PROCEEDINGS OF ALBERTA OIL SANDS TAILINGS WASTEWATER TREATMENT TECHNOLOGY WORKSHOP

RESEARCH MANAGEMENT DIVISION
Alberta Environment

For information on reports published by the Research Management Division, contact:

Research Management Division
Publications Office
14th Floor, Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta
T5J 3N4

(403) 427-3946

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PROCEEDINGS OF ALBERTA OIL SANDS TAILINGS WASTEWATER TREATMENT TECHNOLOGY WORKSHOP

Held at

Mildred Lake Research Station

Fort McMurray, Alberta

1985 October 29-30

Edited by

Earle G. Baddaloo

RESEARCH MANAGEMENT DIVISION
Alberta Environment

TABLE OF CONTENTS

Continued . . .

TABLE OF CONTENTS (CONCLUDED)

ACKNOWLEDGEMENTS

The success of this workshop would not have been possible without the participation and contribution of many people. Special thanks are due to all who attended the workshop and provided such valuable input through their ideas and discussions; to Syncrude Canada Limited, who provided an in-depth tour of their tailings pond site at Fort McMurray; to the staff of the Mildred Lake Research facility, who laboured to ensure that all workshop participants were very comfortable throughout their stay; and to the members of the organizing committee: Steff Stephansson of CanStar Oil Sands Limited, George Lesko of Syncrude Canada Limited, Ray Orr of Environment Canada, and Brian Hammond of Alberta Environment.

WORKSHOP COMMITTEES

ORGANIZING COMMITTEE

Brian Hammond, Alberta Environment, Research Management Division, 14th Floor, Standard Life Centre, 10405 Jasper Avenue, Edmonton, Alberta T5J 3N4

George Lesko, Syncrude Canada Ltd., Geology and Environment, 10030 - 107 Street, Edmonton, Alberta T5J 3E5

Ray Orr, Environment Canada, Environmental Protection Service, 2nd Floor, Twin Atria Building, 4999 - 98 Avenue, Edmonton, Alberta T6B 2X3

Steff Stephansson, CanStar Oil Sands, Environmental and Regulatory Affairs, 1400 - 140 Fourth Avenue, S.W., Calgary, Alberta T2P 3N4

SESSION MODERATORS

Steff Stephansson
Peter Blackall

SESSION CHAIRMAN

Process and Water Treatment Technology	Dean Wallace
Receiving Waters	Merle Korchinski
Capabilities & Co-operation	Mike McKinnon
Resources	George Lesko

ALBERTA OIL SANDS TAILINGS WASTEWATER TREATMENT TECHNOLOGY WORKSHOP

SECTION I: WORKSHOP SUMMARY

1. INTRODUCTION

Syncrude Canada Limited's Fort McMurray oil sands mining operations has been operating under the concept of zero discharge and total containment of wastewaters since start up in 1978. During this period a considerable volume of contaminated water has been assimulated in a large on-site tailings pond at a substantial costs to the company. This zero discharge philosophy has provided time for a large amount of research to be carried out. Syncrude has requested that Alberta Environment consider controlled (release/reclamation) discharge of treated water as part of the waste control guidelines for the plant; however, as witnessed by recent concerns (i.e., Great Lake Pollution, Edmonton drinking water, etc.), discharge criteria must not only address acute toxicity, but also contaminants that are biologically active in small concentrations over long chronic exposures. This will be necessary for the protection of downstream users (drinking water, sport and commercial fisheries, subsistence fishery, etc.). It is prudent also, that the companies involved should address their major environmental problems while in operation, rather than leaving them for future generations.

In response to the formal request from Syncrude to establish discharge criteria for the treatment and release/reclamation of tailings pond water, a departmental committee was formed within Alberta Environment. Meetings have been held and Syncrude has provided an assessment of the treatability of its pond water in relation to the department's "Wastewater Effluent Guidelines for Alberta Petroleum Refineries" (1976). In addition to industry research, the federal government's Panel on Energy Research and Development (PERD) has been funding various projects. Members of the Wastewater Technology Centre in Burlington have also been invited by Syncrude to participate in these studies.

To assess the status of collective knowledge and to co-operate/co-ordinate/set priorities for future research, a two-day workshop was planned with industry, public, and various governmental departments and agencies. The goals of the workshop were:

1. To enable free exchange of information and ideas among the various invited groups;
2. To identify priority areas of research and to assist in providing a co-operative effort in order to deal with them;

3. To ensure that research carried out by industry, government, agencies, and the public is well directed and co-ordinated; and
4. To initiate the idea of a co-operative effort with regard to research planning and development to use funds (provided jointly or otherwise) in an efficient manner.

The workshop was held on 1985 October 29 and 30 at Mildred Lake Research Station in Fort McMurray, Alberta. It was the first time major issues regarding Alberta oil sands tailings pond had been dealt with by a group comprising industry, federal and provincial governments, agencies, and the public (invited but unable to attend).

2. WORKSHOP PROCESS

The workshop consisted of two sessions. The first session began on the first day (1985 October 29) at approximately 1430 hours. The second session commenced on the second day (1985 October 30) at approximately 0830 hours.

The main themes of the workshop sessions were:

a) Process and Water Treatment Technology (Group I); and

b) Receiving Waters (Group II).

The participants were asked to choose one of the two issues of interest, then to enter their names under the chosen topic. Each "think-tank" (Groups I and II) convened in separate rooms. Each group included a session chairman, a recorder, and individuals from governmental departments, agencies, and industry.

Each group answered the following four questions during the first session:

1. What is needed?
2. Where should we be going?
3. How do we get there?
4. Are there priority areas?

During the second session of the workshop the following tasks were discussed by each group:

1. Review priorities and flesh out;
2. Establish logical order for R & D;
3. Determine timeframe; and
4. Estimate costs.

At the end of the session, both groups convened in the conference room and discussed the following agenda items:

1. Reports from separate groups;
2. Discussion on barriers to co-operation and mechanisms to resolve such barriers; and
3. Future direction for ad-hoc committees.

3. RESULTS

This section represents a summary of the group reports for each of the sessions. The ideas, opinions and recommendations that were developed at the end of the sessions represent a consensus of the groups.

3.1 SESSION ONE

Process and water treatment technology research and information is of prime importance to oil sands development because of the quantity of water utilized by the industry. The identification and establishment of research priorities would prevent duplication and enable applied research to be executed. This type of activity would be beneficial to all involved, and might ultimately eliminate useless expenditures because of duplication and ineffective research activities.

This session of the workshop was developed in order to facilitate the discussion of:

a) Issues in process and water treatment technology
b) Receiving waters

The results of the session are as follows.

3.1.1 Process and Water Treatment Technology (Group I)

The session commenced with process water technology as related to potential changes to the hot water extraction process that could reduce consumption. Two broad areas for discussion were suggested: smaller tailings ponds and thermal recovery.

3.1.1.1 Smaller tailings ponds. The following areas in which research should be focused were identified:

1. Better water management for tailings pond size reduction;
2. Earlier recycling - a sludge treatment program earlier in process leads to early recycling; and
3. Permits.

3.1.1.2 Thermal (heat) recovery. Research areas that should be considered were identified, including:

1. Treatment and re-use of wastewater (current practices utilize re-use only);
2. Treated water used for once-through boiler-feed water for add-on systems; and
3. Alternatives to heated water process (warm water process might lessen steam requirements).

Group I expressed the following concerns with regard to research being carried out on the Session One topics:

1. Research might be better concentrated on treatment instead of on the alteration of extraction conditions;
2. If changes are made to extraction processes, there might be different kinds of effects on wastewater;
3. An alternative to early recycling and reduction of existing pond volume might be accomplished by sludge treatment or possibly compaction. Information is needed about how this is done.
4. More rigidly controlled engineering systems reduce tailings ponds problems;
5. With reference to Gulf RTR, and middling to immediate treatment in order to produce clean water and possibly dry tailings in the heated water process, costs might be greatly increased; and
6. Although the dry tailings might be increased, concerns were expressed about dyke building and maintenance; group members were apprehensive also regarding the true cost of the final resting place (suspected wet tailings cost less than dry).

The group also considered the option of pumping the tailings slurry back to the mine (i.e., slurry tailings going out could be used for hydraulic mining, with excess water being fed back to the plant). Additionally, the group noted that new technological developments would give rise to different environmental concerns, therefore steps must be taken to reduce, minimize, or eliminate potential impacts at planning stages for new technology.

3.1.2 Wastewater Treatment (Group 1)

3.1.2.1 **Recycling.** The group indicated that their first goal in the treatment of wastewater would entail recycling to minimize the use of make-up water. Areas/processes identified for recycling were boilers, digestion, flotation, gland water, cooling towers, utility water, and fire water. For the latter four areas, raw water is currently being used; however, standards might be developed for better water management practices.

The following concerns were expressed regarding recycling:

1. If no raw water was used for boiler feed, there could be a 30% reduction in make-up water;
2. Corrosion is a major problem in some systems where recycling methods are used;
3. Bitumen recovery from middlings might be economically desirable; however, the question is whether or not it would affect settling rates or compaction; and
4. Lime addition reduces the volume of sludge because it results in quick and effective settling; however, water treatment of this clear water would be required to remove calcium.

The group concluded that a substitute should be researched for lime. They also noted that sludge treatment research was gaining higher priority than recycled water research because some of the water treatment problems have already been solved. The removal of sludge-forming precursors prior to entry into tailings ponds and the use or treatment of existing sludge were also discussed.

3.1.3 Research Areas

Three areas requiring wastewater treatment research were identified:

1. Treatment for aged water in ponds;
2. Treatment of fresh whole tailings; and
3. Treatment of sludge.

3.1.3.1 Treatment of aged water in ponds. The following items were listed as needs:

1. Criteria for wastewater discharge and re-use;
2. Information on the economics of several methods of wastewater treatment for discharge and/or re-use;

3. Demonstration of a full-scale pilot plant, including biomonitoring; and
4. A decision re the choice of best technology with reference to a developed lab-scale model.

3.1.3.2 <u>Treatment of fresh whole tailings</u>. The following items were listed as needs:

1. More basic research;
2. Tertiary recovery research;
3. Non-aggregating end-products (i.e., separation of water, bitumen, and solids);
4. An alternative to lime; and
5. Change in requirements due to change in disposal site (pond to below grade pits).

3.1.3.3 <u>Treatment of sludge</u>. The following items were listed as needs:

1. Development of methodology to consolidate to a shear strength that will support overburden;
2. Methodology for mixing with tailings or overburden; and
3. Methods to accelerate process while letting sit.

3.1.4 Priorities

The following priorities were listed:

1. Demonstration treatment plant for aged water in ponds;
2. Sludge treatment for existing plants; and
3. Tailings treatment for new plants.

Problems might exist during the setting of priorities. In order to solve some of these potential problems the following suggestions were made:

1. Good communication must be maintained among all parties in to determine what research activities are being pursued; and
2. Mutual co-operation and benefits between governments and industry must be established.

3.1.5 Receiving Water (Group II)

Group II commenced directly by trying to provide answers to the questions indicated on the proposed agenda. The session included discussion on the following topics.

3.1.5.1 What is needed? The following questions were raised:

1. Can pollution be prevented by treatment?
2. What is the assimilative capacity of the river?
3. Can companies deal with issues while in operation (as they do with production)?
4. How can we currently utilize the available database?
5. How much can be introduced into the river without affecting the aquatic resource and downstream water quality?
6. How do organic compounds in the sediment affect the quality of the water column? How can this information be utilized to determine effects on downstream water users?

The following research areas were outlined:

1. Establishment of water quality criteria for discharge of treated waste water based on current trends of industrial performance to protect fish, downstream water users, and to preserve surface and groundwater quality now and for the future;
2. Development of monitoring and research programs to determine baseline data;
3. Development of predictive tools; and
4. Initiation of studies to determine risk assessment.

3.1.5.2 Where should we be going? Group II expressed the following questions with respect to the direction research should be proceeding:

1. Fisheries
   a. What substances and what levels of substances cause tainting?
   b. What are the risk factors?
   c. What are the effects on public health (through consumption)?
   d. What are the effects on fish populations?
   e. How are fish populations affected (fish and wildlife policy)?.

2. Public Health
    a. What kinds of testing are required (multi-tier, organics, bacterial, etc.)?
    b. What are the effects of tainting residues?

3.1.5.3 How do we get there? After much discussion, the following route was developed:

1. To produce applied research that might provide possible answers to the problems, it is imperative that there should be consultation and co-operation between industry and government, with definite input from the public.
2. Approval and funding for research and study programs must have priority; and
3. Appropriate resources and facilities must be utilized to produce results that are scientifically valid.

