HYDRAULICS RESEARCH DIVISION

Technical Note

DATE: 15 May, 1977

REPORT NO: 77-4

(STUDY NO. H77 047)

TITLE: Theoretical and Laboratory Study of Recovery of Spilled Oil in Rivers from Cut-Slots on the Ice Cover.

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REASON FOR REPORT: Progress Report No. 1 to Prairie Region Oil Spill Containment and Recovery Advisory Committee.

CORRESPONDENCE FILE NO: - 2242-1 77/78

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I. INTRODUCTION

The Prairie Region Oil Spill Containment and Recovery Advisory Committee (PROSCRAC) is interested in the feasibility of recovering spilled oil under river ice from cut-slots on the ice cover and also the proper ways to recover the oil should such an approach prove feasible. A field exercise was conducted in the spring of 1976. The field exercise revealed that a theoretical guidance and some laboratory testing are necessary for successful future field exercises or a real oil spill countermeasure should such a winter oil spill occur.

PROSCRAC approached the Hydraulics Research Division, Canada Centre for Inland Waters in late November, 1976, for theoretical and laboratory assistance and as a response to the request a research proposal was submitted in the form of a technical note*. A formal request from PROSCRAC was received on February 10, 1977, to conduct the study according to the proposal. This progress report summarizes the progress to date on the study.

* "Oil Recovery from Ice-Covered Rivers", T.M. Dick, G. Tsang and Y.L. Lau, Technical Note, January 8, 1977. Report No. 77-1, Hydraulics Research Division, CCIW.

II. THEORETICAL DEVELOPMENT

Theoretical study of the problem is divided into two parts:

1. How does the spilled oil move under an ice cover, and
2. How does the oil emerge from the cut-slot and what are the best dimensions and geometry of the cut-slots for best oil recovery.

For part 1, we have classified the spilled oil to move under the following three conditions:

A. The spilled oil moves as a continuous slick under the ice cover. (Fig. 1).

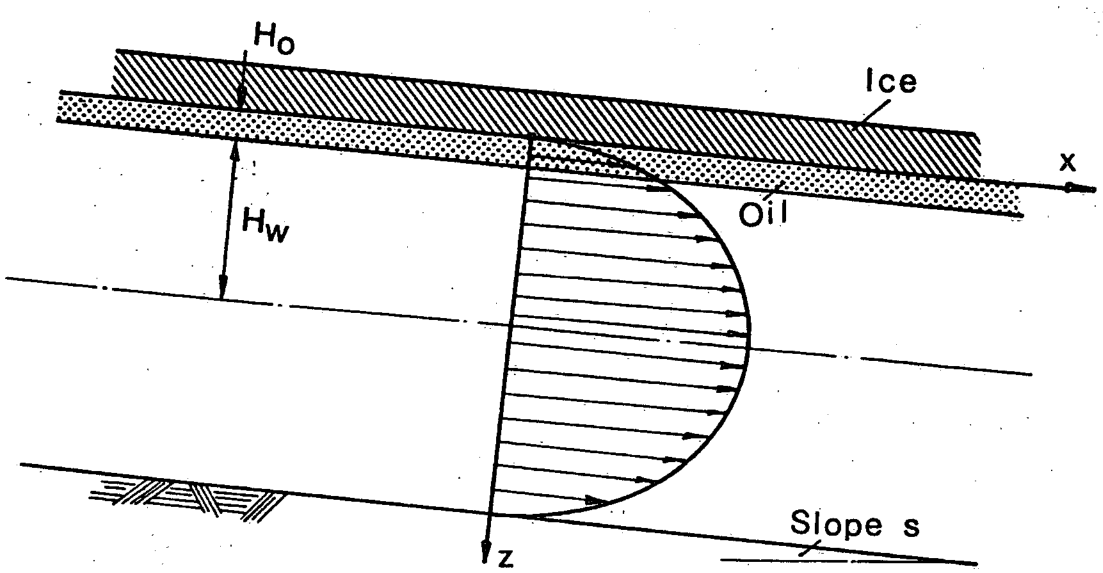

Fig. 1. The movement of a continuous oil slick.

