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OIL SPILL CLEANUP USING A COTTON SORBENT

J. E. Halligan, A. A. Ball, G. F. Meenaghan

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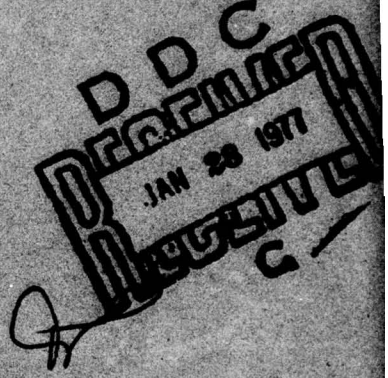

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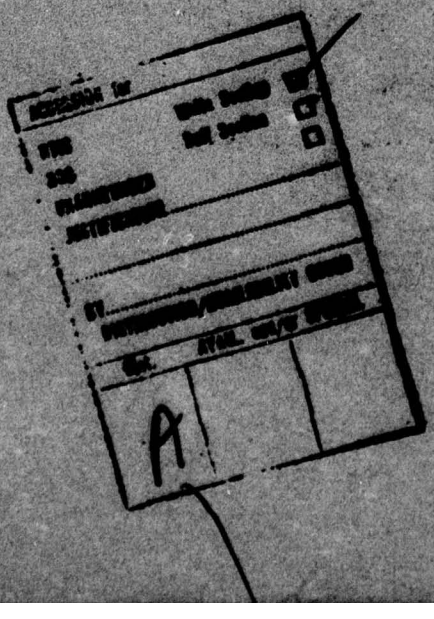

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16. Abstract

A 19-month study was conducted

On June 1, 1974 a nineteen month study was initiated between the United States Coast Guard and Texas Tech University. The overall purpose of this contract was to develop a sorbent dispersal, retrieval, and disposal system using cotton wastes to combat oil pollution.

A test program was conducted to develop the design data base required to evaluate the concept as well as the system components. Major variables studied included crude oil type, sorbent to oil weight ratios, sorbent contact time, removal efficiencies, squeezing techniques, disposal via incineration, and air pollution parameters. It is concluded

The culmination of this effort has shown that the concept of using cotton as an oil spill clean-up agent is viable and that the system as operated was capable of retrieving approximately 95 percent of the oil confronted for water velocities of 2 feet per second or less and dispersion ratios of 0.05 (or greater) pounds of cotton per pound of oil.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

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ILLUSTRATIONS

TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

Symbol		Meaning
Bwo	-	Proportion by volume of water vapor in the gas stream (lb water/lb dry air)
C^o	-	Soluble organic concentration at standard conditions and 12% CO_2 (grains/ft^3)
C_s^p	-	Particulate concentration at standard conditions and 12% CO_2 (grains/ft^3)
CO_2	-	Percent of carbon dioxide in stack
e_3	-	Correction for heat of combustion of the firing wire in calories
H	-	Pressure across meter orifice (in H_2O)
H_g	-	Gross heat of combustion (BTU/lb)
M	-	Mass of sample (mg)
Mn	-	Total mass of particulate collected (mg)
On	-	Total mass of soluble organics collected (mg)
P_{bar}	-	Barometric pressure (in. Hg)
Pm	-	Average dry gas meter pressure (in. Hg)
P_s	-	Pressure in stack (in. H_2)
t_i	-	Initial temperature (°F)
t_f	-	Final temperature (°F)
$\bar{T}m$	-	Average dry gas meter temperature (°F)
Vm	-	Volume of gas sample at meter conditions (ft^3)
Vms	-	Volume of gas sample through the dry meter (standard conditions) (ft^3)

V_s	-	Velocity in stack (ft/sec)
Vws	-	Volume of water vapor in the gas sample (standard conditions - ft^3)
W	-	Energy equivalent of the calorimeter (cal/°C)
W_f	-	Final weight of water in impingers (gram)
W_i	-	Initial weight of water in impingers (gram)
Y_c^a	-	Critical contact angle (radius)

SECTION 1

SUMMARY

On June 1, 1974, a nineteen month study was initiated between the United States Coast Guard and Texas Tech University. The overall purpose of this contract was to develop a sorbent dispersal, retrieval, and disposal system using cotton wasties to combat oil pollution.

To achieve the stated objectives of the study an oval test tank facility was designed and fabricated which was 73 feet long per side and had a channel width of 4 feet. An outboard motor was used as the prime mover of the water and velocities up to 4 feet per second could be obtained. Associated with the test tank facility were (a) a cotton opener mounted over the channel, (b) an oil nozzle system, (c) a continuous conveyor retrieval system mounted in the channel, and (d) a holding basin. External to the test tank facility were a set of squeeze rollers and a commercial type two stage incinerator.

A test program was conducted to develop the design data base required to evaluate the concept as well as the system components. Major variables studied included crude oil type, sorbent to oil weight ratios, sorbent contact time, removal efficiencies, squeezing techniques, disposal via incineration, and air pollution parameters.

The culmination of this effort has shown that the concept of using cotton as an oil spill clean-up agent is feasible and that the system as operated was capable of retrieving approximately 95 percent of the oil confronted for water velocities of 2 feet per second or less and dispersion ratios of 0.05, or greater, pounds of cotton per pound of oil.

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SECTION 2

INTRODUCTION

The first question which must be addressed when considering sorbent systems concerns the advisability of adding an additional component to an oil-spill. At first, this may seem to complicate the clean up process. However, practical experience in analogous situations has shown that such an addition is desirable. Examples include putting oiled sawdust down to clean up a floor, and the use of a mop to pick up spilled water. Therefore, the use of a sorbent to clean up oil spills may have practical advantages.

The purpose of the sorbent is to facilitate a change of phase. The desired effect is similar to that observed with the addition of a small amount of solid gelatin to water which forms a semi-solid. Similarly, a properly dispersed sorbent can markedly change the properties of fifty to one hundred times its weight of oil. Just as it is no particular task to pick up a gelled material with a fork, it is not difficult to pick up oil once it is within a sorbent structure. Since the sorbent-oil mixture has decidedly different physical properties than those of a fluid, this will aid in retrieval operations. This is particularly true when using vacuum hoses where a sorbent and a simple rake can markedly increase the efficiency with which small pockets of oil can be retrieved.

Another benefit of using a sorbent is its ability to capture and retain oil for retrieval at a later time. This may be a major advantage due to the rapid initial rate of spreading of oil slicks on water. In many cases, the oil-sorbent mass is highly oleophillic and hydrophobic which leads to coalescence into clumps facilitating later retrieval.

Additional advantages of a properly chosen sorbent are selectivity, effectiveness, and general applicability. When utilizing some sorbents, at least 90 percent of the oil confronted can be picked up and, of the fluid removed from

the water surface, at least 90 percent will be oil. This latter capability can have a very significant impact on the design of on-board storage and processing facilities. Finally, sorbents can function with oil slicks of varying thicknesses and viscosities. Such a property is essential to allow the design of general systems which can handle a majority of spill situations.

In conclusion, sorbents have physical properties which make their use in oil spill clean up attractive. Beaker scale data have shown that cotton has an unusually high potential for use in sorbent systems. In order to exploit this potential, it is essential to have data at a larger scale to facilitate system design. The purpose of this report is to discuss a series of experiments which were conducted to develop a sorbent dispersal, retrieval, and disposal system using cotton to combat oil pollution.

SECTION 3

SORBENT SELECTION

3.1 Characteristics of an Ideal Sorbent

In order to be able to effectively compare different sorbents it is desirable to specify the characteristics which would be associated with an ideal sorbent. It should be recognized that it may be difficult to obtain an actual sorbent which possesses all of the desired physical properties.

The function of the sorbent is to induce a separation between the oil and water such that the oil can be easily recovered. Because of this it should be highly oleophillic, which, since like frequently attracts like, suggests that the surface of the sorbent should be a carbon derivative.

It is also desirable that the sorbent be selective with respect to the fluid it sorbs. A sorbent which simply acts as a sponge will be effective with respect to oil removal but it will also recover significant amounts of water. Since this water must then be processed by the retrieval device, this would impact directly upon its design. Ideally a sorbent would selectively remove the oil from the surface and reject almost all of the water.

In any large scale operation, a fraction of the sorbent will not be recovered. Total rejection of water by the sorbent could be a disadvantage since, in some cases, it is desirable for the sorbent to sink if it escapes to the environment. The ideal would be for the sorbent to wet out or dissipate after a few days on the water.

The oil removal capability of a sorbent should be large, both on a unit mass and a unit volume basis. The latter should particularly be considered if the spill is located in a remote region which involves difficult transport problems. It is important to recognize that an ideal sorbent should be able to

capture a large amount of oil as well as to retain a significant fraction of this material during sorbent recovery. Since an oil spill spreads very rapidly, circumstances may well arise in which the purpose for sorbent distribution is spill containment. In order to effectively capture adjacent oil, the sorbent must have the capability of drawing the oil into the material matrix. This is most conveniently accomplished by exploiting capillary phenomena. This in turn suggests that an ideal sorbent have a porous structure with a large surface area to weight ratio.

After the oil has been captured it is desirable to be able to easily remove the oil-sorbent mass from the surface of the water. Therefore, ease of recovery is an important property of an ideal sorbent. This may not be a serious restriction since the recovery system may be quite primitive. A cursory consideration might result in the elimination of a particulate sorbent on the basis of this criterion. However, an oil-saturated particulate sorbent can be easily picked up by a simple landing-net used for fishing. In general, an ideal sorbent will sorb such a large quantity of oil that the material being picked up from the surface will have physical properties between those of a solid and a fluid. As noted in the introduction, this change in physical properties can markedly improve the ease of sorbent-oil retrieval.

It would be very desirable for the oil-sorbent mixture to have agglomerating tendencies in order to reduce the retrieval effort. Fibrous materials which have exposed portions would tend to possess this property.

Finally, it is essential that the sorbent and its degradation products be nontoxic to the environment. This will ensure that there is no permanent damage to the ecosystem as a result of the utilization of the sorbent even if a significant fraction is not recovered.

In summary, an ideal sorbent should have the following characteristics:

1. high oleophillic and hydrophobic properties,
2. large oil removal capability both on a unit mass and a unit volume basis,

3. high oil sorption rate,
4. large surface to volume ratio,
5. good buoyant properties both as a dry and an oil-loaded sorbent,
6. ease of retrieval,
7. non-toxic and biodegradable, and
8. low cost.

3.2 Actual Sorbent Performance Criteria

A review of the manpower and the capital resources of several oil spill clean up companies suggests that the primary requirements for an actual sorbent are that it must be usable in a relatively simple, practical system which is low in cost. In addition, the sorbent must be readily available with respect to supply, storable without decomposition over long periods of time, and low in cost.

In order to minimize the mass which must be picked up, the sorbency of the material should be at least 25 pounds of fluid per pound of sorbent. In this event, 96 percent of the mass being removed from the water is fluid with the remainder being sorbent. Higher levels of sorbency are possible but the practical advantages are minimal.

Selectivity with respect to the fluid being removed is also a key variable. Preferably not more than 10 percent of the fluid picked up should be water. If the fraction that is water rises to a higher level, a secondary fluid separation system may be needed.

The physical parameters associated with the slick can also impact to some extent on the type of sorbent needed. If the slick is located in a very remote region, which is not readily accessible to common transport, it may be essential that the sorbent be reusable. In those cases, a system which squeezes and redistributes the sorbent would be needed. However, it should be remembered that

the sorbent probably constitutes only about 4 percent of the material to be recovered. For a 1,000 barrel oil spill the amount of sorbent needed would be:

$$\frac{1{,}000 \text{ BBL}}{} \left| \frac{42 \text{ gallon}}{\text{BBL}} \right| \frac{8 \text{ lb oil}}{\text{gallon}} \left| \frac{\text{lb sorbent}}{25 \text{ lb oil}} \right. = 13{,}440 \text{ lb.}$$

If the sorbent has a cost of $0.35 per pound, the total cost of the sorbent would be approximately $5,000. Very little capital investment in reuse equipment or operating manpower costs can be justified for such a small cost. In addition if a significant amount of debris or other contaminants are present, they may disrupt any on-board squeezing equipment. When the problems associated with slick spreading and system sophistication are considered, sorbent reuse does not appear to be attractive.

A sorbent must also be effective in handling a spectrum of crude types and slick thicknesses. The effectiveness should be such that 90 percent of the oil present should be removed from the water surface when the slick is adequately covered to a surface loading of approximately 25 pounds of oil per pound of sorbent.

Slick thicknesses in the range of 0.1 to 2.0 millimeters should be sorbable by the material. In addition, the sorbency should not be a strong function of viscosity. The latter is not a significant problem with many sorbents.

With respect to floatability, at least 90 percent of the sorbent should float for a significant period of time, but not indefinitely. If the material is not picked up, it should sink rather than pollute the beaches or waterways. A float time of two to three days would be desirable.

The ecological impact of the sorbent should be such that the material is non-toxic to the environment if not recovered, as well as leading to non-toxic degradation products when disposed of in an incinerator, or a sanitary landfill. In addition, it is desirable that the sorbent be biodegradable.

The only remaining criteria for a sorbent concern utilization parameters such as the required contact time to enable the sorption to be complete. This requirement will be determined by the type of dispersal and retrieval device employed to utilize the sorbent. If these operations are uncoupled, a contact time on the order of hours may be acceptable. If the system is one integral unit, a contact time of seconds may be required. Needless to say a sorbent which quickly entraps the oil would be functional in both cases.

In summation, it should be reemphasized that the first and foremost requirement is that the system must be simple, low in capital cost, and practical. A sorbent which can be easily dispersed with such a system will satisfy the needs of an unsophisticated oil spill clean up industry. Retrieval appears to be a secondary problem especially if close to shore due to the large amount of casual labor which can be available at a spill. The disposal characteristics of the sorbent can be important if no suitable landfill site is available.

3.3 Sorbent Effectiveness Evaluations

Procedures which may be utilized to compare the sorbency of materials were initially developed by Schatzberg in his study entitled "Investigation of Sorbents for Removing Oil Spills from Waters" (1972). In brief, the Schatzberg procedure involved the evaluation of the oil sorption capability of the dry sorbent, the retention after water-washing of the oil-soaked sorbent, the water-sorption capacity of the dry sorbent, the oil-sorption capacity of the water-saturated sorbent, the buoyancy of the dry sorbent, and finally the buoyancy of the oil-soaked sorbent.

The detailed experimental procedure is available in the cited reference. However in order to evaluate the data which is to follow, it is desirable to have a brief description of the procedure available.

The oil sorption capacity of a dry sorbent was determined by saturating with oil a tared dry sample of material, then draining for 15 minutes, and weighing.

The oil retention capability of the oil-soaked sample after water washing was determined by taking an oil-soaked sample from the oil-sorption capacity test and shaking for six hours with synthetic seawater, then draining, weighing and determining the water sorbed by the sample.

The water sorption capacity of the dry sorbent was determined by shaking for 30 minutes a tared dry sample with seawater, then draining for five minutes, and weighing. The oil sorption capacity of the water-saturated sorbent was determined after the water sorption capacity experiment by saturating the sample with oil, then draining, weighing and determining the oil retained.

Finally, the quantitative measurement of both the oil-free sorbent buoyancy and the oil-soaked sorbent buoyancy was performed by shaking a tared dry sorbent or oil-soaked sorbent with seawater, separating the floating sorbent from the sunken sorbent, and then draining and weighing the individual fractions.

Forty-nine sorbent materials which included inorganic, natural organic, polymeric hydrocarbons, polymeric foam and miscellaneous products were investigated by Schatzberg. Unfortunately, this list did not include cotton. The study concluded that polymeric foams were the best materials available at that time for oil spill clean up.

Johnson, Manjrekar, and Halligan (1973) conducted investigations relative to the removal of oil from water surfaces by sorption on unstructured fibers. A spectrum of materials which included the natural fibers of cotton and wood, modified cellulose fibers of viscose rayon, cellulose (2.5) acetate, and cellulose triacetate; and synthetic fibers of polypropylene, acrylic, nylon, and polyester were investigated.

In brief, the experimental procedure involved placing a known amount of oil on the surface of a one-liter beaker which contained 500 milliliters of a 3.5 percent aqueous sodium chloride solution to simulate seawater. One gram of fiber, in a loose wad, was then placed on the surface and the assembly shaken for five

minutes at 132 cycles per minute. The fiber wad plus associated oil was then removed by a wire hook inserted at the top of the mass and allowed to drain for one minute. The fiber plus oil and water was then loaded into a petri dish and placed in an efficient hoot until all the water had disappeared. The fiber-oil mass was then weighed.

Cotton and polypropylene exhibited excellent oil removal capabilities. In fact, the oil recovery was almost complete up to a loading of 30 grams of oil per gram of fiber. Polypropylene appeared to have a maximum capacity approaching 40 grams per gram of fiber. No limit for the sorption capability for cotton was observed.

These tests also indicated that straw had an oil sorbance of approximately five times its dry weight. This agreed well with field reports (Walkup et al., 1970; 1971). The combination of this laboratory and on-site experience strongly suggests that straw is not the most desirable sorbent from a capacity point of view. Cotton and polypropylene will sorb eight to ten times as much oil per unit weight of material when compared to straw. The principle advantage of straw appears to be its availability.

Schatzberg and Nagy (1971) suggested that oil sorption on a sorbent might be related to the critical surface tension (γ_c) of the solid sorbent. In this experiment, the oil on the water at the initiation of the experiment (O_{Wi}) was held constant at 40 grams per 500 milliliters of an aqueous solution containing 3.5% sodium chloride. To test this hypothesis, a plot of oil uptake versus γ_c is shown in Figure 3.3-1. In this case, γ_c is defined as the liquid surface tension for which the constant angle is zero on the given solid. As indicated, these data strongly suggest that this parameter is strongly related to the oil removal capability. Although precise data are not available for cotton, the raw fibers have a natural waxy coating which should lead to a γ_c close to the value observed for wool.

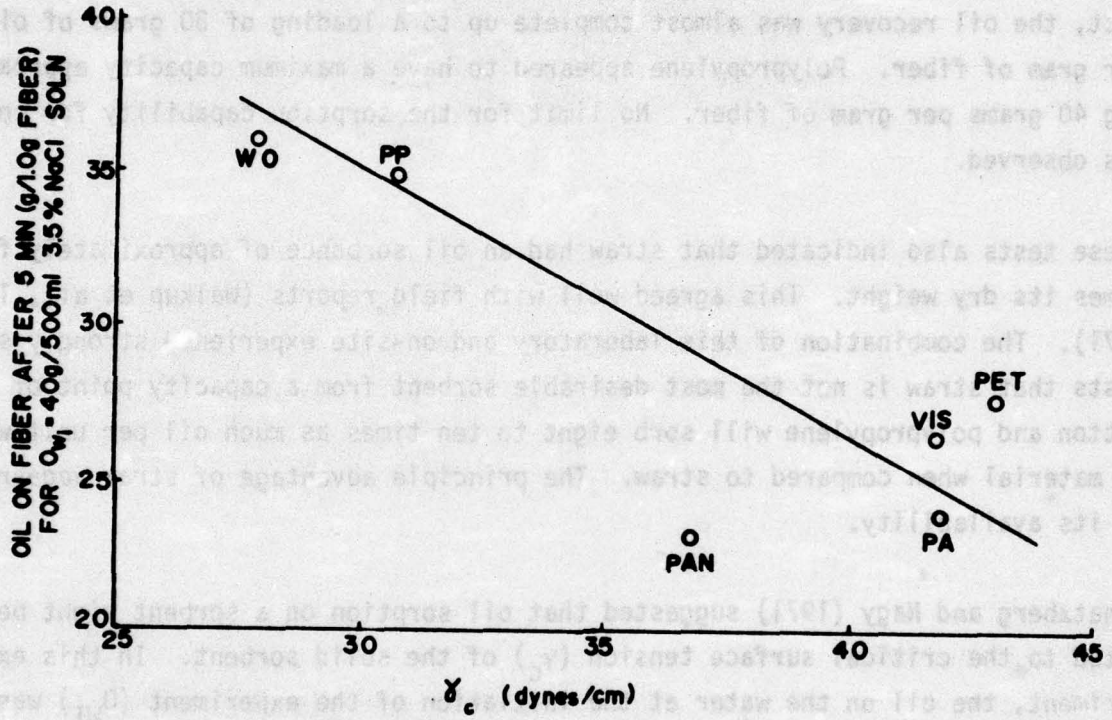

FIGURE 3.3-1 THE INFLUENCE OF CRITICAL CONTACT ANGLE ON OIL SORPTION

TABLE 3.3-I

OIL SORPTION OF WATER-SOAKED SORBENT*
(lbs of oil/lb. of sorbent used)

Type of Oil	Polyurethane Foam #1	Polyurethane Foam #2	First Class Cotton	Cotton Wasties
#2 Fuel Oil	26	35	50	42
Light Crude	27	43	59	50
Heavy Crude	23	62	76	76
Bunker C	24	58	92	85

*Due to the nature of the tests, all data included in this report are probably ± 10% in value.

TABLE 3.3-II

PHYSICAL PROPERTIES OF TEST OILS

TEMPERATURE 76°F

	#2 Fuel	Light Crude	Heavy Crude	Bunker C
Degree API	38	26	15	12
Specific Gravity	0.83	0.89	0.96	0.99
Kinematic Viscosity, CS	3.5	8.2	2600	2800
Surface Tension dynes/cm at 77°F	29	30	35	34
Interfacial Tension with synthetic seawater, dyne/cm	28	24	23	26

On the basis of this favorable comparison of cotton to other fibers at the beaker scale, a sequence of tests, which conformed to the Schatzberg procedure, were conducted to compare polyurethane foam and cotton directly in the same experimental situation. A synopsis of the results of that investigation are given in Table 3.3-I. In this table, polyurethane foam number one was Industrial foam supplied by the Scott Paper Company of Chester, Pennsylvania. The second foam was Stepanpol which was supplied by the Stepan Chemical Company of Northfield, Illinois. The first class cotton was Lambright LX-28 supplied by the Textile Research Center at Texas Tech University. Finally, the cotton wasties, which are the lowest class of ginned cotton (micronaire 2.9 and below) were supplied by the Cotton Classing Office, Lubbock, Texas.

As the data in Table 3.3-I indicate, at the beaker scale the sorption of oil was a function of the type of petroleum fraction being considered. The physical properties of the oils involved are shown in Table 3.3-II. Probably the most meaningful test devised by Schatzberg concerns the oil-sorption capability of the water-saturated sorbent. The intent of this test is to soak the sorbent in synthetic seawater and then measure the amount of oil the material will pick up. The objective is to simulate the worst of conditions, where the sorbent becomes saturated with water before it contacts the oil. As the data in Table 3.3-I indicate, under these conditions cotton sorbed between 42 and 85 pounds of oil per pound of material, depending upon the type of oil tested. The sorbency of cotton was always significantly greater than that observed for the best foam.

It should be noted that all of the values reported here are the average of at least three determinations. If the data for the first class cotton and the polyurethane foam number two are averaged over all the oils reported, the cotton sorbed approximately 20 more pounds of oil per pound of sorbent.

A more important test deals with the selectivity of the sorbent. Many sorbents act as sponges, that is they pick up a large amount of fluid. However, if a sorbent is not selective towards oil, it would not be an efficient material to use. A good sorbent would capture and retain only oil. Schatzberg devised

a test to measure this capability by shaking the oil saturated sorbent in seawater for six hours. The lower the pounds of water picked up per pound of oil, the higher the selectivity of the material. The test data reported in Table 3.3-III shows that once again, cotton proved to be equal to or better than the other materials tested. The cotton sorbed approximately one-tenth of a pound of water per pound of oil picked up. Again the reported results are the averages of at least three determinations.

Finally in order to insure that these results were consistent with those reported elsewhere, a table of comparisons (Table 3.3-IV) was prepared. These data should be interpreted with care since they represent the oil sorption capacity of the dry sorbent with no water present. Because of this, they do not simulate the normal oil spill clean up situation. Nevertheless, they do indicate that the battery of tests performed at Texas Tech University were consistent with those conducted elsewhere.

The principal results to be gleaned from these comparison tests were that cotton had a higher sorbency and a higher selectivity than polyurethane foam. The difference in sorbency was probably not sufficiently great to justify a definite choice between the two materials. However, the difference in selectivity is significant and surely would justify the choice of cotton as the most desirable sorbent. Any sorbent which picks up 0.2 to 0.8 pounds of water per pound of oil would most probably require special retrieval facilities in order to process that much water. The values reported for cotton of 0.1 pound of water per pound of oil are conservative in that no value greater than 0.1 was observed. Values of 0.06 to 0.08 pounds of water per pound of oil were common. This amount of water could be easily disposed of using conventional incineration techniques.

An investigation was also made of the oil spill removal capabilities of cotton in an agitated and an unagitated tank of water. The purpose of these studies was to gain a further insight into the effects of wave motion. In the preliminary trials, an amount of Bunker C sufficient to produce a thin slick was poured onto the surface of a three foot in diameter plastic tub.

TABLE 3.3-III

WATER-OIL CONTENT RATIO AFTER SHAKING

OIL-SOAKED SORBENT IN SEAWATER

(lbs. water/lb. oil)

Type of Oil	Polyurethane Foam #1	Polyurethane Foam #2	First Class Cotton	Cotton Wasties
#2 Fuel Oil	0.3	0.7	0.1	0.1
Light Crude	0.4	0.8	0.1	0.1
Heavy Crude	0.3	0.4	0.1	0.1
Bunker C	0.2	0.3	0.1	0.1

TABLE 3.3-IV

AVERAGE OIL SORPTION CAPACITIES

grams of oil/gram dry sorbent

(N.A. - Capacity not measured or available)

TYPE OF OIL	SORBENT	INVESTIGATOR			
		Texas Tech[1]	Schatzberg[2]	NCEL[3]	Shell[4]
#2 Fuel	cotton wasties	39	N.A.	N.A.	N.A.
	polyurethane foam	27	47	N.A.	N.A.
Light Crude	cotton wasties	54	N.A.	N.A.	N.A.
	polyurethane foam	30	52	21	28
Heavy Crude	cotton wasties	77	N.A.	N.A.	N.A.
	polyurethane foam	44	56	N.A.	N.A.
Bunker C	cotton wasties	85	N.A.	N.A.	N.A.
	polyurethane foam	42	62	39	51

[1] Department of Chemical Engineering, Texas Tech University

[2] Paul Schatzberg, Navshipranddcen,Annapolis Laboratory

[3] NCEL, Port Huenene, California

[4] Shell Pipe Line Corporation, Research and Development

Very loosely packed balls of cotton were then placed on the slick and it was observed that after the cotton sorbed the surface oil, it slowly formed into a thick mass. Visually almost all of the oil was captured by the cotton. In further tests, an eight-foot diameter vinyl plastic swimming pool was used as the containment device. The water was maintained approximately eight inches deep for the two sets of conditions which were studied during the sorption tests. These were a quiescent body of tap water and an agitated pool using salt water with waves approximately four centimeters in height. The frequency of the wave maker was 0.7 cycles per second. The oil slicks were developed by gently pouring a known volume of oil on the surface of the water.

Once the slick was formed, a tared piece of opened cotton larger in diameter than the slick was placed on the surface of the oil. The cotton which was used in these studies was strips of card web. This is a very porous cotton material which is somewhat similar to a fluffy gauze. After a given period of time, the cotton was removed, by hand, from the surface of the pool and the amount of water sorbed by the cotton was determined by ASTM D95-70. Areal data as well as estimates of sorption rates were also taken.

In the studies using quiescent tap water, Bunker C oil, and fully opened cotton, it was generally observed that all of the oil was sorbed by the cotton. Sorption capacities ranged from 64.5 gm oil/gm cotton to 2.6.3 gm oil/gm cotton. On an areal basis, the values ranged from 0.012 to 0.21 gm oil/cm^3 cotton. This variation was a function of how large a slick was initially formed and it should be noted that in all cases total slick removal was achieved over a period of 12 hours. A saturating effect of oil into the cotton web was observed and it was suspected that this phenomenon was caused by capillary action within the cotton web structure.

Studies using salt water and wave action produced similar sorption capacity data and in each case complete slick removal was achieved. One interesting observation was that salt water combined with wave action to decrease the cotton saturation time to approximately four hours. Sorption data relative to both experiments are shown in Table 3.3-V.

TABLE 3.3-V

OIL SLICK REMOVAL CAPACITY OF DRY SORBENT

Data Run	Quiescent Tap Water g oil/g dry sorbent	Water with Wave Action[a] g oil/g dry sorbent
1	64.5	53.7
2	77.4	74.3
3	218.0	69.1
4	122.2	67.2
5	114.6	--
6	106.4	--
Average	117.2	66.1

NOTE: Oil: Bunker C
Sorbent: one-ply fully opened cotton

[a]Frequency: 0.7 cycles per second

A very qualitative experiment was made to determine the potential of opened cotton as a containment vehicle. A light crude was used to form approximately a two-foot in diameter oil slick which was then surrounded by a one foot width of opened cotton. Results indicated that the entire slick could be moved throughout the pool by simply pushing the outer cotton layer with a meter stick. Wave action and salt water did not affect the stability of the encapsulation formed by the cotton. The oil slick was totally contained throughout the duration of the test which was 48 hours under quiescent conditions and 4.5 hours during wave action.