3.1.6 Priorities

The session recommended that an Athabasca River Basin Water Quality Plan should be developed to address the following issues:

1. Public health;
2. Fish tainting;
3. Environmental fate of contaminants discharged; and
4. Effects of phenolic discharges on fish movements (including migration).

3.2 SESSION TWO

The costs of environmental research remain high. In the present climate of economic restraint there is an ever-increasing need for industry and government agencies to pool their R&D resources and capabilities. Duplication of effort, except for planned confirmation work, is simply unacceptable. This is particularly true with respect to the wastewater treatment challenges facing the oil sands industry. Here, even the most promising options are expensive due to the large scale of the existing and planned operations.

This session of the workshop was included to facilitate discussion of:

1. Ways to circumvent existing impediments to good cooperation;
2. The existing expertise and financial resources available through the participating agencies, and
3. The roles and mandate of the participating agencies.

Particular emphasis was placed on the difficulties arising from the confidentiality of information. Approaches adopted by other industrial sectors to overcome this problem were reviewed as a catalyst for discussion.

The results of the session are outlined in the following sections.

3.2.1 Process and Water Treatment Technology Research

The following key areas, together with the order of priority for research and development, timeframe, and costs, were identified:

1. Treatment demonstration of tailings pond water for recycle/discharge

Recycle

- Clarification
- Oil and grease
- Deionization

  Timeframe: 12 months

Discharge

- Review of alternative techniques, database for acidification, and verification of processes

  Timeframe: three months
- Selection of preferred processes

  Timeframe: two months
- Process designs and economic assessment

  Timeframe: three months
- Design, construction, operation and biomonitoring of selected process train

  Timeframe: 24 months
- Process and environmental assessment

  Timeframe: six months

- Commercial-scale economics
  Timeframe: three months

Total cost estimated for demonstration of treatment tailings pond water for recycle/discharge was two million dollars.

2. Development of sludge handling, treatment, and disposal options for existing tailings ponds.
   - Review worldwide state-of-the-art
     Timeframe: six months
   - Assessment of viable options
     Timeframe: three months
   - Establish disposal criteria, e.g. rate of consolidation, "stackability," "trafficability," percentage volume reduction, etc.
     Timeframe: three months
   - Bench and pilot scale evaluation of treatment options
     Timeframe: 24 months
   - Field testing
     Timeframe: 36 months

Total cost estimated was three to five million dollars.

3. Development of treatment, handling and disposal options for fresh whole tailings.
   - Literature review
     Timeframe: six months
   - Fundamental research (physical, chemical, etc. processes)
     Timeframe: 24 months
   - Viability/effectiveness of tailings stream separation
     Timeframe: three months
   - Bench scale/pilot-scale evaluation of preferred options
     Timeframe: 24 months

Total cost estimated was five million dollars.

3.2.2 Receiving Waters

The following research areas, together with the order of priority for research and development, timeframe, and costs were indicated by the group:

1. Research Area: Development of water quality criteria for treatment and discharge of tailings pond water:

Fish Tainting

- Define tainting chemicals
- Follow the pathways of chemicals in the river
- Perform laboratory taste test on treated water

  Timeframe: 12 months

Total estimated cost was five hundred thousand dollars.

Public Health

- Multi-tier testing from outfall

  Timeframe: 24 months

Total estimated cost was two and one-half million dollars.

Fish Response Studies

- Laboratory avoidance studies

  Timeframe: 12 months

Total estimated cost was two hundred thousand dollars.

3.2.3 Barriers to Co-operation and Mechanisms to Resolve

Several barriers to co-operation were uncovered during the session over the two-day period. Some were identified as being within the public sector, while others were within the industry.

Participants pointed out that although government departments have policies for the heavy oil industries, their monitoring and impact evaluation processes are not outlined clearly. They also noted that long-term studies are not well supported by government; instead it is perceived that governments are concerned only with studies to resolve short-term problems. Within the industry, mistrust and misunderstanding appeared to be the major barriers to co-operation. Techniques and technological processes developed by one group are not revealed to the other players who are trying, in most cases, to achieve the same goal.

In summary, the following concerns with respect to co-operation were listed:

1. Confidentiality;
2. Lack of consensus on problems;
3. Different goals and objectives;
4. Access to the right people/agencies/industries;
5. Ignorance/expertise;
6. Policies/political will;
7. Publication rights;
8. Jurisdiction;
9. Existing stakes;
10. Communication;
11. Quality of information;
12. Remoteness of problem from decision-makers; and
13. Interpretation.

To resolve the above concerns, functional communication mechanisms should be developed. These should include:

1. Co-ordination in planning research programs;
2. Information exchange between stakeholders (dissemination of information);
3. Clarification of jurisdiction;
4. Improved communications processes;
5. An outline of governmental polices; and
6. An outline of goals and objectives.

3.2.4 Future Direction for the Ad-Hoc Committee

It was unanimously decided that co-ordination and co-operation should be maintained and further developed among federal and provincial governments, involved industries, and the public.

ALBERTA OIL SANDS TAILINGS WASTEWATER
TREATMENT TECHNOLOGY WORKSHOP

SECTION II: WORKSHOP PROCEEDINGS

WATER MANAGEMENT AT SYNCRUDE

V. Stowell
Syncrude Canada Ltd.

Plate 1. By license, Syncrude must contain all process and bitumen contaminated water on site. The tailings pond has been designed to hold all of the sand, sludge, and water produced through to the mine completion.

Plate 2. Water reaches the site from one of five sources: the Athabasca River, surface drainage, water in tarsand, in-pit mine drainage, and precipitation, steam leaks, and converting steam into hydrogen.

The majority of water used in the plant is recycled from the tailings pond. After use, the water is returned either, directly to the tailings pond as part of the tailings stream, or is sewered and returned via the effluent pond.

Plate 3. The raw system supplies water from the Athabasca River to various users within the Syncrude Plant. Water is withdrawn from the Athabasca River by means of the Low Lift Pumps to a settling basin. From the settling basin, water is pumped through the High Lift Pumps to the Mildred Lake Reservoir. Water is then supplied for use as potable water, tailings and extraction gland seal water, cooling water make-up, utility water, fire water and boiler feed water make-up.

Plate 4. Recycle water is heated utilizing waste heat from the upgrading units (the Cokers and the Diluent Recovery Units). It is then pumped for use in the Extraction Plant. Cold recycle water is used to flush tailings lines.

Plate 5. Approximately 30 M M^3/year of water is imported from the Athabasca River. Most of the water required by the process plant is recycled from the tailings pond (84 M M^3/year).

Plate 6. Syncrude has recognized the need to make efficient use of all water. The water management program has been developed to ensure that raw water consumption is minimized. Since start-up, raw water import has been reduced from 36 M M^3/year to about 30 M M^3/year. A program is in place to minimize raw water import by implementing design changes and optimizing plant operation.

* SYNCRUDE MUST CONTAIN ALL PROCESS AND BITUMEN CONTAMINATED WATER ON SITE.

* THE TAILINGS POND IS THE VEHICLE FOR THIS CONTAINMENT.

* THE TAILINGS POND IS DESIGNED TO HOLD ALL SAND, SLUDGE AND WATER PRODUCED THROUGH TO THE MINE COMPLETION.

Plate 1. Introduction.

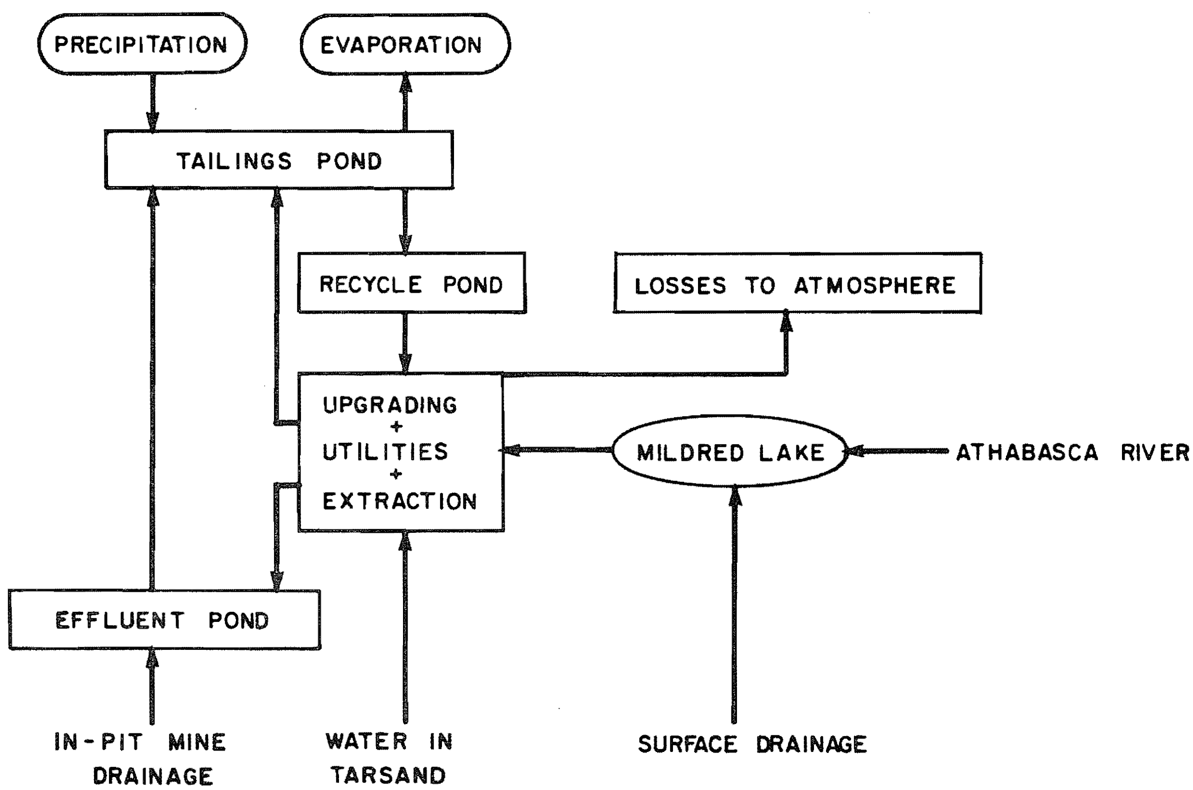

Plate 2. Plant Water Balance.

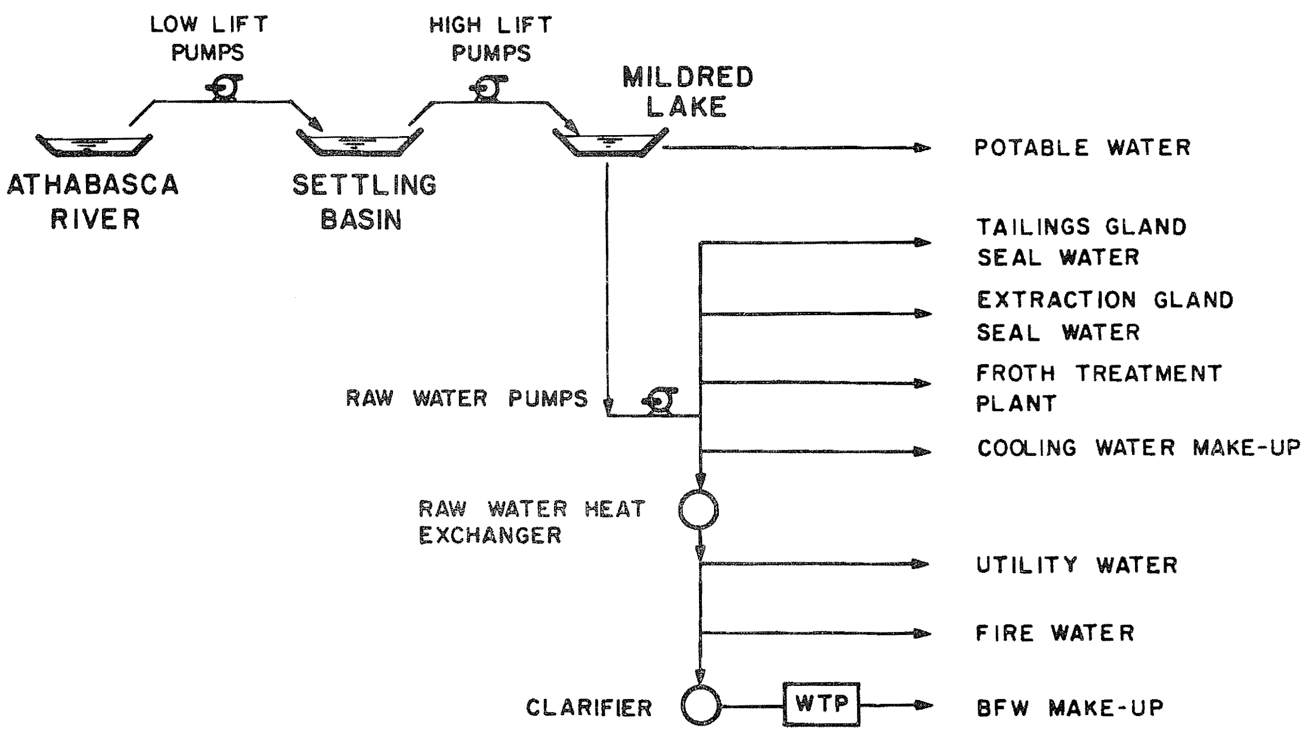

Plate 3. Raw Data System.

