Environment Canada
Water Management

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Polyurethane as an Oil Filter: A Research Study

Final Report

Canadian Plant and Process Engineering Limited

Canada Centre for Inland Waters
Burlington, Ontario, 1972

GW 109-2-1008-59 **Commercial Letter & Litho Inc.**

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April 7 , 1972

The Honourable Jack Davis
Minister
Department of the Environment
Ottawa K1A OH3

Dear Mr. Minister:

We take pleasure in submitting to you this final report on the research project sponsored by Environment Canada referred to in your letter of March 5, 1971.

We feel that the research work has advanced the available knowledge to combat oil pollution and are grateful for having had an opportunity to share in this work with your Department. A close working relationship has existed throughout the study with members of your Department and C.C.I.W. in Burlington and A.O.L. in Halifax and this has contributed appreciably to the completeness of this work.

Respectfully submitted,

JOHN JAY, P.ENG.
President

JJ/bm
encl.

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED

POLYURETHANE AS AN OIL FILTER

A RESEARCH STUDY

FINAL REPORT

This Report concludes the research study relating to a Contract between the Department of the Environment (Fisheries and Forestry) and Canadian Plant and Process Engineering Limited, Consulting Engineers, Halifax, Canada. The First and Second Interim Reports form Appendices II and III of this Report.

The Report deals with various aspects of oil pollution and the feasibility of using polyurethane as an oil filter.

MARCH 1972

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CANADIAN PLANT AND PROCESS ENGINEERING LIMITED MARCH 1972

POLYURETHANE AS AN OIL FILTER

A RESEARCH STUDY

FINAL REPORT

1.0 INTRODUCTION

In April of 1971 an agreement was entered into between the Department of Fisheries and Forestry of Canada and Canadian Plant and Process Engineering Limited, Consulting Engineers, Halifax, Canada, to undertake a research study relating to various aspects of oil pollution in the marine environment and the suitability of polyurethane foam as a medium for the separation of oil from water.

The Conditions of the Contract form Part 1.3 of this report.

1.1 GENERAL SUMMARY

(a) The report concludes that polyurethane is readily available in the developed market economies and consequently its usefullness as a filter medium is enhanced by this manufacturing and marketing pattern.

(b) A variety of petroleum products are transported in bulk with the volume increasing in absolute terms and the conveyance vehicles increasing in size with little or no improvement in environmental safeguards.

(c) Oil pollution in harbour and coastal waters is known to exist on a continual basis being contributed to by a wide variety of sources.

There is no governmental organization or body monitoring this background level of pollution to determine the rate of increase or the affect this oil pollution has on the ecology. Studies have very recently commenced at CCIW dealing with some aspects of this problem.

(d) The hydraulic testing carried out has confirmed a relationship between flow and density with flexible foams in the range of 1.8 lbs./cu.ft. exhibiting the optimum properties under the test conditions which assessed temperature, salinity and filter area in relation to flow.

(e) Of the variety of foams tested, the foam with the best hydraulic properties performed as satisfactorily as the others in the separation of the residual fuels and marine diesel from both fresh and sea water.

In general, flexible polyurethane foams with an average density of 1.8 lbs./cu.ft. have been shown to be 99% effective in removal of Bunker 'C' and 70% effective in the removal of marine diesel from water.

The foams tested were 60% effective in the removal of crude oil from water and not effective in the separation of phenols from water.

(f) It should be noted that very high flow rates have been used throughout the testing; always in excess of 10 gpm/ft^2. These rates compare with rapid sand filtration rates of 3-4 gpm/ft.^{2} and effectively mean that a very large capacity filter can be built and operated in a small area.

(g) It should also be noted that the influent concentrations of oil are extremely high as compared with the levels of pollution which would be encountered in actual practice being in many cases in excess of 100 ppm. With Bunker C particularly, effluent concentrations of less than 1 ppm have consistently been obtained regardless of influent concentrations.

(h) Disposal of the used filter medium can be accomplished by incineration without creating an air pollution problem.

(i) Design parameters have been established in general terms for separation of Bunker 'C' and marine diesel from water.

(j) In our opinion polyurethane has a direct application as an oil/water separator in many pollution problems, specifically as a tertiary treatment of refinery wastes and as a means of dealing with the clean up of water discharged into harbours and oceans from ships' bilges.

1.2 ACKNOWLEDGEMENTS

The authors would like to acknowledge the help, encouragement and support of a wide variety of individuals of organizations without whose help this report would be inconclusive.

A complete list of all those who have been involved in the project would not be possible, however, we wish to specifically acknowledge the contributions of the following:

Mr. A.S. Atkinson	CCIW Environment Canada
Dr. R.W. Durham	
Dr. L. Lau	
Dr. A.L. Lefeuvre	
Dr. E. Nagy	
Mr. S.B. McPhee	AOL Environment Canada
Dr. P.D. McTaggart-Cowan	Science Council of Canada
Mr. J.T. Hanna	Monsanto Canada Ltd. Toronto
Mr. Trevor Housser	Imperial Oil Canada Ltd.

1.3 CONTRACT FOR A RESEARCH STUDY

ON

POLYURETHANE FILTER

This Agreement is made this 8th. day of April 1971.

BETWEEN:

The Department of Fisheries and Forestry

AND:

Canadian Plant and Process Engineering Limited
Consulting Engineers, Halifax, N.S.

Conditions of this Contract

The contractor, Canadian Plant and Process Engineering Limited, shall undertake to:

(a) investigate the commercial manufacture of polyurethane, its manufacturers, availability, and cost per unit on a national and international basis;

(b) investigate practices in the bulk handling of petroleum products nationally and internationally and to report on industry trends in this regard;

(c) assess harbour pollution problems resulting from oil pollution originating in ships or refineries;

(d) carry out and coordinate experiments, using various combinations of petroleum products, water and polyurethane, to determine the physical and chemical characteristics of these compounds and their relationship in order to produce design criteria for oil/water filters; and

(e) analyze these results and report on all of these matters to the Department of Fisheries and Forestry following review with officials of the Department of Fisheries and Forestry.

1.4 DEFINITIONS

The following definitions apply throughout the report.

Adsorption Zone is the concentration gradient or profile resulting from the deposition of solute by adsorption in a fixed bed column in the direction of flow.

The Break Point is the point at which the adsorption zone has just reached the bottom of the bed and the concentration of the solute in the effluent begins to rise for the first time.

Breakthrough Curve is the curve resulting from rapid build up of effluent concentration after the breakpoint is reached.

The Code Numbers referring to the various foams are those used by Monsanto Canada Limited. The first two numbers refer to the average density.

Filter is the term used for the polyurethane adsorption column and does not imply mechanical separation as in conventional filtration.

Flood Point is the maximum flow for a particular filter, at which the column would operate at steady state conditions.

<u>Head</u> is defined as the height of water over the filter bed.

<u>Oil Head Loss</u> is the increase in head due to the build up of oil in the filter. It is the difference between the total head and the hydraulic head.

2.0 POLYURETHANE FOAM

Polyurethane foam is a readily available product throughout the Western World. Its widespread use in the automotive and furniture industries dictates that industrial nations will also have producers of foam. As the basic ingredients of resins and isocyanates are derivatives of the petrochemical industry, in any country with such an industry there will be a plentiful supply of raw materials. The technology is relatively uniform throughout the world, principally because the size of the industry permits new advances in technology to become quickly known and adopted.

There are seven flexible foam manufacturers in Canada:

Delaney and Pettit Industries Ltd.,
Goodyear Tire & Rubber Co. of Canada Ltd.,
Mansonville Plastics Ltd.,
Monsanto Canada Ltd.,
Paramount Industries,
Reeves Industries,
G.E. Shnier Co.

In the United States there are a great number of foam manufacturers; the exact number is difficult to determine because trade directory listings do not clearly distinguish between foam and other plastics derivatives. Directories which might indicate the number and location of foam manufacturers in other parts of the world could not be located. Information on foam prices outside of Canada was not available.

The current quoted price for flexible foam from manufacturers in Central Canada is 11 cents per board foot; in Halifax the broker's price is 18 cents. The one price applies to all densities of foam. <u>It may be assumed that the Canadian experience in polyurethane foam is being duplicated in the other developed market economies, and that factors of availability and price are comparable</u>.

3.0 BULK HANDLING OF PETROLEUM PRODUCTS

The conclusion of the investigation into the practices in the bulk handling of petroleum products and on industry trends in that regard (Appendix II, para. 3.0) is that the actual methods of transferring these products from point to point have changed very little in recent decades, while in the last decade tremendous change has been seen in the volumes of product moved and in the size of oil tankers and pipelines. It is noted that the significance of technological advances in tanker and pipeline building lies in the fact that as units of transportation, giant pipelines and mammoth tankers represent potential threats to the environment of greatly increased scale. Perhaps of even greater significance, however, is the fact that there appears to have been little or no technological advance in the methods of handling petroleum products at the various stages of the transportation and consumption networks. These traditional handling methods cause more pollution of the seas than do major disasters. In our discussion of oil pollution in harbour and coastal waters (Appendix III, para. 2.3) we include the statement of E.M. Levy that "the major portion of this oil originates not, as might be expected, from major disasters, but from the countless day to day incidents that occur during the transportation, transferral, and consumption of oil".

As shipments of petroleum products have increased, as the size of carriers has grown, and as the number of users has broadened, there has developed a variety of international agreements and regulations of national governments designed to minimize the risk of accidental oil spills and to control the pollution being caused by industrial and domestic users. As well, the participants in the petroleum industry have evolved procedures and contingency plans to be employed in the event of accident. As safeguards against risk and as control devices to prevent flagrant violation the effectiveness of these agreements, regulations, and methods will be related to the degree of their acceptance and the strength of their enforcement. Meanwhile, however, traditional handling practices continue with relatively little alteration. The "load on top" method being advocated among tanker operators comprises one new practice; this method is expected to reduce the volume of oil being discharged at sea through deballasting and tank cleaning. It follows that corresponding reductions could be made if new ways, or improvements on existing practices, could be found for other aspects of bulk handling.

4.0 OIL POLLUTION IN HARBOURS AND COASTAL AREAS

4.1 GENERAL

Detailed discussion of the sources and of the level of oil pollution in harbours and coastal areas is contained in Appendices I, II, and III of this report. All of the discussion has proceeded from a basic assumption that the question being considered concerns chronic oil pollution, as distinguished from that caused by shipwreck or other type of disaster.

There are four major categories into which the sources of oil pollution may be grouped, namely, the production of oil, the processing of petroleum products, the transportation and marketing of the products, and their utilization in commerce and industry. The first and second categories apply only in some harbour locations; the third and fourth apply in all harbour installations and their adjacent coastal areas.

4.2 SOURCES OF POLLUTION

In the average port there will be chronic oil pollution resulting from:

Commercial Vessels -	which must take on fuel, pump oily bilge water and discharge oily ballast from fuel tanks;

Naval Vessels - which function similarly;

Oil Tankers - which provide several opportunities for losing oil: faulty hose connections, leaking pumps, overflowed tanks, improperly closed sea-valves, ballast discharge, tank cleaning,and bilge pumping.

Industrial Plants - whose oily wastes and accidental fuel oil losses frequently enter the harbour water directly;

Municipal Sewers - which are known to carry oily substances from an untold number of domestic and commercial sources; and

Run-off - which would carry with it waste oil from a variety of sources.

In a harbour with refinery facilities the degree of pollution will be greater as a result of the several aspects of refinery operations by which oil can escape to the harbour waters. In those harbours with nearby petroleum production activities, either on-shore or off-shore, the potential for pollution of the water is correspondingly greater.

4.3 QUANTITATIVE MONITORING OF POLLUTION

A great deal has been written about the sources of oil pollution, of the probable quantities or volumes the individual sources contribute to adjacent waters, and of the effects of oil pollution on the environment. A variety of international, national, and municipal agreements, regulations, and ordinances attempt to control the more obvious polluters. However, very little appears to have been done to determine the total magnitude of the problem, that is, to determine the overall concentration of oil in any given harbour or coastal area at any given time, or over any given period. It is known that natural biological processes neutralize the effects of a certain quantity of oil in water. In particular harbour areas the capacity of these processes would vary according to such factors as wind direction and flushing rate. A study of the physical and biological oceanography of a harbour, together with a sampling analysis of the water column, would determine the capacity of the harbour to assimilate oil and permit the determination of an acceptable level of pollution, or an "oil pollution index". With such a guideline in hand a government agency could effectively control oil pollution by demonstrating to an "offender", whether it was a municipal sewer system, a refinery, or a shipyard or dockyard, that his activities were accounting for a disproportionate share of the total problem.

In the absence of comprehensive data on the actual quantity of oil contained in the water column we suggest that a valid assessment of oil pollution in harbours and coastal areas is impossible. To know where the oil comes from, and to know, for sources that can be isolated, how much oil they contribute, is to know only part of the total picture. We would recommend that steps be taken to fill in the missing part, by selecting a harbour location and undertaking hydraulic and biological studies to determine what its oil pollution index might be.

5.0 HYDRAULIC TESTING

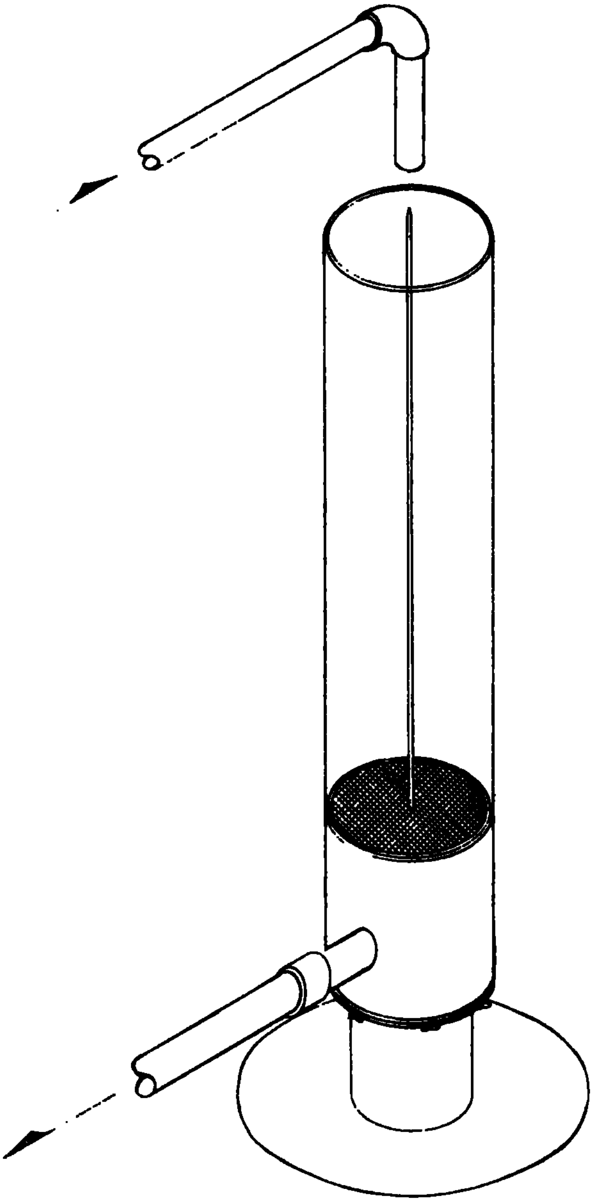
5.1 INTRODUCTION

The use of polyurethane foams for the clarification of oily waste water depends on the affinity of oil for the foam, and on the ability of the foam to pass large quantities of water.

A programme to examine the hydraulic performance of various foams was carried out before examination of the capacity of the foams to adsorb oil. The hydraulic tests are somewhat easier to carry out, and consequently this programme was used to "screen" the various foams and reduce the amount of experimental work to be done in the mass transfer programme.

The equipment used was an 8 in. diameter plexiglass column arranged vertically and capable of accepting discs of foam fitted horizontally as indicated in Figure 5.1. Water was delivered to the upper surface of the foam and was allowed to drain through the foam bed to a sump. Details of the equipment and experimental procedure are given in the 1st Interim Report, Sections 5.3 and 5.4 (Appendix II).

The flood point was used as the limit condition as it is an easily measurable indication of maximum capacity. It was found to depend on foam type and foam bed thickness.



SMALL SCALE APPARATUS

DWG. No. 1

FIG. No. 5.1

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PORT HAWKESBURY, N. S.

Ten foam types were tested in the programme; three of the foams were of the "filled" type and were found to behave differently from and inferior to the unfilled foams. The flood point for the ten foams and for various bed thicknesses are summarized in Table 5.1. As can be seen the flow rates are extremely high as compared with conventional filtration rates.

5.2 EFFECT OF FOAM PROPERTIES

Attempts were made to correlate the differences in behaviour of the foams with differences in physical properties. Correlations were established with density, elongation and resiliency. The correlation with density is the most significant, as this is the way in which foams are identified and characterized, by the various foam manufacturers. The effect of density, for various bed depths, is shown in Figure 5.2. The optimum density is about 1.8 lb./ft.^{3} with Monsanto foam 1835 having the highest flood point of those tested.

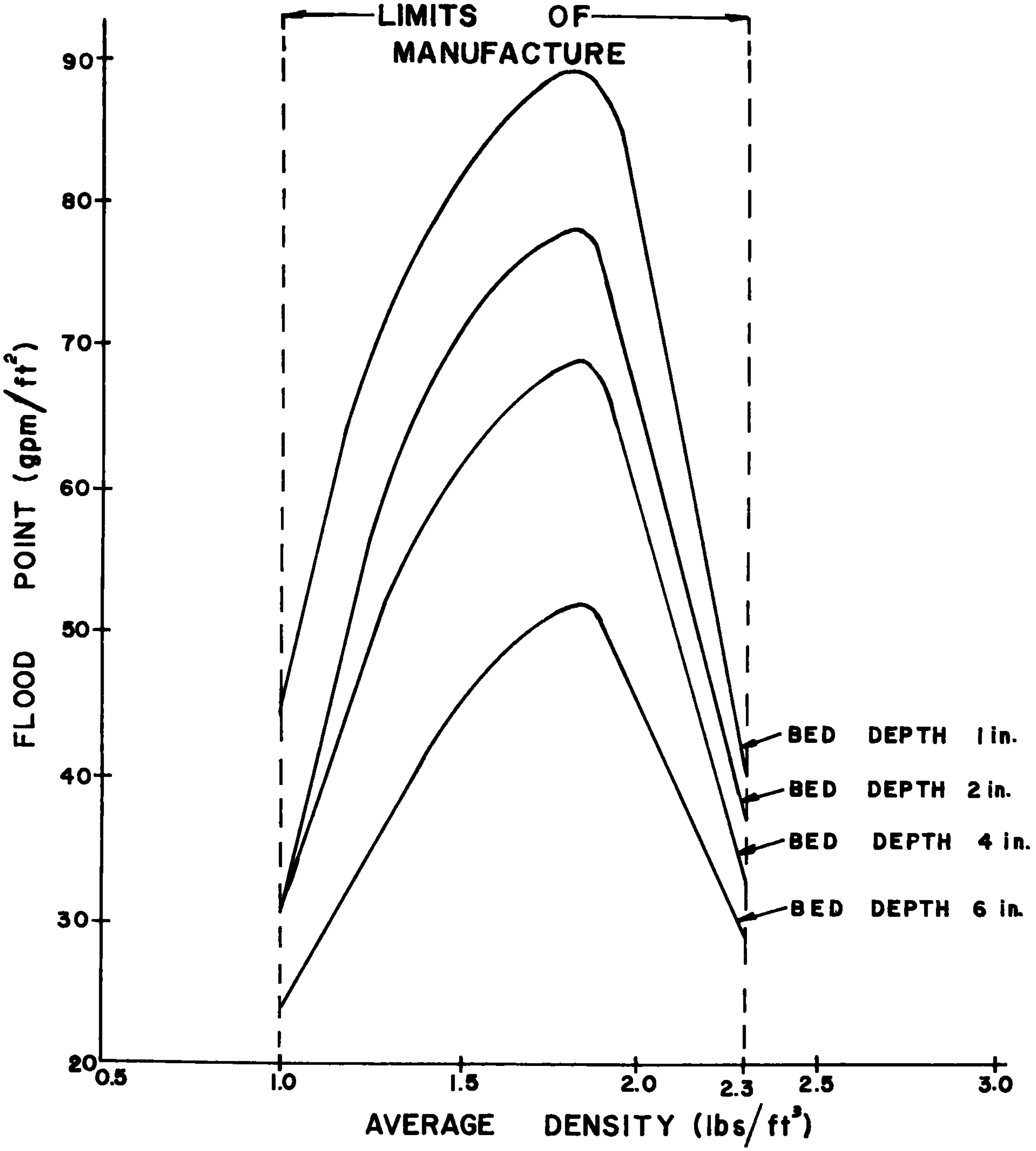
5.3 EFFECT OF SCALE, SALINITY, AND TEMPERATURE

The effect of other variables, i.e. scale, salinity and temperature were also studied,

FOAM TYPE	FLOOD POINT (gpm/ft.^{2})				ELONGATION %	RESILIENCY %	AVERAGE DENSITY lb/ft.^{3}
	1 in.	2 in.	4 in.	6 in.			
1029	65.	35.	35.	26.	150	40	1.00
1130	43.	35.	35.	26.	150	45	1.10
1329	86.	65.	56.	39.	180	50	1.27
1528	86.	56.	52.	39.	170	52	1.52
1835	89.	78.	69.	52.	200	55	1.82
1855 SC	30.	9.	9.	-	120	20	1.82
2045	-	54.	42.	30.	175	40	2.00
2335	56.	48.	39.	30.	150	48	2.27
3337F	39.	30.	17.	13.	100	40	3.30
3865F	56.	52.	48.	30.	90	35	3.75

TABLE 5.1

EFFECT OF FOAM TYPE, BED DEPTH & PHYSICAL PROPERTIES ON FLOOD POINT



FLOOD POINT vs DENSITY
UNFILLED FOAMS

FIGURE 5.2

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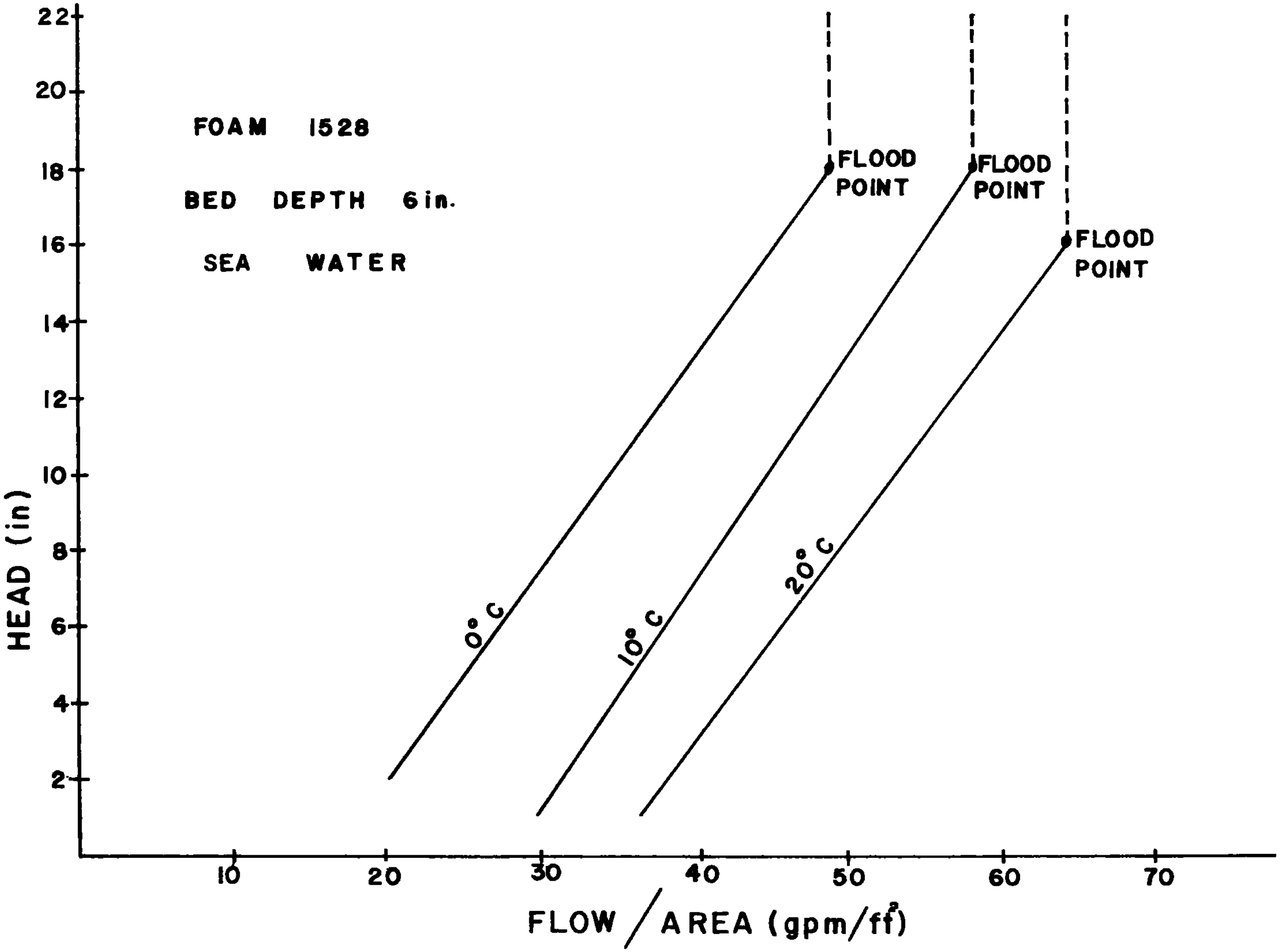
the details being given in the 1st and 2nd Interim Reports. It was found that the flow in gal/min/ft^2 of surface area of bed was a satisfactory parameter for scaling up from an 8 in. to a 22.5 in. diameter filter.

Salinity did not appear to have any great effect on the quantity of water passing through the foams.

Temperature had a distinct effect on the hydraulic behaviour of the foams. Figures 5.3 and 5.4 show the effect of temperature on the relationship between flow through a foam bed and the corresponding head above the bed.



HEAD vs FLOW/AREA

FIGURE 5.3

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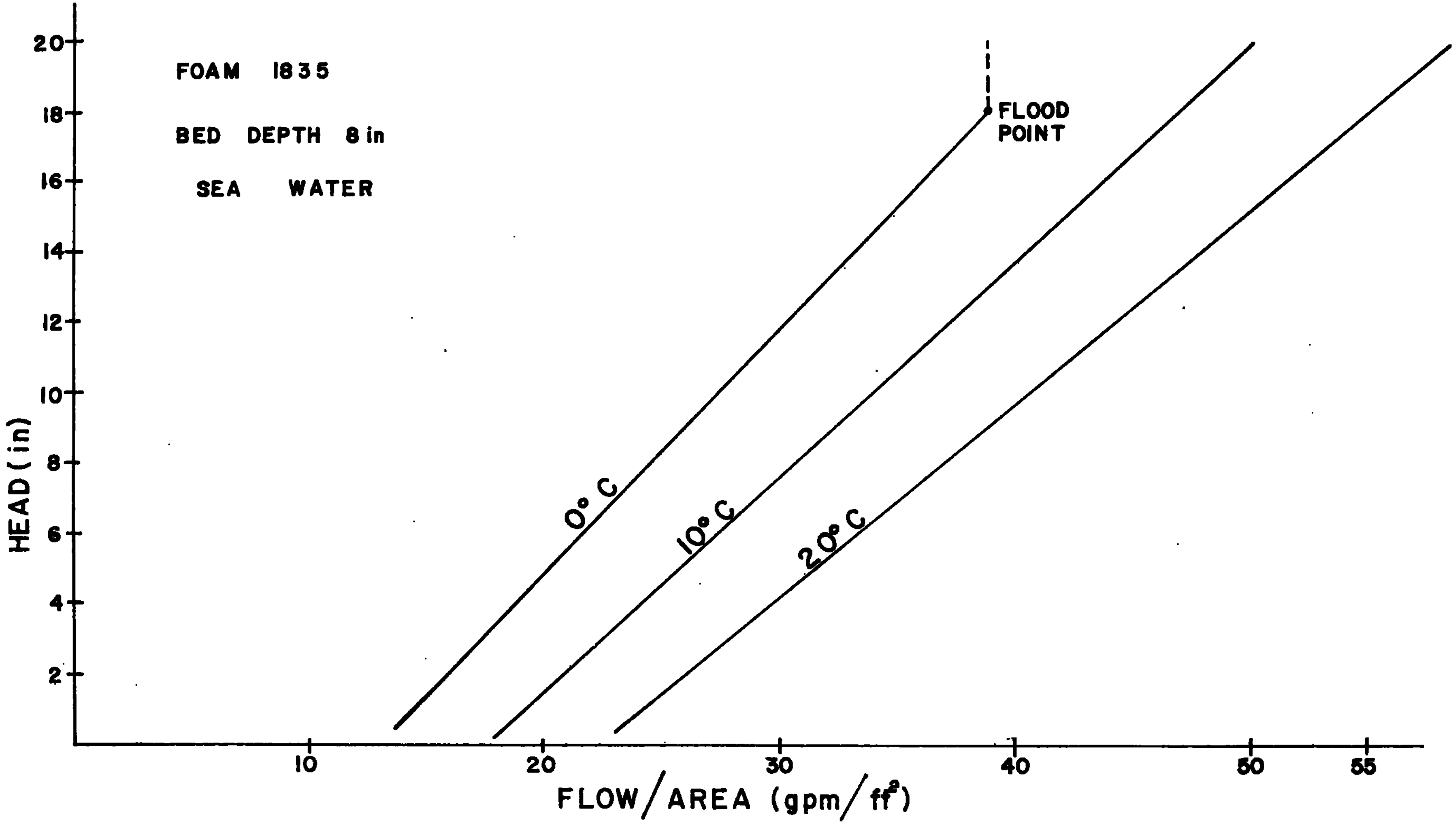

HEAD vs FLOW / AREA

FIGURE 5.4

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6.0 MASS TRANSFER

6.1 INTRODUCTION

Mass transfer studies were carried out with various petroleum products using polyurethane foam as an adsorbent ranging in average density from 1.0 lb./ft.^{3} to 2.3 lb./ft.^{3} for unfilled foams and 3.3 lb./ft.^{3} to 3.8 lb./ft.^{3} for filled foams. Bunker C, marine diesel, and crude oil were the petroleum products tested and a trial was also made with phenol, a commonly occurring substance in petroleum products and wastes.

The trials were done on an 8 in. diameter plexiglass column arranged and operated as described in 2nd Interim Report, Section 4.1 (Appendix III).

6.2 BUNKER C

Removals of up to 99.93% bunker C from fresh water were achieved with effluent concentrations as low as 0.18 ppm. Foams 1835 and 1528 gave the best overall performance both hydraulically and with respect to oil removal.

Effluent concentration was found to be fairly independent of inlet concentration and bed depth.

The limiting factor in the capacity of the foam for bunker C adsorption was found to be hydraulic failure due to blinding of the surface of the bed rather than saturation of the bed with bunker C.

Foam chunks above the bed would greatly increase the life of the foam by adsorbing the poorly dispersed oil. An optimum bed depth was found to be 4 inches.

Temperature of the water was found not to have a discernible difference on effluent concentration. Increase in salinity from fresh water to sea water was found to improve effluent quality slightly.

Filled foams tended to give very poor removals and hydraulic performances compared with natural or unfilled foams.

6.3 MARINE DIESEL

Removals as high as 82.9% of marine diesel from fresh water were obtained. An appreciable increase in removal was obtained with the increase in salinity from fresh water to sea water. Removals as high as 96.9% were obtained with marine diesel in salt water. Temperature was found not to have any appreciable effect on effluent quality.

The lower density foams 1130 and 1329 gave much better removals but hydraulic performance was considerably lower than for the higher density foams.

Capacity runs on foam 1835 with sea water at 0°C. and 20°C. revealed that the foam will fail when the bed is completely saturated with diesel. However, the hydraulic capacity of the foam was found to be a function of diesel build up in the bed so that increasing the bed depth to increase the length of the filter run will be limited by minimum amount of flow required through the filter. An optimum bed depth was found to be 8 inches. The capacity of the foam at an average inlet concentration of 108.3 ppm and at 0°C. was 5.1 lb. diesel/ft.^{3} of foam. At an average inlet concentration of 53.0 ppm and at 20°C. the capacity of the foam was 6.6 lb. of diesel/ft.^{3} of foam. The filled foam 3337F was found to give very poor removal and hydraulic performance.

6.4 CRUDE OIL

Removals of up to 64.6% of crude oil from fresh water were obtained with effluent concentrations as low as 3.8 ppm. Foams 1329, 1528, 1835 and 2045 were tested at a 6 in. bed depth and were found to give very close results with respect to oil removal but there was appreciable difference in hydraulic performance. Foam 1528 gave the best hydraulic performance in these trials.

6.5 PHENOL

The trial conducted with phenol with foam 1835 at an 8 in. bed depth revealed that polyurethane is ineffective for removal of phenol.

7.0 LARGE SCALE TESTING

Large scale testing was carried out at the Bedford Institute with sea water on a 22.5 inch diameter filter to determine whether scale-up factors were necessary in designing larger filters. A description of the equipment is given in the 2nd Interim Report (Appendix III, p.55). Trials were carried out with bunker C, marine diesel and crude oil.

It was found that flow/area was a satisfactory way of allowing for the effect of filter diameter and hence size of filter. The quality of the effluent was found not to be appreciably affected by scale-up.

The filter for the large scale testing was operated on a stop-start basis and found not to have any effect on the quality of the effluent or the hydraulic performance of the foam.

8.0 DISPOSAL OF USED FOAMS

Once the foam has reached its capacity to remove oil, disposal would be necessary. Reclamation is not considered to be practical if in fact possible. Packaging of the used foams in water tight containers such as plastic bags with sealable flaps made especially to accommodate the foam would be required for temporary storage and for transportation to the disposal site.

Incineration is recommended as the most feasible means of disposal. The pyrolysis products from the burning of polyurethane do not produce any serious air pollution problems.

A second means of disposal is by sanitary landfill. Special attention may be required by the operator of the landfill site if large quantities of foams were disposed of at once but otherwise there would be no problems arising from this method of disposal.

9.0 FILTER DESIGN

9.1 INTRODUCTION

In arriving at the limiting conditions two parameters must be considered (a) the capacity of the medium to retain the quantity of oil to be removed and (b) the ability of the medium to pass the quantity of transporting water initially present.

In the case of marine diesel for which examples are given below, the volume of the filter medium is used in calculating the parameter outlined in (a) above while in the case of the residual fuels the surface area of the filter is the governing factor.

The hydraulic capacity of the medium in both cases is related to the physical dimensions of the medium and the amount of oil in or on the medium.

The ability of the medium to pass the transporting water depends on two factors, the resistance inherent in the medium itself and the resistance caused by the oil collecting in the medium.

For a given flow, the first resistance is not a function of the running time, whereas the second resistance obviously does depend on the length of operation.

9.2 DESIGN PARAMETERS - MARINE DIESEL

The design of a filter for use with marine diesel must satisfy two requirements, viz: the foam must be able to adsorb the amount of oil in the water and the foam must be able to accept and discharge the quantity of water transporting the oil.

The limiting design factor will be the greater of the two conditions.

Example 1. Given: 300 gpm sea water @ 20°C containing 100 ppm marine diesel.

Required: a filter to reduce the effluent to 5 ppm for a period of 10 hours without change of filter.

Hydraulic Procedure: 1. Calculate quantity of oil to be removed

$$\frac{100-5}{100{,}000} \times 300 \times 60 \times 10 = \underline{171 \text{ lbs.}}$$

2. From Figure 9.1 choose safe foam capacity (eg.) 5#/ft^3 @ 8 in. bed depth and determine oil head loss of 14 in.

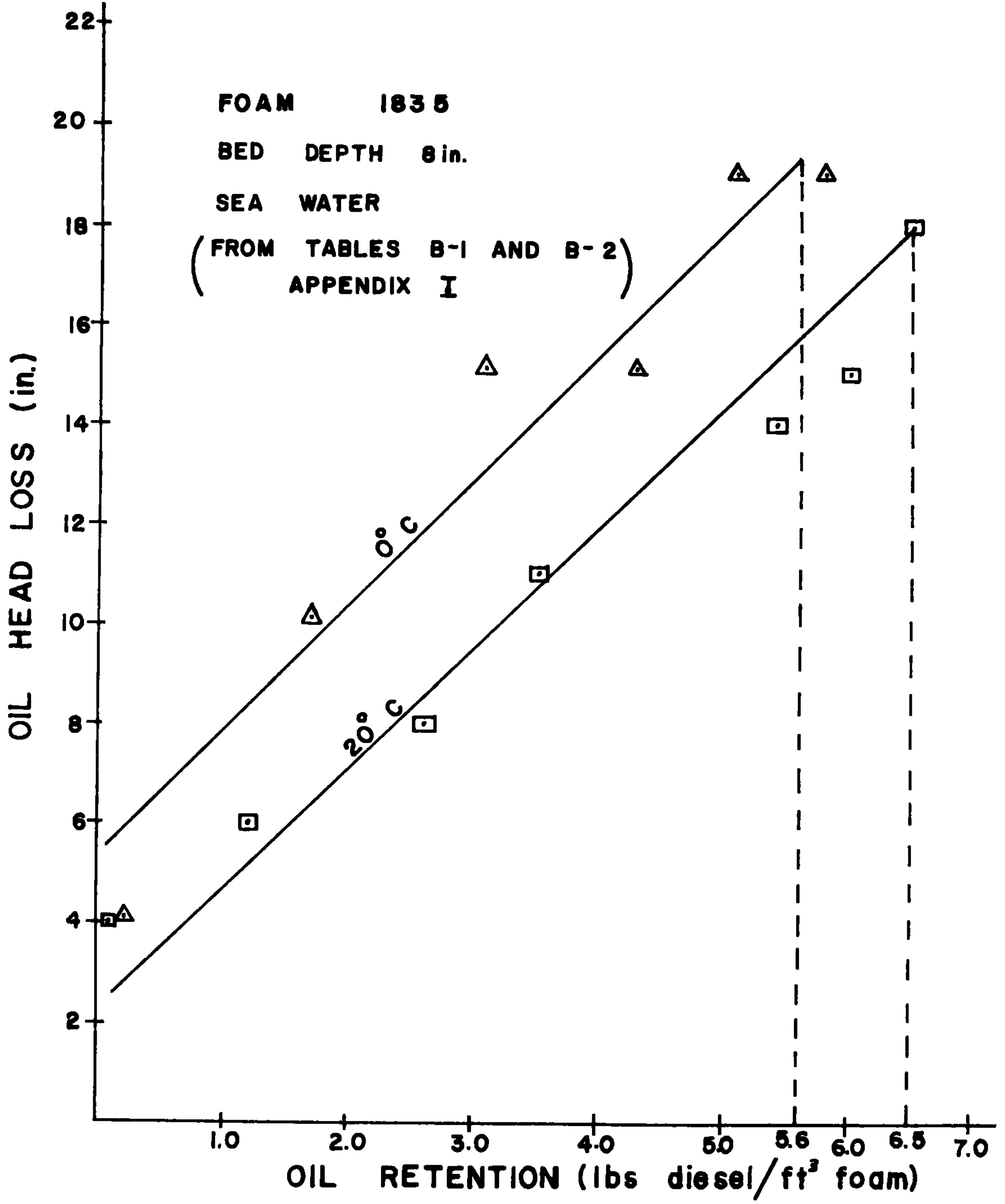
3. From Figure 9.2 with oil head loss of 14 in. determine at 20°C. flow/area of 20 gpm/ft^2

4. Calculate area of filter @ 8 in. thickness.

$$\frac{300}{20} = 15 \text{ ft.}^2$$

5. Diameter $= \sqrt{\frac{15 \times 4}{3.14}} = 4.4$ ft.

$= 53$ inches.



OIL RETENTION vs OIL HEAD LOSS

FIGURE 9.1

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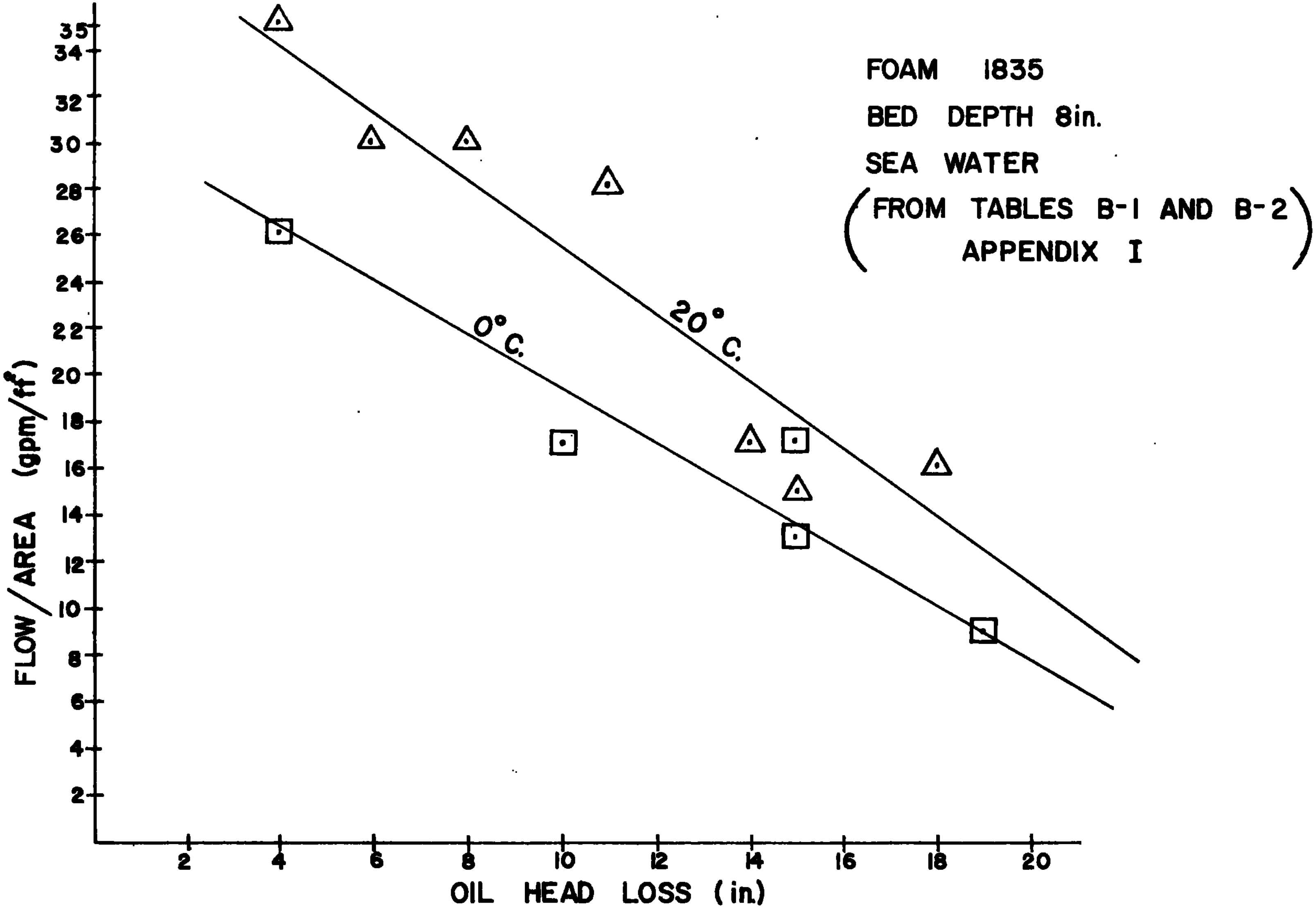

FLOW/AREA VS OIL HEAD LOSS

FIGURE 9·2

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Check Mass Transfer

6. Calculate quantity as in 1. above
   = 171 lbs.

7. Calculate foam volume required: (Table 9.1) $= \frac{171}{5}$ or 34.2 cu. ft.

8. Assume 3 in. filter depth calculate area and diameter

$$\text{Diameter} = \sqrt{\frac{34.2 \times 12}{2 \times \pi}}$$

$$= 8.1 \text{ ft. or } 100 \text{ in.}$$

NOTE: In this example the mass transfer or adsorption is the limiting factor and a 100 in. diameter filter must be used.

Example 2. Given: 1000 gpm sea water @ 20°C. containing 20 ppm marine diesel.

Required: a filter to reduce the effluent to 5 ppm for a period of 10 hours without change of filter.

Hydraulic Procedure: 1. Calculate quantity of oil to be removed.

$$\frac{20 - 5}{100{,}000} \times 100 \times 60 \times 10 = 90 \text{ lbs.}$$

2. From Figure 9.1 choose safe foam capacity e.g. 5#/ft.^{3} @ 8 in. bed depth and determine oil head loss of 14 in.

3. From Figure 9.2 with oil head loss of 14 in. determine at 20°C. flow/area of 20 gpm/ft.^{2}

4. Calculate area of filter @ 8 in. thickness

$$\frac{1000}{20} = 50 \text{ ft.}^2$$

5. Diameter = 96 in.

Check Mass Transfer

6. Calculate quantity as in 1. above = 90 lbs.

7. Calculate volume required from Figure 9.1 = $\frac{90}{5}$ or 18 cu. ft.

8. Assume 8 in. filter depth calculate area and diameter

$$\text{Diameter} \quad \sqrt{\frac{18 \times 12}{2 \times \pi}} \times 12$$

$$= \underline{70 \text{ inches}}$$

NOTE: In this example the hydraulic limitations govern and the 96 in. diameter must be used.

10.0 BIBLIOGRAPHY AND LITERATURE SEARCH

10.1 BIBLIOGRAPHY

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10.2 LITERATURE SEARCH

An extensive search was carried out to review and evaluate the current state of technology of prevention and control of major oil spillage on water, with particular respect to the use of polyurethane foam as a selective filtration medium. Specific areas reviewed were:

(a) on-scene control of gross leakage,

(b) destruction or recovery of oil slicks at sea, and

(c) disposal of recovered mixtures. These areas relate to oil spillage regardless of origin, including that from tankers and from offshore production operations.

The library index facilities of Dalhousie University and the Nova Scotia Technical College, Halifax, were employed in this research, and extensive use was made of the special section of the library at the Bedford Institute devoted to oil pollution. An essential part of the literature search entailed the use of a computerized system for information storage and retrieval organized by the National Science Library of the National Research Council, called the CAN/SDI Project. Scientific and technical information appearing in such data bases as Chemical Abstracts is summarized and stored in the memory of a computer. The user prepares a word description or profile of the particular topic in which he is interested and this is fed into the computer which compares key words from the profile with those of articles in its memory bank. The computer then prints references to literature articles which appear to relate to the interests of the user.