This condition would be satisfied when a large quantity of oil is spilled under an ice cover in a small stream. Theoretical analysis of the problem leads to the following equation for the average velocity of the oil slick ($\overline{V}_o$):

$$\overline{V}_o = \frac{gs\,\rho_w\,H_o\,H_w}{6\,\mu_o}\left(3 + 2\,\frac{\rho_o}{\rho_w}\,\frac{H_o}{H_w}\right) \qquad (1)$$

where g = gravitational acceleration,

s = slope of river or hydraulic gradient of the flow,

ρ_w = density of water,

ρ_o = density of oil,

μ_o = viscosity of oil,

H_o = thickness of oil slick, and

H_w = thickness of the upper layer of the flow measuring from the point of maximum velocity to the undersurface of the oil slick.

In practical situations, the upper water layer thickness H_w would be much greater than the thickness of the oil slick H_o and the above equation is approximately reduced to:

$$\overline{V}_o \doteq \frac{gs\,\rho_w\,H_o\,H_w}{2\,\mu_o} \qquad (2)$$

The above equation states that the velocity of the oil slick is proportional to the channel slope, the thickness of the oil slick, the depth of the flow (since experiences show that H_w increases with depth) and inversely proportional to the viscosity of the oil.

B. The spilled oil moves in large patches under the ice cover. (Fig. 2).

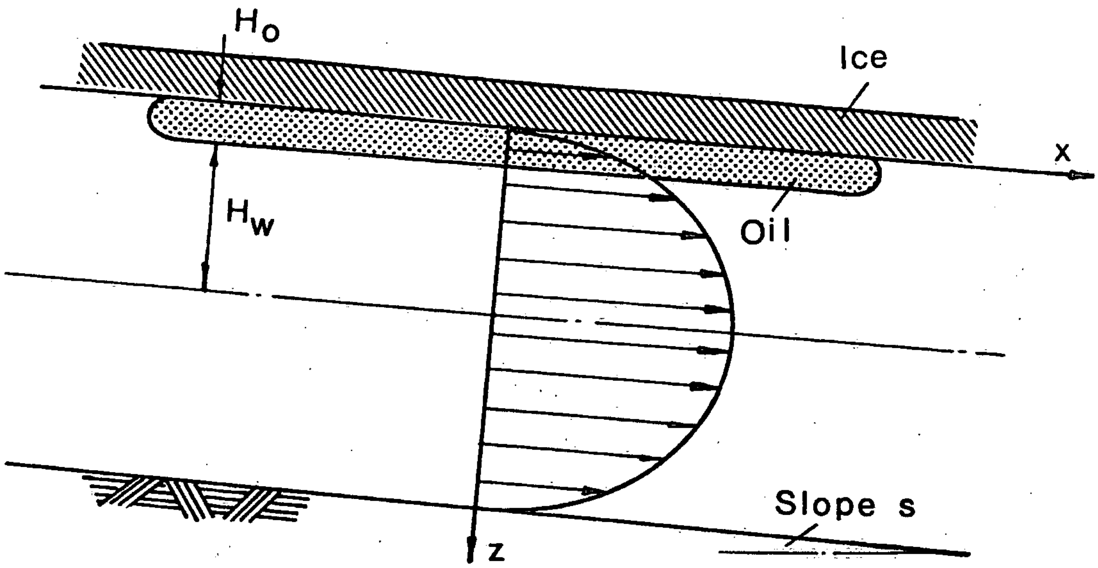

Fig. 2. The movement of a large oil patch.