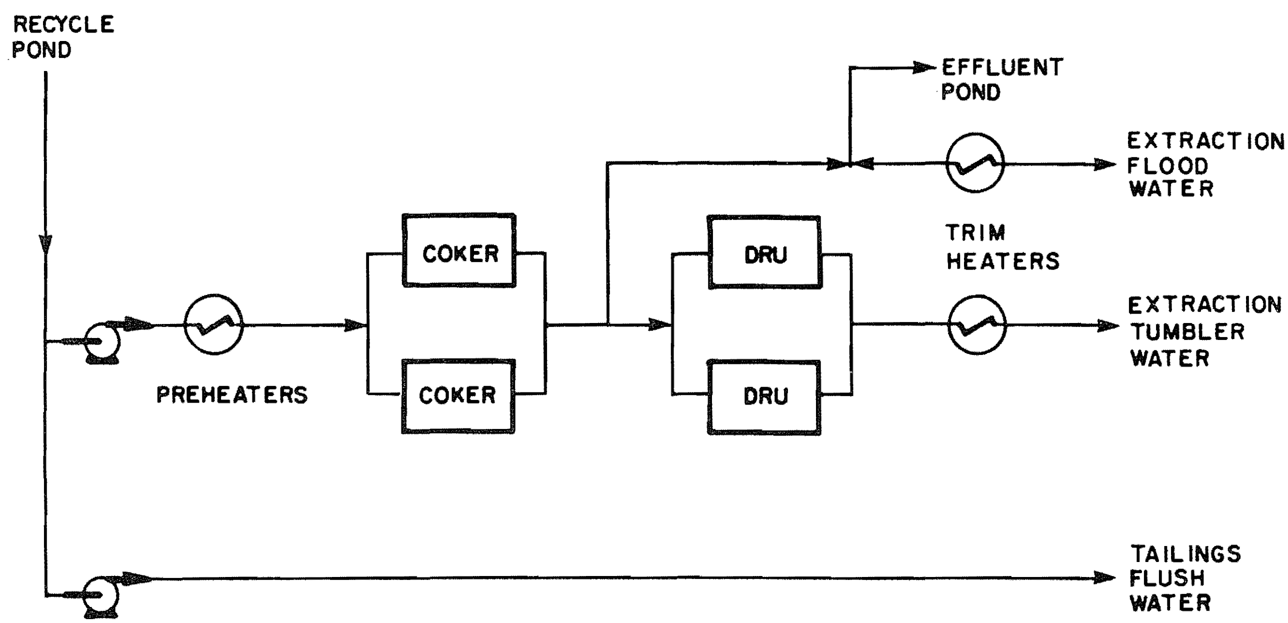

Plate 4. Recycle Water System.

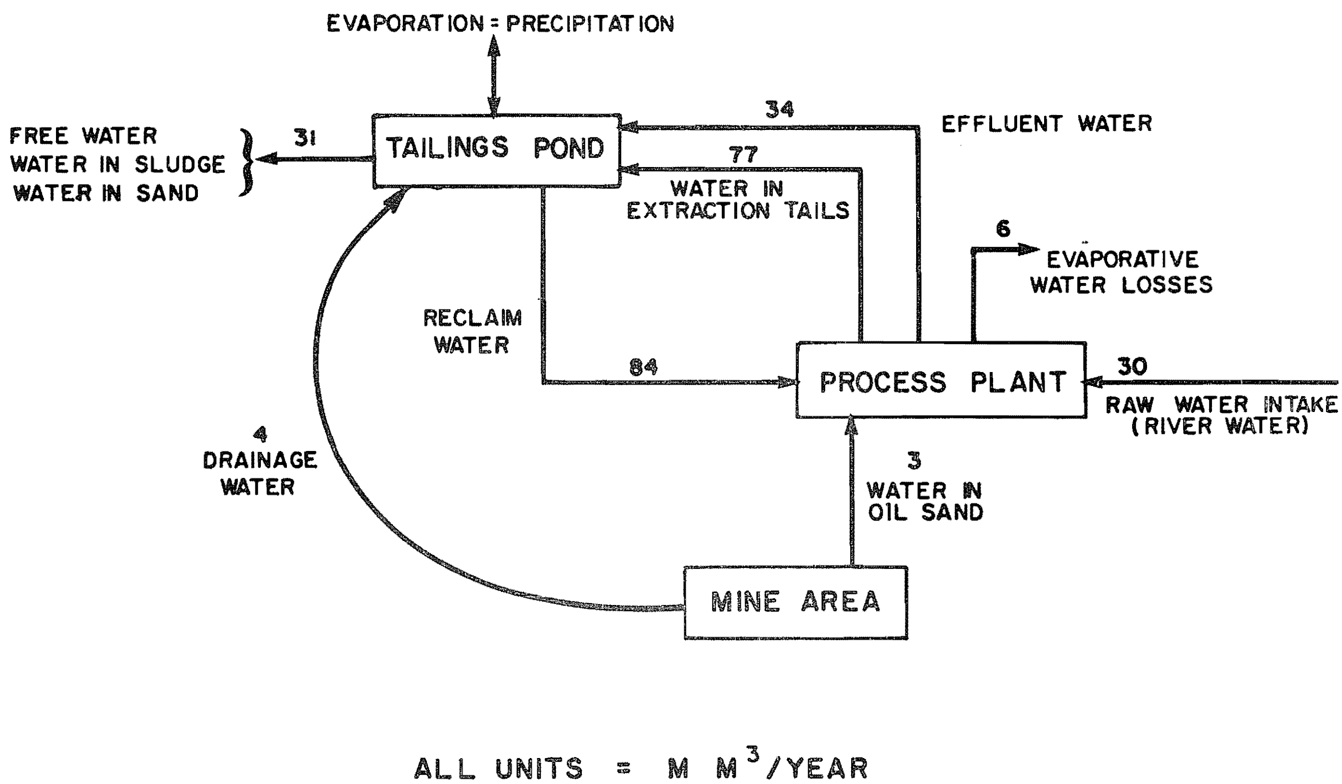

Plate 5. Plant Water Balance.

WATER MANAGEMENT PROGRAM

* SYNCRUDE HAS RECOGNIZED THE NEED TO MAKE EFFICIENT USE OF ALL WATER.

* THE WATER MANAGEMENT PROGRAM HAS BEEN DEVELOPED TO ENSURE THAT RAW WATER CONSUMPTION IS MINIMIZED.

* SINCE START-UP RAW WATER IMPORT HAS BEEN REDUCED FROM 36 M M^3/YEAR TO ABOUT 30 M M^3/YEAR.

* A PROGRAM IS IN PLACE TO MINIMIZE RAW WATER IMPORT BY IMPLEMENTING DESIGN CHANGES AND OPTIMIZING PLANT OPERATION.

Plate 6. Water Management Program.

EXTRACTION TECHNOLOGY

R. Wood
Suncor Oil Sands Group

This session was covered by a video describing the extraction technology utilized by Suncor Ltd. **Figures 1 and 2** respectively show the extraction process and operation of the Suncor plant.