For this project, we used the word profile on oil pollution prepared by Dr. M. McMullen formerly of Bedford Institute for use by the Scientific Co-ordination Team of "Operation Oil". This profile contains key words such as filter, oil, waste water, polyurethane foams, etc., and consequently was extremely suitable for application to this project.

There are many references to methods of using polyurethane foam on large scale oil spills under varying sea conditions, oil viscosities, and temperatures; none of the methods has attracted more than token acceptance. Among the several approaches taken to utilizing the adsorbing properties of foam, there was no reference to any attempt to use foam as a filter medium except as noted in 4.4 Appendix I.

APPENDIX I

POLYURETHANE AS AN OIL FILTER

— a research study

POLYURETHANE AS AN OIL FILTER

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CANADIAN PLANT AND PROCESS ENGINEERING LIMITED

MARCH, 1972

POLYURETHANE AS AN OIL FILTER

A RESEARCH STUDY

FINAL REPORT

APPENDIX I

1.0 INTRODUCTION

This Appendix to the Final Report contains the concluding information on harbour and coastal pollution and the concluding laboratory results dealing with both the hydraulic testing and mass transfer experiments utilizing flexible polyurethane foam as an oil filter.

The products of combustion of flexible polyurethane foams are also reviewed.

2.0 OIL POLLUTION IN HARBOURS AND COASTAL AREAS

2.1 DISCUSSION

In Paragraph 2.3 of the Second Interim Report (Appendix III), it was indicated that research was continuing in our efforts to develop quantitative information on the level of oil pollution in harbour and coastal waters. This research has been concluded, and we can report that we are unable to add to what we have already written, any data specifically related to the question.

We referred the question to the Halifax office of the Water Survey of Canada, Department of the Environment. They knew of no work in this area other than that which was undertaken by Drs. Gordon and Levy at the Bedford Institute, and on which we have reported.

With specific reference to articles and reports of the International Joint Commission, we were advised that there was no collection of these in any local library, either public or private, and were referred to the secretary of the Canadian Section of the IJC in Ottawa.

Officials of the Commission recognize that a distinct information gap exists with respect to the monitoring of oil pollution. Of the three Commission studies[1] recommended to us, none is reported to contain data on the quantity of oil present in a column of water over a given period of time. Commission officials could not suggest where such data might be found. They agree that emphasis should be placed on the need for study in this area, and suggest that with such data the relative success of efforts to control and reduce oil pollution could be measured.

Alcan Shipping Services Ltd., Montreal, has recently published a three-volume report entitled "Pollution in the Maritime Industry".[2] As it is a privately financed and prepared document, the information contained therein is not freely available, and we have not examined it. However, a detailed index was forwarded to us by Alcan, and a perusal of this, together with opinion expressed by one of the authors, Mr. James Balfour, leads us to the conclusion that the report contains no information of a quantitative nature on the presence of residual oils in harbours and coastal areas.

2.2 REFERENCES

1 "The Niagara River Pollution Abatement Program, 1971", "Potential Oil Pollution from Oil and Gas Well Activities in Lake Erie","Report to the International Joint Commission on Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River", Reports of the International Joint Commission, Ottawa, Ontario.

2 "Pollution in the Maritime Industry", Report prepared by Alcan Shipping Services Ltd., Montreal, February 1972.

3.0 HYDRAULIC TESTING

3.1 INTRODUCTION

The bulk of the hydraulic testing programme is reported in Appendices II and III. This section concludes the work done on the effect of scale and salinity and describes the work done on the effect of temperature. The 8 in. diameter and 22.5 in. diameter equipment described in the 1st and 2nd Interim Reports were both used.

3.2 EFFECT OF SCALE

Measurements of the effect of flow rate through the filter bed on the head of water above the bed were carried out on both the 8 in. diameter and the 22.5 in. diameter filter. The tests were carried out using an 8 in. bed depth of foam 1835, which previous testing had shown to have the highest flood point.

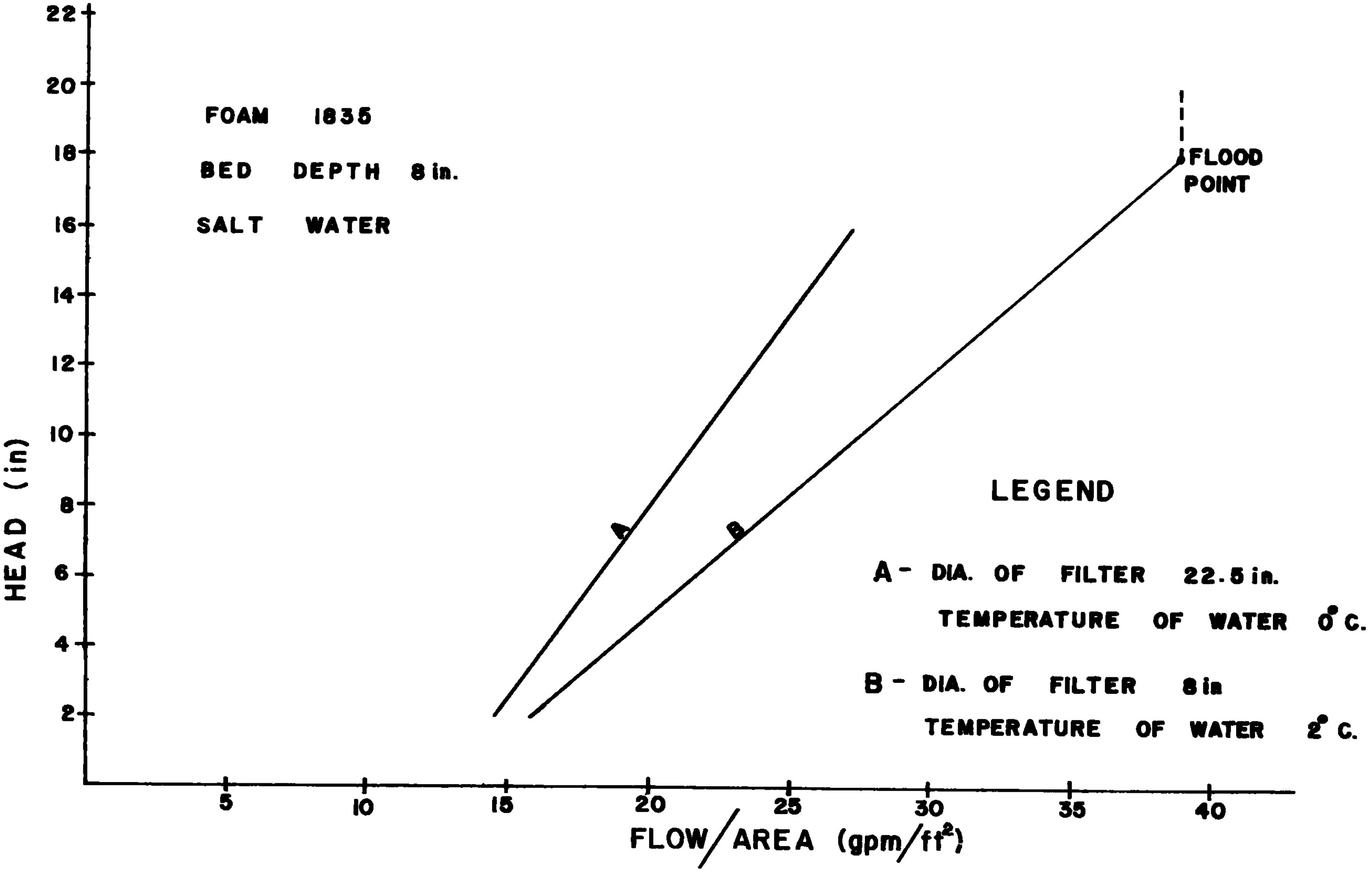
The results for the two diameters are shown on Figure 3.1, the relevant data being recorded on Table 3.1.

The two sets of results are compared using the flow per unit area of bed as the correlating parameter. As can be seen, there is a slight difference in the two sets of results, but when

TABLE 3.1

EFFECT OF SCALE ON HYDRAULIC BEHAVIOUR OF 8 in. BED DEPTH OF FOAM 1835 USING SALT WATER

8 in. DIAMETER BED			22.5 in. DIAMETER BED		
FLOW		HEAD	FLOW		HEAD
gal/min.	gal/min.ft.^{2}	in.	gal/min.	gal/min.ft.^{2}	in.
6.0	17.2	2	40.0	14.2	2
6.0	17.2	3	-	-	-
7.5	21.6	6	55.0	19.9	7
9.0	25.9	8	65.0	19.9	8
9.0	25.9	10	65.0	23.5	13
10.5	30.2	12	70.0	25.3	12
11.1	31.9	14	75.0	27.2	16
12.0	34.5	16	-	-	-
13.5	38.8	18	-	-	-
13.5	38.8	20	-	-	-
TEMPERATURE 2°C.			TEMPERATURE 0°C.		



HEAD vs FLOW/AREA	FIGURE 3.1

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one considers that the head above the bed is inversely proportional to the temperature (as will be discussed in the next section) and that there is a considerable variation in the results obtained from identical experiments carried out on the same foam (Page 31, Appendix III) then the flow per unit area appears to be a satisfactory way of allowing for the effect of filter diameter and size.

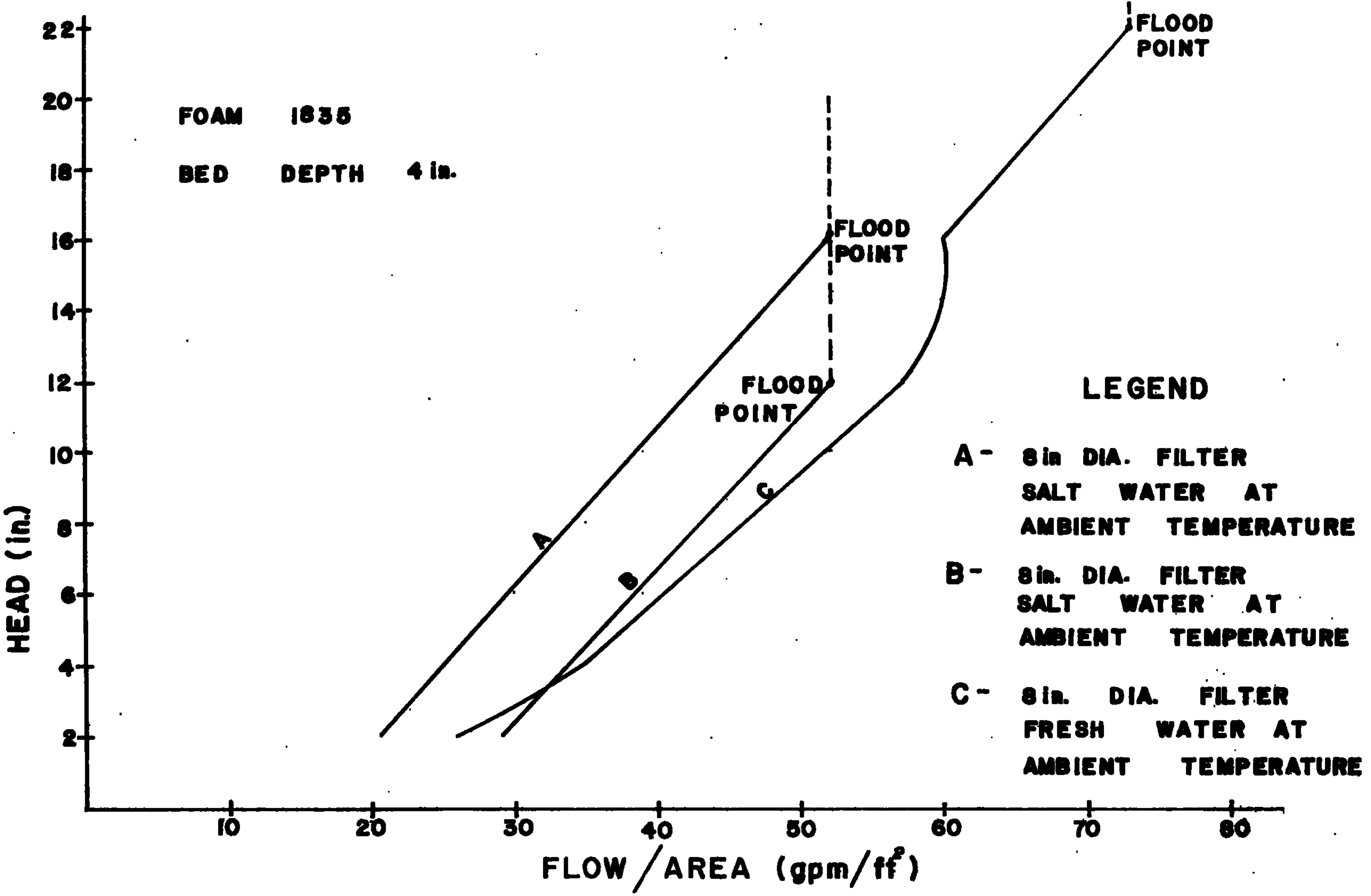
3.3 EFFECT OF SALINITY

Tests were carried out using both fresh and sea water on foam 1835 at a bed depth of 4 in. The results which were reported in Appendix III (Fig. 5.1) indicate that the effect of salinity appears to be much less than the normal variations in behaviour of foams operating under identical conditions. One significant difference was that when sea water was used,flooding of the column began much earlier.

The results are shown in Figure 3.2.

3.4 EFFECT OF TEMPERATURE

Tests were carried out on the 8 in. diameter equipment at temperatures of 9°C, 10°C, and 20°C on foams 1835 and 1528 using 8 in. and 6 in. bed depths respectively.



HEAD vs FLOW/AREA

FIGURE 3.2

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The results presented in Table 3.2 and in Table 3.3 show a definite temperature effect. This is probably due to the change in viscosity of the water. (Special thanks to Drs. Lau and Nagy).

TABLE 3.2

EFFECT OF TEMPERATURE ON HYDRAULIC BEHAVIOUR OF 8 in. BED DEPTH OF FOAM 1835 USING SALT WATER

0°C.		10°C.		20°C.	
FLOW	HEAD	FLOW	HEAD	FLOW	HEAD
gal/min.ft.^{2}	in.	gal/min.ft.^{2}	in.	gal/min.ft.^{2}	in.
17.2	2	19.0	2	25.9	2
17.2	3	21.5	3	25.5	3
21.6	6	30.2	6	34.5	6
25.9	8	30.2	8	38.8	8
25.9	10	34.5	10	40.5	10
30.2	12	38.8	12	45.7	12
31.9	14	40.5	14	49.1	14
34.5	16	14.2	16	51.7	16
38.8	18	47.5	18	51.7	18
38.8	20	50.0	20	55.9	20

TABLE 3.3

EFFECT OF TEMPERATURE ON HYDRAULIC BEHAVIOUR OF 6 in. BED DEPTH OF FOAM 1528 USING SALT WATER

0°C.		10°C.		20°C.	
FLOW	HEAD	FLOW	HEAD	FLOW	HEAD
gal/min.ft.^{2}	in.	gal/min.ft.^{2}	in.	gal/min.ft.^{2}	in.
17.2	1	25.8	2	34.4	1
17.2	2	30.1	3	38.7	2
19.8	3	38.7	6	40.4	3
30.1	6	43.0	8	41.3	6
34.4	8	47.3	10	51.6	8
38.7	10	51.6	12	55.9	10
40.4	12	51.6	14	60.1	12
43.0	14	55.9	16	62.8	14
47.3	16	58.4	18	64.5	16
49.0	18	58.4	20	64.5	18
49.0	20	58.4	22	64.8	18
49.0	22	-	-	-	-

4.0 MASS TRANSFER

4.1 CRUDE OIL ADSORPTION TRIALS

4.1.1 Introduction

Monsanto foams 1329, 1528, 1835 and 2045 were tested at a 6 in. bed depth, a 13 in. head and approximately the same inlet concentration of crude oil to compare the various foam types with respect to flow rate and oil removal. Previous work (2nd Interim Report, Appendix III) with marine diesel and bunker C indicated that varying the bed depth and inlet concentration did not have any appreciable effect on effluent concentration. These variables were not investigated with crude oil.

4.1.2 Procedure and Results

The equipment for the crude oil trials was the same as that used in the bunker C and marine diesel trials (Appendix III, Dwg. 4.1). The total time of each trial was 3 hours, with a sampling frequency as described in Section 4.2.2 of the Appendix III. Fluorescence spectrophotometry was used for the examination of the samples. The method and procedure was identical to that used for the bunker C analysis described in Appendix III, p.49.

The four foams tested gave very similar results with respect to oil removal but there were appreciable differences in hydraulic performance.

Results from the trials are shown in Tables A-1 to A-4, Appendix A. The trial with foam 1835 gave a removal rate of 64.6% which was only marginally better than the other trials. The best hydraulic performance was achieved with foam 1528, followed by foam 2045. A plot of the flow/area versus time is shown in Figure 4.1. The abnormally low flow with foam 1835 was probably due to the particular batch of foam used for the trial.

4.2 CAPACITY OF FOAM 1835

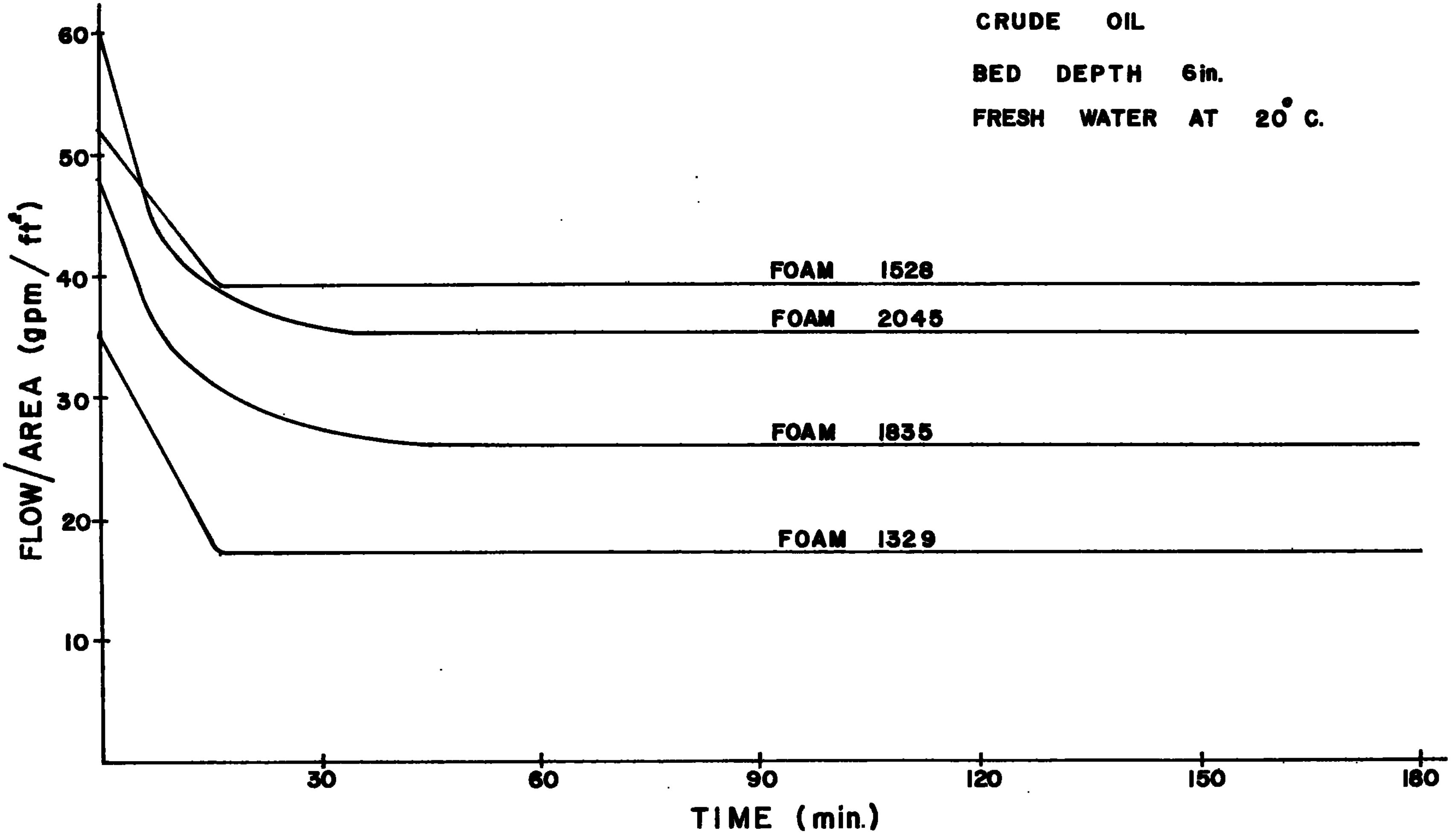
4.2.1 Introduction

Trials were carried out at the Bedford Institute on foam 1835 to determine its capacity for adsorbing marine diesel and bunker C.

The trials were done on the small scale 8 in. diameter column using sea water. The equipment was arranged to operate as a flow-through system rather than the water being recirculated as in the previous trials with fresh water. An insufficient supply of fresh water prevented a flow-through operation for these trials. The only modification in the equipment involved discharging from the effluent wier to drain rather than recirculation.

A heat exchanger at the Bedford Institute made it possible to run these trials at both 0°C. and 20°C.

The marine diesel trials were at an 8 in. bed depth and the bunker C trials were at a 4 in. bed depth.



FLOW / AREA vs TIME

FIGURE 4.1

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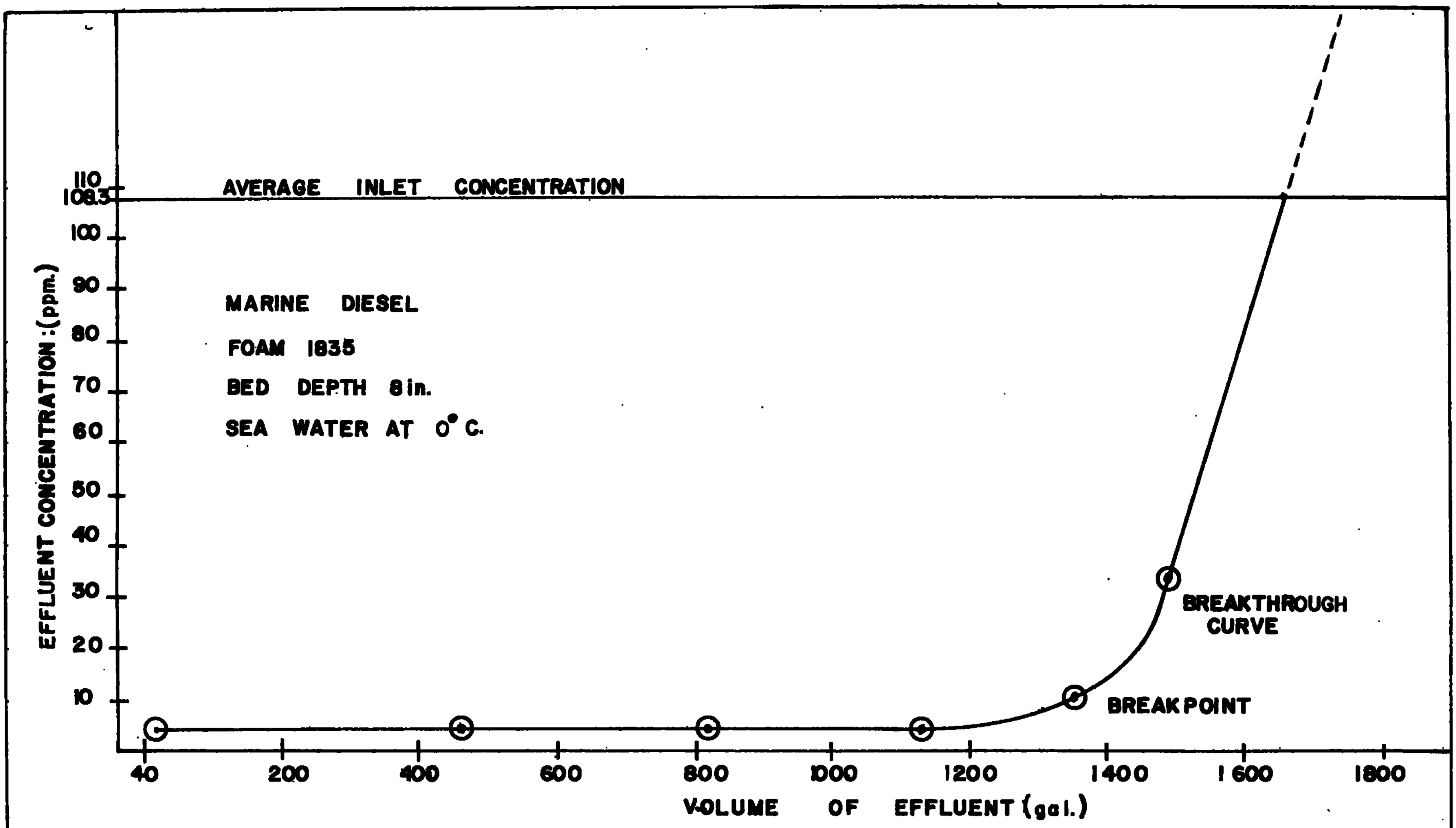
4.2.2 Results

Results from the marine diesel trials at 0°C. and 20°C are shown in Tables B-1 and B-2, Appendix B. Plots of volume of effluent versus effluent concentration (Figures 4.2 and 4.3) show a very distinct break point and a sharp break point curve for both trials. The effluent concentration in both trials remained fairly constant up to the break point, then rose sharply as the adsorption wave reached the bottom of the bed, indicating that it would be possible to operate the filter to saturation without any decrease in effluent quality. Figure 4.4 illustrates break point and the passage of an adsorption profile through a fixed bed.

The capacity of the foam at an average inlet concentration of 108.3 ppm and at 0°C. was 5.1 lb. of diesel/ft^3 of foam. At an average inlet concentration of 53.0 ppm and at 20°C. the capacity of the foam was 6.6 lb. of diesel/ $ft.^3$ of foam.

It is evident from Figure 4.5 that the flow/area decreases with time as a result of the transfer of oil from the influent to the filter medium.



EFFLUENT CONCENTRATION
VS
VOLUME OF EFFLUENT

FIGURE
4.2

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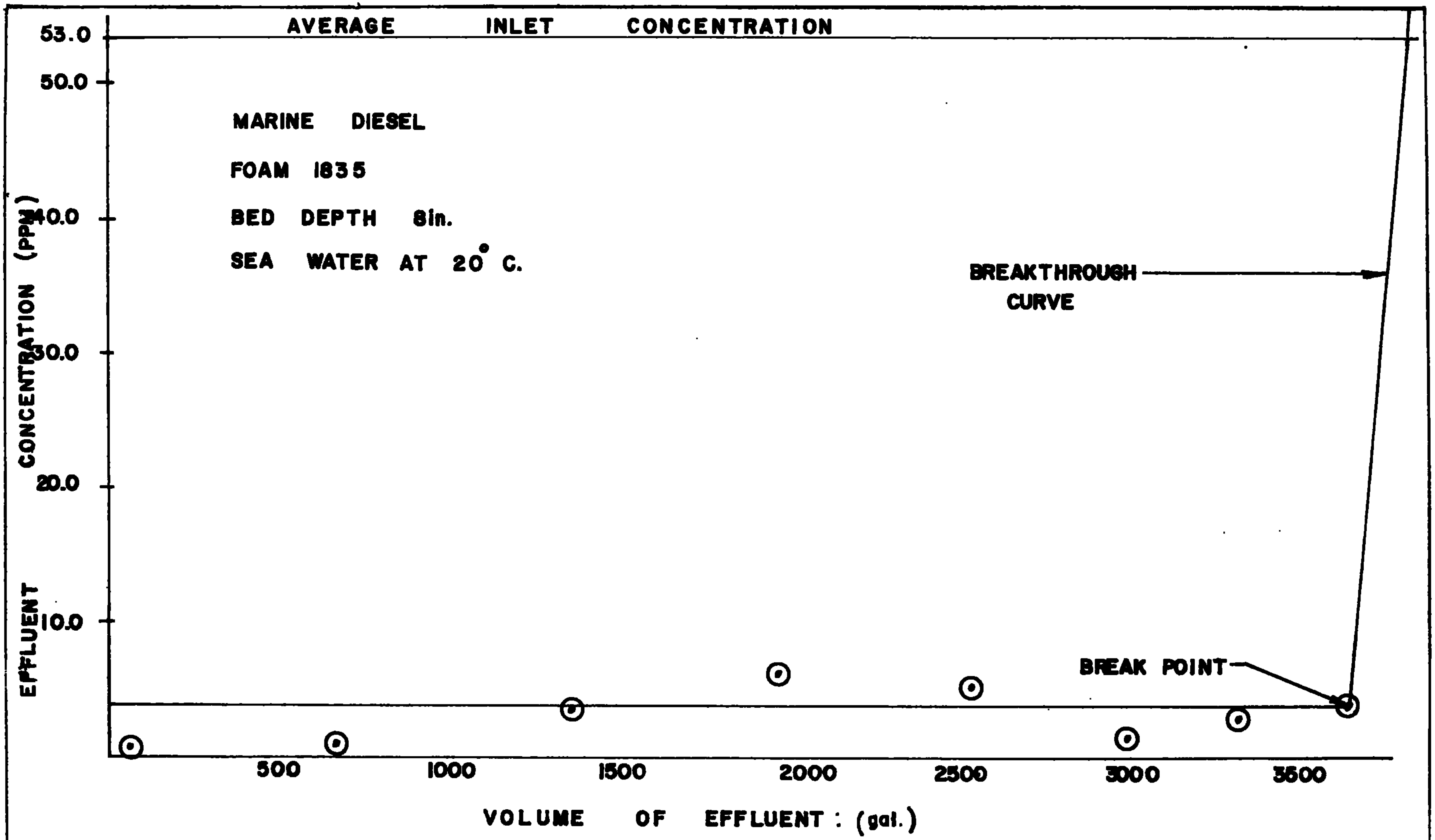

EFFLUENT CONCENTRATION
VS
VOLUME OF EFFLUENT

FIGURE
4.3

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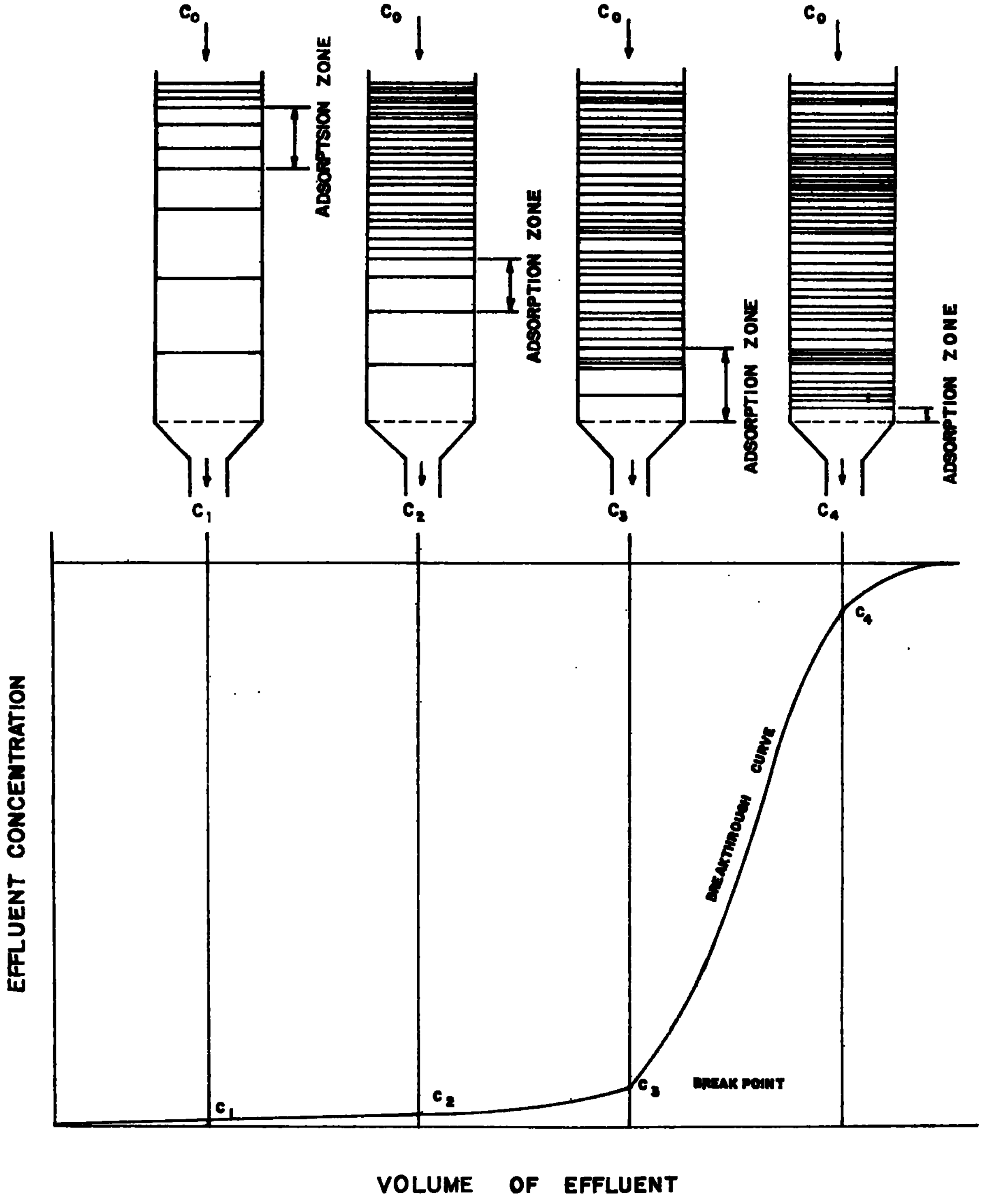

MECHANISM OF ADSORPTION

FIG. 4.4

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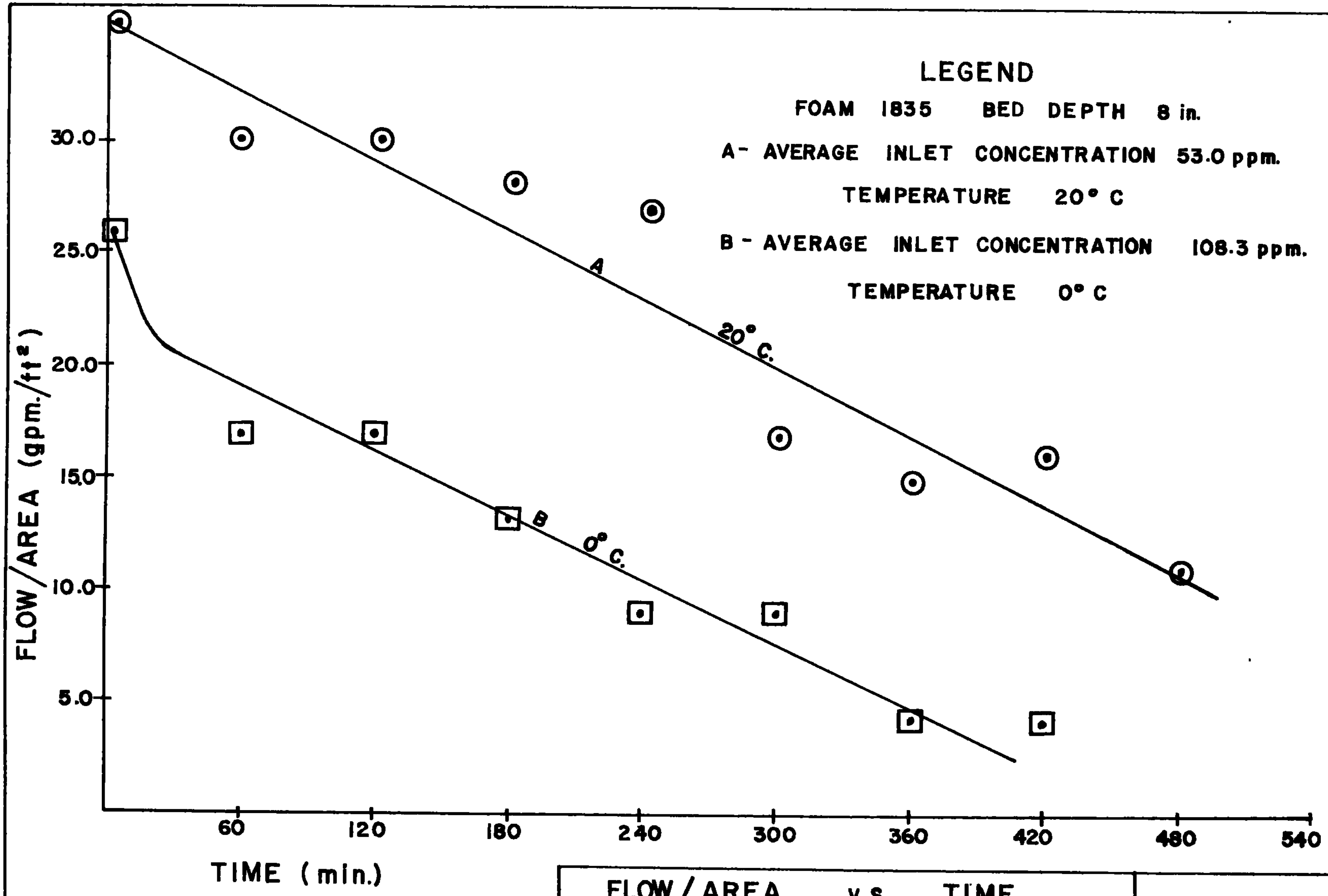

FLOW/AREA vs TIME
MARINE DIESEL

FIGURE 4.5

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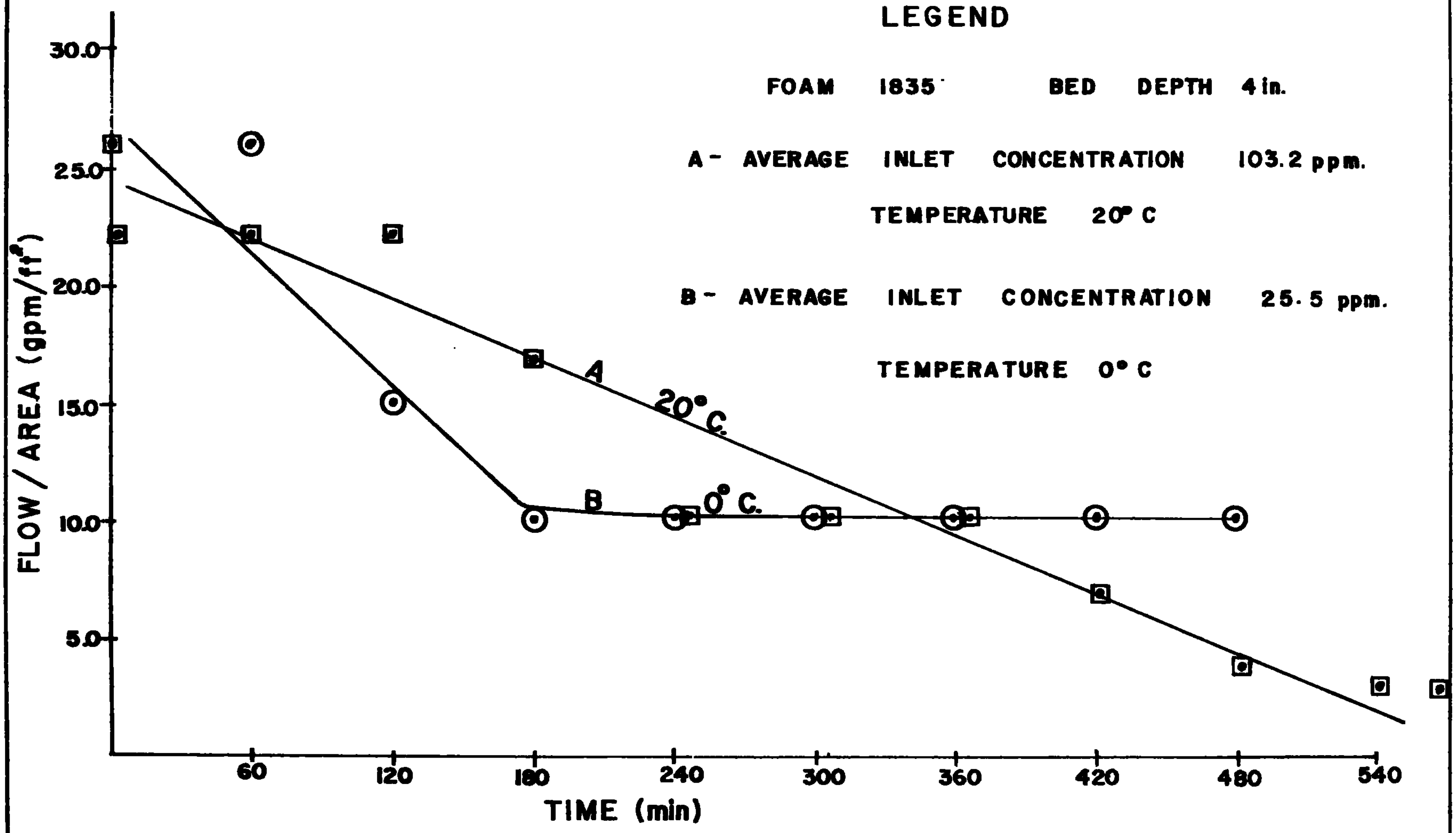
The bunker C trials did not give as favourable results. As the flow through the bed decreased it became exceedingly difficult to obtain a good mix of oil and sea water because of less turbulence in the water column above the bed and low flows through the pump. Results of the trials are shown in Tables B-3 and B-4 Appendix B. It is evident that the foam will reach its hydraulic capacity before oil breaks through the filter. Plots of the flow/area over time are shown in Figure 4.6.

Under an actual system, however, oil which was not well dispersed would be removed in a roughing filter or centrifuge, requiring the foam filter to remove only the remaining emulsified and finely dispersed oil, prolonging filter life. The effluent concentration will remain constant throughout the run and it could be run until the flow decreases to an unacceptable limit.

4.3 EFFECT OF TEMPERATURE AND SALINITY ON ADSORPTION

The capacity trials shown in Tables B-1 to B-4 were carried out at 0°C and 20°C. for both marine diesel and bunker C. As can be seen from these results there is no discernable difference in effluent concentration with change in temperature.



FLOW / AREA vs TIME
BUNKER C

FIGURE 4.6

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS HALIFAX, N.S.

Increasing salinity by going from fresh water to sea water improves adsorption of marine diesel remarkably. Table B-8, Appendix III and Table B-2 show the results of trials at a temperature of 20°C and the same inlet concentration with foam 1835 at an 8 in. bed depth. The degree of removal increases from 48.6% with fresh water to 94.7% with sea water. The average outlet concentration for the sea water trial was 2.83 ppm while the fresh water trial had an average effluent concentration of 23.9 ppm.

Similar results can be seen for bunker C shown in Table A-6, Appendix III, and Table B-4, although the effect is not as pronounced as with marine diesel. After 9-1/2 hours of operation the sea water trial had an average of only 0.83 ppm while the trial with fresh water had an average effluent concentration of 1.64 ppm after only 24 minutes.

4.4 REMOVAL OF PHENOLS

Phenols are often associated with oily wastes and since many are water soluble and toxic, they can present a threat to life.

Experiments were carried out on the 8 in. filter to ascertain the effectiveness of polyurethane foam in removing phenolic type compounds from water, Phenol, itself, (hydroxy-benzene) was used in the tests. A solution of 5% phenol was made up and by means of a metering pump, the solution was fed continuously into the inlet stream of water to the filter to ensure an inlet concentration of approximately 20 ppm. Samples of the influent and effluent were taken and analysed for phenol using a colorometric method described in "Standard Methods for the Examination of Water and Wastewater ", The results, reported in Table 4.1, show that the polyurethane foam is largely ineffective in removing phenol, consequently polyurethane foam could not be recommended for this function although the investigation of specially treated foams should be considered. United States patent No. 3617531 by Schlicht and McCoy describes experiments in which reticulated polyurethane foams were used to remove phenol from heptane with efficiencies of 50 to 85%.

TABLE 4.1

CONCENTRATION OF PHENOL IN WATER BEFORE & AFTER PASSAGE THROUGH POLYURETHANE FILTER

FOAM 1835 BED DEPTH 8 in. SEA WATER AT 0°C.

INFLUENT SAMPLE	EFFLUENT SAMPLE
19.1 ppm phenol	18.3 ppm phenol
20.0 ppm	18.0 ppm
30.0 ppm	21.0 ppm
17.5 ppm	16.5 ppm

5.0 LARGE SCALE TESTING

Since the 2nd Interim Report (Appendix III) additional mass transfer testing has been conducted on the large scale apparatus (22.5 in. diameter) with marine diesel and crude oil. Results of the trials are shown in Tables C-1 to C-5, Appendix C of this report.

Effects of scale on the hydraulics were discussed in Section 3.2. It was concluded that Flow/Area was a satisfactory way of allowing for the effect of filter diameter and hence size of filter.

The results from the capacity runs on marine diesel and bunker C shown in Tables B-1 and B-3, Appendix B, were also carried out on sea water at 0°C and at bed depths of 8 in. and 4 in. respectively on the small scale (8 in. diameter) apparatus. The results from the marine diesel trial, Table B-1, Appendix B, and Tables C-1 to C-3, Appendix C ,indicates that there is no appreciable difference in effluent quality.

The bunker C trials shown in Table B-3 of this report and in the 2nd Interim Report (Appendix III, Tables C-1 to C-4) indicate much better removal with the large scale apparatus. This is attributed to a better dispersion of oil and water with the small scale apparatus rather than to effects of scale.

In all the trials on the large scale apparatus the foam was only replaced when changing from one petroleum product to another, that is, all the trials on each petroleum product were conducted with the same foam. From the results given in the 2nd Interim Report (Appendix III, Tables C-1 to C-4), and in Tables C-1 to C-5 of this report, it can be seen that the filter can be operated very effectively on a stop-start basis over several days without any deterioration in effluent quality or hydraulic characteristics.