This condition would be satisfied at the early stage of an oil spill of limited quantity before the oil patches are finely broken up by the flow and dispersed by turbulence. To recover the spilled oil in a river, apparently the recovery site should not be too far away from the spill site. Such oil patches therefore are likely to be encountered at the cut-slots. Since the thickness of the oil patches is small compared to their length, the form drag on the oil patch is neglected in the analysis. Dynamic analysis of the problem leads to the following equation for the average velocity of the oil patches.

$$\bar{V}_o = \frac{gs\ \rho_w\ H_o\ H_w}{6\ \mu_o}\left[3 + 2\ \frac{\rho_o}{\rho_w}\frac{H_o}{H_w} - 2\frac{H_o}{H_w}\right] \qquad (3)$$

which is similar to equation (1) except for the third term in the bracket.

C. The spilled oil moves as oil pockets of finite size under the ice cover. (Fig. 3).

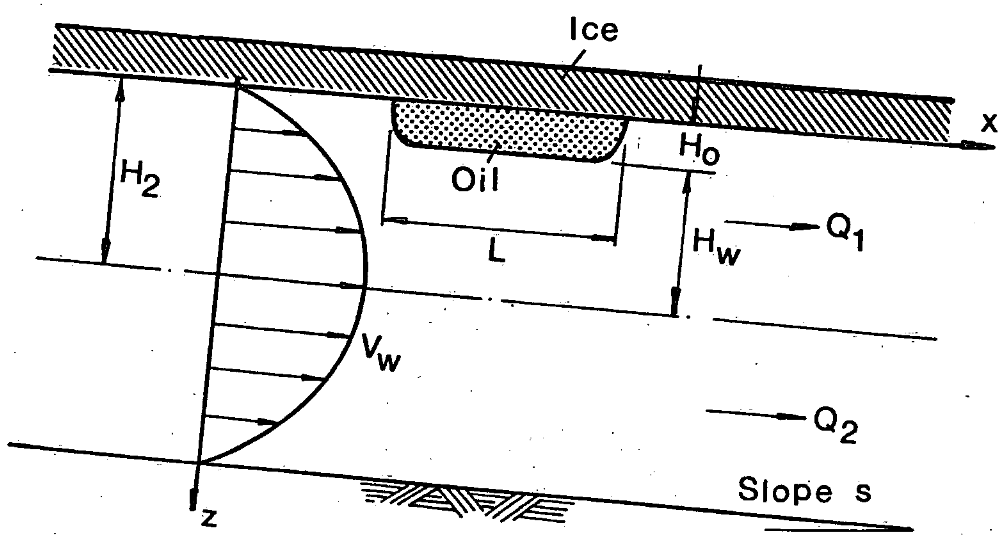

Fig. 3. The movement of an oil pocket of finite size.

This condition will be satisfied at the late stage of an oil spill of limited quantity. At the early stage of an oil spill, part of the oil will be invariably broken up as small oil pockets and these small oil pockets will be falling into the present catagory also. For small oil pockets, the form drag will be an important part of the acting force. Dynamic analysis of the problem leads to the following equations:

For fully turbulent stream flow:

$$\frac{d^2V_o}{dz^2} + CV_o^2 - C\ (2A\ \ell nz + 2B)\ V_o + ABC\ \ell nz$$

$$+ A^2C(\ell nz)^2 + B^2C - D = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

For smooth turbulent flow in the stream:

$$\frac{d^2V_o}{dz^2} + CV_o^2 - 2\ CEV_o z^{1/7} + CE^2 z^{2/7} - D = 0 \quad \ldots\ldots \quad (5)$$

where

$$A = \left[gs\ Hw\ \left(\frac{Ho}{Hw} + 0.5\right)\right]^{\frac{1}{2}} \Big/ 0.4$$

$$B = A\ell n\varepsilon_2 + 8.48$$

$$C = C_D\rho_W/wL\mu_o$$

$$D = (\rho_W - \rho_o)gs/\mu_o$$

$$E = 8Q_2/H_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

with ε_2 being the roughness of the ice cover, C_D being the form drag coefficient, Q_2 being the discharge of the upper layer of the flow (see Fig. 3) and H_2 being the thickness of the upper layer of the flow. The boundary conditions for solving Equations (4) and (5) are:

$$\text{at } z = H_o; \quad \frac{dV_o}{dz} = \mu_o \rho_w gs\, H_w$$

and at $z = \varepsilon_2/30$ (e.g. (4)) or at $z = 0$ (e.g. (5)); $V_o = 0$

The solution of Equations (4) and (5) for the velocity of the oil pocket V_o is possible with the help of a computer and this will be done at the next stage of the project. Knowing the velocity distribution in the oil pocket, the average velocity of an oil pocket moving under ice can be obtained by integration.

