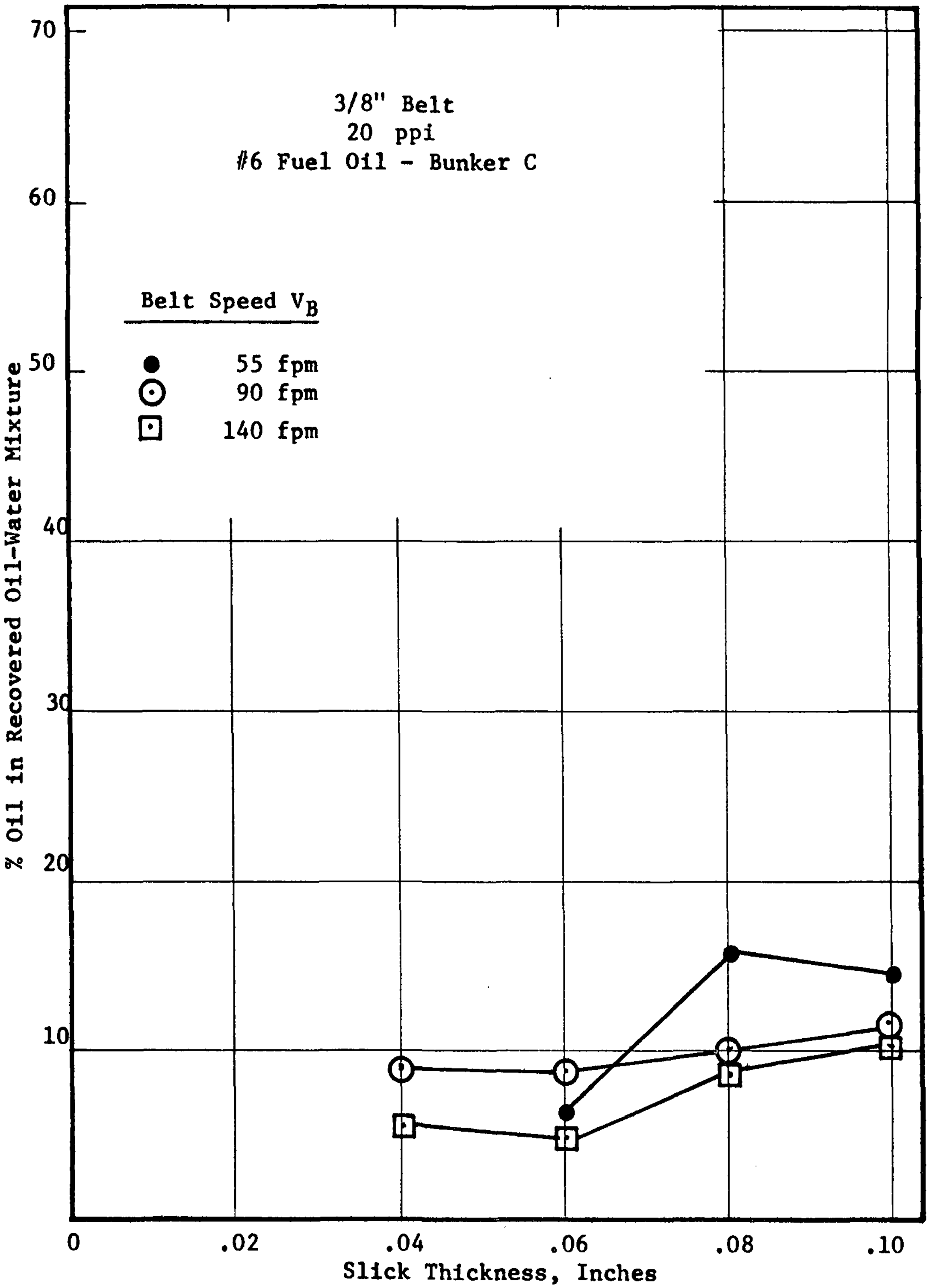


FIGURE 31

PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

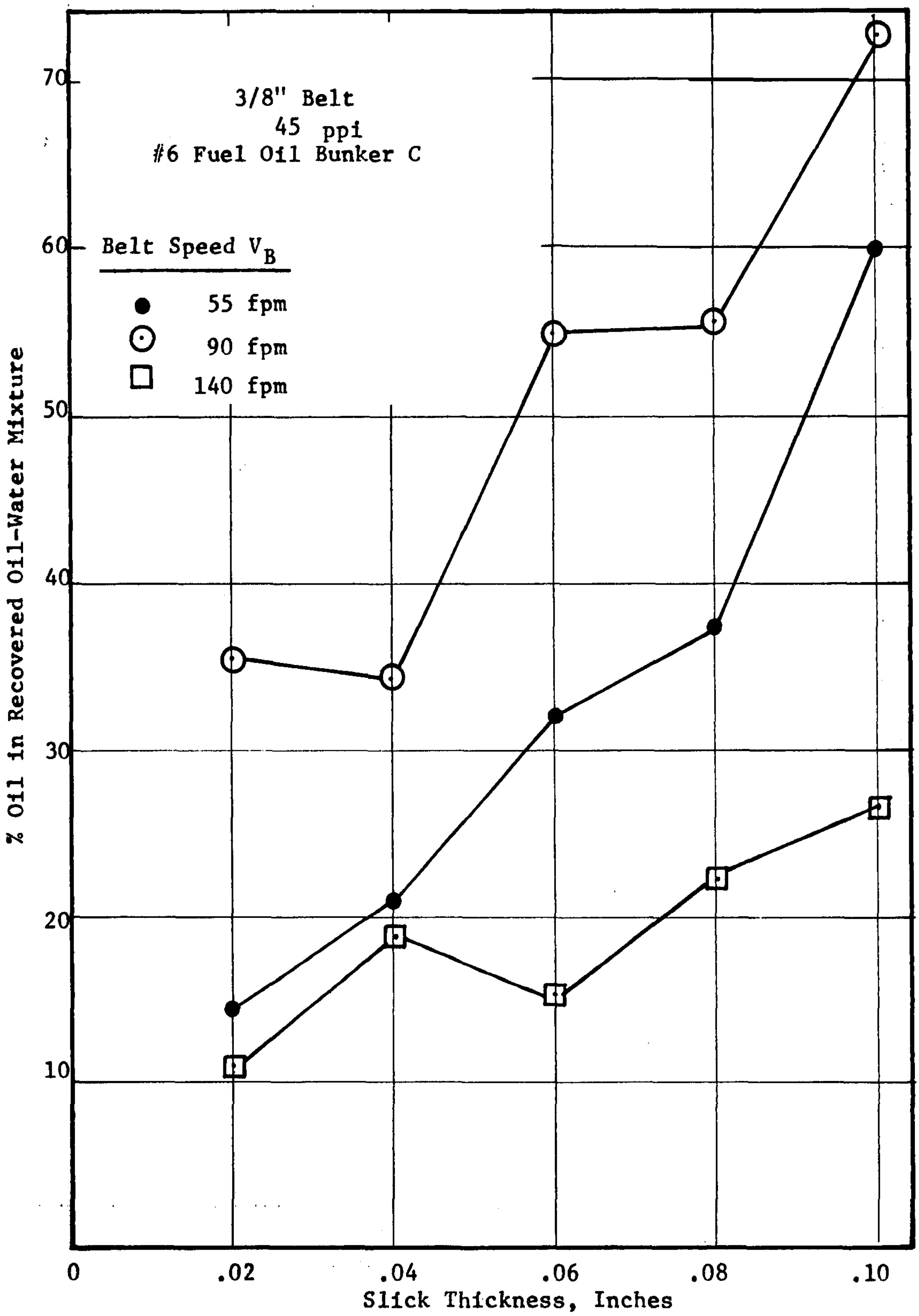


FIGURE 32

PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

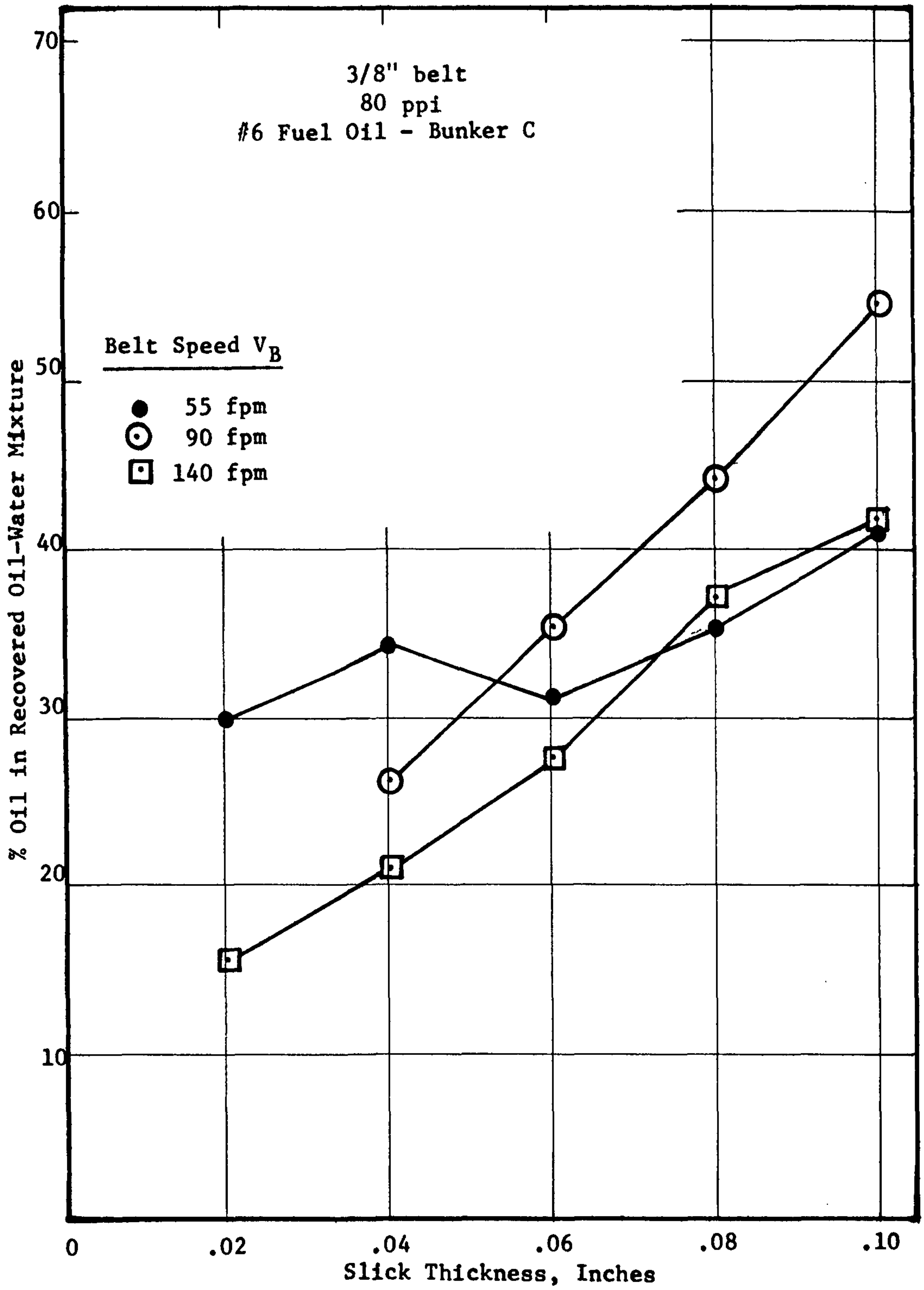


FIGURE 33

PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

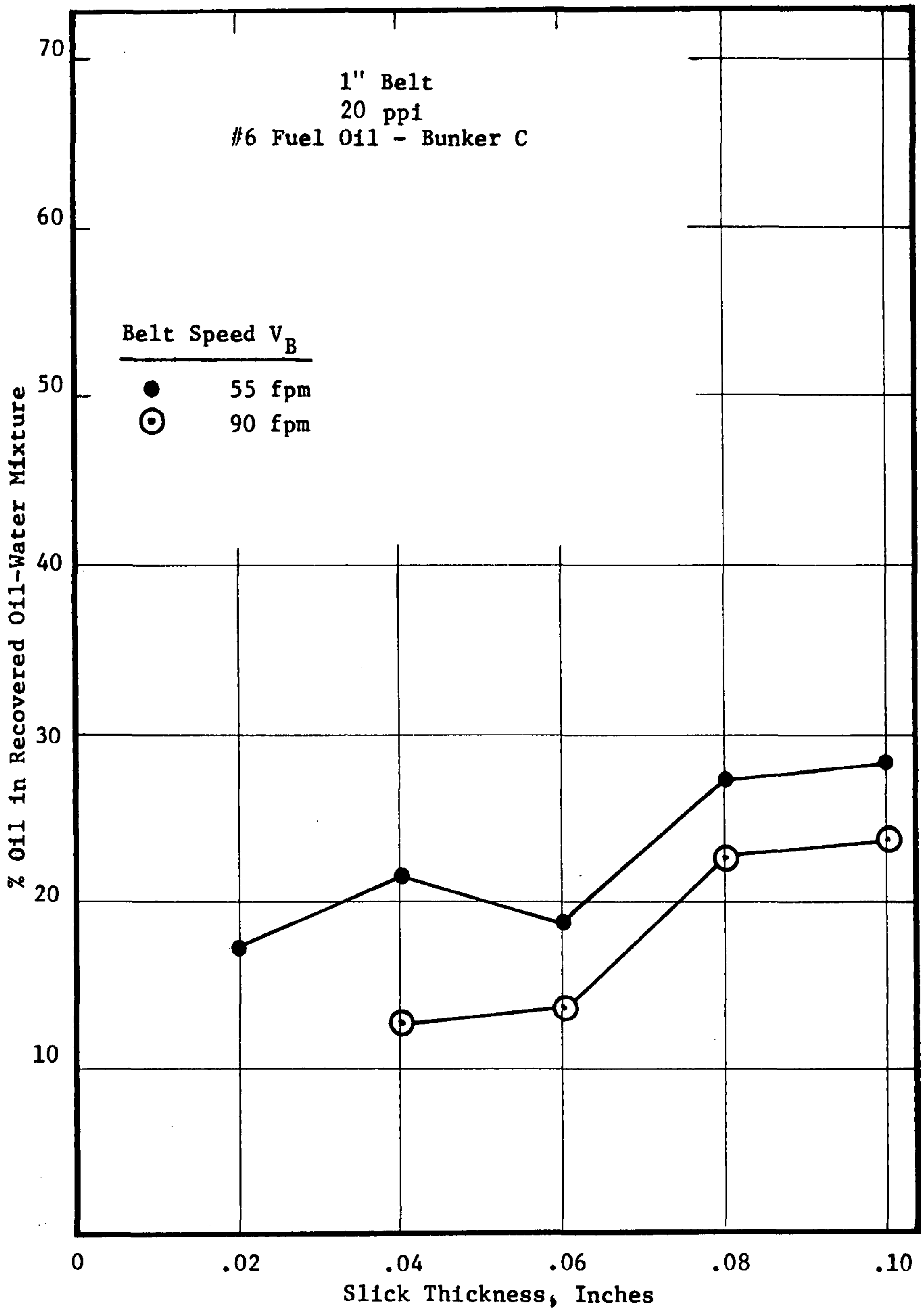


FIGURE 34

PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

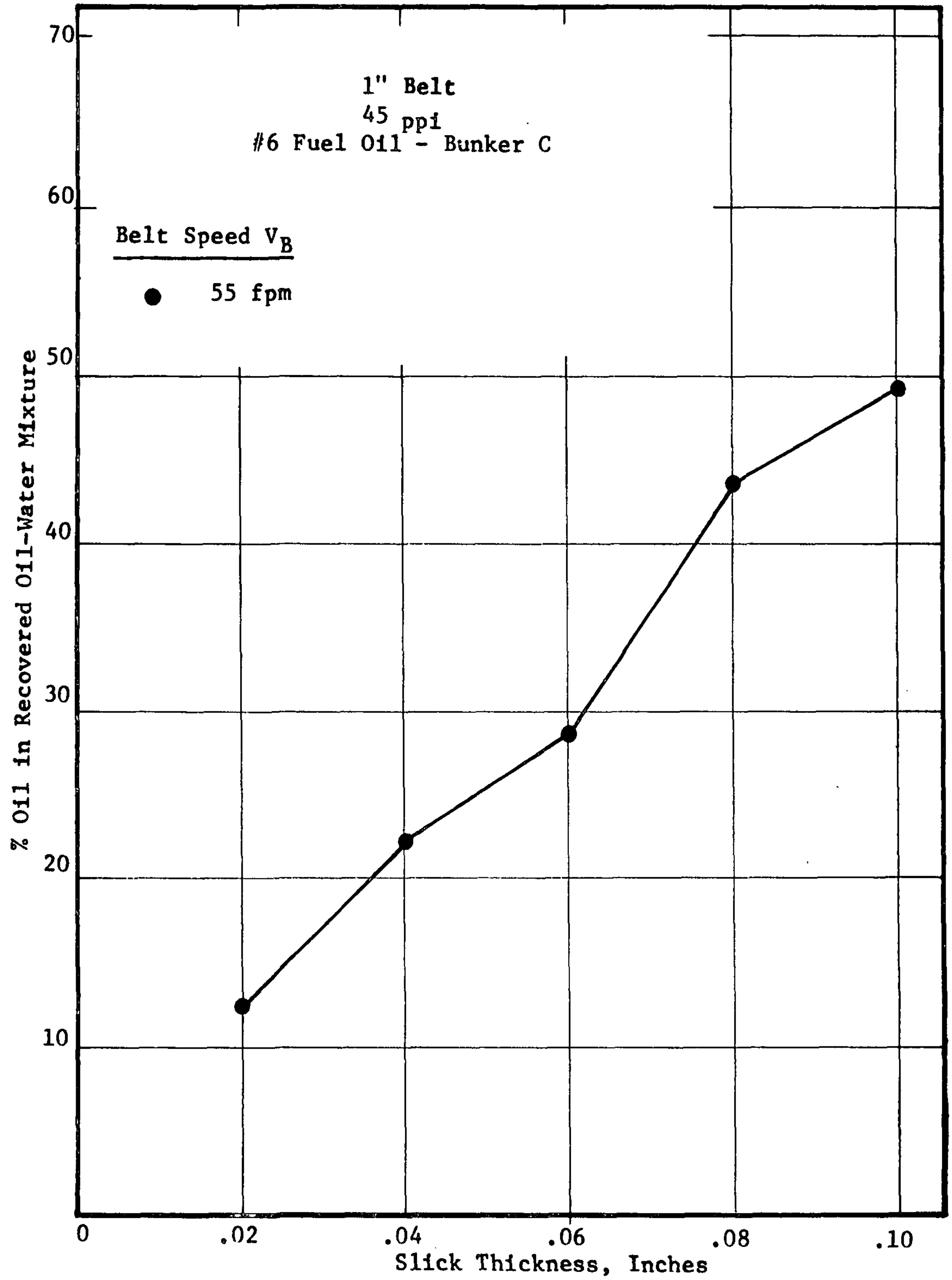


FIGURE 35

PERCENT OIL IN RECOVERED MIXTURE VS. SLICK THICKNESS

This oil tended to emulsify very easily and required the use of 3000-4000 ppm of Nalco 7713 to break the emulsion. After the addition of the Nalco 7713 the emulsion separated by gravity with the oil containing only 1-2% water.

During the entire duration of the Oklahoma crude experiments the percent oil in the recovered mixture were quite low. Subsequent investigations demonstrated that the oil was in fact emulsifying on the surface of the test tank. The reason for this emulsification is thought to be due to the oil characteristics in combination with the extremely turbulent conditions created by the wave action.

Samples collected from the surface of the oil slick after the wave generator had been in operation for approximately 10 minutes indicated that the oil contained 45% water. Although the skimmer was able to effectively recover the emulsified oil, it was not possible to accurately evaluate the skimmer performance unless frequent analysis of the water content of the emulsion was made. Consequently, it was decided to use the information collected for #2 Fuel Oil as being representative of the low viscosity oils.

As a result of this experience, it is recommended that in the case of spills of easily emulsified oils either shipboard or shore aide facilities will be required to de-emulsify the recovered oils. This facility would require either chemical treatment equipment or some other feasible means for emulsion breaking.

SECTION VIII

DISCUSSION OF RESULTS

The results obtained during the evaluation of the experimental prototype skimmer have been presented in the previous section. In addition to the quantitative data developed in these tests, certain qualitative information and engineering observations were made which provide additional insight into the overall project objectives.

Mechanical Wringer and Drive System