6.0 DISPOSAL OF FOAMS

In the 2nd Interim Report (Appendix III, Section 7.0) incineration was suggested as a means of disposal of used foams provided the products of combustion of polyurethane would not produce an air pollution problem by the emission of toxic gases. Since the report, excerpts from a report by Underwriters Laboratories Inc. were obtained from Monsanto on a survey of available information on the toxicity of the combustion and thermal decomposition properties of certain building materials under fire conditions.

The report states that the burning of polyurethane and many other organic materials produces trace amounts of a great number of toxic gases, including carbon monoxide, hydrogen cyanide, and oxides of nitrogen. Of these carbon monoxide normally occurs in greater toxic concentrations than those of any other gases present. Polyurethane foam plastics are not more hazardous with respect to pyrolysis products and critical pyrolysis temperature than other foamed plastics in common use,including natural rubber latex. Polyurethane foam does not produce more hydrogen cyanide than do many other natural and synthetic consumer products under an identical pyrolysis procedure, including paper and cotton.

In view of the information, incineration is recommended as the most feasible means of disposal of used foam.

(An investigation should be made to determine the most suitable material for packaging the used foams. The various petroleum products adsorbed in the foam will attack certain plastics, thus making them unsuitable.)

APPENDIX A

TABLE A-1

EXPERIMENTAL DATA FOR CRUDE OIL ADSORPTION

DATE Feb. 17/72   FOAM 2045   BED DEPTH 6

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	60.	13	6	-	-
4	-	-		38.8	9.1
8	43.	-		37.8	15.7
16	-	-		36.4	17.0
24	-	-		34.8	20.0
34	35.	-		61.6	20.0
44	-	-		71.6	18.0
60	-	-		55.2	20.4
90	-	-		55.2	20.4
120	-	-		64.8	20.4
150	-	-		100.0	29.2
180	35.	-		72.8	41.6
				57.2 Av.	21.1 Av.
					% Removal 63.1

TABLE A-2

EXPERIMENTAL DATA FOR CRUDE OIL ADSORPTION

DATE Feb. 15/72 FOAM 1835 BED DEPTH 6

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	48.	13	6	-	-
4	-	-		22.2	7.8
8	35.	-		33.2	18.0
16	-	-		66.0	15.8
24	-	-		62.2	33.0
34	-	-		48.0	33.0
44	26.	-		47.2	28.2
60	-	-		73.6	25.0
90	-	-		72.0	23.8
120	-	-		66.4	9.2
150	-	-		67.2	12.2
180	26.	-		60.0	13.4
				56.2 Av.	19.9 Av. % Removal 64.6

TABLE A-3

EXPERIMENTAL DATA FOR CRUDE OIL ADSORPTION

DATE Feb. 18/72 **FOAM** 1528 **BED DEPTH** 6

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	52.	13	6	-	-
4	-	-		69.6	29.6
8	-	-		50.4	29.6
16	39.	-		48.0	31.6
24	-	-		49.6	27.6
34	-	-		50.4	27.6
44	-	-		78.4	24.0
60	-	-		72.1	18.0
90	-	-		41.6	19.6
120	-	-		52.4	13.1
150	-	-		64.4	16.1
180	39.	-		120.0	19.5
				63.3 Av.	23.3 Av. % Removal 63.2

TABLE A-4

EXPERIMENTAL DATA FOR CRUDE OIL ADSORPTION

DATE Feb. 14/72 FOAM 1329 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	35.	13.	6	-	-
4	-	-		51.2	3.8
8	-	-		45.0	9.6
16	17.	-		74.0	17.6
24	-	-		118.0	40.0
34	-	-		51.0	47.0
44	-	-		43.0	30.0
60	-	-		85.0	39.0
90	-	-		82.0	32.0
120	-	-		60.0	28.0
150	-	-		80.0	25.2
180	17.	-		60.0	19.4
				68.1 Av.	26.4 Av. % Removal 61.2

APPENDIX B

TABLE B-1

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE March 6, 1972 FOAM 1835 BED DEPTH 8 in.

TEMP. 0°C. FILTER AREA .35 ft.^{2} Salt Water

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	DIESEL CONCENTRATION (ppm) OUTLET
0	26.	13	8	-	-
5	26.	13		79.0	2.18
60	17.	13	6-3/4	93.0	2.66
120	17.	15	6-1/2	79.0	2.60
180	13.	15	5-1/2	113.0	1.78
240	9.	19	5	115.0	7.80
300	9.	19	4-3/4	135.0	28.20
360	4.	19	4-3/4	152.0	203.0
420	4.	22	4-1/2	100.0	400.0
				108.3 Av.	3.40 Av. at break point % Removal 96.9%

TABLE B-2

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE March 16, 1972　FOAM 1835　BED DEPTH 8 in.

TEMP. 20°C.　FILTER AREA .35 ft.^{2}　Salt Water

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	-	-	4-1/2	-	-
5	35.	11		0.62	0.54
60	30.	10		31.8	0.82
125	30.	12		56.0	3.70
185	28.	14		54.0	5.60
245	27.	20		33.5	5.00
305	17.	14		39.0	0.92
365	15.	15		68.5	2.78
425	16.	18		77.5	3.30
485	11.	16		110.5	80.50
				53.0 Av.	2.83 Av. at break point

% Removal
94.7%

TABLE B-3

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE March 10, 1972 FOAM 1835 BED DEPTH 4 in.

TEMP. 0°C. FILTER AREA .35 ft.^{2} Salt Water

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	-	-		-	-
5	26.	12	4	9.2	0.06
60	26.	14		8.6	0.16
120	15.	13		9.8	0.24
180	10.	12	3-1/2	12.0	0.26
240	10.	14	3-1/4	23.0	0.42
300	10.	14		46.0	0.54
360	10.	14	3	82.0	0.60
420	10.	14		27.0	0.90
480	10.	14		12.0	1.54
				25.5 Av.	0.52 Av.

TABLE B-4

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE March 15, 1972 FOAM 1835 BED DEPTH 4 in.

TEMP. 20°C. FILTER AREA .35 ft.^{2} Salt Water

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	26.	12		-	-
5	22.	14		60.0	0.60
60	22.	14		29.0	0.64
120	22.	18		38.0	0.60
180	17.	20		37.0	0.52
245	10.	18		56.0	0.76
305	10.	18		45.0	0.92
365	10.	18		82.0	0.48
425	7.	15		218.0	0.94
485	44.	11		46.0	0.68
545	3.	10		216.0	1.26
580	3.	20		308.0	1.94
				103.2 Av.	0.79 Av.

APPENDIX C

TABLE C-1

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE February 25, 1972 FOAM 1835 BED DEPTH 8 in.

TEMP 0°C. FILTER AREA 2.8 ft^2. Salt Water

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	-	-	-	-
5	20.	10	980.	1.8
35	21.	13	1960.	5.4
65	20.	14	290.	5.8
95	20.	13	490.	2.9
			930. Av.	4.0 Av.

TABLE C-2

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE February 25, 1972 FOAM 1835 BED DEPTH 8 in.

TEMP 0°C. FILTER AREA 2.8 ft.^{2} Salt Water

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	18.	7	-	-
5	18.	7	214.	4.20
45	18.	8	122.	3.30
65	18.	10	126.	3.40
95	18.	10	210.	3.76
125	18.	11	135.	4.38
			161. Av.	3.81 Av.

TABLE C-3

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE February 28, 1972 FOAM 1835 BED DEPTH 8 in.

TEMP 0°C . FILTER AREA 2.8 ft^2. Salt Water

TIME (min.)	FLOW/AREA (gpm/ft2)	HEAD (in.)	DIESEL CONCENTRATION (ppm) INLET	DIESEL CONCENTRATION (ppm) OUTLET
0	-	-	-	-
5	5	16.	5.0	4.42
30	5	16.	92.8	1.60
60	6	16.	24.5	1.60
90	7	16.	176.	1.88
			74.6 Av.	2.38 Av.

TABLE C-4

EXPERIMENTAL DATA FOR CRUDE OIL ADSORPTION

DATE February 29, 1972 **FOAM** 1835 **BED DEPTH** 8 in.

TEMP 0°C. **FILTER AREA** 2.8 ft.^{2} Salt Water

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	OIL CONCENTRATION (ppm) INLET	OIL CONCENTRATION (ppm) OUTLET
0	18.	7	-	-
6	18.	7	118.0	0.72
36	18.	8	39.8	0.94
66	18.	8	19.6	0.86
96	18.	8	19.6	3.42
126	18.	7	220.0	2.00
			83.4 Av.	1.59 Av.

TABLE C-5

EXPERIMENTAL DATA FOR CRUDE OIL ADSORPTION

DATE March 1, 1972 **FOAM** 1835 **BED DEPTH** 8 in.

TEMP 0°C. **FILTER AREA** 2.8 ft.^{2} Salt Water

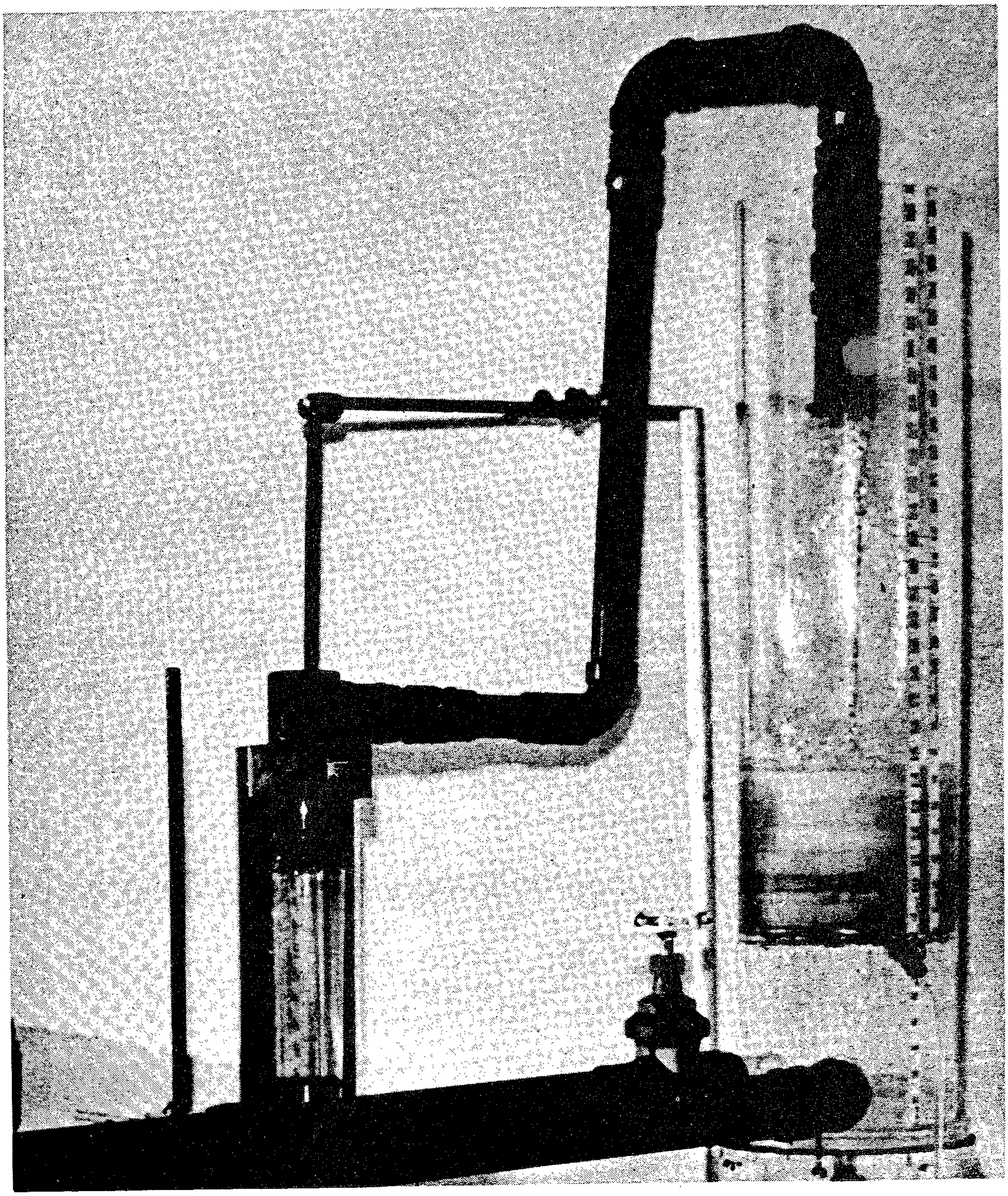
TIME (min.)	FLOW/AREA (gpm/ft2)	HEAD (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	18.	6	-	-
6	18.	7	210.	2.36
30	18.	9	484.	2.76
90	18.	11	130.	3.42
120	18.	12	316.	3.56
			285. Av.	3.03 Av.

APPENDIX II

POLYURETHANE AS AN OIL FILTER

– a research study

–1st interim report



DEPARTMENT OF FISHERIES AND FORESTRY

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED

SEPTEMBER 1971

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED

POLYURETHANE AS AN OIL FILTER

A RESEARCH STUDY

1ST INTERIM REPORT

This first Interim Report relates to a Contract dated April 1971, between the Canada Department of Fisheries and Forestry and Canadian Plant and Process Engineering Limited, Consulting Engineers, Halifax, Nova Scotia, the terms of which require the latter to study various aspects of the threat to the world's waters by pollution with oil, and the feasbility of polyurethane foam as a filter medium to separate oil from water.

SEPTEMBER 1971

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CANADIAN PLANT AND PROCESS ENGINEERING LIMITED SEPTEMBER 1971

POLYURETHANE AS AN OIL FILTER

A RESEARCH STUDY

1ST. INTERIM REPORT

1.0 INTRODUCTION

This report outlines the progress to date on a Contract for a research study on a polyurethane filter, entered into in April, 1971 between the Canada Department of Fisheries and Forestry, and Canadian Plant and Process Engineering Limited, Consulting Engineers, Halifax, Nova Scotia. A copy of the contract forms Part 1.1 of this report.

This research project commenced shortly following the grounding of the tanker 'Arrow' and the subsequent pollution of Chedabucto Bay. At that time Canadian Plant and Process Engineering Limited designed and installed, following a brief research period, the first known polyurethane filter which had a capacity of 600 GPM.

In addition, this contract provides for an analysis of the bulk handling practices in the petroleum industry and also the commercial manufacture of polyurethane. These sections which form Parts 2 and 3 of this report are in their final form, while the balance of the report dealing with harbour and coastal pollution and the research work itself, are to be considered as progress reports.

It is anticipated that the second Interim Report will be available early in 1972 with the Final Report on the research program completed by April of 1972.

1.1 CONTRACT FOR A RESEARCH STUDY

ON

POLYURETHANE FILTER

This Agreement is made this 8th. day of April 1971.

BETWEEN:

The Department of Fisheries and Forestry

AND:

Canadian Plant and Process Engineering Limited
Consulting Engineers, Halifax, N.S.

Conditions of this Contract

The contractor, Canadian Plant and Process Engineering Limited, shall undertake to:

(a) investigate the commercial manufacture of polyurethane, its manufacturers, availability, and cost per unit on a national and international basis;

(b) investigate practices in the bulk handling of petroleum products nationally and internationally and to report on industry trends in this regard;

(c) assess harbour pollution problems resulting from oil pollution originating in ships or refineries;

(d) carry out and coordinate experiments, using various combinations of petroleum products, water and polyurethane, to determine the physical and chemical characteristics of these compounds and their relationship in order to produce design criteria for oil/water filters; and

(e) analyze these results and report on all of these matters to the Department of Fisheries and Forestry following review with officials of the Department of Fisheries and Forestry.

2.0 A REVIEW OF THE MANUFACTURE, AVAILABILITY AND PRICE OF POLYURETHANE FOAM

2.1 Introduction

The manufacture of plastics is a vast, world-wide industry engaged in turning out a countless variety of products for almost every conceivable use. "Plastics" refers to that large and varied group of synthetic materials that are processed by molding or forming them to final shape. Chemically, plastics are composed of chain-like molecules of high molecular weight, called polymers, that usually have been built up from simpler chemicals called monomers. There are about forty basic plastics families with commercial significance today, and each differs from all others. For example: a plastic may be soft(polyurethane foam), or hard(melamine); clear(acrylic), or opaque(phenolic); heat resistant(silicone) or softened by hot water(polyethylene). The possible combinations of properties, processing requirements, and economics is practically endless.

2.2 The Science of Polyurethane

Urethane foams are among the most versatile of all plastics. They range from soft, flexible foams used in pillows to rigid foams used as building materials. In 1968, use of urethane foams in the United States climbed to a record high of over 600 million pounds.

Urethane foams are cellular plastics formed by the reaction of two liquids - a polyol and polyisocyanate - in the presence of a blowing agent, a catalyst, and a surfactant. The blowing agent produces gas for foaming, the catalyst speeds the reaction, and the surfactant stabilizes the rising foam and controls cell size. By varying the type and amount of the ingredients, different urethane foams can be made whose densities can be varied from less than one to more than 60 lbs./ft.^{3}.

The choice of the polyol has a major influence on the properties of the foam and its rigidity or flexibility. The crosslink density of the urethane polymer determines whether the foam will be flexible (low crosslink density), or rigid(high crosslink density). Flexible foams are produced from polyols of moderately high molecular weight and low degree of branching, while rigid foams are prepared from lower molecular weight, highly-branched resins.

Polyols generally used for rigid and most flexible urethanes are polyethers. Some flexible urethane foams are also made with polyester polyols, and are used for textile laminates. For the biggest flexible markets - bedding, cushioning for furniture, and automotive use - polyether polyols are employed. These applications, and rigid urethane uses(in refrigeration, building, etc.) will be discussed further.

A polymeric structure is formed by the reaction of polyol with isocyanate. The hydroxyl groups of the polyol and the terminal NCO groups of the isocyanate react to build the urethane polymer chain. The most widely used isocyanate is 80/20 tolylene diisocyanate(TDI).

Catalysts are required to accelerate and control the foaming reaction to obtain proper cure. The most widely used catalysts are tertiary amines, alone or in combination with tin compounds.

Carbon dioxide, generated when isocyanate reacts with water, is the primary blowing agent in flexible foam production. Inert materials such as fluorocarbons, which are vaporized by the exothermic heat of the polyol-isocyanate reaction, are used are supplemental blowing agents.

2.3 Rigid Foams

Rigid urethane foams have become basic materials in several key industrial segments - commercial refrigeration, transportation insulation, building materials, furniture, construction, home appliances, marine, automotive, aerospace, packaging, and industrial insulation.

Rigid urethane foam has the advantage of several important properties: insulating efficiency, lightweight strength, adhesion, buoyancy, and ease of application.

It is the most efficient insulating material commercially available. Only half as much rigid urethane foam is needed to give the same insulation as the next best material. And it retains its insulating efficiency far longer than other materials. Strength and high insulating efficiency have brought about the widespread use of rigid urethane foam in refrigeration - cold storage warehouses, home refrigerators and freezers, commercial fishing vessels, LPG tankers, food freezing equipment,cold storage shipping containers, and ice buckets and picnic lockers.

The closed cell structure of rigid urethane foam does not absorb water. One cu. ft. of rigid urethane foam can give 60 lb. of buoyancy, making it one of the best flotation materials commercially available. Rigid urethane foam has been used as flotation and structural material in nuclear submarines since 1958. It is finding increasing use in ships, boats, floats, docks, and bridges.

Production of rigid urethane foam involves metering the resin mix(polyol, silicone surfactant, blowing agent, and catalyst) and activator(isocyanate) into a high speed mixer. However, because of reaction speed, timing is critical, and the metering and mixing equipment required is quite sophisticated. The blended components may be used for slab stock, molding, frothing, or spraying.

Slab stock: The metered mix of foam chemicals is dispensed directly from a mixing head which traverses back and forth, giving an even lay-down onto a conveyor belt. Rising foam is held between side plates to form a continuous bun 36-48 in. wide, and 12-24 in. high. In about 5 min., the foam is firm enough to be cut into lengths and stored for curing and cooling. After cure, buns may be trimmed and cut into boards and slabs of various thicknesses.

2.4 Flexible Foams

Most flexible polyether urethane foam is made by the one-shot *slab stock* technique, the continuous process which has been discussed for rigid foams. Slab stock flexible foam is made in 2- 8 ft. widths and may be from one to 5 ft. high , although normally 35-45 in. high. The foam is cut into 10-60 ft. lengths and allowed to cure as a bun or block for 10-24 hr. at ambient conditions. After curing, the foam buns are sold to fabricators or cut into various shapes and sizes depending on end-use(commonly cushioning for furniture, mattresses, and bed pillows).

Flexible urethane foam can also be made by *molding*. The molding of any part starts with the mix and pour from standard urethane foam making equipment. Molds of the appropriate size, usually made of cast aluminum, must be heated to 100-200°F. before charging to prevent heat absorption from the foaming mass. This technique, along with the proper use of a release agent, helps to provide reproducible parts having good properties. Another important factor is the quick heating of the molded foam to a temperature of 300-450°F. (accomplished in 3-6 minutes). Compression set, a significant property, is influenced by this heating step. Although mechanical and heat transfer variables can be critical in the molding process, the formulation determines most end properties. The largest application for this so-called conventional, or hot molded flexible, urethane foam is in automotive, particularly seat topper pads.

A new approach to molding urethane foam permits the manufacture of molded flexible pieces without the application of external heat. Since these foams do not require high temperature curing, they are frequently identified as "*cold molded foams*". Cold molded foams are produced most successfully in "insulated" or non-conducting molds, with plastic or wood performing better than metal molds. With initial mold temperatures of 80-100°F., these foams can be de-molded in 5-10 min., and require curing only at ambient temperatures. This cold molding process eliminates the expenses involved in metal molds and high temperature ovens to cure the foams. Very resilient molded parts can be prepared using this system.

2.5 Growth in the Industry

Most rapid growth in 1970 was in rigid foam formulations which gained 43 mi. lbs. for an increase of 20% over 1969 (U.S.). The flexible added 77 mi. lb., increasing 11%. Big gains for the rigids came from building where they moved ahead by 32% as improved spray formulations and slab stock continued to replace the less-efficient, pour-in-place formulations; the latter now account for less than 20% of the urethane in building and construction. Flexible foams rose 63% in packaging, 38% in textile laminates, and 39% in rug and underlay. They were up by 11% in transportation, but still fell 5% below industry expectations because of the auto strike and generally slow sales. The only area that actually declined was furniture, where the flexibles fell off by 2%. (See Table 2.1)

2.6 Manufacturers, Availability, and Price

Polyurethane foam is a readily available product throughout the Western world. Its widespread use in the automotive and furniture industries dictates that industrial nations with such industries will also have producers of foam. As the basic ingredients of resins and isocyanates are derivatives of the petrochemical industry, in any country with such an industry - and there are many - there is a plentiful supply of raw materials. The technology is relatively uniform throughout the world,

TABLE 2.1

URETHANE FOAM

PATTERN OF CONSUMPTION (U.S.A.)

MARKET	MILLION LBS. 1969	MILLION LBS. 1970
Flexible Foam -		
Bedding	58	75
Furniture	245	240
Packaging	5	13
Rug & underlay	18	25
Textile laminates	54	75
Transportation	175	195
Miscellaneous	21	30
TOTAL	576	653
Rigid Foam -		
Appliances	55	62
Building	63	83
Furniture	25	28
Industrial Tanks	12	12
Marine flotation	8	10
Mine tunnel seals	2	2
Packaging	4	6
Transportation	38	45
Miscellaneous	2	4
TOTAL	209	252

Source: Modern Plastics/January/1971

principally because the size of the industry permits new advances in technology to become quickly known and adopted.

While everything points to a large number of foam producers, however, this is in fact not the case. The economics of foam manufacture tends to limit the number of producers. To be profitable a plant has to be able to produce and market very large quantities of foam because of very narrow profit margins. Thus, in spite of there being a large number of users, there are in Canada, for example, only seven manufacturers of flexible foam. It would not be economical for even the largest user, say a furniture or bedding manufacturer, to produce his own foam requirements. Apparently the seven producers have found that their respective shares of the foam market afford them a satisfactory return on their investment in capital equipment. Competition is keen, but it involves such factors as service rather than price. There is virtually no room in the price structure for price-cutting. Nor, on the other hand, does there appear to be any evidence of price maintenance among the industry partners. It seems that artificially sustained prices would invite entry into the industry by outsiders who know they can make and sell for less.

The seven flexible foam manufacturers in Canada are:

Delaney and Pettit Industries Ltd,
Goodyear Tire & Rubber Co. of Canada Ltd.
Mansonville Plastics Ltd.
Monsanto Canada Ltd.
Paramount Industries
Reeves Hardifoam Ltd.
G.E. Shnier Co.

Their products are identical in every way, and can be supplied either in sheet form, measuring 54 in. x 72 in. and any thickness up to 4 ft., or cut to the user's specifications. The foam can be made in densities varying from 0.8 lb./ft^3 to 4.0 lb./ft^3. To illustrate, Monsanto Canada Ltd. lists in its catalogue 32 flexible foams in varying densities.

The situation with respect to semi-flexible and rigid urethane foams is similar. There are four Canadian manufacturers of rigid foam; one of these, Uniroyal Ltd., is the only maker of semi-flexible foam. Semi-flexible foam is used mainly by the automotive industry as crash-pad material. The three other producers are:

H.L. Blachford Ltd.,
Foamcoat Products, and
Ure-al Corp.(Canada) Ltd.,

These companies produce foam for special applications, such as pipe coverings and flotation material. In addition to these there is an unknown number of manufacturers making foam for use in their own products. For example, Guildford's Ltd., of Dartmouth, Nova Scotia, manufactures rigid foam as the first step in its continuous process for making insulation panelboard.

Generally speaking, rigid foam has much fewer uses than flexible, and therefore, it is not as readily available. Flexible foam is a stock item with its manufacturers and an unknown but certainly large number of distributors across Canada who represent them. The distributors usually only carry one or a few grades or densities of foam - those most commonly in demand- but other grades can be quickly ordered from their suppliers. It may be said unequivocally that flexible urethane foam is readily available from a variety of sources, anywhere in Canada.

As the product is uniform in every respect, so is the price. However, our investigation found that price varies with location in the country. This undoubtedly is a reflection of transportation costs, but a distributor's margin would also be involved. The Toronto price for polyether foam from any of the manufacturers is 11 cents per board foot (12 in. x 12 in. x 1 in.); in Halifax the price is 18 cents per board foot. An additional charge of 2 cents is made if cutting is required. Prices in other Canadian commercial centres may be considered comparable, but delivery charges could be expected on orders from outlying communities.

2.7 The International Scene

Except for the consumption data in Table 2.1 and the information in Paragraph 2.5 on growth in the industry, our investigation has been confined to the Canadian scene. Our search of local library facilities and discussions with individuals in the plastics industry have failed to reveal any definitive information on the number of manufacturers in other countries, their names, the relative availability of foam, or the price structure on a world-wide scale.

Notwithstanding the foregoing, it is our conviction that by virtue of the universality of the petrochemical industry which produces the raw materials of the plastics industry, and of the universal nature of the industries having a demand for plastics and urethane foams, it may be assumed that throughout the developed world there is a readily available supply of both flexible and rigid foams, at prices which will be comparable to Canadian prices.

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3.0 BULK HANDLING OF PETROLEUM PRODUCTS

3.1 INTRODUCTION

The Terms of Reference of the Contract for a Research Study on a Polyurethane Filter provide that the contractor shall undertake to "investigate practices in the bulk handling of petroleum products nationally and internationally and to report on industry trends in this regard." The following is intended to fulfill that term of the contract. No distinction has been made between "nationally and internationally"; the discussion proceeds from a worldwide point of view.

The approach taken was that common to an industry research assignment. In every sense of the word the bulk handling of petroleum products is an industry in itself, whether the method is by tanker or by pipeline, and therefore the research was concerned more with aspects of the transportation industry than it was with the petroleum industry per se. This will explain the absence of any reference to any particular corporate bodies in the world petroleum industry; the research was concerned with the "where from", the "where to", the "how much", and the "how" of petroleum movements, and not the "who".

It was from corporate members of the petroleum industry, however, that we received valuable assistance in our efforts. We are indebted to

Imperial Oil Ltd. and the British Petroleum Co. Ltd. for the cooperation they provided. Imperial Oil Ltd. graciously provided access to their extensive library facilities in Toronto, and BP was quick to comply with our request for statistical data.

Apart from these sources, information was obtained through local public and university library facilities, which were found to contain a variety of reference and periodical material. The Bibliography will acknowledge the several sources of material.

3.2 THE PETROLEUM TRANSPORATION NETWORK AND TECHNOLOGY

The simple fact that for whatever the commodity, the supply has to be taken to the areas of demand, explains the existence of worldwide cargo transportation networks. It explains the mammoth tanker fleets of today, and the pipelines that are criss-crossing the continents, for petroleum products, like other commodities, must be physically moved to their places of consumption. Indeed, few commodities are as universally demanded as oil, and hence the vastness of the networks along which petroleum products move.

Further, the demand is growing rapidly, so that of greater significance than the vastness of the networks is the ever increasing volumes of products being transported. As the volumes increase, so also does the threat of pollution of the seas by oil. A study of the bulk handling practices of the industry, therefore, should consider whether handling technology has kept pace with the increasing volume and the corresponding danger to the environment.

If we consider the modern tanker as a piece of materials handling equipment, we can readily say that technology has kept pace. While by no means are all tankers being built today in the "mammoth" category, certainly the mammoths are proof of greatly advanced technology in the tanker-building industry. Also, whether they are big or small, modern tankers employ the benefits of advanced technology in the fields of electronic navigational aids, propulsion and pumping and tank cleaning equipment.

Likewise, if we think of the oil pipeline as a piece of equipment for moving a product from point A to point B, we can say again that handling technology has kept pace with demand. It matters not whether the demand forced the advance; the fact remains that proof of advancing technology can be found in the larger sizes of pipelines and in the improved materials and methods of fabricating and laying them.

For our purposes, however, the significance of these advances lies in the fact that as units of transportation giant pipelines and mammoth tankers represent potential threats to the environment of much greater scale. The handling method has not changed, only the size of the carrier. We find, in fact, that relatively little change has been made in the traditional methods of handling petroleum cargoes when they reach the various connecting points in the transportation network.

3.3 THE SIZE AND CAPACITY OF THE SYSTEM

The International Petroleum Encyclopedia lists 204 world tanker ports(see map Exhibit I). Delivering crude oil to, or picking up products at these ports at the end of 1970 was a fleet of approximately 4100 tankers totalling 155.7 million deadweight tons in carrying capacity (Exhibits III, IV). It is significant as an indication of the rapid growth in volumes being moved that the 1970 figure of 155.7 million DWT is an increase of 20.5 million DWT over the tonnage at the end of 1969. At the end of 1970 new ships, both building and on order, totalled 70.3 million DWT, or almost 50% of the whole existing fleet! Of today's fleet, approximately one-quarter(1006) of the total number of ships, and two-thirds(103.3) of the total DWT, have been built within the last ten years (1961-1970). Seventeen percent of all tankers, carrying 5.5% of the total DWT are more than 20 years old. (The implication here is that the oldest ships are the smallest ships, and it is the small ships which do the local transporting, and carry a higher risk factor than their ocean-going cousins).

While there are no exact figures on how much crude and petroleum products the world tanker fleet carried in 1970, we know that exports from three of the major producing areas of the world - the Near East, Africa, and the Caribbean - totalled 21, 184,000 barrels per day, or 1,059 million metric tons for the year (Exhibit II). All of this was carried by tanker, and when we consider that total Refinery Crude Throughput for the world in 1970 was 2,235 million tons, and that a significant proportion of this was distributed via sea transport, then the total volume carried by tanker was significantly greater than 1,059 million tons.

3.4 THE HANDLING PROCEDURES

Spokesmen for the industry claim there are significant operating differences between deep-sea vessels and those engaged in coastal distribution operations. No doubt there are, but for the purposes of this study they are of minor importance. A major distinction lies in the size of the vessel involved; another lies in the fact that deep sea vessels as a rule carry only one or a few grades of crude oil at a time, and rarely nothing but crude, while coastal vessels generally carry a wide range of products in a continually changing "mix". There are many exceptions to the latter rule, where a vessel 's whole activity is devoted to carrying a single product, e.g. gasoline, from a refinery to a distribution point.

Loading and discharging methods are standard throughout the industry. Loading is accomplished by pumping from storage tank installations on shore through the vessel's distribution system to a specific cargo tank. Larger vessels have more than one loading point in order to speed operations; a vessel of 10,000 DWT would have one loading point serving the whole vessel. This is not to say there is only one receiving pipe on board through which to load cargo, but rather that there is one location, usually amidships, where up to four separate lines can be used at once. Product is directed through these lines to various cargo tanks by a system of valves.

Discharging is accomplished by pumping through the same systems from the cargo tanks to facilities ashore, usually to storage tanks, but in some cases to railway tank cars or tank trucks. Where products are involved, this assumes later distribution to consumers; in fact, in major world ports, tankers - albeit small ones - deliver products, e.g. Bunker "C", directly to industrial plants and to other vessels. When crude is discharged it is always to refinery storage tanks, where it is held for processing. The only difference in the procedure for discharging is that it is done by the ship's pumps, whereas loading is done by pumps on shore.

There are certain standard procedures which are followed throughout the industry during loading and discharging operations. "Scupper plugs" must be in place. The scuppers are openings in the ship's side, above the deck but below the rail, which allow rain and sea water to run off. When plugged the effect is to make the deck into a large "catch basin", and this is exactly the purpose of the exercise; if a hose coupling should part while cargo was being handled, or any accident should happen causing cargo to be spilled on deck, having the scuppers plugged allows a brief period in which to halt operations and correct the condition before any product is lost overboard. Prevention of pollution is the objective, not the possible salvage of spilled product.

It is general practice to have men posted on board and on dockside during loading or discharge. In average operations there would be two watchmen on board and two on the dock. These men keep a constant surveillance over the activities; they are thoroughly familiar with the routine procedures, and are trained to act in emergency situations.

One specific duty of the watchmen on board is to see that the ship's sea-cocks are sealed. The sea-cocks permit a ship to take on sea water as ballast. The same pumps that discharge cargo pump ballast to various tanks. Sealing the sea-cocks during discharging operations ensures that no cargo will be pumped by mistake directly into the sea.

One major United States oil company retains its retired ship's officers to act as "pollution officers" on its deep-sea tankers. Their sole responsibility is to see that laid-down operating procedures are followed.

Should any amount of product get to the sea alongside, either by accident or neglect, then it is usual for ports today to be equipped to move quickly to correct the situation. Dispersent spray equipment, used to spray a foam on a "spill" and disperse the oil particles, is standard on vessels and at dock facilities. It is common for major oil companies to be prepared for cooperative action in the event of an emergency in an area that is common to them. To illustrate, the major companies on the East Coast of Canada have contingency plans for united action on a threat to that environment.

3.5 BALLAST DISCHARGING AND TANK CLEANING PRACTICES

Whether large tankers are carrying crude oil thousands of miles from producing areas to refineries, or small tankers are delivering product from refinery to consumer, they have one thing in common: they must make the return trip in ballast.

Ballast, of course, provides manoeuvrability and a margin of safety; without ballast a tanker would be quite unseaworthy. The amount of ballast that must be carried depends on the season: in the summer seaon 35-40% of displacement is usually sufficient, while the stormy winter season would require about 60% ballast.

What the vessel does with its ballast as it approaches port depends on the facilities available at that port. Tanker ports fall into two general categories:
1. those in either producing or consuming areas with refinery installations,with their attendant "slop facilities" for receiving ballast, and
2. those in producing areas which are simply trans-shipment points and have no facilities for receiving ballast.

As an example of the first group, ports in the producing country of Venezuela have refineries with facilities to receive ballast from tankers arriving to take on crude oil for North America and Europe. Likewise, a port like Halifax has refineries with similar facilities to receive ballast from vessels calling to take on products for local distribution. To illustrate the second group, Persian Gulf ports are merely trans-shipment points where vessels pick up their loads of crude, destined mainly for refineries in Europe.

The justification of having slop facilities at refineries are both economic and social. There is value in the oil that is mixed with the ballast, and this can be realized by re-cycling. Thus it is a salvage operation, whereby the company which owns or charters the tanker can recover what would otherwise be lost if the ballast was simply pumped into the sea. The social justification is obvious: by not pumping ballast into the sea contamination of the environment is avoided. Generally, the industry appears to have accepted the responsibility to prevent such contamination. However, it has been estimated by Max Blumer that present practices in tanker ballasting, in spite of the presence of slop facilities at some ports and the "Load on Top" technique employed when there are no such facilities, introduce about 3 million tons of petroleum into the ocean.[1] Further, the pumping of bilges by vessels other than tankers contributes another 500,000 tons, and in-port losses from collisions and during loading and unloading contribute another estimated one million tons.

[1] Blumer, Max, "Scientific Aspects of the Oil Spill Problem", Colloquium on Oil Pollution of the sea, CCMS, North Atlantic Treaty Organization, Brussels, 1970.

The slop facilities are relatively simple in concept. They consist of one or more series of settling tanks into which the ballast is pumped directly from the tanker at the dock. The series of tanks (or "ponds", which is more accurate) permits several periods of relative stillness for the total flow, during which the oil content floats to the surface. This is skimmed off by one of a variety of mechanical means, the most basic of which comprises a long-handled wooden paddle wielded by a man standing on a cat-walk. Commonly, the layer of oil is directed into a slotted pipe which leads away to a storage tank, and eventually to the refinery for processing. At the end of the series the "clean" ballast water is returned to the sea.

The tanker arrives in port prepared to discharge ballast. If the vessel is in the commercial trade delivering products, tank cleaning is required when changing cargo types. Aviation fuel cannot be put into a tank which previously held diesel fuel. Butterworth cleaning equipment is the type most commonly used whereby cleaning is done by lowering hot water spray equipment into the tank and flushing down its sides. It is done as the tanks are emptied of product, and when completed, the washing water is pumped into a separate holding tank. Then the tank can be used for ballast, and this ballast, because it is not contaminated, may be discharged to the sea as the vessel approaches port. The practice of moving washing water to one or two tanks for discharge into slop facilities is known as consolidated washing. Ballast in tanks which have not required cleaning is also discharged into the slop tanks when the vessel reaches port.

Similar circumstances prevail in the ocean-going trade, when the port has refinery facilities. However,relatively little tank cleaning is required, because crude products vary slightly. The slop facilities in these source areas are much larger than those found in the consuming areas. This is necessitated by the size of the vessels. They discharge ballast at the rate of 40-50 thousand barrels per hour, versus the 2700 bph of the 10,000 ton Imperial Acadia.

Tankers arriving for cargo at ports without refineries and slop facilities have to operate differently. As they approach their port, they start discharging their ballast into the sea, but they only pump out what is relatively clean sea water. That is, they draw off the ballast water from beneath the oil residue. Then the tank is washed down by the Butterworth method referred to above, or a variation of it. The ballast residue and the washing water is collected successively from each tank and concentrated in one tank, where it is all allowed to settle. Then the water is drawn from this tank and pumped overboard, leaving one tank on board with a residue of oil sludge. The amount and composition of this residue is reported, and cargo is loaded in on top of it. This practice is known in the industry as the Load on Top method; it was developed and put into practice by the Shell Oil organization in the mid-1950's.

3.6 TRENDS IN HANDLING METHODS

We have referred to the very real trend to larger size in the pipelines and tankers which carry petroleum products. We concluded, however, that the significance of this was in the risk to the environment posed by large size carriers, and that the actual methods of handling petroleum products had changed only slightly. If there are trends at all in handling methods, they would appear to social rather than technological, being brought on more by governmental authority than by the initiative of the industry. They are concerned with safeguarding the traditional handling methods. The "pollution officers" we referred to earlier, the improved navigation facilities being provided by governments, viz. the guidance system at the Strait of Canso, proposed legislation to limit the size of oil tankers in territorial waters, and the likelihood of the building of more deep-water ports to accommodate super-tankers, really have little to do with the actual handling of the product. These are measures being considered or taken to reduce the hazard of massive pollution of the environment. Traditional handling practices continue.

The "clean ballast system" is an exception. There is a trend to construct tankers with separate compartments for ballast only. It is the opinion of one oil company marine superintendent that legislation ultimately will require all new tankers to be built this way, and that existing tankers will have to isolate specific cargo tanks for ballast purposes only. Obviously, tanker owners will not encourage the trend because of the increased building and operating costs these provisions will incur. From the owner's point of view any tanks that can not be used for cargo are waste space, and in the tanker business, space is money. However, it is not likely the owners would suffer for long: whether the "clean-ballast system" is made mandatory by legislation, or whether the major companies simply adopt the system in the name of social responsibility, it will ultimately be the consumer who pays for the increased costs.

Another dimension to the trend toward mammoth tankers is the trend toward multi-purpose vessels. In the never-ceasing struggle to minimize costs by increasing payloads, there are now being developed ore/bulk/oil vessels which handle, in addition to ore or oil, such bulk commodities as grain, minimizing even further the necessity to travel in ballast on any leg of a voyage.

Developments such as these, however, do not relate directly to the bulk-handling practices of petroleum products. We conclude that the traditional methods of transferring the commodity between vessel and shore installation will obtain for the foreseeable future, with increasing attention being paid to accident prevention and the provision of clean-up equipment and crews.