SECTION 4

TEST FACILITY AND EXPERIMENTAL PROCEDURES

4.1 Construction of Test-Tank Facility

This section of the report contains the details of the construction of test-tank facility and the sequence of operations. The construction phase included the fabrication of the test tank, outboard-motor mounting, flow straighteners, cotton-opener mounting and tracks, oil-dispersal system, retrieval-system mounting and tracks, false-bottom, and the holding-basin.

Test Tank. A schematic of the overall test-tank facility is shown schematically in Figure 4.1-1 and photographically in Figure 4.1-2. The test tank itself was fabricated from 26-gauge galvanized sheet metal. The oval-type design was selected to satisfy both space and operational requirements. The width and depth of the channel were 48 and 32 inches, respectively. The inner and outer radius of the end sections were 23.5 and 74 inches, respectviely. The tank was fabricated in place using 1/16- and 1/8-inch aluminum rivets. The joints were sealed using an asphaltic plastic cement containing asbestos. The sides of the tank as well as the top crimped edge were supported by a 1 1/2-inch angle iron support frame. A drain plug was installed at the west end of the north straight section.

Outboard-Motor Mount. The prime mover in the system was a 50 Hp, 1975 Evinrude outboard motor equipped with a 13-inch propeller. The pitch of the propeller was 15 inches. The motor was mounted in the tank using a 5-inch steel channel and a 2 x 6-inch board cut to fit. In order to prevent cavitation and severe turbulence the width of the tank on the inlet side of the propeller was narrowed to gain sufficient hydrostatic head. The discharge side of the propeller had flow baffles mounted in the channel to reduce turbulence. Figure 4.1-3 shows a schematic view of the outboard mount and baffles. The clearance between the propeller and tank bottom was approximately one inch. An outboard-marine tachometer having a range of 0-6000 rpm was connected to the motor to

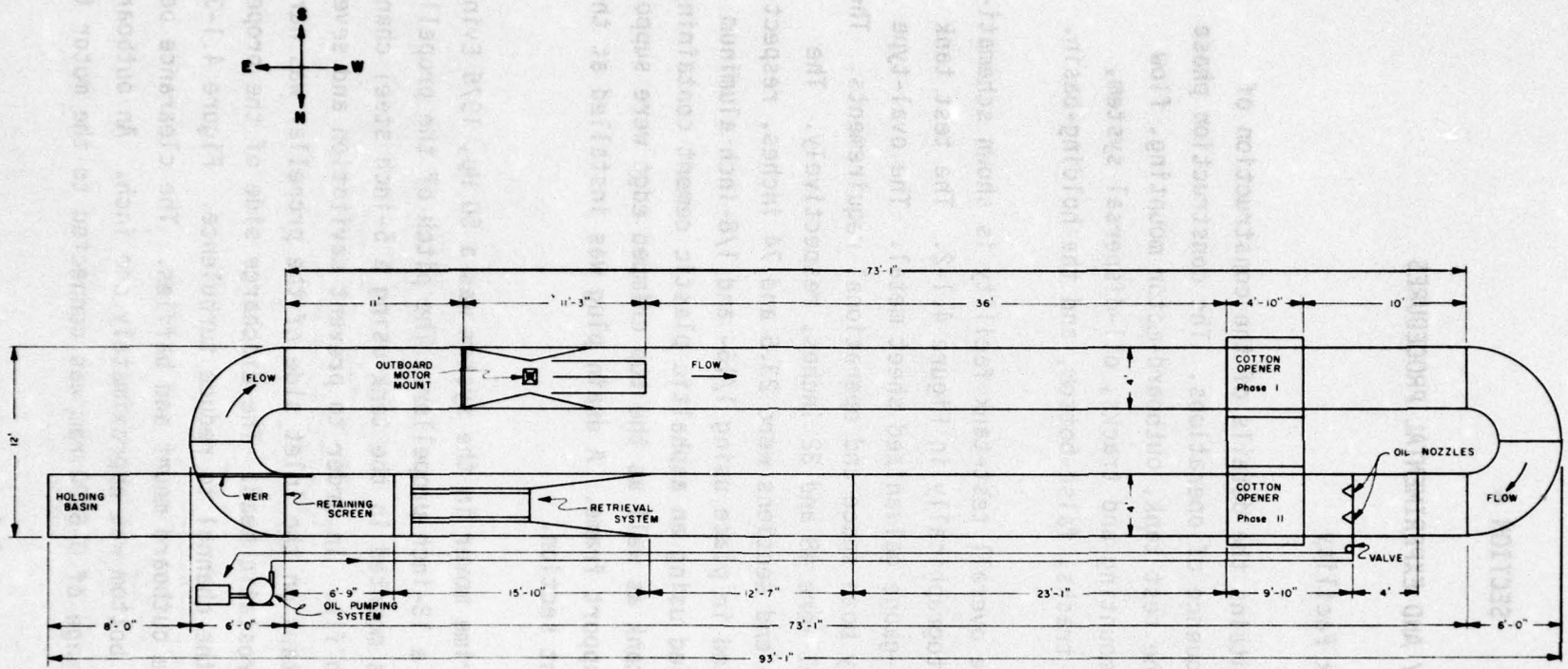

FIGURE 4.1-1 SCHEMATIC OF TEST FACILITY

FIGURE 4.1-2 PHOTOGRAPH OF TEST TANK

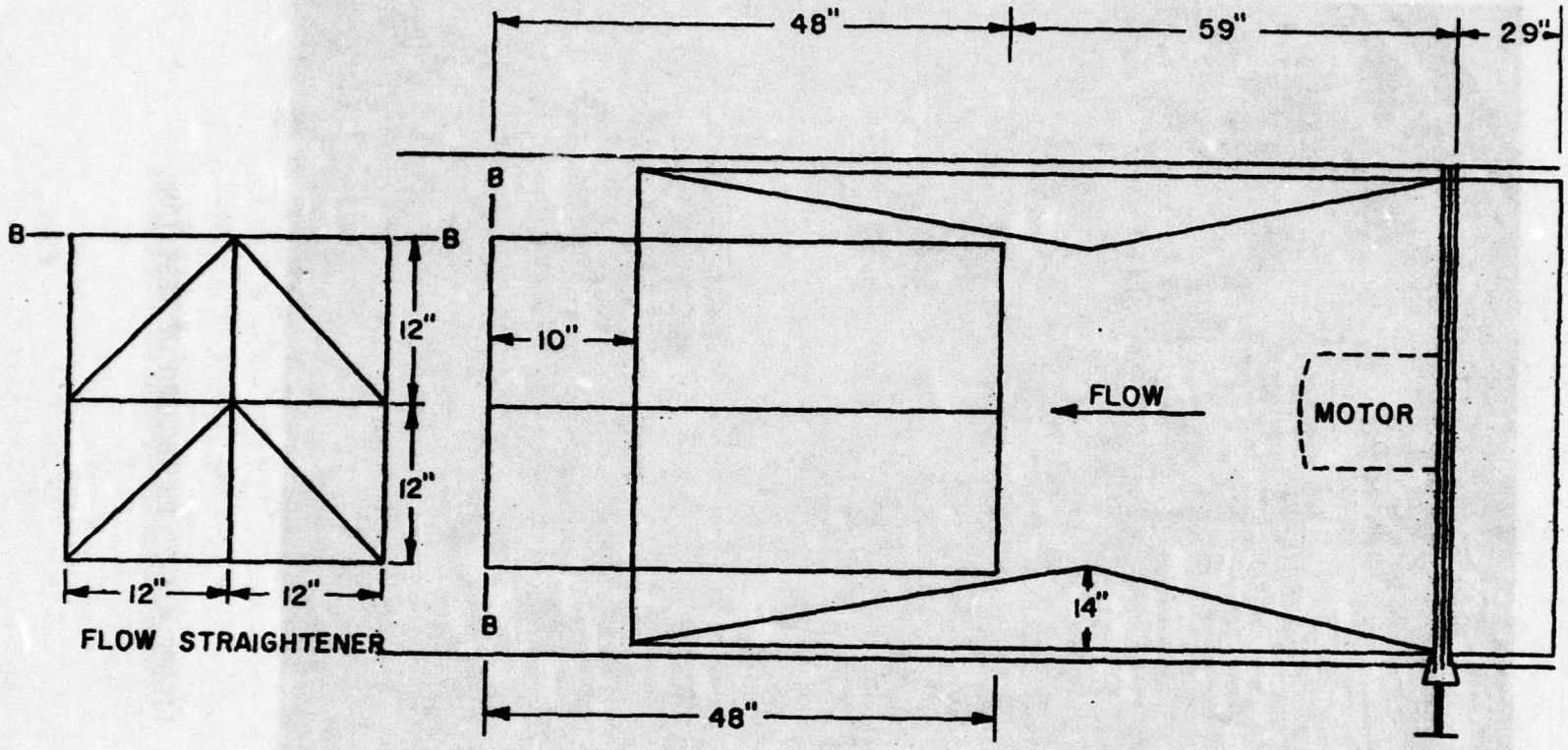

FIGURE 4.1-3 SCHEMATIC OF MOTOR MOUNT AND STRAIGHTENERS

allow for duplication of throttle settings. For reasons of safety during operation the outboard motor was also equipped with a continuous, separate water supply to the cooling system via a garden hose.

Flow Straighteners. Initial trial runs on moving the water around the test tank indicated that flow straighteners would be required at each curved end of the test tank to prevent both hydraulic gradients and surface slippage. A series of baffles were fabricated from 29-gauge galvanized sheeting adjustable in height from 21 1/2 to 25 inches were placed in the west end of the tank. See Figure 4.1-4. Similar baffles, only 16 inches in height, were placed in the east end of the tank. It should be noted that the normal operating water level was 22 inches.

False-Tank Bottom. Near the end of the experimental period it was found to be necessary to increase the velocity of the water in the tank. This was accomplished by fabricating a false-bottom section in the north-straight section of the tank between the cotton-dispersal system and the cotton-oil retrieval system. A section 32 feet long constructed from 14-gauge galvanized sheeting was supported by 1 1/2-inch angle iron. The height of the false bottom was 12 inches with approximately 9 inches of water above this level.

Cotton-Dispersal System. A small-scale Continental/Moss-Gordin lint cleaner was used as the cotton opener and dispersal system. A photograph of the cotton dispersal system is shown in Figure 4.1-5. This unit which weighed approximately 2500 pounds was initially mounted over the south-straight section of the test tank. The cotton opener was moved to the north-straight section to reduce the transit distance. This was accomplished by fabricating a track over the total tank such that the opener could be used on either straight section. Figure 4.1-6 shows a schematic view of the opener mounting and tracks. The mounting frame was fabricated from two inch angle and the tracks were three inch channel iron. A cotton discharge chute fabricated from 26-gauge galvanized sheet was mounted to the opener. A set of scales was mounted on top of the unit and next to the inlet of the opener to allow for feed rate measurements.

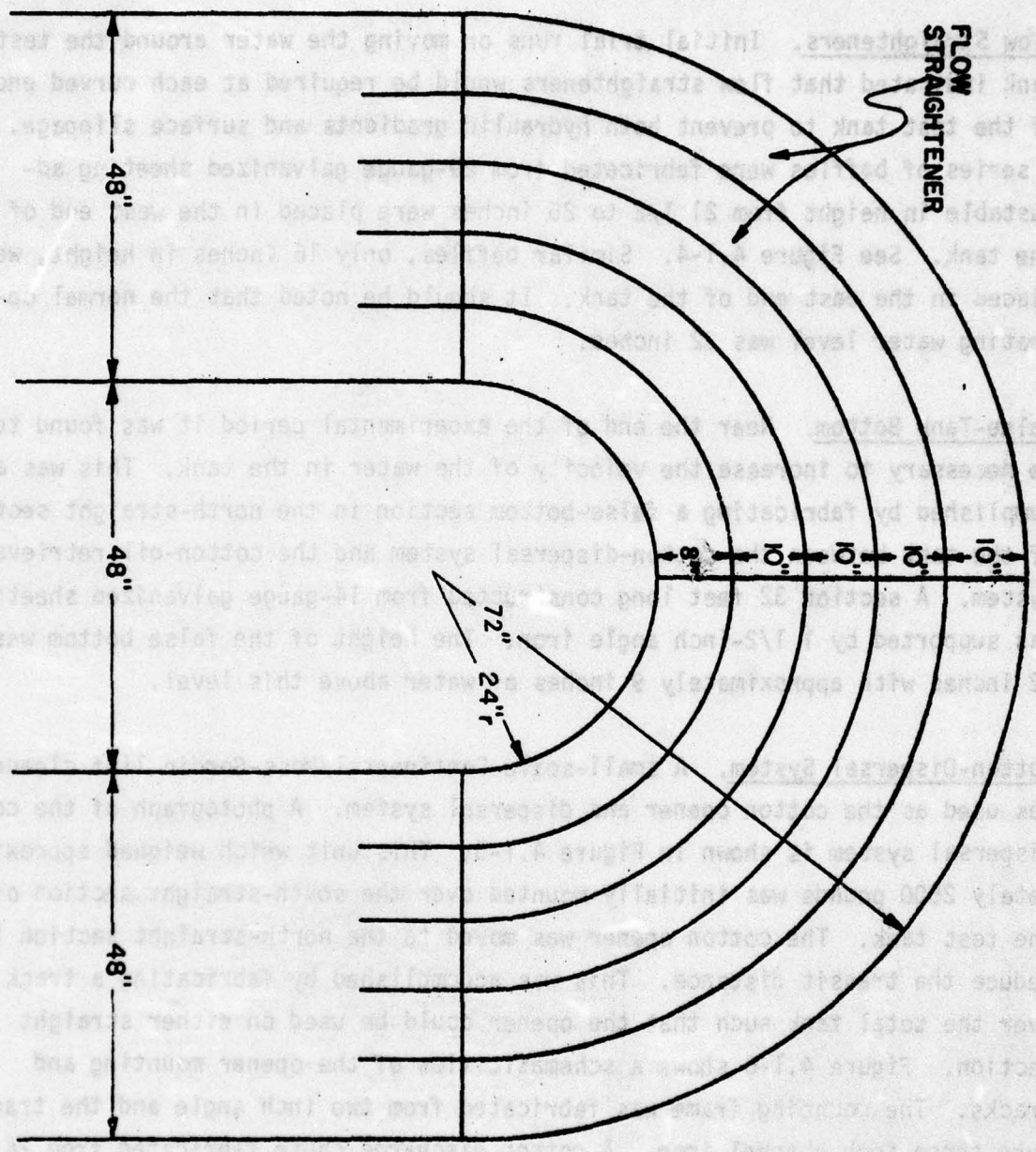

FIGURE 4.1-4 SCHEMATIC OF WEST END OF TANK AND BAFFLES

(31)

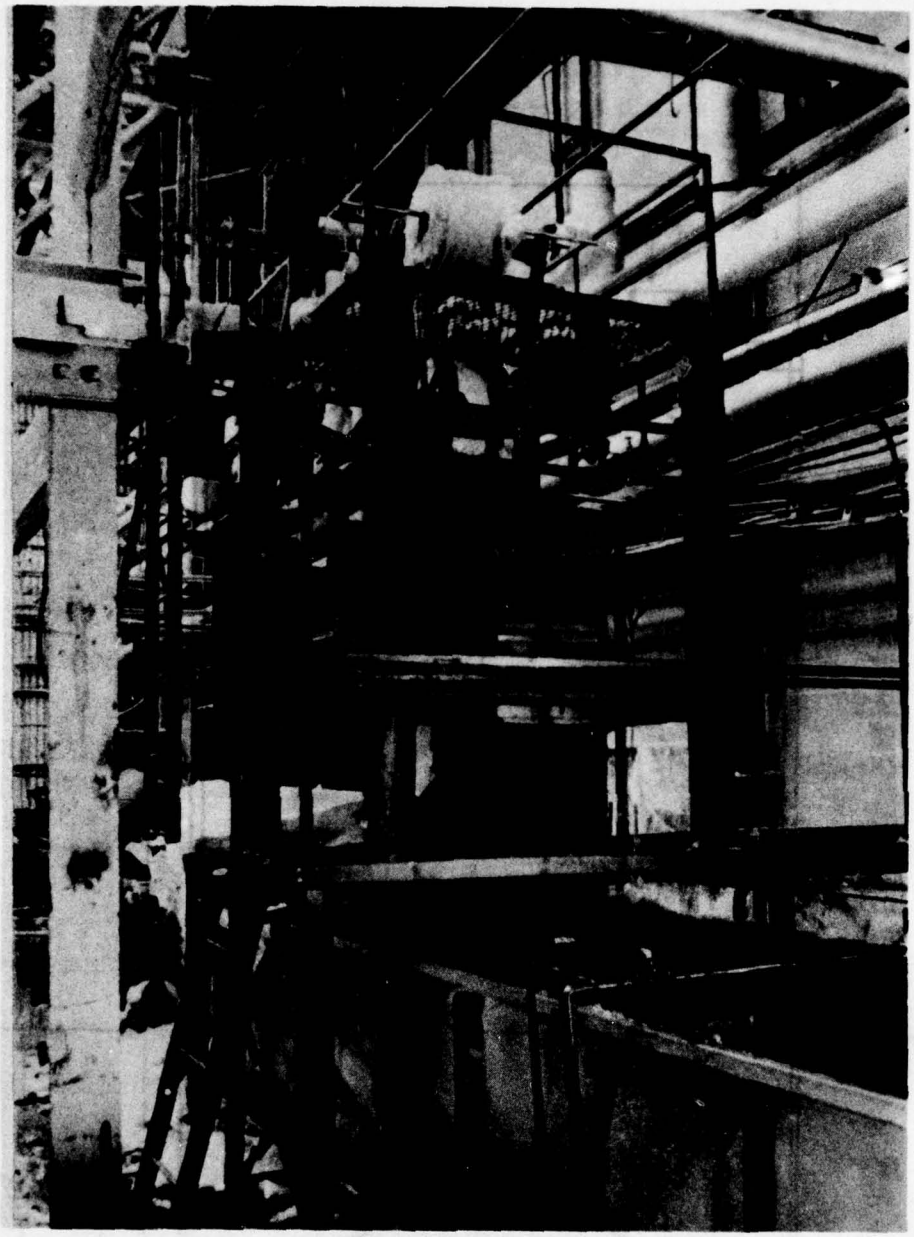

FIGURE 4.1-5 PHOTOGRAPH OF COTTON OPENER

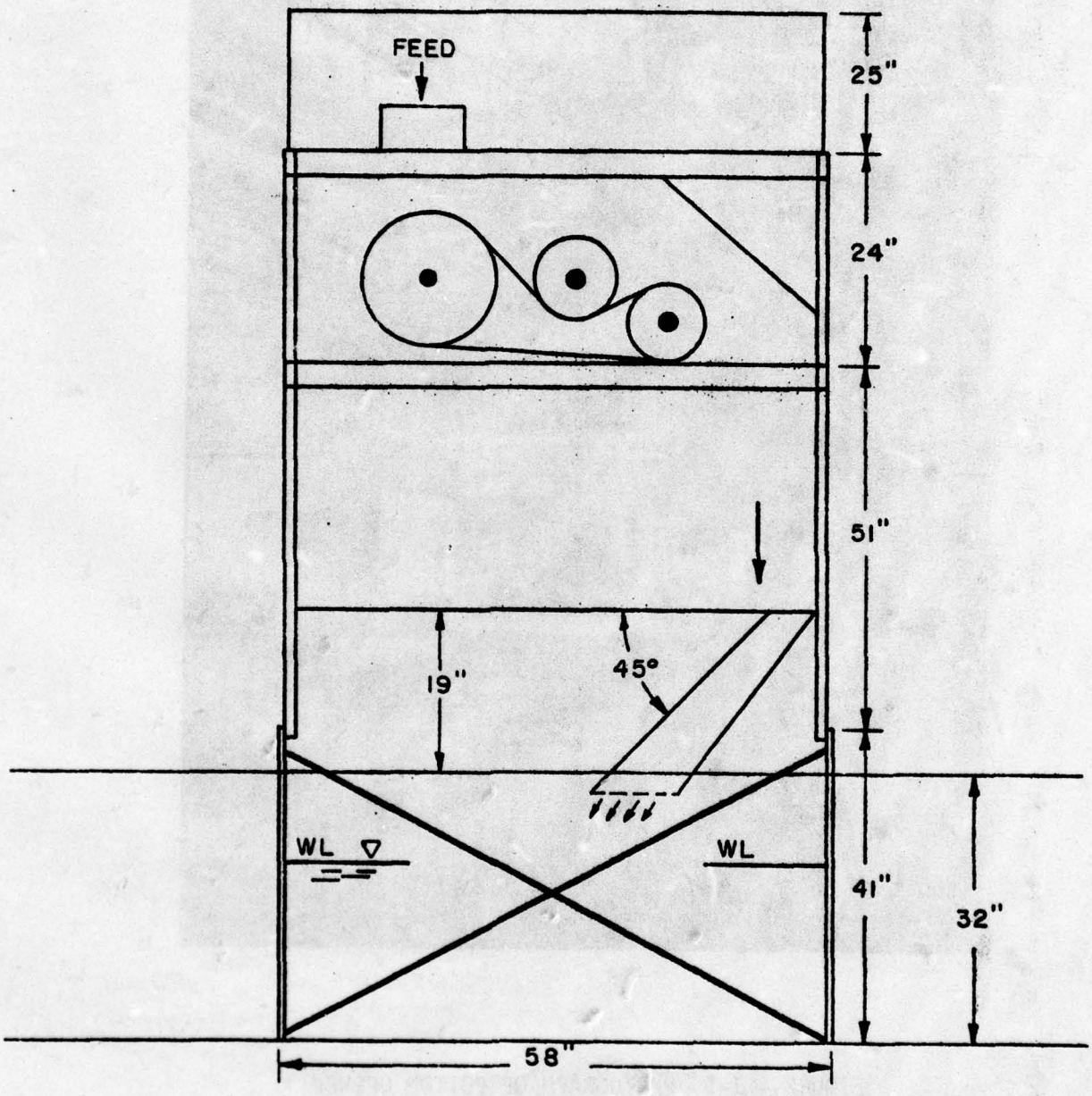

FIGURE 4.1-6 SCHEMATIC OF COTTON OPENER AND MOUNTING PLATFORM

Oil-Dispersal System. The oil-dispersal system as shown in Figure 4.1-7 was comprised of a 71-gallon steel reservoir, a 1000-pound capacity portable platform scale, a 3-Hp 50-gpm centrifugal pump, and a nozzle system using flat spray-9506E Teejet nozzles. A distance of approximately 65 feet separated the oil reservoir and the nozzles. There was a continuous recycle between the reservoir and nozzles for the purpose of air cooling the oil to alleviate pump overheating. The nozzle geometry and spacing provided a relatively uniform oil slick to be applied.

The system as described was not capable of handling one of the test crudes, namely Lact. In this case, the heavy crude was poured manually from 2-1/2-gallon buckets on to a flat plate. The steel plate was mounted on the test tank at an inclined angle to the water surface.

Cotton-Oil Retrieval System. The retrieval system was comprised of a commercially available conveyor belt unit, Variac, drip pan, air nozzles, product chute, sump pumps, and guiding booms. The conveyor unit was equipped with a 20-inch wide steel mesh belt, with one-half inch diamond spacings. A schematic view of the overall system is shown in Figure 4.1-8. The drive motor was 1/2-Hp and was interconnected to an Impak-type Variac which was used to control the linear velocity of the steel belt. A mounting frame, fabricated from 1 1/2-inch angle iron, was used to support the conveyor in the test tank. A pulley arrangement was developed for adjusting the depth of the load end of the conveyor in the water. This arrangement also varied the angle of inclination of the belt. The discharge end of the conveyor was equipped with four 1/8-inch, 108 degree angle, K-15, Teejet air nozzles to facilitate the removal of the oil-laden cotton from the belt to the product chute. The air pressure was 80 psig. A plexiglas window was installed at one location in the side of the test tank to allow visual observation of the load-end water interface.

Initial shakedown runs indicated considerable dripping of oil through the upper belt (efficiency loss) and a drip-pan assembly was fabricated from

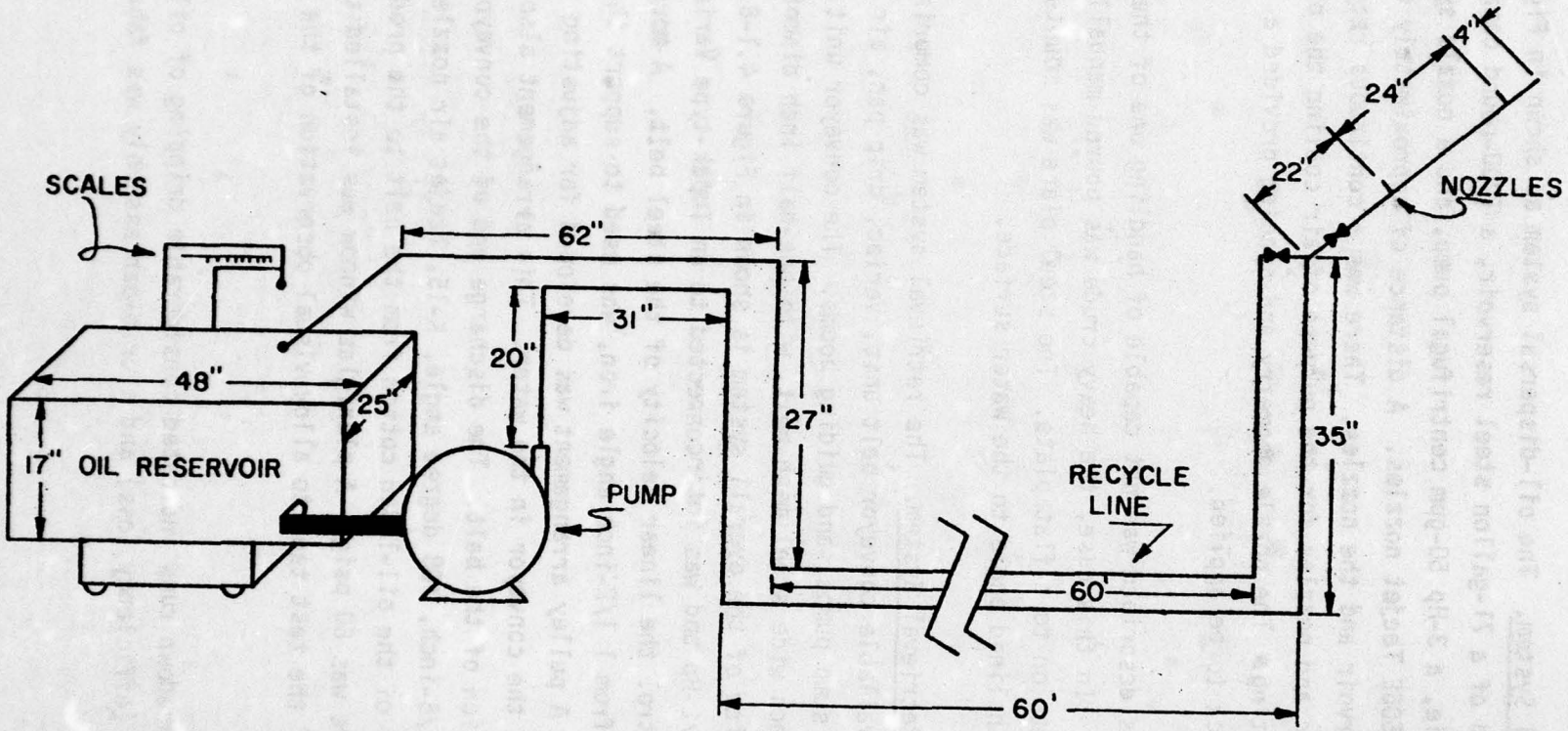

FIGURE 4.1-7 SCHEMATIC OF OIL-PUMPING SYSTEM

29-gauge galvanized sheet metal and installed between the upper and lower (return) belts. The drip pan drained by gravity to a sump located on the side of the load end. The drippings were continuously pumped from the sump by two Little Giant sump pumps to a 32 gallon receiver. The product chute was also fabricated from 29-gauge galvanized sheet metal and was fix mounted under the discharge end of the conveyor and extended out over the side of the test tank. The chute was manually unloaded into a 32 gallon reservoir by means of a squeegee.

In that the belt width was 20 inches and the tank width was 48 inches, it was necessary to install a set of guiding booms in front of the load end of the conveyor. The booms were fabricated from 29-gauge galvanized sheet metal and attached to the sides of the conveyor and the tank wall with a throat of 14 inches. These booms were 12 inches in depth and were immersed to a depth of 6 inches.

The entire retrieval system was capable of being moved within the tank in any direction within the north-straight section.