The efficient wringing of sorbent materials is essential to reuse of the sorbents. As was indicated in the previous sections, the conveyor wringer used in this skimmer has proven to be a highly effective method for removing oil from compressible, resilient sorbents. The wringer assembly, although somewhat complex in appearance, proved to be essentially maintenance and trouble free during the duration of the project.

The conveyor wringer also provides a very effective means of powering belts and should have application with other commercial concepts such as the Shell Pipeline Corporation "Oil Scrubber". Very little belt slippage occurs even with a heavily oil laden belt because of the large contact area available for driving the belt.

There are two items on the wringer assembly which should be modified in future designs to provide improved performance.

1. The number of powered rollers can be reduced with no loss in drive capabilities. This will simplify the apparatus and help to reduce the cost of manufacturing.

2. The size of the rollers on the conveyor wringer should be increased to enable the installation of a large oil collection pan under the pressure plate. This will prevent oil overflow at high oil pickup rates.

If sorbent materials are used which are strong enough so that a nonporous backing material is not required, the bottom pass of the belt, which is used to invert the belt surface prior to passage through the wringer, could be eliminated.

Belt Integrity

During the bench scale testing phase, questions were raised as to the strength of the polyurethane materials and the bond of the polyurethane to the neoprene rubber backing. An endurance test was conducted to evaluated the useful life of a 45 ppi neoprene backed polyurethane belt. The endurance test was conducted on the bench scale skimmer under the conditions shown in Table 8. Although the belt was severely slashed by the foreign materials intentionally inserted in the belt, it retained its integrity through 100 hours of operation. At that time, the endurance test was terminated since it was felt that no additional information would be derived from further testing.

TABLE 8

CONDITIONS OF ENDURANCE TEST 45 PPI POLYURETHANE BELT

Hours	
0-6	Run on bench scale skimmer in tap water with Mobil Naprex #920 - viscosity 60 SUS/100°F oil layer
6-13	Run on bench scale skimmer in tap water with Bunker C - viscosity approximately 3000 SUS/100°F oil layer
13-35.5	The belt was impregnated with sticks, approximately 10 2-inch long nails, large chunks of broken glass and 5 triangular shaped steel wedges. The belt was run in water covered with a layer of Bunker C oil.