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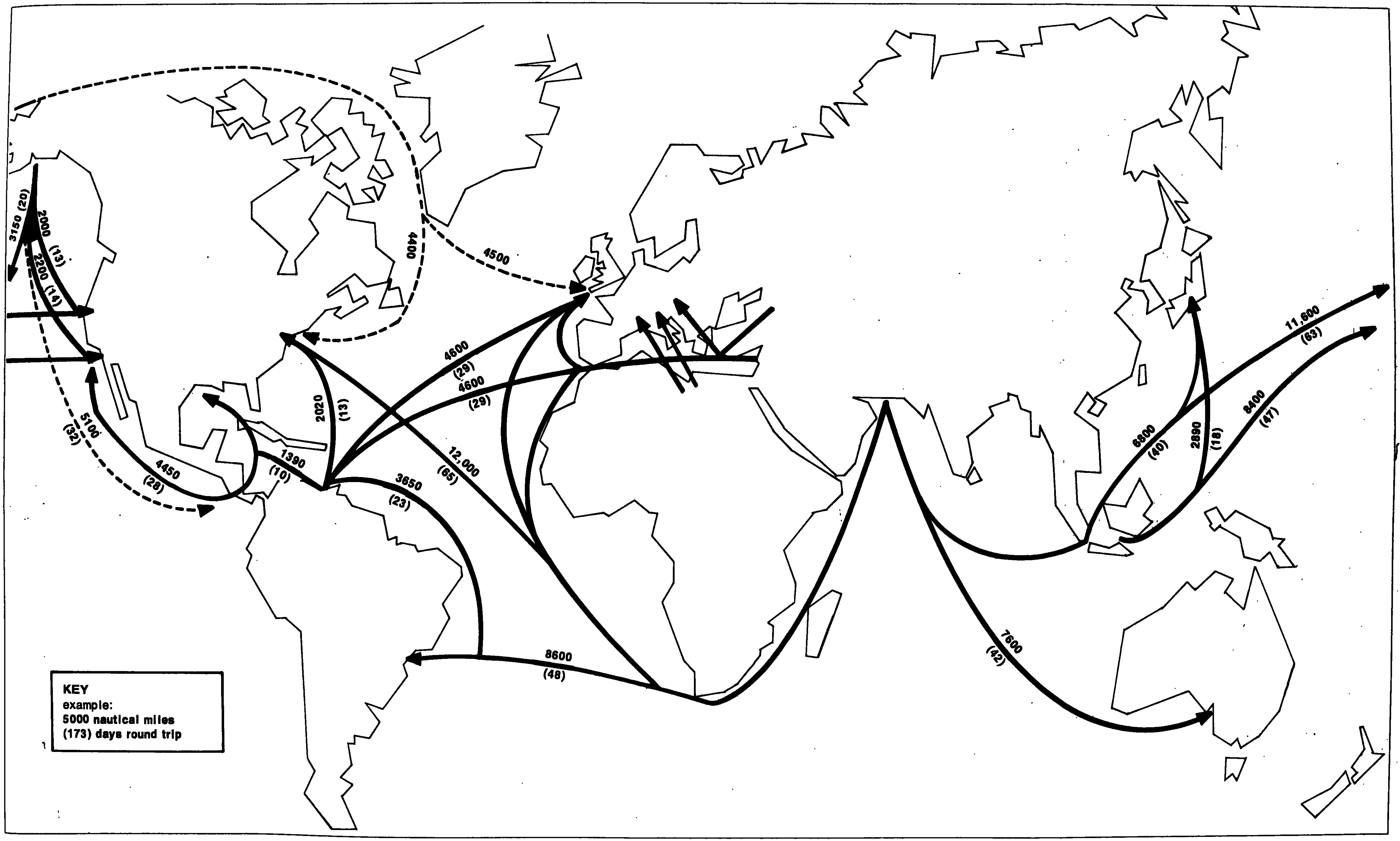
World Tanker Ports and Routes

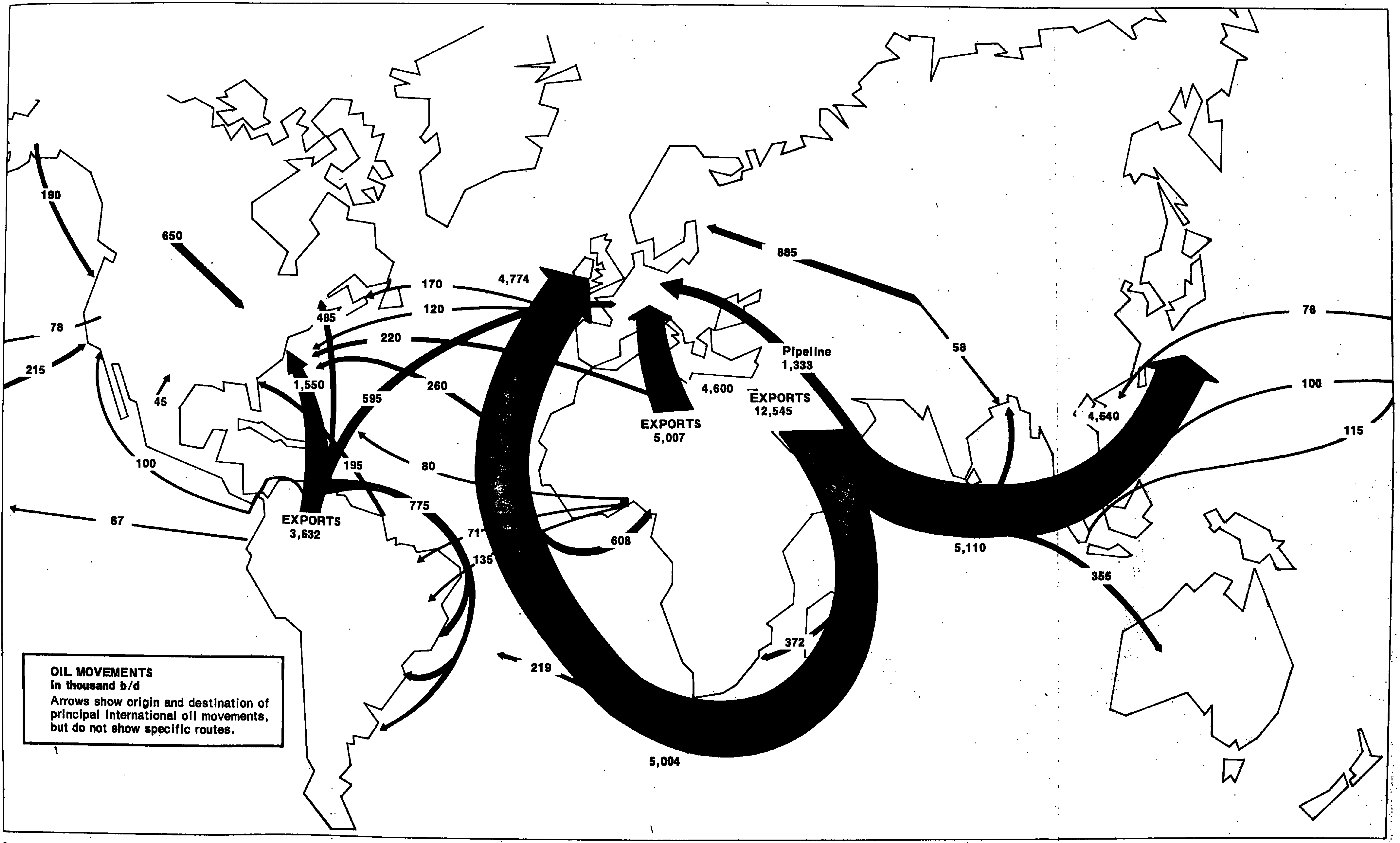
Exhibit I



Source: International Petroleum Encyclopedia, 1971

Worldwide Petroleum Flow, 1970

Exhibit II



Source: International Petroleum Encyclopedia, 1971

Exhibit III

WORLD TANKER FLEET AT END 1970
(EXCLUDING COMBINED CARRIERS)
(2,000 D.W. Tons and over)
BY FLAG AND OWNERSHIP

FLAG	OWNERSHIP						Change 1970 over 1969	Share of Total 1970
	Oil Company	Private	Govern-ment	Other	Total 1970	Total 1969		
	MILLION TONS DEADWEIGHT							
Liberia	6·5	31·3	—	—	37·8	30·7	+ 7·1	24%
Norway	0·2	17·0	—	—	17·2	15·7	+ 1·5	11%
U.K.	15·7	5·8	0·2	0·2	21·9	18·8	+ 3·1	14%
Japan	2·5	13·1	—	—	15·6	13·7	+ 1·9	10%
U.S.A.	4·0	3·7	1·8	—	9·5	9·1	+ 0·4	6%
Panama	3·4	2·2	—	—	5·6	5·3	+ 0·3	4%
France	3·5	2·2	0·1	—	5·8	5·2	+ 0·6	4%
Greece	—	7·8	—	—	7·8	5·8	+ 2·0	5%
Other Western Europe	9·9	11·4	0·1	—	21·4	19·5	+ 1·9	14%
Other Western Hemisphere	2·7	0·5	0·2	—	3·4	3·1	+ 0·3	2%
U.S.S.R., E. Europe & China	—	—	6·1	—	6·1	5·4	+ 0·7	4%
Other Eastern Hemisphere	0·8	2·6	0·2	—	3·6	2·9	+ 0·7	2%
TOTAL	49·2	97·6	8·7	0·2	155·7	135·2	+20·5	100%
Fleet as at end 1969	43·0	83·9	8·1	0·2	135·2			
Net increase 1970	6·2	13·7	0·6	—	20·5			

BY AGE, SIZE AND PROPULSION
MILLION TONS DEADWEIGHT

SIZE IN '000 D.W.T.	YEAR OF CONSTRUCTION							PROPULSION		New Building in progress and on order at end 1970*
	Up to end 1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970	Total	Motor	Other	
Under 25	4·8	1·4	8·5	7·4	2·5	3·7	28·3	19·3	9·0	1·3
25- 45	1·0	1·3	5·0	14·7	4·1	1·3	27·4	7·4	20·0	2·1
45- 65	0·1	—	0·9	5·1	14·6	1·8	22·5	7·5	15·0	0·2
65- 85	—	—	—	1·1	8·2	7·8	17·1	11·2	5·9	0·6
85-105	—	—	—	0·7	5·2	9·5	15·4	8·8	6·6	0·8
105-125	—	—	—	0·4	0·6	5·0	6·0	3·5	2·5	1·5
125-145	—	—	—	—	0·1	2·6	2·7	1·2	1·5	2·6
145-165	—	—	—	—	—	2·5	2·5	1·9	0·6	0·6
165-185	—	—	—	—	—	1·2	1·2	0·2	1·0	—
185-205	—	—	—	—	—	3·9	3·9	0·4	3·5	0·6
205 and over	—	—	—	—	—	28·7	28·7	0·5	28·2	60·0
TOTAL	5·9	2·7	14·4	29·4	35·3	68·0	155·7	61·9	93·8	70·3

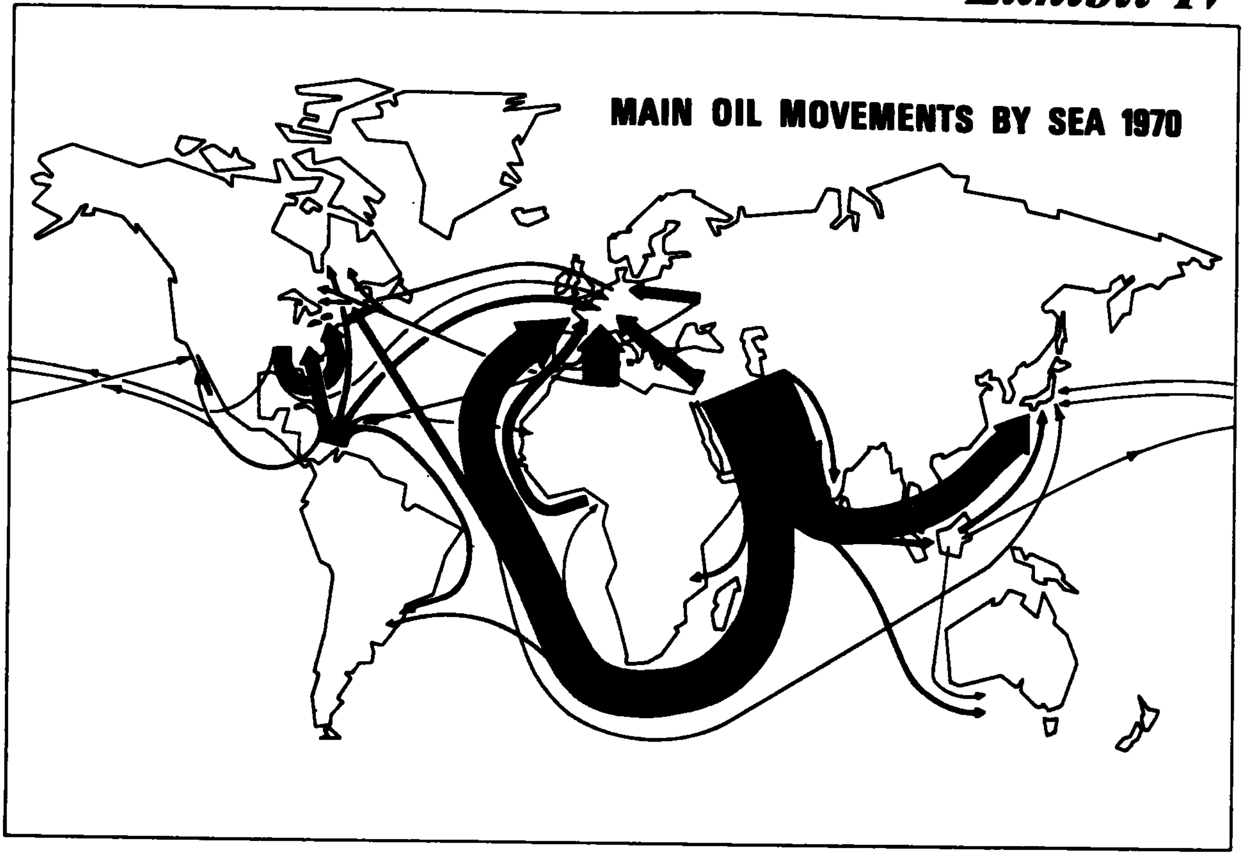
MOTOR	0·9	1·2	7·3	8·9	17·6	26·0	61·9
OTHER	5·0	1·5	7·1	20·5	17·7	42·0	93·8

*Excludes 20·3 Million D.W.T. combined carriers.

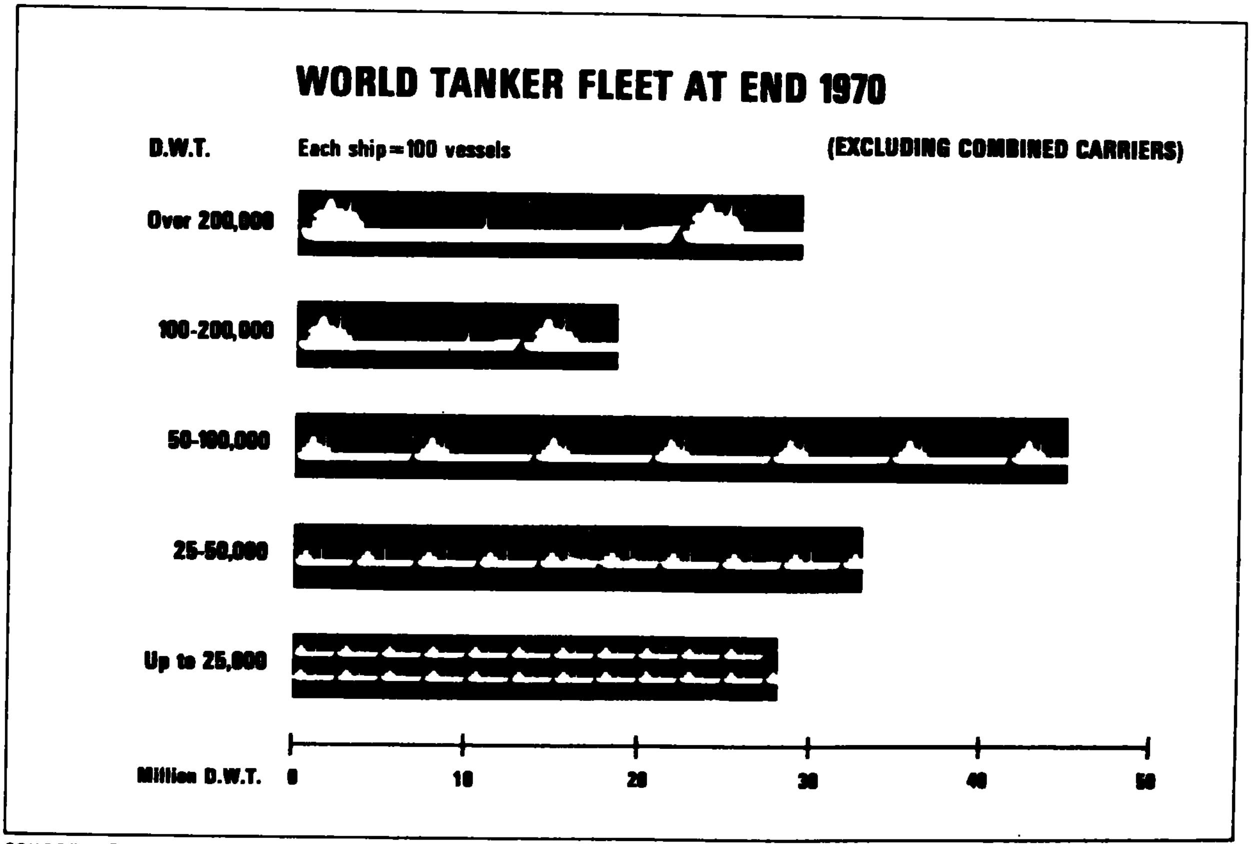
COUNTRY/AREA	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	Yearly Change 1970 over 1960	Yearly Change 1970 over 1965
REFINERY CRUDE THROUGHPUTS	MILLION TONS												
U.S.A.	405	410	422	436	443	454	474	492	517	532	545	+ 3·0%	+ 3·8%
Caribbean	110	119	127	131	132	143	145	148	152	158	161	+ 4·0%	+ 2·5%
Western Europe	185	209	236	269	311	355	400	437	496	550	617	+12·8%	+11·8%
Middle East	63	66	70	72	74	77	78	82	91	94	95	+ 4·3%	+ 4·5%
Rest of World	304	337	376	413	459	497	554	605	668	742	817	+10·5%	+10·5%
WORLD	1,067	1,141	1,231	1,321	1,419	1,526	1,651	1,764	1,924	2,076	2,235	+ 7·8%	+ 8·0%

SOURCE: B P STATISTICAL REVIEW OF THE WORLD OIL INDUSTRY, 1970

Exhibit IV



MAIN OIL MOVEMENTS BY SEA 1970



WORLD TANKER FLEET AT END 1970

SOURCE: BP STATISTICAL REVIEW OF THE WORLD OIL INDUSTRY, 1970

4.0 A PRELIMINARY REVIEW OF HARBOUR AND COASTAL POLLUTION BY OIL

4.1 INTRODUCTION

Condition (c) of the Contract requires the contractor to "assess harbour pollution problems resulting from oil pollution originating in ships or refineries". Only a preliminary assessment of the nature of harbour pollution problems has been made to date, and the following is not to be considered complete.

Further, it is recognized that oil pollution in harbours has wider origins than "ships or refineries". Other sources of oil pollution include municipal sewage systems, leaking storage tanks at industrial plants and service stations, the direct discharge of oil wastes from industrial plants, and the normal run-off through storm or sanitary sewers.

4.2 SHIPS

4.2.1 Sources

(a) Bilges
(b) Cargo Tanks
(c) Fuel Tanks
(d) Fuel Transfer
(e) Lubricating Oil
(f) Separators

4.2.2 Bilges All vessels accumulate water in their bilges and this water will contain an amount of oil depending on the state of machinery and housekeeping practices, as some ships deliberately drain oil into the bilge when carrying out maintenance. It is general practice to pump bilges at sea at night, and in some cases pumping is continued only until oil appears at the discharge.

Large vessels are fitted with separators on bilge discharges from machinery spaces so that the oil might be recovered. Typical ships bilges will be sampled and the water/oil mixture analysed later in the study.

4.2.3 Cargo Tanks. The object of oil tankers and their various ballast disposal practices has been discussed at length in Section 3.5. Reference was made to Blumer's estimate of the extent of oil pollution being caused in ocean and harbour waters by current ballast disposal practices. Of the total of approximately 4.5 million tons of petroleum introduced to the ocean annually by all causes, 3 million tons are contributed by ballasting practices. With specific relation to harbour pollution, Blumer estimates that about 1 million tons of petroleum is lost per year through collisions and loading operations.[1]

Attempts will be made to analyse local harbour waters to determine the quantity of oil present.

[1] Blumer, Max, "Scientific Aspects of the Oil Spill Problem"

4.2.4 Fuel Tanks. Ships may ballast fuel tanks with sea water and normally pump this water overboard before refuelling. The residue is handled in the same way as for cargo tanks.

Some vessels are fitted with water displacement fuel systems. When refuelling, the fuel is pumped into the tanks until fuel appears at the sea inlets.

4.2.5 Fuel Transfer. Fuel may enter the harbour due to broken pipes, poor joints, or on uncoupling. Adequate arrangements are necessary to drain lines if fuel spills are not to occur.

4.2.6 Lubricating Oils. Lubricating oils, may enter the bilges due to poor "housekeeping" practices or be deliberately drained overboard. Normal practice places used oil in drums for disposal by burning.

4.2.7 Separators. Separators suffer from many drawbacks when used at sea. They are sensitive to vibration and rolling, they are complicated by the need to handle a large range of viscosities of oils and wide temperature changes. The amount of water to be handled may be very large if all the water/oil mixture is passed through the separator. If only the water/oil mixture with a high percentage of oil is passed through the separator, a reliable means of determining when this percentage is reached is required.

4.3 REFINERIES

4.3.1 Sources

(a) Cooling and Process Water
(b) Run-off water
(c) Ships alongside

4.3.2 Cooling and Process Water. Cooling and process water picks up oil (and other contaminants). The mixture is passed through a clarifier permitting the recovery of the oil and reducing the oil in the final effluent. Typical refinery wastes will be sampled and analysed.

4.3.3 Run-Off Water. Run-off water is not normally oil contaminated but in case of major tank or process leaks, the effluent would be treated as an "oil spill".

4.3.4 Ships Alongside

See Ship Section.

5.0 LABORATORY RESEARCH PROGRAM

5.1 GENERAL

The laboratory program to date has consisted of the hydraulic testing of polyurethane foam. This has been found to be a necessary prelude to mass transfer studies in that it serves as a reliable method of eliminating some foam types as possible filter media. The philosophy behind the screening process is, that a particular foam, regardless of its capacity to absorb oil is useless unless it will allow the passage of water in sufficient quantities.

At the time of the Arrow oil spill and subsequent clean up operations, some experimental work was carried out on F-14 polyurethane foam as a filter medium. One of the findings of that work which will be adopted without further proof is that a pressure filter is not practical. The main reason for this, is that comparatively small pressures have been found to cause the foam to compress to the extent that the pores close off. The result of this, is that the flow is reduced to an undesirably low level.

Mass transfer studies will be made, using only the foams with acceptable hydraulic characteristics as filter media in gravity filter vessels. Pressure filters will not be utilized.

5.2 OBJECTIVE

The purpose of this portion of the research program was to assess the hydraulic capacity of a number of selected polyurethane foams. These data were considered necessary in order to identify the type or types of foam which would sustain the highest flow rates.

Eleven grades of foam were examined. Nine of these were of the flexible open cell variety, and were obtained from Monsanto Canada Limited in Toronto. The other two were of the rigid variety and were obtained from Guildfords Limited of Dartmouth, N.S. The flexible type were coded by the manufacturers as follows:

1029, 1120, 1329
1528, 1835, 2335
3337F, 3865F, 1855 SC

The properties of these foams are given in Table 5.1 of this report.

5.3 APPARATUS

The apparatus used in this study was bought or fabricated locally, and installed so as to create a completely closed hydraulic system.

The individual pieces consisted of a 20 gallon polyethylene circular container in which was placed a high-capacity sump pump(50 U.S. gpm against a 5 ft.head).This was pipe-connected to

TABLE 5.1

FOAM SAMPLES AND PROPERTIES

TYPE	DENSITY	TENSILE	TEAR RESIS.	ELONG.	COMPRES.	RESIL.	I.L.D.	HYST.	MOD.	L.B.L.	CELL COUNT	K
1029	1.00	12.0	1.5	150	10	40	29	60	1.7	32.5	45	0.24
1130	1.10	14.0	1.8	150	8	45	29	65	1.7	27.5	45	0.24
1329	1.27	14.0	2.0	180	8	50	29	68	1.7	27.5	48	0.24
1528	1.52	15.0	1.8	170	6	52	28	70	1.7	26.0	45	0.24
1835	1.82	16.0	2.0	200	6	55	39	72	1.8	22.5	45	0.24
1855S	1.82	20.0	1.5	120	30	20	55				45	0.24
2335	2.27	12.0	1.5	150	10	48	35	75	2.0	20	48	0.24
3337F	3.30	7.0	0.7	100	6	40	37	73	2.3	20	50	0.24
3865F	3.75	10.0	0.8	90	10	35	65	65	2.2	20	50	0.24

Density - lbs. per cubic foot

Tensile - breaking strength in lbs./sq.in.

Tear Resistance - Tear strength in lbs./in. thickness

Elongation - % stretch over original measure at 70°F

Compression Set - % loss @ 75% deflection, 22 hrs., 158°F.

Resiliency - % rebound by 1/2" steel ball at 18".

Indent Load Deflection - lbs. @ 25% deflection, 50 sq.in in 4" thick

Hysteresis - Ratio of 25% ILD and 25% ILD after 65% deflection

Modulus - Ratio of 25% ILD and 65% ILD

Load Bearing Loss - % @ 75% deflection, 100,000 cycles

Cell Count - Avg. number of cells per linear inch

"K" Factor - B.T.U. inch/sq.ft./hr/°F @ 82°F

Source - Technical Service Catalogue, Monsanto Canada Ltd.

a Fischer & Porter Model 10A 3565A rotameter type flow meter, and from there to a nozzle discharging into the filter vessel. The filter consisted of one to six, 8 in. diameter by 1 in. thick polyurethane discs, center-mounted on a 30 in. by 1/4 in. diameter spike and supported on an expanded metal mesh. This filter arrangement was housed in an 8 in. internal diameter transparent plexiglass tube vertically oriented and bottom capped.

At a distance of eight inches from the bottom on the inside face of the cylinder wall, a 1/8 in. x 1/8 in. annular ring was plastic welded. This served as a support for the expanded metal mesh on which the filter media was mounted.

At a centre distance of three inches from the bottom, two 2 in. diameter outlet pipes were installed. These emptied into two channels leading to a 1/2 in. x 10 in. rectangular notched weir, calibrated with the rotameter. The weir emptied into the sump, thus completing the hydraulic system. The weir was built and calibrated during the hydraulic testing as it was recognized that the rotameter will not be of use during the mass transfer experiments due to the sight glass becoming oil coated.

5.4 PROCEDURE

The purposes of the procedure which was followed were to establish the steady-state flowrate at which flooding of the filter occurred, and then to observe the physical behaviour of the flooded filters under increased flowrates and the hydraulic head build-up resulting from these increased flow rates. These conditions are shown on Plates 5.2 to 5.5 for 1 in. and 6 in. filters respectively.

The procedure was as given below, and was used for each of the eleven foam types.

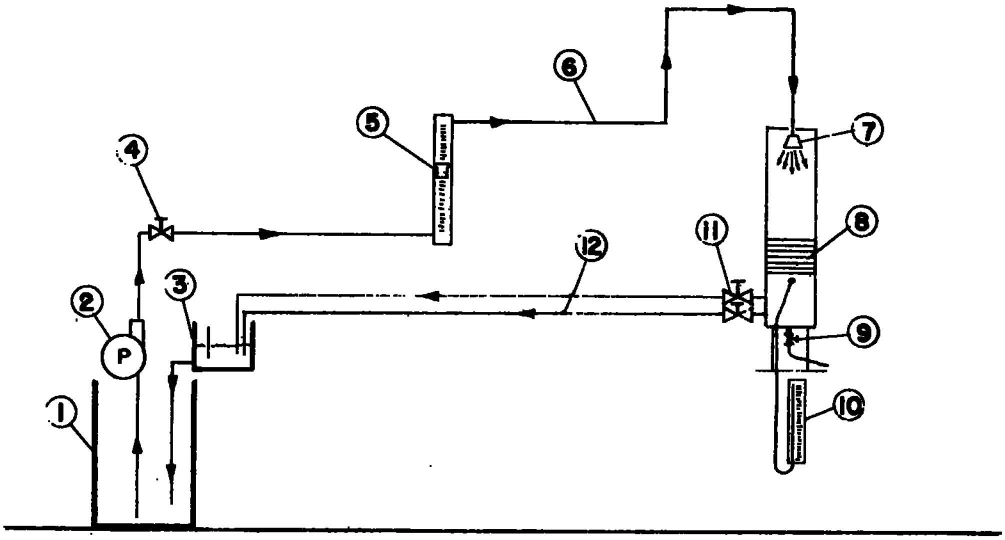
1. Mount one - 1 in. disc on the spike and mesh, and insert this into the filter housing so that the mesh is brought to bear on the annular ring.

2. Start the pump, and by means of the valve located in the line from the pump to the flow-meter, increase the flow until the filter bed floods. Retain this flowrate to ensure that a steady-state across the filter has been established. Adjust the flowrate if necessary to ensure that both flooding and a steady flowrate occur. See Plate 5.2.

3. Record flow and note any changes in the physical appearance of the medium.

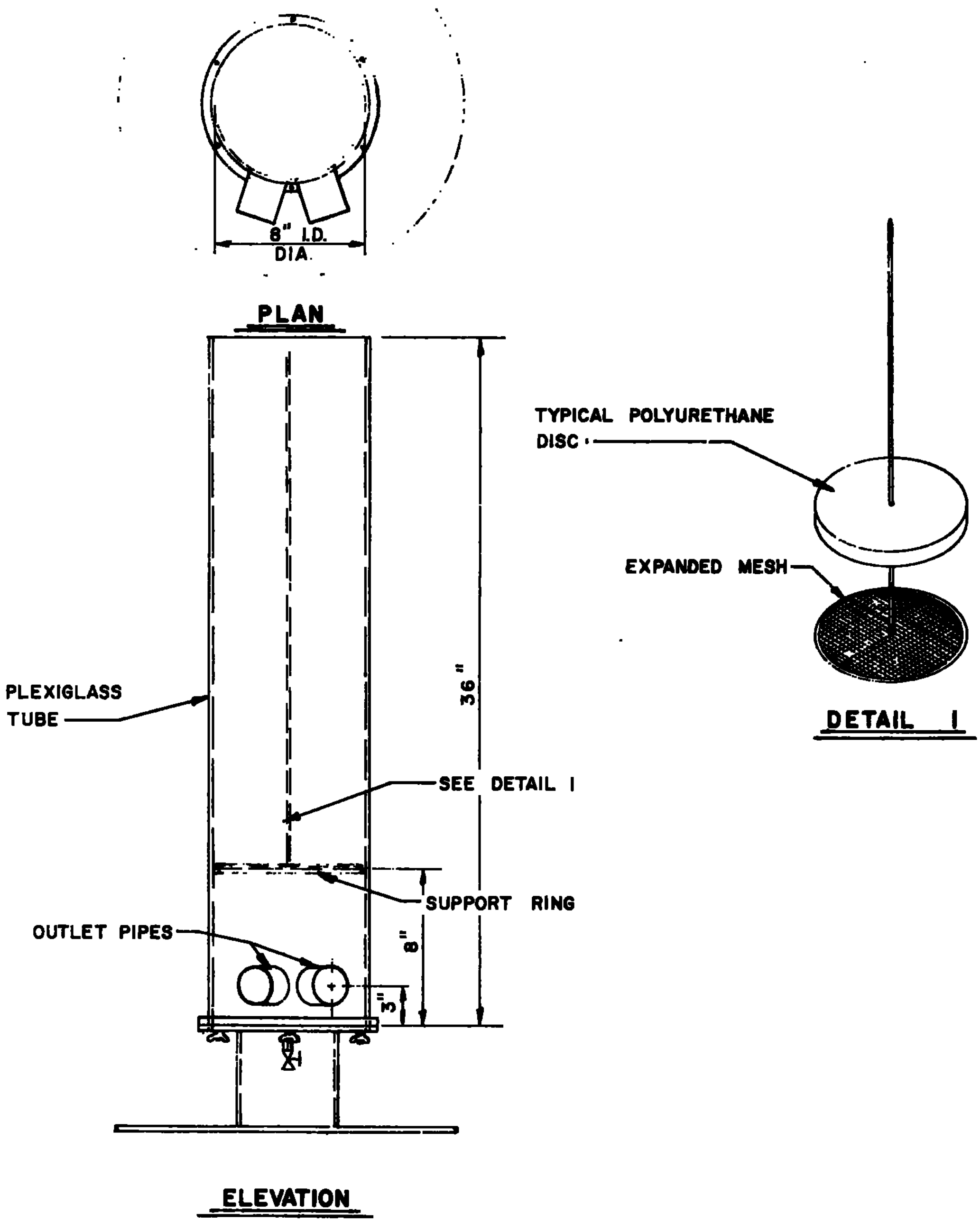
4. Increase the flowrate by 1.5 g.p.m. increments, and for each such increment, record the steady state flowrate, the head buildup above the filter, and any change in the physical appearance of the filter. See Plate 3.

5. Repeat steps 2,3 and 4 for 2, 4 and 6 in. of filter medium.



1. 20 imp. gal. PLASTIC RESERVOIR
2. SUMP PUMP - 50 u.s.g.p.m. CAPACITY - CANADIAN TIRE CORPORATION
3. RECTANGULAR NOTCHED WEIR
4. THROTTLE VALVE - 1 1/4" BRONZE GATE VALVE
5. ROTAMETER - 2.4 to 36 u.s.g.p.m. - F.P. 10A3565A
6. 1 1/2" A B S PIPE
7. 1 1/2" SPRAY NOZZLE
8. FILTER MEDIUM (POLYURETHANE DISCS 1" THICK)
9. SAMPLE VALVE
10. MANOMETER
11. DRAIN VALVES - 2" BRONZE GATE VALVES
12. 2" A B S PIPE

DRAWING 5.1



PLAN

DETAIL I

ELEVATION

DRAWING 5.2

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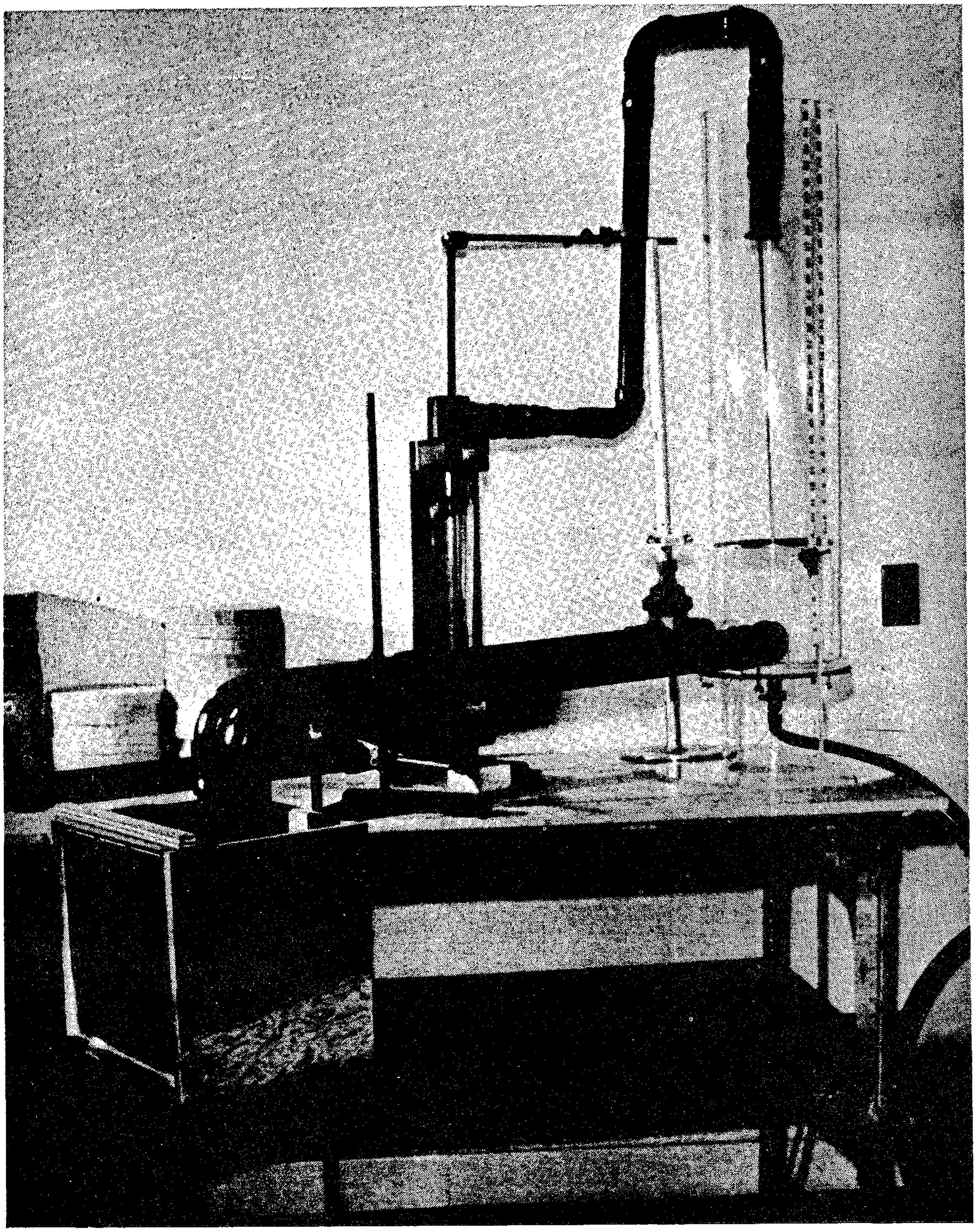


PLATE 1 - EQUIPMENT WITH FILTER COLUMN EMPTY

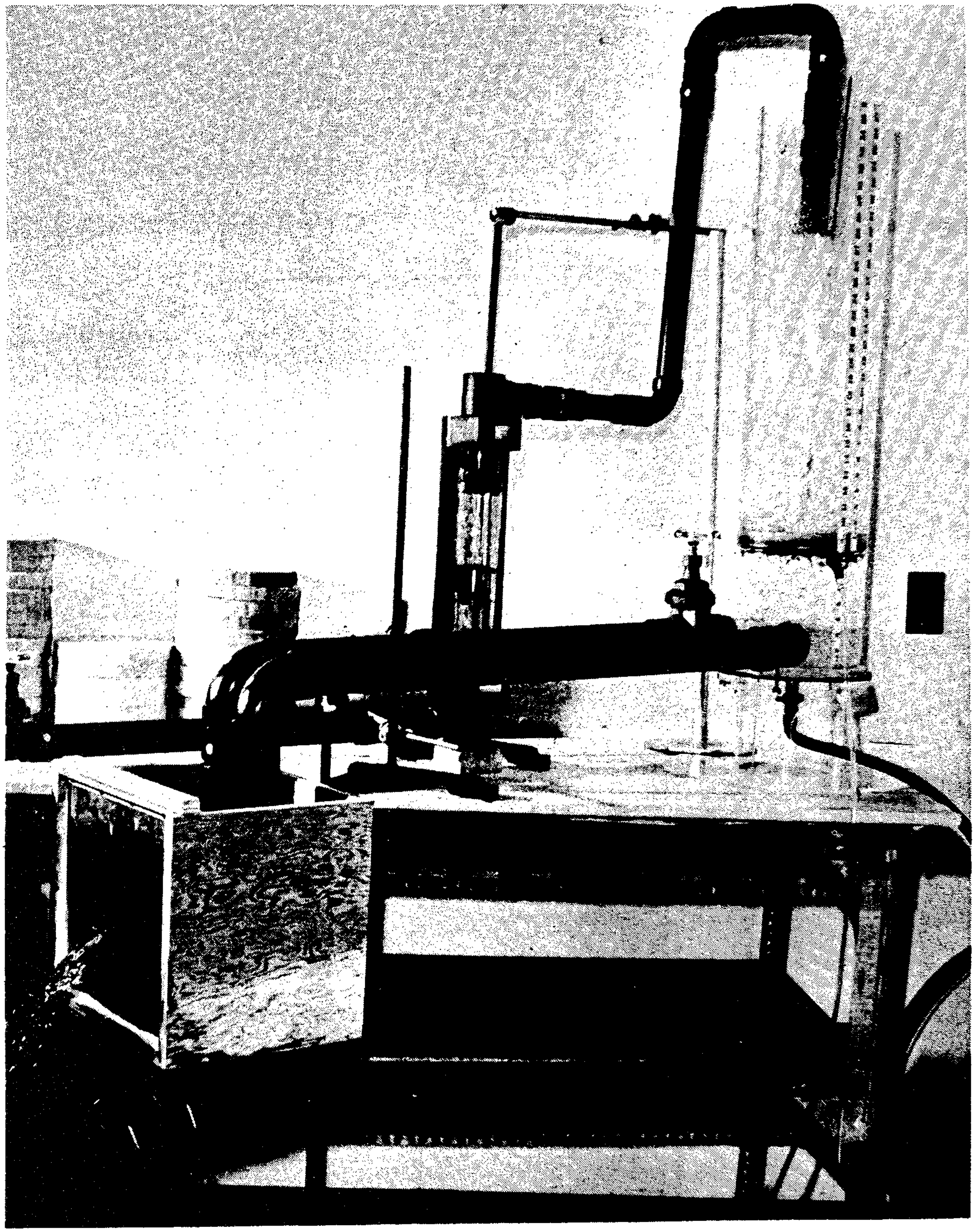


PLATE 2 - FLOOD POINT CONDITION USING ONE FILTER DISC.

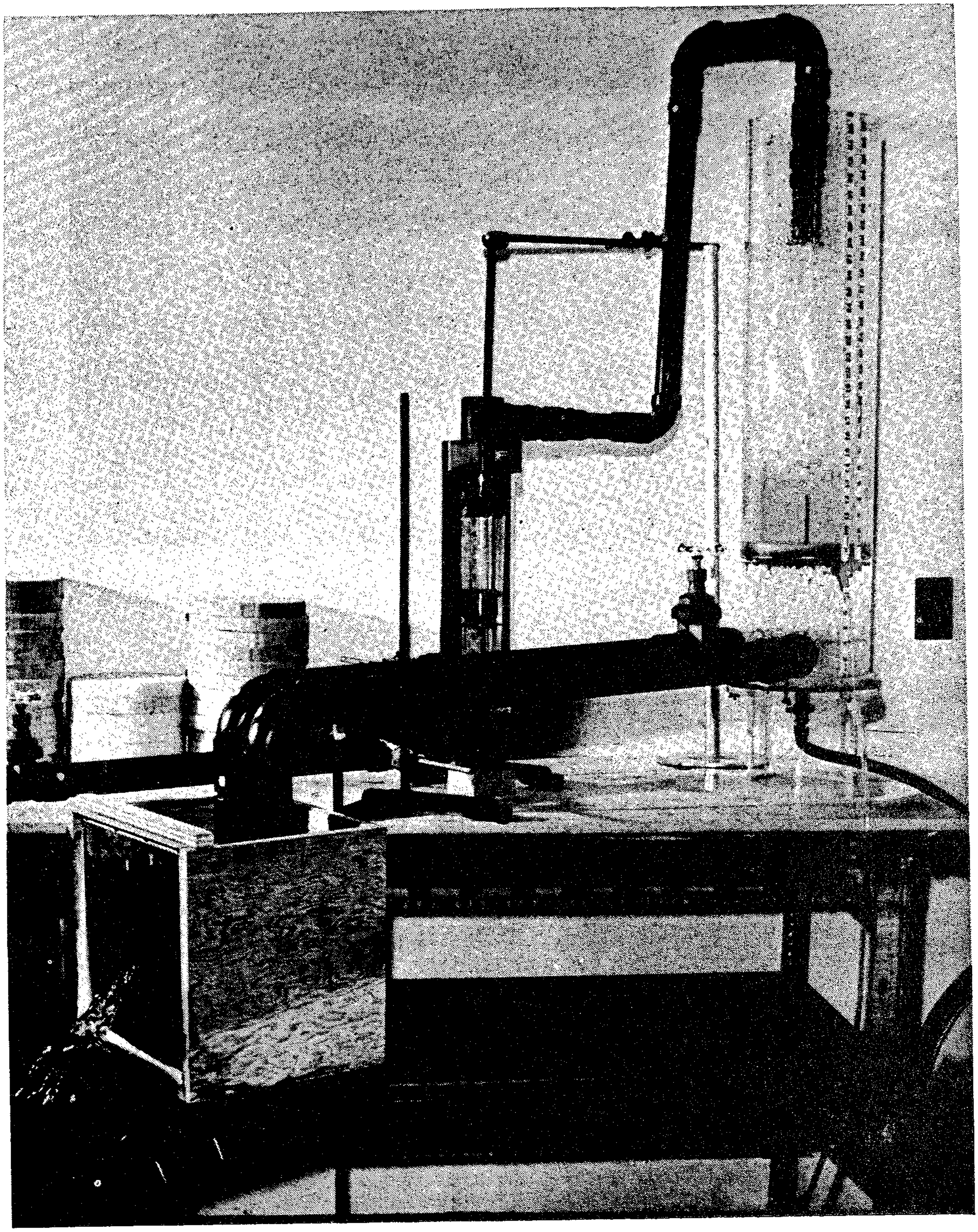


PLATE 3 - FLOODED FILTER AND HEAD BUILD UP USING ONE FILTER DISC

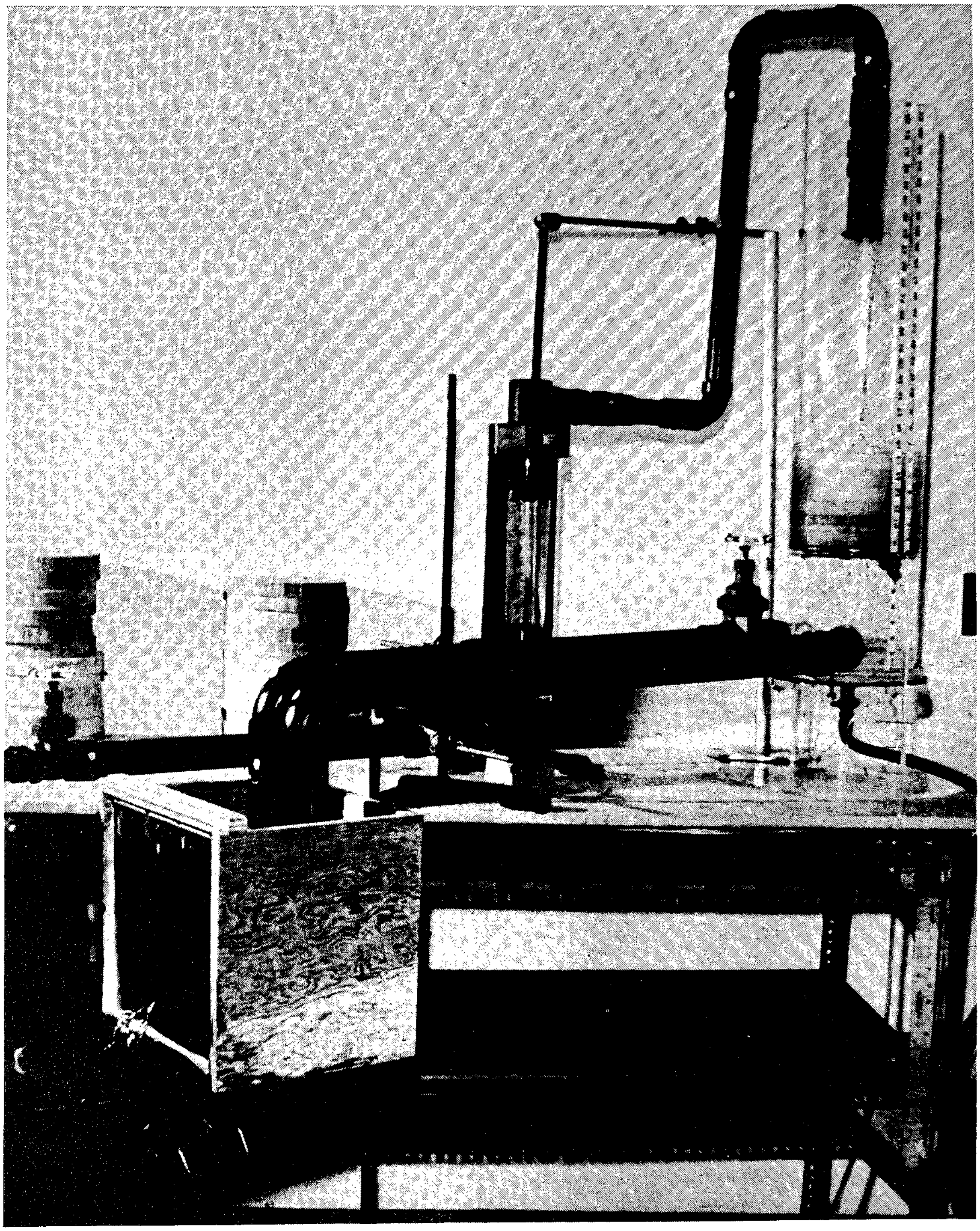


PLATE 4 - FLOOD CONDITION USING SIX FILTER DISCS

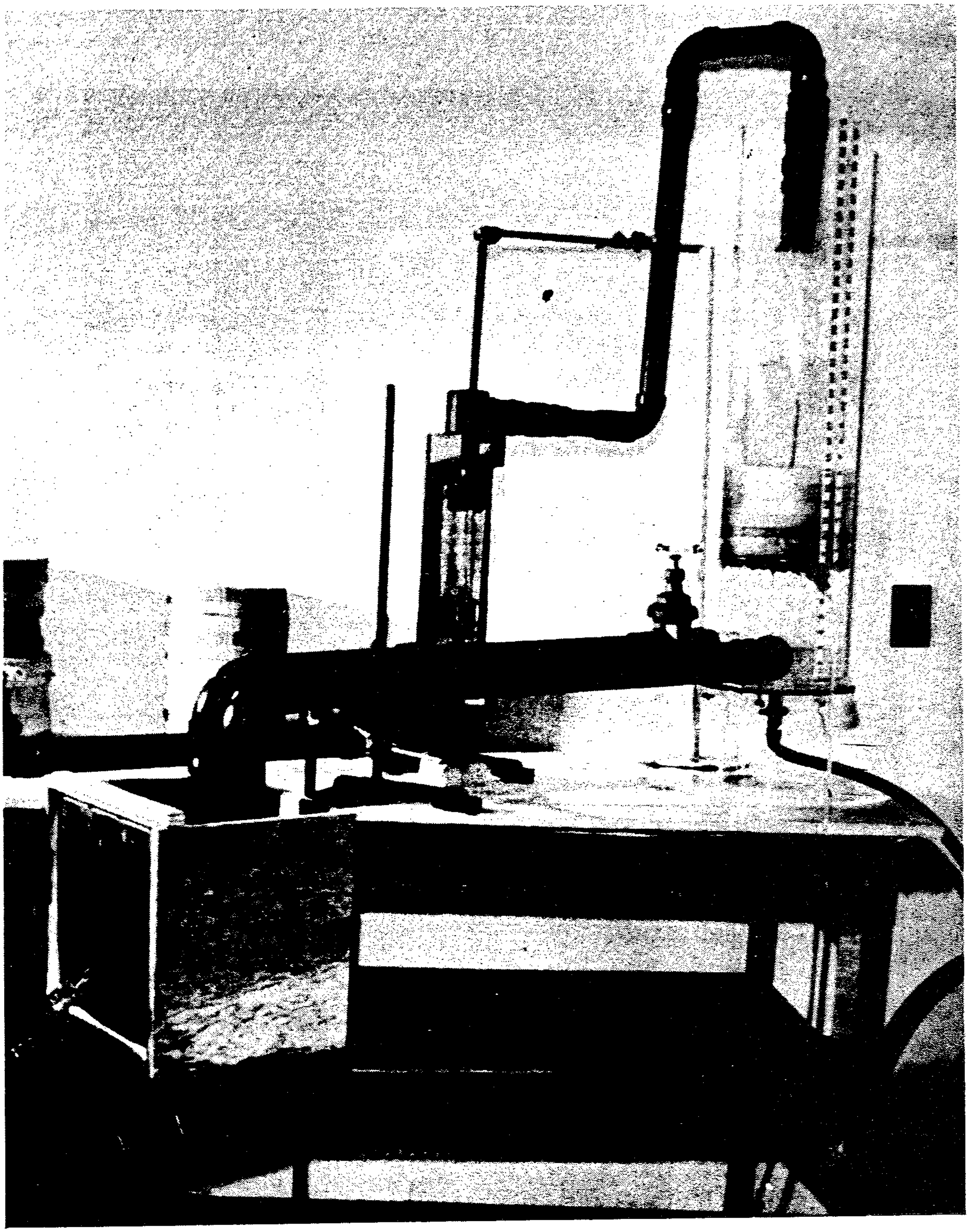


PLATE 5 - FLOODED FILTER AND HEAD BUILD UP USING SIX FILTER DISCS

5.5. RESULTS

The most important variable in comparing the hydraulic performance of various types of filter material is the maximum flow which the material can sustain before flooding. This flow termed the flood point, is shown in Table 5.2 for each type of foam studied and for each foam thickness studied, i.e. 1 in., 2 in., 4 in., 6 in.