Holding Basin and Weir. In order to determine the overall material balance for the system it was necessary to determine the amount of material which passed through and around the retrieval system. A holding basin and weir were fabricated at the east end, north side of the test tank. Figure 4.1-8 shows a schematic view of this section. An underflow-type weir plate was mounted in the tank at the east end parallel to the north-straight section. The weir was submerged approximately 4 inches below the surface. An additional 9 feet of tank was fabricated and added to the north-straight section at the east end to provide the holding basin. The weir plate effectively reduced the surface velocity and allowed the momentum of any oil-laden cotton or free oil on the surface which passed the retrieval system to flow into the holding basin and not continue around the test tank. The holding basin was cleaned manually after each run. The free oil was removed by sorbing it with a known weight of cotton.

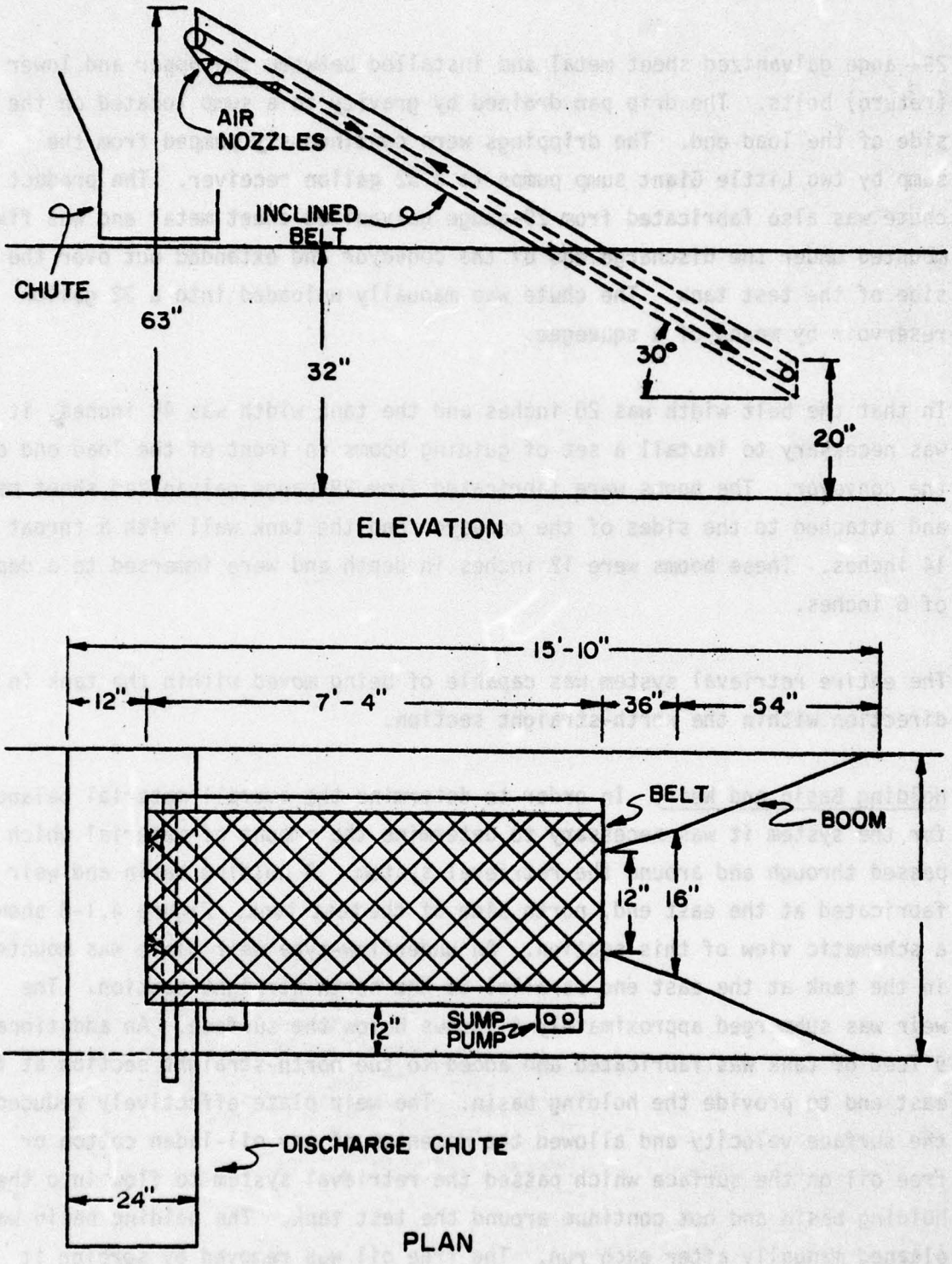

FIGURE 4.1-8 SCHEMATIC REPRESENTATION OF RETRIEVAL SYSTEM

During the final phase of the experimental work, a 1/4-inch mesh screen was placed across the entire tank at the east end of the north-straight section. The 18-inch screen was immersed to a depth of 12 inches. A known mass of cotton was placed on the upstream side of the screen prior to initiating the oil slick. The cotton sorbed almost all of the free oil which passed the retrieval system and any oil-laden cotton which was not recovered was enmeshed in the cotton barrier. The material retained by the screen was weighed after each run. The latter system was more effective in closing the material balances but did have a significant effect on the overall pressure drop in the system.

4.2 Sequence of Operation

The following sequence of events was followed in obtaining the data for the experiments performed in the test-tank facility.

1. The test tank was filled with tap water using several hoses. Once the desired water level was obtained, normally 22-24 inches, the hoses were turned off and the temperature of the water recorded.
2. Prior to starting the outboard engine the induced cooling water system for the motor was turned on. The outboard was started and the revolutions per minute indicated by the tachometer was adjusted to the desired level by the throttle. The desired level was dictated by the velocity of the water in the tank to be used for that particular run.
3. The surface velocity of the water in the tank was measured by observing the transit time for a piece of cotton to travel through a 50-foot portion of the north-straight section. Several observations were made and if the averaged velocity was not at the desired level changes were made on the outboard motor tachometer setting. This sequence was repeated until the appropriate velocity was obtained. The upstream end of the conveyor was then adjusted to the appropriate depth in the tank.
4. A predetermined amount of cotton, normally two pounds, was then hand opened and distributed either on the surface of the catch basin or on

the surface upstream of the retaining screen. This location depended upon the method being used to determine the system losses.

5. At a preset signal the flow of cotton to the opener was initiated. Due to the fact that it required a brief time, approximately 15 seconds, for the cotton to work its way through the opening device the oil flow was not initiated until cotton could be seen issuing from the outlet chute. The feed rate of cotton to the opener was controlled by a variable speed drive on the feed roller to the opener. Prior to starting the opener the initial weight of the cotton-feed spool was recorded.

6. Prior to a given series of runs the crude-oil reservoir was filled with the appropriate crude and the pump-around system---activated so as to remove any air which may have accumulated in the pump and recycle lines. Following this the initial weight of the oil reservoir was recorded. After the cotton had been observed striking the water surface, the oil was directed to the nozzles by switching two valves and the stopwatch was started. It should be noted that when Lact crude was being used, a predetermined weight of the crude was poured from buckets onto an inclined-flat plate over a specified period of time to effect the oil slick.

7. Preparatory to a given run the retrieval system was readied by the following sequence of events (a) the speed of the conveyor belt was set by referring to a calibration chart; (b) the air nozzles were turned on; (c) the depth of immersion of the load-end of the conveyor was checked; (d) all receivers were tared and placed in position; (d) the drip-pan sump pumps were activated. Depending upon the nature of the runs, that is, the specified sorbent effective contact times, the conveyor belt was started when confronted with the oil-cotton material or delayed for a specific period of time.

8. The system was then operated for the desired run time, this normally ranged from three to seventeen minutes. During this period of time, the material being removed by the retrieval system, namely cotton ladened with oil and drip-pan effluent were being collected in their respective receivers. The rate of dispersed oil was in the range of 25 pounds per

minute, and the weight of cotton applied through the opener was varied to obtain a spectrum of experimental conditions. The particular values were recorded for individual runs.

9. After any particular run the final weights of the crude oil and feed cotton were recorded. The mass of material from the conveyor chute and drip pan were also determined. Next the two pounds of cotton and any oil which had by-passed the conveyor, were retrieved from either the catch basin or retaining screen. This material was weighed and the amount of oil which had by-passed the retrieval system was determined by difference. Finally, the fluid which had been captured by the drip pan was poured into a large vessel and the oil and water allowed to separate. The amount of water picked up with the oil was determined by catching it in a volumetric cylinder as it was drained from the bottom of the vessel. Once all of this measurement was made a complete material balance could be undertaken.

10. After each run and prior to changing variables, sufficient quantities of cotton were placed on the surface of the water, with the outboard motor running, to effect a clean up operation. In most cases this period of time was in the range of 5-10 minutes. The material from the conveyor discharge chute was labelled and stored for further tests, e.g., squeeze rolls and incineration studies, after its final net weight was determined.

A typical run sheet is shown in Table 4.2-I which illustrates the various data taken during a typical experimental run. The particular data are for Run #4, April 11, 1975, and are reported in the April monthly report.

4.3 Fiber Dispersal System

In the small scale studies a light web of cotton fiber was placed on the surface of floating oil and it was observed that the web-like matrix entrapped the oil within the area of the web. The entrapped oil/fiber ratio was greatly

TABLE 4.2-I

TYPICAL DATA CALCULATION SHEET

Date 4/11/75 Run Number 1

1. Oil dispersed, difference in holding tank weights, (lb)	86
2. Fiber dispersed, difference in lap weights, (lb)	2.75
3. Conveyor chute product, difference in weights, (lb)	73.5
4. Fluid collected in the drip pan, difference in weights, (lb)	22.75
5. Total fiber plus fluid collected at conveyor, (3-4), (lb)	96.25
6. Total fluid collected, (5-2), (lb)	93.5
7. Oil from holding basin, difference in weights, (lb)	3
8. Water picked-up with sorbent, (6-1+7), (lb)	10.5
9. Oil picked-up at conveyor, (6-8), (lb)	83.5
10. Oil-sorbent ratio (9/2), (lb/lb)	30.4
11. Sorbent selectivity (100 x 8/6), (%)	11
12. Overall efficiency (100 x 9/1), (%)	97
13. Surface velocity, by timing observations, (ft/sec)	0.53
14. Oil density, by laboratory test, (lb_m/ft^3)	57.6
15. Width of tank, (ft)	4
16. Run time, (min)	10
17. Slick thickness ((5.1) x 1/(16 x 14 x 15 x 13)), (mm)	0.36
18. Sorbent effective contact time, (min)	min
19. Conveyor approach velocity, (ft/sec)	0.5
20. Crude type	Talco
21. Water temperature, (°C)	15.5
22. Oil temperature, (°C)	~15°C
23. Wave height (cm)	0
24. Fiber density (lb/ft^3)	~ 0.086

in excess of the oil/fiber ratio obtained by employing sorbency tests. It was deduced that a fine fiber matrix could provide an effective entrapment media in addition to being an effective sorbent.

It was understood that commercially available sheets of sorbent material had been used to remove oil from water but the weight/unit area of them was more than 25 times greater than that of the web used in our earlier tests. The web-like matrix had the effect of stabilizing the area of the entrapped oil and inhibiting the spread. In the small tank tests, it was found to be possible to displace the oil relative to the water by pulling the edge of the flimsy web. On occasions, oil up to 200 times the weight of the web was controlled.

The webs which had been used were preformed and laid over the oil. One phase of the project was to determine whether discrete fiber could be deposited on the surface of the oil to form a continuous sheet which would have integrity and oil capture capability in excess of the sorbent capability. Additionally, it was required that a determination be made as to the capability of removing oil from the water surface by retrieval of the fiber.

Equipment and processes used in the textile and associated fiber industry were considered for suitability in the present study. The guidelines issued by the Coast Guard during the formative stages of the project stated that fiber opener development be minimized until the basic principles had been established and subsequent scale-up or development work be commissioned.

The simplest device available to the project was a "Cotton Sample Opener" which was made operational to disperse opened fiber. The device is represented by Figure 4.3-1 and in which loose cotton was gravity fed through the inlet to contact the rotating opener rolls. The rolls were covered with saw-like teeth, and the direction of rotation and setting of the rolls relative to each other determined the degree of openness of the discharged fiber. On the basis of the initial trials, it was decided that a fiber opener with positive control of fiber flow rate and of improved operational reliability was required.

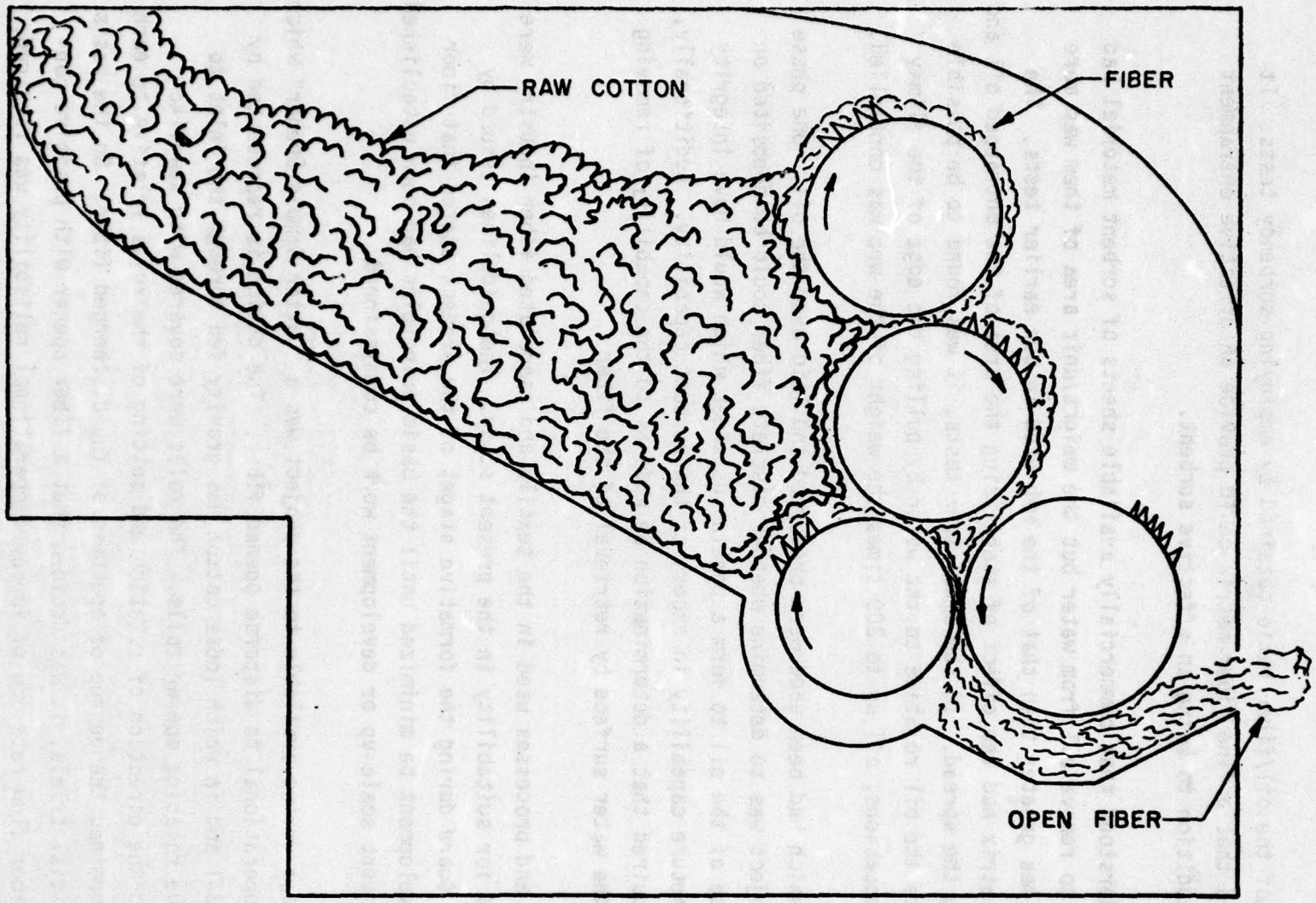

FIGURE 4.3-1 SAMPLE FIBER OPENER

A small scale Continental Moss-Gordin Lint Cleaner was renovated and fitted with a variable speed feeding arrangement. Lint cleaners are used in cotton gins to handle cotton after the seed and fiber have been separated. The primary functions are to separate fibers and to permit the dust and trash to be removed therefrom. Other than the installation of the variable speed feed it was only necessary to adjust the settings of the machine in order to obtain satisfactory operation. A sectional view of the opener is shown in Figure 4.3-2.

In order to ensure a consistent fiber flow rate, preformed cotton rolls of uniform weight per unit length were produced at the Textile Research Center, Texas Tech University on a conventional "picker". The cotton rolls were necessary for continuous operation of the opener.

The fiber opening machine was mounted on a trestle straddling the tank and positioned so as to blow the cotton toward the oil-water surface. The arrangement of opener, trestle and tank is shown in Figure 4.1-6. The fiber opener relies upon the cotton being transferred from one roll to another to progressively separate the fibers. The fibers are removed from the last roll by an induced air flow which is generated by a bristle covered roll. The use of a brush roll is desirable to enable close settings to be achieved and to minimize risk of roll damage.

The air flow is determined by the rotational speed of the brush roll and the size of the air intake opening. Initially problems were experienced because the air used to blow the fibers out of the machine created high air turbulence between the opener and the water/oil surface. The equipment and facilities limited the height to which the opener could be raised. It would have been preferable for the fiber to freely settle onto the oil surface rather than be blown onto it. However, most of the fiber was carried by the air above the oil and in a direction along the tank. Eventually the fiber settled by gravity onto the oil. The control of the airborne floating fibers was a problem until a cover was fitted to the tank which contained the air and fiber within the tank until the fibers had settled. A 9 foot extension was found

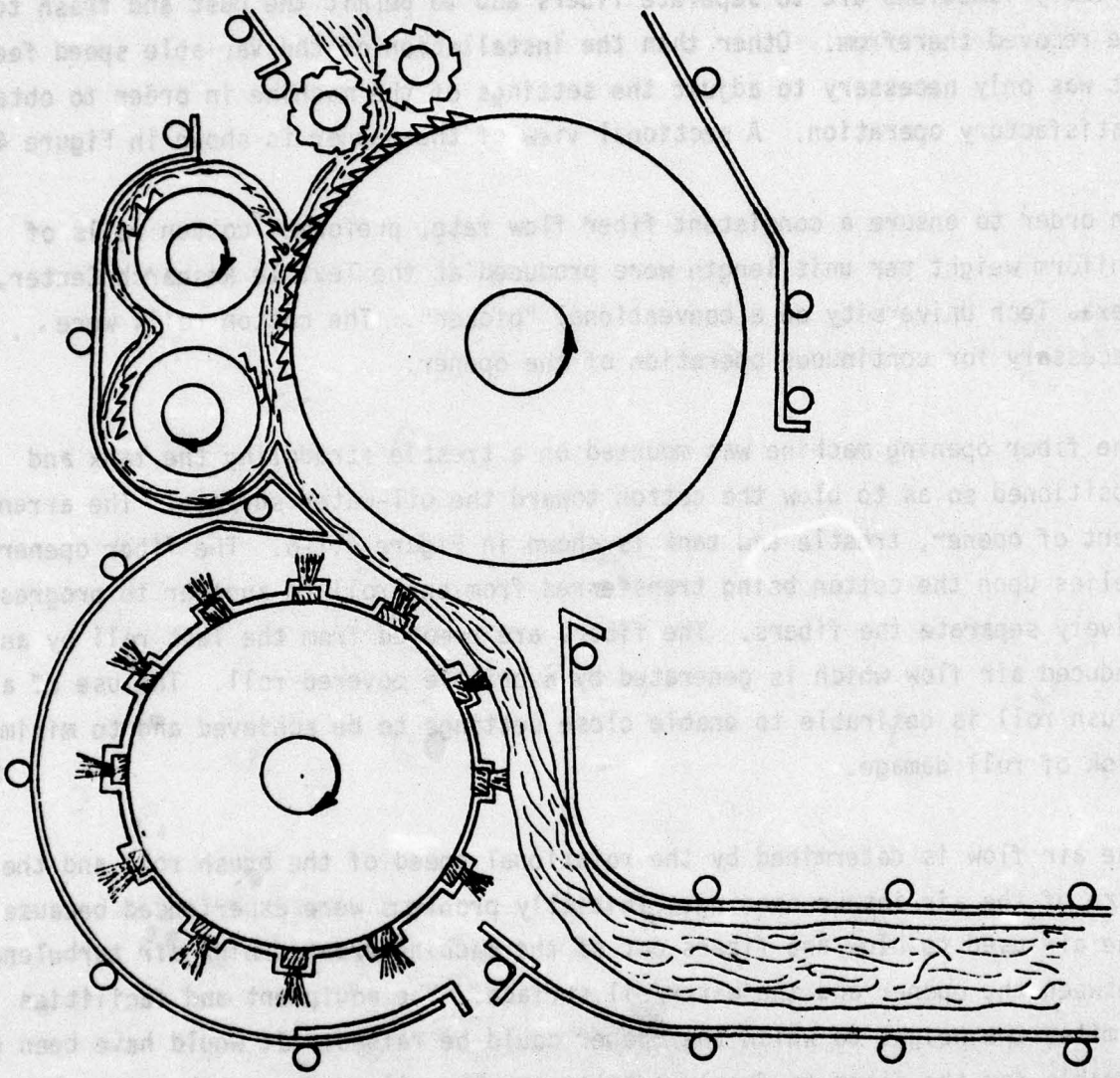

FIGURE 4.3-2 CONTINENTAL MOSS-GORDIN LINT CLEANER

to be sufficient, but to minimize contamination of the building, a 12 foot portion of the tank was covered when possible.

During the test runs, the speed of the opening section of the machine was maintained constant. The degree to which the cotton was opened was determined by the feed rate. It would have required extensive machine modification to provide machine variable speed controls and ensure effective fiber transport. By varying the feed rate, two test variables were changed; 1) the degree of fiber separation which can be represented as bulk density, and 2) the rate of dispersal of fiber onto the oil which determined the surface loading. However, the surface loading is also a function of the speed of the water under the opener.

The fiber bulk density was determined for the following feed rates:

low feed rate	-	15 lb/hr, density 0.059 lb/ft^3
medium feed rate	-	45 lb/hr, density 0.079 lb/ft^3
high feed rate	-	75 lb/hr, density 0.086 lb/ft^3

This density is a function of opener design and can be varied by changing design parameters. Presently, lint cleaners are used in cotton gins and a typical operational condition would involve a five foot roll processing 4000 pounds per hour. Approximately 25 horsepower is required.

In considering a practical fiber opener, the condition of the infeed material is important. In the cotton gin where a lint cleaner handles 800 lb/hr/ft of working width the input material is in a lightly compacted state of bulk density approximately 5 lb/ft^3. The fiber used in the tests was in roll form and had a bulk density of 15 lb/ft^3 which required a density change of approximately 187:1 to become opened. It should be noted that cotton can be most effectively transported and stored in bales of dimension 54" x 27" x 21", weighing approximately 500 lb each and with a bulk density of 28 lb/ft^3. To convert baled cotton into opened fiber of approximately 0.08 lb/ft^3 required a 350:1 density change and such a large change of condition will require considerably more energy input per pound than the gin lint cleaner or the unit used in this project. Nevertheless, it is technologically feasible, if the Coast Guard deemed it with the developmental effort.

4.4 Squeeze Roll Procedures

The objective of this phase of the study was to determine the effect of passing oil-cotton mixtures through a conventional squeeze roller. Perhaps it is well to note at the outset that the device used in this study is not well suited to field operations. However, it was useful in proving the concept envisioned here for generating meaningful data which can be employed for system design.

Experimental tests were performed to determine the oil retention, ash content, moisture content, and heat of combustion of compressed cotton. These data were needed to be able to specify the input to the incinerator.

The squeeze roll studies and the test tank studies were not coupled for several reasons. Initially there was considerable difficulty in securing delivery of the conveyor belt. After it had been delivered there was not an adequate amount of manpower on-hand to operate both sections simultaneously. Finally, the experimental procedure followed in obtaining the data called for catching all of the chute product for weighing in order to allow a material balance to be made. When the cotton is collected, the oil quickly distributed itself among the material in the catch pan. This is probably a better simulation of an actual recovery sequence than immediate squeezing since a system with no surge bin between the conveyor and squeeze section would be closely coupled and difficult to control from a systems point of view.

To prepare the materials for passage through the squeeze rolls, a ten-gallon temperature controlled tank was used to soak the cotton samples. An oil spill was simulated by pouring oil onto the surface until a layer one-tenth of an inch thick was formed. A sample of cotton, weighing one ounce, was then spread out to a surface loading of approximately 16 grams per square foot and then placed on the miniature oil spill. After twenty minutes the sample was removed with tweezers and put through the pneumatically operated squeeze roller which was obtained from the Texas Tech University Textile Research Center.

The squeeze roller which was manufactured by Liard M. Machine Works, TTU property number 129096, had an air cylinder diameter of 5 inches and the rollers were 22 inches long and 5 inches in diameter. A photograph of this device is shown in Figure 4.4-2. The air pressure range studied was between 15 and 50 pounds per square inch. The order in which pressures were tested was determined by pulling the air pressure values, written on cards, from a box containing the values to be tested so as to randomize the data.

The speed of the squeeze rolls was set at 1.2 feet per second. This velocity was deemed to be the maximum value consistent with safe operation. The cotton-oil mixture was fed to the rollers and removed from the device by hand. The principal problem was that the rollers were not designed for the particular purpose of their actual use during this project. It is suggested that a simple helix which pushed the cotton down the inside of a screened, truncated cone could be developed.

After the cotton-oil sample had passed through the squeeze rolls, it was then weighed to determine the oil retained on the cotton fiber. This sample was subsequently used to determine either the heat of combustion, ash content, or moisture content.

Four different crude oils whose physical properties spanned a broad range were used in the study. The crudes chosen were Arabian Light, Refugio, Talco, and Lact. The characteristics of the crude oils are listed in Tables 4.4-I and 4.4-II.

A. Ash Content

The ash content was considered to be the residual solids after the cotton sample was subjected to a temperature of 800°C for a period of two hours.

1. Experimental Materials

None

2. Experimental Apparatus

a. Muffler Furnace

b. Crucible

c. Tongs

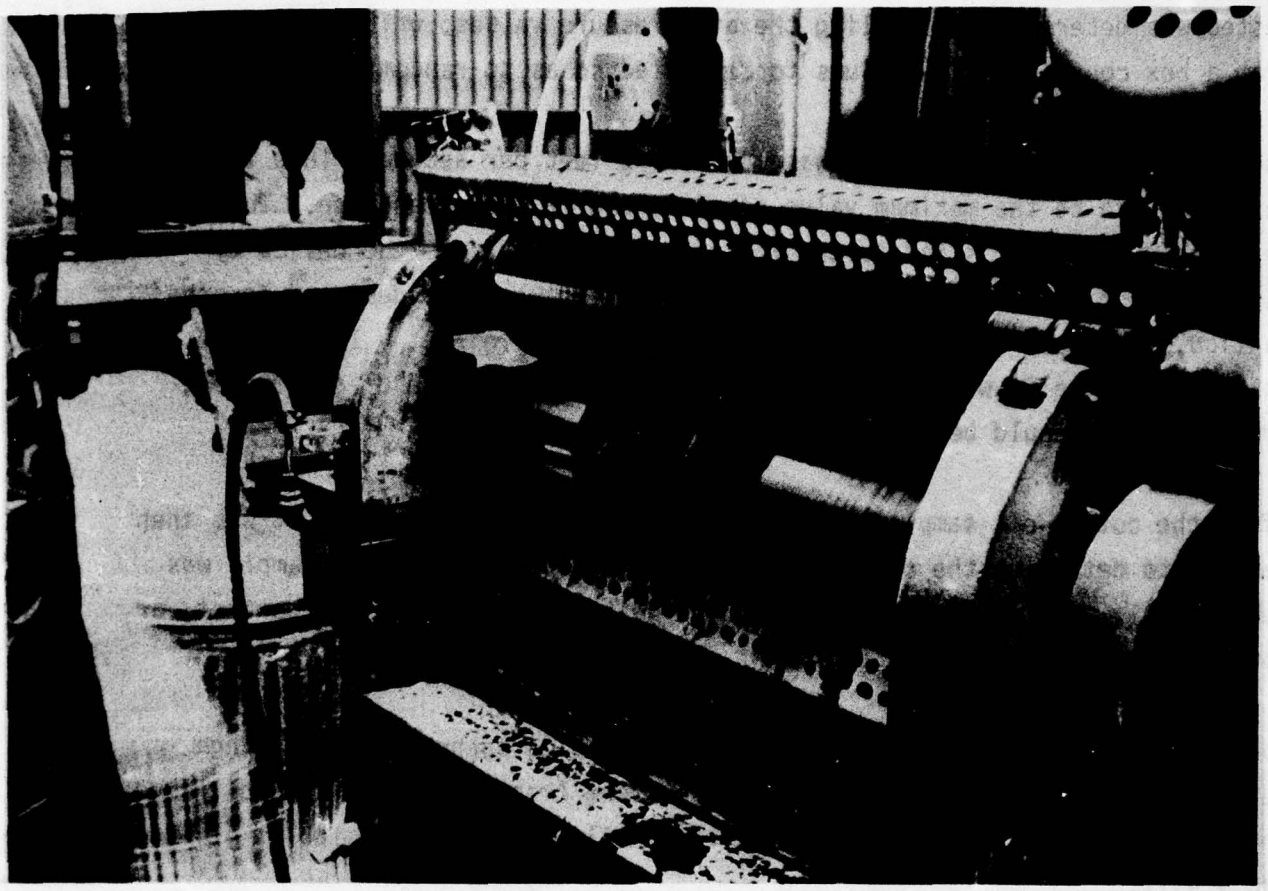

FIGURE 4.4-1 PHOTOGRAPH OF SQUEEZE ROLL DEVICE

TABLE 4.4-I

PROPERTIES OF EXXON CRUDES

Crude	Arabian Light	Refugio	Talco
Type	Light - Sour	Heavy - Sweet	Heavy - Sour
API Gravity	34.5	23.5	21.5
Sulfur Wt %	1.7	0.26	3.0
Pour Point, °F	-30	-80	-15
Viscosity, SSU			
@ 100°F	44	61	501
@ 80°F	50	82	994
@ 60°F	59	127	2,207
Reid Vapor Pressure, psia	3.5	0.5	1.7
Distillation, Vol %			
C_5 - Light ends	4.3	0.1	1.1
C_5 - 375°F Naphtha	26.1	5.3	11.1
375°F - 530°F Kero	15.5	35.4	11.1
530°F - 650°F Lt. Gas Oil	12.1	24.3	9.8
650°F -1050°F Gas Oil	32.0	32.6	32.5
1050°F - Residuum	12.7	2.4	32.3

TABLE 4.4-II

PROPERTIES OF Lact CRUDE

Production Source	Station L
Sample Source	Getty Oil Company
Crude Type	Heavy-Sour
°API Gravity	13.8
Sulfur Wt %	1.1
Pour point, °F	25
Viscosity, SSU	
@ 122°F	1,670
@ 200°F	172
@ 250°F	78
Ash Content, wt %	0.11
Conradson Carbon Residue, wt %	7.13
Heating Value, BTU/lb	18,380
Fensky-Martens Closed Cup Flash Point, °F	175

3. Experimental Procedure
   a. Tare the crucible, then place the sample into the crucible and weigh the crucible with its contents.
   b. Put the crucible in the preheated furnace at 800°C and leave for two hours.
   c. Remove the crucible and allow the crucible to cool to room temperature.
   d. Weigh the crucible and ash
4. Experimental Calculations
   a. Weight of sample = weight of crucible and sample - weight of crucible
   b. Weight of ash = weight of crucible and ash - weight of crucible
   c. Ash Content (wt%) = $\frac{\text{weight of ash}}{\text{weight of sample}}$ (100)

B. Moisture Content

ASTM method DD15-65 (reapproved 1968) was used to determine the water content of bituminous materials by co-distillation with a water-immiscible, volatile solvent.