35.5-100	The intentionally "tortured" belt was run in oily, sea water obtained from the hold of a tanker to determine whether sea water would exert an acceleration on rate of hydrolysis.
100	Endurance test terminated

During the experimental prototype test phase, close attention was paid to belt integrity. At no time during the tests was any belt deterioration noted even though some belts were operated for up to 30 hours and remained oil wetted for periods up to 5 months.

Due to the free floating orientation of the belt, it is extremely unlikely that the belt will pick up or be severely damaged by the debris which is normally encountered in spill cleanup operations.

Based on these results, it is felt that neoprene backed polyurethane foams will provide a minimum of 1-2 days serviceable life even under adverse spill conditions.

Use of Polyurethane Sorbents

As a result of the extensive testing done with the polyurethane foams (Scott Industrial Foam, Reticulated) during this project certain conclusions can be drawn regarding the suitability of this material as an oil sorbent medium.

1. When backed with a suitable material, polyurethane foams are

durable and can be expected to provide a minimum of 1-2 days of service in oil recovery operations.

2. Although highly touted in both commercial and technical literature as a hydrophobic, oleophilic material, polyurethane foams absorb significant quantities of water (≈50% of total liquid sorbed) when used to absorb oil on thin slicks (0.10 in. or less).

3. Because of the short sorption times available, polyurethane foams when used in an endless belt concept are incapable of sorbing the same unit volumes of oil that are reported in the literature.

4. Utilizing the free floating belt concept developed in this project the polyurethane foams are more effective in recovering light oils (#2 Fuel) than heavy oils (#6 Fuel).

Studies with Other Sorbent Materials

An attempt was made to evaluate the sorption of oils with materials other than polyurethane foam. Three materials were investigated, Acrylonitrile bonded polyester mats, zero twist polypropylene fiber and polypropylene microbatt.

The Acrylonitrile polyester mats were bonded to neoprene rubber backing using Carboline adhesive. This belt proved unsatisfactory in that it was not resilient enough to permit continued wringing. Belt deterioration was noted almost immediately and belt failure occurred after approximately 15 minutes of use. Because of these difficulties, no further tests were conducted with this material.