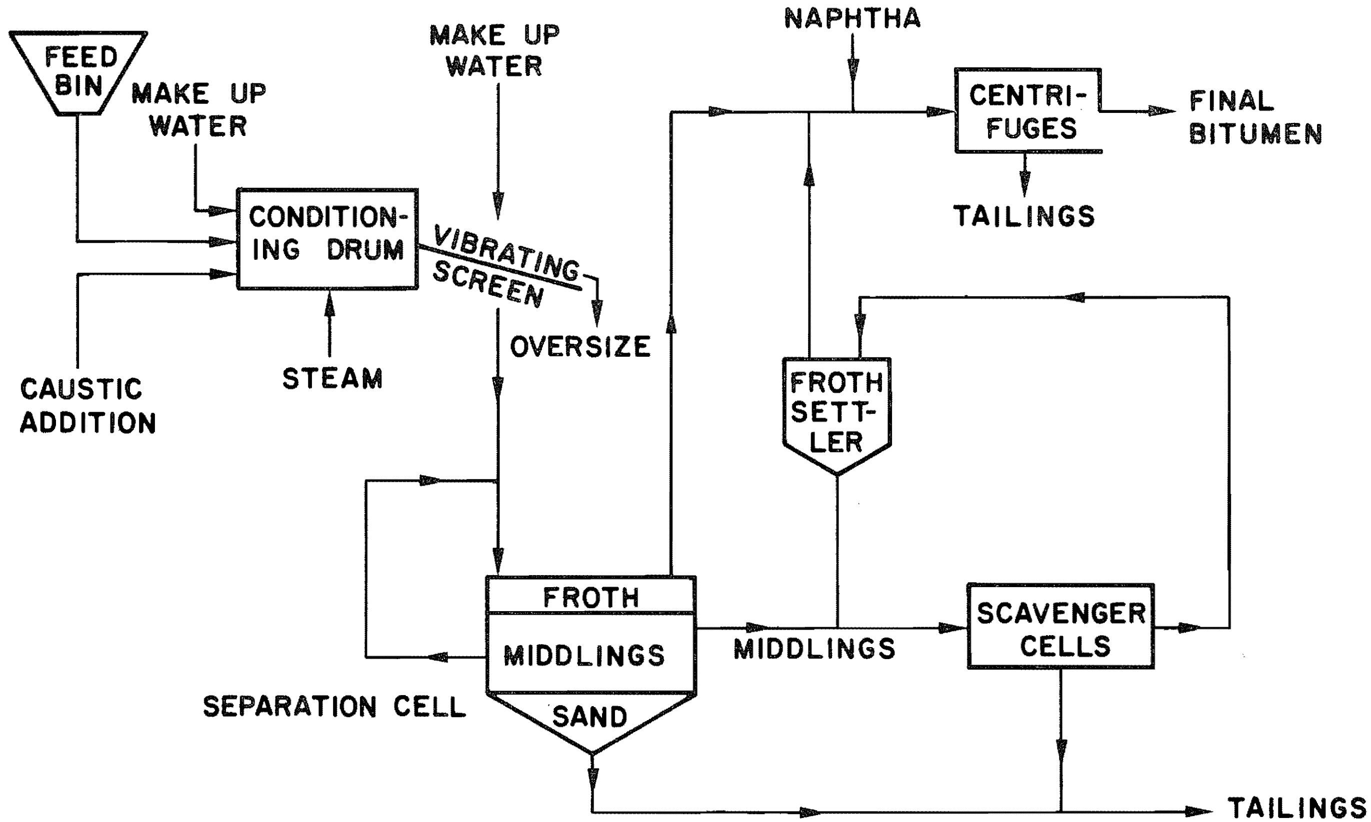

Figure 1. EXTRACTION PROCESS

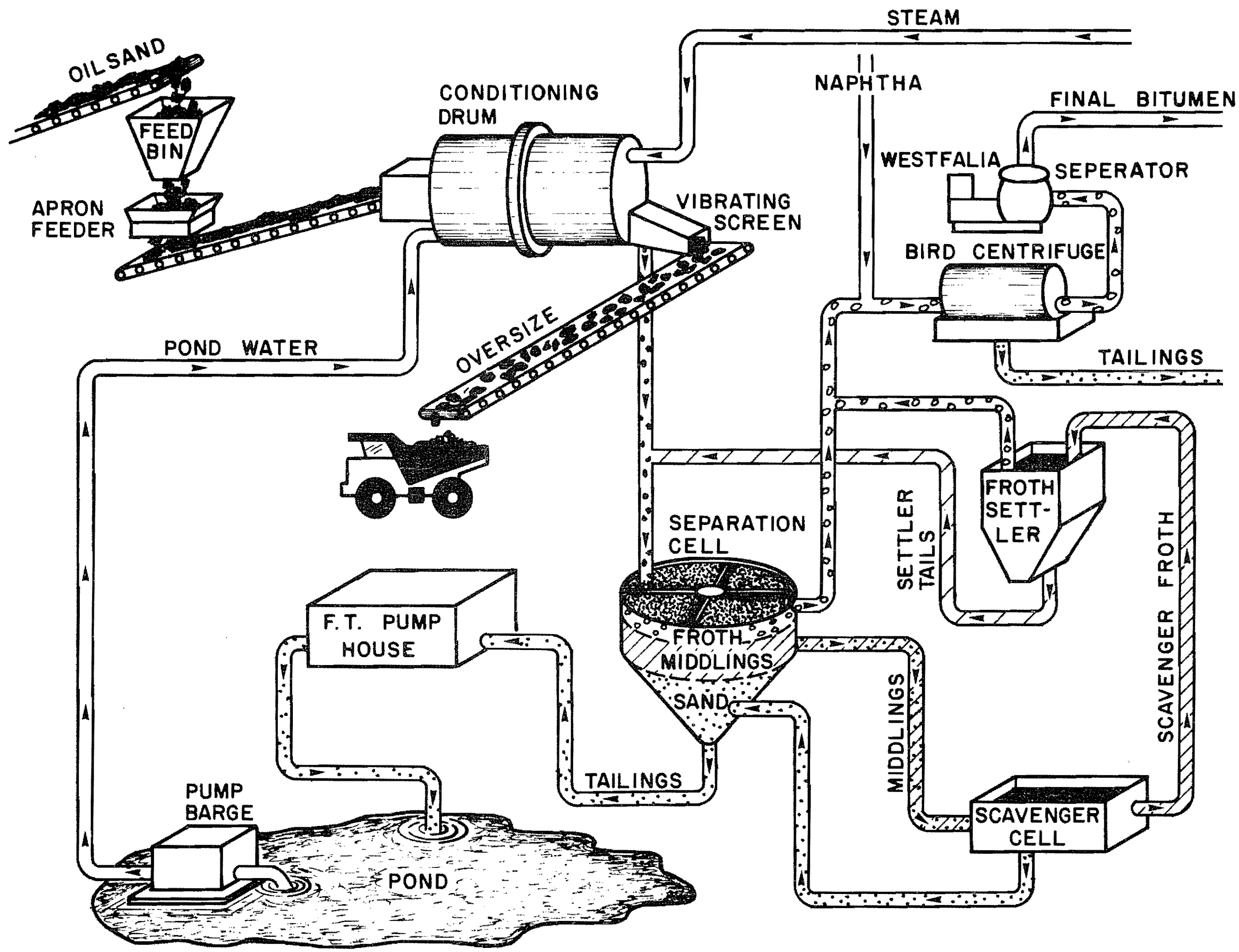

Figure 2. **EXTRACTION OPERATIONS**

FUTURE TECHNOLOGIES

R.R. Germain
Alberta Oil Sands Technology and Research Authority

INTRODUCTION

AOSTRA is a provincial crown corporation established by an Act of Legislature in 1974 whose mandate is (1); to promote research and development into the technological methods required for the efficient and economic recovery and processing of crude bitumen and other oil sands products from the oil sand deposits of Alberta; (2) to promote research into the technological methods required to ensure an acceptable quality of the environment during and after such recovery and processing operations; and (3) to promote and implement solutions to technological problems impeding the development of production capacity to meet the demand of crude oil, synthetic crude oil and products derived from crude oil. The Authority's involvement in technology development ranges from fundamental, academic and institutional research to the support of large scale field pilots and demonstration units in cooperation with industry, foreign and national, and various government bodies, both federal and provincial.

MAIN BODY

Over the past decade the Authority has been evaluating and developing new and improved technology for the recovery of bitumen from Alberta's mineable oil sand deposits, technology that would offer a number of significant advantages over the commercial hot water extraction process (HWEP). In assessing any new extraction process the authority established six objectives that such a process would have to meet to be of practical interest to industry. These are:

* improved bitumen recovery
* improved processing of lower grade oil sands
* improved energy efficiency
* reduced capital and operating costs
* reduced water consumption
* elimination of tailings ponds

Two processes which the Authority feels can meet most of these objectives are direct coking and solvent extraction of mined oil sands.

AOSTRA has been most heavily involved in the area of direct coking through the development of the Taciuk Process invented by Mr. W. Taciuk of UMATAC Industrial Processes, Calgary, A Division of UMA Engineering Limited. The process (Figure 1), utilizes concentric, horizontal, rotating kilns consisting of a preheat zone to heat oil sand feed to reaction temperatures, drive off connate water and ablate frozen material; a reaction zone to thermally crack and vapourize the bitumen, a combustion zone to burn the coke formed by cracking and provide for the majority of process heat requirements; and a heat recovery zone to recover the sensible heat in the bitumen free, coke depleted tailings sand.

The process is capable of accepting mined oil sand as feed material and produces a dry spent sand suitable for in mine or surface disposal; hydrocarbon vapour and flue gases requiring downstream processing; and minor amounts of water which require further treatment. The process has been under development since 1976 and has successfully processed oil sand ranging from 6 to 14% bitumen by weight. A 5 ton/hr pilot plant is currently located in SE Calgary.

From a water use standpoint the Taciuk Process offers the potential benefit of eliminating tailings ponds as we know them today and substantially reducing the overall water consumption over that associated with the HWEP. To process one ton of medium grade oil sand, 11.6% bitumen content, the Taciuk Process will require approximately 210 lbs. of water to quench the hot tailings and wet the tailings to a moisture content of 4 wt% and an additional 150 lbs. to saturate the flue gases for a net water consumption of 360 lbs./ton of oil sand processed. Approximately 65 lbs. of water are recovered as condensed connate water from the preheat zone and a further 20 lbs. of sour water are recovered from the hydrocarbon vapour. In comparison hot water extraction requires in the order 1500 and 2000 lbs. of water and steam per ton of oil sand processed.

With the use of proper water management and dry in kiln desulphurization the overall consumption of water by the Taciuk Process may be

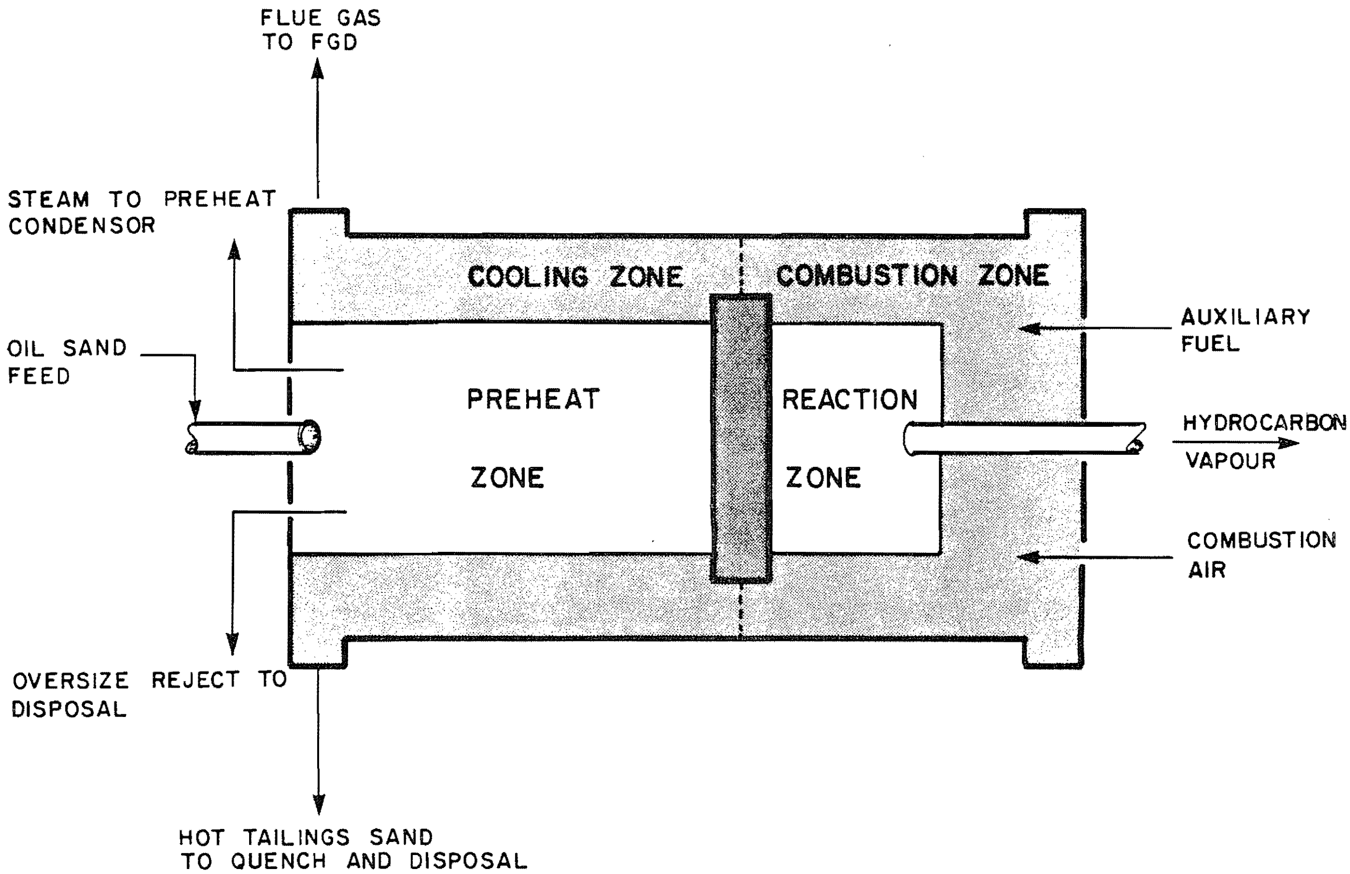

Figure 1. Taciuk Processor.

reduced even further. However, due to the hydrocarbon and phenolic content of the sour water, and emulsion formation in the condensed connate water further treatment prior to internal usage or surface disposal is required. In a recent review of treatment options for these streams it was concluded that the connate water would require the least treatment, primarily oil removal, prior to use, possibly as quench water for the hot tailings. The sour water will require more extensive treatment. Possible options include flotation, filtration, clarification, aerobic biological treatment and activated carbon adsorption (similar to those processes required for refinery waste water treatment).

The future of the Taciuk Process appears promising. Negotiations are now underway with an industry partner for the construction of a one hundred ton/hour demonstration unit to be built in Northern Alberta.

As with the direct coking process, solvent extraction also offers the attractive benefit of eliminating tailings ponds and lowering the water consumption over that associated with the HWEP. At the present time the Authority is undertaking preliminary evaluations of two solvent extraction processes for the recovery of bitumen from whole oil sands: SESA, which stands for Solvent Extraction-Spherical Agglomeration, a process developed by the National Research Council in Ottawa that uses a conical counter-current rotating drum solvent/feed contacting device; and Dravo, a moving perculating bed extraction process developed by Dravo Engineers Inc., Pittsburgh, Pennsylvania.

Solvent recovery from the extracted oil sand is a key technical concern. It is also the point at which water consumption and subsequent contamination are likely to be the highest depending on the recovery scheme, process conditions and the type of solvent used. Water displace- ment for solvent recovery has been proposed by some, however, bench scale studies have indicated that this method can lead to serious emulsion problems, fine particulate entrainment and unacceptably hgh solvent losses. At present steam distillation appears to be the preferred route to solvent recovery. Although energy intensive it avoids, to a greater extent, those problems associated with water displacement techniques and both the condensed steam and solvent can be recovered with minimal treatment required (depending on the properties of a given solvent).

Treatment of tailings pond sludge to enhance solid/liquid separation, recover emulsified bitumen and allow for the subsequent reuse of the clarified water has been examined by AOSTRA through the development of two processes since 1978. The first, know as the Xana Water Clarification process was based on the well known concept of electrostatic or electrophoretic precipitation of suspended solids. The novelty of the process centered around using a moving belt of charged surface travelling through the water upon which solids would precipitate and subsequently be removed allowing for the continued reintroduction of a "fresh" collection surface (Figure 2).

From 1979 to 1983 a series of programs were undertaken to determine the influence of such factors as cell geometry, applied voltage, electrode materials and feed stream composition on performance criteria such as energy consumption, throughput capacity, bitumen/water/solids content of the extracted sludge and quality of the clarified water. In conjunction with the piloting program technical and economic evaluations were performed at various stages to determine if continued development of the process was warranted.

In October 1983, the project was terminated and the Authority does not intend to pursue it further. A final assessment of the process indicated that, while technically feasible and capable of treating tailings pond water with a solids content of 15 wt% to a clarified water with less than 3 wt% solids the limited throughput capacity, excessive physical size requirements and prohibitive capital and operating costs made the process impractical for large scale commercial application.