As can be seen from Table 5.2, the foams with the highest values of flood point, i.e., greatest capacity, were Nos. 1835, 1329, and 1528. The maximum flood point recorded was 31 U.S. gal./min. for a 1 inch thick bed of foam No. 1835 and the minimum flood point was exhibited by a 6 in. bed of foam No. 1855S, the value being less than 3 U.S. gal/min.

Typical data collected in the laboratory program are shown on Table 5.3.

5.6 DISCUSSION OF RESULTS

5.6.1 Significance of Properties

The properties of the various types of foam, as supplied by the manufacturer, are shown on Table 5.1. An attempt was made to correlate the various properties with flood point in order to establish an explanation for the variation. Figures 5.1 - 5.12 show attempted correlation for flood point with resiliency (expressed as the percentage rebound by 1/2 in. steel ball dropped from a height of 18 in.), density and elongation (expressed as the percentage of stretch over original measure at 70°F).

There would appear to be a correlation with resiliency and elongation but no obvious correlation with density. The anomolously high value of flood point for foam No. 3865F, is no doubt due to the fact that it is made by a specialized manufacturing process as indicated by the suffix F.

The conclusion which emerges is that, the greater the resiliency and elongation of a foam, the greater will be its capacity when used as a filter medium.

5.6.2 Effect of Foam Thickness

Figures 5.13 and 5.21 indicate the effect of filter thickness on flood point for each type of foam studied. It is obvious that there is a consistent decrease in capacity as the thickness of filter bed is increased for each type of foam studied.

FOAM TYPE	FLOOD POINT (U.S. gal/min.)				ELONGATION %	RESILIENCY %	DENSITY lb./ft.^{3}
	1 in.	2 in.	4 in.	6 in.			
1029	22.5	12.0	12.0	9.0	150	40	1.00
1130	15.0	12.0	12.0	9.0	150	45	1.10
1329	30.0	22.5	19.5	13.5	180	50	1.27
1528	30.0	19.5	18.0	13.5	170	52	1.52
1835	31.0	27.0	24.0	18.0	200	55	1.82
1855$_{SC}$	10.5	3.0	3.0	--	120	20	1.82
2335	19.5	16.5	13.5	10.5	150	48	2.27
3337 F	13.5	10.5	6.0	4.5	100	40	3.30
3865 F	19.5	18.0	16.5	10.5	90	35	3.75

TABLE 5.2

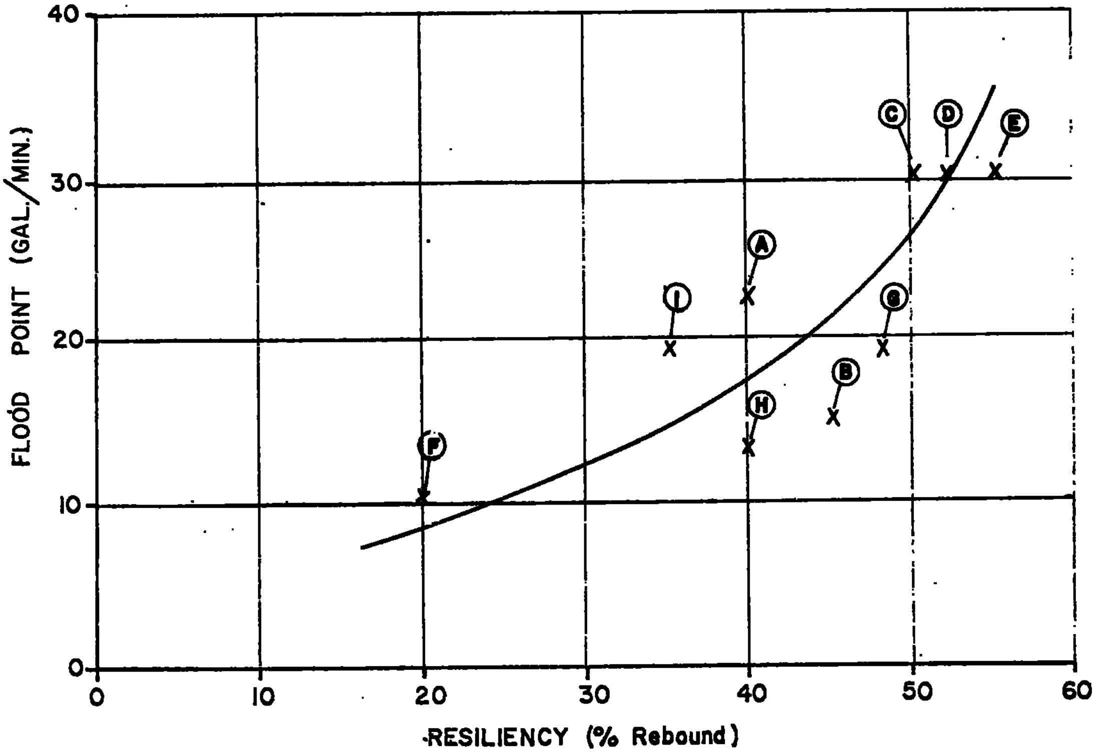
EFFECT OF FOAM TYPE, BED DEPTH & PHYSICAL PROPERTIES ON FLOOD POINT

TABLE 5.3

TYPICAL DATA SHEET

DATE	FOAM TYPE	FILTER THICKNESS	FLOW MAX.	FILTER THICKNESS AFTER COMPACTION	HEAD
July 15/71	1835	4 in.	6.6gpm	4.0 in.	0.25 in.
		4 in.	7.5	4.0 in.	1.50 in.
		4 in.	9.0	3.75 in.	3.75 in.
		4 in.	10.5	3.75 in.	4.25 in.
		4 in.	12.0	3.75 in.	5.50 in.
		4 in.	13.5	3.75 in.	7.0 in.
		4 in.	15.0	3.75 in.	8.50 in.
		4 in.	16.5	3.75 in.	10.0 in.
		4 in.	18.0	3.75 in.	12.0 in.
		4 in.	19.5	3.75 in.	13.75 in.
		4 in.	21.0	3.75 in.	15.0 in.
		4 in.	22.5	3.75 in.	18.25 in.
		4 in.	24.0	3.75 in.	22.0 in.

FOAM THICKNESS 1in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq.ft.

FIGURE NO. 5.1

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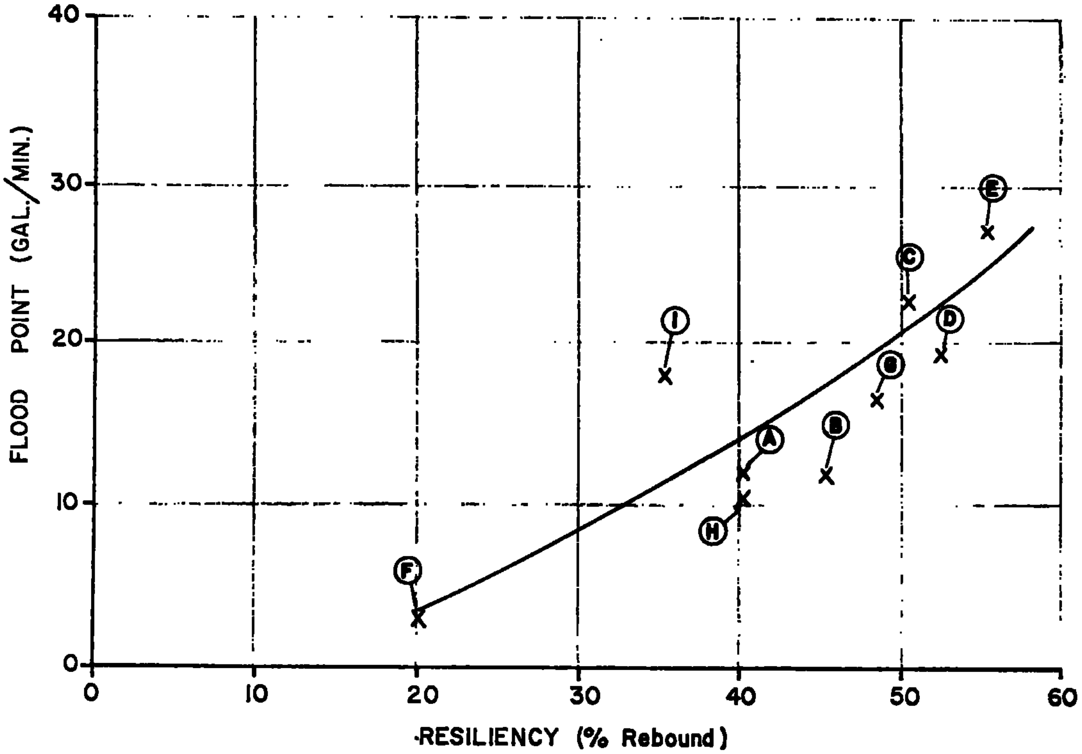
FOAM THICKNESS 2 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq.ft.

FIGURE NO. 5.2

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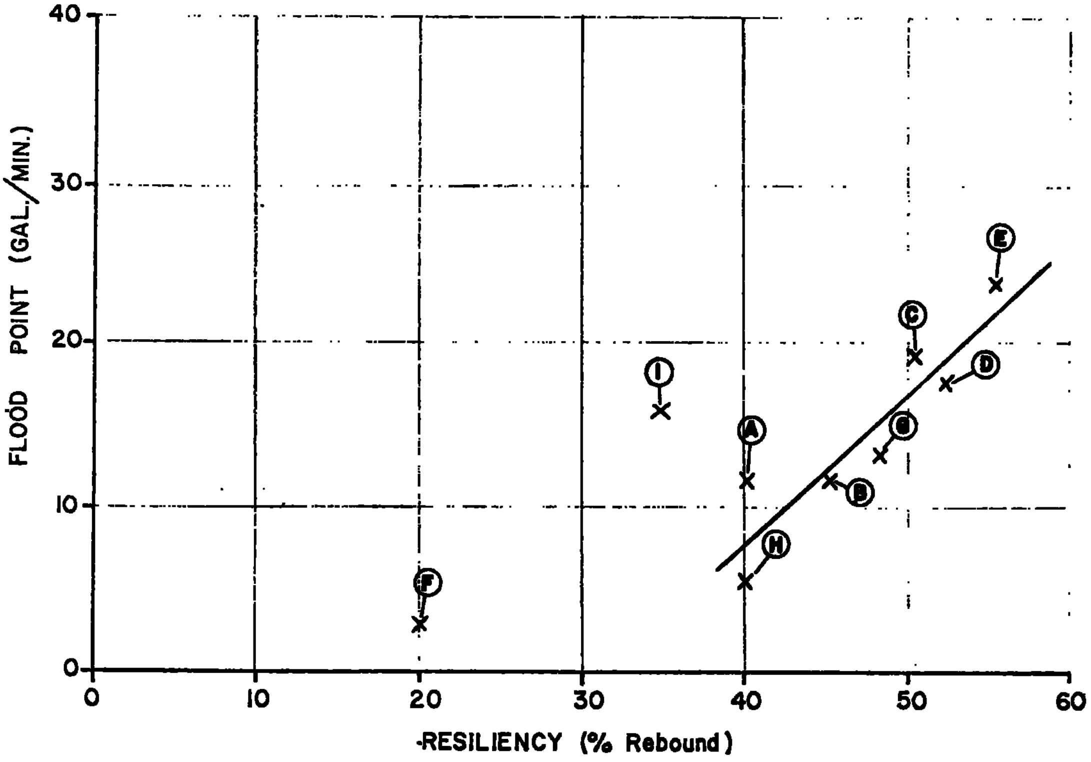
FOAM THICKNESS 4 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq, ft.

FIGURE NO. 5.3

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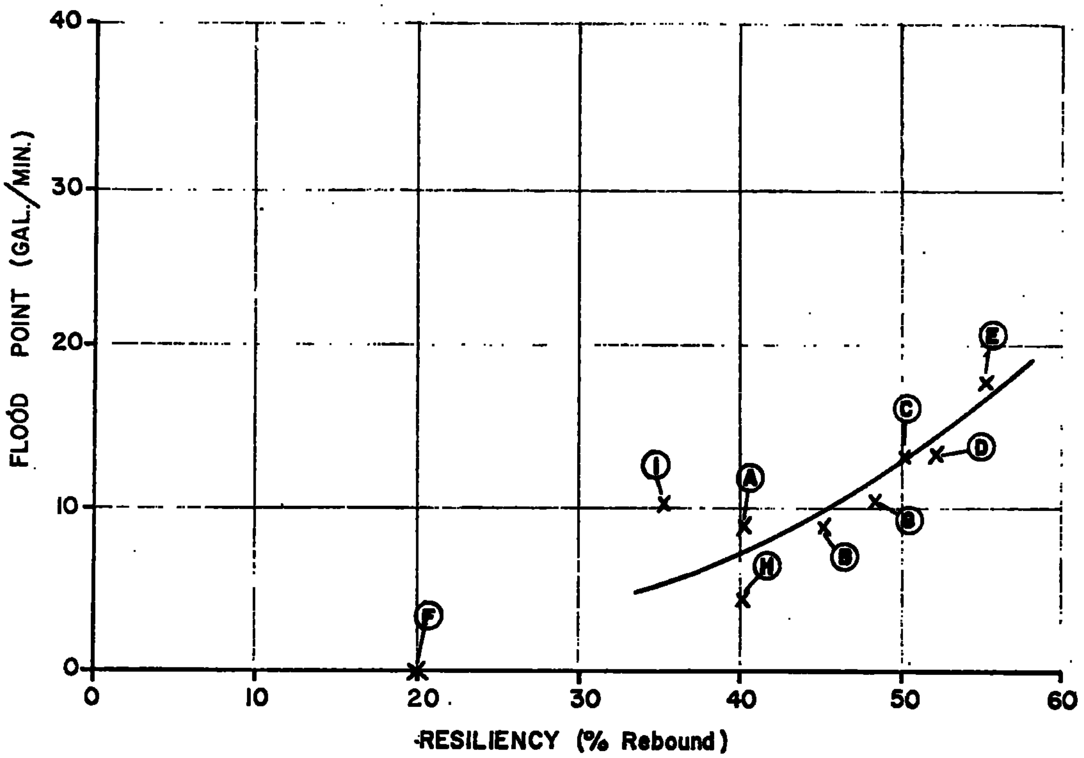
FOAM THICKNESS 6 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.4

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
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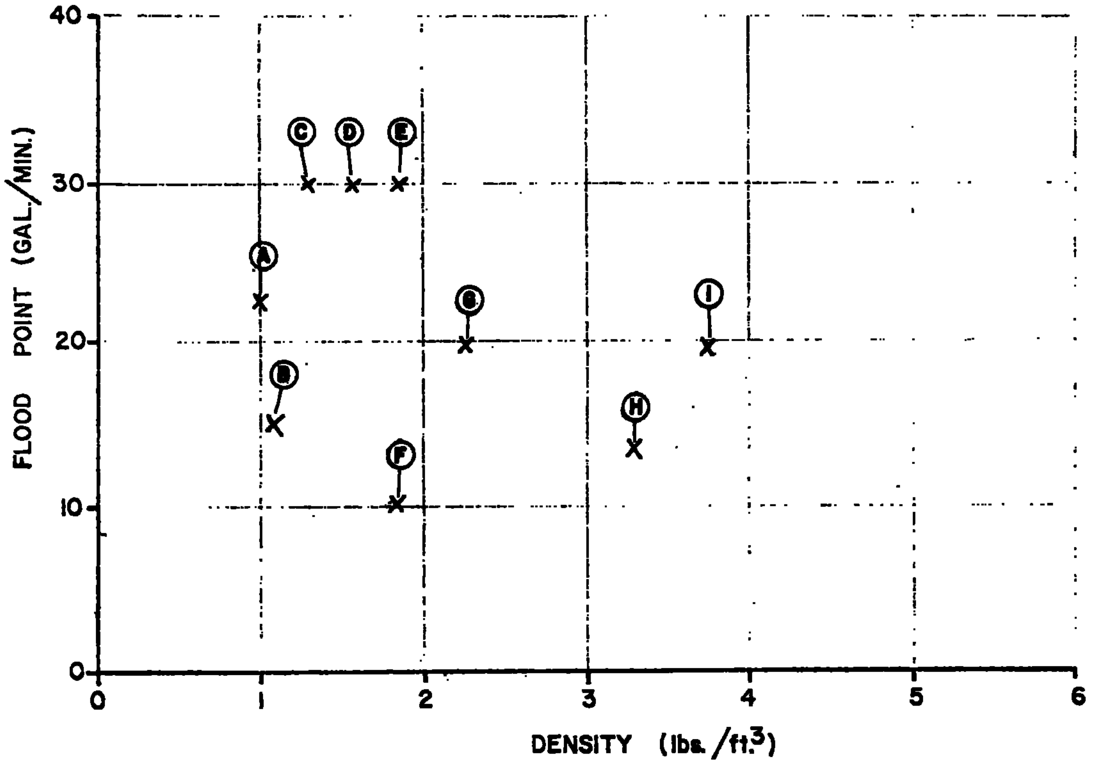
FOAM THICKNESS 1 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.5

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
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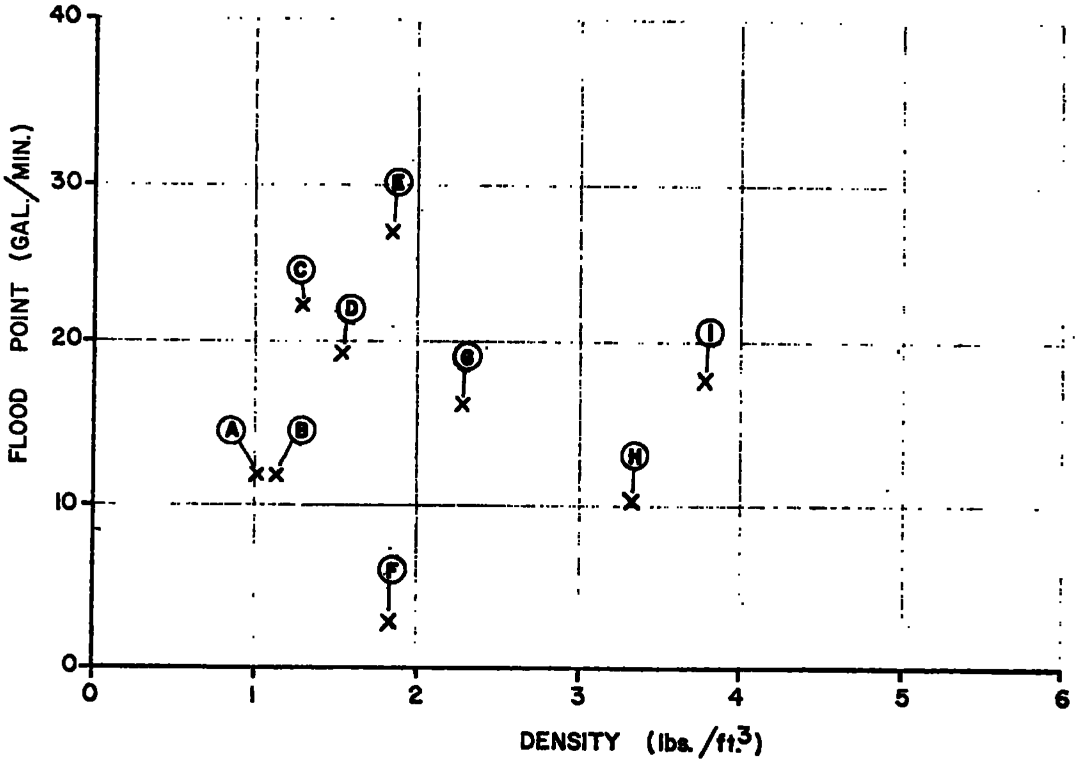
FOAM THICKNESS 2in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.6

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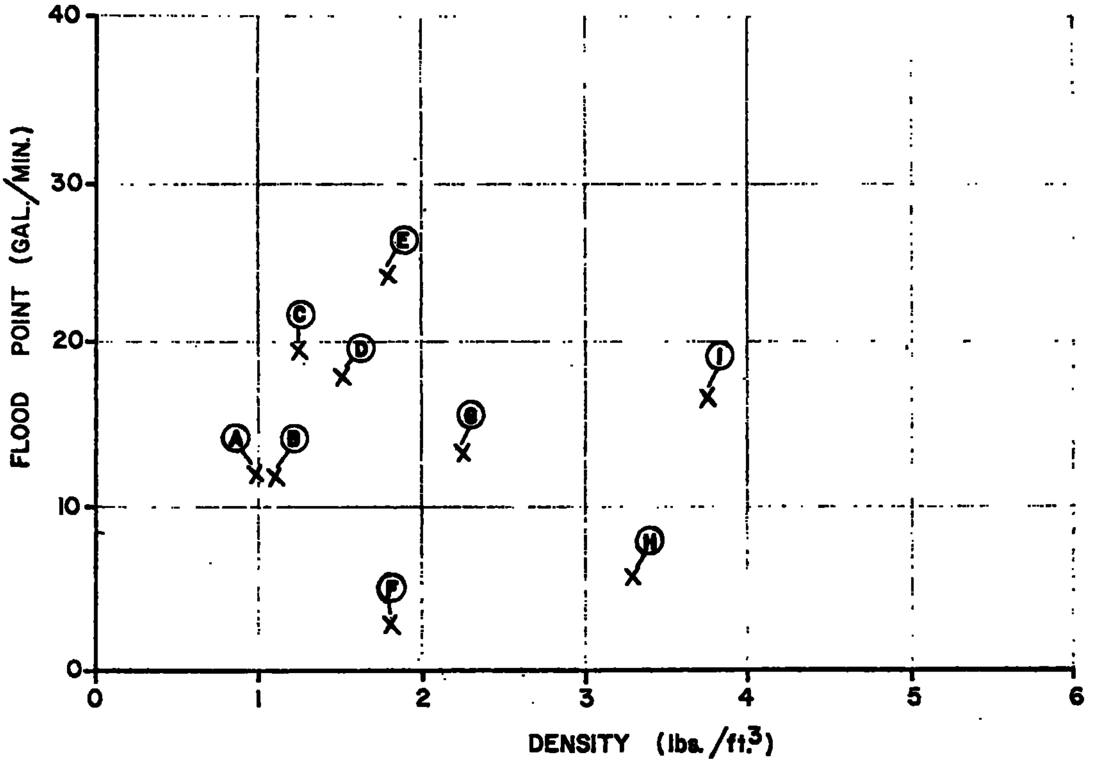
FOAM THICKNESS 4 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.7

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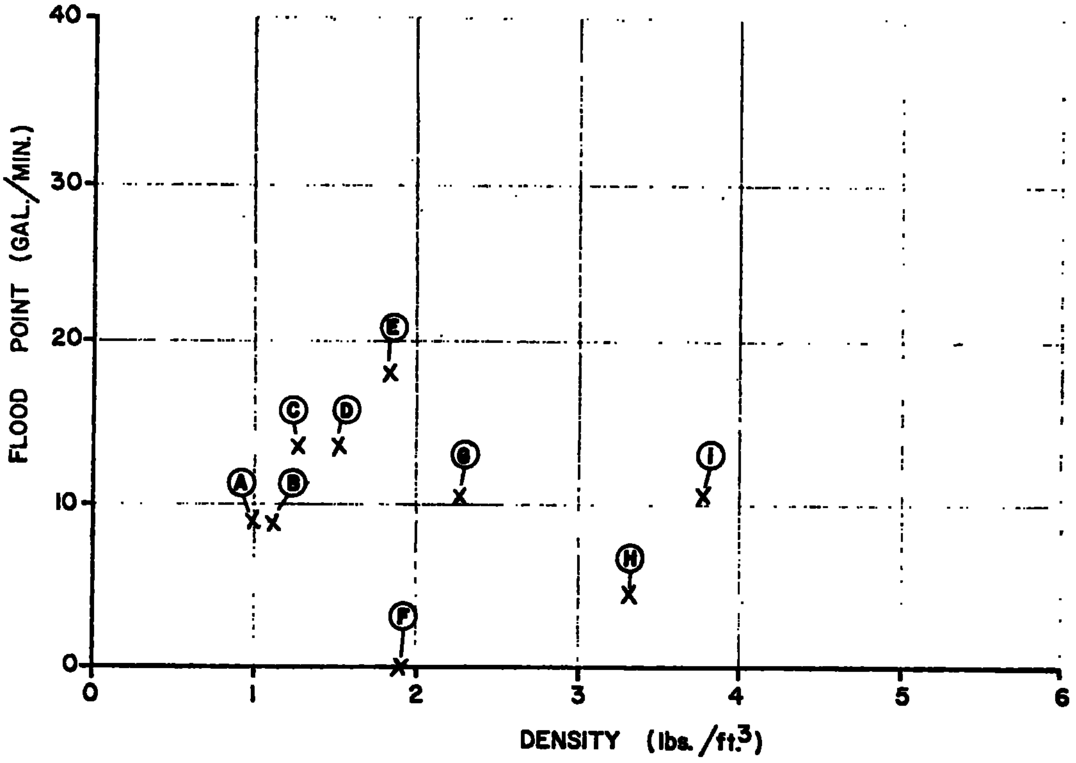
FOAM THICKNESS 6 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.8

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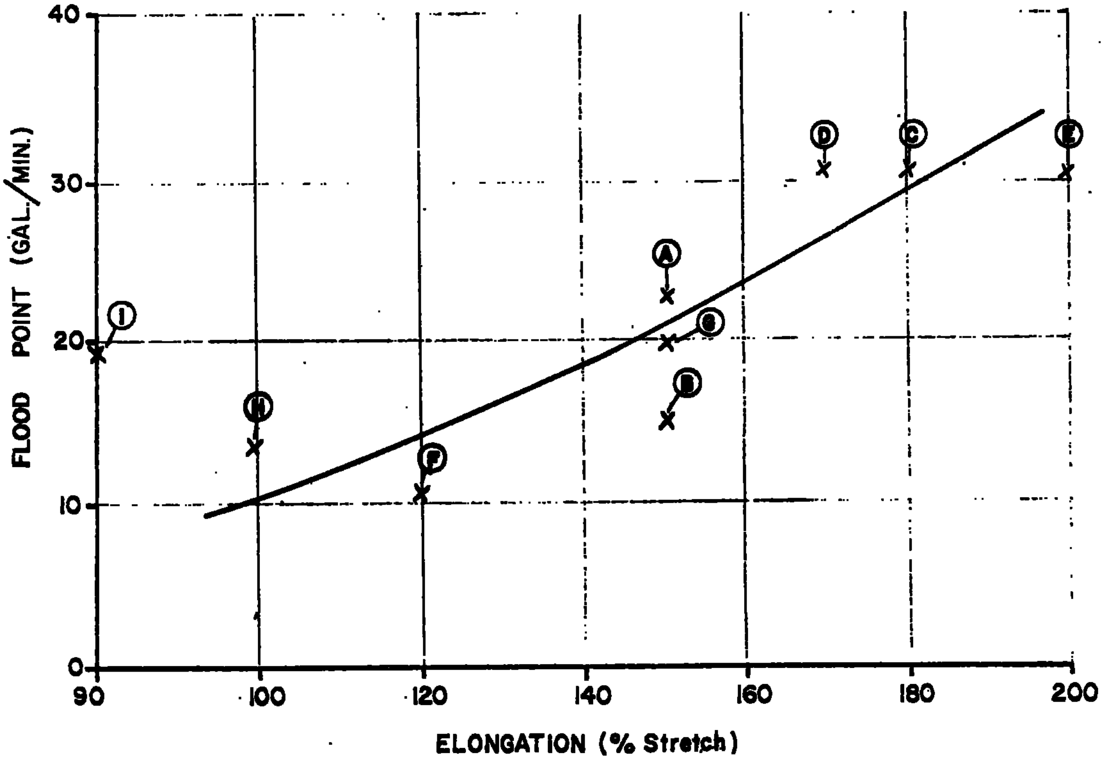
FOAM THICKNESS 1 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.9

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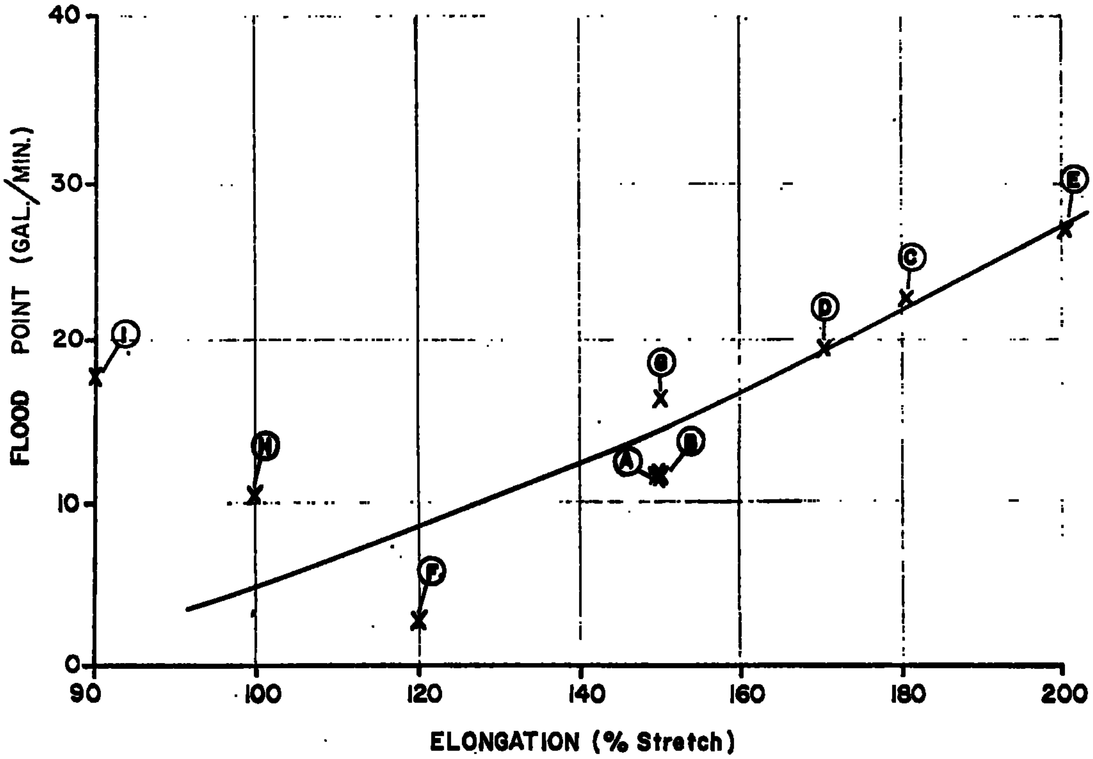
FOAM THICKNESS 2 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.10

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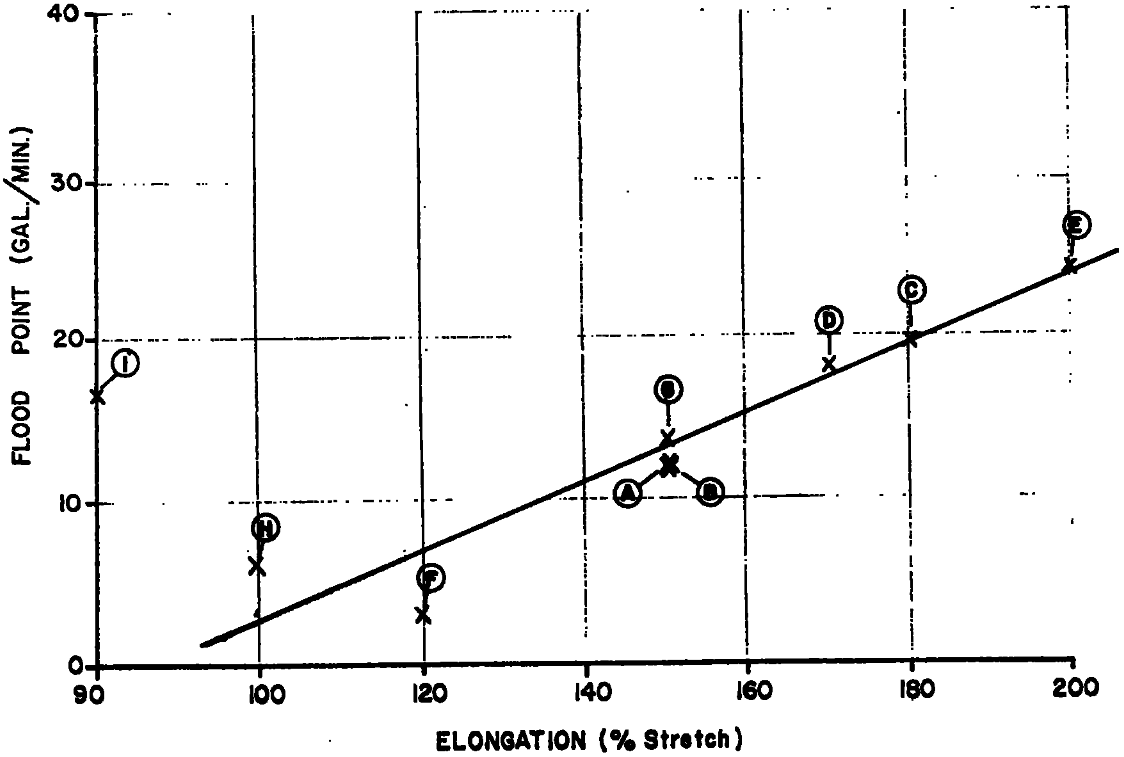
FOAM THICKNESS 4 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.11

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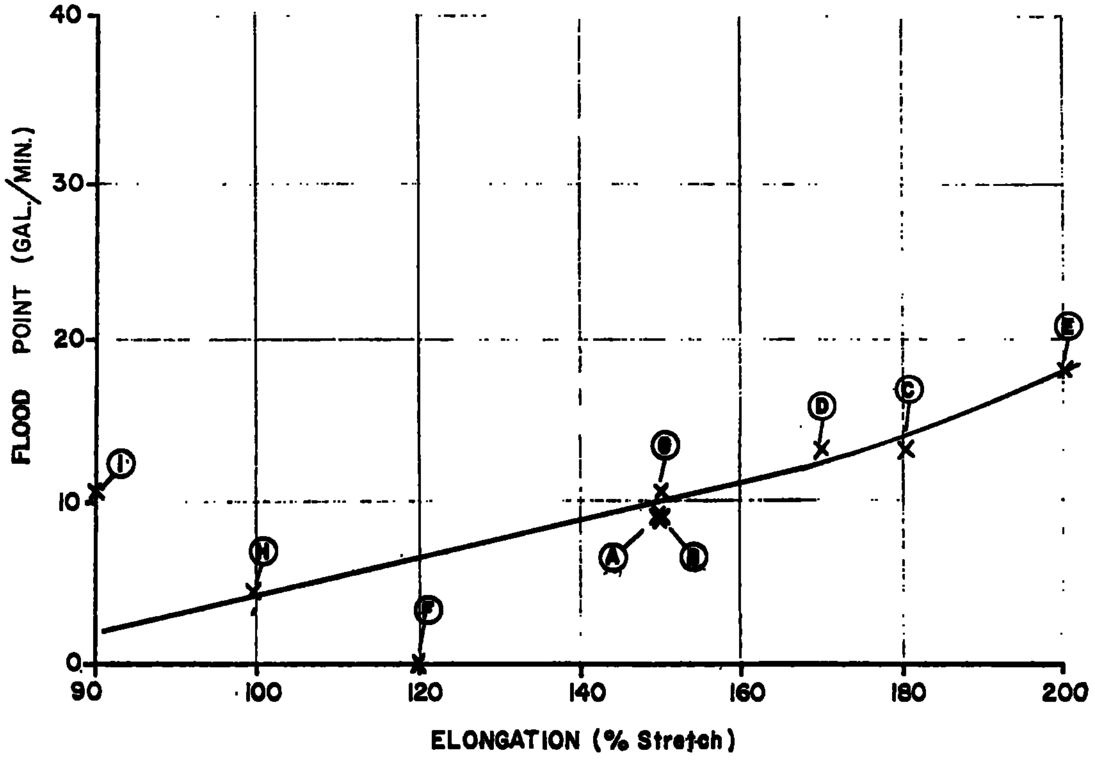
FOAM THICKNESS 6 in.



LEGEND

A - 1029
B - 1130
C - 1329
D - 1528
E - 1835
F - 1855 S.C.
G - 2335
H - 3337 F
I - 3865 F

NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.12

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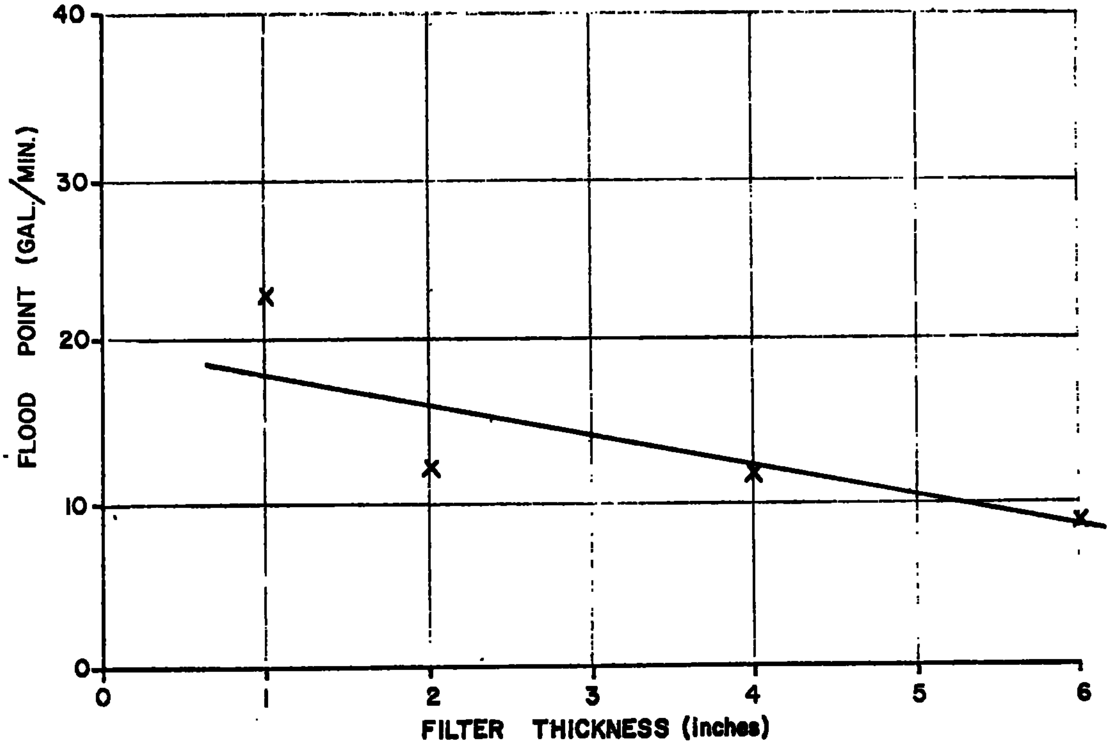
HALIFAX, N.S.

FOAM TYPE 1029

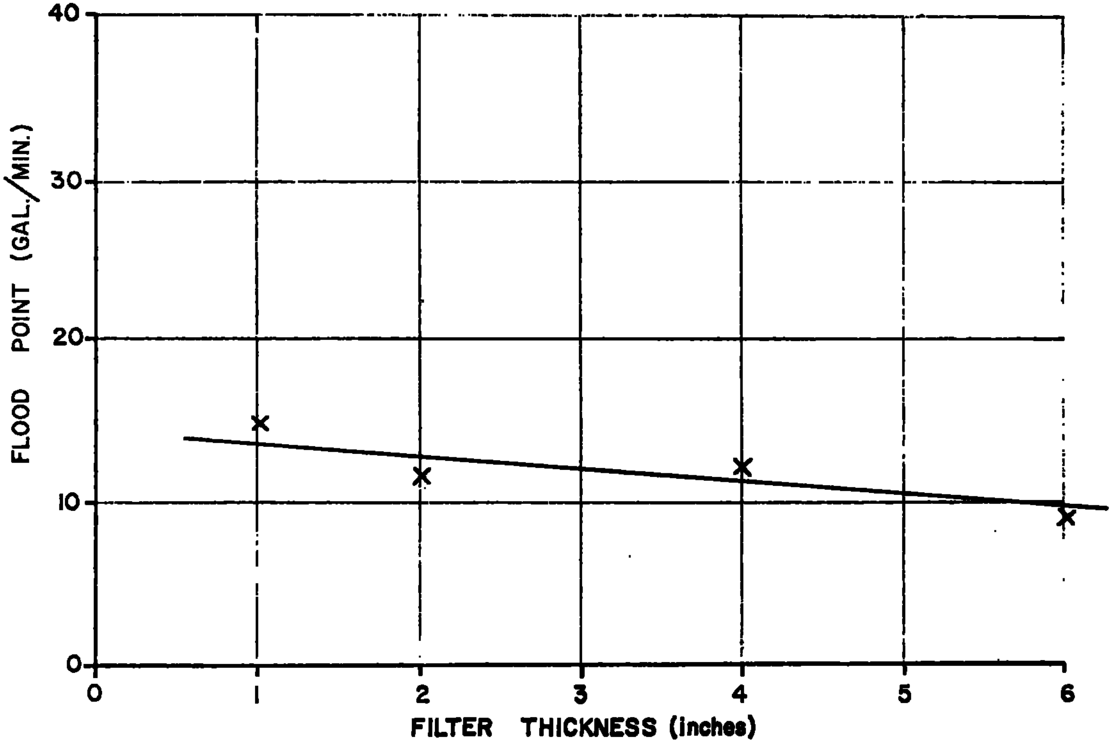


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.13

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N.S.

FOAM TYPE 1130

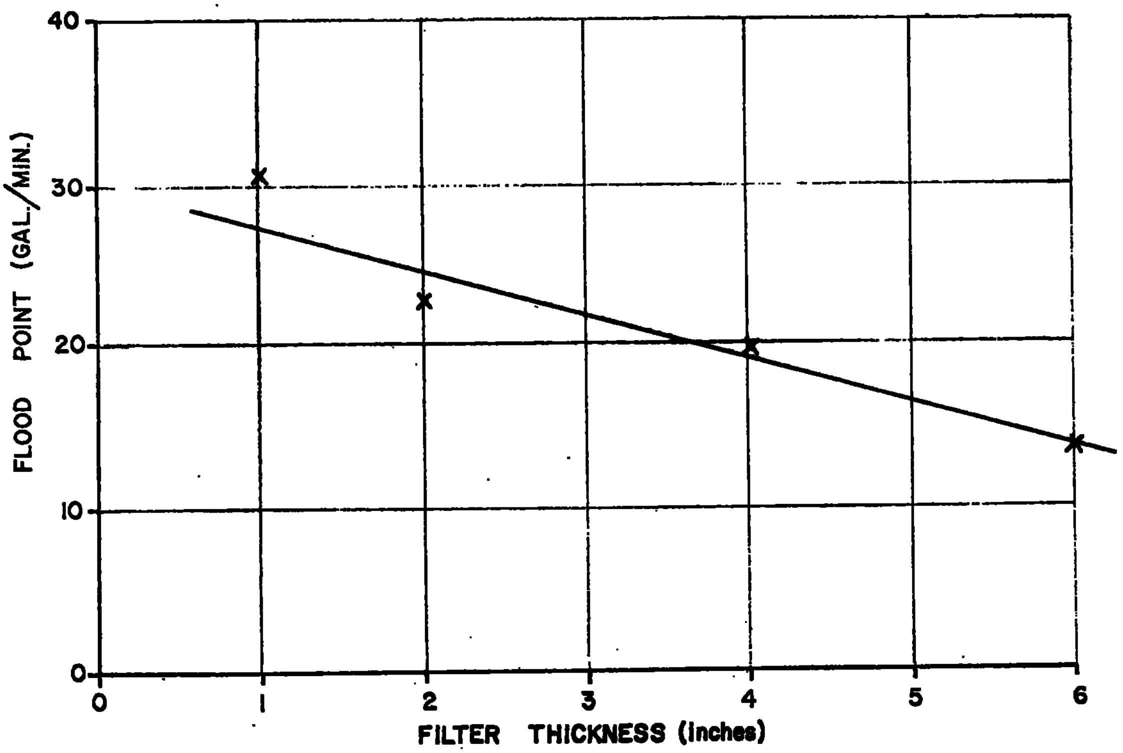


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.14

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N. S.