1. Experimental Materials
   Naphtha - solvent
2. Experimental Apparatus
   a. Still - a glass vessel having a capacity of 500 ml with a ground glass fitting.
   b. Heater - an electrical heating mantle was used with the glass still.
   c. Condenser - a straight tube condenser.
   d. Trap - a 25 ml capacity glass trap.
3. Experimental Procedure
   a. Transfer a weighed amount of the sample to the still.
   b. Rinse the material adhering to the beaker used to weigh the sample with two 25 ml portions of naphtha.
   c. Add 200 ml of naphtha to the still.

d. Clean and assemble the still, trap, and condenser making all connections vapor tight.

e. Insert glass wool into the top of the condenser to prevent atmospheric moisture from condensing inside of the condenser.

f. Circulate cold water through the jacket of the condenser.

g. Apply heat to the still, adjusting the rate of boiling so that condensed distillate discharges from the condenser at a rate between two and five drops per second.

h. Continue distillation until no water is visible in any part of the apparatus except in the trap. If water drops adhere to the condenser wall, increase the rate of distillation.

i. When the evolution of water is completed, allow the trap and contents to cool to room temperature.

j. Read the volume of the water in the trap to the nearest scale division.

4. Experimental Calculations

$$\text{Water Content (wt\%)} = \frac{\text{weight of water in trap}}{\text{weight of sample}} (100)$$

C. Heat of Combustion

A Parr (model 1241) automatic, adiabatic, oxygen-bomb calorimeter was used to determine the heat of combustion of the squeezed oil-saturated cotton samples. The calorimeter consisted of two water baths that were kept at equal temperatures by an automatic sensing device to maintain the system in adiabatic condition.

1. Experimental Materials

a. Oxygen available at 40 atmospheres

b. Parr 45C10 nickel alloy wire

2. Experimental Apparatus

Parr automatic adiabatic oxygen bomb calorimeter

3. Experimental Procedure

a. Weigh 0.5 grams of squeezed oil-saturated cotton and place in the stainless steel capsule.

b. Connect a 10 ml length of fuse wire between the electrodes. Bend the fuse wire against the sample.

c. Slide the bomb head into the cylinder and push it down as far as it will go. Set the screw cap on and hand tighten it.

d. Fill the bomb with 40 atmospheres oxygen.

e. Fill the bucket with 2 liters of distilled water and lower into the calorimeter.

f. Place the bomb into the bucket of water and connect the ignition wires to the bomb.

g. Close the lid of the calorimeter and start stirrer by turning on the power.

h. Place the calorimeter in run mode and wait for the jacket temperature to match the bucket temperature.

i. Record the temperature.

j. Ignite the bomb.

k. When the jacket temperature is equal to the bucket temperature, record temperature and turn off power.

l. Disassemble the bomb and measure all lengths of unburned fuse wire.

4. Experimental Calculations

a. Correction for the heat of combustion of the firing wire in calories

$$e_3 = (\text{length of wire burned}) \left(2.3 \frac{\text{calories}}{\text{millimeter}}\right)$$

b. Heat of combustion

$$H_g = \frac{(t_f - t_i)(W) - e_3}{m}$$

The data obtained using these procedures were then analyzed to determine the influence of the squeeze roll operations on the properties of compressed cotton and on the operation of the squeeze roll.

4.5 Incineration Procedures

The objective of the incineration portion of this study was to identify the air pollution problems associated with the incineration of oil-cotton mixtures which had passed through the squeeze rolls. To accomplish this, the concentrations of nitrogen oxides, sulfur oxides, polycyclic organics, and particulates were measured in the effluent gases issuing from a typical incinerator.

An analysis of the data from the squeeze roll studies had shown that a pressure of 25 pounds per square inch would lead to an oil loading which was representative of the data obtained during that phase of the investigation. Therefore, this pressure was used in preparing samples for the incineration portion of the study. Special procedures were needed to prepare the cotton since up to 120 pounds of material were needed to conduct a three hour incineration test. It must be remembered that only one to four pounds of cotton were dispersed per test tank run. Therefore, it was necessary to prepare the cotton-oil mixture specifically for the incinerator tests.

Samples of squeezed oil-saturated cotton using Talco, Refugio, and Arabian Light crudes were prepared by saturating a 20-gallon can full of cotton with oil and then squeezing the saturated cotton in the squeeze roller at an air pressure of 25 pounds per square inch. The Lact crude proved so difficult to squeeze (due to the high viscosity) in the squeeze roll phase that Lact crude was excluded from this phase of the study. The 25 pounds per square inch air pressure was chosen as a mean value of the pressure range studied.

The incinerator used was a model C-18, serial number 2473, manufactured by Consumat System, Inc. The typical flow scheme for such a device is shown in Figure 4.5-1. The fuel flow rate to the top burner was set at 1.6 gallons per hour and the bottom burner was set at 1.4 gallons per hour. The squeezed, oil-saturated cotton feed rates tested were 15, 30, and 40 pounds per hour which covered the operating range of the incinerator. A photograph of the incinerator is shown in Figure 4.5-2.

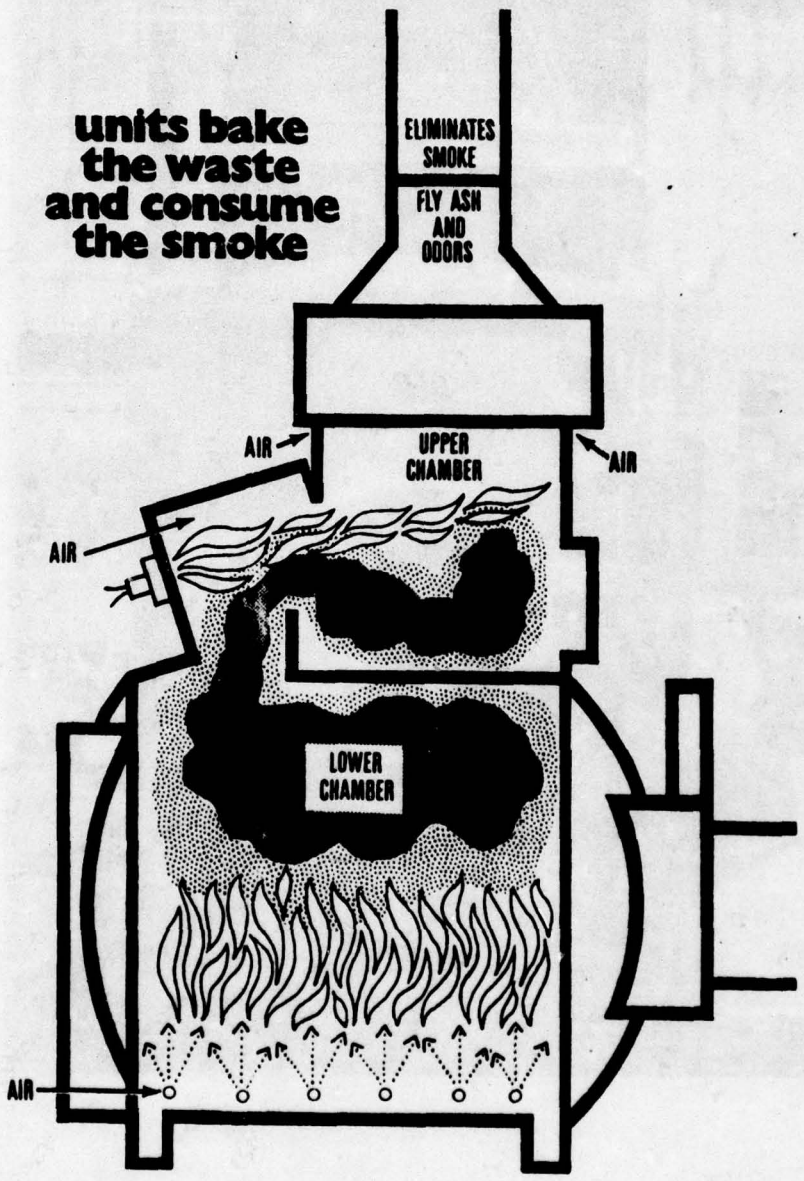

FIGURE 4.5-1 INCINERATOR FLOW SCHEMATIC

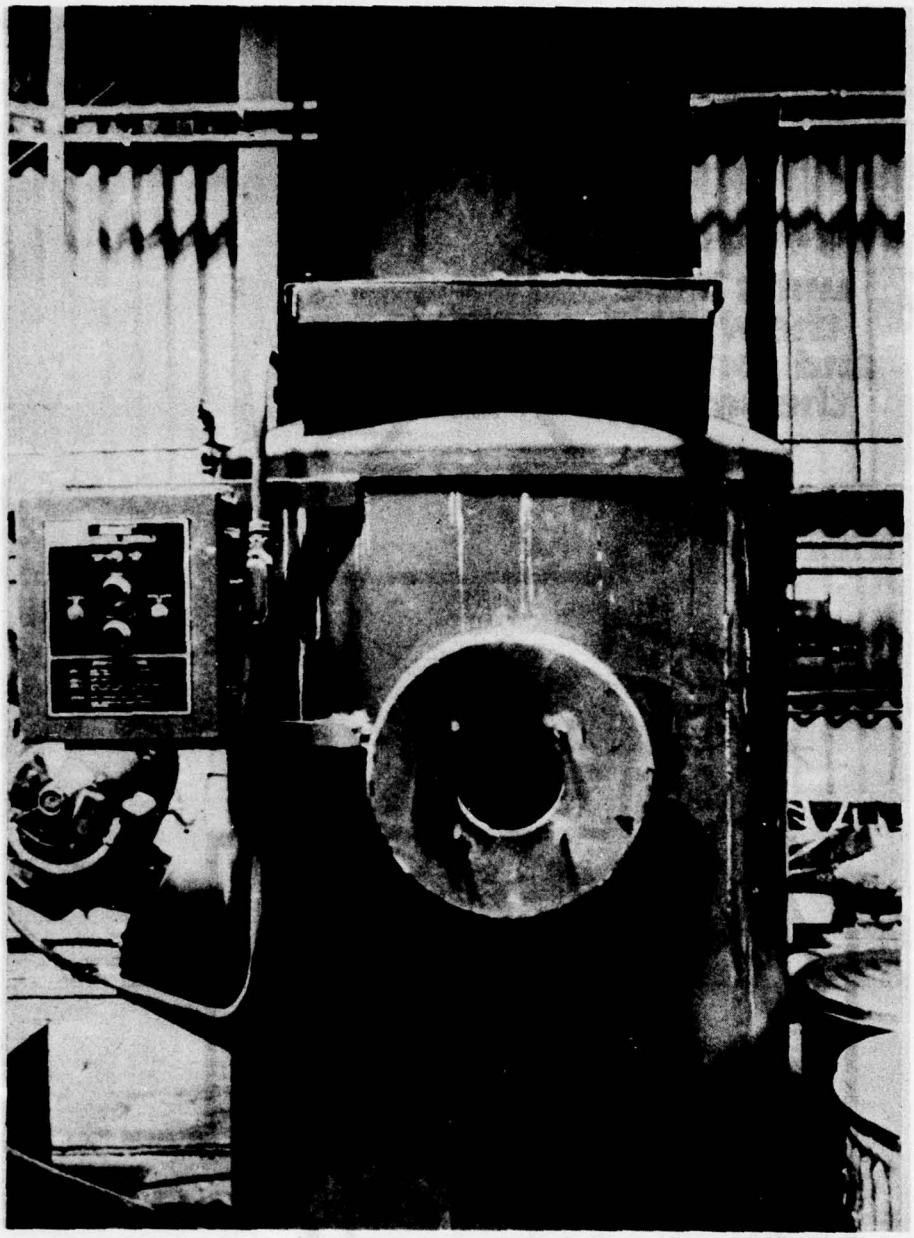

FIGURE 4.5-2 PHOTOGRAPH OF INCINERATOR

A. Nitrogen Dioxide and Sulfur Dioxide

The technique for measuring the stack gas concentrations of nitrogen dioxide and sulfur dioxide using 50 ml plastic syringes was developed by Meador (1969). The syringes were conditioned with the gas to be tested for 4 hours prior to sampling. Before sampling the syringes were rinsed two times with 5 ml of the absorbing solution for the gas to be tested and then filled with either 5 ml of nitrogen dioxide absorbing solution or 3 ml of sulfur dioxide absorbing solution. This method uses Saltzman's reagent for nitrogen dioxide and Lyshkow's reagent for sulfur dioxide. The Lyshkow-modified Saltzman method for nitrogen dioxide was accurate in the range of 0.07 to 50 parts per million. The Lyshkow method for sulfur dioxide was accurate in the range of 0.17 to 30 parts per million. Beer's Law was followed over these ranges.

The relative error was 2.5% for sulfur dioxide and 1.09% at 29 parts per million for nitrogen dioxide.

The absorbing solutions were calibrated using the permeation tube method as outlined by Meador (1969).

1. Experimental Materials
   a. Saltzman reagent
   b. Lyshkow reagent
2. Experimental Apparatus
   a. Syringes - 40 ml polypropylene-conditioned and filled
   b. Colorimeter - Bausch and Lomb Model 340
   c. Side draw tube - curved tube placed in the center of the incinerator stack to continuously withdraw samples
3. Experimental Procedure
   a. Place the side draw tube in position
   b. Start the incinerator and allow it to warm up for 15 minutes

c. Start feeding squeezed, oil-saturated cotton to the incinerator and begin sampling after ten minutes.

d. Continue sampling every ten minutes for 20 minutes.

e. When sampling, fill the syringes slowly over a 15 second period so that the sample has time to cool.

f. After the color formation is complete, expel the reagent into a 1 cm cuvette and measure the percent transmittance with the colorimeter at 750 nanometers (NO_2) and 760 nanometers (SO_2) using an unexposed sample as a standard.

4. Experimental Calculations

a. From calibration curves of log % T versus concentration in parts per million, obtain the concentrations of the samples.

b. $$\frac{\text{grams pollutant}}{\text{million BTU}} = \frac{(\text{concentration})(\text{area})(\text{velocity})(\text{density})}{(\text{million BTU fed})}$$

B. Oxygen and Carbon Dioxide

The oxygen and carbon dioxide concentrations were determined using a Fyrite sampler made by Bacharach Instrument Company based on the Orsat absorption method. The fluid in the units absorbs the oxygen or carbon dioxide, therefore causing the liquid column to rise in proportion to the percent of gas absorbed by the liquid. The Fyrite samplers are accurate to 1/2 percent. The samples, which were taken after the nitrogen dioxide and sulfur dioxide samples, were taken at ten minute intervals.

1. Experimental Materials

a. Fyrite carbon dioxide absorbing fluid

b. Fyrite oxygen absorbing fluid

2. Experimental Apparatus

a. Fyrite carbon dioxide indicator - Model CNO

b. Fyrite oxygen indicator

3. Experimental Procedure

a. Adjust zero percent scale mark to top of fluid column in small, central Fyrite bore.

b. Pump the sample to be analyzed into the Fyrite.
c. Absorb the carbon dioxide from the sample with the Fyrite fluid by inverting the Fyrite 4 times.
d. Read the percent carbon dioxide on the Fyrite scale at the top of the fluid column in the small Fyrite bore.
e. Repeat for oxygen.

4. Experimental Calculations

a. Percent of excess air = $\frac{(\text{percent oxygen})}{20.9-(\text{percent oxygen})}(100)$

C. Particulate, Moisture, and Polycyclic Organic Content

Particulate sampling must be done isokinetically to obtain an accurate measurement. Isokinetic sampling required that the velocity of the sample entering the probe be the same as the stack flow rate at the sampling location.

A total sample is obtained by sampling equal area segments of the source an equal amount of time. The samples were taken at 4 locations on each traverse, the traverses being 90° apart as outlined in the Federal Register No. 247, Vol. 36, Part II.

The sampler used was produced by Glass Innovations, Incorporated and supplied to the project by Dr. R. M. Bethea.

The polycyclic organics were considered to be the material soluble in dichloromethane using the procedure of Jones (1975) to isolate polycyclic organics.

1. Experimental Materials
   a. 200 ml of distilled water
   b. 11.0 cm glass fiber filter paper
   c. Dichloromethane
   d. Silicon stopcock grease
2. Experimental Apparatus - Figures 4.5-3 and 4.5-4

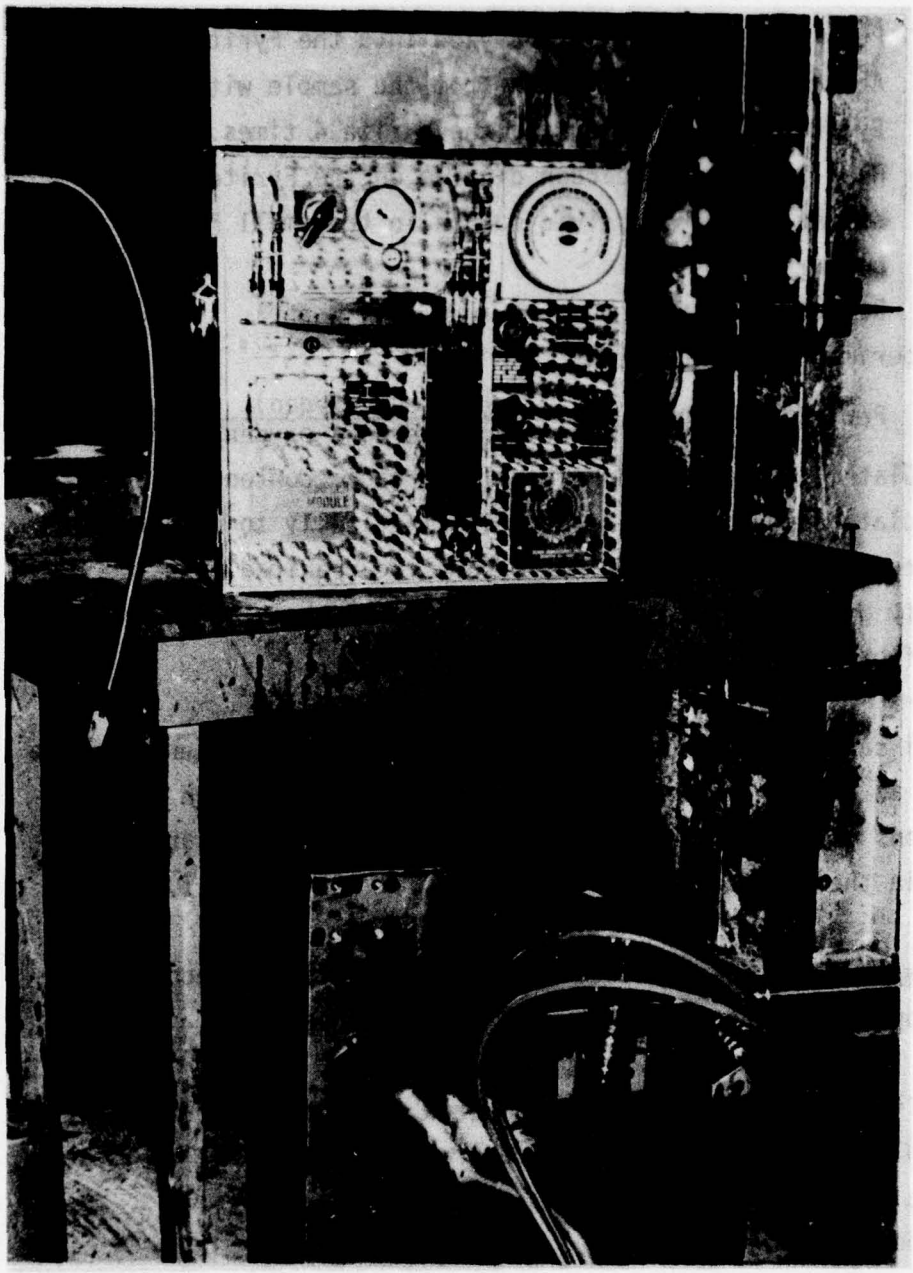

FIGURE 4.5-3 CONTROL PANEL OF STACK GAS SAMPLER

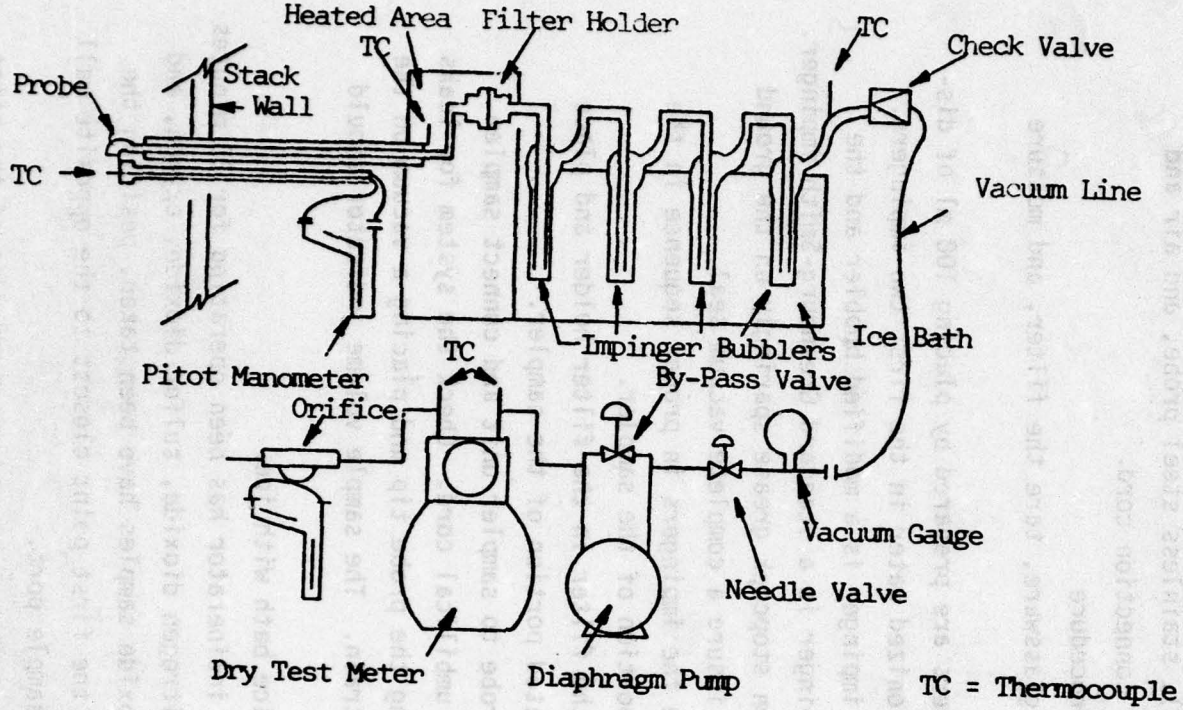

FIGURE 4.5-4 SCHEMATIC OF GAS SAMPLING TRAIN

a. Stack sampler - meter control box, sampler box, glassware (four impingers, filter, cyclone, glass connectors), stainless steel probe, and air and electrical connection cord.

3. Experimental Procedure
   a. Clean all glassware, tare the filter, and measure the water.
   b. The impingers are prepared by placing 100 ml of distilled deionized water in the first two impingers.
   c. The first impinger is a modified bubbler and the second impinger is a standard Greenburg-Smith impinger.
   d. Use silicon stopcock grease sparingly on the ground joints to insure a complete vacuum seal.
   e. Then place the impingers in proper sequence in the ice bath portion of the sampler.
   f. Assemble the filter in the filter holder and place in the heated portion of the sampler.
   g. Connect probe to sampler unit and connect sampler unit with umbilical cord. Check the system for leaks by plugging the probe tip and placing a vacuum on the sampling train. The sample volume indicator should not move.
   h. Fill the ice bath with ice.
   i. After the incinerator has been operating for 30 minutes and all nitrogen dioxide, sulfur dioxide, oxygen, and carbon dioxide samples have been taken, position the sample at the first point closest to the opposite wall from the sample port.
   j. Record the temperature and pressure drop of the pitot tube and using the calculator supplied with the sampler, calculate the required pressure drop across the orifice.
   k. Record the volume reading and start the pump.
   l. While the sample is being taken, record all temperatures.
   m. Sample for 5 minutes at every point.

n. Allow the sampler to cool and measure the final water volume and the final weight of filter and all particles that can be removed with a brush or rinsed with acetone from the glass-lined probe.

o. Extract the water and rinse the probe liner, filter holder, and impingers with dichloromethane.

p. Filter the dichloromethane and place it in a tared beaker and allow to evaporate. Do all work with dichloromethane under a hood.

q. Record the weight gain as dichloromethane soluble organics.

4. Experimental Calculations

a. Correct sample volume measured by the dry gas meter to standard conditions.

$$Vms = \frac{(Vm)(Pm)}{(Tm)} \frac{(17.71°R)}{\text{in Hg}}$$

b. Correct water vapor volume in the gas sample to standard conditions.

$$Vws - (W_f - W_i)\ (0.074\ \frac{ft^3}{ml})$$

c. Moisture Content

$$Bwo = \frac{V_{ms}}{V_{ms} + Vms} + 0.25$$

d. Particulate and polycyclic concentration corrected to 12% CO_2

$$C_s^p = \frac{Mn}{Vms}\ (0.0154\ \frac{g}{mg})\ \frac{12}{(\%CO_2)}$$

$$C_s^\circ = \frac{On}{Vms}\ \frac{12}{(\%CO_2)}\ (0.0154\ \frac{g}{mg})$$

4.6 Retrieval System Design

The initial thinking on the retrieval system concerned itself with employing current technology from the cotton picking industry. A survey of that technology indicated that conventional cotton pickers worked efficiently on dry cotton but would not be practical for use at an oil-water-cotton interface. Furthermore the complexity of this type unit would not lend itself to application in the field.

A rotating type cylinder with "fingers" was next considered. This type of unit, although simple in design had potentially several disadvantages, namely, cotton becoming entangled in the finger mechanisms, excessive weeping of the oil-laden cotton on the fingers themselves, and the associated fluid streamlines around the rotating cylinder.

In that success in retrieving straw had been achieved by other investigators (Miller, 1973) using conventional conveyor belt systems it was decided to use this type of system in our test tank facility. It was predicted that an open mesh belt would remove the oil from the water because the oil would be contained by the fiber matrix. Due to supply problems the conveyor system was fabricated, installed, and tested. Several modifications were then made to increase the efficiency of the system. A variac was used to provide a variable speed for the belt drive.