The Eastman Chemical Company provided samples of zero twist polypropylene fiber. This material was hand woven into a pigtail type braid and tested on the bench scale skimmer. Although the material does not release oil very well in the braided form, it is felt that if the material could be woven into a belt material and tufted, it would provide a satisfactory sorbent material. One of the real advantages of polypropylene is that it is extremely hydrophobic and should enable the recovery of essentially water free oil.

Rex is currently pursuing the development of a polypropylene woven belt for testing on future oil skimming applications.

Some effort was devoted to evaluating a microbatt polypropylene belt. Polypropylene in this form is extremely weak and must be encased in some support media to provide strength and resiliency. A belt of this material was provided by the Hercules Corporation for testing on the experimental prototype skimmer. The microbatt was encased in Delnet GQ16 and a crimped fibrillated web was mixed with the microbatt to provide resiliency. Although laboratory tests had shown the microbatt polypropylene to be extremely hydrophobic the field tests indicated that approximately 50% of the recovered liquid was water. Further investigation revealed that water was being mechanically trapped in the Delnet casing which was the reason for the high water pickup.

Future attempts to evaluate the polypropylene microbatt should utilize a more open casing material to facilitate oil penetration as well as free water drainage.

<u>Summary</u>

In general the results of this project have been encouraging, particularly the performance of the conveyor wringer and the free floating belt concept. Accordingly a conceptual design of a boat and the neceasary support equipment for a five foot wide free floating belt skimmer is presented in the following section.

It is felt that significant improvements can be made in the overall results and performance of this proposed skimmer with the development of new sorbent materials and/or the incorporation of existing materials (polypropylene) into a suitable belt structure. The general concept for skimming and wringing which was developed in this project is applicable to future developments in sorbent materials with little or no mechanical alterations.

SECTION IX

DESIGN CONCEPT FOR BOAT MOUNTED SKIMMER

A conceptual design of a full scale floating belt oil skimmer and support vessel has been prepared based on the results obtained in this study. The design of the vessel was performed by R. A. Stearn Inc. of Sturgeon Bay, Wisconsin. The following description of the vessel is taken almost in its entirety from a report submitted to Rex Chainbelt Inc. by R. A. Stearn Inc.

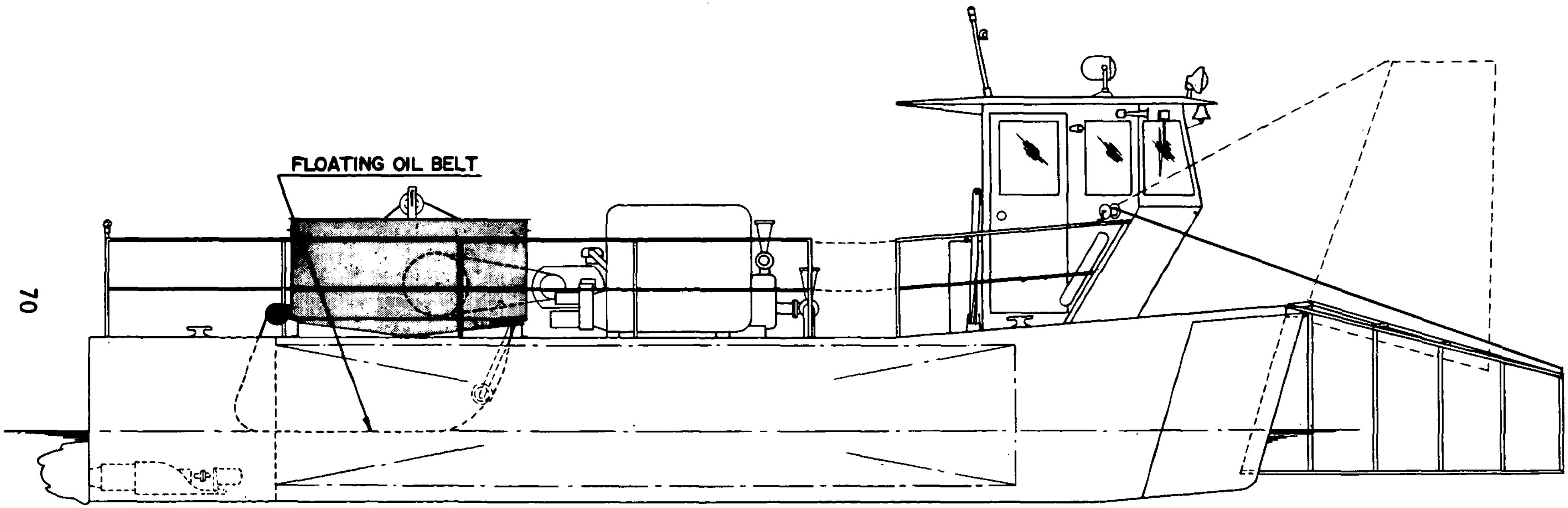
Introduction

The craft described below and illustrated in Figures 36 and 37 is designed to accommodate a single five (5) foot wide free floating oil belt skimmer. Based on results obtained in this study, it is anticipated that this skimmer could recover 5000 gallons of liquid/hour with an oil content of 50% for #2 Fuel Oil, 2 foot waves and a slick thickness of 0.10 inch. For Bunker C oil the recovery would be approximately 2500 gallons/hour of liquid containing 50% oil under similar wave height and slick thicknesses.

This is not an attempt to prepare a final design, but is rather a description of a concept of boat design which will best perform the assigned functions. Some refinements will become apparent during the preparation of the final design since certain components such as the propulsion units have not been fully researched. The successful use of water jet propulsion will, in part, depend upon a detailed analysis by the jet unit manufacturer of the maneuverability characteristics at slow speeds. Alternative types of propulsion, such as inboard-outboard units, are feasible but felt to be more vulnerable to damage from floating debris, and less able to cope with draft.

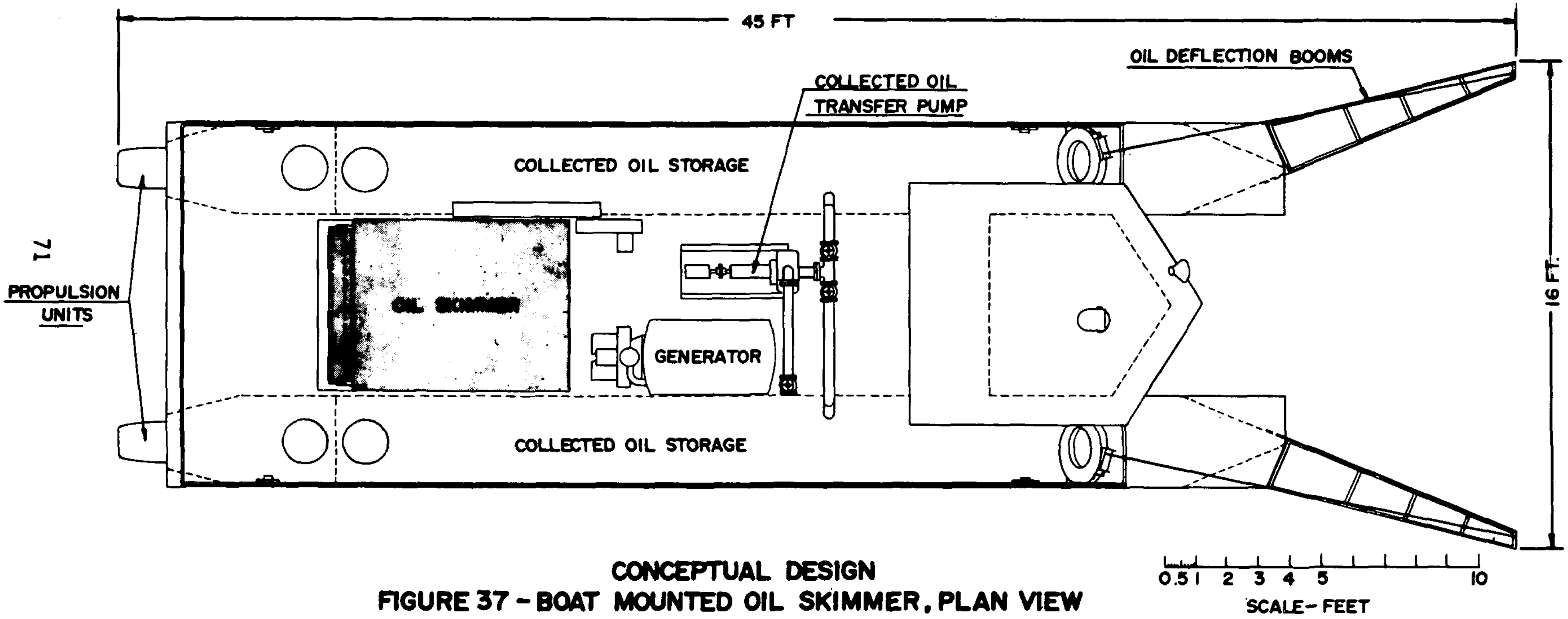
The dimensions (length and width) of the craft described are felt to be the minimum necessary to provide a stable platform for the oil belt skimmer and to obtain sea-keeping characteristics required for operation in two-foot seas. Reduced hull depth, resulting in reduced weight and cost, is possible for the non-cargo carrying model described as one of the options, without loss of sea-keeping characteristics.