FOAM TYPE 1329

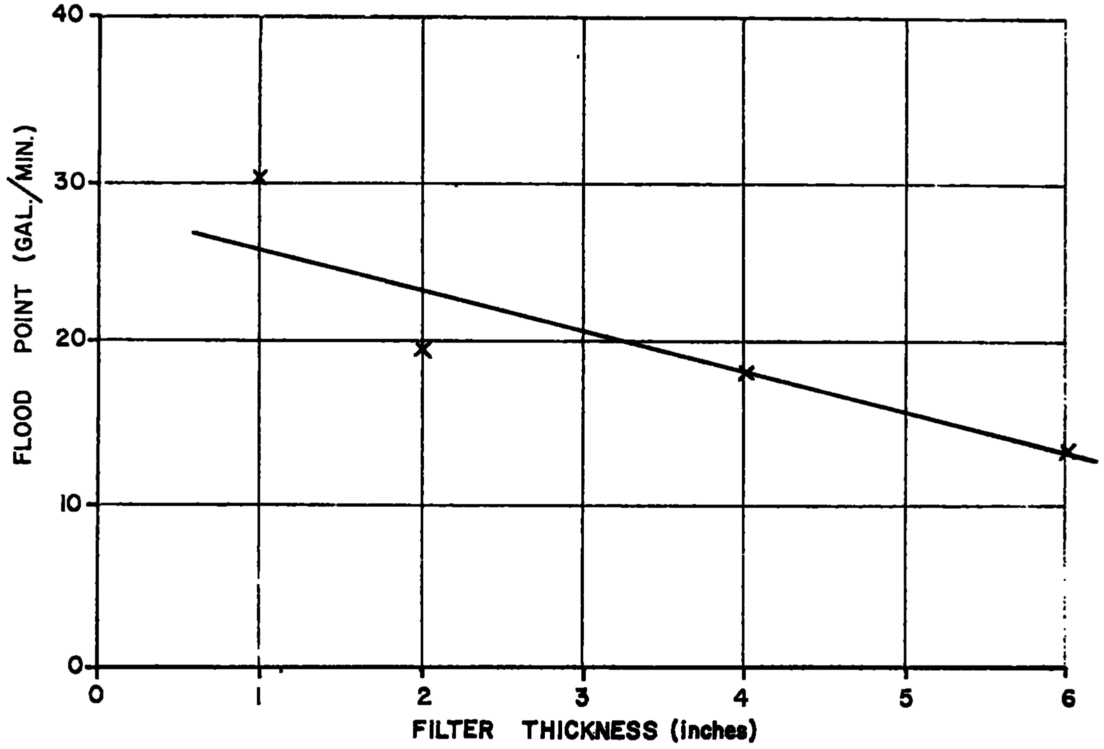


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.15

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N.S.

FOAM TYPE 1528

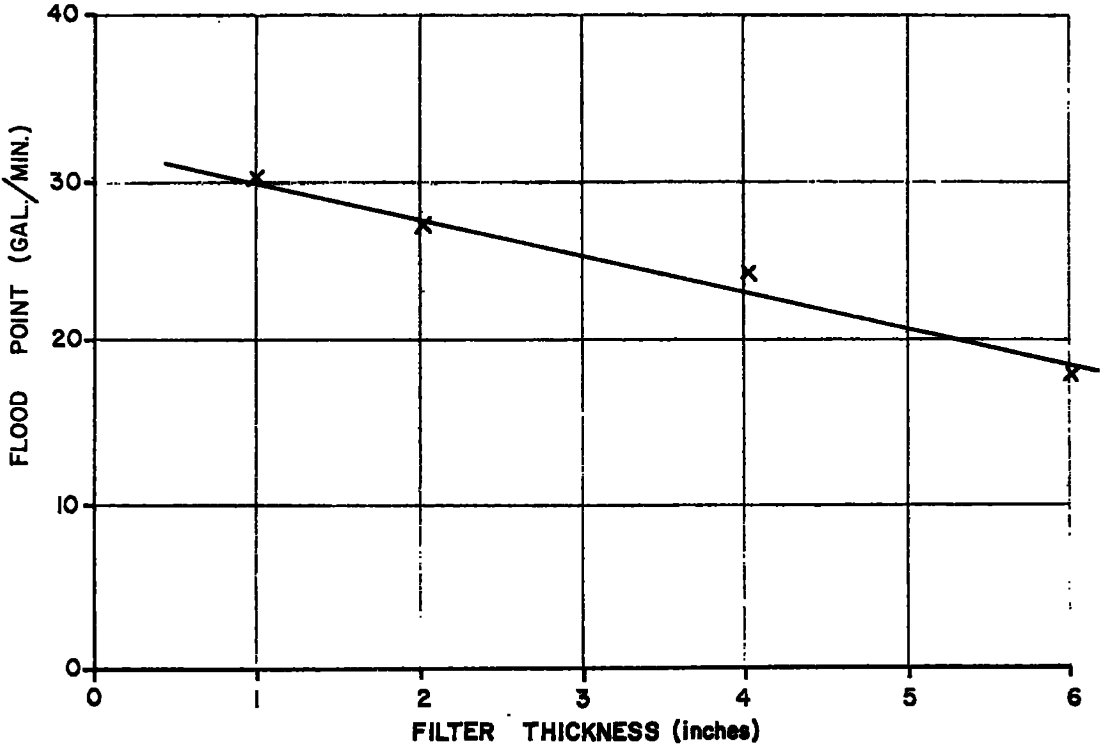


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.16

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N.S.

FOAM TYPE 1835

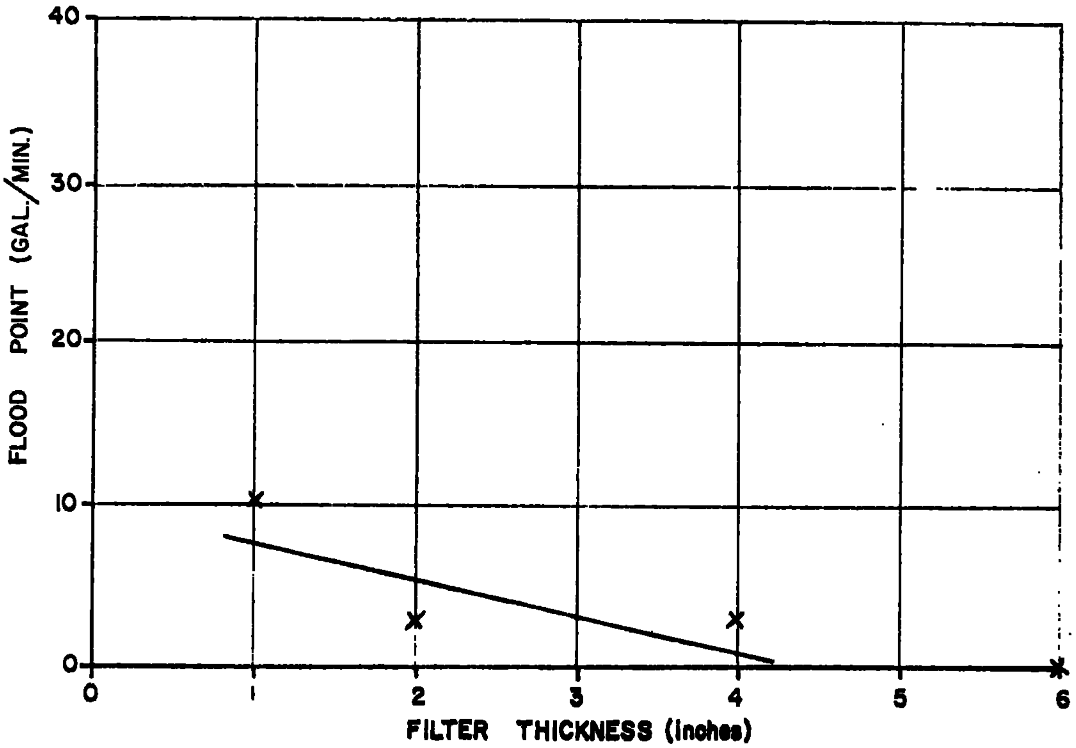


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO.5.17

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N.S.

FOAM TYPE 1855s.c.

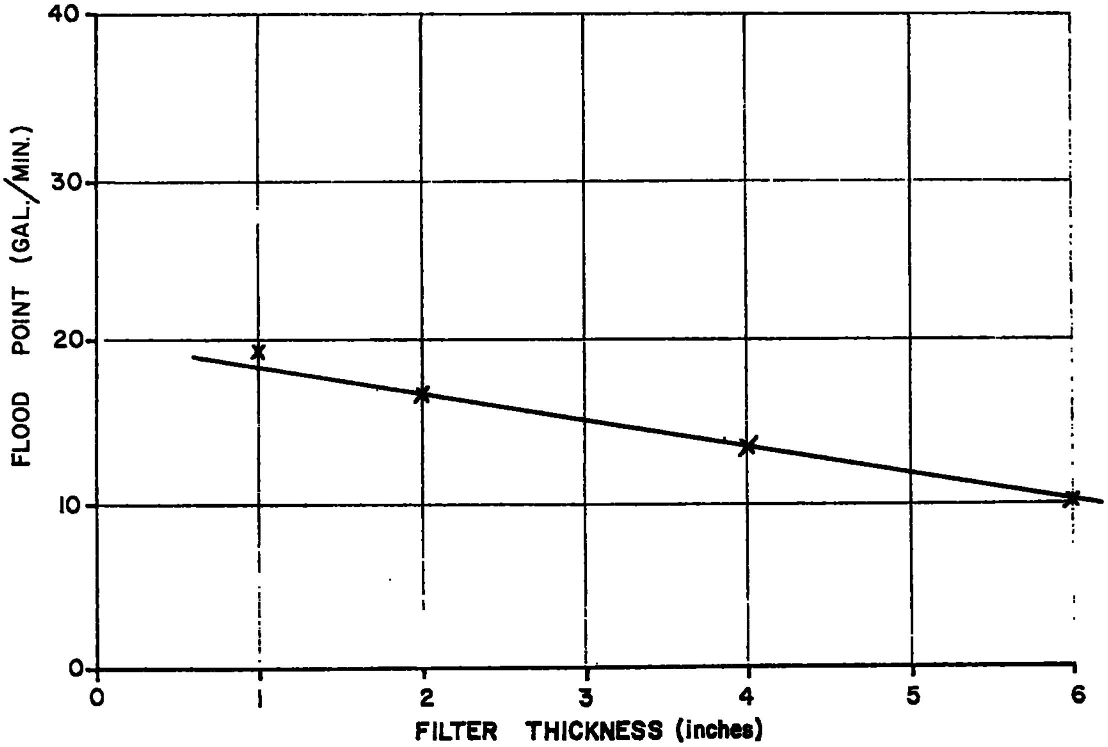


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.18

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N.S.

FOAM TYPE 2335

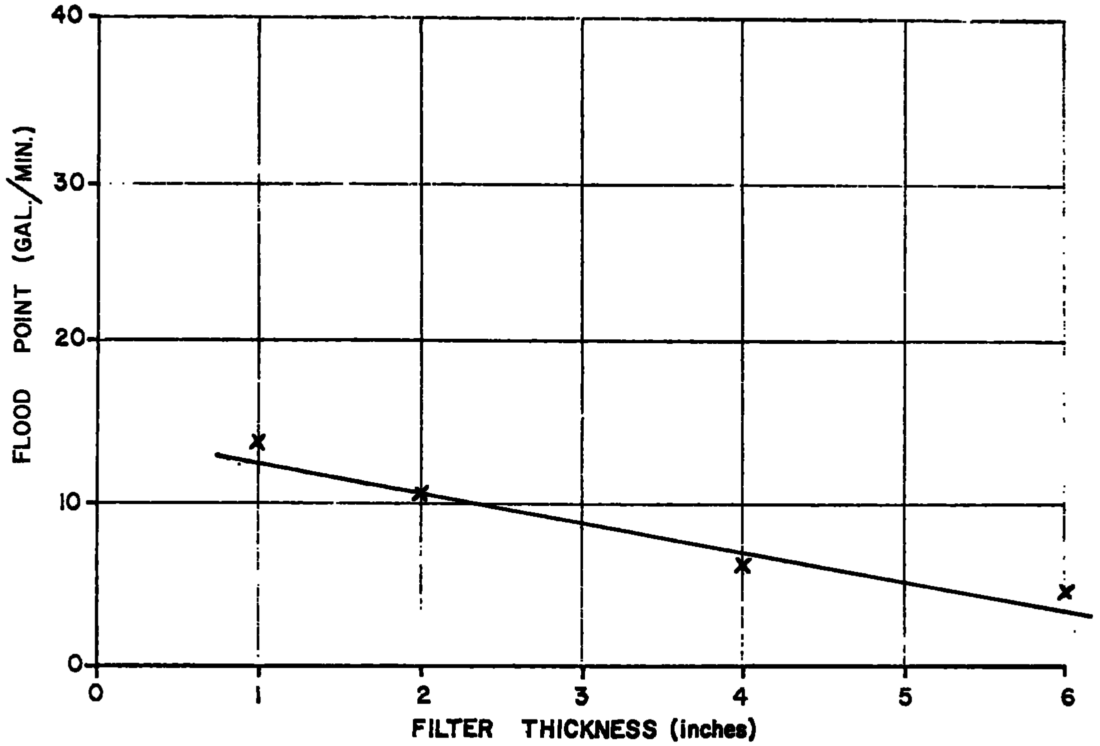


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.19

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N. S.

FOAM TYPE 3337 F.

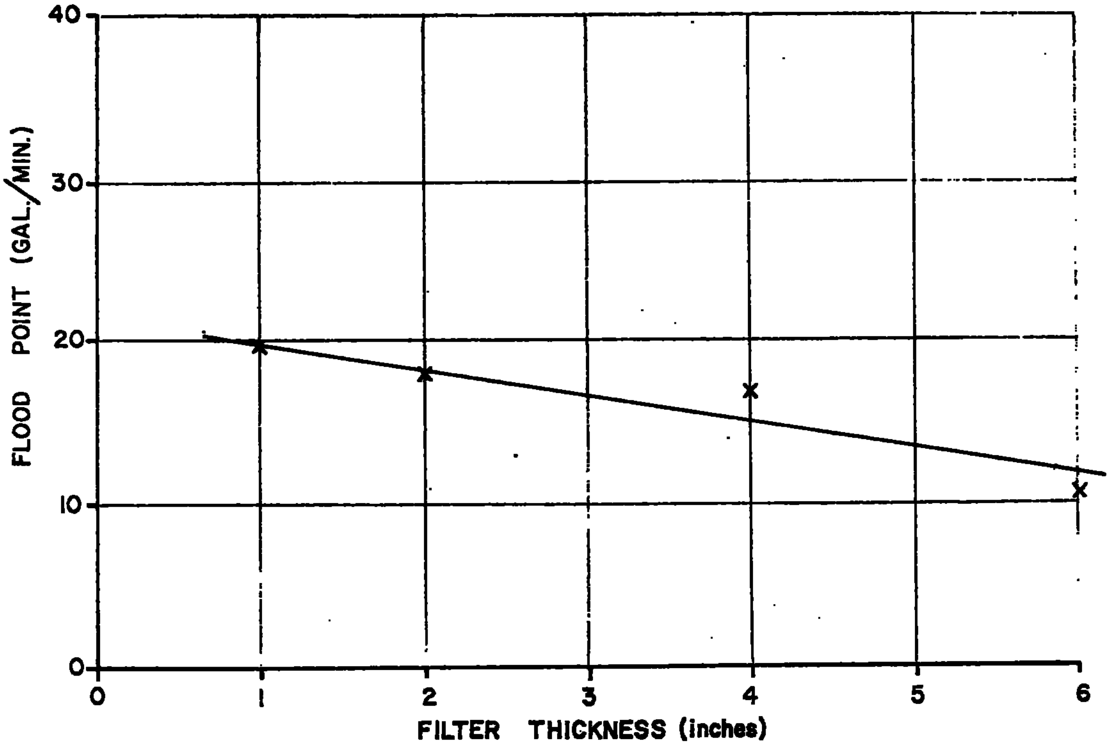


NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.20

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS HALIFAX, N.S.

FOAM TYPE 3865 F.



NOTE: Surface Area of Filter Medium = 0.35 sq. ft.

FIGURE NO. 5.21

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED
CONSULTING ENGINEERS
HALIFAX, N.S.

5.6.3 Compressibility

The extent to which the filter bed was compressed during operation was recorded. No significant changes were observed. One pattern which did emerge was that the lowest disc was always compressed more than any other disc, irrespective of the total height of the bed.

5.6.4 Head Above Filter Bed

It was observed during each run that the head of water above the bed for a given flow rate, would build up to a maximum value, and would then decrease to a stable value which was recorded. The relationship between the flood point of a particular foam and the corresponding stable value of the head above the filter bed was examined but no obvious connection could be established.

It is likely that differences in the manufacturing processes for the foams used in this study result in wide differences in the interior structures of the foams and that the complex differences between the various types of foam did not permit simple correlations such as those between the ability of the foam to allow the passage of water and the hydrostatic head above it.

5.6.5 Rigid Foams

The rigid foams were tested in 1 in. thicknesses but proved to be impervious to flow under gravity filter operating conditions.

5.7 DETERMINATION OF THE PRESENCE OF OIL IN WATER.

In advance of the mass transfer experiments, a methodology is being developed to detect and identify various oils and their concentration in water.

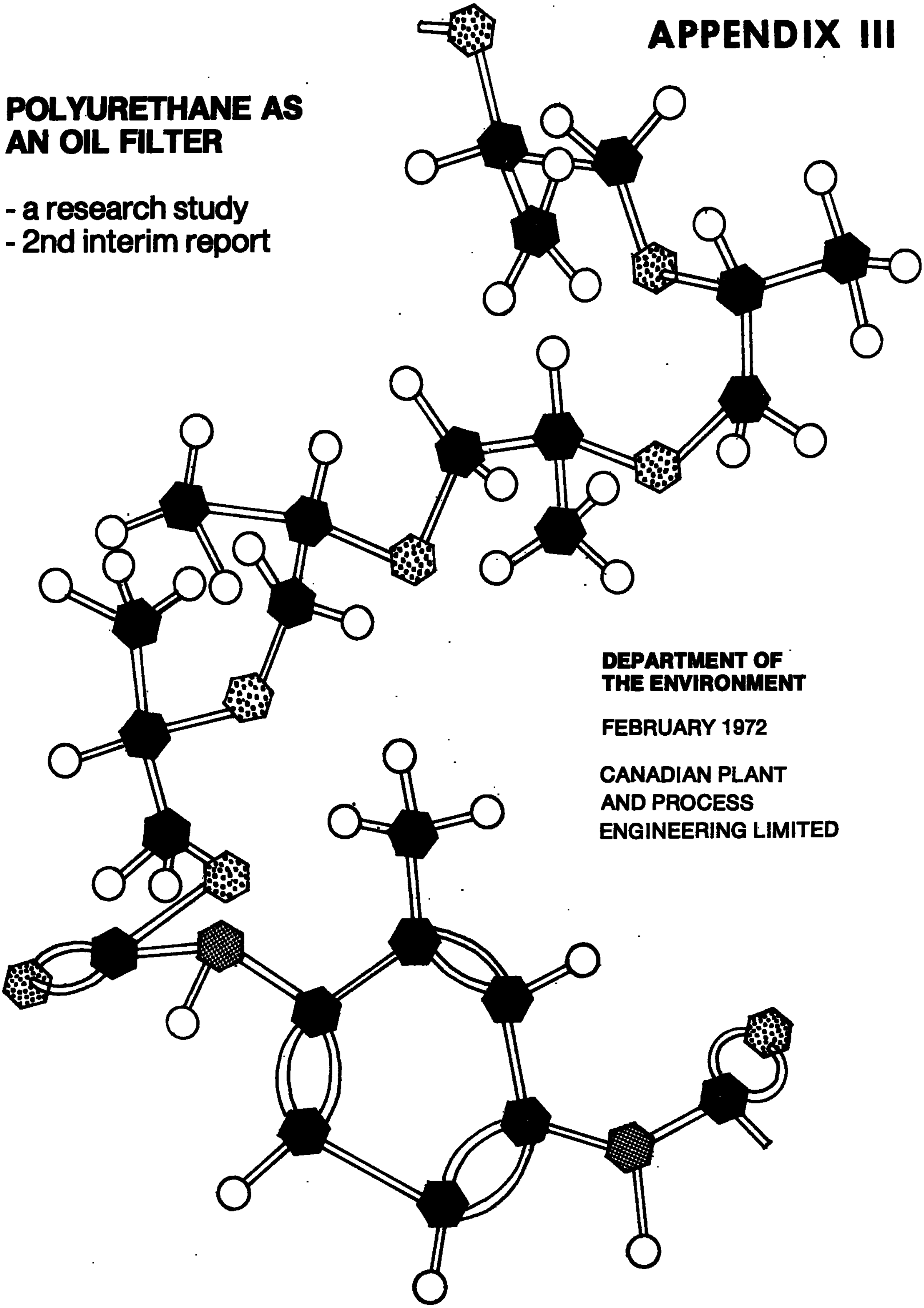
To date ultra-violet spectrophotometric absorption curves have been run on bunker fuel oil in cyclohexane at various concentrations and also the corresponding fluorescence intensity curves, in an attempt to find a basis on which a quantitative determination of the oil can be made by means of the intensity of the fluorescent emission. The work in this line is not at the present time complete, but results obtained to date are very promising, and it appears that a method has been worked out which will give a straight line relationship between fluorescence intensity and concentration of oil in the sample. At the present time a large series of concentrations are being processed in order to be assured that the straight line relationship does hold and that this can be used as a direct measure of the quantity of oil present.

When this phase of the work is finished the problem of extracting known quantities of oil from water samples and determining how efficiently this extraction can be done, and what kind of a relationship can be drawn between the amount of oil detected and the amount that was actually added to known samples will be undertaken. While this part of the work is under way, work on the detection and the measurement of small quantities of phenols dissolved in water will also be undertaken.

APPENDIX III

POLYURETHANE AS AN OIL FILTER

- a research study
- 2nd interim report



DEPARTMENT OF
THE ENVIRONMENT

FEBRUARY 1972

CANADIAN PLANT
AND PROCESS
ENGINEERING LIMITED

CANADIAN PLANT AND PROCESS ENGINEERING LIMITED

POLYURETHANE AS AN OIL FILTER

A RESEARCH STUDY

2ND. INTERIM REPORT

This Report is the Second and Final Interim Report pertaining to a Contract between the Department of the Environment (Fisheries and Forestry) and Canadian Plant and Process Engineering Limited, Consulting Engineers, Halifax, Canada. Under the conditions of the Contract the consultant was to study various aspects of oil pollution and the feasibility of using polyurethane as an oil filter.

FEBRUARY 1972

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APPENDIX C - Experimental Data for Bunker C Oil Adsorption - Large Scale Apparatus

POLYURETHANE AS AN OIL FILTER

A RESEARCH STUDY

2ND. INTERIM REPORT

1.0 INTRODUCTION

This report outlines the progress to date on a Contract for a research study on a polyurethane filter entered into in April 1971 between the Department of the Environment, then known as the Department of Fisheries and Forestry, and Canadian Plant and Process Engineering Limited. A copy of the Contract forms Part 1.1 of this report.

The first Interim Report issued in September of 1971 reviewed the manufacture and availability of polyurethane foam; the bulk handling of petroleum products; provided a preliminary review of harbour and coastal pollution; and reported on the hydraulic testing of a variety of polyurethane foams.

This report amplifies and concludes the harbour and coastal pollution work and reports on additional hydraulic testing, and mass transfer trials utilizing Bunker C and marine diesel oils. The original bench scale laboratory procedure has been scaled up and salt water and variable temperatures have been introduced.

An analysis has been made of various bilge water samples and the disposal of the used filter medium is dealt with.

It is anticipated that the Final Report concluding this research program will be available in accordance with the Contract, in April of 1972.

1.1 CONTRACT FOR A RESEARCH STUDY

ON

POLYURETHANE FILTER

This Agreement is made this 8th. day of April 1971.

BETWEEN:

The Department of Fisheries and Forestry

AND:

Canadian Plant and Process Engineering Limited
Consulting Engineers, Halifax, N.S.

Conditions of this Contract

The contractor, Canadian Plant and Process Engineering Limited, shall undertake to:

(a) investigate the commercial manufacture of polyurethane, its manufacturers, availability, and cost per unit on a national and international basis;

(b) investigate practices in the bulk handling of petroleum products nationally and internationally and to report on industry trends in this regard;

(c) assess harbour pollution problems resulting from oil pollution originating in ships or refineries;

(d) carry out and coordinate experiments, using various combinations of petroleum products, water and polyurethane, to determine the physical and chemical characteristics of these compounds and their relationship in order to produce design criteria for oil/water filters; and

(e) analyze these results and report on all of these matters to the Department of Fisheries and Forestry following review with officials of the Department of Fisheries and Forestry.

2.0 OIL POLLUTION IN HARBOURS AND COASTAL AREAS

2.1 INTRODUCTION

Condition (c) of the Contract requires the contractor to "assess harbour pollution problems resulting from oil pollution originating in ships or refineries." Because the problems so created by ships and refineries are not restricted to the confines of harbours, we have broadened our assessment to include coastal areas; also, in recognition of the fact that oil pollution in harbours has wider origins than ships and refineries, this report gives consideration, as well, to such sources as municipal sewerage systems, leaks at commercial and industrial locations, the discharge of oil wastes at industrial plants, and run-off water.

Our research has clearly revealed a distinct scarcity of written material on the subject, particularly in the area of quantitative estimating. Most of the literature that we have been able to locate, and to which we refer herein, deals with the qualitative, esthetic, and biological aspects of oil in water, and very little study seems to have been done to find out "how much" oil there is in a body of water. It is a paradox that while major oil spills set off dramatic mop-up operations, spark a general outcry for better protective measures and larger penalties, and spawn masses of written material, the daily introduction to harbours, through normal activities, of volumes of oil many times that of major spill volume goes on relatively unrecorded. Actual volumes are not known, but one indication is the estimate that at a water-cooled refinery, where as much as 100,000 gal./min of cooling water may be used and the discharge may well contain anything between 10 and 30 ppm oil, the resulting chronic pollution would amount to 1500 gal. of oil per day.[1] From all sources, in any given harbour location, the quantity of oil present in the water at all times will be considerable, and it would be reasonable to suggest that the pollution problem would be brought into clearer public focus if, through physical analysis, firm data was made available. Such analysis, on a periodic basis, would indicate any worsening or easing of the problem.

2.2 THE SOURCES OF HARBOUR AND COASTAL POLLUTION

There are four major categories into which the sources of oil pollution may be grouped, namely, the production of oil, the manufacture or processing of petroleum products, the transportation and marketing of such products, and their utilization in commerce and industry.

2.2.1 The Production of Oil

In the drilling and production of oil wells, whether on land or off-shore, oil pollution may occur as a result of (a) the discharge of waste waters, (b) the disposal of oil-contaminated drilling mud, and (c) the leakage of oil from pipelines and storage tanks at the drilling site.

Pollution caused as a result of off-shore drilling operations frequently spreads to coastal waters because of their proximity. Exploration has not extended beyond the continental shelf, and consequently most off-shore operations are conducted within a few hundred miles of land. Off California and Louisiana some wells are within sight of land.

2.2.2 The Manufacture of Petroleum Products

The discharge of refinery cooling water is probably the greatest single cause of chronic pollution, except in locations where the cooling water is recycled. We have referred to one estimate of the amount of oil that might be discharged daily by a water-cooled refinery. Another source estimates that "the amount of oil that gets into refinery drain lines is about 2% of the volume of crude oil processed, with extremes of 0.5% and 3.0%."[2]

Oily wastes from a refinery originate from almost all operations. They generally occur in small quantities from loose connections, pump-gland leakage, water withdrawals from product accumulators, spillage at sampling taps, valve and pipeline leaks, losses and spills at times of shutdown or clean-up for process changes, tank-bottom drawoffs, and similar conditions.

The oil in waste waters will exist in three conditions. Some of it will be separable and tend to float on the surface. Some of it will be in solution, and some will be carried as minute droplets which constitute an emulsion.

2.2.3 The Transportation and Marketing of Oil

Moving oil from the source of production to the manufacturing facilities and from there to the consumer involves extensive and diverse operations of transportation and marketing. As water transportation is almost invariably involved, many of these operations take place in harbour installations. The operations utilize pipelines, tank farms, sea-going tankers and inland barges, docks, terminals, tank cars, tank trucks, bulk plants, and service stations. In all of these functions oil may be discharged to receiving waters as a result of accidental leakage, careless overflow and other spillage, and cleaning operations.

Tanker loading operations are major contributors to oil pollution in harbours. Blumer reports that "in-port losses from collisions and during loading and unloading contribute an estimated 1 million tons"[3] to marine oil pollution annually.

Captain G. Dudley, harbourmaster at Milford Haven, the largest oil port in the United Kingdom, includes among the causes of such in-port losses these factors: poor design in ships, mechanical failure, out-dated operating procedures, and human error.[4] Of these, human error is considered to be the main cause, and it results in the overflowing of cargo tanks, bunker and ballast tanks, the pumping-out of bilges, and the failure to ensure that sea-valves are correctly closed.

It is impossible to estimate how great a contribution to harbour oil pollution is made by petroleum marketing facilities, but when one considers the sheer number of service stations, bulk plants, and delivery vehicles, and the greater number of opportunities for leaks and spillages to occur, one might reasonably suggest that the contribution is considerable, in spite of the many preventive and protective measures the industry takes to prevent it, and of the municipal ordinances designed to control it.

2.2.4 The Utilization of Oils

Petroleum products are utilized by industry and commerce, ashore and afloat, in a great variety of ways. There can be no doubt that many of them find their way, as waste, to harbours and coastal waters. ZoBell refers to a report that about one-third of the oil polluting Narragansett Bay over a four-year period originated at shore installations.[5] Industrial wastes, sewage, cleaning oils, and oil-surfaced roadways are a few of the sources. To illustrate the extent of harbour pollution caused by untreated domestic and industrial wastes, Blumer reports that nearly

2 million tons of used lubricating oil is unaccounted for each year in the United States alone, and estimates that a significant portion of this reaches coastal waters.[6]

While tanker operations may be major contributors to harbour pollution, a far greater contribution is made by cargo, passenger, and government ships which use tanks alternately for fuel oil and salt water ballast. When the fuel oil is consumed, the tanks are filled with sea water to maintain stability of the ship. Then, preparatory to taking on more fuel, which, almost without exception, is done in harbour, the oil-polluted ballast water is discharged.

All ships discharge a certain amount of oil into water, from the smallest outboard motor boat to the largest super-tanker. If we forget for a moment all about tanker operations and ballast practices, we are left with the fact that all ships, with the possible exception of the little outboard, accumulate in their bilges, water which will contain, depending on the state of machinery and housekeeping practices, a certain quantity of waste lubricating oil and centrifugal wastes. Canadian steamship regulations, like those of most nations, prohibit the discharge of oil or oil-polluted water in any river, harbour, or bay.[7] However, it is well known that, accidently or surreptiously, undetermined quantities of bilge waters are discharged into harbour and coastal waters. Otherwise, there would not be the number of violations of such occurrences on record. Table 2.1 records the experience at Milford Haven.

2.3 THE LEVEL OF OIL POLLUTION IN HARBOUR AND COASTAL WATERS

In the Introduction we deplored the lack of quantitative measures of the levels of oil pollution. The comment was based on the results of a reasonably extensive literature search in the Halifax libraries of the Bedford Institute, the Nova Scotia Technical College, and the National Research Council, and of verbal enquiries made to such agencies as the National Harbours Board, Department of the Environment, and the Canada Centres for Inland Waters. For inclusion in this Report we discuss the findings of researchers of the Bedford Institute; in the Final Report we will include any evidence we should locate in sources such as the International Joint Commission, to which we have been referred, but have yet to check.

Michalik and Gordon have reported on the "Concentration and Distribution of Oil Pollutants in Halifax Harbour, 10 June to 20 August 1971", for the Fisheries Research Board of Canada.[8]

TABLE 2.1

Incidence of Pollutions, Causes of Pollutions, and Legal Proceedings at the Port of Milford Haven, 1961-1969

Incidence of Pollutions

	No. of pollutions					Treatment	
Year	Under 80 gal	80–160 gal	Over 160 gal	Total	No. of pollutions per 100 vessels	Sprayed	Not sprayed
1961	25	9	11	45	4·2	31	14
1962	18	4	11	33	2·75	22	11
1963	18	6	6	30	2·4	21	9
1964	27	14	2	43	3·1	26	17
1965	46	28	18	92	4·6	64	28
1966	42	22	14	78	3·3	61	17
1967	32	16	7	55	2·0	44	11
1968	26	25	2	53	2·0	47	6
1969	34	19	5	58	1·8	52	6

Note: Since 1966 details have also been kept of "unattached" pollutions—with one exception these were small and totalled 41 in 1966; 32 in 1967; 21 in 1968; and 23 in 1969.

Causes of Pollution

From ships	1961	1962	1963	1964	1965	1966	1967	1968	1969
(*a*) Overflow cargo	3	5	5	8	14	12	11	9	14
(*b*) Overflow bunkers	7	4	1	4	14	6	4	9	8
(*c*) Sea valves	11	4	2	4	5	10	8	9	12
(*d*) Bilges/ballast	12	10	6	9	18	14	9	4	6
(*e*) Hull defects	5	7	3	5	1	11	12	8	10
(*f*) Miscellaneous	2	3	5	..	12	6	4	1	2
From jetties									
(*a*) Pipelines/hoses	1	..	3	4	10	10	3	9	6
(*b*) Sumps/slop tanks	3	2	1	1	11	2	2	3	..
(*c*) Outfalls	..	..	4	5	5	3	..	1	..
(*d*) Miscellaneous	1	..	..	3	2	4	2	..	..

Legal Proceedings

	1961	1962	1963	1964	1965	1966	1967	1968	1969
Proceedings instituted	15	12	9	8	25	19	17	15	22
Prosecutions heard	11	8	7	6	22	18	15	8	12
Successful	10	8	7	6	21	17	15	8	12
Unsuccessful	1	Nil	Nil	Nil	1	1	Nil	Nil	Nil
Withdrawn	2	4	2	2	2	4	3	1	1
Average fine	£95	£70	£72	£92	£101	£135	£450	£520	£446

<u>Source</u>: Milford Haven Conservancy Board

The following is taken from that report.

"The distribution and concentration of oil in the waters of Halifax Harbour were monitored from 10 June to 20 August 1971. Average concentrations at individual stations ranged from 1.9 to 71.7 ppb at the surface and from 0.8 to 2.8 ppb at 5m. The highest concentrations were found in the central portion of the harbour, especially on the Dartmouth side.

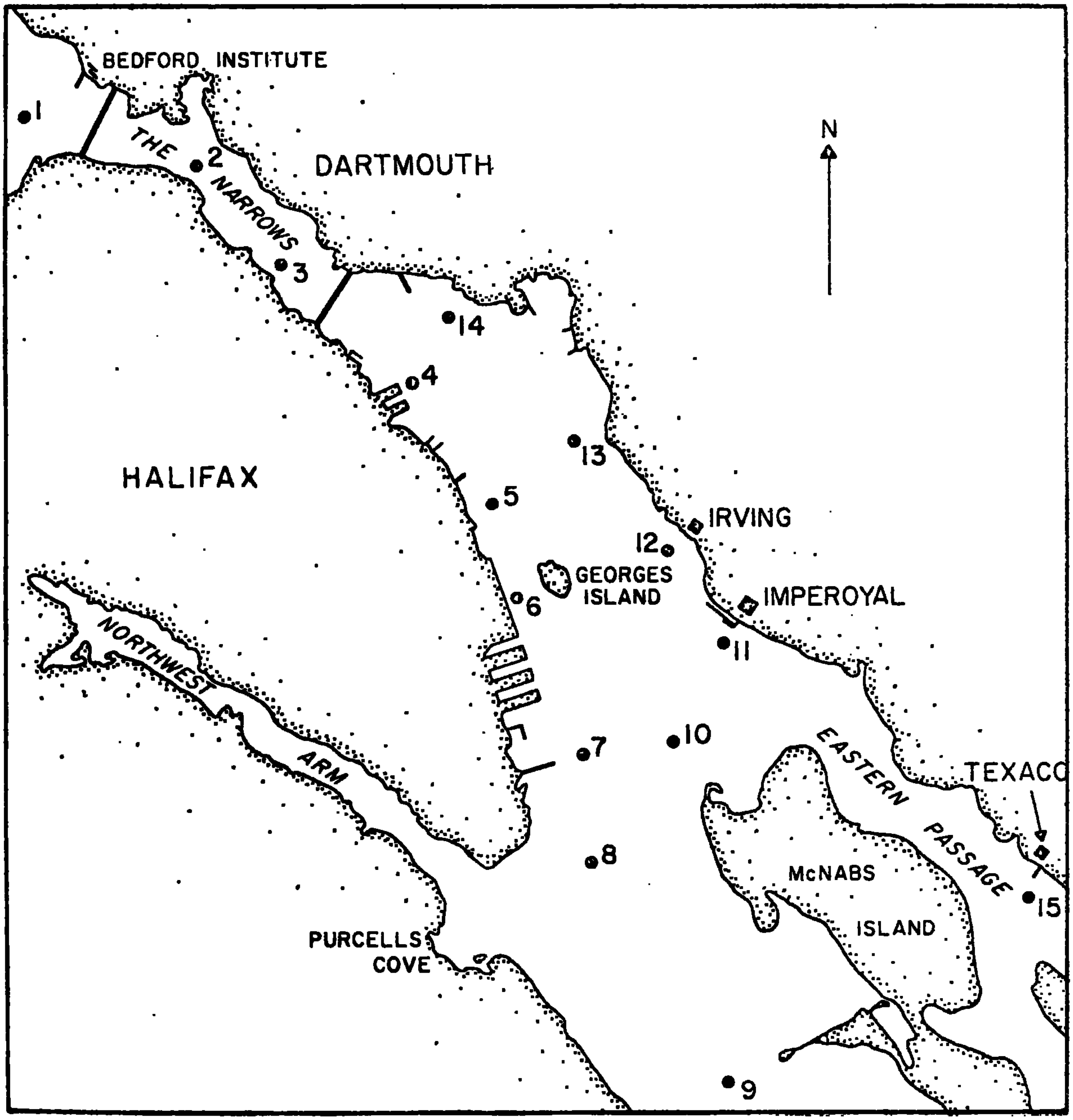
"Water samples were collected from the FRB research vessel Navicula at fifteen stations in the harbour (Figure 2.1)on the following dates:

June 10, 17, 24, 29 - 1971
July 9, 13, 22, 28 - 1971
August 5, 10, 19 - 1971

"All oil concentrations are (recorded) along with weather, sea state, rainfall over the twenty-four hour period preceding sampling, visual observations and apparent oil type. Concentrations ranged from a low of 0.1 ppb to a high of about 3 grams per litre. The pattern of distribution was quite similar on all sampling dates, and the average surface oil concentrations at each station over the entire two and one-half months study are presented in Table 2.2 Concentrations were greatest

FIGURE 2.1

Sampling Station Locations in Halifax Harbour, 1970



Source: Donald C. Gordon, Jr.

TABLE 2.2

Average Oil Concentration (ppb) at Each Station in Halifax Harbour at the Surface

Station	Surface
1	2.0
2	2.3
3	3.2
4	45.4
5	15.1
6	6.7
7	2.6
8	2.0
9	1.9
10	9.4
11	69.5
12	51.5
13	48.9
14	71.7
15	2.1

Source: Donald C. Gordon, Jr.

along the Dartmouth side of the harbour (Stations 11 to 14), extending from off Imperial Oil to the red buoy just off the Dartmouth ferry terminal. The next highest concentrations occurred on the Halifax side in the area between the Dockyard and the Cable Wharf near the ferry terminal (Stations 4 and 5). The lowest concentrations were repeatedly found at the extremities of the harbour; Station 1 - in the narrows off Bedford Institute, Station 9 - off Meagher's beach at the harbour entrance, and at Station 15 - in Eastern Passage.

"As expected,concentrations at 5m were always lower and less variable than those at the surface (Table III).High surface concentrations were generally accompanied with greater than average concentrations at 5m.

"The highest concentration observed in this study was found between Stations 2 and 3 on 28 July, near the northern end of the Dockyard. This sample was taken from a very large slick of Bunker C. The following week, this slick had disappeared and very little oil was detected at this location.

"For comparative purposes, samples from both Petpeswick Inlet and St. Margaret's Bay were also collected and analyzed. These areas, being free of industrial and shipping activity, should have little or no oil pollution and the observed concentrations (Table IV) most likely approach the level of background fluorescence

TABLE 2.3

Comparison of Oil Concentrations at the Surface and 5m in Halifax Harbour

Date	(ppb) Surface	 5 m
9 July	5.9	1.5
28 July	37.7	2.7
5 August	1.9	1.1

Source: Donald C. Gordon, Jr.

TABLE 2.4

Background Concentrations Observed at Petpeswick Inlet and St. Margaret's Bay

Location	Station	Concentration (ppb)
Petpeswick Inlet (20 July, 1971)	1	0.6
	2	0.5
	3	0.4
St. Margaret's Bay (17 August 1971)	1	0.0
	2	0.1
	3	0.2

Source: Donald C. Gordon, Jr.

caused by naturally occurring or organic material.

E. M. Levy, in "The Presence of Petroleum Residues Off the East Coast of Nova Scotia, in the Gulf of St. Lawrence, and the St. Lawrence River"[9], concludes that his "survey of the open ocean off Nova Scotia and in the St. Lawrence system indicated low, but significant levels of residual oils in these waters, and has demonstrated the necessity, in view of the ever increasing number of oil spills in our waters, for more detailed investigations to cover greater expanses of the North Atlantic and to monitor the accumulation of these substances in both coastal and economic areas."

In his Introduction, Levy remarks that the "introduction of crude and refined petroleum into inland waterways, coastal areas and the ocean itself, has become a problem of major importance during the past decade. The major portion of this oil originates not, as might be expected, from major disasters, but from the countless day to day incidents that occur during the transportation, transferral, and consumption of oil. If this trend is allowed to continue the problem of oil pollution of the ocean can be expected to become increasingly more acute as both the size and the number of shipments of oil continue to increase as the exploration for and the exploitation of offshore reserves are expanded." [10]

Levy conducted his study in the spring and summer of 1970, primarily to observe the effects of pollution caused by the Arrow incident. Consequently, much of his study was concerned with the Chedabucto Bay area. However, because they were essentially beyond the area effected by the Arrow disaster, his findings on the Halifax area and in the St. Lawrence River system, are useful for this report.

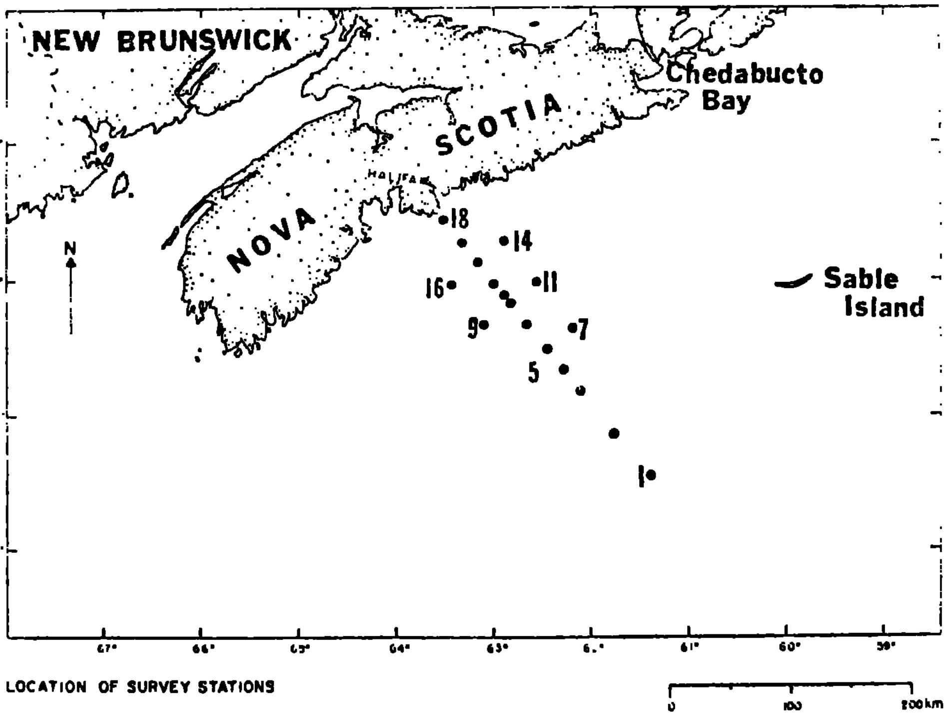
On May 11 and 12, 1970, Levy took seawater samples from a series of stations extending in a southeasterly direction from the entrance to Halifax Harbour to beyond the limits of the Continental Shelf (Figure 2.2). His findings are shown in Table 2.5 and we quote from his report as follows:-

> "The presence of residual oils was detected at all stations by the fluorescence method of analysis, and the concentrations observed suggest relatively low, but nevertheless significant levels of pollution from petroleum residues."