It was found from experience that the belt speed should be maintained at the same velocity as the water in the test tank. When the speed of the belt was less than the water velocity the oil-laden cotton would tend to build up in front of the load-end of the conveyor causing problems in determining the actual sorbent effective contact time. Also, and probably more important, the cotton mat in front of the conveyor would, if not picked up after a short period of time, become compressed by both the surface movement of the water and the continuous flow of new cotton-oil from the system. This compression caused weeping of the entrapped oil which would flow either around or through

the conveyor belt. However, if adequate sorbent was available, satisfactory system performance could be achieved.

In the case of the belt speed being greater than the water velocity the fluid streamlines actually prevented the oil-laden cotton from moving up the belt. In this case the feed to the load-end of the conveyor was manually moved onto the belt. In almost every run, the cotton-oil had to be manually urged onto the conveyor as the material tended to choke in the throat of the booms. The dimensions of the boom and conveyor were such that the throat was so narrow that bridging occurred. Had the throat been wider, the longitudinal forces would probably have maintained movement of the material.

During the course of the experimental work several modifications were made on the retrieval device. When considerable weeping was encountered through the belt it was decided to cover the mesh with a flat sheet of plastic material. Although we were successful in reducing the amount of weeping in the system, the added pressure drop at the load-end of the conveyor created serious hydraulic problems. The material would bypass the conveyor belt due to increased water velocities at the sides of the tank. This experience led to the development of a drip pan under the top belt. This provided an extremely valuable solution to both the weeping and the pressure drop problems.

No observable change in system performance was noted when the angle of inclination of the conveyor belt was changed. However, we would not recommend that the angle be significantly different than the value shown on the schematics.

Section 5

DISCUSSION OF RESULTS

5.1 Test Tank Studies

The test tank was constructed so as to provide the maximum sorbency time or Sorbent Effective Contact Time (SECT) within the available facilities. The straight portions of the tank were designed to be used as the primary operational zones and the curved portions were engineered to provide minimum surface disturbance as the water, oil and fiber passed around the bend. It was found necessary to install baffles to prevent the movement of the oil and fiber toward the outer portion of the curve. The baffles were placed as close to the water surface as possible, but the practical limit was reached when the oil soaked cotton engaged the baffles and tended to hang.

The curved end of the tank did have an influence on the form of the oil slick. In the first series of tests oil and fiber were placed on the water on south straight section of the tank and then passed around the curve and into the north straight section where the retrieval device was located. The oil and fiber were evenly distributed on the water surface when approaching the curve, but, even with the baffles some surface slip occurred which tended to compress the fiber and oil into narrow sections. This had the effect of causing the loose fiber to pile up in such a form as not to be accessible to the oil, which reduced the amount of sorbent-oil contact. On the other hand, the sideways movement around the curve tended to cause free oil to be contacted by sliding fiber which had the effect of promoting oil capture by the fiber. The curved portion, even after the baffles were installed, caused the continuous slick and fiber to be broken into smaller areas which covered between 30% and 70% of the water in the north straight section, and under these conditions there appeared to be some unconstrained oil. During subsequent tests, the oil and fibers were placed on the water in the north straight section and consequently did not pass around the curve.

System Operation. The tank was fabricated to form a water channel and Lubbock city water was used throughout the test program. The decision was made not to add NaCl to simulate ocean salineness because of the necessity to drain the tank periodically and the large quantity of NaCl required. An outboard motor was used to propel the water around the tank, the maximum water velocity with full cross-sectional flow and with the retrieval device and screen in place was 1.8 ft/sec. This water velocity was obtained by providing flow straighteners to minimize turbulence immediately downstream of the motor, and by using water intake channels to overcome cavitation.

The oil was sprayed through nozzles to form the slick, sufficiently downstream of the prime motor that the surface was essentially smooth. The nozzle type was selected to provide a flat fan discharge which evenly covered the width of the tank when approximately 25 lb/minute of the median viscosity oil was used. The nozzles were not changed as the oils were changed. However, the pressure drop required for dispersal varied. In all tests except those with the Lact oil which had viscosity of 1,670 SSU at 122°F satisfactory operation was achieved. In the case of the Lact it was too viscous to be pumped and had to be poured over an inclined plate to form the slick.

The opener was positioned downstream of the oil spraying nozzles at a sufficient distance from the oil sprayers to allow the oil time to float to the surface and form a slick. To ensure that oil did not pass through the system without being exposed to fiber, the opener was operated for several seconds before the oil was applied. The amount of fiber intially dispersed to the water prior to the oil slick was relatively small and was considered not to have any bearing on the system performance.

In the first series of tests in which the oil and cotton were applied at the south straight section of the tank, the SECT was taken to begin as the oil passed beneath the opener and ended when the fiber and oil were removed from the water. In some of the runs extended SECTs were used, e.g., 5, 10

and 30 minutes, which were greater than the water transit time. To obtain the extended SECTs, barriers were sequentially placed on the water surface in the north straight section so as to hold back the oil and fiber. It was found necessary to use several barriers because compressive forces built up in the mat as the oil and cotton collected and were held against the water current. The compression built up to a point at which the mat could not withstand the forces and collapsed and thus compacted to about 1/5 of the original mat area. Under these conditions, oil was squeezed out of the mat and was lost to the holding basin. When multiple barriers were used and placed about 10 feet apart, the mat size was controlled and thus compressive collapse did not occur and cause oil to be lost from the system. When water velocities below 1 ft/sec. were used, there was not any tendency for oil to be squeezed from the mat. At higher speeds when oil loss occurred, the freed oil was recaptured by the next barrier downstream or the retrieval device if pick-up was in progress, otherwise it was lost to the holding basin.

The barriers used were pieces of wood with a 4" x 2" cross-section which were cut to length such that they could be wedged between the tank sides and remain in place when partially submerged in the water. During a run the first barrier was placed upstream of the retrieval device to prevent the oil and cotton reaching the conveyor. Subsequent barriers were sequentially placed upstream of each other at time intervals of one minute and at a distance greater than the formed mat. In the majority of runs in which extended SECTs were investigated the slick formation and fiber dispersion were performed for four minutes and as barriers were inserted at one minute intervals four barriers were used. These barriers were sequentially removed to facilitate pick-up after the appropriate holding time.

Table 5.1-I shows typical SECTs produced throughout the program under the prevailing conditions.

Table 5.1-I Typical Sorbent Effective Contact Times

Transit Distance ft	SECT[1] minutes	Water Surface velocities ft/sec.	Multiple Barriers #
70	30	.5, 1.0, 1.5	4
70	10	.5, 1.0, 1.5	4
70	5	.5, 1.0, 1.5	4
70	Min[2] - 2.33	.5	0
70	Min - 1.17	1.0	0
70	Min - 0.78	1.5	0
40	5	.5, 1.0, 1.5	4
40	Min - 1.34	.5	0
40	Min - 0.67	1.0	0
40	Min - 0.47	1.5	0
5	Min - 0.083	1.0	0
5	Min - 0.055	1.5	0
12.75	Min - 0.053	4.0	0

1 - SECT - Sorbent effective contact time
2 - Min - minimum transit time

The conveyor-type, retrieval device was originally located close to the east end of north straight section of the tank, but in later studies it was moved toward the opener in order to reduce the fiber transit distance to a minimum. The conveyor was provided with a chain belt to enable water to flow unimpeded while the cotton with the oil was entrained on the conveyor. The bottom roll of the conveyor was solid and tended to interfere with the water flow. Several conveyor immersion depths were tested, including the setting in which the solid bottom roll was not totally below the water level. When the center of the solid roll was close to the water level, an ineffective operation existed. The solid roll created the formation of excessive surface eddies which tended to carry the oil and some fiber around the sides and underneath the conveyor. This problem was in part created by the increased angle of removal of the oil from the water due to the curvature of the solid roll.

Under normal running conditions there was a tendency for oil to flow around the side of the conveyor. To overcome this oil loss the guiding booms

which were used to reduce the slick width to less than that of the conveyor, were fitted so as to closely conform to the lower portion of the conveyor at the water interface. It was not considered necessary to use flexible seals although they would have reduced oil loss around the sides of the conveyor.

In the early stages of setting up the system, it was realized that all of the oil was not being effectively sorbed or captured and some free oil was reaching the conveyor. The free oil tended to flow either through or around the conveyor and consequently the system overall efficiency was low. It was realized that the free oil was propagated at the curved portion of the tank. If the fiber and oil was not given time to agglomerate before the curve, break-up of the slick occurred and the oil which had not been adequately covered with fiber would be relatively free. This presented a major problem to the fiber dispersal system because there was no opportunity to even out the fiber distribution particularly when light applications were being tested.

In an attempt to improve the system efficiency, the retrieval device and operation were considered. It was realized that if the conveyor was operated at a speed which would generate the formation of a mat on the water the free oil would be captured by the mat and consequently effectively removed from the water. In the first-phase, minimum-SECT runs, a mat was allowed to build at the conveyor before the device was started. The conveyor speed was slower than the water velocity and a thick layer of fiber and oil was carried up the conveyor.

As the testing program continued, experience was gained in operating the opener and eventually the problem of free oil was almost eliminated particularly after the opener had been moved to the north straight section and the fiber and oil did not pass around the curved portion.

The conveyor and fiber effectively removed the oil from the water, however, it was immediately realized that the chain conveyor enabled the oil contained in the fiber matrix to be released and drip onto the water and become part of the oil not retrieved by the system. Therefore a drip pan was placed in the conveyor to collect the released oil. It was necessary to have the drip pan located as close as possible to the oil-water separation point because oil would drip through the conveyor immediately after leaving the water. In recording the test data, the fluid collected in the drip pan was shown separate from the oil transported by the conveyor.

The chain conveyor operated effectively in removing the oil from the water but, as mentioned above, did not completely retain the oil. Another problem was associated with the removal of the fiber and oil from the chain. To promote controlled separation of the fiber and oil from the chain, air nozzles were located at the top of the conveyor to blow the material from the chain. In general, the arrangement worked satisfactorily but some oil adhered to the chain and then dripped into the water from the return side of the conveyor. The oil lost to the water was subsequently picked up as oil not retrieved by the system. The amount dropped from the conveyor usually was small and no attempt was made to catch it. It was realized that the calculated efficiency of the system would be affected and would appear lower than could be claimed.

In the early stages of the program, the oil not removed by the conveyor was deflected from the main stream into a holding basin. A weir was installed at the second curved portion so as to skim the water surface. The oil was subsequently removed from the holding basin by using a preferred sorbent. A known quantity of cotton was used to sorb the oil and then reweighed. It was assumed that a negligible amount of water would be picked up with the sorbent. There was some water picked up with the oil in the holding basin and was included in the data as oil not collected at the conveyor. This had the effect of lowering the calculated system efficiency and increasing the percentage of water contained in the retrieval material.

During the course of the project 111 test runs were made and included in this number are those runs in which set-up and operational problems were experienced. A summary of the data is shown in Appendix A. In the great majority of runs, the procedures and operations were maintained as established, however some test produced erroneous data and these are noted in the table. Occasionally problems experienced were:-

1) oil pump choked or overheated resulting in reduced oil flow rate;

2) fiber opener choked and overloaded when input material was not fed consistently, e.g. double thickness, this resulted in the fiber's not being discharged until the choke cleared during which time the oil passing beneath the opener was not contacted by fiber and consequently not effectively entrapped or sorbed;

3) the drip pan on the retrieval conveyor was flooded with water; this occurred due to three different problems:

a) the outboard motor was water cooled and tap water was used, the cooling water was discharged into the tank and caused the water level to change; water level controls were used after this problem was realized;

b) when the water velocity was increased the operating water level became higher because of the increased head which developed at each point of resistance to flow, but usually the conveyor position was adjusted before the test run was performed; and

c) if the outboard motor stopped suddenly due to some malfunction, a surging wave flowed around the tank and temporarily raised the water above the top of the drip pan.

The above identified problems affected the data. The most critical problem was that of the opener choking because of the excessive free oil which tended to pass the conveyor and hence show a low throughput efficiency. A gradual increase in the water level whereby the drip pan top was partially submerged resulted in a very high water content in the drip pan and a higher than normal throughput efficiency because the drip pan acted partially

as a skimmer to remove some oil and water. The surging wave did not substantially change the throughput efficiency but did affect the water/oil selectivity.

Materials: The crude oils tested and identified in Table 5.1-II covered a wide spectrum of type and viscosity. After consultation with the U. S. Coast Guard, we requested from Exxon Incorporated a selection of oils typical of those involved in large volume transport and representing the normal spectrum of types and viscosities.

Table 5.1-II List of Crude Oils

Name	Type	Viscosity SSU 100°F
Refugio	Heavy - Sweet	61
Talco	Heavy - Sour	501
Tia Juana Medium	Heavy - Sour	132
Coastal	Light - Sweet	61
Arabian Light	Light - Sour	44
West Texas Sour	Light - Sour	46
Lact	Heavy - Sour	1670[1]
Lee Harrison	Light - Sour	NM[2]

1 - Measured at 120°F
2 - Not measured

The cotton used as the dispersed sorbent was obtained from Plains Cotton Cooperative Association, Lubbock and also from the Textile Research Center, Texas Tech University. The classification of the cotton was "Wasties", which is the lowest grade of ginned cotton, with physical properties of; fineness, 2.6 micronaire and a 2.5% Span Length of 0.94 inches as measured by the Fibrograph length measuring device. The system did not appear sensitive to the type of cotton used, for example several kinds of carding waste and comber noils were satisfactorily used to clean up the holding basin.

The equipment was initially installed and operated to determine the feasibility of using a fibrous sorbent to remove oil from the surface of water. The First Phase allowed the maximum cotton/oil transit distance by locating the oil sprays and cotton opener on the south straight section and the retrieval device at the end of the north straight section.

Data was recorded throughout the adjustment period. However, the results contained in this report and summarized in Table A-I in Appendix A were taken after the system had been made satisfactorily operational using Lee Harrison crude.

The first and most comprehensive series of tests were then undertaken using Talco crude oil. The water velocity was controlled at each of three speeds: 0.5, 1.0 and 2.0 ft/sec, and SECT was minimum (no barriers), 10 minutes and 30 minutes. Barriers were used to hold the cotton and oil stationary against the water current until the required contact time had elapsed. The data obtained revealed that the installed system was capable of consistently removing greater than 95% of the crude oil. In this series of tests, the fiber opener was operated to disperse cotton onto the oil at such a rate as to produce an oil/fiber ratio of between 13:1 and 30:1. The performance was partially confirmed by testing the West Texas Sour with a water velocity of 1.0 ft/sec and oil/fiber ratios between 24:1 and 53:1 with 10 minute SECTs. The condition of oil/sorbent ratio 53:1 produced the lowest overall efficiency, as was expected, but even then 89% of the oil confronted was picked up.

After consideration of the test data and discussions with Coast Guard contract personnel, the decision was made to determine the limits of practicality of the system. The oil nozzles and the opener were moved to the north straight section so as to greatly reduce the SECT and to minimize slick disturbance as was inevitable when the oil and cotton travelled around the curved portion of the tank. The distance between the opener and the retrieval device was 41 ft and the minimum transit time or SECT was 0.67 min at 1.0 ft/sec. This part of the program was identified

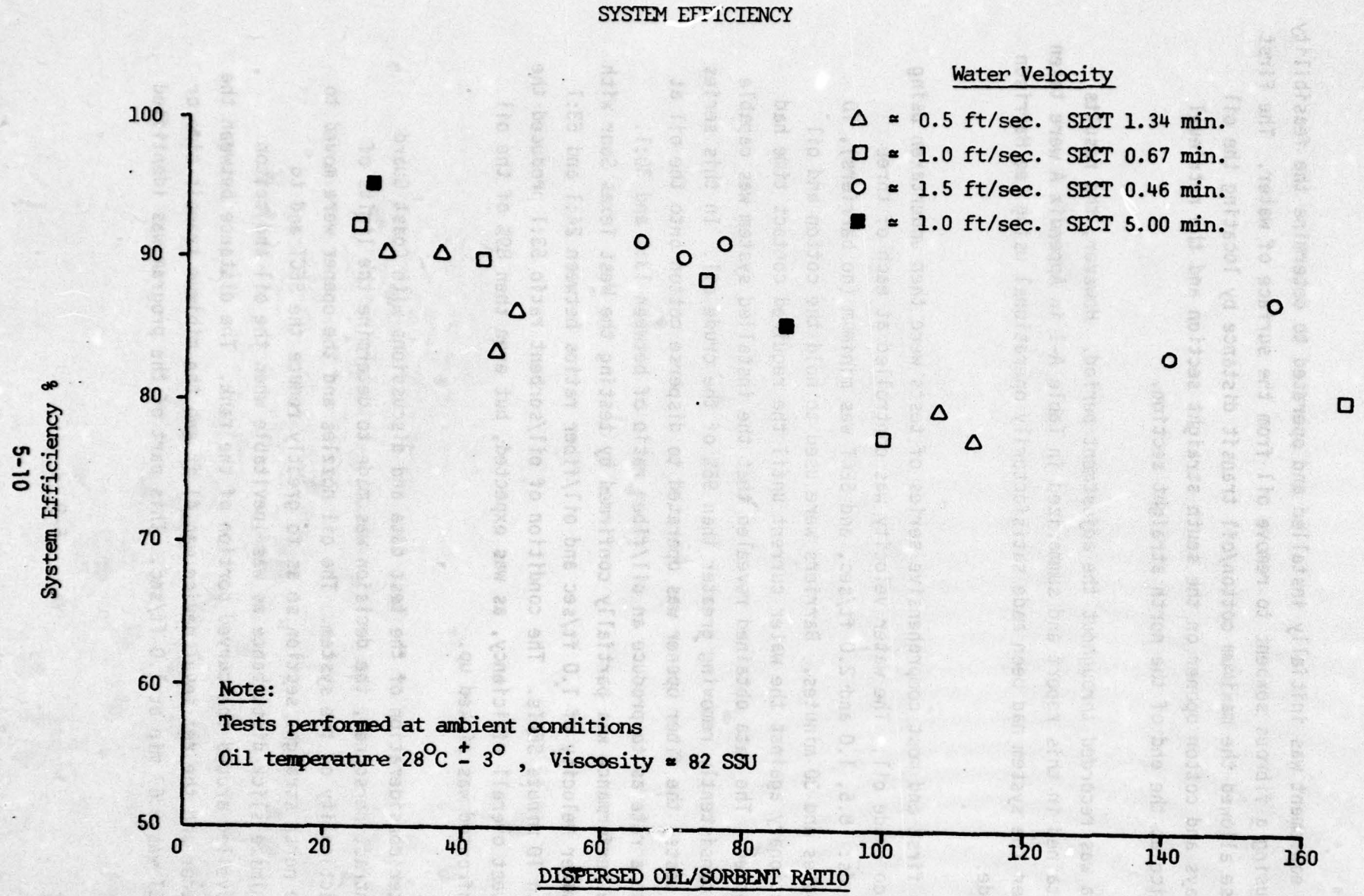

FIGURE 5.1-1 COMPREHENSIVE REFUGIO SERIES PHASE II

as phase II and Refugio oil was used for the first series of tests in which water velocities of 0.5, 1.0 and 1.5 ft/sec, and dispersed oil/sorbent ratios of between 22:1 and 168:1 were tested. The data obtained are included in the data summary tables. Additionally, data are shown in Figure 5.1-1 in which system overall efficiency is plotted against oil/sorbent ratio. The SECT was varied only in as much as when the water velocity was increased, the SECT was proportionally reduced.

This series of tests showed that there was not a critical operational condition but that the efficiency generally diminished as the oil/sorbent ratio increased. It also appeared that SECT was not a major factor in the system overall efficiency. The performance with a water velocity of approximately 1.5 ft/sec (SECT 0.46 minutes) was consistently better than with a water velocity of 0.5 ft/sec.

To determine the influence of the retrieval device on oil removal, two runs were made in which cotton was not applied to the oil. One run was with a water velocity of 0.5 ft/sec in which 25% of the oil was removed; the water velocity of the second run 1.5 ft/sec and 35% of the oil was removed. The improved pick up can be explained in terms of conveyor drainage time. The conveyor was operated at the same speed as the water surface velocity and the distance between the water surface and the drip pan was approximately 3/4 inch. Oil which dropped from the chain conveyor between the water and the drip pan was not retrieved. The slower the conveyor belt velocity, the more time existed to lose oil from the chain and hence, a lower percentage of oil was collected from the conveyor.

Two additional runs were made to determine the influence of a 5 minute SECT in which barriers were used. The water velocity was set at 1.0 ft/sec and with oil/sorbent ratios of 26:1 and 86:1; the overall efficiencies were 96% and 86% respectively. These runs suggest that SECT is not a major factor in determining the overall system efficiency.

Having developed a general system performance curve using Refugio oil, several other oil types were tested to see if there was any gross change in efficiency as a function of oil type and viscosity. Arabian Light and Tia Juana crudes were tested, each at 1.0 and 1.5 ft/sec water velocity and with a range of oil/sorbent ratios. The results are plotted in Figures 5.1-2 and 5.1-3. The data are consistent with that developed for Refugio.

An attempt was made to test the heavy Lact crude but the viscosity was too high for the pump. Consequently, an oil spreading plate had to be used. The oil was manually poured to form a slick, but it was not possible to form a consistent oil film. Even though the oil was not uniformly distributed over the water, the fiber adhered adequately to it and the oil and fiber were removed from the water. A major problem was encountered in removing the oil and fiber from the conveyor. The oil tended to stick to the chain and not fall into the collecting chute. The material which remained on the conveyor wrapped around the chain and rollers. Continuing operation squeezed oil out of the material being wrapped around the rollers. Such oil dropped into the water and flowed into the holding basin and was considered as being oil not removed by the retrieval device. This decreased the calculated efficiency.

The conveyor cleaning arrangement was not suitable for the heavy Lact crude. The data indicated that the retrieval device did not effectively remove the oil, but upon visual examination of the operation, it was estimated that a very high percentage (>95%) of oil was removed from the water surface by the conveyor. It was later determined that by slowing the conveyor to build a thick oil-fiber mat, removal could be accomplished using an increased air flow rate.

The retrieval device was moved as close as possible toward the opener so as to reduce the oil-fiber transit distance to a minimum (5 ft). Two series of tests were made in which the water surface velocities were firstly, 1.0 and, secondly, 1.5 ft/sec, the oil/sorbent ratio was varied at each water velocity Tia Juana crude was used and only minimum SECTs were evaluated. However,

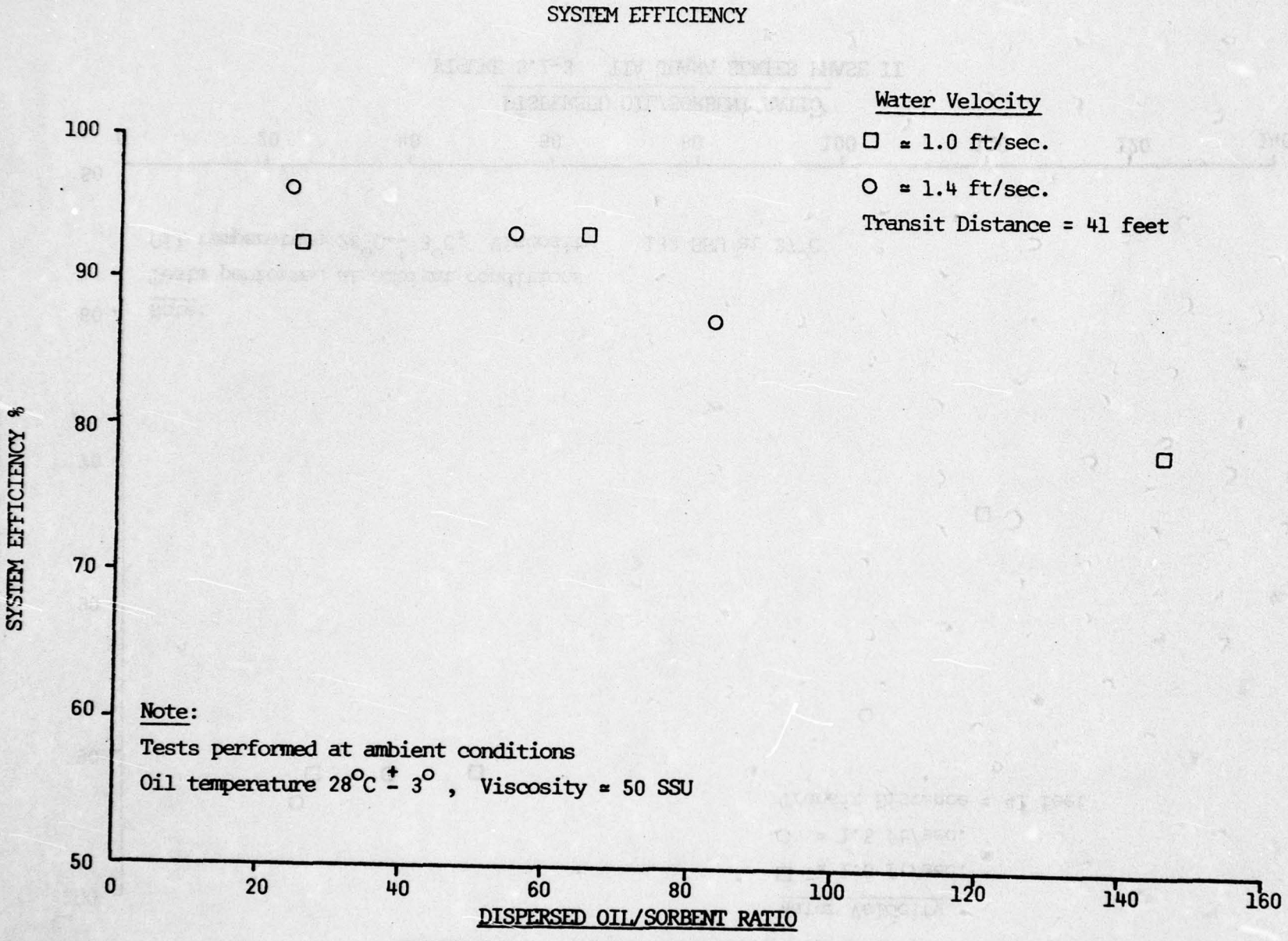

FIGURE 5.1-2 ARABIAN LIGHT SERIES PHASE II

SYSTEM EFFICIENCY

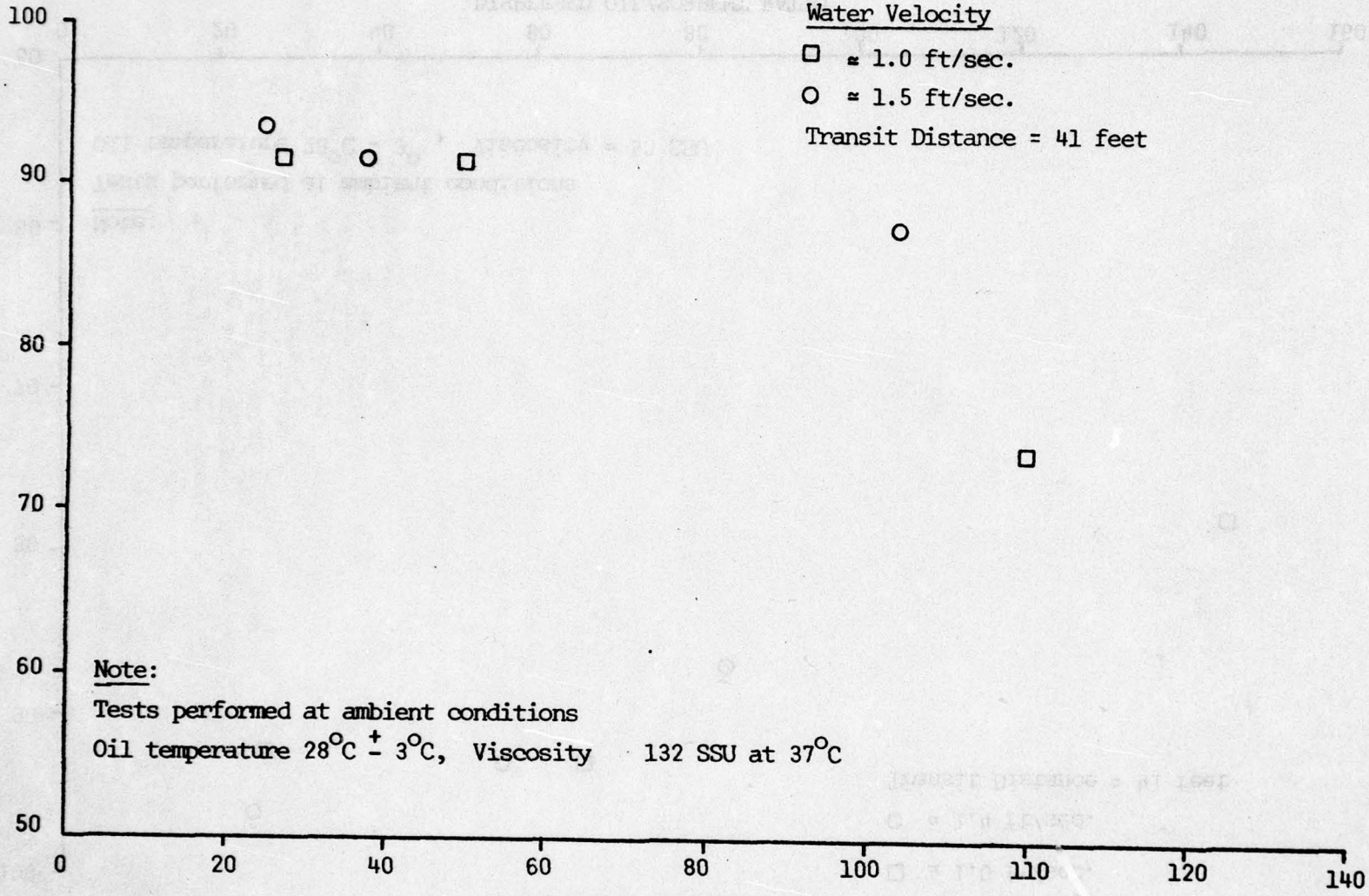

FIGURE 5.1-3 TIA JUANA SERIES PHASE II

it must be understood that the actual SECT was greater than the calculated SECT because of the slight lap dwell time in front of the conveyor.