The second process examined by the Authorty is the Kruyer Oleophilic Sieve Process developed at the Alberta Research Council by Jan Kruyer in 1975. It has potential application to the recovery of bitumen and hydrocarbons from slurried oil sand, tailings pond water and other process effluent streams generated by the HWEP.

The process uses a perforated rotating drum containing oleophilic balls to collect and agglomerate bitumen in the feed stream (Figure 3).

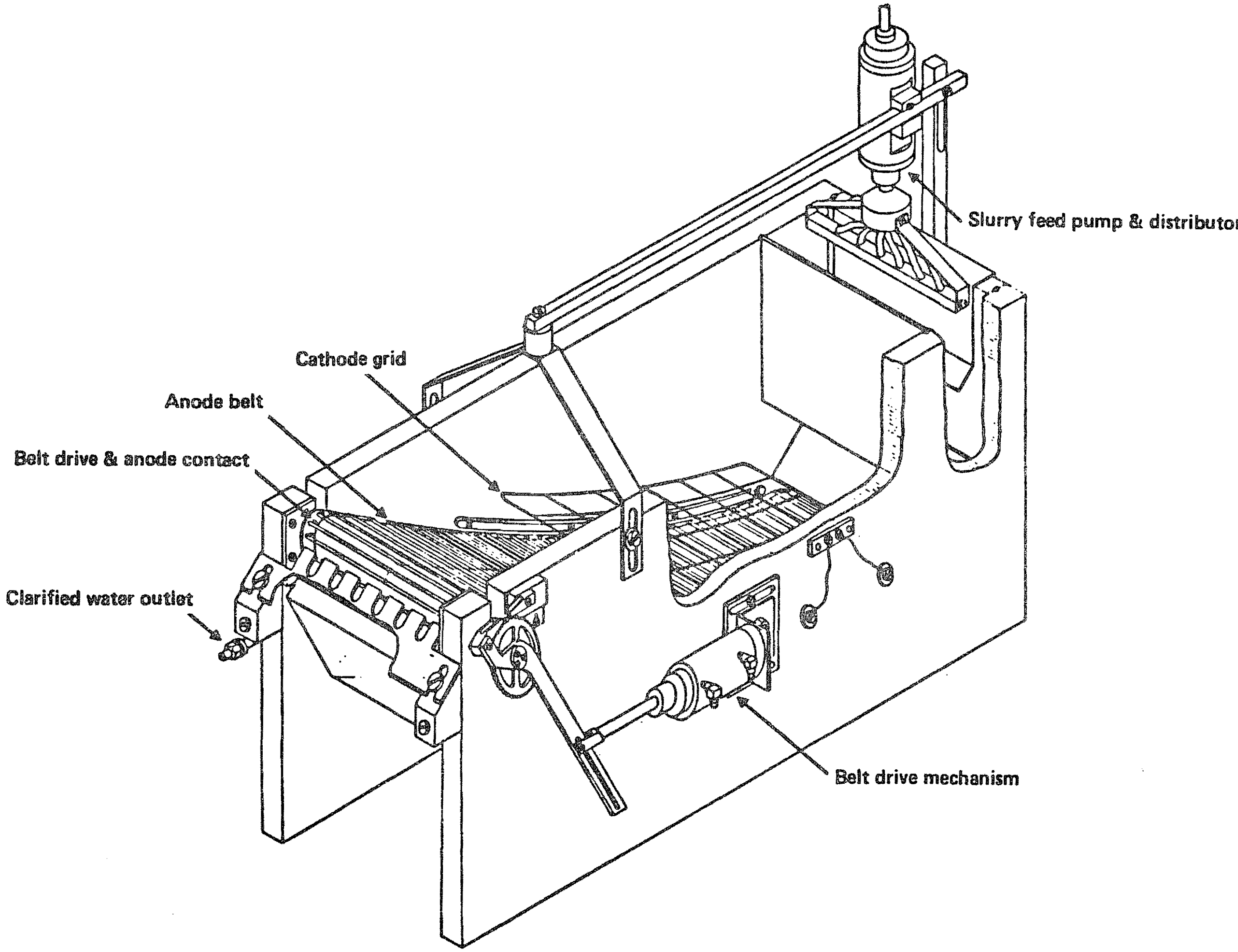

Figure 2. Xana water clarification process.

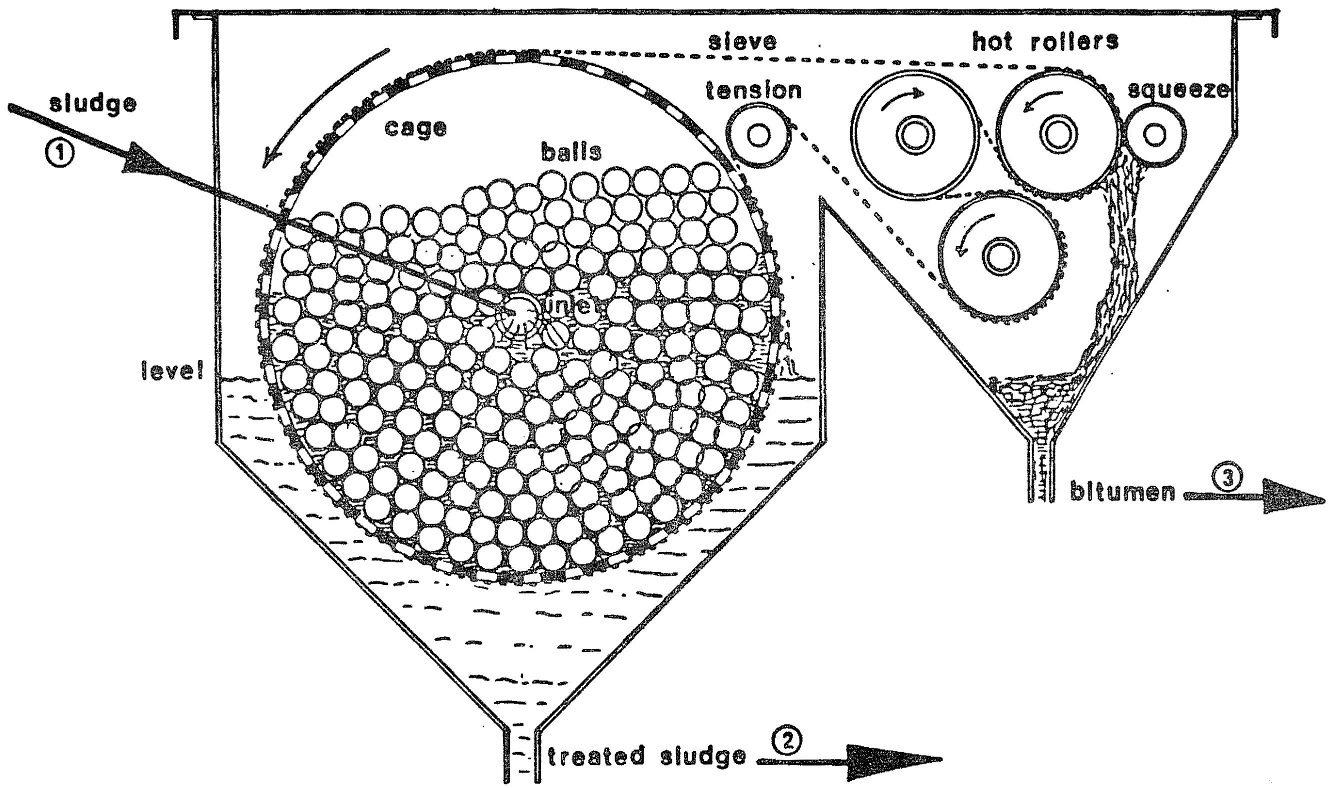

Figure 3. The Kruyer process.

Agglomerated bitumen, water and solids pass through the drum's circumference and the bitumen is captured on an endless perforated oleolphilic belt for subsequent recovery and processing while the water and solids pass through the belt to a collection basin for disposal.

The Authority has provided financial assistance for development of the process since 1980. On tailings pond sludge with a bitumen/water/solids content of 6/23 and 71 wt% respectively 85% of the bitumen can be typically recovered to yield a product containing 58% bitumen, 15% solids and 27% water. A drawback of the process is that the feed sludge is highly agitated as it proceeds through the various processing steps and despite the lower bitumen content the effluent may prove to be as difficult to settle as fresh tailings discharge from the HWEP.

Results from the pilot program have been sufficiently promising to warrant further study. Settling characteristics of the treated sludge and additional process applications will be investigated. At the present time a field study is underway in cooperation with Suncor to test the process under field conditions.

AOSTRA and Syncrude are currently investigating the use of dredging for overburden removal. One aspect of the dredging program that has potential to tailings wastewater treatment is the use of tailings pond water and sludge as a dredging media. It is felt that coprecipitation of solids and sludge may be possible enhancing the settling characteristics of the dredging effluent and ultimate quality of the water available for recycle.

Preliminary tests have been completed and further field trials are planned for the spring of 1986.

USE OF TOXICITY TESTS IN STUDIES OF OIL SANDS TAILINGS WATER DETOXIFICATION

H. Boerger
M. MacKinnon
M. Aleksiuk
Syncrude Canada Ltd.

INTRODUCTION

Syncrude Canada Ltd. is designed to produce over 40 x 10^6 barrels of synthetic crude oil annually from the Athabasca Oil Sands near Fort McMurray in northeastern Alberta. A caustic hot water process is used to extract the bitumen from the oil sand, followed by the upgrading of the bitumen through coking and hydrotreating to produce synthetic crude oil. Over 100 x 10^6 m^3 of waste water and sludge are produced annually and are stored in a tailings pond. However, most of the water is recycled, resulting in a net annual accumulation of 20 to 30 x 10^6 m^3 of waste water and sludge.

By mid-1984, the tailings pond contained 180 x 10^6 m^3 of waste water and sludge, covered an area of 13 km^2 and had a maximum depth of 35 m (Figure 1). The pond is stratified into a surface water zone (0 to 10 m) with a low concentration of solids (less than 1%) and a deeper sludge zone containing 5 to 45% solids. The tailings pond water is acutely toxic, with 96 hr LC_{50} values for trout and Daphnia being less than 10%. Bacteria (mainly Alcaligenes spp. and Acinetobacter spp.) appear to be the only organisms present in the pond.

Under the present zero-discharge policy, Syncrude's tailings pond is projected eventually to cover 17 km^2, have a maximum depth of 60 m and contain over 400 x 10^6 m^3 of wastewater and sludge. Current reclamation options provide for either reclaiming the pond in situ as a viable, non-toxic water body, or of treating and discharging the wastewater in an environmentally acceptable manner and revegetating the disturbed land area.

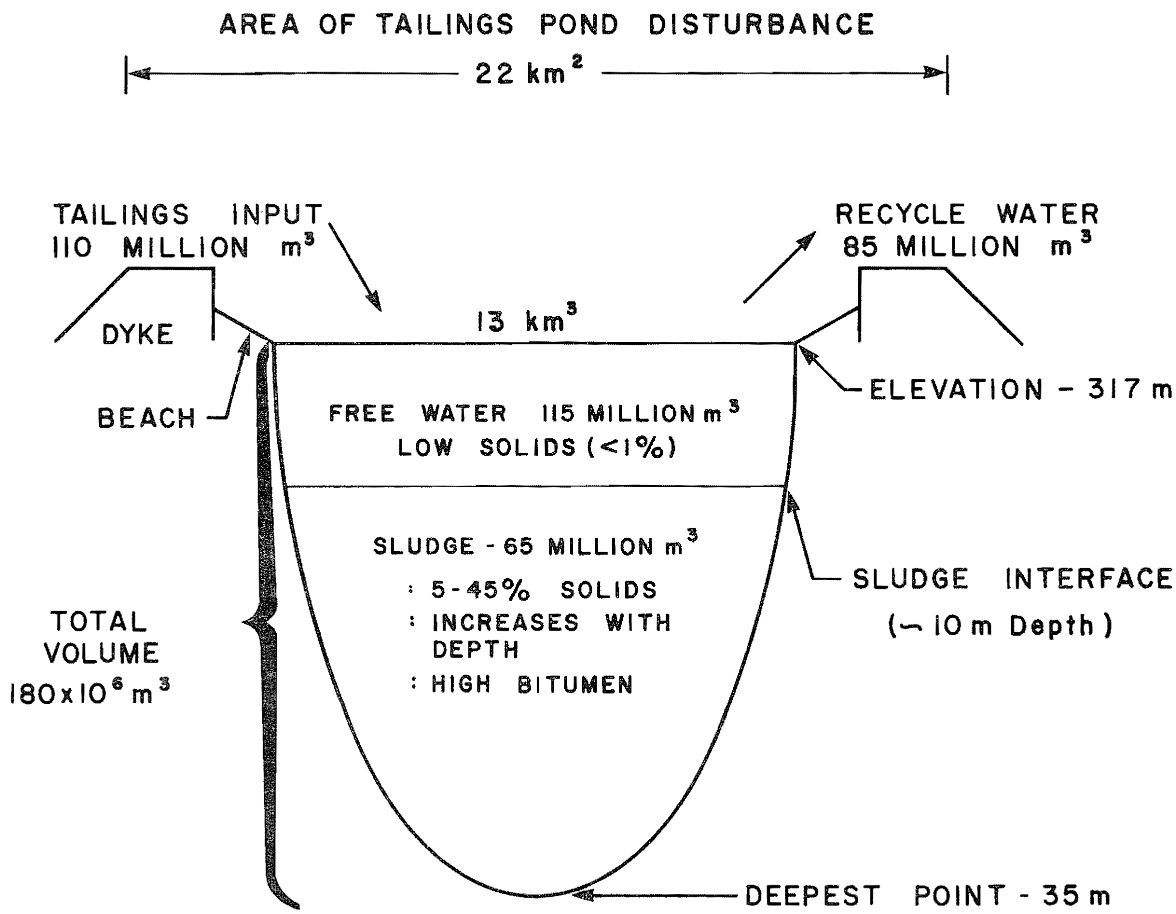

Figure 1. Schematic cross-section of Syncrude Canada Ltd. tailings pond, July 1984. Volume of tailings input excludes sand.