On July 15 to 22, 1970, Levy collected water samples at a series of stations extending from the Cabot Strait through the Gulf of St. Lawrence and upriver as far as Montreal (Figure 2.3) His findings are shown in Table 2.6 and he reports as follows:

FIGURE 2.2

Sampling Stations off Halifax, Levy Study, 1970



Source: E.M. Levy

TABLE 2.5

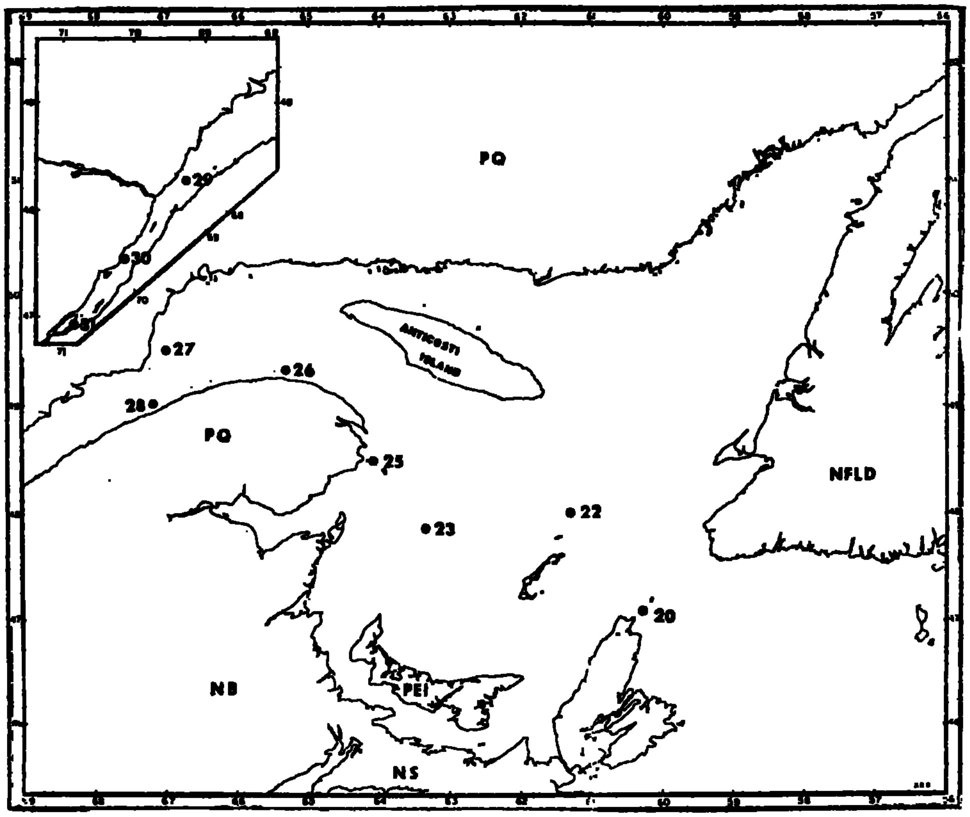
Concentration of Residual Oils Observed at the Stations on the Halifax Section (May 11-12, 1970)

Station	Concentration (ppb) Fluorescence 2m	Concentration (ppb) Fluorescence 10m
1	2.8	1.9
2	3.4	7.5
3	2.2	1.8
4	11.1	13.5
6	1.7	1.6
8	3.5	2.9
10	13.0	9.0
12	6.9	9.3
15	7.8	11.4
17	8.7	10.5
18	4.8	2.4

Source: Donald C. Grodon, Jr.

FIGURE 2.3

Sampling Stations in St. Lawrence River and Gulf, Levy Study, 1970



Source: E. M. Levy

TABLE 2.6

Concentration of Residual Oils Observed in the Gulf of St. Lawrence and the St. Lawrence River (July 15-27, 1970)

Station	Depth (m)	Concentration (ppb)
20	1	2.6
	75	2.3
	150	2.9
22	1	3.4
	50	2.1
	175	2.9
23	1	2.3
	30	1.6
	75	1.3
25	1	4.2
	50	1.3
	100	2.8
26	1	1.5
	75	2.4
	175	1.4
27	1	2.1
	50	1.5
	175	2.9
28	1	2.5
	50	1.5
	150	1.9
29	1	2.9
	150	2.5
	300	3.0
30	1	2.3
	25	3.3
	45	2.7
31	1	4.4
	10	3.7
	20	3.9
32	1	3.1
	10	3.2
	20	5.5
33	1	2.6
	10	2.8
34	1	2.9
	10	2.9

Source: E. M. Levy

> "A low background of residual oils was observed. There did not,however,appear to be any definite relationship between the concentrations of these substances and either the location or the depth at which samples were collected. In view of the extensive use to which this river is being put, substantially higher concentrations were expected to be present there than in the Gulf. Since this was not observed, it would appear that the oil is effectively removed by naturally occurring processes ....and deposition on the shores of the river and the estuary. It is of interest to note that the concentrations of petroleum residues observed in the River and Gulf were both lower and more uniform than those found in the open Atlantic as indicated by the samples collected on the Halifax section."

With perhaps a degree of optimism, Levy concludes that "the concentration of oil introduced into the river is being effectively controlled by natural processes."

Donald C. Gordon, Jr., and his research assistant made a second study of Nova Scotia coastal waters in April, 1971.[11] The purpose was to determine whether the Bunker C. fuel oil originating with the ARROW disaster could still be detected in Chedabucto Bay. The significance for the present study is that Gordon took samples along the coast from Halifax to Canso with which he could formulate conclusions about concentrations in Chedabucto. As indicated in Table 2.7, Gordon found that the concentration of oil along the Atlantic coast averages 1.4 ppb, a level which, on the basis of his earlier study, he considers "typical".

Also, it is to be noted that concentrations in Chedabucto Bay in April 1971, are much lower than those observed in Halifax Harbour, June - August, 1970. Apart from meaning that little, if any, of the oil released from the ARROW remains in the water column of the Bay, it emphasizes the extent and seriousness of the oil pollution problem that comes with industrial development of a port.

2.4 CONCLUSION

It would appear that very little is known about the size of the oil pollution problem in harbours and coastal waters. The causes of the problem are known, and because they are many and varied, there appears, in official circles, to be no further evidence required to demonstrate that the problem is a serious one. Without knowing the extent of pollution in any particular area, control measures are designed simply to ensure that the problem gets no larger if comprehensive studies were undertaken along the lines of that done by Gordon in Halifax

TABLE 2.7

Summary of Bunker C Fuel Oil Concentrations Observed April 13-15, 1971

Location	Depth (m)	n	Mean Total Concentration (ppb)	Range
Chedabucto Bay and Outer Reaches	5	15	1.2	0.0 - 2.7
	6-25	11	1.4	0.0 - 4.0
	26-50	11	1.8	0.7 - 3.4
	51	3	1.9	1.5 - 2.5
	ALL	40	1.5	0.0 - 4.0
N.S. Coast between Halifax and Chedabucto Bay	5	7	1.4	0.5 - 2.6

Source: Donald C. Gordon, Jr.

Harbour, the true size of the problem would be known, and the need for measures to reduce its size would be demonstrated.

2.5 REFERENCES

1. Dudley, G., "Oil Pollution in a Major Port", in C.B. Cowell, ed., Ecological Effects of Oil Pollution on Littoral Communities, (Elsevier, London, 1971) p.7

2. Anon, Report on Oily Substances and Their Effects on the Beneficial Uses of Water, State Water Pollution Control Board, Sacramento, Californis, 1956, p.24

3. Blumer, Max, "Scientific Aspects of the Oil Spill Probelm," Colloquim on Oil Pollution of the Sea, CCMS, North Atlantic Treaty Organization, Brussels, 1970, p.1

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7. Canada Shipping Act, RSC, 1960-61, c.32, s.28, SOR/71-137

8. Gordon, Donald C. and Michalik, Paula A.,"Concentration and Distribution of Oil Pollution in Halifax Harbour, 10 June to 20 August 1971," Fisheries Research Board of Canada, Technical Report No. 284.

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10. Levy, E. M., Ibid

11. Gordon, Donald C., Jr., and Paula A. Michalik, "Concentration of Bunker C. Fuel Oil in the Waters of Chedabucto Bay, April, 1971," Unpublished report for the Fisheries Research Board of Canada.

3.0 HYDRAULIC TESTING

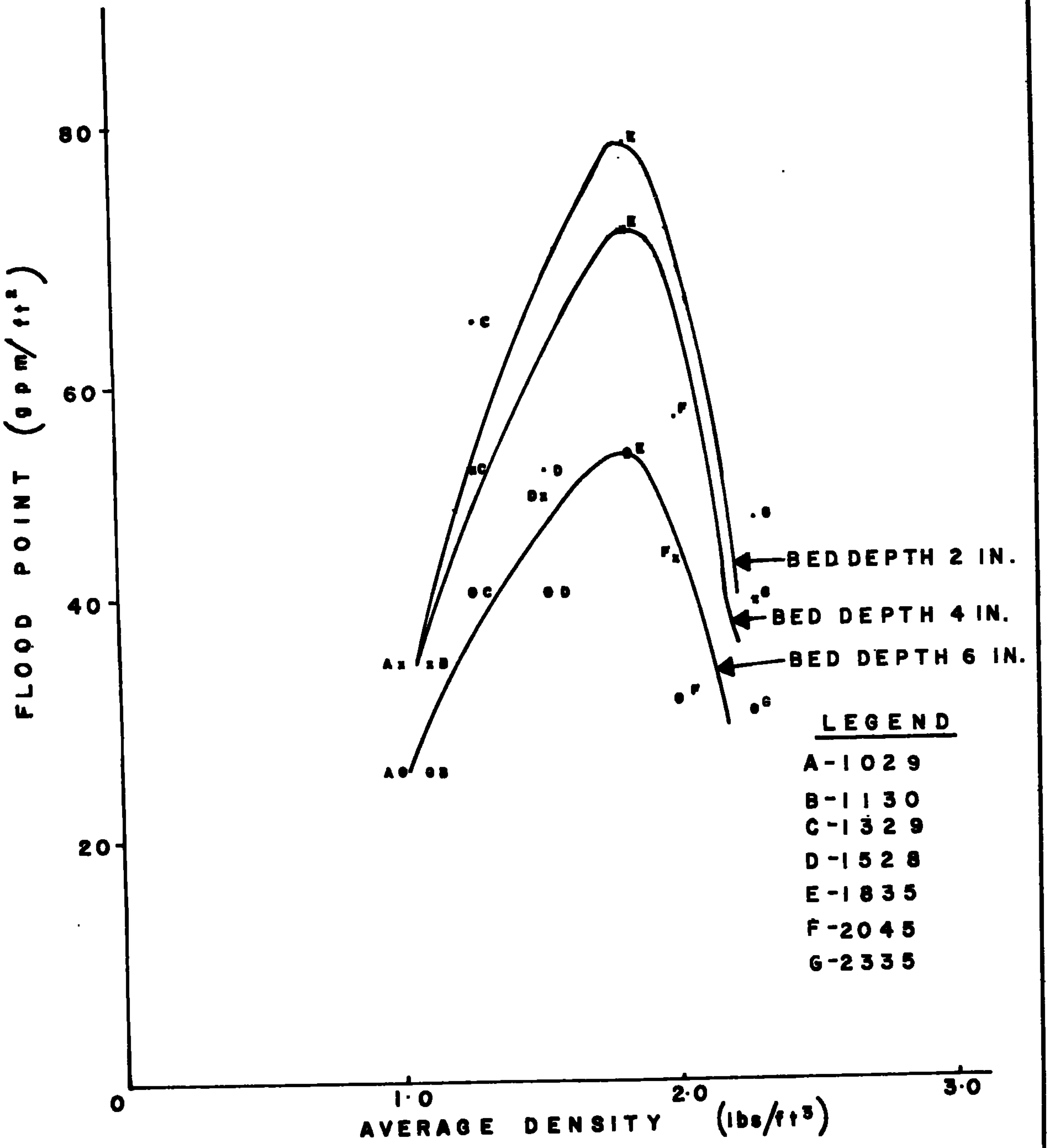
In the First Interim report[1] various foams were compared for hydraulic capacity by determining the flood point at various bed depths. This hydraulic testing eliminated rigid foams from being considered for mass transfer work because of their inability to pass sufficient quantities of water. Of the remaining foams the natural or unfilled foams 1835, 1329, and 1528 gave the highest flood points but the filled foams 3337F and 3865F gave favourable enough flood points* to be considered in the mass transfer work.

3.1 EFFECT OF DENSITY AND RESILIENCY ON FLOOD POINT

Since the First Interim report[1] a new foam 2045 has been produced by the manufacturers. Hydraulic testing of this foam revealed that there is a correlation between flood point and density for the unfilled foams. Figure 3.1 shows flood point versus density at various bed depths for the unfilled foams. Foam 1835 has the maximum flood point of the foams tested.

A new high resiliency, high density, fireproof second generation foam (Monsanto HR) was hydraulicly tested and found to have a very low capacity. At a 2 inch bed depth the flood point was 6 gpm at a 15 inch head and at a 6 inch bed depth the flood point was 3 gpm at a 14 inch head. Earlier work[1] reported that the flood point increased

* <u>Flood Point</u>: the flood point was defined as the maximum flow, for a particular filter, at which the column would operate at steady state conditions. Above this point the head above the filter would increase dramatically and the filter column would flood.



FLOOD POINT VS DENSITY
UNFILLED FOAMS

FIG. 3.1

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with resiliency but that it was low at high values of density. The purpose of this trial was to ascertain which was the more important variable. The results indicate clearly that density is the more important variable. This is most convenient as foams are usually specified in terms of their density.

3.2 RELIABILITY TESTS

A series of tests were carried out to establish the variation in flood point between different samples of nominally similar foams operating under the same experimental conditions.

Two different batches of foams 1329, 1528 and 1835 were available from the same manufacturer. One batch had been used extensively in previous testing and the other was unused. The flood point for a 2 inch bed depth was measured for 3 different samples from each batch of the three foams giving, therefore, 6 separate determinations of the flood point for each foam.

The recorded results are shown in Table 3.1. Also included is the measured value of the flood point for this bed depth. The arithmetic mean and the standard deviations for each foam type are given in Table 3.2.

As can be seen the variations to be expected for a given foam type are quite high. There appears to be no discernable difference between the used and unused foam in the case of 1329 and 1835. However, this does not appear to be the case with foam 1528.

3.3 FATIGUE TESTING

Fatigue testing of foams 1528, 1835, and 3865F was carried out at a 3 inch bed depth over a 24 hour period to determine any deterioration of the foam over extended periods. Foams 1528 and 1835 were run at 16 inch and 6 inch heads respectively and flows of 48.9 gpm/sq.ft. and 43.9 gpm/sq.ft. respectively. Both foams initially compressed to 2 1/4 inches but after 24 hours there was no change in the head or flow of either foam. Foam 3865F started at 26.9 gpm/sq.ft. at a 16 inch head but over a 4 hour period the head increased to 22 inches. The flow was reduced to 22.9 gpm/sq.ft. at a 13 1/2 inch head but over the following 8 hours the head increased to 22 inches. There was no compression of the bed during the entire run. From these results it can be concluded that the natural or unfilled foams will not deteriorate with time but the filled foams lose their hydraulic capacity with time.

TABLE 3.1

CONSISTENCY TESTS -

POLYURETHANE FOAM

MONSANTO FOAM TYPE	BED DEPTH (in.)	FLOOD POINT (gpm)	RUN NO.	FOAM HISTORY
1329	2	19.5	1	used
"	2	19.5	4	used
"	2	22.5	3	used
"	2	22.5	7	used (orig.)
"	2	18.0	3	unused
"	2	21.0	5	unused
"	2	19.5	6	unused
1528	2	18.0	1	used
"	2	21.0	2	used
"	2	18.0	3	used
"	2	19.5	7	used (orig.)
"	2	25.5	4	unused
"	2	19.5	5	unused
"	2	25.5	6	unused
1835	2	21	2	used
"	2	25.5	3	used
"	2	27.0	7	used (orig.)
"	2	22.5	1	used
"	2	27.0	4	unused
"	2	19.5	5	unused
"	2	27.0	6	unused

TABLE 3.2

STANDARD DEVIATIONS

MONSANTO FOAM TYPE	ARITH. MEAN (all)	STAND. DEV.	ARITH. MEAN USED	ARITH. MEAN UNUSED
1329	20.3	1.7	21.0	19.5
1528	21.0	3.0	19.1	23.5
1835	24.2	2.9	24.0	24.5

3.4 HYDRAULIC TESTING AT 12 INCH BED DEPTH

Additional hydraulic testing was carried out at a 12 inch bed depth for the foams 1029, 1329, 1528, 1835, and 2335 because of anticipated mass transfer work at this bed depth. Results are shown in Table 3.3. The physical height of the filter prevented the determination of the flood points of the higher capacity foams but it can be seen from the data that the flood point was being approached. This data agrees with previous hydraulic testing at lesser bed depths.

3.5 SUMMARY

Foam 1835 (Monsanto) with an average density of 1.8 pounds per cubic foot has the optimum hydraulic properties.

Density is a better indication of hydraulic capacity than resiliency.

Variations in foam capacity from one batch to another are to be expected.

The unfilled foams tested continued to perform well through extended periods of time.

TABLE 3.3

HYDRAULIC TESTING

BED DEPTH - 12 IN.

DATE	FOAM TYPE	FLOW (gpm)	FOAM THICKNESS AFTER COMPACTION (in.)	HEAD (in.)
Aug.27/71	1029	9.0	11 3/4	0.25
		10.5	11	11.5
Aug.27/71	1329	12.0	11 3/4	0.25
		13.5	9 1/2	flooded
Aug.27/71	1528	12.0	11 3/4	0.25
		13.5	12	12.0
Aug.30/71	1835	10.5	12	0.25
		12.0	12	8.0
		13.5	11 1/2	9.0
		15.0	11 1/2	11.5
Aug.30/71	2335	5.4	-	0.25
		6.0	11 3/4	1.75
		7.5	10	flooded

3.6 REFERENCES

1. Polyurethane as an Oil Filter, A Research Study, 1st Interim Report - Canadian Plant and Process Engineering Limited, September 1971. (Appendix II)

4.0 MASS TRANSFER

4.1 BUNKER C ADSORPTION TRIALS

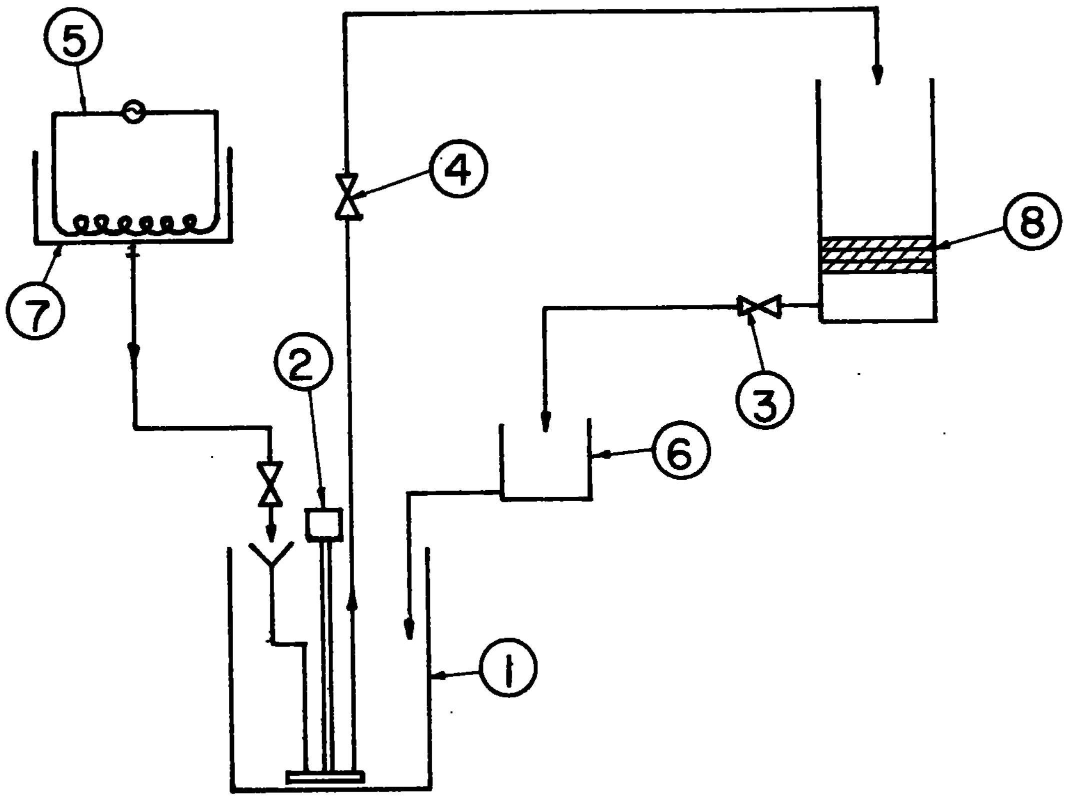
4.1.1 Introduction

The equipment for the mass transfer studies was the same as that used in the hydraulic testing with the addition of a constant head feeder to meter in the oil. The equipment is shown schematically in Drawing 4.1. The feeder consisted of a tank with a fairly large surface area so that the head in the tank would change very slightly during the course of a trial. An immersion heater was installed in the tank to maintain the oil at 71°C - 82°C to decrease the viscosity and thus making it easier to feed and mix. The oil was fed into the water stream at the intake of the pump. The temperature of the water in these trials was at ambient (20°C.).

4.1.2 Procedure and Results

Results from the laboratory trials are shown in Tables A-1 to A-21 Appendix A. The initial trials were run at near flood point dictated by the foam type and head loss due to oil build up. The remainder of the trials were run at a 13 inch head so that the performance of the various foams could be compared with respect to flow rate and oil removal.

It should be noted that these trials make no attempt to assess foam capacity (see Section 8.1) but compare the mass transfer efficiency of various foams.



1 — PLASTIC RESERVOIR 20 IMP. GAL.
2 — SUMP PUMP 50 G.P.M.
3 — DISCHARGE VALVE - 2" BRONZE GATE
4 — THROTTLE VALVE - 1¼" BRONZE GATE
5 — IMMERSION HEATER - 1500 WATTS
6 — RECTANGULAR NOTCHED WEIR BOX
7 — CONSTANT HEAD FEED TANK
8 — FOAM DISCS

DWG. NO. 4.1

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Samples were taken at 4 minute intervals for about the first 30 minutes then at 30 minute intervals for a total run time varying from 1 to 2 hours. The high frequency of sampling during the first 30 minutes was considered necessary because the effluent concentration had a tendency to steadily decrease and then level off during this time interval. An example of this can be seen from the results given in Table A-15 where the effluent concentration was 4.28 ppm after 4 minutes and then steadily decreased to 0.22 ppm at the end of 28 minutes. In later trials, the sampling was spread out to cover runs up to 3 hours as shown in Table A-21. The first samples were taken at 4 minute intervals then increased to 8, 10, and 30 minute intervals.

The number of samples taken was limited by the number of samples which could be analysed in one day. This was found to be a maximum of 22 samples.

Sampling of the inlet was very difficult since a single droplet of oil would radically increase the quantity of oil in the sample. Although the oil was fed at a constant rate the problems of mixing oil and water made it difficult to take a sample which was representative of the actual inlet concentration.

The feed rate of the oil had to be decreased as the flow rate through the filter decreased due to head loss.

As a check on the laboratory analysis described in section 4.3.1,tap water samples were substituted on a regular basis for effluent samples from the trials. For instance, the third outlet concentration recorded in Table A-19 was tap water substituted for the regular sample.

4.1.3 Effect of Bed Depth and Inlet Concentration on Effluent Concentration

In all the trials there was always a small amount of oil remaining in the effluent. In an effort to reduce this quantity of oil to zero, bed depths from 4 inches to 10 inches were tried. It was found from these trials that increased bed depth had no noticeable effect on the concentration of oil in the effluent. Tables A-3 and A-5 give the results of two trials with foam 1528 at bed depths of 8 inches and 10 inches with the same average inlet concentration of 224. ppm. The trial at the 8 inch bed depth gave an average effluent concentration of 0.88 ppm and a minimum effluent concentration of 0.39 ppm. The trial at the 10 inch bed depth gave an average effluent concentration of 1.82 ppm and a minimum effluent concentration of 1.20 ppm.

Inlet concentration was found to have no effect on the concentration of the effluent. Tables A-7 and A-8 shows the results of two trials with foam 1835 at a 6 inch bed depth at different inlet concentrations. The average inlet concentration of 235.4 ppm (Table A-7) gave an average effluent concentration of 1.06 ppm with a minimum during the trial of 0.68 ppm. The much lower average inlet concentration of 17.2 ppm gave an average effluent concentration of 1.25 ppm with a minimum during the trial of 0.88 ppm.

4.1.4 Effect of Foam Types on Oil Removal

Seven different foam types were tested in the Bunker C adsorption trials which consisted of five unfilled foams Monsanto numbers 1329, 1528, 1835, 2045, and 2335 and two filled foams numbers 3865F and 3337F.

Of these foams only 3337F and 2335 gave consistently poor results as seen in Tables A-16, A-17, A-18, and A-19. The remaining foams gave similar results with 1835 and 1528 giving marginally better results. These also were the two foams which were found to have the highest flood points from the hydraulic testing programme. Foam 1528, however, has a tendency to compress although it still maintains an appreciable flow (Tables A-3, A-4, and A-5).

4.1.5 Foam Chunks Above Discs

The results shown in Tables A-9 to A-12 were trials in which foam chunks were put in on top of the foam to a depth of approximately 14 inches. These chunks were to act as a roughing filter to take out the bulk of the oil and the foam discs were to act as a polishing filter for removal of the remainder of the oil. A sampling point was installed between the chunks and the foam discs to determine the effectiveness of the chunks. Tables A-11 to A-14 show the oil concentration at the inlet, between chunks and foam discs and effluent from the filter. It is evident from these results that the efficiency of the chunks increases with increasing inlet concentration.

4.1.6 Short Circuiting

An investigation was made into the possible problems caused by short circuiting down the sides of the filter. In one trial a rubber gasket ring was held securely against the filter bed by a circular expansion ring. The results, shown in Table A-1,indicated no difference in effluent quality.

A sampling point, incorporating a small funnel, was installed beneath the centre of the bed inorder to ensure that samples did not contain water which had bypassed the filter. Results in Tables A-13 and A-14 compare the effluent.

from the filter and the sample from beneath the center of the bed.

It is evident from these results that short circuiting is not a major factor in effluent concentrations.

4.1.7 Rinsing of Foam

In the manufacture of filled foam barytes is used as the filler. Sometimes trace amounts of barytes are left in the lines that feed chemicals into the pouring head so that unfilled foams will sometimes contain trace amounts of barytes. In some of the trials these fine barytes particles were washed out of the foam. The oil coats these particles and when they are washed through the filter they impart a dark brown color to the effluent. This happened occasionally with different foam types.

The high effluent values recorded in Table A-13 was a result of oil soaked barytes particles being dislodged from the filter. The run does, however, show the effectiveness of foam chunks and also indicates there was no short circuiting down the sides of the bed.

It was also observed that the foams when first wetted had a soapy feeling. This is due to the surfactant which is used in the foam formulations as a bubble stabilizer.

It would be possible in the manufacture to limit drastically the particle problem by careful cleaning of the lines that feed the chemicals to the pouring head but the surfactant additive in urethane is vital to the process.

The problem of any further occurrences of barytes particles in the effluent was eliminated by first rinsing the foams thoroughly before any oil adsorption trials. Rinsing also removed the residual surfactant from the foams and consequently, must be considered as a pre-treatment for the medium.

4.2 MARINE DIESEL ADSORPTION TRIALS

4.2.1 Introduction

Foams 1130, 1528, 1835, 2045 and 3337F were tested at varying bed depths and inlet concentrations. Results from the laboratory trials are shown in Appendix B, Tables B-1 to B-10. A bed depth of 6 inches was used to compare the performance of the various foam types.

4.2.2 Procedure and Results

The equipment for the marine diesel adsorption trials was the same as that used in the Bunker C adsorption trials except the immersion heater in the constant head feed tank was not required for the marine diesel (Drawing 4.1).

A maximum of 22 samples were taken during each trial and analysed according to the method described in Section 4.3.2. During the first hour the time intervals between samples were increased after every 2 samples by 4, 8, and 10 minutes. After 1 hour the sampling frequency was every 30 minutes for a total run time of 3 hours.

It was difficult to determine whether inlet concentration and bed depth had any significant effect on removal because of variations in the performance of each individual foam type from one trial to the next. There was, however, better removal with the lower density foams 1130 and 1329 although hydraulic performance dropped off sharply as the density decreased.

The best removal of 82.9% was achieved in the trial with the lowest density foam 1130 at a 6 inch bed depth, results of which are shown in Appendix B, Table B-1. This trial also gave the lowest effluent concentration of 5.4 ppm for the effluent samples taken at the end of 4 minutes and 8 minutes. The flow rate, however, of 9 gpm/ft.^{2} throughout the run was considerably less than trials with any of the other unfilled foams at the same bed depth.

Two trials with the second lowest density foam 1329 gave the next best removals of 80.9% and 76.6% (Tables B-2 and B-3 respectively). The flow rates for these trials at the end of one hour were 17 gpm/ft.^{2} and 13 gpm/ft.^{2} respectively compared with the next higher density foam 1528 which gave 35 gpm/ft.^{2} (Table B-5) at the end of one hour.

The filled foam 3337F (Table B-10)gave the highest average effluent concentration (42.1 ppm) and the lowest flow rate (final flow rate 3 gpm/ ft.^{2}) of all the trials. There was also a steady increase in effluent concentration from the beginning of the trial (10.0 ppm) to the end (100.0 ppm) which indicated the foam had reached its capacity.

4.2.3 Conclusion of Testing

Additional trials are being carried out to determine optimum adsorption conditions and will be reported in the final report in this programme. Reference is also made to Section 8.0 of this report.

4.3 ANALYTICAL PROCEDURES

The mass transfer work necessitated the measurement of the concentrations of oil in the fluid streams entering and leaving the filter. Fluorescence spectrophotometry was used in analysis of samples containing Bunker C oil and infra red spectrophotometry was used for the examination of samples containing diesel oil. These analyses were carried out in the laboratories of Wyman and West Ltd.

Gas liquid chromatography was used in the examination of bilge water samples at the Chemical Engineering Department of the Nova Scotia Technical College.

The details of each procedure are given below.

4.3.1 Fluorescence Spectrophotometry

Many aromatic materials fluoresce and since hydrocarbon products obtained from crude oil, such as Bunker C, contain these materials, the measurement of the fluorescence intensity under standardised conditions can be used as a method of quantitative measurement. This procedure[1] was used extensively during operations subsequent to the grounding of the tanker Arrow in Chedabucto Bay, N.S. and was also used[2] in a recent survey of the levels of oil pollution in Halifax Harbour.

A calibration curve was prepared using the same oil as was to be used in the mass transfer work. Conditions of maximum fluorescence were with an excitation wave length of 310 mμ and an emission wave length of 450 mμ The instrument used was a Perkin Elmer Fluorescence spectrophotometer model number 303, using a 10 mm cell.

Two hundred and fifty ml samples of the influent and effluent of the filter were extracted with 50 ml of chloroform, thus giving a 5:1 concentration factor. Some of the chloroform solution was then placed in the spectrophotometer cell, the fluorescence intensity was measured and the concentration of oil was then obtained from the calibration curve. It was found that the technique was rather insensitive to concentration above 13 ppm in chloroform and consequently aliquot samples were taken and diluted to concentration below 13 ppm where necessary.

The procedure allowed the measurement of concentrations down to 10 ppb with a precision estimated to be 0.2% in the better part of the concentration range. Concentration of the chloroform extract will lower the limit of resolution down to 1 ppb.

The mass transfer experiments were carried out using tap water. This was found to contain some fluorescing material and interference from this source was eliminated by the periodic examination of blank samples of tap water from which appropriate corrections could be made.

4.3.2 Infra Red Spectrophotometry

The fluorescence method used in the Bunker C oil determination could not be applied to the measurement of diesel oil as no proportionality could be established between concentration and fluorescence.

The technique ultimately used relied on the absorption by hydrocarbons of light in the infra red region. This technique is used extensively in the examination of hydrocarbons and has been suggested[3] as a method for the characterisation of oil slicks.

The instrument used was a Perkin-Elmer 456 IR Spectrophotometer. One hundred millimeter cells were used to increase the sensitivity. A calibration curve was prepared using a sample of the diesel oil to be used in the mass transfer work dissolved in carbon tetrachloride(which contained no carbon-hydrogen bonds). The extraction of the influent and effluent water samples was similar to that used in the Bunker C analysis except that the extract was dried by filtering through anydrous sodium sulphate. The sensitivity of the method decreased above 20 ppm of oil and accordingly aliquots of the extract were taken and diluted to bring the concentration below 20 ppm where necessary. This procedure permitted the measurement of diesel oil concentrations down to 20 ppb, the precision being estimated to be 0.2%.

Interference from the tap water used in the mass transfer work was eliminated by the use of "blank" samples.

4.3.3 Gas Liquid Chromatography

Gas liquid chromatography (glc) has been used extensively to analyse oil pollutants and is a recommended method of the Institute of Petroleum[4]. The procedure has been in regular use in the Chemical Engineering Department at Nova Scotia Technical College on research projects supported by the Department of the Environment.

The instrument used was an F & M 810 model fitted with a flame ionisation detector. The columns are packed with Chromosorb W coated with 5% silicone gum rubber.

The samples of bilge water were extracted with carbon tetrachloride and approximately 6 μl of the extract were injected into the instrument which was temperature programmed to rise from 50°F to 350° F at a rate of 4 degrees/minute. Comparison of the resulting chromatogram which indicates the distribution of hydrocarbons in the sample, with chromatograms of materials of known type then allows the nature of the oil component being examined to be determined. The boiling range of the unknown material can also be established by injecting a hydrocarbon mixture of known composition into the instrument and using the resulting chromatogram for calibration purposes. This boiling range can also be used to establish the nature of the material in question. A chromatogram of a typical calibration mixture is shown as Figure 4.1.

This technique, although useful for quantitative determinations, has been used here for qualitative examination only.

4.3.4 The Composition of Oil in the Effluent

The process by which oil is removed from water by polyurethane involves a chemical interaction between the oil and the foam. Since oil contains a large number of different chemical compounds, it is possible that differential adsorption due to the difference in behavior of the chemical compounds would result in the "oil" in the effluent being significantly different from that in the influent. This obviously has a bearing on the analysis of samples.

To elucidate this point, influent and effluent samples were extracted and analysed by gas liquid chromatography using the methods described in section 4.3.3. When diesel oil was used, there appeared to be no difference in the chromatograms of the influent and effluent sample extracts indicating that no differential adsorption takes place. In samples containing Bunker C oil there did appear to be preferential adsorption of the lighter compounds, however, as this represents only a small proportion of the total mass of oil, it was concluded that this would have no significant effect on the results of the analysis.

4.4 REFERENCES

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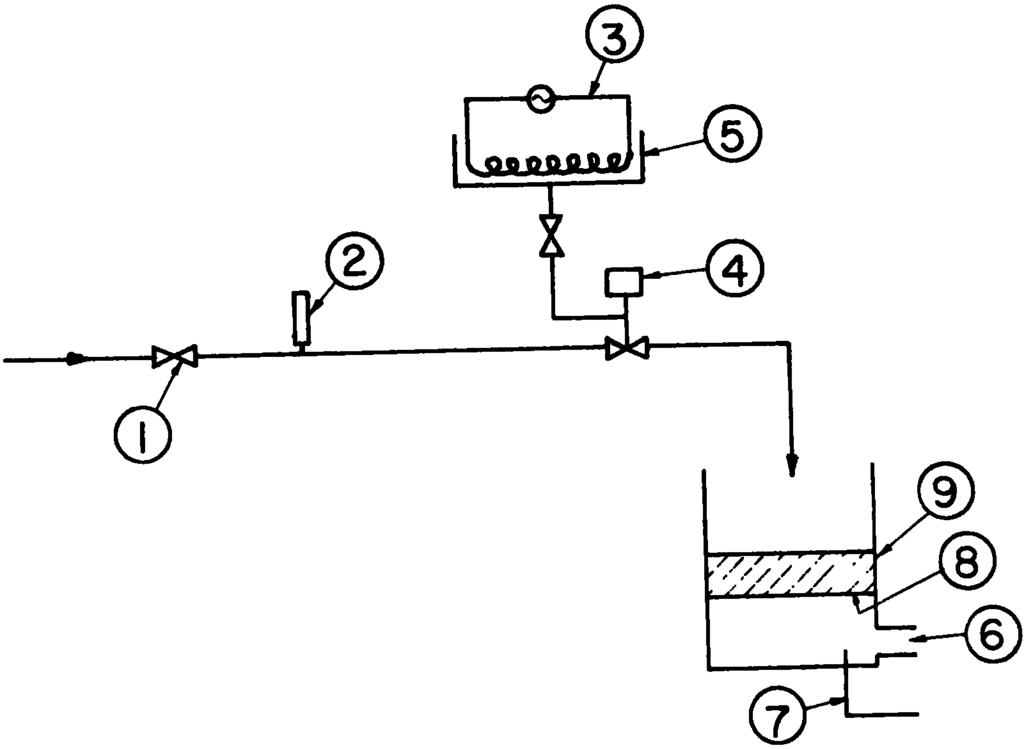
5.0 LARGE SCALE TESTING

5.1 INTRODUCTION

Preliminary work began at the Bedford Institute on a 22 1/2 inch diameter filter to determine whether scale-up factors were necessary in designing larger filters. The equipment (Drawing 5.1) consisted of a 22 1/2 inch diameter filter with an expanded metal underdrain supported by angle iron tack welded to the sides of the filter. Discharge from the filter was through a 6 inch diameter pipe at the bottom of the filter. A continuous supply of salt water was available from the Fisheries Research Board laboratories located at the Bedford Institute. A 3 inch diameter line was connected to this source and a Fisher and Porter Model 71K1000A flowmeter was installed in the line to measure flow. An inline mixer was installed downstream from the flowmeter and the oil was fed into the water at this point. The same constant head feeder arrangement was used as that in the small scale work. The water was then fed directly into the inlet at the top of the filter.

5.2 HYDRAULIC TESTING

A hydraulic test was run on the filter using foam 1835 at a 4 inch bed depth at 2.2°C. Results



1 — PVC GATE VALVE - 3"
2 — FLOW INDICATOR 20-160 G.P.M.
MODEL 71K1000A
3 — IMMERSION HEATER - 1500 WATTS
4 — INLINE MIXER
5 — CONSTANT HEAD FEED TANK
6 — DISCHARGE - 6" DIA.
7 — SAMPLE POINT - 1/2" DIA.
8 — EXPANDED METAL UNDERDRAIN
9 — FOAM DISC

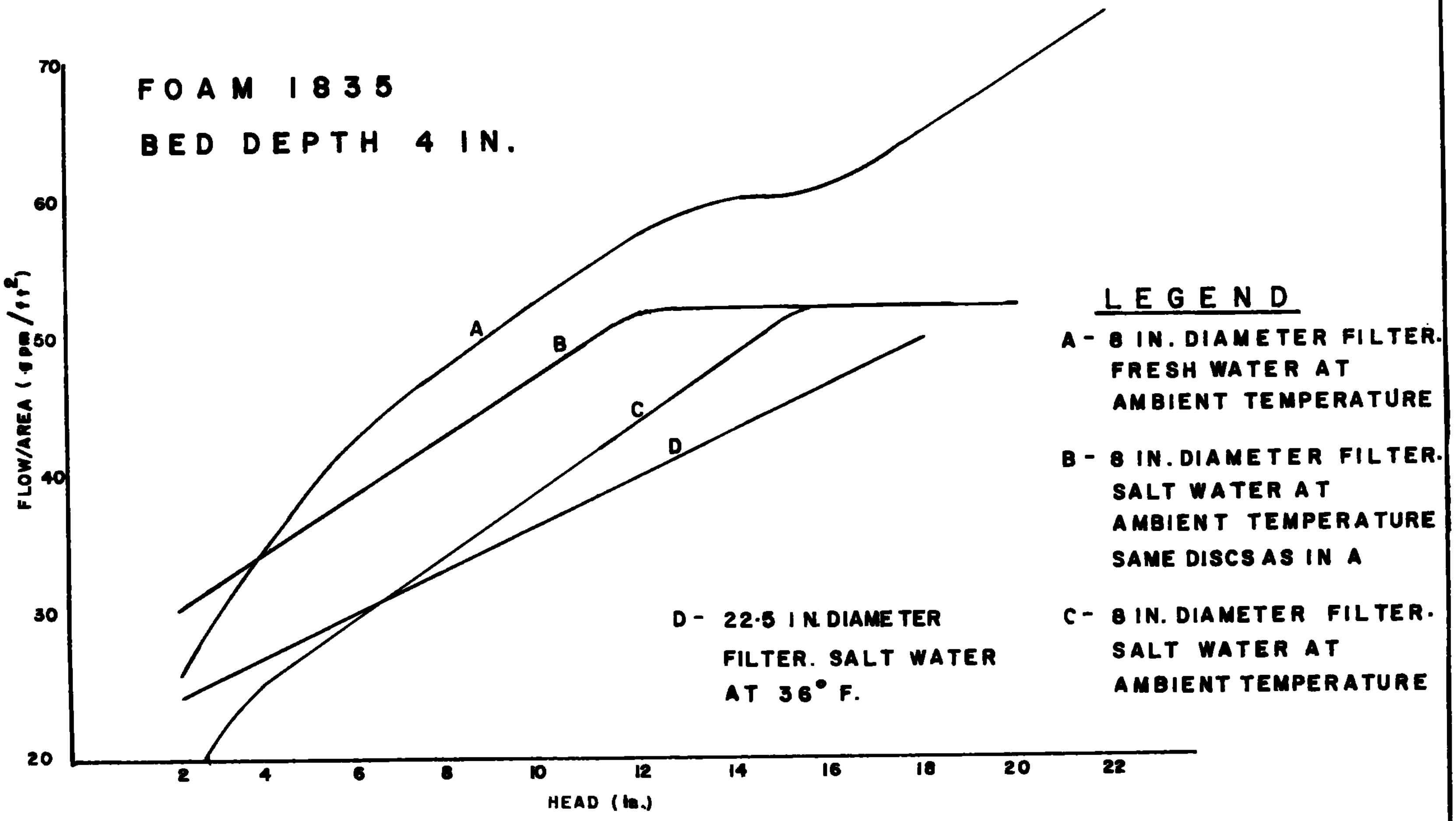
DWG. NO. 5.1

[illegible] PLANT AND PROCESS ENGINEERING LIMITED
HALIFAX N.S.
[illegible]

from the test are shown in Table 5.1 Hydraulic tests were also run using foam 1835 at a 4 inch bed depth on the 8 inch diameter filter at Wyman and West Laboratories with both salt and fresh water at ambient temperature (Tables 5.2, 5.3, 5.4). Results of the tests are plotted in Figure 5.1. Correlation of data from the two filters would seem to be reasonable, in view of the variations in performance between similar foams operating under similar conditions as described in Section 3.2 Additional testing will be carried out on the small filter at 2°C to determine whether temperature plays a significant role on the hydraulic performance. There was a considerable change noted in flood point between salt and fresh water.

5.3 MASS TRANSFER TRIALS USING BUNKER "C"

Preliminary work on Bunker C adsorption gave effluent residuals of 0.01 ppm. Results from the trials are shown in Tables C.1 to C.4, Appendix C. Additional testing will have to be carried out on the small 8 inch diameter filter with salt water at 2°C. in order to correlate these results with previous trials with fresh water at ambient.



FLOW/AREA VS. HEAD

FIG. 5.1

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TABLE 5.1

HYDRAULIC TESTS

DATE January 13, 1972 FOAM 1835 BED DEPTH 4 in.

FILTER DIAMETER 22 1/2 in. TEMPERATURE 2°C. SALT WATER

FLOW (gpm)	FLOW/AREA (gpm/ft^2)	HEAD (in.)
70.	25.	2
85.	31.	6
90.	33.	7
95.	35.	9
95.	35.	10
100.	36.	11
110.	40.	12
110.	40.	13
115.	42.	14
130.	47.	17
140.	51.	18

TABLE 5.2

HYDRAULIC TESTS

DATE January 17, 1972 FOAM 1835 BED DEPTH 4 in.

FILTER DIAMETER 8 in. AMBIENT TEMPERATURE SALT WATER

FLOW (gpm)	FLOW/AREA (gpm/ft^2)	HEAD (in.)
6	17.	2
9	26.	4
11	30.	6
12	35.	8
14	39.	10
15	43.	12
17	48.	14
18	52.	16
18	52.	18
18	52.	20

TABLE 5.3

HYDRAULIC TESTS

DATE January 17, 1972 FOAM 1835 BED DEPTH 4 in.

FILTER DIAMETER 8 in. AMBIENT TEMPERATURE SALT WATER

FLOW (gpm)	FLOW/AREA (gpm/ft^2)	HEAD (in.)
9	26	2
12	35	4
14	39	6
15	43	8
17	47	10
18	52	12
18	52	14
18	52	16
18	52	18
18	52	20
18	52	22

NOTE: Same discs as in Table 5.4

TABLE 5.4

HYDRAULIC TESTS

DATE January 17, 1972 FOAM 1835 BED DEPTH 4 in.

FILTER DIAMETER 8 in. AMBIENT TEMPERATURE FRESH WATER

FLOW (gpm)	FLOW/AREA (gpm/ft^2)	HEAD (in.)
9	26	2
12	35	4
15	43	6
17	47	8
18	52	10
20	57	12
21	60	14
21	60	16
23	65	18
24	69	20
26	73	22

5.4 SUMMARY

The scale up testing to date has provided encouraging results, with the best mass transfer to date being achieved.

The improved efficiency of the large scale filter is probably a function of several variables including the lower temperature of the water being used, the salinity and the area circumference ratio as compared with the smaller filter. Additional data is being assembled in this regard.

The hydraulic analysis previously carried out has confirmed the advisability of utilizing a foam with an average density of 1.8 lbs./cu.ft. (Monsanto 1835 or equal) and the results to date indicate that while salinity and temperature affect the overall performance, they do not change the position of this foam relative to the others tested.

Additional work at this larger scale is being carried out on marine diesel and crude oil.

6.0 BILGE WATER SAMPLES

6.1 GENERAL

As part of a project to study the possible use of polyurethane filters to clean oily bilge water before its discharge, samples from 12 different vessels were taken and analysed in order to gain some information of the types of hydrocarbons likely to be present in bilge water.

These samples, taken by the Department of National Defence,contained amounts of oil varying from a very thin film on the surface of water to about 90% of the sample. A brief description of each sample is given in Table 6.1.

6.2 ANALYSIS AND DISCUSSION OF RESULTS

The oily phase was examined by injecting a sample either directly or as a carbon tetrachloride extract into a gas liquid chromatograph and inspecting the ensuing chromatogram. The machine used was an F & M 810 and the procedure followed was one normally used for the analysis of oil products at the Chemical Engineering Department, Nova Scotia Technical College and is discussed in section 4.3.3.

The chromatograms suggested that the oily components of the 12 samples could be grouped into three different types, (A) those which contained virtually no material boiling above 750°F, (B) those which contain significant quantities of material boiling above 750°F and (C) those which contain material almost all of which boils above 750°F.

Results of the analyses are summarized in Table 6.2. Three of the four samples in group A had no material boiling below about 420°F and the comparatively narrow temperature range would suggest that the samples all contained the same type of distillate fuel oil. The "Bluethroat" sample appears to contain a slightly lighter variety of the same fuel.

The three group B samples contain hydrocarbons of a very wide spectrum of boiling points. That and certain discontinuities in the appearance of the chromatogram, which suggest blending, would indicate that the samples contained residual fuel oil. The appearance of the three chromatograms is very similar indicating the same type of oil. Differences in the distribution of hydrocarbons within the sample are probably due to weathering.