Initial problems were experienced because the distance between the opener and the conveyor was not sufficient to allow the fiber time to settle onto the oil and consequently an excessive amount of fiber was lost from the system and, therefore the oil was not effectively contacted by the cotton. The system was improved by installing a cover between the opener and the conveyor so that the fiber-oil contact zone was totally enclosed and virtually zero fiber was lost. The data obtained with the enclosed zone is shown in Figure 5.1-4. As can be seen, the system performance was consistent with earlier tests even though the SECT was reduced to only a few seconds.

Arabian Light and Coastal crude oils were tested under the minimum transit condition. In general, the system performance was confirmed, however, the installation of the cover between the opener and the conveyor obscured the pick-up zone and the operation of the equipment was not easy.

The physical nature of the test tank limited the water velocity to slightly below 2 ft/sec. To test higher water velocities, a third phase was entered which required the installation of a false bottom which reduced the cross-sectional area of the water in the zone between the oil nozzles and the retrieval device. The false bottom increased the maximum water velocity to 4.0 ft/sec. The conveyor was located close to the end of the high velocity zone so as to permit maximum transit time. Under these conditions, the fiber-oil transit distance was 12'8" and the SECT was approximately 3 seconds. Three crude oil types were tested at 4 ft/sec water velocity, Coastal, Talco and Lact. The system did not function as satisfactorily at this water velocity, the best observed overall efficiency for each oil was 87%. The turbulence at the retrieval zone was high and there was a strong tendency for the oil to pass both through and under the conveyor. The data obtained at 4 ft/sec water velocity is shown in Figure 5.1-5. It was obvious that a different type of retrieval mechanism would be needed to effectively remove the oil at such velocities.

SYSTEM EFFICIENCY

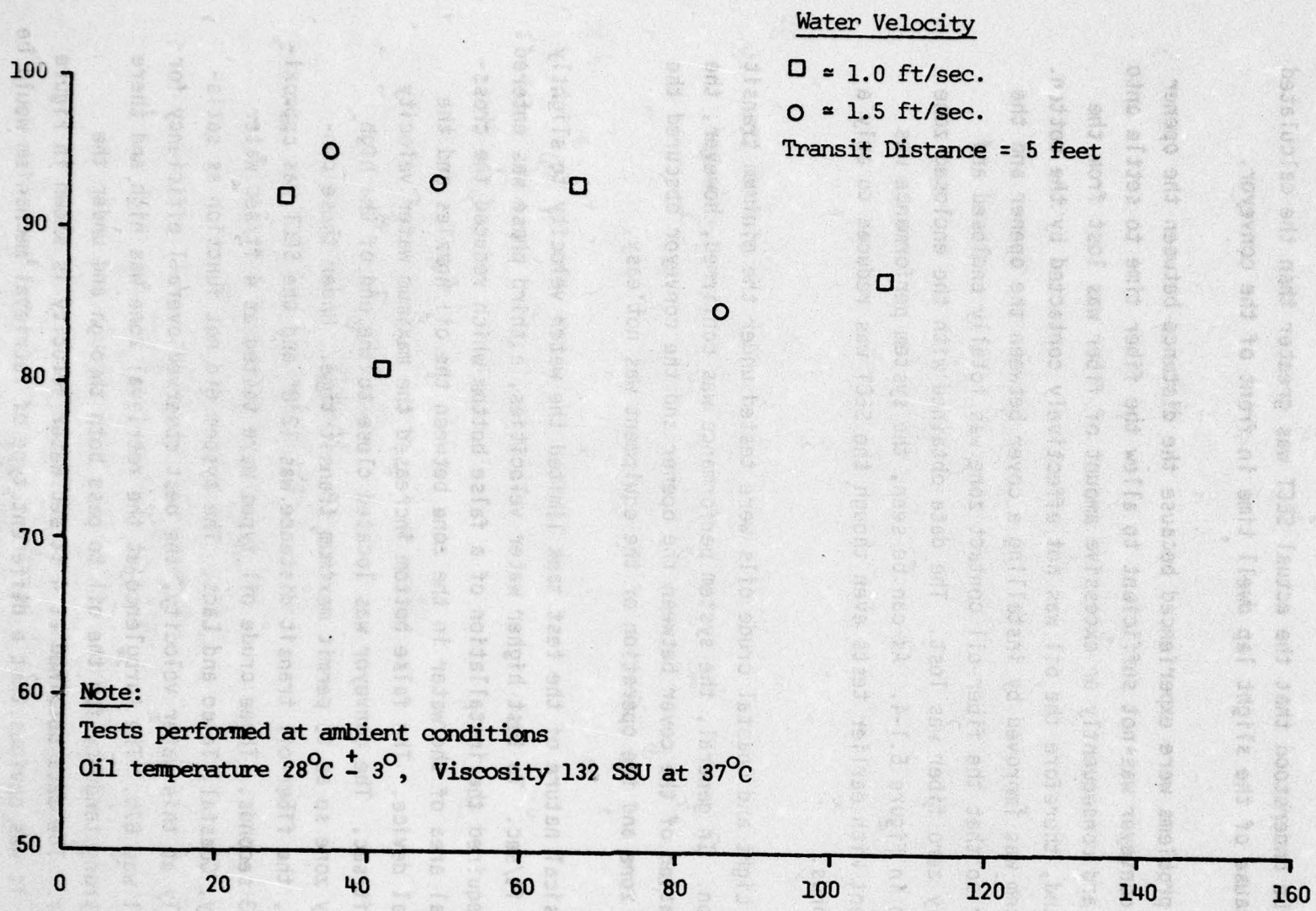

FIGURE 5.1-4 TIA JUANA SERIES PHASE II

Generally, throughout the tests, oil was sprayed onto the water at the rate of 25 lb/min or 1,500 lb/hr. The booms in front of the conveyor reduced the slick width to approximately 10 inches and when operated continuously, the loading on the conveyor was light. In some runs, the oil and cotton were allowed to float on the water and subsequently be retrieved as quickly as convenient. Under these conditions, approximately 50 lbs. of oil and cotton were removed from the water by the conveyor in less than 20 seconds which is a rate of greater than 9,000 lb/hr which is in excess of 1,000 gallons per hour. If such a rate were to be continuously required, it would be necessary to use booms which would collect the required area of oil and then direct it to the retrieval device.

On the basis of this data, a conveyor belt similar to the one used in this study could be expected to recover 95 percent of the oil-soaked cotton wasties it confronted at a recovery rate of 1,000 gallons per hour if suitable booms were in front of the conveyor to capture the required oil. No definitive statements can be made concerning operation in one foot to two foot seas. Operation at eight knot speeds of any device which skims through the water would most probably create a massive head wave. Hence operation of a system based on this concept at those speeds is not considered probable at this time. Installation of this equipment on a barge or tender with an independent power supply should pose no technical problems.

After making these comments, it is important to state the contention of the authors that what is needed is a simple, low cost system which can be utilized by the small oil spill cleanup concerns now in operation. The concept proposed here can be easily adapted to that need.

One of the principal concerns in applying the concept developed here is the probability of flooding of the drip pan under high seas conditions. It was noticed during this study, that as the fiber-oil ratio increased the amount of oil in the drip pan decreased. For example in Phase I, when the oil-sorbent ratio was in the range of 15-25 pounds per pound,

SYSTEM EFFICIENCY

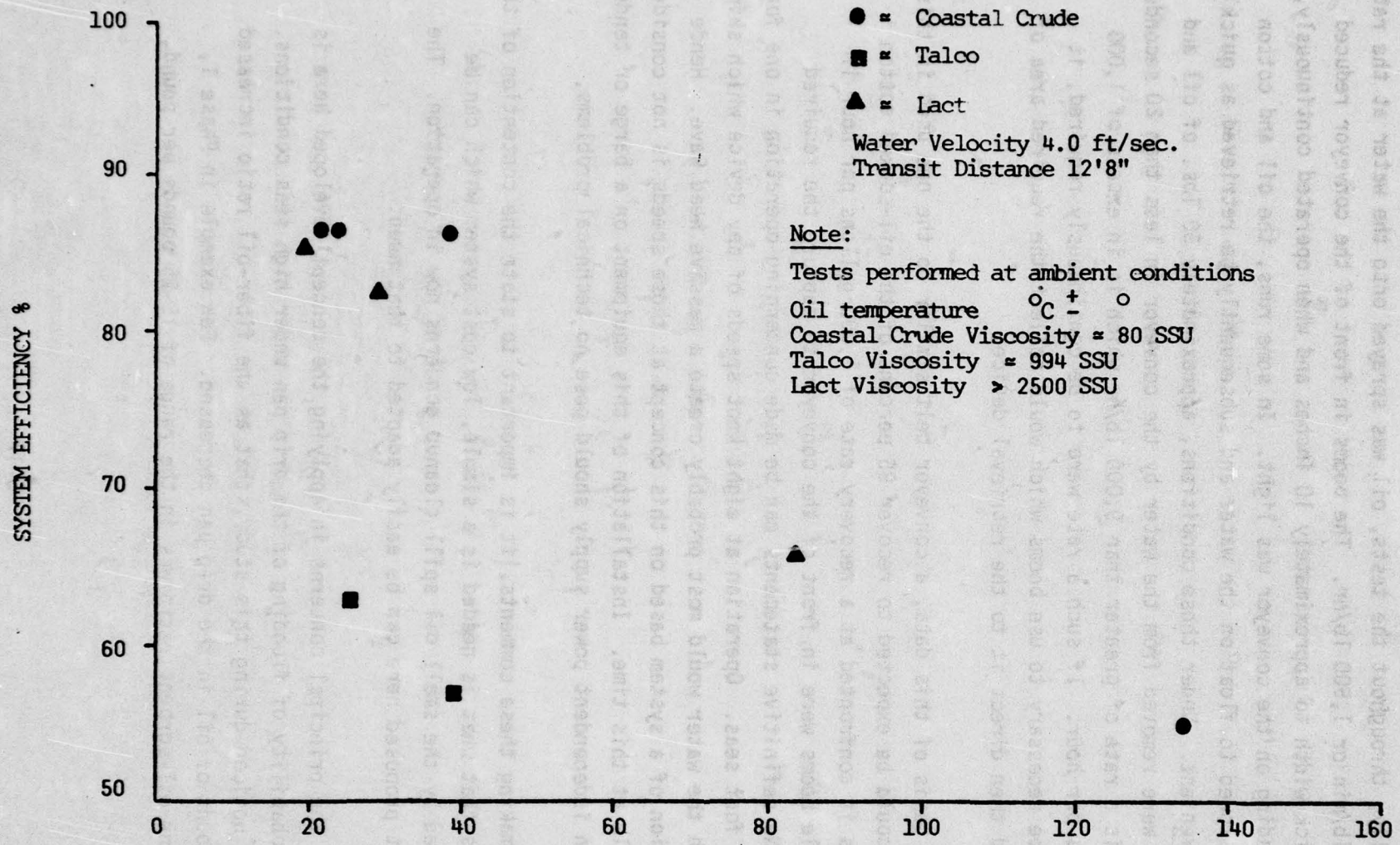

FIGURE 5.1-5 HIGH WATER VELOCITY SERIES

the amount of oil in the drip pan was approximately one to two percent of that confronted. Had this oil not been recovered in the drip pan, the system efficiency would have decreased to approximately 93 percent.

The relationship between the sorbent retention efficiency, which was defined as the percentage of the oil confronted which travelled up the chain conveyor and fell into the collection chute, and the oil-sorbent ratio is shown in Figures 5.1-6 and 5.1-7. This data, which covers all of the oils studied, is divided into two general categories of sorbent effective contact times. From 0.4 to 30 minutes was characterized as a normal SECT, while from 0.0 to 0.4 minutes was labelled as a short SECT. The results indicate that for SECT's above 0.4 minutes and oil-fiber ratios less than 20 pounds per pound approximately 93 percent of the oil confronted can be transported up the conveyor to the chute. This suggests that if an adequate oil sorbent ratio is employed a practical high seas system can be designed.

An analysis of the chute product was made to determine the average observed oil-sorbent ratio as a function of SECT.

TABLE 5.1-III

Normal Sorbent Retention Data

SECT Minutes	Chute OSR
0.055	24
0.083	22
0.43	39
0.48	24
0.67	28
1.21	23

The net conclusion from these data was that, independent of SECT, the cotton will retain approximately 24 pounds per pound as it travels up the conveyor.

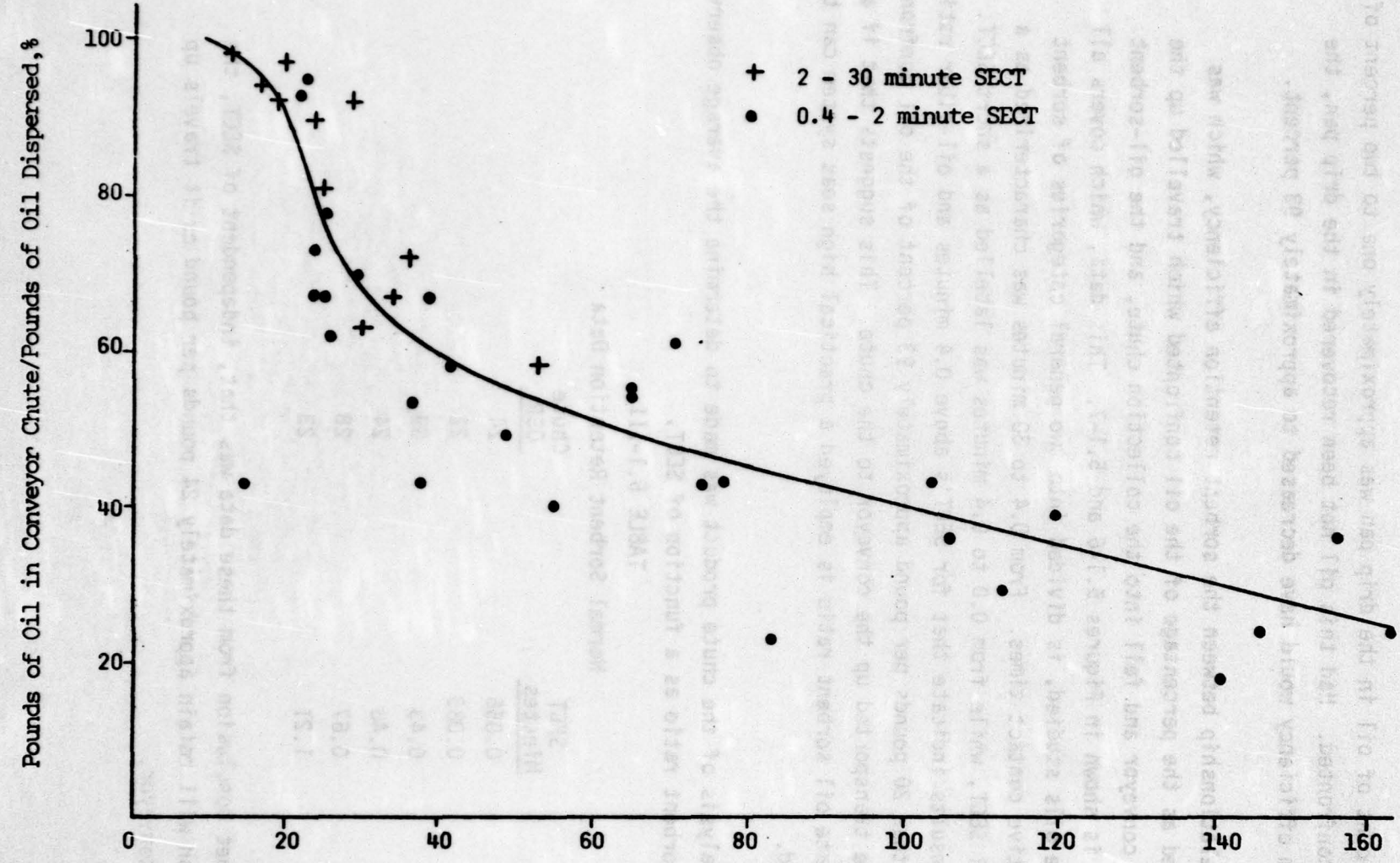

FIGURE 5.1-6 SORBENT RETENTION EFFICIENCY-NORMAL SECT

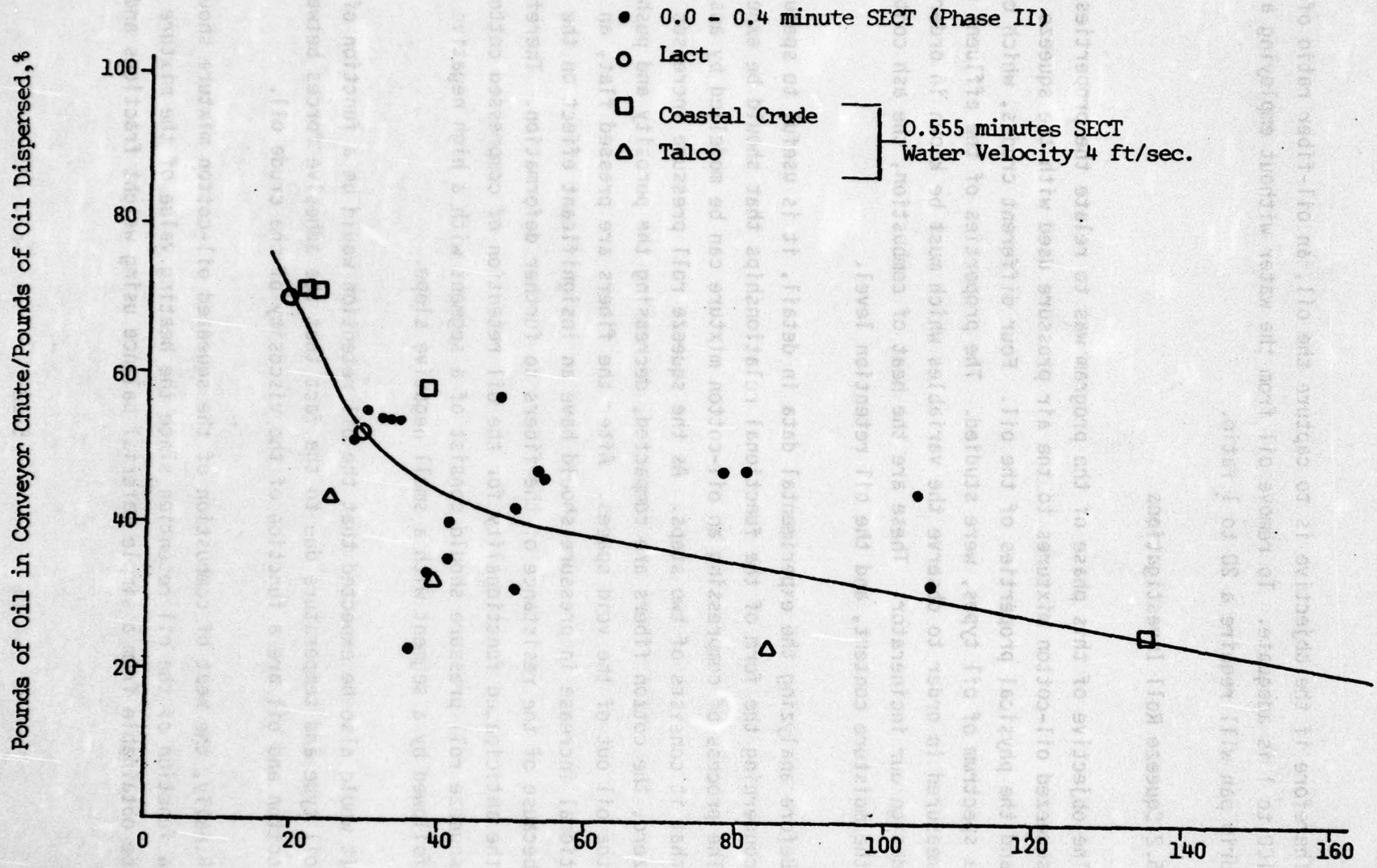

FIGURE 5.1-7 SORBENT RETENTION EFFICIENCY-SHORT SECT

Therefore if the objective is to capture the oil, an oil-fiber ratio of 100 to 1 is adequate. To remove oil from the water without employing a drip pan will require a 20 to 1 ratio.

5.2 Squeeze Roll Investigations

The objective of this phase of the program was to relate the properties of squeezed oil-cotton mixtures to the air pressure used with the squeeze rolls and the physical properties of the oil. Four different crudes, which covered a spectrum of oil types, were studied. The properties of the effluent were measured in order to observe the variables which must be known in order to design our incinerator. These are the heat of combustion, the ash content, the moisture content, and the oil retention level.

Before analyzing the experimental data in detail, it is useful to speculate concerning the form of the functional relationships that should be expected. The process of compressing an oil-cotton mixture can be modelled by assuming that it consists of two steps. As the squeeze roll pressure increases from zero, the cotton fibers are compacted, decreasing the porosity and pushing the oil out of the void spaces. After the fibers are pressed flat, an additional increase in pressure should have an insignificant effect on the loading because of the resistance of the fibers to further deformation. Therefore, the anticipated functionality for the oil retention of compressed cotton versus squeeze roll pressure should consist of a segment with a high negative slope followed by a segment with a small negative slope.

It would also be expected that the oil retention would be a function of crude oil type and temperature due to the fact that the adhesive forces between the cotton and oil are a function of the viscosity of the crude oil.

Finally, the heat of combustion of the squeezed oil-cotton mixture should be a function of the oil retention since the heating value of the mixture should be obtainable from a simple material balance using weight fractions and the

individual heating values. A literature review indicated the cotton had a heat of combustion of approximately 7,500 BTU per pound (Plant, 1975).

The ash content of the squeezed cotton is important in incinerator design for two reasons, the heat lost in the ash, and the removal system required within the incinerator. It was anticipated that the ash content would be low because cotton is almost pure cellulose and oil has little ash. However not only the amount, but the characteristics of the ash may be important since a light and fluffy material may have a tendency to become airborne.

The moisture content of the influent to the incinerator can be significant because of the heat required to vaporize the water and raise its temperature to that of the exit gas. A high moisture content may also require a long drying time prior to influent ignition.

Visual and tabular data with respect to the oil retention of compressed cotton is presented in Figure 5.2-1 and 5.2-2 and in Table 5.2-I. The raw data concerning the variation of oil content with squeeze roll pressure is reported in Appendix B. As the data in Table 5.2-I, which were obtained from a least-squares analysis, indicate, the mean value for the oil retentions all fell in the range of 0.97 to 2.34 grams of oil per gram of cotton. In addition, the change of oil loading with respect to pressure was so small that the loading may be considered as a constant over the range of 15 to 50 psi on the squeeze rolls. It should be noted that the pounds of oil per pound of cotton in the squeeze roll effluent were basically independent of the squeeze roll influent. Typical values for initial or zero pressure loadings were in the range of 25 to 50 pounds of oil per pound of cotton.

The net conclusion from this phase of the study was for the spectrum of crude oils and pressures investigated, the effluent oil loading from the squeeze rolls was independent of the influent loading and the pressure. The average oil loading leaving the squeeze rolls was approximately 1.4 pounds of oil per pound of cotton. This statistic should be very useful in system design of an incinerator system to dispose of oil-cotton mixtures.

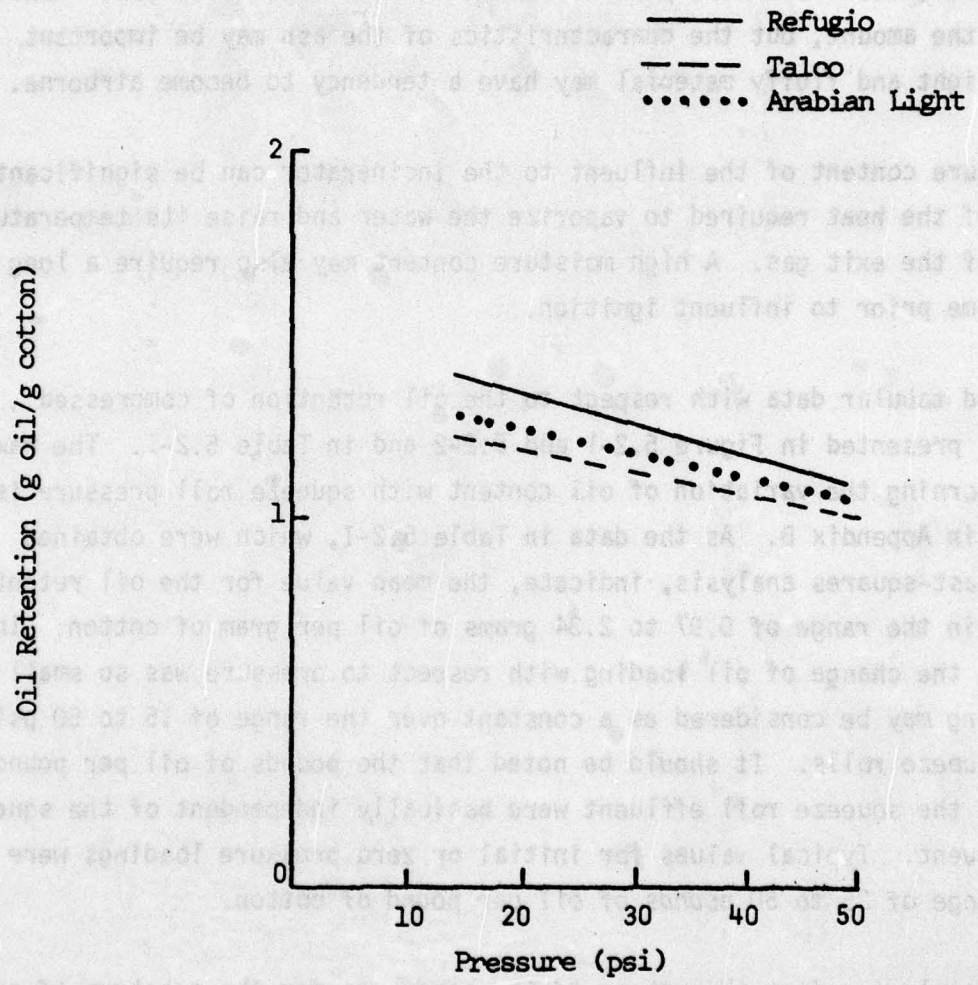

FIGURE 5.2-1 OIL RETENTION OF EXXON CRUDE

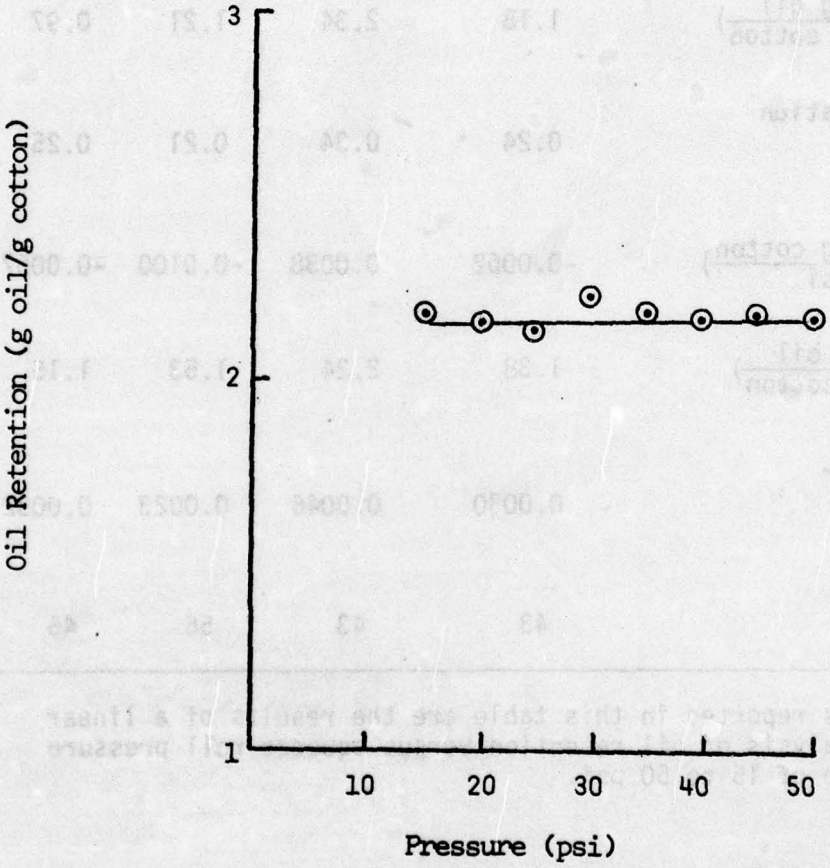

FIGURE 5.2-2 OIL RETENTION OF LACT CRUDE

AD-A034 955 TEXAS TECH UNIV LUBBOCK DEPT OF CHEMICAL ENGINEERING F/G 13/2
OIL SPILL CLEAN UP USING A COTTON SORBENT.(U)
JAN 76 J E HALLIGAN, A A BALL, G F MEENAGHAN DOT-CG-42557-A
UNCLASSIFIED USCG-D-63-76 NL

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TABLE 5.2-I

OIL RETENTION RESULTS*

Crude	Arabian Light	Lact	Refugio	Talco
Mean Value ($\frac{g\ oil}{g\ cotton}$)	1.18	2.34	1.21	0.97
Standard Deviation ($\frac{g\ oil}{g\ cotton}$)	0.24	0.34	0.21	0.25
Slope ($\frac{g\ oil/g\ cotton}{psi}$)	-0.0062	0.0038	-0.0100	-0.0057
Intercept ($\frac{g\ oil}{g\ cotton}$)	1.38	2.24	1.53	1.15
Standard Error of Slope	0.0030	0.0046	0.0023	0.0032
Number of Observations	43	43	56	46

*The values reported in this table are the results of a linear regression analysis of oil retention versus squeeze roll pressure over the range of 15 to 50 psi.