MacKinnon and Retallack (1982) examined the effectiveness of various chemical and physical treatments in detoxifying tailings pond water. The only method found which resulted in a high degree of detoxification involved coagulation of the suspended solids under acidic conditions, with subsequent separation and neutralization of the clarified water. The objective of this paper is to provide further data showing that rapid detoxification of tailings water can be accomplished by acidification and that the effectiveness of this treatment can be improved by incorporation of a suitable flocculant. We also describe the naturally-occurring detoxification of tailings pond water stored in experimental pits free from fresh tailings input since 1983 June 30. We have evaluated both the short-term chemical treatment and the long-term natural detoxification using various acute bioassays. Experience with these bioassays led to the development of a sequential testing procedure which we feel has application in development of treatment plans for other toxic wastewaters.

METHODS

Chemical Treatments

In May 1984, three different chemical treatments of tailings water were evaluated: coagulation of the suspended solids with acid (Treatment 1), coagulation with acid followed by addition of a flocculant (Treatment 2), and coagulation with alum followed by addition of a flocculant (Treatment 3). These treatments were chosen in order to assess the effectiveness of the flocculant (Treatment 1 vs. 2) and the importance of acid as the coagulant (Treatment 2 vs. 3).

Tests were carried out in polyethylene-lined barrels containing 200 L of water collected from 25 cm below the surface of the tailings pond and allowed to stand for one week at 20^{o}C to remove volatiles. Treatment 1 consisted of slowly adding 1 M H_2SO_4 under constant agitation until the pH was reduced from 8.1 to 4.5 (approximately 12 meq/L of acid). Treatment 2 consisted of acidification to pH 4.5 followed by the addition of a 5 ppm high molecular weight, medium charge density, anionic polyelectrolyte (CFA30, manufactured by Crossfield Polyelectrolytes, U.K.) under mild agitation. In Treatment 3, alum ($Al_2(SO_4)_3$ as a 10 mg/L stock solution) was added to give a final concentration of 100 ppm. After rapid agitation for 2 minutes, CFA30 was added as in Treatment 2. A fourth barrel of tailings water used as a control was agitated to a similar degree as the water in the three treatment barrels.

After 24 hours, samples were taken from all four barrels and pH adjusted to 8.0 with 1 M NaOH. In order to compare the rate of clarification, samples for suspended solids were also taken 0.25, 1, 2, 24 and 48 hr after treatment. Physical and chemical analyses and toxicity tests were carried out as described below. For comparison, a natural water sample taken from the Athabasca River just upstream from Syncrude's pumping station was included in the analysis. This sample was intended as a reference against which to compare the untreated tailings pond water and the waters produced by the three treatments.

Aging of Tailing Pond Water

Two experimental pits were excavated adjacent to the tailings pond. Each pit measured 13 m by 13 m at the surface, had walls with a 1:1 slope, a maximum depth of 3 m in the central area and a volume of 300 m^3. Each pit was lined with a 10 mil sheet of nylon-reinforced polyethylene. On 1983 June 30, the pits were filled with water from the surface zone of the tailings pond. The chemistry and toxicity of the water in the pits was monitored at 1 to 3 month intervals.

Physical and Chemical Analysis of Water Samples

Dissolved oxygen, conductivity and pH were measured with a Hydrolab meter calibrated prior to use. Total solids were determined gravimetrically after drying 12 to 20 mL of whole sample at 100^oC. Dissolved solids were determined gravimetrically after removal of suspended solids by filtration through a 0.8 u Millipore filter. Suspended solids were determined by difference. Turbidity was measured with a Hach Model 2100 Turbidity Meter. Analysis of other chemical parameters followed standard procedures as described by Alberta Environment (1977). Minor elements were analyzed by atomic absorption.

Toxicity Tests

The Beckman Microtox method was used for routine screening of water samples for toxicity. This is essentially a 15-minute static bioassay using a bioluminescent bacterium as the assay species. The amount of light produced by the bacteria, as measured with a luminometer, is inversely proportional to the toxicity of the solution being tested (Bulich et al. 1981). Tests were carried out as described in Beckman Instruments Interim Manual No. 110679B-9-80.

Ninety-six hour static toxicity tests were carried out with rainbow trout as described by Alberta Environment (1978). Each test consisted of five effluent concentrations plus a control. Five or ten fish (0.5 to 1.0 gm) were tested in 20 to 25 L of each concentration.

Static acute (96 hr) tests were also conducted with *Daphnia magna*. The acute test involved five concentrations (0, 25, 50, 75, and 100%) with five animals being exposed to 100 mL of each concentration. Each concentration was replicated three times (total of 75 animals).

RESULTS AND DISCUSSION

a) Evaluation of Chemical Treatments

In **Table 1**, the physical, chemical and toxicological properties of the waters resulting from the three chemical treatments (T1, T2, T3) are compared with untreated tailings pond water (TP) and Athabasca River water (AR). Both the acid and the alum in combination with flocculant (T2 and T3) resulted in greater than 95% removal of suspended solids from the tailings pond water, with a decrease from over 1000 mg/L to 20 mg/L in 24 hours. Turbidity also decreased from 680 NTU to about 30 NTU. The major effect of the flocculant was to increase the rate of clarification **(Figure 2)**.

With all three treatments there was about a 75% reduction in color (from 1 000 TCU to 200 to 300 TCU), most likely due to the reduction in tannin and lignin concentrations from 9 mg/L to about 4 mg/L. All treatments also resulted in significant reductions in COD (30 to 55%) and BOD (40 to 60%). As expected, the addition of H_2SO_4 and NaOH during

Table 1. Comparison of physical, chemical and toxicological properties of water from the Athabasca River (AR) and Syncrude's Tailings Pond (TP), as well as that obtained by treatment of tailings pond water with acid (T1), with acid and flocculant (T2), with alum and flocculant (T3), and by 10-month storage in experimental pits (P1). Samples collected 1984 May 03. Numbers in brackets beside minor elements give detection limits in ug/L. GT = greater than, LT = less than.

Parameter	Units	AR	TP	T1	T2	T3	P1
General Parameters							
pH	pH units	8.4	8.1	8.3	8.4	8.3	8.4
Conductivity	uS.cm	270	1410	1900	1790	1350	860
Dissolved solids	mg/L	134	1191	1750	1570	1300	659
Suspended solids	mg/L	55	1007	160	20	20	154
Turbidity	NTU	8	680	78	34	32	66
Color	TCU	30	1000	300	200	200	300
BOD	mg/L	2	32	19	12	15	2
COD	mg/L	16	422	189	299	289	120
Tannin + Lignin	mg/L	0.6	9.0	4.5	3.5	3.5	1.8
Dissolved oxygen	mg/L	9.0	2.0	8.0	8.0	8.0	3.5
Major Ions							
Sodium	mg/L	13	395	540	525	390	232
Potassium	mg/L	1.5	9.0	8.5	9.1	8.5	5.2
Magesium	mg/L	8.9	3.3	3.4	3.4	3.5	3.0
Calcium	mg/L	34.4	8.1	7.3	7.3	6.7	8.7
Chloride	mg/L	7	117	114	116	114	69
Sulphate	mg/L	26	215	605	595	250	158
Fluoride	mg/L	0.05	2.50	2.50	2.12	2.12	1.25
Total Inorganic C	mg/L	21	102	74	69	100	58
Alkalinity (as $CaCO_3$)	mg/L	154	542	344	322	508	264
Nutrients							
Total Organic C	mg/L	6.3	42.5	40.0	42.5	43.5	22.5
Total Kjeldahl N	mg/L	0.9	7.1	5.0	6.6	6.6	1.2
Nitrite + Nitrate-N	mg/L	0.02	0.02	0.04	0.08	0.12	0.86
Ammonia-N	mg/L	0.05	2.87	2.57	2.82	2.20	1.24
Phosphate-P	mg/L	0.003	0.070	0.030	0.020	0.200	0.041
Toxic Substances							
Oil + grease	mg/L	0.9	19.0	5.0	2.9	12.0	5.4
Surfactants (MBAS)	mg/L	0.12	2.00	1.95	1.90	2.05	1.40
Phenols	mg/L	0.001	0.150	0.145	0.125	0.120	0.007
Cynanide	mg/L	0.001	0.950	0.920	0.920	0.950	0.013

Table 1. Concluded.

Parameter	Units	AR	TP	T1	T2	T3	P1
Minor Elements							
Aluminium (10)	ug/L	10	140	130	90	160	--
Antimony (0.2)	ug/L	2.6	12.0	12.0	6.5	12.0	--
Arsenic (0.1)	ug/L	1.0	7.1	9.4	10.5	4.7	6.7
Barium (10)	ug/L	250	230	180	130	90	--
Boron (20)	ug/L	60	1680	1740	1720	1720	890
Cadmium (1)	ug/L	LT1	LT1	LT1	LT1	LT1	LT1
Chromium (1)	ug/L	LT1	4	1	LT1	LT1	--
Cobalt (1)	ug/L	LT1	LT1	3	LT1	LT1	2
Copper (1)	ug/L	1	2	LT1	LT1	LT1	1
Iron (10)	ug/L	110	390	510	760	10	870
Lead (2)	ug/L	LT2	LT2	LT2	LT2	LT2	LT2
Manganese (4)	ug/L	15	41	95	57	44	107
Mercury (0.10)	ug/L	LT0.10	0.16	LT0.10	0.10	0.10	0.25
Molybdenum (1)	ug/L	--	63	110	110	62	--
Nickel (1)	ug/L	LT1	14	15	14	15	9
Selenium (0.2)	ug/L	LT0.2	10.6	9.5	12.2	9.7	--
Silica (as SiO_2(20)	ug/L	3600	4500	5250	4520	4500	3350
Silver (1)	ug/L	LT1	LT1	LT1	LT1	LT1	--
Titanium (10)	ug/L	50	60	LT10	LT10	LT10	LT10
Vanadium (1)	ug/L	10	24	100	136	34	183
Zinc (1)	ug/L	4	1	19	19	8	2
Toxicity							
Microtox	EC_{50} (%)	GT100	43	GT100	GT100	45	GT100
Trout	LC_{50} (%)	GT100	7	GT100	GT100	7	GT100
Daphnia	LC_{50} (%)	GT100	2	93	GT100	38	GT100