The cost of the unit described is estimated to be $35,000, not including cost of the oil belt skimmer, if built in quantities of 5 to 10 units. Larger quantities should result in savings by application of production techniques, whereas smaller quantities will result in higher costs to offset production plan preparation and costs incidental to pattern preparation and low quantity purchasing.



0.5 1 2 3 4 5 10
SCALE-FEET

CONCEPTUAL DESIGN
FIGURE 36-BOAT MOUNTED OIL SKIMMER, ELEVATION VIEW



CONCEPTUAL DESIGN
FIGURE 37 - BOAT MOUNTED OIL SKIMMER, PLAN VIEW

Hull Requirements

The following approximate parameters are established to best serve the functional requirements of the oil belt skimmer:

1. The craft is to be roadable. Dimensions have been established at 12' overall beam, 36' length of hull, and 12' overall height. Weight without fuel or crew is approximately 13,000 lbs. The unit is capable of being transported by trailer.

2. A catamaran type of hull is used to accommodate the 5' wide belt which is suspended between the pontoons. The pontoons are 3' wide each leaving a 6' width between pontoons, reduced to 5' at the belt.

3. Each pontoon contains an oval shape tank of 1,600 gallons capacity for a total of 3,200 gallons cargo capacity.

4. Light draft is 14". Loaded draft with 3,200 gallons of oil-water mixture at 8 lbs per gallon is 3'-4". Depth of pontoons is 5' leaving 20" freeboard in fully loaded condition.

5. The craft is to operate in 2' maximum height waves therefore, sheer has been added at the forward end of the pontoons, with bow rake and overhanging deck forward. Bulwark rake and slope have been added to enhance the sea-keeping qualities of the craft.

6. A solid deck of raised tread plate spans between the pontoons, except in way of the oil belt skimmer, to provide a dry, slip-resistant deck.

7. A weathertight pilot house is installed at the bow, with doors port and starboard, and containing propulsion and steering controls. This location is chosen for good visibility and to obtain maximum usable deck space.

8. A trash grid, extending from deck to keel between the pontoons, should be installed to protect the skimmer belt from damage by large floating debris such as logs.

9. Aluminum construction is contemplated to keep weight to a minimum. Styrofoam, foamed in place between the pontoon plating and the cargo tanks, up to the loaded draft, is considered a possibility to protect the lightweight hull plating against damage.

Propulsion and Speed

1. Jet propulsion is recommended because of possible operation amid debris which would tend to foul and damage propellers. Jet units should be of a type which are capable of operating with control at low speeds, and should be steerable and reversible with pilot house control.

2. Jet units should be capable of operating from low maneuvering speeds for docking to full capacity of the propulsion power unit.

3. One propulsion unit is shown for each pontoon to enhance maneuverability characteristics, and should enable the craft to turn in its own length.

4. A speed of about 2½ knots is contemplated for the collection mode of operation. A speed of 8 knots is contemplated for free running without cargo and 5 miles per hour for free running when loaded with cargo.

Power Unit

It is proposed that a single radiator-cooled gasoline engine rated at 85 hp be mounted on deck forward of the oil belt skimmer driving hydraulic pumps to service all power requirements. With proper design, this arrangement will minimize maintenance on engine equipment, shorten controls from the pilot house for propulsion purposes, give good flexibility for speed control on the propulsion jets and the oil belt skimmer, and will make available the optimum power for propulsion in the free travel mode and for transfer pumping to shore or barge unit. Approximate horsepowers contemplated are as follows:

1. Free travel mode - two propulsion units at 30 hp each
2. Collection mode - two propulsion units at 20 hp each, oil belt skimmer at 7½ hp maximum, oil collection transfer pump at 1/2 hp
3. Shore transfer mode - one self-priming centrifugal transfer pump at 15 to 25 hp, for 500 gpm.

It is felt that with the use of a hydraulic system the oil belt skimmer can obtain its required 5 to 1 speed variation without the need for a mechanical variable speed unit. Propulsion units can be varied in speed precisely to obtain optimum vessel speed for collection purposes. One of the propulsion pumps can be utilized for driving the shore transfer pump.

Outfit Equipment

The craft should be fitted with the following principal outfitting equipment:

1. Mooring and anchoring - anchor, anchor line, deck cleats, fenders, mooring lines

2. Personnel safety - railings and stanchions, life rings and electrical water lights, life preservers

3. Fire protection - fire extinguishers

4. Navigation - compass, fog bell, horn, ship-to-shore radio, or walkie-talkie set

5. Miscellaneous - Pilot house seats, pilot house console, window wiper, monomatic toilet (optional).

6. Electric power - engine attached alternator, shore power connection, battery charger, 12 volt batteries, electric power panel.

7. Lighting - general lighting including wiring, navigation lights, flood light, spot light, yellow flashing light, fused lighting panel.

8. Oil Recovery Equipment - shore transfer hose, 3" or 4" size.

9. Self-priming Bilge Pump - with suctions to propulsion compartments and to holds

Bow Booms

Booms are shown port and starboard, hinged at the decks. Distance between the leading edges of the booms is 15', giving a concentration factor of 3 to the surface oil being fed to the collector belt. Buoyancy will be installed near the leading edges of the booms to retain freeboard in waves. The lower edges of the booms will be flanged inboard to prevent escape of oil under the booms. The booms will be raised above the water during the free travel mode, by hand winches mounted on the top outboard corners of the forward bulwark. The boom inner surfaces will be of light gage aluminum, plywood, or durable fabric, supported by a lightweight truss of aluminum tubing, and will overlap the bow ends of the pontoons. Booms will be removable for shipping.

Surface area covered by the craft with booms extended, at a speed of 2.5 knots (15,000 feet per hour), is about 5 acres per hour.

Options

1. Craft without pontoon storage tanks - This option would provide pontoon depth of about 3'-6". Collection of the oil would be into rubber storage bags stowed on deck and launched off of the stern as they are filled to be picked up by accompanying barge. A small surge tank would be installed on the collector transfer pump to permit uninterrupted collection during transfer of collecting bags. With this arrangement, the oil belt skimmer, engine and transfer pump should be moved forward to increase clear deck spaces aft.

2. Larger craft to accommodate two 5' wide belt skimmers - This concept would result in a semi-portable unit; in other words, one that would have to be dismantled to be trucked from one site to another.

Two pontoon hulls, each 6' wide and from 35' to 50' in length, would be shipped side by side on a trailer. The deck and oil belt skimmer module would be 11' to 12' wide, would also be trailable, and would be assembled to the pontoons with structural bolts. Connection of the hydraulic supplies to the propulsion units would be by quick-disconnect hydraulic hose.

An erection crane would be required to assemble the unit. It is contemplated that assembly could be done afloat in protected waters to avoid the necessity of elaborate launching devices.

A craft designed to this concept would have considerably greater storage capacity and would be capable of operation in more severe sea conditions than the smaller craft described in this report.

3. Trash Collector - A basket type collection unit may be suspended between the pontoons, extending from the bows to the oil collector unit. The collector should contain sufficient flotation to support its own weight, should extend from the bottom on the pontoons to 6" above the loaded waterline at the sides and up to the underside of the deck at its after end. Bow doors should be fitted, or the trash grid previously described should be hinged at the deck to permit basket removal.