At second stage of the project, besides attempting to solve Equations (4) and (5), theoretical pursuit will be made to evaluate H_o, H_w, H_2, Q_2, and ε_2 from open water flow and ice covered flow measurements. These parameters are needed for calculating the velocity of the spilled oil.

Part 2 of the theoretical investigation is to study the emergency of the spilled oil in a cut-slot, the best geometry and dimensions of the slot and the best device to fit into the slot for recovering the oil. Thus far, some preliminary theoretical work has been done on the trajectory of the spilled oil rising in the slot. This trajectory will determine the minimum width of the slot. A detailed analysis will be made to confirm the preliminary findings at the second stage of the project. A skimming weir appears to be a desirable recovery intake to be fitted into the slot. More theoretical and laboratory investigation on the design of the skimming weir will be made.

III. LABORATORY INVESTIGATIONS

The main laboratory investigations are planned to be conducted in the recirculating flume (0.6 m wide x 0.5 m deep x 11 m long) located in a large cold room (Cold Room A) at CCIW. The flume was available from May 7, 1977 and presently preparation on the flume is being made.

Preliminary laboratory tests

To guide later experiments in the large recirculating flume, a small recirculating flume measuring 27 cm wide x 35 cm deep x 300 cm long (see Fig. 4) was constructed and installed in a small cold room (Cold Room 2B) for conducting preliminary experiments. A crude oil available at hand (Norman Wells crude oil, sp. gr. 0.83 and viscosity 6.5 c.p. at 15^{o}C) was used for the tests. The experiments were conducted at an ambient temperature of -10^{o}C and with an ice cover of about 3 cm thick. 500 ml of oil was injected from the bottom of the flume by way of a nozzle (Fig. 5). The flow of water was then started, the oil behaviour was observed and the oil movement was recorded.