A digest of a least-squares analysis of the data for the ash content of the squeeze-roll effluent is given in Table 5.2-II. If it is assumed that most of the ash in the effluent is the result of the presence of the oil, and the oil content has been shown to be relatively independent of pressure, then the ash content should also be relatively independent of pressure. The data in the cited table supported this interpretation. Figure 5.2-3 reports average values for Talco in order to provide a visual verification of the independence of ash content with respect to squeeze roll pressure.

The principal conclusion from this phase of the study was that since the ash content of the compressed mixture was always below 2 weight percent, the heat lost in the incinerator due to the presence of the ash could be ignored. In addition, for design purposes, the ash required to be removed from an incinerator will be approximately 2 pounds for every 100 pounds of squeezed oil-saturated cotton fed to the device. In real world situations, debris and foreign matter may be a part of the slick and hence influence the ash content.

Data of a form similar to that recorded for the ash content were calculated for the observed effluent moisture contents of compressed oil-cotton mixtures. As indicated in Table 5.2-III, the mean value ranged from 0.65 to 2.66 pounds of water per 100 pounds of compressed oil-cotton mixture. The average value over the spectrum of pressures and oils investigated was 1.5 percent. As indicated in the description of the experimental technique, the moisture level was measured using ASTM method D15-65. Other methods may have yielded other results.

These results are consistent with the concepts presented in the sorbent selection section in that it was anticipated that a cotton-oil mixture, which is basically oleophillic, would reject most of the water during compression. Most importantly, these data indicate that the amount of water to be processed by an incinerator will be minimal. Therefore, the amount of heat and the residence time required within the incinerator to vaporize the water would be small.

TABLE 5.2-II

ASH CONTENT OF THE SQUEEZE-ROLL EFFLUENT*

Crude	Arabian Light	Lact	Refugio	Talco
Mean Value (wt %)	0.817	0.463	0.840	0.808
Standard Deviation (wt %)	0.202	0.205	0.352	0.240
Slope (wt %/psi)	0.0098	0.0054	0.0176	-0.0029
Intercept (wt %)	0.498	0.285	0.274	0.901
Standard Error of Slope	0.0037	0.0043	0.0064	0.0052
Number of Observations	16	17	17	17

*The values reported in this table are the results of a linear regression analysis of oil retention versus squeeze roll pressure over the range 15 to 50 psi.

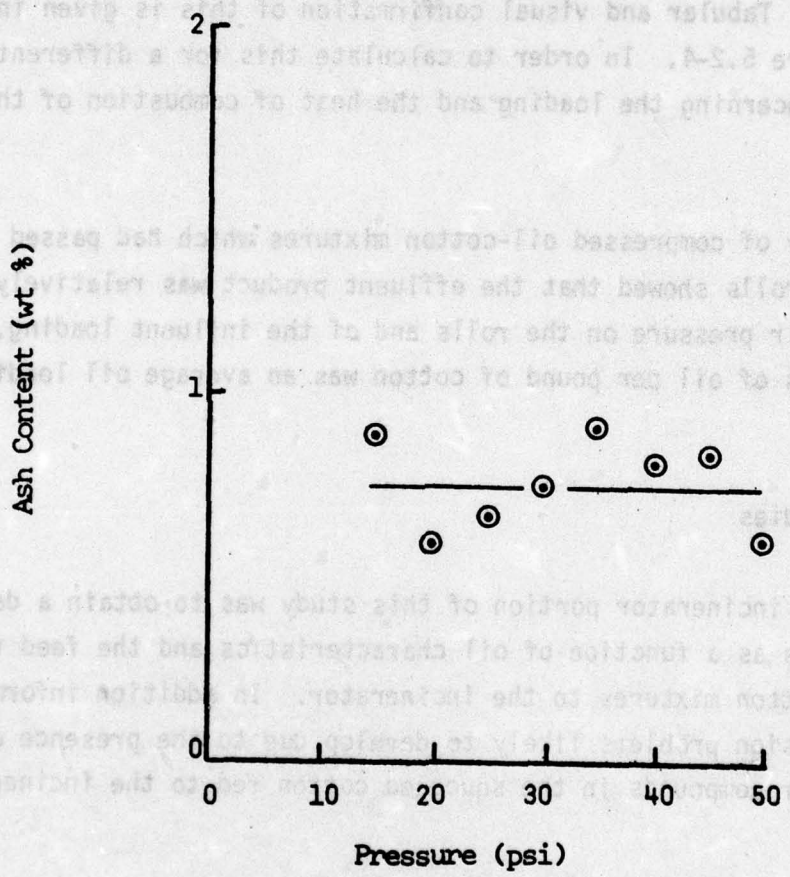

FIGURE 5.2-3 ASH CONTENT OF TALCO CRUDE

Finally, on the basis of the previous results it would be anticipated that the experimental heat of combustion would also be relatively independent of squeeze roll pressure because the oil content, water content, and ash content were deemed to be independent of this variable. The data in Table 5.2-IV support this contention. The average of the mean values reported in this table is 12,922 BTU per pound of compressed oil-cotton mixture. This value, along with the range of 12,241 to 14,890 should be useful in incinerator design.

The heat of combustion can be calculated if the amount of oil retained by the sample is known. Tabular and visual confirmation of this is given in Table 5.2-V and Figure 5.2-4. In order to calculate this for a different type of oil, data concerning the loading and the heat of combustion of the oil would be needed.

In summary, the study of compressed oil-cotton mixtures which had passed through the squeeze rolls showed that the effluent product was relatively independent of the air pressure on the rolls and of the influent loading. A value of 1.4 pounds of oil per pound of cotton was an average oil loading for the effluent.

5.3 Incinerator Studies

The objective of the incinerator portion of this study was to obtain a data base on the emissions as a function of oil characteristics and the feed rate of compressed oil-cotton mixtures to the incinerator. In addition information with regard to corrosion problems likely to develop due to the presence of salt water and sulfur compounds in the squeezed cotton fed to the incinerator was desired.

The effluent contaminants that were studied were polycyclic organics, particulates, nitrogen dioxide, and sulfur dioxide. The Environmental Protection Agency presently only limit the particulate emissions (0.08 grams per standard cubic foot corrected to 12% CO_2) but the sulfur dioxide, nitrogen dioxide,

TABLE 5.2-III

EFFLUENT MOISTURE CONTENTS*

Crude	Arabian Light	Lact	Refugio	Talco
Mean Value (wt %)	1.06	0.65	1.49	2.66
Standard Deviation (wt %)	0.39	0.39	0.58	1.85
Slope (wt %/psi)	0.0065	-0.0045	-0.0017	0.0025
Intercept (wt %)	1.42	0.79	1.55	2.57
Standard Error of Slope (wt %/psi)	0.008	0.008	0.012	0.042
Number of Observations	16	17	19	16

*Computed values reported in this table are the results of a multiple linear regression analysis of moisture content versus squeeze roll pressure over the range 15 to 50 psi.

TABLE 5.2-IV

EXPERIMENTAL HEAT OF COMBUSTION*

Crude	Arabian Light	Lact	Refugio	Talco
Mean Value (BTU/lb)	12679	14890	12241	11879
Standard Deviation (BTU/lb)	337	470	724	1335
Slope $(\frac{BTU/lb}{psi})$	-7	21	-40	3
Intercept (BTU/lb)	12884	14223	13581	11794
Standard Error of Slope $(\frac{BTU/lb}{psi})$	9	12	18	34
Number of Observations	11	9	9	13

*Computed values reported in this table are the results of a multiple linear regression analysis of the experimentally observed heat of combustion data versus squeeze roll pressure over the range 15 to 50 psi.

TABLE 5.2-V

CALCULATED HEAT OF COMBUSTION

Squeeze Roll Pressure (PSI)	O.R.* of Individual Samples $\frac{\text{lb oil}}{\text{lb cotton}}$	Observed H.C.** of Individual Samples (BTU/lb)	H.C. Calculated from O.R. of Sample (BTU/lb)
15	2.35	15116	15020
20	1.40	13899	13690
20	2.46	14920	15127
25	1.81	14451	14373
30	2.48	14994	15145
35	2.25	14742	14915
40	2.69	15380	15326
45	2.48	14219	15149
50	2.69	15290	15329

*O. R. - Oil Retention

**H. C. - Heat of Combustion

Heat of Combustion of Lact = 18380. BTU/lb

Heat of Combustion of Cotton = 7125 BTU/lb

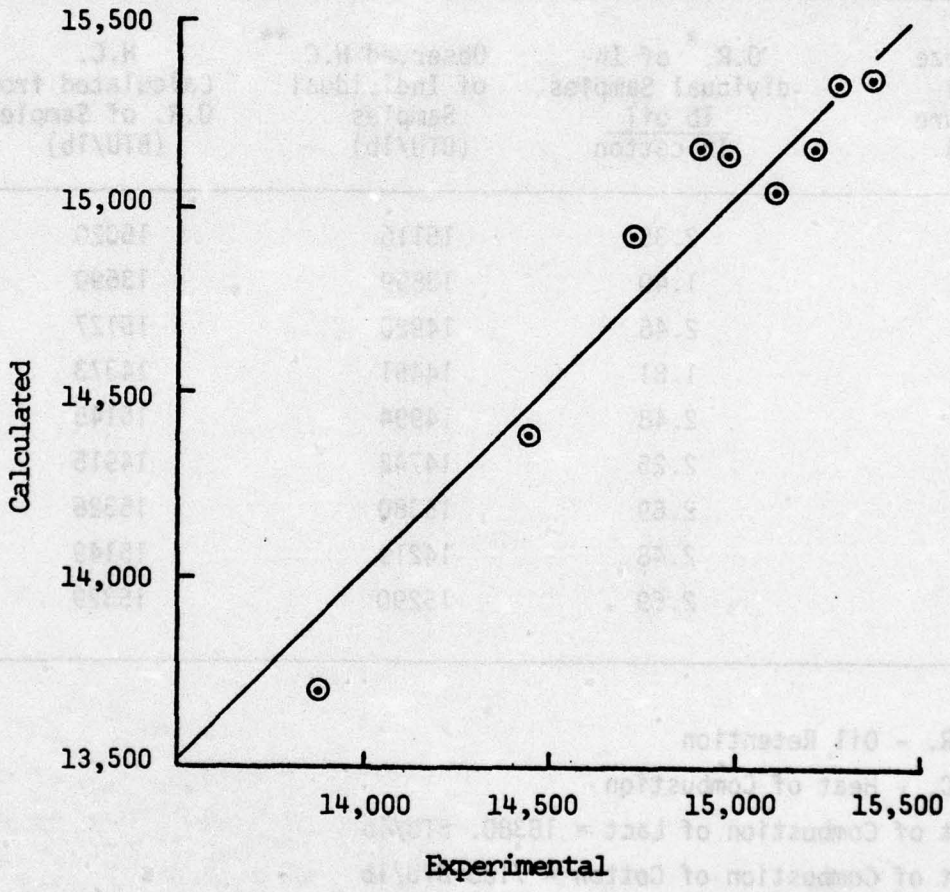

FIGURE 5.2-4 EXPERIMENTAL VERSUS CALCULATED HEAT OF COMBUSTION OF LACT CRUDE

and polycyclic organic emissions may be limited in the future. The standard EPA tests outlined in the Federal Register No. 247, Vol. 36, Part II were the procedures used for the air pollution tests.

It was anticipated that the particulate emission level would be a function of ash content, incinerator turbulence, and ash characteristics. The level and nature of the turbulence will be different for each incinerator but the ash characteristics and ash content of the feed will not change. Since cotton and oil contain little nitrogen, all of the nitrogen in the nitrogen dioxide in the effluent was assumed to come from the air. The nitrogen dioxide and unburned hydrocarbons in the effluent should be a function of residence time, temperature, and turbulence which depends upon the incinerator and the energy in BTU per hour fed to the incinerator (Ross, 1972). According to the previous studies, sulfur oxides are the product of the combustion of all the sulfur in the feed (Corey, 1969). If the squeeze roll pressure (therefore the oil retained in the squeezed cotton) nd the sulfur content of the oil are known, the sulfur dioxide produced can be estimated.

The incinerator utilized for the study was a brick-lined dual chamber incinerator with a capacity of 75 pounds per hour for type 0 waste which has a heating value of 8,000 BTU per pound and was a model C-18, serial number 2473, manufactured by Contex System, Incorporated of Houston, Texas. There were burners in both chambers for combusting diesel fuel. The system was a starved-air incinerator in which 50% of the stoichiometric air required was supplied to the bottom. The excess air added in the upper chamber served to complete the combustion and to cool the stack gases. This particular model was selected from many because it was deemed to have the potential to satisfy the Coast Guard requirements for this study.

This incinerator was specifically designed to combust type 0 waste with a minimum of manual attention and at a minimum cost. It was difficult to secure an incinerator which was even moderately well suited to the needs of this study at a reasonable cost. The level of instrumentation and control on this unit was minimal. An example of this can be shown by noting that the

fuel flow to the lower chamber could not be shut off. However, the results of this investigation are adequate to answer the basic questions posed.

An exemption for burning sulfur containing crude oil was obtained from the Texas Air Control Board on the basis that the incinerator would be used for only a short period for each run. The capacity was less than one hundred pounds per hour, and the incinerator was hooked to a ninety foot stack. Therefore the ground level concentrations of contaminants should not have been changed.

As noted above the incinerator being utilized was typical of those used for disposing of municipal and industrial waste. The corrosive effects of chlorine salts and sulfur oxides under combustion gas atmospheres have been extensively studied for municipal incinerators (Miller et al., 1971; Miller et al., 1972; Miller, 1972). The reaction of hydrogen chloride with iron is

$$Fe + 2HCl \rightarrow FeCl_2 + H_2, \qquad (5.3\text{-}1)$$

and the reaction of sulfur dioxide with iron is

$$SO_4^{=} + 3Fe \rightarrow 2Fe^{+++} + Fe^{++} + S^{=} + 4O^{=}. \qquad (5.3\text{-}2)$$

Therefore, chloride and sulfur oxides are important factors in the corrosion reaction. It has been determined that the corrosion is more severe when both are present than when only one is present (Miller et al., 1972). The function of sulfur dioxide in the presence of chloride salts is to form hydrogen chloride directly adjacent to the metal surface as indicated by the equation

$$4NaCl + 2SO_2 + O_2 + 2H_2O \rightarrow 2Na_2SO_4 + 4HCl \qquad (5.3\text{-}3)$$

The SO_4 ion can also combine with other positive ions such as Ca^{+}, and K^{+}. The corrosion is speeded up because of the ability of hydrochloric acid to break down passive films on metals.

Because of the reactions of the sulfur dioxide and chloride salts mentioned above, the corrosion in the gas phase is not as severe as in the molten phase.

The order of magnitude of the gas phase corrosion rate has been reported as 0.5 mils per month at 427°C for the boiler tubes (Miller et al., 1971).

The corrosion rates increased as the temperature rose and the molten phase of salt deposits corroded the metal faster than the gas phase (Miller, 1972). The reported corrosion rate of the metal walls for the molten phase was about 40 mils per month at 538°C for molten chlorine and sulfate salts. Therefore, the corrosion problems of chlorine and sulfur can be minimized by using a brick lining in the bottom chamber where the salts would lead to a high metal corrosion rate. After 45 hours of cyclic operation, no corrosion was observable in the brick-lined incinerator used in this investigation. It is not anticipated that it will pose a significant problem for the type of service and time of operation envisioned for a normal oil spill.

Although no data were obtained during this study using seawater, it is not anticipated that corrosion would be a major problem during the relatively short operational periods envisaged during a typical spill. If necessary, ceramic repair could become a part of normal maintenance procedures.

The Environmental Protection Agency's regulation for particulate loading for waste incinerators is 0.08 grains per standard cubic foot at 12% carbon dioxide (Fed. Reg. No. 247). A summary of the experimental data obtained in this study is shown in Table 5.3-I. As indicated, all of the averages of the observed particulate loading for each feed rate and crude type were below the government regulations. The runs are coded in this table by using the first letter to represent the crude type, followed by a sequence of numbers indicating the compression pressure used to prepare the cotton in pounds per square inch, the feed rate in pounds per hour, and finally the number of the run at each condition. With the simple squeezing device available, there was considerable difficulty in processing large amounts of cotton laden with Lact crude. It was our assessment that this was due to the device having solid, smooth squeeze rollers. Because of this, we were unable, within the time frame of the project, to prepare the large quantity of sample needed for the incineration study with this crude. However, it is our judgement that existing technology could be easily adapted to process Lact laden cotton.

Average values, which were calculated for each of the crude types and feed rates, are displayed in Table 5.3-II. There is some trend in the data to suggest that the particulate concentration may decrease as the feed rate increases. One possible explanation for this is that an increase in the temperature in the upper chamber resulted in the combustion of a higher mass fraction of the particles. The difference in particle loading between crudes could be caused by the difference in the heat of combustion and the metal content of the crude oil. Talco which had the highest particulate loading also had the lowest heat of combustion.

The Environmental Protection Agency's regulation for solid fossil fuel fired steam generators is 0.7 pounds of nitrogen dioxide and 1.2 pounds sulfur dioxide per million BTU's heat input. As indicated in Table 5.3-I, the observed values for the sulfur dioxide and nitrogen dioxide concentrations were all below those requirements.

Although the Environmental Protection Agency does not have regulations on polycyclic organics at this time, regulations will probably be formulated in the near future due to the carcinogenic nature of polycyclic organics. All of the polycyclic organics were below 0.007 grains per standard cubic foot at 12% carbon dioxide except one value. It is suspect since it was the first data point taken for polycyclic organics and the high reading could have been due to vacuum grease that was rinsed from the ground glass connections in the stack sampler.

During extended periods of operation, the incinerator velocity appeared to surge. The reason for the pulsation was attributed to the fact that the burning rate for a batch process was not constant. When the squeezed, oil-saturated cotton was fed to the incinerator in slugs, (approximately every 30 seconds), the individual burning curves became superimposed on each other causing an uneven total burning rate. This uneven burning rate was reflected in the sulfur dioxide analysis. Figure 5.3-1 suggests that the sulfur dioxide concentration appeared to fluctuate after reaching steady state with respect to temperature. If the feed rate could be made more continuous, the sulfur dioxide concentration in the effluent gases should approach a constant.

TABLE 5.3-I

INCINERATOR STUDY RESULTS

Run Number	Particulate Loading grains/scf at 12% CO_2	Polycyclic Organics grains/scf at 12% CO_2	Stack temperature °F	Nitrogen Dioxide $\frac{lb}{10^6 BTU}$	Sulfur Dioxide $\frac{lb}{10^6 BTU}$
T-25-15-1	0.044	NM	640	NM	NM
T-25-15-2	0.103	NM	665	NM	NM
T-25-15-3	0.065	0.0024	884	0.110	0.52
T-25-30-1	0.101	NM	993	NM	NM
T-25-30-2	0.022	0.0018	1312	0.128	NM
T-25-40-1	0.048	0.0056	1030	NM	NM
T-25-40-2	0.081	0.0012	1225	0.075	0.20
R-25-15-1	0.091	NM	773	0.104	0.19
R-25-15-2	0.063	0.0075	467	0.121	0.23
R-25-30-1	0.107	0.0218	1118	0.082	0.09
R-25-30-2	0.050	0.0057	1112	0.126	0.11
R-25-40-1	0.030	0.0031	1268	0.161	0.20
R-25-40-2	0.046	0.0051	656	0.192	0.11
A-25-15-1	0.063	0.0024	862	0.061	0.23
A-25-15-2	0.070	0.0063	440	0.103	0.84
A-25-30-1	0.044	0.0042	1225	0.080	0.55
A-25-30-2	0.050	0.0022	993	0.136	1.00
A-25-40-1	0.054	0.0035	1500	0.079	0.61
A-25-40-2	0.019	0.0059	1143	0.122	0.58

NM - Not Measured

TABLE 5.3-II

PARTICULATE CONCENTRATION*

Feed Rate (lb/hr)	Crude Type		
	Talco	Arabian	Refugio
15	0.070	0.077	0.066
30	0.062	0.078	0.047
40	0.064	0.038	0.036

*Each value listed is the average of two runs.

When the feed rate exceeded 40 pounds per hour of compressed oil-cotton mixture the temperature in the upper chamber of the incinerator exceeded the temperature limit suggested by the manufacturer. The incinerator used in this study was designed to combust 75 pounds per hour of type 0 waste which had an energy content of 8,000 BTU per pound. If the oil-cotton mixture has an energy content of approximately 13,000 BTU/lb, then actual energy input would be 40x13,000 or 520,000 BTU/hr which compares favorably to the design value of 75x8,000 or 600,000 BTU/hr. This suggests that, as an approximation, when sizing larger scale incinerators that the capacity when feeding compressed oil-cotton mixtures would be roughly 40/75 or one-half of that expected with type 0 wastes.

In summary, this phase of the study indicated that compressed oil-cotton mixtures could be combusted in accordance with current federal requirements using a conventional incinerator designed to dispose of municipal solid waste. There appears to be no significant technological problems which need to be investigated further before a suitable incinerator could be designed by commercial incinerator manufactures.

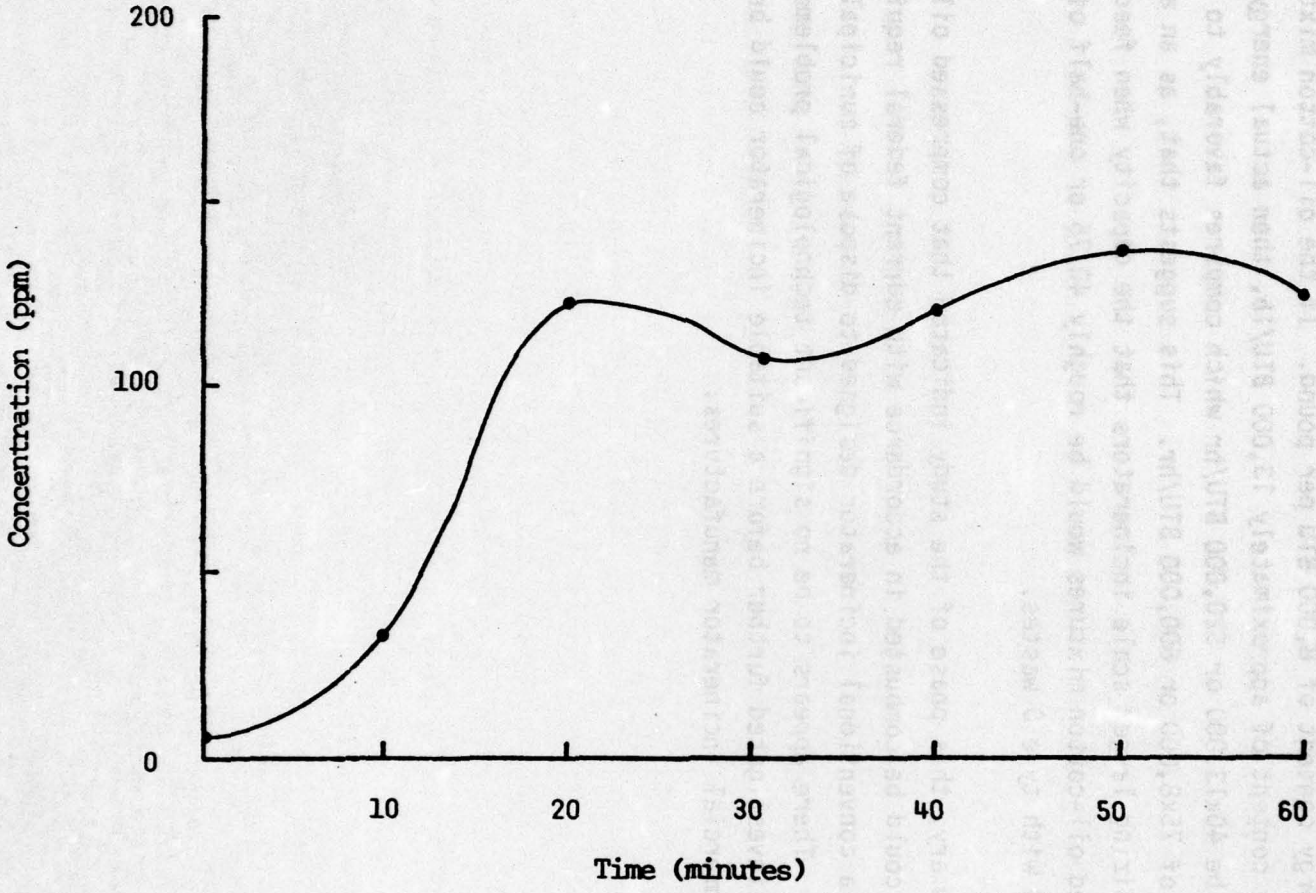

FIGURE 5.3-1 SULPHUR DIOXIDE CONCENTRATION IN INCINERATOR EFFLUENT

SECTION 6

CONCLUSIONS

For the range of conditions investigated within the course of this study, the following can be concluded:

Primary

P 1. The concept of using cotton as an oil-spill clean up agent has been demonstrated to be feasible. A test system which formed an oil slick, covered it with dispersed cotton, retrieved the oil-cotton mixture, and incinerated the solid residue was successfully operated.

P 2. The test data indicated that cotton could be used effectively as a sorbent, independent of the type of crude oil tested.

P 3. The contact time between the sorbent and the oil did not significantly influence the system performance.

P 4. At reasonable dispersion ratios, namely 0.05 pounds of cotton per pound of oil, the system retrieved approximately 95 percent of the oil confronted when the approach velocity was two feet per second or less.

P 5. For the oils which could be processed through the simple squeezing device available, ninety percent of the oil was separated from the cotton by a simple squeezing action.

P 6. Pre-squeezed oil-cotton mixtures were successfully disposed of, by two-state incineration, in compliance with air pollution standards using commercially available equipment.

Secondary

S 1. When problems associated with the spreading tendencies of an oil slick are considered, the first emergency step should be to contain the oil, and if sorbents are to be employed as an

aid to clean up they should not compromise the primary goal of containment. The advantages of polyurethane reuse are minimal in comparison to the agglomerating tendency of cotton. In addition, water-borne debris will greatly complicate any reuse mechanism and thereby compromise the clean up operation.

S 2. A sorbent dispersal and retrieval system based on cotton can be effectively operated separately and independently of each other.

S 3. The sorbent dispersal system should not be dependent upon the retrieval device recovering the sorbent, removing the oil and continuously providing the sorbent for reuse. The primary function of the sorbent is capture and containment.

S 4. The sorbency of cotton was significantly greater than that of polyurethane foam when compared using test procedure prescribed by Schatzberg.

S 5. An open mesh chain type conveyor was used to remove oil-laden cotton from a water interface, the oil retained by the cotton being primarily a function of the oil-fiber ratio; e.g., with oil-fiber ratios less than 20 pounds per pound approximately 93 percent of oil confronted was retained by the cotton during transportation up the conveyor to the collection chute.

S 6. Additional development work on the retrieval device would be needed to effectively retrieve the oil-cotton mixture at approach velocities at and above four feet per second.

S 7. Independent of Sorbent Effective Contact Time (SECT), cotton, ladened with oil and removed from a water interface, then transported up an inclined open mesh conveyor, will retain at least 24 pounds of oil per pound of cotton.