The chromatograms of the five group C samples, since they contain only very high boiling material, are more difficult to interpret. They are certainly not indicative of weathered fuel oil and

TABLE 6.1

PHYSICAL APPEARANCE OF BILGE WATER SAMPLES

NAME	DATE	AMOUNT OF OIL	APPEARANCE
Quest (motor room)	16.11.71	approx. 5%	water layer clear, oil layer brown with white flocculated particles at interface.
Riverton	16.11.71	thin film	water layer clear, oil layer dirty brown.
Saguenay	17.11.71	thin film	water layer clear, oil layer brown.
CNAV Bluethroat	16.11.71	thin film	water clear, oil slightly brown.
Ojibwa	17.11.71	approx. 10%	water layer cloudy with black particles at bottom, oil layer very black.
Dundalk (tanker)	18.11.71	approx. 40%	water layer very clear, oil layer black
Yard Craft (YFP23)	16.11.71	approx. 90%	water layer dirty, oil layer very dark brown.
P.St.Louis	17.11.71	approx. 60%	water clear, contains some black particles oil layer dark brown with black sediment at interface.
Protecteur	18.11.71	very thin film	water layer clear.
Yard Craft	18.11.71	very thin film	water layer clear.
Ft. Francis	18.11.71	very thin film	water layer clear.
Sackville	18.11.71	very thin film	water layer cloudy contains black particles insoluble in CCl_4.

TABLE 6.2

COMPARISON OF SAMPLES OF OILY COMPONENT OF BILGE WATER

Group A

Quest	Boiling range about 420°F-750°F, little or no residual material, indicative of distillate fuel oil.
Riverton	Similar to Quest.
Saguenay	Similar to Quest, contained some high boiling material.
Bluethroat	Similar to Quest, contained some material boiling below 400°F.

Group B

Ojibwa	Contained wide range of hydrocarbons including significant amounts of asphaltic type material boiling above 800°F, indicative of residual fuel oil.
Dundalk	Similar to Ojibwa, contained more high boiling material, less low boiling.
Yard Craft YFP23	Similar to Ojibwa but also with more high boiling material and less low boiling material, indicative of weathered fuel oil.

Group C

St. Louis	Contained very high proportion of material boiling above 750°F (ca. 90%) appearance of sample would suggest lubricating oil.
Protecteur	Similar to St. Louis
Ford Craft 313	Only traces of material boiling above 750°F, probably similar to St. Louis.
Fort Francis	Similar to Yard Craft 313.
Sackville	Similar to Yard Craft 313.

the visual appearance of the oil component of the "St. Louis" sample and the similarity of that chromatogram with the others would suggest that the five samples contain lubricating oil only. Typical chromatograms are shown in Figures 6.1 to 6.5.

6.3 CONCLUSION

Of the twelve samples of bilge water examined, the oil component of seven appeared to consist of fuel oil, the rest containing varying amounts of lubricating oil only. The seven containing fuel oil may also have contained some lubricating oil, especially the "Saguenay" sample, but the occurrence would be masked by the fuel oil. Residual fuel oils, which contain high boiling compounds similar to those in lubricating oils would, if present in bilge water tend to disguise the presence of lubricating oils unless they were present in much bigger concentration than the fuel oils.

The occurrence of lubricating oil and fuel oil in a ship's bilge water is hardly unexpected but the oil in the bilge water from the tanker Dundalk requires more examination. Since it appeared to be residual fuel oil, it may have come from her own fuel supply or her cargo. If it comes from the cargo, then bilge water from a tanker could also contain crude oil.

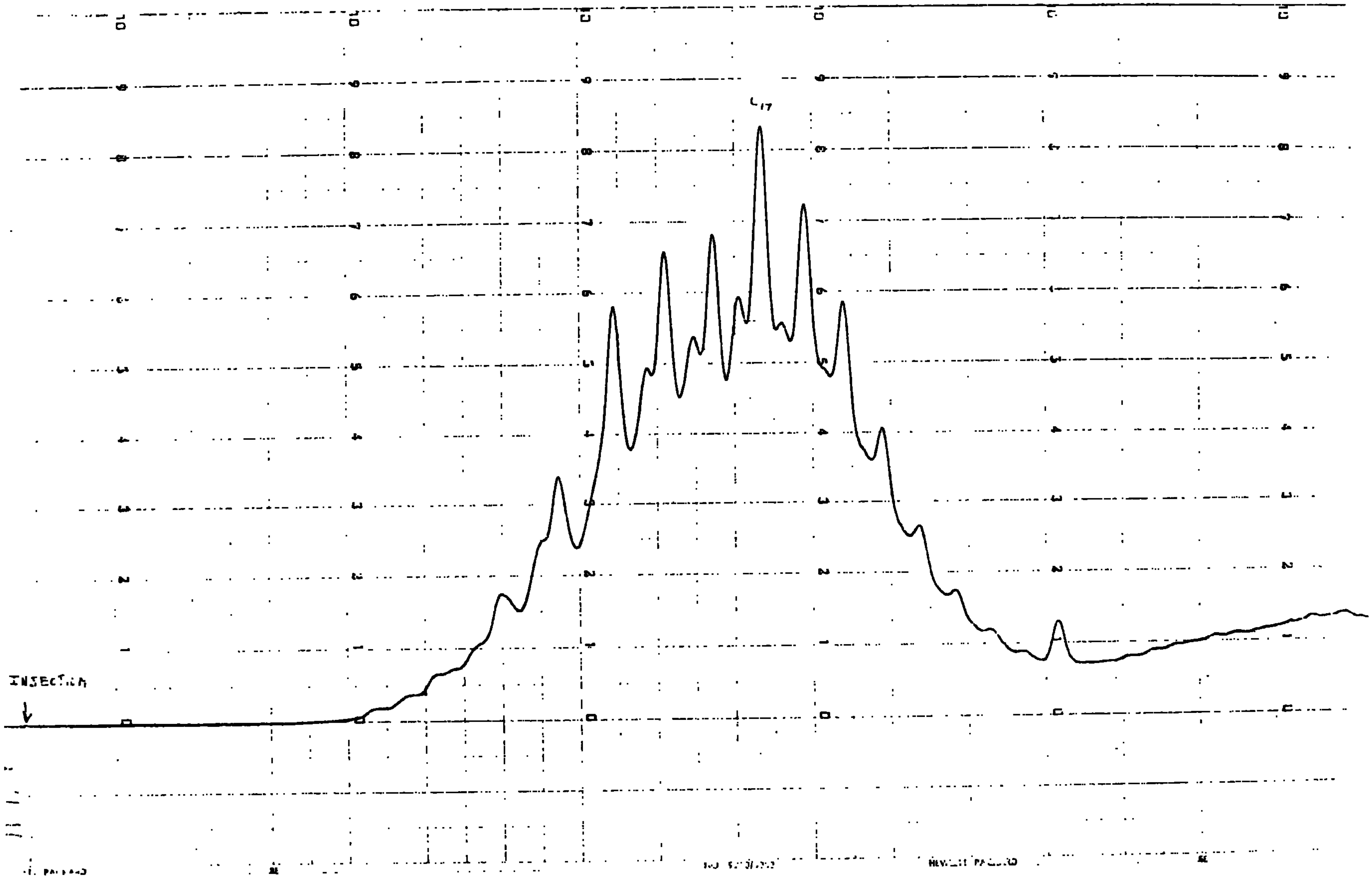

FIGURE 6.1 - Chromatogram of oily component of bilge water ~~from~~ CFAV Quest. The distribution of hydrocarbons and the lack of volatile material after the injection point, indicates that the oily component is a distillate fuel oil.

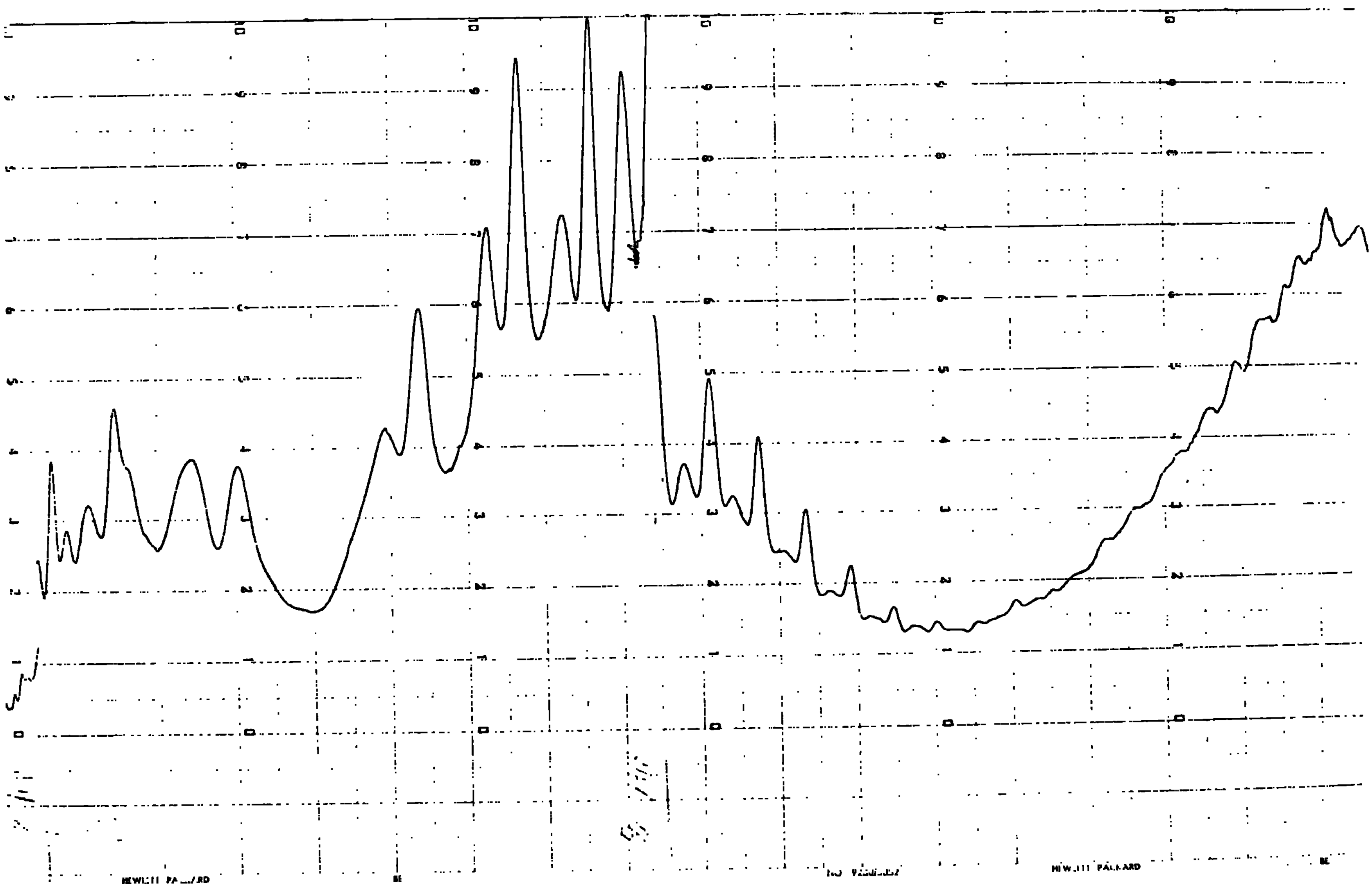

FIGURE 6.2 - Chromatogram of oily component of bilge water from the tanker CFAV Dundalk. The distribution of hydrocarbons, and the presence of involatile material (on the right of the chromatogram) indicates a residual fuel oil.

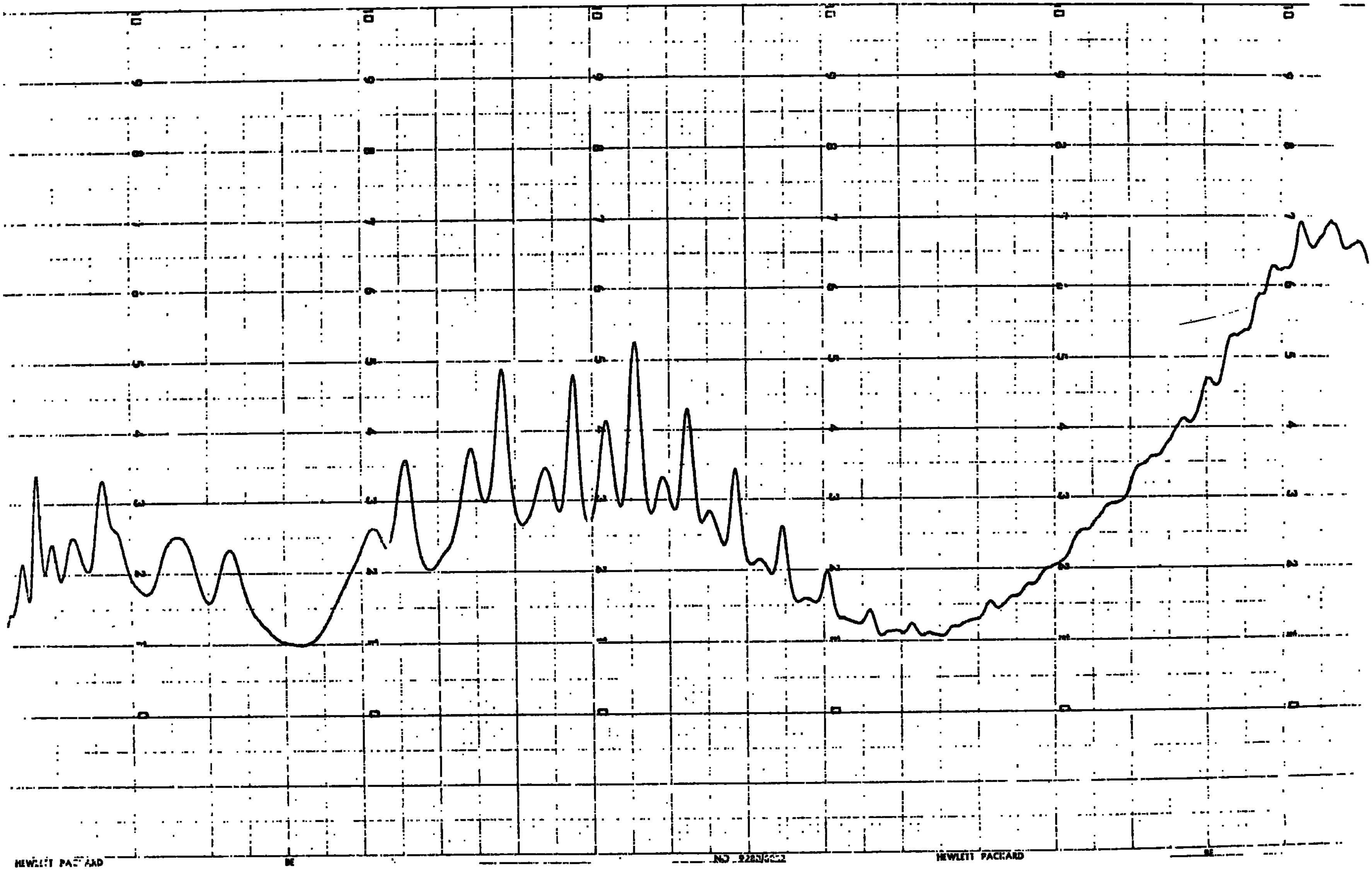

FIGURE 6.3 - Chromatogram of oily component of bilge water from yard craft YFP23. The broad distribution of hydrocarbons indicates that the oily component is mostly residual fuel oil.

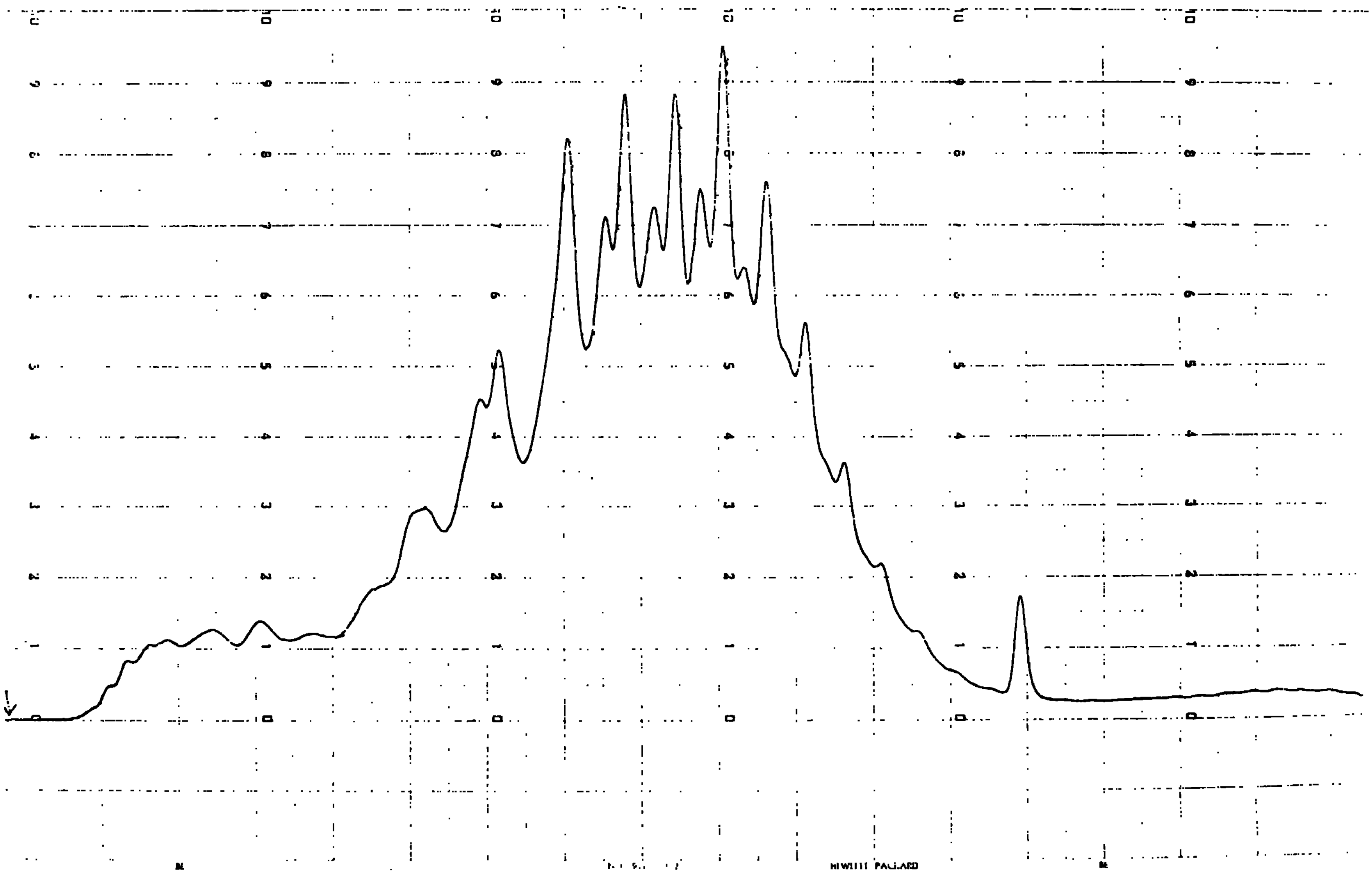

FIGURE 6.4 - Chromatogram of oily component of bilge water from CFAV Bluethroat. The narrow distribution of hydrocarbons and the lack of high boiling material indicates that the oily component is distillate fuel oil.

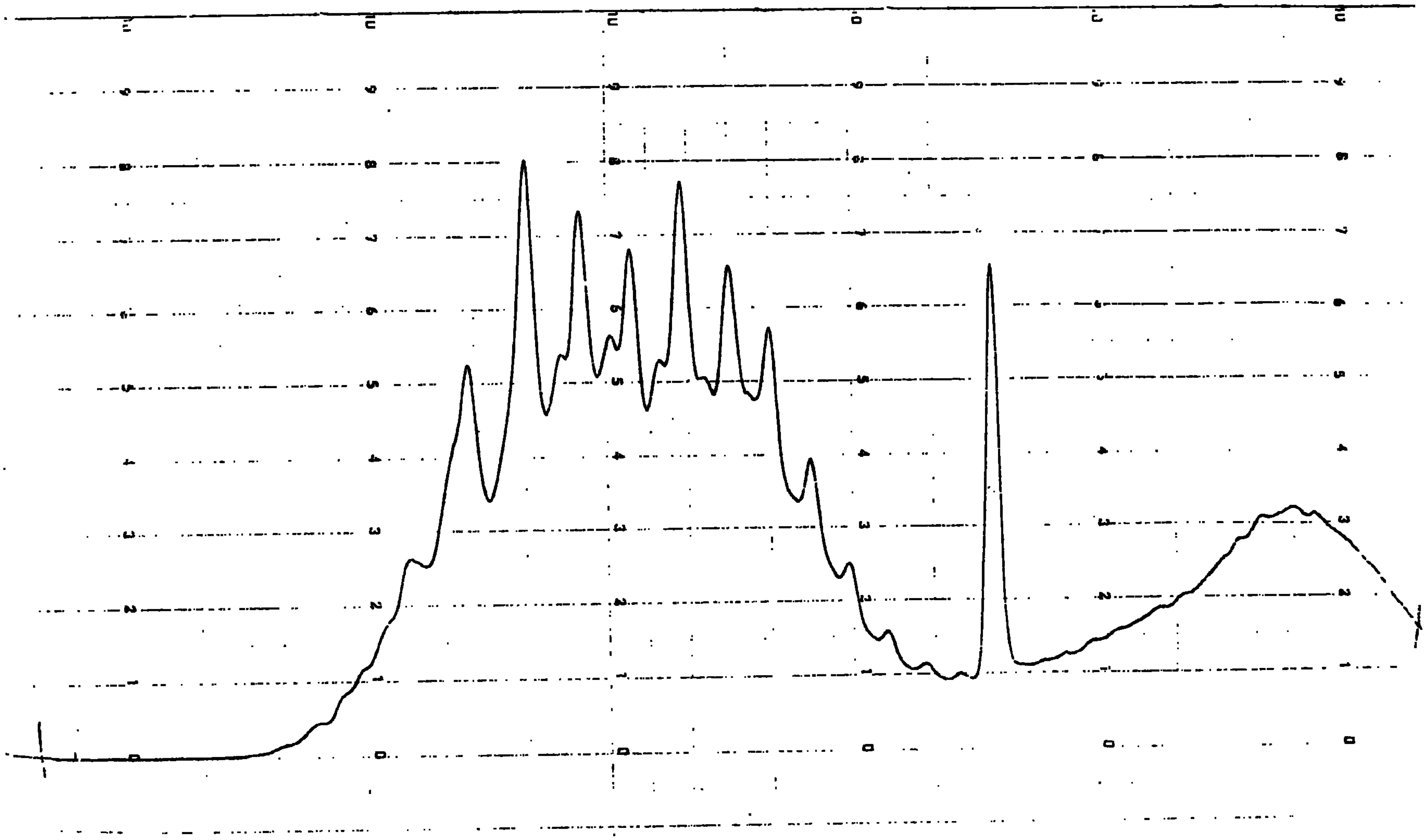

FIGURE 6.5 - Chromatogram of oily component of bilge water from HMCS Saguenay. The distribution of hydrocarbon suggests that distillate fuel is the main component but the presence of high boiling material (on the right of the chromatogram) indicates that lubricating oil may also be present.

The results of this study indicate that the oily component of bilge water is remarkably homogeneous and could be easily "synthesised" for use in testing the polyurethane filters. Also since residual fuel oils (and crude oils) contain all the components likely to be in bilge water, then a medium effective in removing residual fuel oil (and crude oil) from water will also be effective in cleaning bilge water.

7.0 DISPOSAL OF USED FOAMS

Once a foam has reached its capacity to remove oil, disposal would be necessary. Reclamation is not considered to be practical, if in fact possible. Packaging of the used foams in water tight containers such as plastic bags with sealable flaps made especially to accommodate the foam would be required for temporary storage and for transportation to the disposal site.

Incineration would be the most attractive method since the foams would have been used to adsorb some form of petroleum product which would readily support combustion and polyurethane by itself also supports combustion. Information is being developed to determine the products of combustion and to assess the air pollution problems, if any, which would result.

Sanitary landfill would also be a feasible way of disposal. Special attention may be required by the operator of the landfill site if a large quantity of foams were disposed of at once but otherwise there would be no problems arising from this method of disposal.

8.0 BALANCE OF PROGRAMME

The following brief outline describes work being carried out during the preparation of this report and intended to be carried out during the balance of the contract period.

8.1 LABORATORY WORK

In addition to the results herein reported mass transfer trials will be conducted using crude oil and phenols. Data on foam capacity will also be reported. Both the bench scale and larger scale filters will be used. This programme will be concluded by March 1, 1972.

8.2 FINAL REPORT

The final report will contain an editing together of all data presented in the two interim reports along with new data resulting from the work described above.

A final analysis and recommendations for implementation of some projects will be made.

At this time, however, the construction of a prototype for the pumping of ship's bilge could be considered. If such a filter was constructed in such a position that various ships could "come along side" and pump their bilges through it then samples could be taken at this "ultimate scale-up" and assessed over the period of say one year.

This programme extension might best be considered at this time as the laboratory procedures are set up to do the analysis.

APPENDIX A

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

SMALL SCALE APPARATUS

TABLE A-1

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec. 2, 1971 FOAM 1329 BED DEPTH 4 in. + gasket ring

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OIL CONCENTRATION (ppm) OUTLET
0	17.0	13	-	-	-
5	-	13	-	18.4	0.38
9	-	13	-	47.0	0.54
13	13.0	13	-	14.2	0.64
17	-	13	-	16.4	0.66
21	-	13	-	12.6	0.90
25	9.0	13	-	20.0	0.70
29	-	13	-	11.0	0.78
33	-	13	-	45.0	0 (blank)
60	-	13	-	39.0	1.00
90	7.0	13	-	30.0	1.88
				25.4 Av.	0.83 Av.
				13.8 SD	96.73% Removal

TABLE A-2

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 30, 1971 FOAM 1329 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	26.0	13	6	-	-
4	-	13	-	8.2	0.90
8	-	13	-	12.0	1.10
12	22.0	13	5	8.2	0.84
16	17.0	13	-	21.0	1.16
20	-	13	-	12.6	1.52
25	-	13	-	16.8	0 (blank)
29	-	13	-	50.0	1.78
33	-	13	-	33.6	1.90
60	13.0	13	4	24.0	3.04
99	10.0	13	-	25.2	3.04
129	-	13	-	8.8	3.04
				20.0 Av. 13.5 SD	1.83 Av. 90.85% Removal

TABLE A-3

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 18, 1971 FOAM 1528 BED DEPTH 8 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	30	13	6	-	-
5	-	13	-	105	2.68
9	-	13	-	428	1.32
13	22	13	5	288	0.72
17	-	13	-	53	0.48
21	-	13	-	174	0.48
25	17	13	-	116	0.68
29	13	13	4	136	0.40
33	-	13	-	42	0.39
65	-	13	-	680	0.76
				224.7 Av	0.88 Av
				210 S.D.	99.60% Removal

TABLE A-4

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 22, 1971 FOAM 1528 BED DEPTH 8 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	60.0	13	8	-	-
2	-	13	-	51	1.32
6	52.0	13	7	82	1.48
10	43.0	13	6	82	1.42
14	39.0	13	5	142	2.46
18	35.0	13	4	110	3.60
22	30.0	13	4	100	2.96
26	26.0	13	3.5	110	3.16
30	-	13	-	148	1.42
60	22.0	13	-	162	2.96
				109.7 Av.	2.31 Av
				36 S.D.	97.9% Removal

TABLE A-5

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 22, 1971 FOAM 1528 BED DEPTH 10 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	52.0	11	10	-	-
2	-	11	-	80	1.20
6	43.0	11	7	148	1.68
10	35.0	11	5	190	2.00
14	26.0	11	-	368	2.26
18	22.0	11	-	368	2.68
22	17.0	11	4 1/2	368	1.84
26	17.0	11	-	94	1.26
30	13.0	11	-	216	2.26
60	9.0	11	4	184	1.20
				224 Av	1.82 Av
				116 S.D.	99.19% Removal

TABLE A-6

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 5, 1971 FOAM 1835 BED DEPTH 4 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	69	9	-	-	-
4	-	-	-	26.8	2.24
8	-	-	-	15.8	1.68
12	-	-	-	22.4	2.04
16	-	-	-	25.8	1.68
20	-	-	-	37.6	1.10
24	43	24	-	26.8	1.12
				25.9 Av.	1.64 Av.
				7.2 S.D.	93.8% Removal

TABLE A-7

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 15, 1971 FOAM 1835 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OIL CONCENTRATION (ppm) OUTLET
0	35	12	-	-	-
4	-	-	-	18.4	1.16
8	-	-	-	268	2.14
12	22	22	3	316	1.26
18	-	-	-	41.2	0.90
22	-	-	-	400.	0.71
26	-	-	-	152	0.68
30	17	-	-	70.	0.68
36	13	25	-	452	0.92
				235.4 Av.	1.06 Av.
				149. S.D.	99.54% Removal

TABLE A-3

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 29, 1971 FOAM 1835 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	30.0	13	-	-	-
4	-	13	-	50.0	2.58
8	-	13	-	13.6	1.58
12	17.0	13	-	24.2	1.46
16	-	13	-	20.0	0 (blank)
20	-	13	-	12.6	0.90
24	-	13	-	14.2	0.88
28	-	13	-	13.2	0.84
32	-	13	-	6.8	0.94
62	17.0	13	-	10.2	0.94
92	-	13	-	7.4	1.26
				17.2 Av 12.4 SD	1.26 Av 92.67% Removal

TABLE A-9

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec. 1, 1971 FOAM 1835 BED DEPTH 2 in. + approx. 14 in. chunks

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	35.0	13	-	-	-
5	-	13	-	7.4	0.48
9	-	13	-	7.4	0.48
13	-	13	-	10.0	0.22
17	-	13	-	12.6	0.28
21	-	13	-	13.4	0.24
25	-	13	-	7.4	0.26
29	-	13	-	5.8	0 (blank)
33	-	13	-	3.8	0.18
65	30.0	13	-	2.6	0.29
95	30.0	13	-	4.8	0.26
				7.5 Av.	0.30 Av
				3.6 SD	96.00% Removal

TABLE A-10

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec. 6, 1971 FOAM 1835 BED DEPTH 4 in. + approx. 14-in. chunks

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	35.0	13	4	-	-
4	-	13	-	5.5	0.78
8	30.0	13	-	11.6	0.56
12	-	13	-	14.4	0.44
16	-	13	-	13.4	0.58
20	-	13	-	6.6	0.60
24	26.0	13	-	11.6	0.30
28	-	13	-	13.0	0 (blank)
32	-	13	-	11.6	0.62
60	-	13	-	11.4	1.48
90	22.0	13	3 1/2	16.0	2.22
120	-	13	-	11.4	2.56
				11.5 Av. 3.1 SD	1.01 Av. 91.22 % Removal

TABLE A-11

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec. 7/71 FOAM 1835 BED DEPTH 4 in. + chunks

TIME (min)	FLOW/AREA (gpm/ft^2)	HEAD (in)	FILTER THICKNESS AFTER COMPACTION (in)	OIL CONCENTRATION (ppm)		
				INLET	OUTLET	BETWEEN FOAM DISC & CHUNKS
0	52.	13	4	-	-	-
4				12.0	1.10	-
8				12.6	0.90	8.0
16				11.6	0.62	-
24	43.			13.4	0.72	6.2
34				13.2	0.72	-
44	39.			13.2	0.66	4.3
60	35.			7.4	0.64	-
90	30.			16.4	0.82	16.2
				12.5 AV	0.77 Av	8.7
				2.5 SD	93.8% Removal	30.4% Removal

TABLE A-12

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec.10/71 FOAM 1835 BED DEPTH 4 in. + chunks

TIME (min)	FLOW/AREA (gpm/ft^2)	HEAD (in)	FILTER THICKNESS AFTER COMPACTION (in)	OIL CONCENTRATION (ppm) INLET	OUTLET	BETWEEN FOAM DISC & CHUNKS
0	-	13	4	-	-	-
3	35.			20.0	0.96	-
7				8.0	0.52	5.1
13				13.6	0.28	-
21	30.			13.2	0.40	4.8
29				19.0	0.52	-
39	26.			10.6	0.60	5.3
49				14.2	0 (blank)	-
60				12.2	0.76	5.6
90				10.6	1.10	-
120	22.			10.2	1.44	6.7
150				15.2	1.52	-
180	22.			12.6	1.58	4.5
				13.3 Av	0.88 Av.	5.3 Av.
					93.4% Removal	60.2% Removal

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec. 17/71 FOAM 1835 BED DEPTH 4 in. + chunks

TIME (min)	FLOW/AREA (gpm/ft.^{2})	HEAD (in)	FILTER THICKNESS AFTER COMPACTION (in)	OIL CONCENTRATION (ppm) INLET	OUTLET	A	B
0	43.	13	3 1/2	-	-	-	-
4	-			2540.0	-	25.8	-
8	26.			50.0	-	12.0	-
16	13.			-	12.0	13.6	72.0
24	-			154.0	-	5.8	-
34	-			88.0	4.5	4.5	47.0
44	9.			264.0	-	13.2	-
60	-			138.0	7.4	10.0	50.0
90	-			92.0	-	12.0	-
120	7.			184.0	16.8	17.4	50.0
150	-			158.0	-	21.0	-
180	7.			144.0	18.8	24.8	86.0
				381.0	11.9	14.6	Av.61. 84.% Removal

A. - Sample taken from sample point beneath center of bed.

B. - Sample taken between foam disc and chunks.

TABLE A-14

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec. 23/71 FOAM 1835 BED DEPTH 4in. + chunks

TIME (min)	FLOW/AREA (gpm/ft.^{2})	HEAD (in)	FILTER THICKNESS AFTER COMPACTION (in)	OIL CONCENTRATION (ppm)			
				INLET	OUTLET	A	B
0	35.	13	3 1/2	-	-	-	-
4	-			120.0	-	1.74	-
8	-			248.0	1.48	2.48	10.0
16	30.			66.0	-	0.90	-
24	26.			110.0	2.40	0.68	10.0
34	-			13.2	-	0.46	-
44	-			42.0	1.16	0.90	13.2
60	22.			528.0	-	<0.05)blank)	-
90	17.			45.0	1.96	2.00	16.8
120	13.			154.0	-	1.96	-
150	-			96.0	3.08	2.80	36.0
180	9.			168.0	-	3.92	-
				155.0 AV	2.09 98.7% Removal	1.78 98.8% Removal	17.2 88.9% Removal

A. - Sample taken from sample point beneath center of bed.

B. - Sample taken between foam disc and chunks.

TABLE A-15

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 17, 1971 FOAM 2045 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OIL CONCENTRATION (ppm) OUTLET
0	43	13	-	-	-
4	30	13	-	174.	4.28
8	22	13	-	472	3.16
12	-	13	-	110	1.74
16	-	13	-	50	1.58
20	17	13	-	79	1.16
24	-	13	-	146	1.20
28	-	13	-	230	0.22
32	13	13	4 1/2	158	0.72
72	-	13	-	38	0.31
				161.9 Av	1.60 Av
				131.5 S.D.	99.01 % Removal

TABLE A-16

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 5, 1971 FOAM 2335 BED DEPTH 4 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	39	16	-	-	-
4	34	-	-	40.8	1.32
8	30	-	-	16.8	1.74
12	30	23	-	27.2	1.42
16	30	-	-	15.2	1.90
				25.0 Av.	1.60 Av.
				10.2 S.D.	93.5 % Removal

TABLE A-17

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 25, 1971 FOAM 2335 BED DEPTH 4 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm)	
				INLET	OUTLET
0	22.0	13	-	-	-
4	-	13	-	13.6	3.36
8	17.0	13	-	26.8	2.00
12	-	13	-	33.6	1.32
16	13.0	13	-	30.6	1.42
20	-	13	-	-	1.99
24	-	13	-	31.6	0 (blank)
28	-	13	-	41.2	2.04
32	-	13	-	71.0	2.46
60	13.0	13	-	76.0	5.04
				42.8	2.44
				19.8 S.D.	94.30% Removal

TABLE A-18

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 16, 1971 FOAM 2335 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OIL CONCENTRATION (ppm) OUTLET
0	17	15	-	-	-
2	-	21	-	216.	2.84
6	9	-	5 1/2	348	3.16
10	-	-	-	58	2.64
14	-	-	-	252	2.52
18	-	-	-	218.8	2.67
22	-	-	-	56	2.32
26	-	-	-	107	0.58
32	-	-	-	2.56	3.04
57	-	-	-	-	2.92
65	-	-	-	27.8	6.30
				171.2 AV. 112.0 SD	2.85 AV 98.33% Removal

TABLE A-19

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 26, 1971 FOAM 3337F BED DEPTH 4 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OIL CONCENTRATION (ppm) OUTLET
0	17.0	13	4	-	-
2	-	13	-	12.0	1.52
6	-	13	-	26.2	0.92
10	13.0	13	3	23.6	0 (blank)
14	9.0	13	-	27.0	1.18
18	-	13	-	33.6	1.14
22	-	13	-	26.2	1.18
26	-	13	-	26.8	1.34
30	9.0	13	-	33.8	1.62
60	7.0	13	-	40.4	4.16
90	7.0	13	-	46.0	4.16
				29.6 Av	1.91 Av
				9.45 SD	93.55 % Removal

TABLE A-20

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Nov. 19, 1971 FOAM 3865F BED DEPTH 4 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	30	13	4	-	-
6	-	13	-	120	1.90
10	26	13	-	60	1.26
14	22	13	-	178	1.20
18	17	13	3 1/2	470	0.75
22	-	13	-	116	1.16
26	-	13	-	242	0.50
30	-	13	-	158	1.62
34	13	13	-	210	1.58
63	9.0	13	-	70	0.96
				180.4Av	1.21 Av
				124 S.D.	99.93% Removal

TABLE A-21

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE Dec. 15, 1971 FOAM 3865F BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft.^{2})	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	26.0	13	-	-	-
4	13.0		5 1/2	95.0	1.88
8	-			24.2	2.30
16	-			23.2	2.40
24	-			23.8	2.52
34	-			20.0	2.54
44	-			24.2	4.20
60	9.0			24.8	4.20
90	-			22.6	4.20
120	-			25.8	4.84
144	-			21.6	4.20
180	9.0			18.6	4.40
				29.4 Av.	3.43 Av. 88.3% Removal

APPENDIX B

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

SMALL SCALE APPARATUS

TABLE B-1

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Feb. 8, 1972 FOAM 1130 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	9	13	4 1/4	-	-
4	-	-		160.0	5.4
8	-	-		150.0	5.4
16	-	-		108.0	14.2
24	-	-		120.0	21.6
34	-	-		126.0	33.6
44	-	-		203.0	54.0
60	9	-		136.0	49.6
90	-	-		71.0	10.0
120	-	-		102.0	17.6
150	-	-		145.0	19.6
180	9	-		154.0	21.2
				134.1 Av.	22.9 Av. 82.9% Removal

TABLE B-2

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Jan.21/72 FOAM 1329 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	39.	13	6	-	-
4	-			39.5	10.0
12	22.			75.0	20.0
30	-			61.6	26.4
60	17.			87.5	24.6
90	-			190.0	14.2
120	17.			108.0	12.4
				103.6 Av.	17.9 Av. 80.9% Removal

TABLE B-3

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Feb. 7/72 **FOAM** 1329 **BED DEPTH** 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm)	
				INLET	OUTLET
0	26.	13	5 1/2	-	-
4	-	-		80.0	11.0
8	-	-		70.0	20.6
16	17.	-		100.0	24.0
24	-	-		116.0	28.0
34	13.	-		95.0	26.4
44	-	-		89.0	24.0
60	-	-		100.0	24.0
90	-	-		120.0	22.4
120	-	-		75.0	19.0
150	-	-		50.0	13.6
180	13.	-		88.0	16.8
				89.4 Av.	20.4 Av.
					76.6% Removal

TABLE B-4

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Jan. 13/72 FOAM 1528 BED DEPTH 4 in. + chunks

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	39.	13	4	-	-
4	39.	-		148.0	29.6
8	39.	-		58.0	28.8
16	39.	-		48.0	27.8
24	34.	-		50.0	31.0
34	-	-		70.0	28.8
44	-	-		55.0	23.2
60	-	-		63.0	19.2
90	-	-		50.0	14.4
120	34.	-		35.0	15.2
150	-	-		48.0	18.0
180	34.	-		30.0	18.0
				59.6 Av.	23.1 Av. 61.2% Removal

TABLE B-5

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Jan.24/72 **FOAM** 1528 **BED DEPTH** 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm)	
				INLET	OUTLET
0	52.	13	6	-	-
4	-	-		77.5	28.0
8	-	-		92.0	36.0
16	35.	-		67.0	40.0
24	-	-		71.0	34.2
34	-	-		92.0	32.8
44	-	-		48.0	26.8
60	-	-		55.0	22.0
90	-	-		33.0	16.4
120	-	-		31.5	11.0
150	-	-		21.5	9.0
180	35.	-		19.0	8.0
				55.2 Av.	24.0 Av.
					56.5% Removal

TABLE B-6

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Feb. 2/72 FOAM 1528 BED DEPTH 12 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	34.	13	12	-	-
4	-	-		24.0	10.0
8	-	-		28.4	14.8
16	-	-		26.0	15.2
24	-	-		34.2	19.0
34	-	-		26.0	14.2
44	-	-		28.4	13.6
60	-	-		27.2	13.8
90	34.	-		20.0	11.0
120	-	-		26.0	11.0
150	-	-		18.4	10.0
180	34.	-		27.0	16.0
				26.0 Av.	13.5 Av.
					48.1% Removal

TABLE B-7

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Jan. 19/72 **FOAM** 1835 **BED DEPTH** 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	52.	13	6	-	-
4	-	-		54.0	20.8
8	-	-		52.0	25.6
16	39.	-		52.0	25.6
24	-	-		43.0	28.0
34	-	-		60.0	24.0
60	30.	-		60.0	15.8
90	-	-		19.0	16.4
120	-	-		71.5	11.0
150	-	-		13.0	7.6
180	30.	-		17.5	8.6
				44.2 Av.	13.8 Av. 58.6% Removal

TABLE B-8

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Jan.27/72 **FOAM** 1835 **BED DEPTH** 8 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	52.	13	8	-	-
4	-	-		50.0	15.0
8	-	-		55.0	22.5
16	-	-		55.0	25.0
24	35.	-		40.0	22.5
34	-	-		59.0	22.5
44	-	-		57.0	27.5
60	-	-		43.0	29.5
90	-	-		40.0	24.5
120	-	-		49.0	24.5
150	-	-		33.0	24.5
180	35.	-		30.0	24.5
				46.5 Av.	23.9 Av. 48.6% Removal

TABLE B-9

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Feb. 10/72 FOAM 2045 BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	69.	13	5 1/2	-	-
4	52.	-		33.5	8.2
8	-	-		25.0	13.4
16	39.	-		39.6	16.4
24	-	-		30.5	17.4
34	-	-		24.0	13.4
44	-	-		33.5	14.6
60	-	-		19.8	12.0
90	-	-		39.5	11.0
120	-	-		21.2	11.0
150	-	-		31.6	8.6
180	26.	-		72.8	8.4
				33.7 Av.	12.2 Av. 63.8% Removal

TABLE B-10

EXPERIMENTAL DATA FOR MARINE DIESEL ADSORPTION

DATE Jan.25/72 FOAM 3337F BED DEPTH 6 in.

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	FILTER THICKNESS AFTER COMPACTION (in.)	DIESEL CONCENTRATION (ppm) INLET	OUTLET
0	9	13	6	-	-
4	-	-		100.0	10.0
8	-	-		68.0	13.4
16	-	-		79.0	11.0
24	4	-		59.0	21.6
34	-	-		172.0	23.2
44	-	-		135.0	48.0
60	-	-		140.0	60.8
90	-	-		168.0	91.0
120	3	-		176.0	100.0
				121.9 Av.	42.1 Av.
					65.5% Removal

APPENDIX C

EXPERIMENTAL DATA FOR
BUNKER C OIL ADSORPTION

LARGE SCALE APPARATUS

TABLE C-1

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE January 19, 1972 FOAM 1835 BED DEPTH 4 in.

TEMP. 2°C. FILTER AREA 2.8 ft.^{2} SALT WATER

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	OIL CONCENTRATION (ppm)	
			INLET	OUTLET
0	36.	13.	-	-
10	32.	11	590.	< 0.01
25	32.	11	965.	< 0.01
40	27.	9	132.	< 0.01
55	27.	9	200.	< 0.01
70	27.	11	99.	< 0.01
90	27.	11	610.	0.045
			Av. 432.7	0.01 Av. 99.99% Removal

TABLE C-2

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE January 20, 1972 FOAM 1835 BED DEPTH 4 in.

TEMP. 2°C. FILTER AREA 2.8 ft.^{2} SALT WATER

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	OIL CONCENTRATION (ppm)	
			INLET	OUTLET
0	20.	7	-	-
15	20.	7	11.2	< 0.01
45	20.	7	105.	< 0.01
75	20.	7	145.	< 0.01
105	20.	7	195.	< 0.01
135	20.	7	92.5	< 0.01
			Av. 109.7	< 0.01 Av. 99.99% Removal

TABLE C-3

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE January 25, 1972 FOAM 1835 BED DEPTH 4 in.

TEMP. 2°C. FILTER AREA 2.8 ft.^{2} SALT WATER

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	OIL CONCENTRATION (ppm)	
			INLET	OUTLET
0	18.	6.	-	-
15	18.	6.	536.	< 0.01
30	18.	6.	308.	0.02
			Av. 422.	0.01 Av. 99.99% Removal

TABLE C-4

EXPERIMENTAL DATA FOR BUNKER C OIL ADSORPTION

DATE January 31, 1972 FOAM 1835 BED DEPTH 4 in.

TEMP. 2°C. FILTER AREA 2.8 ft.^{2} SALT WATER

TIME (min.)	FLOW/AREA (gpm/ft^2)	HEAD (in.)	OIL CONCENTRATION (ppm) INLET	OUTLET
0	4.	1.	68.0	0
15	4.	1.	156.0	0.16
45	4.	1.	84.0	0.18
75	4.	1.5	368.0	0.18
105	4.	2.	132.0	0.22
135	4.	2.	148.0	0.20
			Av.159.3	0.16 Av. 99.89% Removal