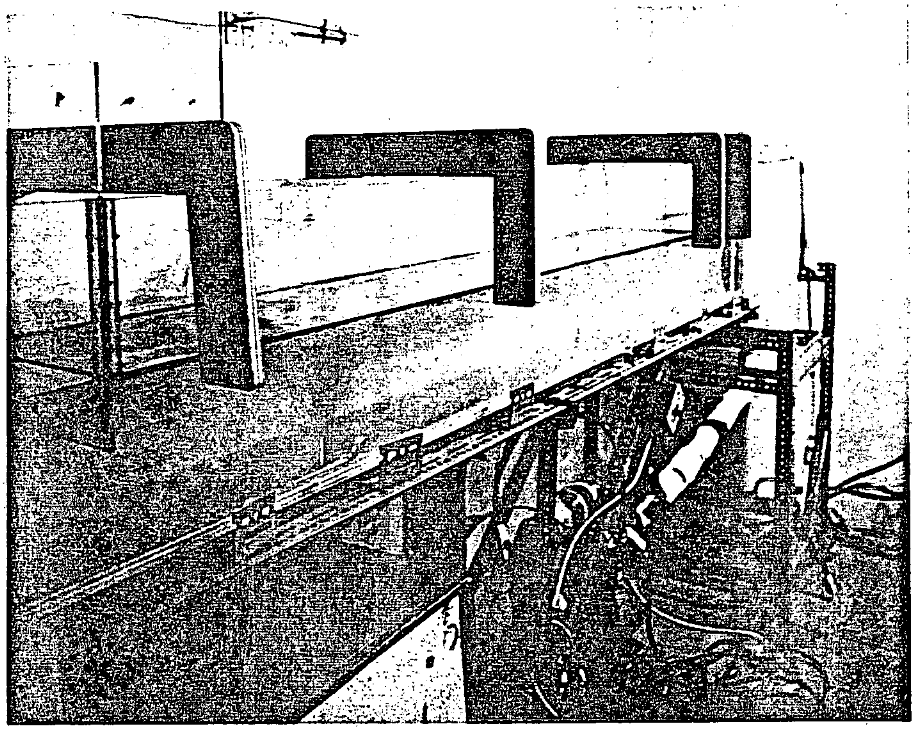

Figure 4 Photograph of the flume used for preliminary tests

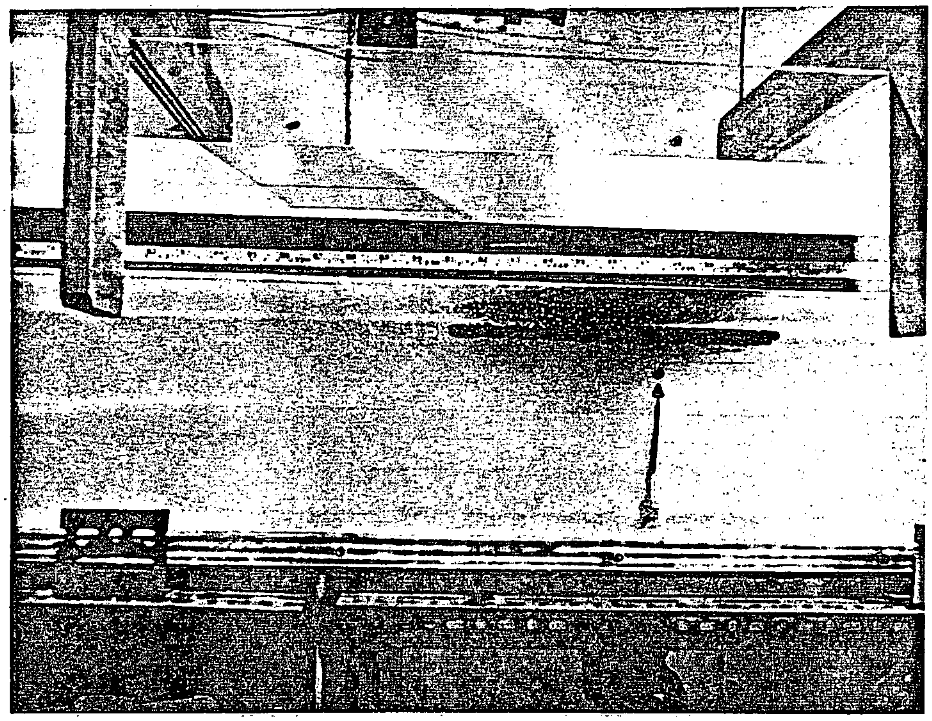

Figure 5 Oil rising to the underside ice surface

The water velocity was measured by a current meter while the oil velocity was determined by timing the travel of the oil front for a given distance. Results of the tests which may be used to guide future experimental planning are summarized as follows:

(1) The oil slick formed under the ice is rather irregular and sometime is actually nothing but a collection of oil drops (Figure 6).

(2) If the ice cover is not uniform in thickness, the oil tends to accumulate under the thinner ice, i.e. it tends to float to a higher place.

(3) The velocity of oil moving under an ice cover is extremely slow, amounting only to about 4% of the water velocity measured at the centre of the flow. (Figure 7 is a photograph of a moving slick under the ice cover).

(4) The oil shows no sign of adhering to the underside of the ice if the ice surface is relatively smooth.

(5) If temperature of the flow water is higher than $5^{O}C$, melting of the ice is appreciable, thus roughening the underside ice surface, creating small pockets and as a result, trapping some of the oil.

(6) When oil flows under ice and reaches an open water, it rises quickly to the top of the water and may be easily collected by a gate placed downstream; this demonstrates the feasibility of recovering spilled oil from slots cut in the ice.