S 8. The effluent oil loading of cotton after processing through a simple squeeze roll device was independent of the influent oil loading.

On the basis of these conclusions and field observations of an actual oil spill, it is the considered judgment of the authors that with minimal technology transfer, the concepts demonstrated here could be quickly adapted to clean up operations in protected waters and near shorelines.

SECTION 7

OPERATIONAL SCENARIO

7.1 Observations Concerning the Florida Keys Spill

As part of the project, team members visited an oil spill clean up operation in progress at the Florida Keys. The following observations and comments have a bearing on our views as to how a sorbent system can be effectively used.

1. The Gulf Strike team of the U. S. Coast Guard was well organized and had adequate equipment and manpower to coordinate the clean up effort.

2. The private contractors (Danmark and Clean River) knew how to clean up oil once it had hit the shoreline or the beaches. This was facilitated in this instance by the presence of Turtle Grass which functioned as a sorbent containment media.

3. Local residents commented that there was an extraordinarily great accumulation of Turtle Grass. It was hypothesized that this was due to either 1) the action of the migration of the oil across the water surface, or 2) an unusual wind field.

4. The contractors were responsive to Coast Guard requests for personnel but they were not available as soon as they were needed and they were mostly casual labor. However, by the third day adequate manpower was available.

5. There appeared to be no major problems with supplies.

6. The equipment used to clean oil entrapped in turtle grass in boat docks involved suction trucks, rakes, nets, and plastic bags. The water to oil ratio in the suction truck influent appeared to be very high.

7. Catchment booms were deployed in some channels before we arrived on the scene and vacuum trucks used to remove the oil. This was done only for a few hours. To our knowledge this was the only attempt to capture free-floating oil.

8. Water and weather conditions were ideal for conducting operations at sea. However the water was shallow in places, perhaps as little as 12 inches depth at low tide.

9. The contractors had a large number of sorbents on hand (particulates, pads, rolls). Chemical herders were also on-hand.

Concluding Comments

1. There was no attempt made to capture the oil in the open sea before it became a threat to the beaches. On the basis of our research experience and this visit we recommend that in future similar situations, sorbent materials be dispersed using a blower, hose, and nozzle from boats on the perimeter of the spill in order to minimize the tendency for fragmentation and to present several slick management options. After sorbent dispersal, slick movement will be influenced by the prevailing wind rather than being predominantly under the influence of water movement making it more predictable. The options available would include: 1) guiding with a helicopter, 2) containment and directional control using simple nets from boats, 3) pick up slightly offshore by people either in boats or wading using small nets.

2. The presence of a sorbent facilitates spill clean up using vacuum trucks due to the fact that the sorbent can be easily handled and hence readily presented to the suction hose.

3. Assuming that a particular beach has been selected as a catchment zone, sorbents make it much easier to clean up the oil.

4. With regard to the concepts under development in our research project, the three elements of sorbent dispersal, retrieval, and disposal do not have to be implemented collectively. We believe that a sorbent dispersal system can be beneficially implemented immediately without the existence of a mechanical pick up device.

   At this time we do not feel that the development of a mechanical pick up device should impede the application of fiber sorbents to oil spills. Single manually operated pick up devices may be the most suitable means in terms of flexibility, and cost effectiveness. However, for large spills the development of a mechanical pick up device is justifiable.

   It is obvious that disposal of oil-saturated material (dispersed sorbent and natural debris) is a significant problem. Landfill operations close to sea level can potentially contribute contaminants at high water levels. Therefore we recommend that a transportable incinerator system be actively pursued.

5. As a result of seeing an actual oil spill clean up operation the research team's perception of the problem improved significantly. Future oil spills should be observed in order to develop useful clean up techniques and a meaningful scenario.

These comments should not be construed as a criticism of the Gulf Strike Team. They are based on our research activity and limited exposure to actual spills. Our overall consensus is that sorbent systems have considerable potential for improving the efficiency of oil spill clean up.

The future adoption of the techniques developed under this project are dependent upon their acceptability as determined by the companies presently engaged in oil spill clean up. Because of the nature of oil spills, their unpredictable size, frequency of occurrence and location, it is difficult for the clean up companies to justify high capital outlay. Therefore the equipment should be:

1) low in cost,
2) simple in operation,
3) separate dispersal and retrieval devices,
4) dispersal device should be portable,
5) disposal incinerator should be on shore,
6) sorbent material should be in adequate supply, and
7) sorbent should be easy to disperse.

7.2 Scenario Specifics

One of the most important features of a fiber sorbent is that it changes the phase of the oil from that of a fluid phase to a fluid-solid phase.

The oil-cotton material can be contained more easily on the water than can free oil. It is envisaged that simple nets could be deployed to contain an oil-cotton slick and hold or direct the slick in a controlled manner.

On the basis of the research and field experience, the following scenario appears to be viable to handle small spills on open water.

A small boat carrying a fiber dispenser and a supply of compressed, short, low-cost cotton would approach the oil slick.
The opener would be a gasoline engine fitted to a rugged materials handling fan with a hose attached to the outlet.
Approximate capital cost less than $500.
As the boat circumnavigated the slick, the fiber would be blown onto the oil to effect adequate coverage at the outer regions of the oil. If necessary, the boat could pass through the slick to enable total sorbent cover to be obtained.
The presence of the fiber on the oil changes the responsiveness to wind forces and rather than moving primarily with the current, the slick will change direction and form.
The wind blowing against the fiber will tend to compact the slick so that the slick will be corralled.
Additional fiber can be continuously blown onto the slick to minimize the tendency of seepage.

The contained slick can be held indefinitely by the net. If desired, the slick can be towed to a pick up area near some suitable beach where any convenient retrieval means can be used.

Fiber and oil can be removed from the water by rakes, nets of vacuum trucks depending upon availability.

The slick could be held in quiet water close to the beach or it could be pulled onto the beach and then removed.

It is not recommended that the slick be "Beached" because it is easier to effectively remove the sorbed cotton from water than it is from sand or rocks.

The oil soaked cotton can be bagged for hauling in trucks or it can be carried by tanker to the disposal site.

SECTION 8

RECOMMENDATIONS FOR FUTURE STUDIES

PRIMARY

1. On-site testing (at the location of the spill) of small-scale dispersion and retrieval devices which are consistent with the technological skills and manpower resources of a typical oil-spill clean up company.

Our contacts and experience in this area indicates that many clean up concerns minimize capital and operating expenses while waiting for a spill to occur. When an incident is reported, casual labor and rental equipment is used to clean up the oil. Even though sophisticated dispersal and pick up devices may have technological advantages, their capital cost and complexity would probably preclude adoption by most small concerns.

What is needed are small scale, inexpensive devices which can be used to open and disperse cotton sorbents. These only can be perfected by actual on-site developmental evaluations using the type of personnel normally associated with oil-spill clean up operations.

2. Concurrent with field evaluations of developmental prototypes, studies should be continued in the laboratory using existing test facilities to incorporate the field experience into improved prototype models.

Based on the experience of the authors, it is our judgment that a suitable dispersion device could be developed which would open and effectively deposit the fiber on the oil with small losses to the ecosystem under conditions of moderate winds.

Identifiable problems in this area include the type of driver for the opening-dispersing device, weight and maneuverability of the device, feed mechanism, nozzle deployment and support, man-powered pick up systems (simple nets), and deployment of simple, inexpensive containment devices.

3. Development of a truck-transportable incinerator which can be quickly moved to the spill site should receive high priority. This should be simple to operate with casual labor. If possible, it would be desirable to be able to feed the incinerator using a simple device such as a scoop shovel.

Many spills occur at or near sites which are not readily accessible to landfills for refuse disposal. This can be a serious problem on islands where the water table is close to the surface. A portable incinerator would minimize the pollution and transportation problems associated with disposal operations of the debris and oil-soaked sorbent associated with spill clean up.

SECONDARY

1. In-situ burning should be investigated as a disposal technique for oil-soaked sorbents in remote areas. Factors which should be investigated are:

   a. Burning rates as a function of cotton-oil loadings - residence time, environmental conditions, area, and oil characteristic
   b. Flame spread as a function of the variables
   c. Effects of burning on wicking and containment action of cotton-oil mixtures
   d. Ecological effects of gaseous and solid residues
   e. Enhancement of the cotton matrix using additives, e.g., fiberglass, for maintaining porosity.

2. Development of a containment boom using a cotton-fiber matrix. Factors which should be considered in such a development would be:

   a. Design of booms as a function of
      i. Environmental conditions
      ii. Mechanical integrity
      iii. Length
      iv. Depth of immersion

b. Types of booms
   i. Permanent (ring-type)
   ii. Movable/towable
c. Methods of replenishing cotton "in-situ" on boom
d. Type of cotton matrix.

The principal comment that is imbedded in all of these recommendations is the need for simplicity and low capital investment in order to ensure that the entrepreneurs in the oil-spill clean up business will adopt the technology developed as a result of these studies.

3. It is recommended that an oil/sorbent separating device be developed which would be capable of effective operation independent of oil type and viscosity. It is desirable that the device be capable of handling oil soaked sorbent moderately contaminated with debris. Such device could employ centrifugal or squeezing techniques either individually or in combination.

SECTION 9

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APPENDIX A

SUMMARY OF TEST TANK DATA

TABLE A-1
TEST TANK DATA SUMMARY PHASE I

Run Number	Date	Oil Type	Slick Thick-ness mm	Fiber Loading lb oil/lb cotton	SECT Minutes	Velocity ft/sec	Selectivity %	Throughput Eff. %
1	4-11-75	T	0.36	30	min.	0.5	11	97
2	4-11-75	T	0.40	32	10	0.5	12	97
3	4-11-75	T	0.36	26	30	0.5	10	97
4	4-15-75	T	0.18	25	min.	1.1	47	97
5	4-15-75	T	0.18	21	10	1.1	12	97
6	4-15-75	T	0.18	24	30	1.1	15	97
7	4-15-75	T	0.12	18	min.	1.6	32	90
8	4-15-75	T	0.11	17	10	1.8	18	96
9	4-17-75	T	0.45	15	min.	0.5	19	98
10	4-17-75	T	0.43	13	10	0.5	14	96
11	4-17-75	T	0.42	14	30	0.5	100	98
12	4-23-75	T+N	0.76	22	min.	0.5	8	99
13	4-23-75	T+N	0.86	24	10	0.5	8	99
14	4-25-75	T+N	0.52	13	min.	1.0	33	99
15	4-25-75	T+N	0.49	20	10	1.0	10	98
16	4-25-75	T+N	0.45	19	30	1.0	9	98
17	4-29-75	T+N	0.19	28	min.	1.9	33	95
18	4-29-75	T+N	0.22	17	10	1.9	17	88
19	4-29-75	T+N	0.14	16	30	1.9	21	95

TABLE A-1
TEST TANK DATA SUMMARY PHASE I continued

Run Number	Date	Type	Slick Thickness mm	Fiber Loading lb oil/lb cotton	SECT Minutes	Velocity ft/sec	Selectivity %	Throughput Eff. %
20	4-29-75	T+N	0.15	22	10	1.9	16	91
21	5- 1-75	WT	0.55	47	10	1.0	2	89
22	5- 1-75	WT	0.59	34	10	1.0	3	95
23	5- 1-75	WT	0.48	30	min.	1.0	13	93
24	3- 7-75	LH	0.33	41	~10	1.1	100	87
25	3- 7-75	LH	0.10	18	~15	1.8	100	97
26	3- 7-75	LH	0.10	19	~10	2.0	100	91
27	3-18-75	LH	0.25	20	~ 8	1.2	100	97
28	3-18-75	LH	0.15	20	~ 8	2.0	6	93
29	3-19-75	LS	--	27	>60	0	5	94

T - Talco
T+N - Talco + Naptha
WT - West Texas Sour
LH - Lee Harrison
LS - Light Sour

R - Refugio
AL - Arabian Light
TJ - Tia Juana
G - Lact
CC - Coastal Crude

$$\text{Throughput Efficiency} = \frac{\text{lb oil picked up}}{\text{lb oil confronted}} \times 100$$

$$\text{Selectivity \%} = \frac{\text{lb water captured}}{\text{lb fluid captured}} \times 100$$

TABLE A-1
TEST TANK DATA SUMMARY PHASE II

Run Number	Date	Oil Type	H_2O Velocity ft/sec	Slick Thickness mm	Oil Fiber Ratio, Fiber Loading lb/lb	SECT Min	Oil Distribution %			Selectivity %	Throughput Eff. %
							Drip Pan	Conveyor Chute	Holding Basin		
30	May 28	R	1.0	.64	86.33	5.0			14.3	28	85
31	28	R	1.0	.64	25.57	5.0	16.0	79.5	4.5	10	95
32	29	R	1.0	.50	42.02	.67	33.0	57.5	9.5	33	90
33	29	R	1.0	.57	74.28	.67	46.2	43.1	10.7	27	89
34	29	R	1.0	.49	100	.67	76	3	22	39	78
35	29	R	1.0	.55	∞	--	53	--	37	25	65
36	29	R	1.0	.58	166	.67	57	24	19	12	81
37	29	R	1.0	.51	24	.67	20	73	7	35	93
38	29	R	1.6	.28	71	.43	30	61	9	44	91
39	29	R	1.6	.29	65	.43	37	55	8	34	92
40	29	R	1.6	.28	156	.43	52	36	12	35	88
41	29	R	1.6	.25	77	.43	49	43	8	16	92
42	29	R	1.6	.25	141	.43	66	18	16	16	84
43	29	R	.55	1.30	113	1.21	49	29	22	6	78
44	30	R	.55	1.50	108	1.21	48	32	20	5	80
45	30	R	.55	1.38	47	1.21	46	41	13	13	87
46	30	R	.55	.78	36	1.21	47	44	9	21	91
47	30	R	.55	.98	44	1.21	43	41	16	11	84
48	June 3	R	.52	1.20	28	1.28	31	60	9	6	91
49	3	R	.52	1.02	∞	--	25	--	75	--	25

TABLE A-1 continued PHASE II

Run Number	Date	Oil Type	H_2O Velocity ft/sec	Slick Thickness mm	Oil Fiber Ratio, Fiber Loading lb/lb	SECT Min	Oil Distribution %			Selectivity %	Throughput Eff. %
							Drip Pan	Conveyor Chute	Holding Basin		
	June										
50	3	R	1.79	.36	30	.37	27	70	3	32	97
51	3	R	1.79	.36	∞	--	40	--	65	--	35
52	25	AL	1.0	.24	65	.67	40	54	6	9	94
53	25	AL	1.0	.27	146	.67	55	24	21	13	79
54	25	AL	1.0	.3	25	.67	26	67	7	25	93
55	25	AL	1.0	.25	∞	--	33	--	43	--	57
56	25	AL	1.4	.25	55	.48	54	40	6	31	94
57	25	AL	1.4	.15	83	.48	65	23	12	29	88
58	25	AL	1.4	.18	23.4	.48	2	95	3	36	97
59	25	AL	1.4	.22	∞	--	86	--	28	33	79
60	30	TJ	1.0	.26	120	.67	35	39	26	--	74
61	30	TJ	1.0	.28	49	.67	43	49	8	15	92
62	30	TJ	1.0	.26	26	.67	30	62	8	14	92
63	30	TJ	1.0	.27	∞	--	--	--	42	--	29
64	30	TJ	1.35	.16	104	.49	45	43	12	4	88
65	30	TJ	1.35	.18	37	.49	39	53	8	18	92
66	30	TJ	1.35	.16	24	.49	27	67	6	20	94
67	30	TJ	1.35	.10	∞	--	45	--	52	--	48
68	30	G	1.0	.22	38	.67	38	43	19	--	81
	July										
69	1	G	1.0	.23	39	.67	28	67	5	--	95
70	1	G	1.0	.24	106	.67	38	36	26	--	73

TABLE A-1 continued PHASE II

Run Number	Date	Oil Type	H_2O Velocity ft/sec	Slick Thickness mm	Oil Fiber Ratio, Fiber Loading lb/lb	SECT Min	Oil Distribution %			Selectivity %	Throughput Eff. %
							Drip Pan	Conveyor Chute	Holding Basin		
71	July 1	G	1.0	.22	15	.67	34	43	23	3	77
72	7	TJ	1.0	.18	41	.083	42	40	18	--	81
73	7	TJ	1.0	.28	36	.083	42	23	35	37	65 *
74	7	TJ	1.0	.3	106	.083	55	32	13	13	87
75	7	TJ	1.0	.28	53	.083	46	47	7	16	93
76	7	TJ	1.0	.26	28	.083	41	51	8	24	92
77	7	TJ	1.0	.28	∞	--	--	--	28	--	25
78	7	TJ	1.5	.18	85	.055	62	24	14	26	86
79	7	TJ	1.5	.18	48	.055	36	47	7	15	93
80	7	TJ	1.5	.18	34	.055	41	54	5	7	95
81	7	TJ	1.5	.19	∞	--	--	--	24	--	44
82	15	AL	1.0	.34	92	.083	24	--	17	--	52 *
83	15	AL	1.0	.34	50	.083	40	42	18	12	82
84	15	AL	1.0	.32	30	.083	36	55	9	11	91
85	15	AL	1.0	.33	∞	.083	14	3	83	6	17
86	15	AL	1.5	.2	78	.055	40	47	13	--	87
87	16	AL	1.5	.2	54	.055	42	46	12	11	88
88	16	AL	1.5	.2	33	.055	37	56	7	13	93
89	16	AL	1.5	.2	∞	--	--	--	28	--	17
90	18	CC	1.0	.3	104	.083	20	44	36	--	64 *
91	18	CC	1.0	.3	50	.083	27	42	31	--	69 *

TABLE A-1 continued PHASE II

Run Number	Date	Oil Type	H_2O Velocity ft/sec	Slick Thickness mm	Oil Fiber Ratio, Fiber Loading lb/lb	SECT Min	Oil Distribution % Drip Pan	Conveyor Chute	Holding Basin	Selectivity %	Throughput Eff. %
92	July 18	CC	1.0	.3	38	.083	34	33	33	24	67
93	18	CC	1.0	.16	∞	--	7	--	85	--	11
94	18	CC	1.5	.2	81	.055	29	47	24	--	76
95	18	CC	1.5	.14	41	.055	40	35	25	17	75
96	18	CC	1.5	.2	32	.055	29	54	17	4	83
97	18	CC	1.5	.11	∞	--	10	--	79	--	15
98	Aug 25	CC	4.0	.055	38	.053	29	58	13	28	87
99	25	CC	4.0	.057	21	.053	16	71	13	54	87
100	25	CC	4.0	.073	135	.053	30	25	45	--	55
101	25	CC	4.0	.091	∞	.053	3	--	79	73	21
102	25	CC	4.0	.048	14	.053	11	28	61	47	39*
103	Sept 10	T	4.0	.07	84	.053	3	23	74	--	26*
104	10	T	4.0	.067	39	.053	25	32	43	28	57
105	10	T	4.0	.078	25	.053	20	43	37	24	63
106	10	T	4.0	.07	∞	.053	3	4	93	--	7
107	5	CC	4.0	.06	23	.053	16	71	13	30	87
108	5	G	4.0	.065	19	.053	16	70	14	24	86
109	5	G	4.0	.057	29	.053	31	52	17	25	83
110	5	G	4.0	.055	84	4.0	3	63	34	--	66
111	5	G	4.0	.052	∞	--	4	10	86	2	14

* Actual recorded data. The throughput efficiency is below normal because of a malfunction of at least one component in the system, e.g. surging due to prime mover, choking of the cotton-dispersal unit, depth or speed of retrieval device, or the system operational shakedown had not been completed for a specific condition. It should be noted that the later part of the study was directed toward finding the unacceptable operational limits of the system and consequently many tests were run with low performance margins.

The symbol ∞ was used for the oil/fiber ratios in those runs in which no fiber was dispersed.

APPENDIX B

SUMMARY OF SQUEEZE ROLL DATA

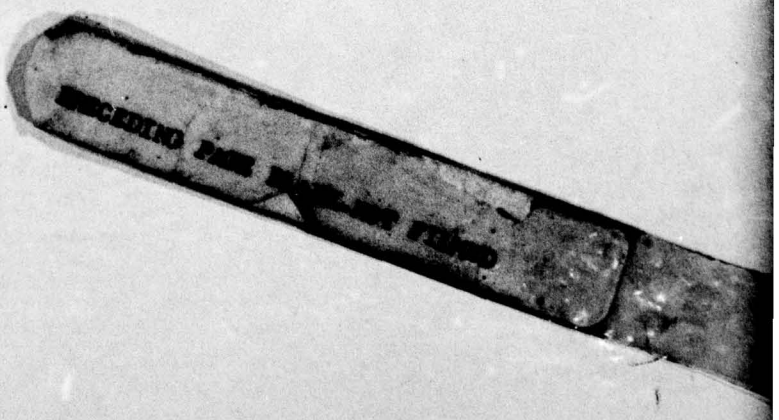

TABLE B-I

SQUEEZE ROLL DATA SUMMARY

LACT

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
35	2.04	0.533		
	2.48		1.004	
	2.37		0.158	
	2.27	0.436		
	2.25			14,742
	(2.35)	(0.485)	(0.581)	(14,742)
40	2.43	0.486		
	2.69		0.493	
	1.71	0.714		
	2.31	0.300		
	2.07		0.358	
	2.29		0.253	
	2.68			15,380
	(2.31)	(0.500)	(0.367)	(15,380)
45	2.14		0.812	
	2.91	0.401		
	2.07	0.473		
	2.17		1.019	
	2.48			15,219
	(2.35)	(0.437)	(0.916)	(15,219)
50	2.55	0.450		
	2.02	0.464		
	2.11		0.202	
	2.69			15,290
	3.14		0.778	
	(2.50)	(0.457)	(0.490)	(15,290)

*Figures in parentheses are averages.

Table B-I (continued)

LACT

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
15	2.06	0.379		
	2.34		0.159	
	2.55	0.420		
	2.38		0.819	
	2.36			15,116
	(2.34)	(0.399)	(0.669)	(15,116)
20	2.32	0.129		
	2.41	0.368		
	2.28	0.468		
	1.39			13,899
	2.47			14,920
	2.87	0.568		
	(2.29)	(0.248)	(0.518)	(14,409)
25	2.20	0.328		
	2.51		0.508	
	2.33	0.290		
	2.34		1.583	
	1.81			14,451
	(2.24)	(0.309)	(1.045)	(14,451)
30	1.47	1.066		
	2.57		0.300	
	2.32	0.459		
	2.48			14,994
	2.36	1.243		
	(1.74)	(0.762)	(0.772)	(14,995)

Table B-I (continued)

ARABIAN LIGHT

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
15	1.22			12,848
	1.22		1.600	
	1.26	0.592		
	1.35			12,337
	1.22		1,480	
	1.25	0.802		
	(1.25)	(0.697)	(1.540)	(12,592)
20	1.23			12,896
	1.15	0.767		
	1.29			12,994
	1.27		1.870	
	1.12	0.546		
	1.21		1.630	
	(1.22)	(0.657)	(1.750)	(12,945)
25	1.22	0.784		
	1.32			13,319
	1.09	0.762		
	1.21		1.740	
	1.06		0.542	
	(1.19)	(0.773)	(1.141)	(13,319)
30	2.15			12,156
	1.18	0.602		
	1.10		1.990	
	1.14	0.639		
	1.16		1.470	
	1.07			12,576
	(1,31)	(0.621)	(1.730)	(12,366)

Table B-I (continued)

ARABIAN LIGHT

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
35	1.00	0.859		
	0.99	1.160		
	2.12			12,561
	1.02		1.585	
	1.10		1.820	
	(1.25)	(1.009)	(1.703)	(12.561)
40	1.21	0.580		
	1.15		1.520	
	1.16	1.170		
	1.06			12,794
	1.12		2.190	
	(1.14)	(0.875)	(1.855)	(12,794)
45	1.07	0.816		
	1.02	0.952		
	1.13			12,350
	1.12		1.940	
	1.20		1.502	
	(1.11)	(0.884)	(1.721)	(12,350)
50	0.93			12,703
	1.00		2.070	
	0.87	1.050		
	1.04		1.230	
	1.06	0.999		
	(0.98)	(1.025)	(1.650)	(12,703)

*Figures in parentheses are averages.

Table B-I (continued)

REFUGIO

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
15	1.39		2.220	
	1.34	0.465		
	1.65	0.767		
	1.69		1.079	
	1.15			12,880
	1.17		1.320	
	(1.44)	(0.616)	(1.649)	(12,880)
20	0.99			
	1.32	0.510		
	1.26	1.060		
	1.42		1.580	
	1.44		1.060	
	1.18			12,599
	(1.26)	(0.785)	(1.320)	(12,599)
25	1.57		1.110	
	1.24			
	1.54		1.210	
	1.26		0.780	
	1.16			
	1.58	1.108		
	1.37			
	1.25			12,551
	1.49	0.461		
	1.08	0.639		
	(1.39)	(0.736)	(1.033)	(12,551)

Table B-I (continued)

REFUGIO

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
30	1.10			
	1.40	0.524		
	1.30		2.590	
	1.26			
	1.31	0.677		
	1.81			12,430
	1.12		2.450	
	(1.26)	(0.600)	(2.520)	(12,430)
35	1.33		1.680	
	1.03			
	1.29			
	1.26		1.630	
	1.24	0.932		
	1.23	0.373		
	1.20			13,369
	0.71			11,268
	(1.16)	(0.653)	(1.655)	(12,318)
40	0.86			
	1.12	0.759		
	1.19	0.700		
	1.32		0.921	
	1.30		0.840	
	1.07			12,093
	0.97		2.600	
	(1.14)	(0.729)	(1.454)	(12,093)

Table B-I (continued)

REFUGIO

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
45	0.94			
	1.04		1.556	
	1.19	0.682		
	1.02			
	1.13	0.833		
	1.10		1.370	
	0.47			11,775
	(1.08)	(0.758)	(1.463)	(11,775)
50	1.09	0.869		
	1.23		1.270	
	1.09	0.763		
	1.35		1.110	
	1.03			11,203
	(1.19)	(0.816)	(1.190)	(11,203)

*Figures in parentheses are averages.

Table B-I (continued)

TALCO

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
15	1.22		3.060	
	1.16	0.900		
	1.05			11,929
	0.99	0.871		
	1.01		1.536	
	(1.09)	(0.885)	(2.298)	(11,929)
20	1.79	1.390		
	0.53	0.561		
	1.05			6,064
	0.93		2.330	
	0.95			12,088
	0.44		2.060	
	1.01	0.621		
	0.96			12,274
	(0.84)	(0.591)	(2.195)	(10,142)
25	1.78	0.951		
	0.98		7.45	
	0.94	0.371		
	0.92			10,835
	0.94		0.633	
	0.84			10,029
	(1.07)	(0.661)	(4.041)	(10,432)
30	1.52			11,658
	0.92		4.200	
	0.95	0.776		
	0.95		2.560	
	0.81	0.707		
	(1.03)	(0.742)	(3.380)	(11,658)

Table B-I (continued)

TALCO

Squeeze Roll Pressure	Oil Retention (lb oil/lb cotton)*	Ash Content (wt %)*	Moisture Content (wt %)*	BTU Value (BTU/lb)*
35	1.57	1.042		
	0.97		2.310	
	0.97			12,108
	0.87	0.999		
	0.89		1.188	
	0.78			
	(1.01)	(0.916)	(1.749)	
40	0.84		1.270	
	0.89	1.020		
	0.82			11,151
	0.80		0.634	
	0.91	0.605		
	(0.85)	(0.812)	(0.952)	(11,151)
45	0.84		5.690	
	0.92	0.889		
	0.88	0.798		
	0.84			11,040
	0.92		1.820	
	1.05			
	(0.91)	(0.843)	(3.755)	
50	0.86	0.577		
	0.83		3.768	
	0.88			11,432
	0.87			11,721
	0.83		2.02	
	0.75	0.6625		
	(0.84)	(0.6797)	(2.894)	(11,576)

*Figures in parentheses are averages.

TABLE B-II

RELATIONSHIP BETWEEN EFFLUENT AND INFLUENT

REFUGIO OIL RETENTION DATA

Pressure (psi)	Influent g oil/g cotton	Effluent g oil/g cotton
15	31.4	1.39
	32.7	1.34
	47.7	1.65
20	29.7	0.99
	37.5	1.26
	40.0	1.42
	41.8	1.33
	45.7	1.44
25	32.3	1.24
	26.6	1.16
	49.1	1.37
	49.2	1.54
	44.5	1.58
	40.7	1.48
	47.3	1.57
30	27.1	1.1
	37.8	1.3
	34.9	1.31
	48.8	1.4
	34.0	1.26
35	30.4	1.03
	39.3	1.26
	34.4	1.23
	43.6	1.24
	41.8	1.34
40	35.9	0.86
	38.3	1.18
	42.4	1.32
	42.1	1.12
	38.7	1.30
45	25.9	0.94
	28.0	1.19
	55.9	1.04
	51.8	1.13
	39.6	1.1
50	47.3	1.08
	41.0	1.09
	48.9	1.35