SECTION X

ACKNOWLEDGEMENTS

Rex Chainbelt Inc. extends its sincere appreciation and gratitude to the following people, without whose cooperation project completion would have been difficult if not unachievable.

Mr. Ralph Rhodes and Mr. Kurt Jakobson of the EPA Agricultural and Marine Pollution Control Branch, each of whom served as Project Officer during respective contract time periods. Mr. J. Stephen Dorrler provided valuable technical input to the project.

Mr. Clifford Mortimer, Director, Center for Great Lakes Studies, The University of Wisconsin-Milwaukee, and Mr. R. A. Stearn, R. A. Stern Inc., Marine Architects, who served as project consultants.

The team effort required to design, build, and test the experimental prototype skimmer was due to attendant individual contribution of the following Ecology Division personnel:

Mr. Arlyn Albrecht served as Project Director during the initial phases of the contract. The materials selection studies were conducted by Mr. Egmont Helmer while Mr. Robert Scholz was responsible for the mechanical design and much of the concept development. Messrs. John Pernusch, Mahendra Gupta, Charles Hansen, Donald Murray, Ronald Holasek and Kenneth Witter provided valuable assistance during the design and data evaluation phases, with Mark Scholz and Timothy Riesing operating the prototype skimmer during the test phase.

Dr. Robert W. Agnew served as the Project Director during the final twelve months of the project and was the principal author of this report.

The support of the project by the Environmental Protection Agency and the willing assistance and helpful advice of EPA personnel is gratefully acknowledged.

SECTION XI

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SECTION XI

APPENDICES

APPENDIX A

BENCH SCALE SKIMMER INVESTIGATIONS

Preliminary studies were conducted to select and evaluate various sorbent materials for use on the oil skimmer. In addition, a bench scale model was constructed and operated to determine the basic feasibility of the proposed concept and assist in developing mechanical design criteria. The basic methodology and results obtained in these studies are presented in this section.

Selection of Belt Materials

Trade directories as well as firms with whom Rex Chainbelt Inc. has previous contacts were contacted to obtain information regarding materials that were potentially suitable for oil belt skimmers. Thirty-three suppliers of various types of sorbent materials were contacted. Of those responding less than half had materials which were judged to be suitable for oil recovery. Certain sorbent materials which appeared to be quite promising were unavailable for evaluation because of the proprietary interests of the suppliers.

Materials which were available and which were evaluated include polyurethane foams and various types of felts.

Samples of polyurethane foam were obtained from two sources for evaluation:

1. Scott Paper Company, Foam Division, Eddystone, Pennsylvania
2. Foam Rubber Products, Milwaukee, Wisconsin

Samples of felts were obtained from:

1. Synthetic Fiber Felts, GAF Corporation Industrial Products Division, Greenwich, Connecticut

2. Natural Fiber Felts, Western Felt Works, Chicago, Illinois

The samples of foam and felts obtained were subjected to screening tests to determine which of the various densities and porosities available appeared to be most promising for a skimmer belt.

The following test procedure was used to evaluate the various foams and felts:

1. The foam or felt material was cut to predetermined dimensions and volume

2. The test material was weighed.

3. The test material was then dipped into a mixture of oil-Milwaukee tap water for three seconds. This mixture consisted of tap water at room temperature topped by a 1/2" layer of oil.

4. The test material was then drained until the frequency of dripping was greater than once every 10 seconds and weighed.

5. The liquid (oil and water) was then squeezed out of the material and collected.

6. The test material was then weighed

7. The oil and water content of the liquid was determined by gravity separation.

8. The oil recovery was then calculated from the difference in weight before and after squeezing the liquid from the test material. This recovery was then related to the volume of the test material.

Two oils were used in these tests:

1. Light oil, viscosity - 60 SUS/100^{o}F
2. Heavy Oil, viscosity - 3100 SUS/100^{o}F

The test results ruled out the felts as potential materials for skimmer belts. The felt materials absorbed some oil but were not sufficiently resilient to release of oil under pressure. As a result the felt materials were considered unsatisfactory for use as a skimmer belt.

The results of the laboratory screening tests on the polyurethane foams indicated that the recoveries of 60 SUS/100^{o}F oil + water ranged from 1.32 gal/cu ft up to 4.38 gal/cu ft and that of 3100 SUS/1000^{o}F oil + water from 1.72 to 5.06 gal/cu ft. The heavy oil water mixtures contained from 11 to 19% water. In addition, water was contained in the oil in the form of an emulsion and/or a solution. It was estimated that the concentration of water in emulsion and/or solution was less than 1%.

It was evident that foam with large pores corresponding to a pore rate of 30 pores or less is incapable of holding oil to a satisfactory degree independent of oil viscosity. There was a tendency for increased capacity to hold oil with increased pore rates (smaller pores) which was particularly pronounced with the high viscosity oil.

Up to 69% of the pores were filled with liquid in the tests with heavy oil and up to 60% on those with light viscosity oil. The amount of oil/cu ft in the foam was practically independent of the thickness of foam in the thickness range of 1/2 to 2 inches investigated.

The conclusions derived from these screening tests were:

1. Polyurethane foams are feasible for use as belt materials.

2. Small pore foams are expected to yield higher recovery rates than large pore foams.

3. It is advantageous to use as thick a foam as is compatible with the mechanical functioning and desired service life of the belt.

Based on these conclusions it was decided to test 1 inch and 2 inch foam thicknesses and foams with pore rates of 45 to 80 ppi. It was also decided to test an ester base foam (Scott Industrial Foam brand) against an ether base foam (Foam Rubber Products) because the former is supposed to provide higher resistance against hydrolyzation by sea water.

Preparation of Test Belts

Since the polyurethane foam is mechanically too weak to be used as such in a belt, it was necesaary to equip the foam with a supporting backing of a higher strength material. The backing materials selected were:

1. Neoprene
2. Polypropylene Filter Cloth

The neoprene backing was adhesive bonded by Stephenson and Lawyer in Grand Rapids, Michigan with an oil resistent adhesive of their selection. The adhesive used by Stephenson and Lawyer was not disclosed. An experimental adhesive (*) made by the Hughson Chemical Company in Erie, Pennsylvania produced a bond between polyurethane foam and neoprene backing which was of satisfactory strength and resistant to petroleum oils and water.

The polypropylene filter cloth was Mero Fabric No. ICH-27, construction 60 x 32, weight 8.2 oz., supplied by Mero and Company, Inc., Chicago, Illinois. The foam was sewn to the filter cloth. Sewing reduced the effective width and cross section of the foam to about 3.9 in^2 from 6 in^2 for 1" thick foam of 6" width.

(*) Adhesive TS 1966-40A, Catalyst CS9988

One belt of each of the following design and materials were tested:

Designation	Kind	Thickn. in.	Porosity ppi	Backing Material	Effective Cross Section of 6" Wide Belt
Upholstery	Polyether	1	80-100	polypropylene	3.88 in^2
Upholstery	Polyether	1	80-100	Neoprene	6 in^2
Scott Indus.	Polyester	1	80	Neoprene	6 in^2
Scott Indus.	Polyester	2	80	Neoprene	12 in^2
Scott Indus.	Polyester	2	45	Neoprene	12 in^2

Bench Scale Apparatus

The bench scale oil belt skimmer used in the tests is shown in Figure I-1. Its main features are a pair of wringer rolls located above each other and between them the skimmer belt. The lower roll was connected to the driving mechanism. The upper roll was loaded by a dead weight. The liquid wrung out of the belt collected in a container located below the wringer roll. From this container the liquid is discharged through a pipe either into the tank of the machine or outside the tank. The belt hung freely in the tank in a wide loop with the foam covered side toward the water. The wide loop results from a 3rd roll located parallel to the wringer in a horizontal plane some distance away from the roller. Variable speed control, speed indicator, a water level control (overflow weir) and an oil supply pump with hand adjustable oil supply valve completed the arrangement.

Test Procedures

All but one test in this phase of investigation were run with Mobil Naprex oil (#920) having a viscosity of 60 SUS @ 100°F and specific gravity of 0.862 @ 60°F. The oil layer thickness (1/4") was controlled only at a belt speed of 26 fpm because of the operational difficulties in controlling the oil layer at higher belt speeds. However, for higher belt speed and thicker oil layer tests, a modified procedure was utilized. A known amount of oil was placed in the tank (corresponding to a given known oil layer thickness) prior to an experiment. No additional oil was added to replenish that removed. The oil was removed from the water by the skimmer belt resulting in a gradually and progressively decreasing oil layer thickness. The quantity of oil removed was measured at predetermined time intervals and plotted against time of operation resulting in curves from which the recovery rate change with diminishing oil layer thickness could be obtained by differentiation.