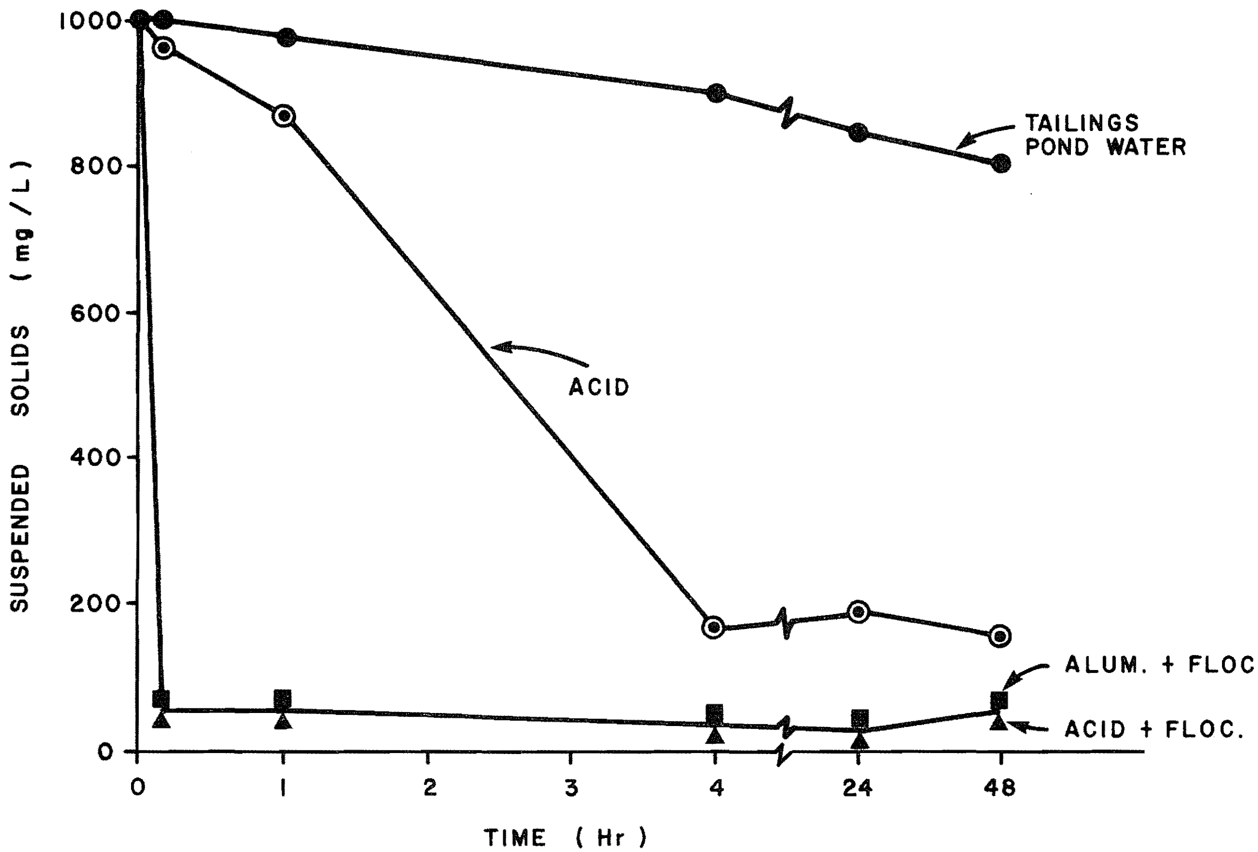

Figure 2. Effect of three treatment methods (acid alone, acid and flocculant CFA 30, alum and flocculant) on the rate of clarification of tailings pond water.

Treatments 1 and 2 resulted in increases in conductivity, sulphate and sodium in these samples.

Although removal of suspended solids can be achieved with either alum or acid as coagulant, only acidification results in detoxification to a level where values of EC_{50} (for Microtox) and LC_{50} (for fish and Daphnia) are over 100%. The reduction in toxicity with alum as determined with Daphnia (increase in LC_{50} from 2% to 38%) is quite likely related to the removal of suspended solids, high concentrations of which clog the filtering mechanism of the animals (MacKinnon and Retallack 1982). Alum treatment did not result in any detoxification when tested with Microtox or fish.

Potentially toxic substances present in the tailings pond water showed various degrees of removal with chemical treatment. Oil and grease were reduced by 75 to 85% with acid, but only by 37% with alum. No significant reductions in cyanide, phenols or surfactants were measured. Ammonia, which occurs in the tailings pond at high levels, was reduced no more than 25% by any of the three treatments. With regard to nutrients, none of the treatments caused significant changes in dissolved organic carbon or total Kjeldahl nitrogen. Nitrification, as indicated by the reduction in ammonia and increase in nitrite and nitrate, appears to have been somewhat faster with alum. Phosphate was decreased somewhat with acid and increased with alum.

With regard to minor elements, treatments tended to have little effect on the relatively low concentrations present in tailings pond water. With both T2 and T3 there were increases in the concentrations of vanadium and zinc, and a decrease in the concentrations of barium and titanium. With acid treatment there was an increase in iron, manganese and molybdenum and a decrease in aluminum and antimony. Alum treatment increased aluminum and decreased arsenic and iron. However, these changes probably have little significance since the concentrations of all except boron are below the level deemed to be deleterious to aquatic biota (Train 1979).

b) Effect of Storage on Tailings Pond Water

The water in the surface zone of the tailings pond is affected by the continous input of fresh tailings and the underlying sludge layer. Comparison of data in Table 1 with that obtained in 1980 (MacKinnon 1981) shows that there has been an increase in dissolved solids as well as a reduction in suspended solids. However, the toxicity has remained high, with LC_{50} to trout and Daphnia being less than 10% at all times. By placing tailings pond water in the 300 m^3 experimental pits, changes in the quality of pond water, free from the effects of fresh tailings input and out of contact with the sludge zone, could be followed.

Following filling, the volume of water in the two experimental pits was affected by evaporation, precipitation and freezing. These changes in water volume are reflected by changes in the concentration of chloride. After filling, chloride remained about 100 mg/L, but rose to 200 mg/L under the winter ice which was 0.7 to 1.0 m thick (Figure 3). Since dissolved solids are excluded during freezing, this indicates that about half of the water in the pits was frozen. During the spring, chloride decreased to 70 to 80 mg/L as a result of dilution by melting snow and ice, and then increased as a result of evaporation. In September 1984, chloride concentration was 110 mg/L. Seasonal changes in the concentrations of other major constituents (sulphate, total organic and inorganic carbon, sodium) were similar to that of chloride. Since the surface area of the pits (169 m^2) was large relative to the depth (3 m), mixing by wind prevented stratification except immediately after ice melt. Even unrder the ice differences between top and bottom of the water never exceeded 10%.

Concentration of dissolved oxygen in the surface zone of the tailings pond is less than 30% saturated. The continous input of large quantities of fresh tailings (100×10^6 m^3/yr) with high concentrations of readily-oxidized material (i.e., organic carbon, phenols, ammonia, sulphide) keeps the COD at over 400 mg/L and the 5-day BOD at over 30 mg/L (Table 1). However, once the tailings pond water was placed in the experimental pits, D.O. rose rapidly, reaching 100% saturation within 4 months (Figure 4). After freeze-up, D.O. decreased to 1 to 2 mg/L, indicating that the oxygen demand of the water was still very high. Samples collect in May 1984, showed that the 10-months storage had decreased COD by 72% and BOD by 94% (Table 1). Following ice-melt, D.O. again increased rapidly till the water was 100% saturated. Turbidity decreased rapidly at first but appears to have stabilized at 50 to 100 NTU after the first year of storage (Figure 5).

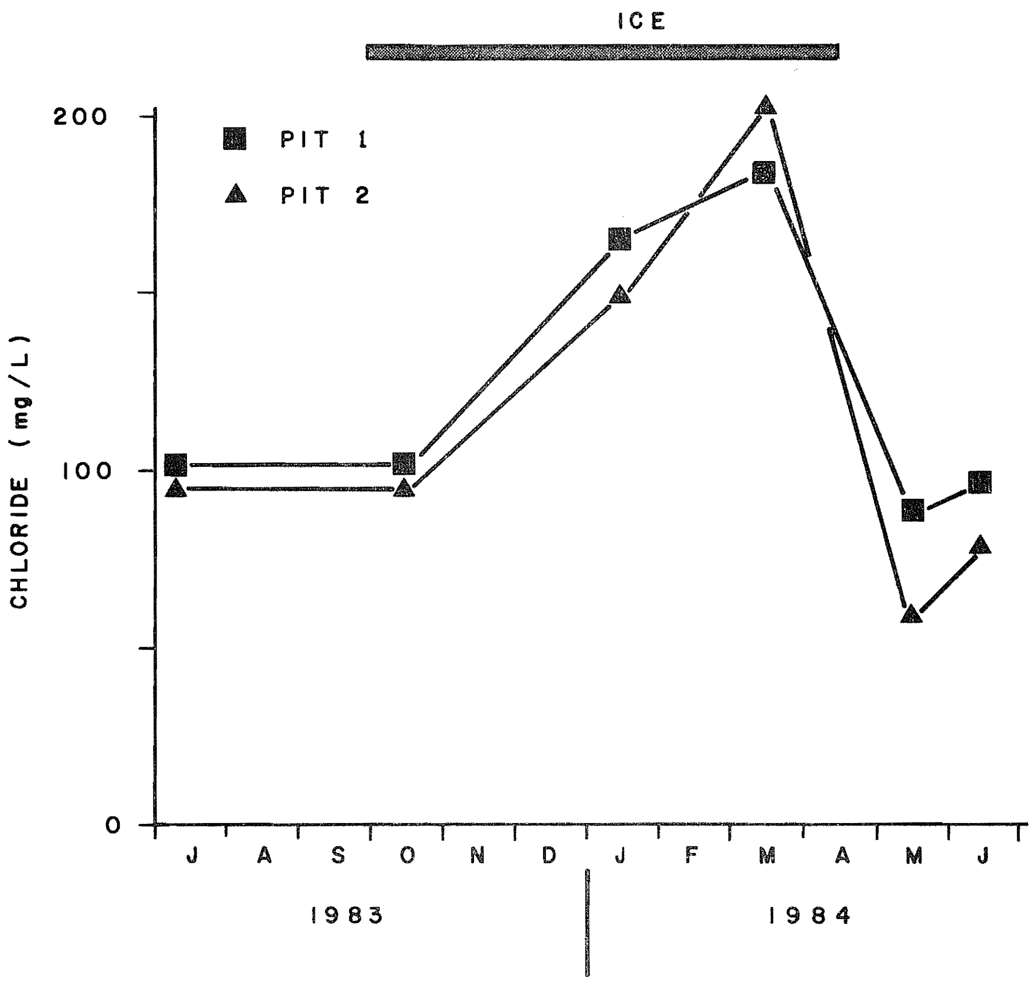

Figure 3. Seasonal changes in the concentration of chloride in experimental pits 1 and 2. Data based on samples collected 25 cm below the water surface.

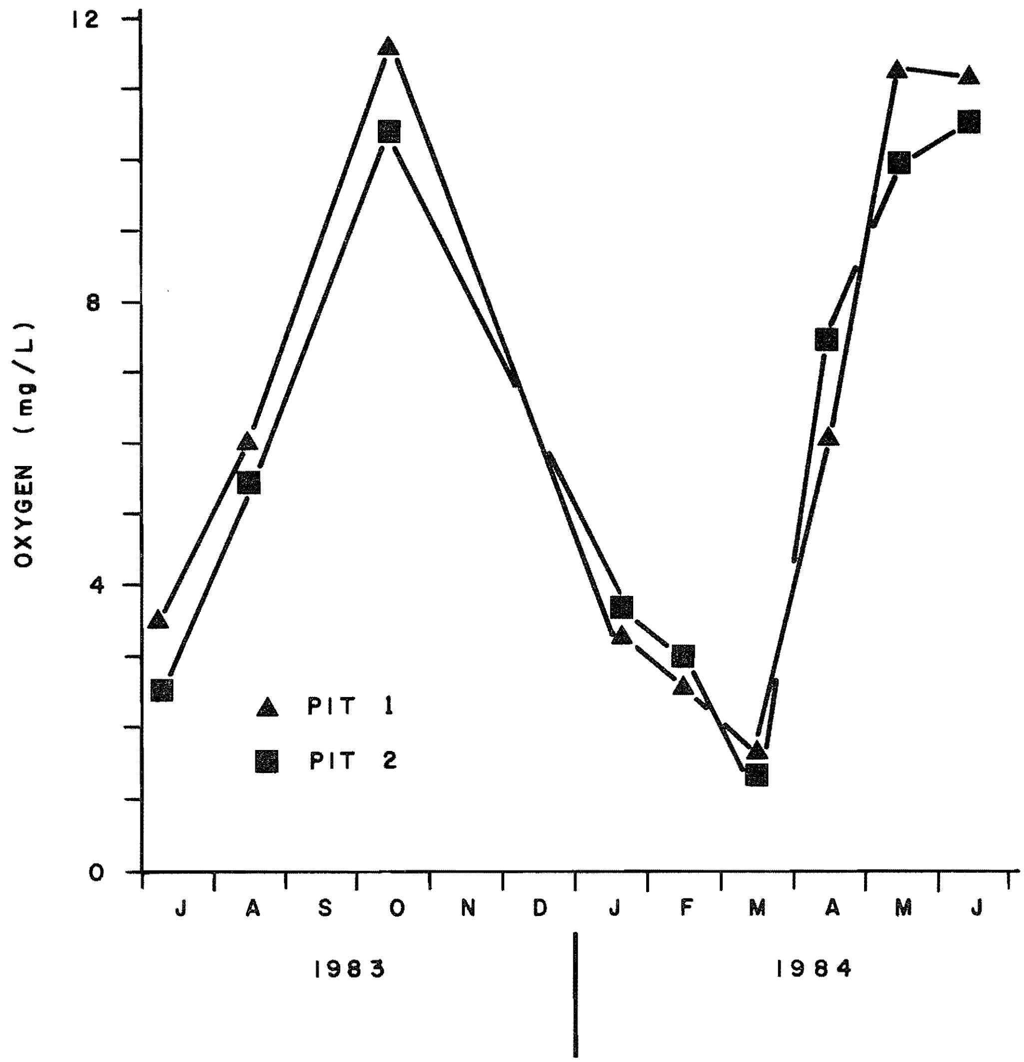

Figure 4. Seasonal changes in the concentration of dissolved oxygen in experimental pits 1 and 2. Data based on samples collected 25 cm below the water surface.