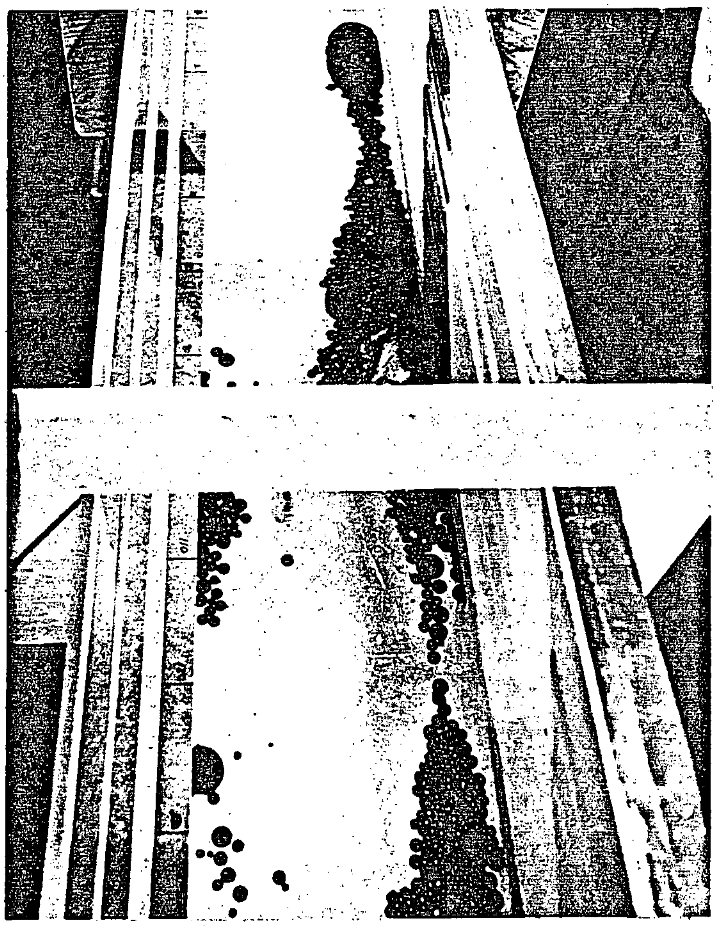

Figure 6 Oil slick under ice before water in motion (top view)

(The oil globules form a slick as water begins to flow).