Samples of water-oil mixture were collected in a weighed 5-gallon container at predetermined time intervals and after reweighing, the contents were transferred into a transparent plastic separatory funnel. A separation time of 1/2 - 1 hour was allowed and the separated oil was measured after draining out the water.

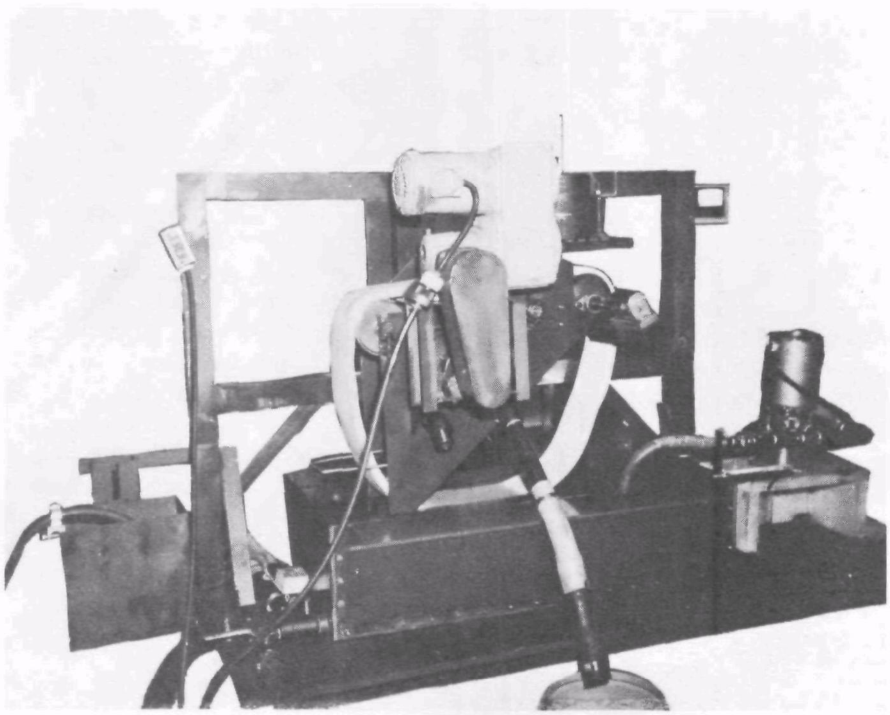

FIGURE I-1

OVERALL VIEW OF BENCH SCALE OIL SKIMMER

Tests at Constant Oil Level with Various Foams

A summary comparison of all the tests at the identical test conditions of 26 fpm belt speed and 1/4 inch oil layer thickness is shown in Table I-1. The results indicated that the recovery rate of light (60 SUS 100°F) oil was highest with the 2 inch thick Scott Industrial foam at 80 ppi porosity and lowest with the one inch thick upholstery foam sewn to a polypropylene filter cloth backing. Oil recovery rate was proportional to foam thickness at the identical porosity of 80 ppi but water content in the recovered mixture increased almost 5 times with double the foam thickness. The recovery rate for light oil was reduced by larger pore size (45 ppi) and the rate of water absorption in the recovered liquid was 3 times that of the smaller pore size (80 ppi) foam.

Tests at Varying Belt Speeds and Diminishing Oil Layer Thickness

The effect of belt speed was tested in a series of tests conducted with a one inch thick upholstery foam at an initial oil layer thickness of 1.25 inches. The oil layer diminished gradually as the test progressed and oil was removed from the surface of the water. The results of these tests are summarized in Figure I-2.

Basically these tests indicate that the oil pickup rate decreases logarithmically with diminishing slick thicknesses for a given belt speed. In addition it was found that the water content of the recovered oil-water mixture generally increased with decreasing oil slick thickness.

High Viscosity Oils

Attempts were made to evaluate the pickup rate of #6 Fuel Oil - Bunker C by means of the bench scale skimmer. Many problems were encountered but the primary one was the difficulty in getting the highly viscous oil to flow to the skimmer so that it could be picked up. A very minimal amount of data indicated two basic conclusions:

1. That wringer rollers cannot adequately remove Bunker C from low porosity (80 ppi) polyurethane belts.

2. That the rate of oil pickup is substantially less for Bunker C than for low viscosity oils.

Conclusions

The following conclusions were drawn based on the bench scale testing phase of this project and were used as the basis for material selection and design criteria for the experimental prototype evaluation.

TABLE I-1

COMPARISON OF BELT PERFORMANCE - SUMMARY
60 SUS/60°F Oil, Oil Layer Thickness 1/4", Constant Belt Speed 26 fpm (3.12 cycles/min)

Test #	Kind of Belt	Foam Thickness, Inches	Foam Properties (ppi)	Average Water Volume (%)	Average Water Gal/Hr.
45-48	Upholstery Foam Polypropylene Filter Cloth Backing 4.5" Effective Width; 3.88 in^2 cross sec.	1	80-100	40.8	34.3*
53-56	Upholstery Foam, Neoprene Backing	1	80-100	18.1	48.6
58-61	Scott Indust. Foam Neoprene Backing	1	80	5.2	50.8
63-66	Scott Indust. Foam Neoprene Backing	2	80	24.9	100.7
68-72	Scott Indust. Foam Neoprene Backing	2	45	75.6	77.7

* Corrected to 6 in^2 cross section: $\frac{6.00}{3.88} = 1.55$

Remarks: Polypropylene backed belt 115" long, 2.71 cycles/min at 26 fpm; Neoprene backed belt 100" long, 3.12 cycles/min. at 26 fpm; All belts in contact with liquid over 20 inches of belt length.

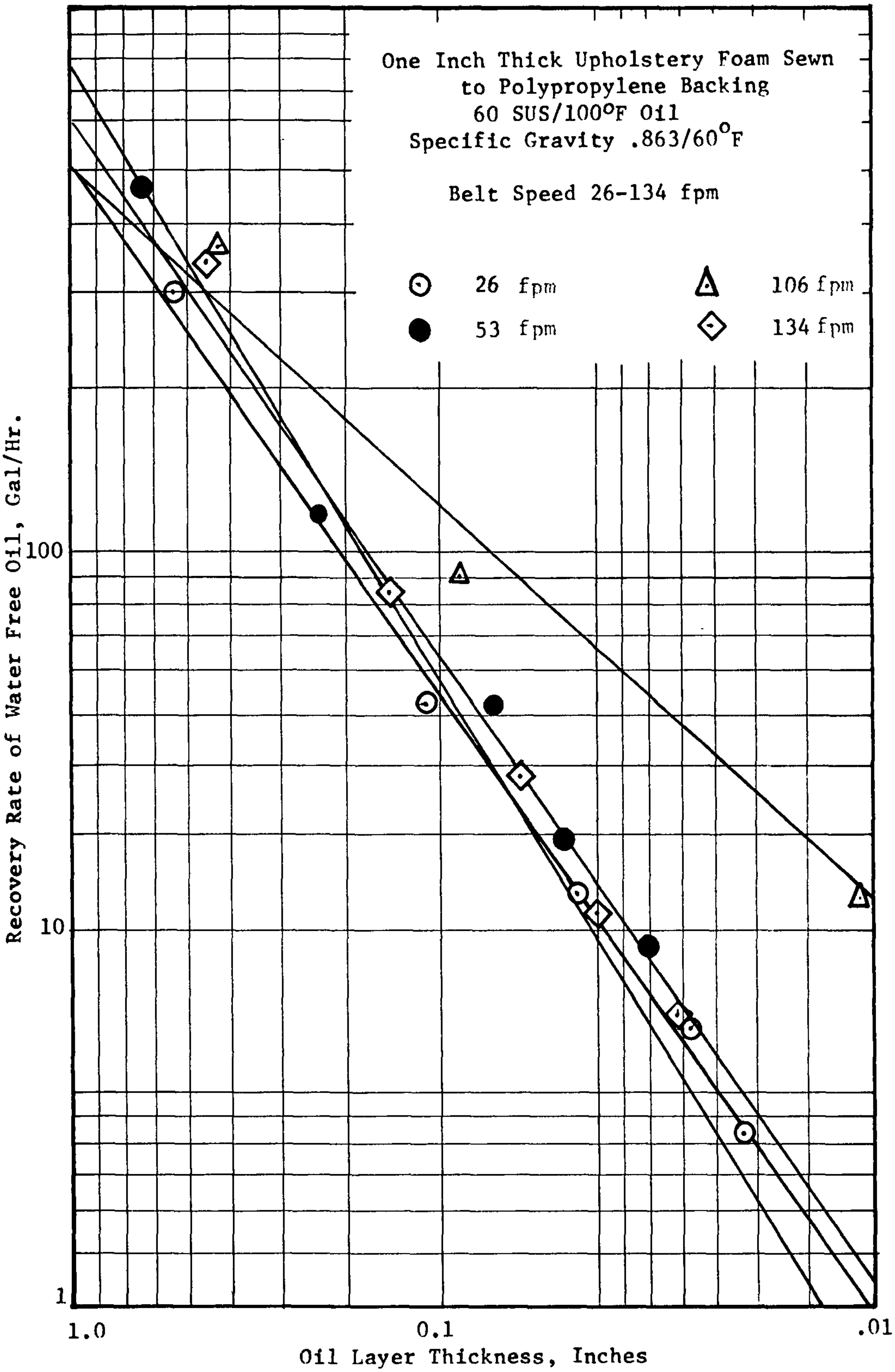

FIGURE I-2
OIL RECOVERY RATE AS FUNCTION OF OIL LAYER THICKNESS

1. A 2 inch thick Scott Industrial foam of 80 ppi porosity produced the highest oil recovery rates at all belt speeds and all oil layer thicknesses.

2. Oil recovery rates are proportional to the cross sectional area of the foam.

3. Foams with small pore, such as 80 ppi, are not suitable for the recovery of very high viscosity oil. It is likely that an optimum foam porosity exists for each oil viscosity.

4. Oil recovery rates increase with increasing belt speed. The information obtained was insufficient to indicate conclusively whether an optimum speed exists.

5. Oil recovery rates decrease with decreasing oil layer thickness and water content of the recovered liquid increases simultaneously.

6. The upholstery foam with a permeable polypropylene backing recovered a higher percent of water than upholstery foam of the same thickness with a neoprene backing. No advantage of using the permeable polypropylene backing can be seen in recovering light oil. In recovering heavy oil the relatively light weight of the backing may be an advantage in helping to make the belt float.

7. The polyether based upholstery foams pick up a higher percentage of water than the polyester based Scott Industrial foam. The polyester based foam should be used in future tests.

8. The bench scale tests have, in spite of the experimental difficulties, provided much insight into the potential problems of oil belt skimmers.

APPENDIX B - COMPUTER PROGRAM PETSKI

TABLE II-1

PROGRAM LISTING PETSKI

```
10:RUN NUMBER    ####
20:AMOUNT OF OIL SPREAD  ###.## GAL    INITIAL OIL DEPTH
     #.#### INCHES
30 READ R,T8,T9,D1,D2,D3,D4
40 V5=(D1-D2)*13.1*12
50 D6=12*V5/(364.4*7.48)
60 PRINT USING 10,R
70 PRINT USING 20,V5,D6
80 PRINT
90 PRINT
100 PRINT"TIME  VOLUME  VOLUME PERCENT  COLLECTION   SAMPLE
     CUMULATIVE
110 PRINT"INTO    OF      OF      OIL        RATE     MIDPOINT
     OIL     PCT
120 PRINT"RUN   SAMPLE   OIL              MIX   OIL
     VOL     REC
130 PRINT"(MIN.) (GAL)  (GAL)    (PCT)    (GPM) (GPM)   (MIN)
     (GAL) (PCT)
140 PRINT
150:###.#  ##.##    ##.##  ###.##  ###.##  ##.##  ####.#    ###.#
     ###.# #.###
160 T7=0
170 V4=0
175 F3=0
180 V8=0
190 READ T1
200 IF T1<0 THEN 390
210 READ T2,T3,V1,V2
220 T4=T1+T2/60
230 T5=T4+T3/60
240 T6=(T4+T5)/2
250 F1=V1/(T3/60)
260 IF  V2>5 THEN 280
270 GO TO 290
280 V2=V2/3785
290 F2=V2/(T3/60)
```

```
300 P1=(V2/V1)*100
310 V4=V4+(((F2+F3)/2)*(T6-T7))
320 D5=12*(V5-V4)/(7.48*364.4)
330 F3=F2
340 T7=T6
350 P2=(V4/V5)*100
360 V8=V1+V8
370 PRINT USING 150,T4,V1,V2,P1,F1,F2,T6,V4,P2,D5
380 GO TO 190
390 V9=((D4-D3)*16.1*12)+V8
400 PRINT
410 PRINT USING 420,V9
420:TOTAL MIXTURE COLLECTED  ####.# GAL
421 PRINT
422 P3=100*V4/V9
423 A1=V9/(T8+T9/60)
424 A2=V4/(T8+T9/60)
425 PRINT USING 426,P3
426:PERCENT OIL IN THE MIXTURE  ###.## PERCENT
427 PRINT
428 PRINT USING 429,A1
429:AVERAGE COLLECTION RATES:    MIXTURE  ####.## GPM
430:                                 OIL  ####.## GPM
431 PRINT USING 430,A2
432 PRINT
433 PRINT
434 PRINT
435 PRINT
436 GO TO 30
999 END
```

TABLE II-2

DEFINITION OF VARIABLES

Variable		Units
A1	Average oil-water mixture collection rate	gal/min
A2	Average oil collection rate	gal/min
D1	Initial oil depth in the supply tank	ft
D2	Final oil depth in the supply tank	ft
D3	Initial mixture depth in the collection tank	ft
D4	Final mixture depth in the collection tank	ft
D5	Equivalent oil depth on the water surface	in
D6	Initial oil depth on the water surface	in
F1	Mixture collection rate during sampling	gal/min
F2	Oil collection rate during sampling	gal/min
F3	Internal variable (F3=F2)	gal/min
P1	Percent oil in sample	percent
P2	Percentage of total oil collected	percent
P3	Percent oil in the total mixture collected	percent
R	Run number	
T1	Time (integer minutes) at the start of sample collection	min
T2	Time (remaining seconds) at the start of sample collection	sec
T3	Sample collection time	sec
T4	Time at start of sample collection	min
T5	Time at end of sample collection	min
T6	Time at midpoint of sample collection	min
T7	Internal variable (T7=T6)	min
T8	Time (integer minutes) at the end of the run	min
T9	Time (remaining seconds) at the end of the run	sec
V1	Total volume of the sample	gal
V2	Volume of oil in the sample	gal or ml
V4	Cumulative estimate of the volume of oil collected	gal
V5	Volume of oil spread on the surface	gal
V8	Cumulative volume of samples	gal
V9	Total volume of oil-water mixture	gal

TO SIGNIFY THE END OF A DATA SET ENTER A -1 AS THE LAST PIECE OF DATA FOR THAT RUN

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6 *Title*

A FREE FLOATING ENDLESS BELT OIL SKIMMER

10 *Author(s)*

AGNEW, ROBERT W.

16 *Project Designation*

EPA CONTRACT 14-12-908 PROJECT 15080 GBJ

21 *Note*

22 *Citation*

Environmental Protection Agency report
number EPA-R2-72-006, August 1972

23 *Descriptors (Starred First)*

25 *Identifiers (Starred First)*

27 *Abstract*

A free floating endless belt oil skimmer was developed as a means of recovering spilled oil from surface waters. The skimmer utilizes a unique high efficiency conveyor wringer to power and wring the belt. The belt is designed to float on the water surface and responds rapidly to the shape of the waves, thereby maximizing oil-sorbent contact time. Evaluation of the skimmer was conducted in a 60 foot diameter annular test tank under the conditions of slightly progressive waves having an amplitude of two feet. One foot wide neoprene backed polyurethane foams were utilized as the sorbent material.

The experimental results indicate that the oil pickup rates will vary with the belt speed, oil slick thickness and belt porosities. Oil pickup rates of 8.3 and 3.7 gpm per foot of belt width were attained for #2 Fuel Oil and Bunker C oil respectively at a slick thickness of 0.10 inches. The recovered liquid contained approximately 50-70% oil at 0.10 inch slick thickness.

A conceptual design of a five foot wide boat mounted skimmer capable of harvesting approximately 5 acres per hour of spilled oil is presented.

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