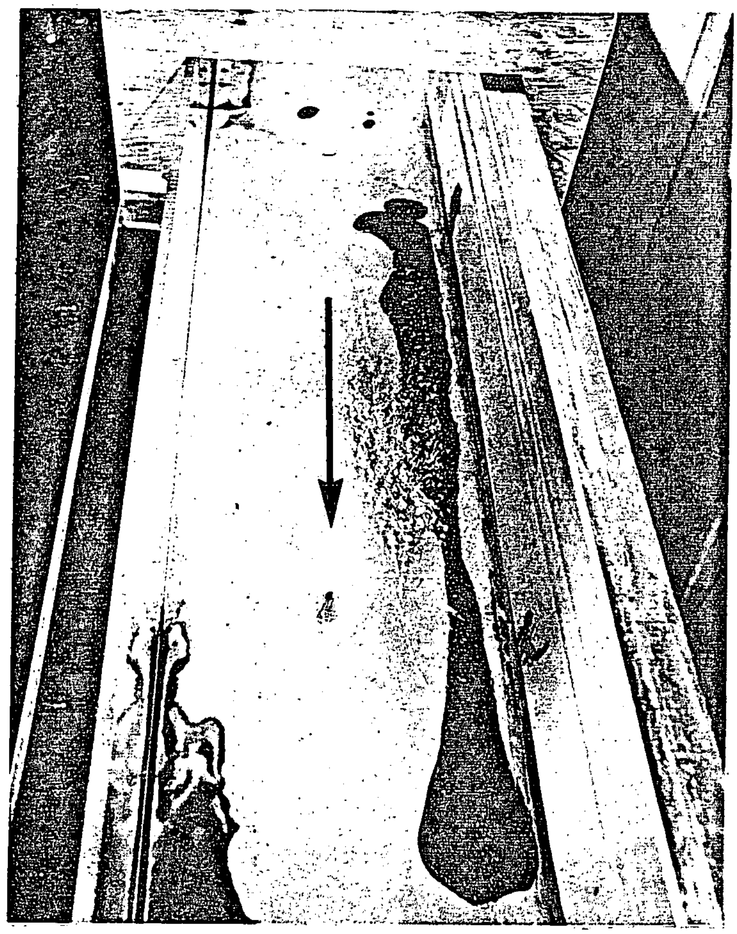

Figure 7 Oil flowing under ice cover (top view)

Main experiment planning and preparations

The following tasks for successfully conducting experiments in the large flume have been identified and are presently being taken care of:

(1) The design, construction and installation of an oil releasing device. This device is to ensure that an oil slick of uniform thickness and front will be reproducible.

(2) The design, construction and installation of a protective cushion guard to protect the flume. This cushion guard is to be placed on the walls of the flume to absorb the pressure generated with the formation of ice and the accompanying volume expansion. The cushion guard should not unduly affect the uniformity of the ice cover.

(3) The development of a technique for maintaining a low temperature of the recirculating water. This technique is to ensure that the recirculating water will be at all times close to $0^{o}C$ so no melting or erosion of the ice cover will take place.

(4) The development of a slotting technique. This is for a quick and easy way to provide slots with a desirable geometry on the ice cover.

(5) Roughening of the flume bottom. To reduce the wall effects; the bottom effect should be amplified by roughening up the bottom of the flume.

(6) The design, construction and installation of an oil recovering device. This device is for recovering the oil at the end of the flume to avoid the trapping of the oil in the recirculation system.

A request for five different types of oil sample, two barrels each, was made to Imperial Oil Ltd. (see appendix). The main experiments are scheduled for the first week of June 1977, upon receiving the oil samples.

IV. FINANCIAL STATEMENT

A sum of $17,000.00 was assigned to the CCIW account for conducting the project. Although the project officially started on February 15, 1977, the date of receiving the authorization letter from PROSCRAC, the above account was not allocated until April 1, 1977. The expenses incurred prior to April 1, 1977, both for actual project expenditures and for project development expenditures will be absorbed by Hydraulics Research Division and are not reflected in the following statement:

Financial statement as of May 15, 1977

Allotment:	$ 17,000.00
Expenditure:	
1. Casual labour:	
spent	$ 1,032.10
committed (est.)	$ 1,056.00
2. Material and supplies:	
spent	$ 1,810.60
committed (est.)	$ 300.00
Balance:	$ 12,801.29

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Appendix 5325-4

April 22, 1977

Mr. Erwin Birchard
Environmental Protection Department
Biological Advisor
Imperial Oil Ltd.
111 St. Clair Avenue, West
Toronto, Ontario M5W 1K3

Dear Mr. Birchard:

Re: <u>Oil Recovery from Cut Slots on Ice</u>

Following our telephone conversation this morning, I am writing to confirm that for conducting the study of oil recovery from cut slots on an ice cover, we would like to have two barrels each of the following five types of oil:

a. Swanson crude,
b. A heavier crude than Swanson,
c. A lighter crude than Swanson
d. Bunker C
e. No. 2 fuel oil

As a brief report of the project, we have constructed a small flume and have conducted some preliminary studies in it to guide later studies in the large flume. Preparation for experiments in the large flume has also been started. At the moment, preparation is confined to the design and construction of the oil recovery device. Preparation of the flume itself is scheduled for the first half of May. Unless major problems arise, we antivipate conducting experiments in the large flume by the end of May. Our preliminary study so far seemed to indicate that oil recovery from cut slots on the ice cover is feasible.

Yours sincerely,

G. Tsang
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