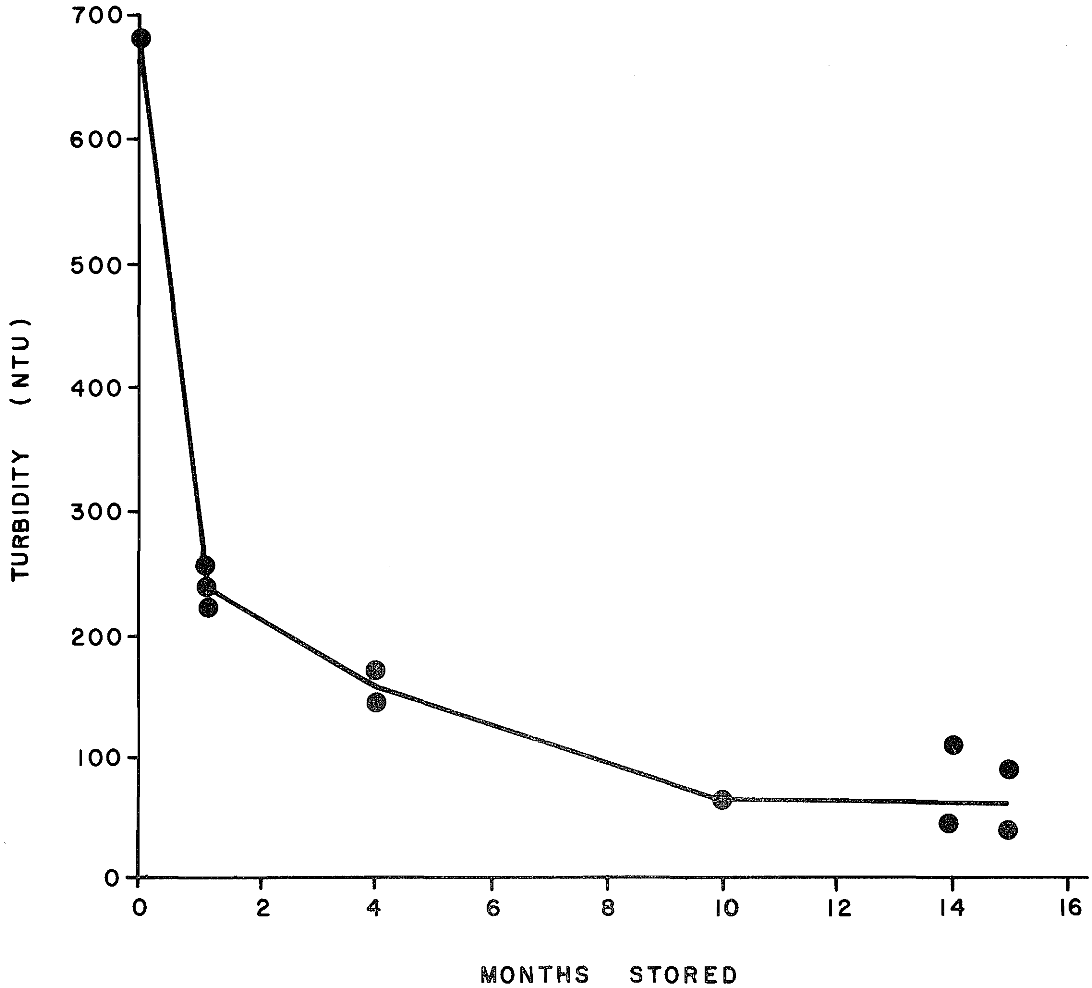

Figure 5. Changes in turbidity of tailings pond water during storage in experimental pits.

The values for Experimental Pit 1 given in Table 1 refer to water which was collected in May at a time when it was diluted about 30% by melt water (i.e., chloride was 69 mg/L compared to 100 mg/L on 1983 June 30).

Hence the Pit 1 values should be increased about 1.4 times before comparing them with the other values in Table 1. With this correction, suspended solids would be about 216 mg/L, or over ten times higher than the level of reduction accomplished by T2 in a matter of hours. Compared to T2, storage was not as effective in removing oil and grease, and like T2, did not result in any significant reduction in surfactants. However, unlike T2, storage removed most of the phenol and cyanide and some of the ammonia. Along with the reduction in ammonia there was a significant increase in nitrite and nitrate.

Toxicity of the tailings water, as measured with the Microtox Test, was reduced substantially during storage (Figure 6). After eight months, the EC_{50} had increased from 35% to 100% in both pits. Detoxification rate appeared to occur at about the same rate in winter as in summer.

The reduction in acute toxicity was confirmed in bioassays with trout and Daphnia. As indicated in Table 1, the 96-hr LC_{50} for both species was over 100% when tested with the water stored in the pits for ten months. The Daphnia and trout kept in full-strength water from Treatment T2 all survived (Table 2). When exposed to full stength tailings pond water which had been stored for 10 months, 60% of the trout and 80% of the Daphnia survived. Taking into account that the water from the pits was about 30% diluted when tested as described above, then one sees that the 10-month storage resulted in less detoxification than Treatment T2.

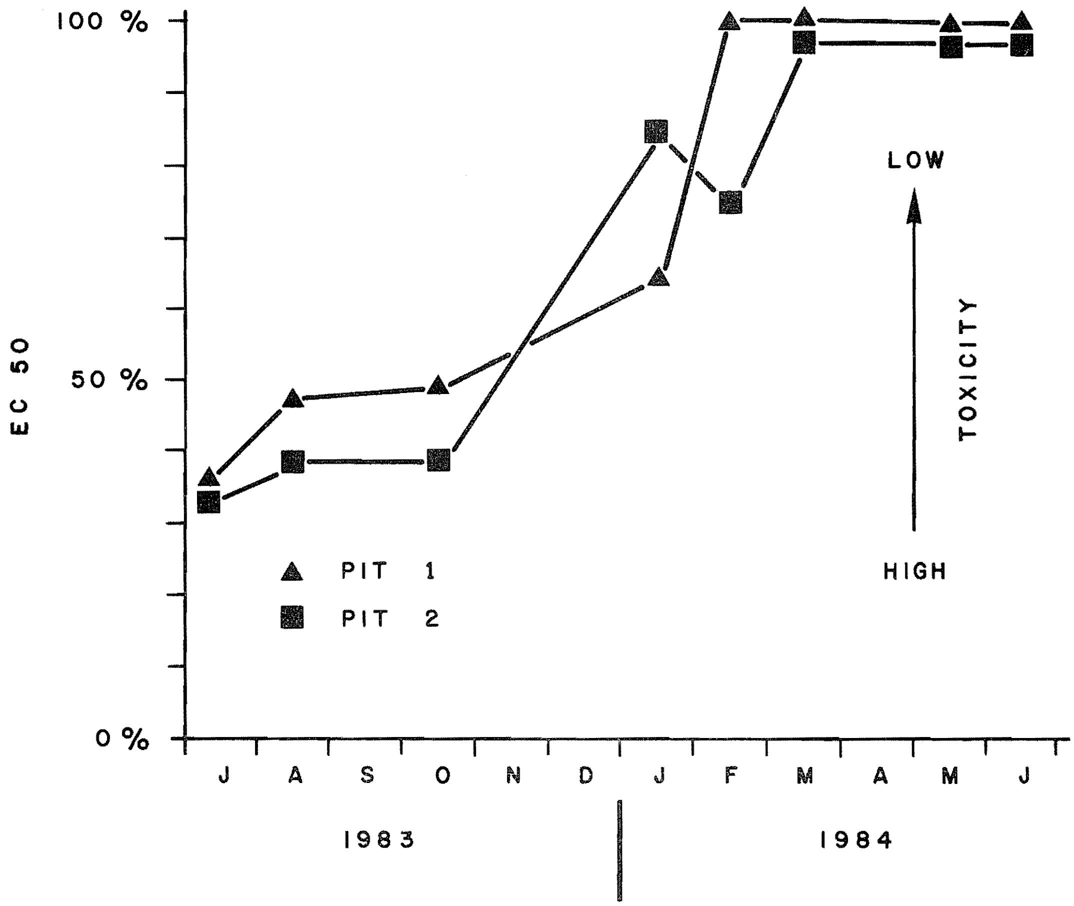

Figure 6. Changes in toxicity of tailings pond water placed in experimental pits 1 and 2.

Table 2: Summary of 96-hour static trout bioassays with tailings pond water from various sources and stored for various times. Numbers in parentheses indicate fish showing stress. GT = greater than. The recycle pond holds tailings pond water prior to its recycling to the extraction plant. Pits 3 and 4 are identical to Pits 1 and 2.

Source of water	Storage time	No. fish surviving in various dilutions and control water: Control	5%	10%	20%	50%	75%	100%	LC_{50}
1) Tailings Pond May 1984	0 days	10	10(4)	0	0	-	-	-	7%
2) Tailings Pond Sept. 1984	0 days	5	5	1(1)	0	-	-	-	8%
3) Recycle Pond Sept. 1984	1-2 days	5	5	5(2)	0	-	-	-	15%
4) Pit 3 Sept. 1984	5 mos.	5	-	5	5	5	0	0	60%
5) Pit 4 Sept. 1984	5 mos.	5	-	5	5	5	0	0	60%
6) Pit 1 May 1984	10 mos.	10	-	10	10	10	10(1)	6(6)	GT100%
7) Pit 1 Sept. 1984	14 mos.	5	-	5	5	5	5	5	GT100%
8) Pit 2 Sept. 1984	14 mos.	5	-	5	5	5	5	1(1)	90%
9) Acid Treatment	1 day	10	-	10	10	10	10	10	GT100%
10) Acid & Floc Treatment	1 day	10	-	10	10	10	10	10	GT100%
11) Alum Treatment	1 day	10	10(4)	0	0	--	--	--	7%

The 96-hour bioassays with trout were repeated in September 1984, at which time the water in the pits was completely mixed and had been aged for 14 months. Whereas in Pit 1 the LC_{50} was greater than 100% and all fish survived in the full-strength water, in Pit 2 the LC_{50} was 95% and only 20% of the trout survived in the full-strength water (Table 2). The reason for this variability is not clear.

c) Sequential Testing Procedure

As described above, we have used a variety of toxicity tests in studies on treatment procedures for wastewater resulting from the production of synthetic crude oil from oil sands. In general, we have used a hierarchial approach in which the results from one type of bioassay are used to determine if we should proceed with the next test in the sequence. We have found this sequential testing procedure extremely practical and feel that it has application in the development of treatment methods for other toxic wastewaters.

The four-stage testing procedure is built around the Beckman Microtox test, the 96-hour static trout bioassay and conventional biomonitoring of the receiving water (Figure 7). The first stage is an evaluation of the toxicity of the wastewater wth the Microtox test. If the Microtox EC_{50} is 100% then one proceeds to the 96-hour trout bioassay. If EC_{50} is less than 100% one goes to Stage 2 where the Microtox is used to screen the effectiveness of various treatment methods. We chose this test for our routine work because it: (1) provided results in 15 minutes, (2) required only a 5 mL water sample, (3) used only a small bench area (75 cm x 150 cm), (4) cost little (about $3 to 5/test), and (5) gave reproducible results with a fairly high degree of precision (+/-20%). As has been shown to be the case with other wastewaters, we have found that with tailings pond water the Microtox technique shows a good correlation with other tests (MacKinnon and Retallack 1982).

We subdivide Stage 3 depending on the parameter used in the test. Stage 3A is primarily concerned wth the confirmation of the Microtox results with the trout bioassy. LC_{50} is used as the test parameter because if this

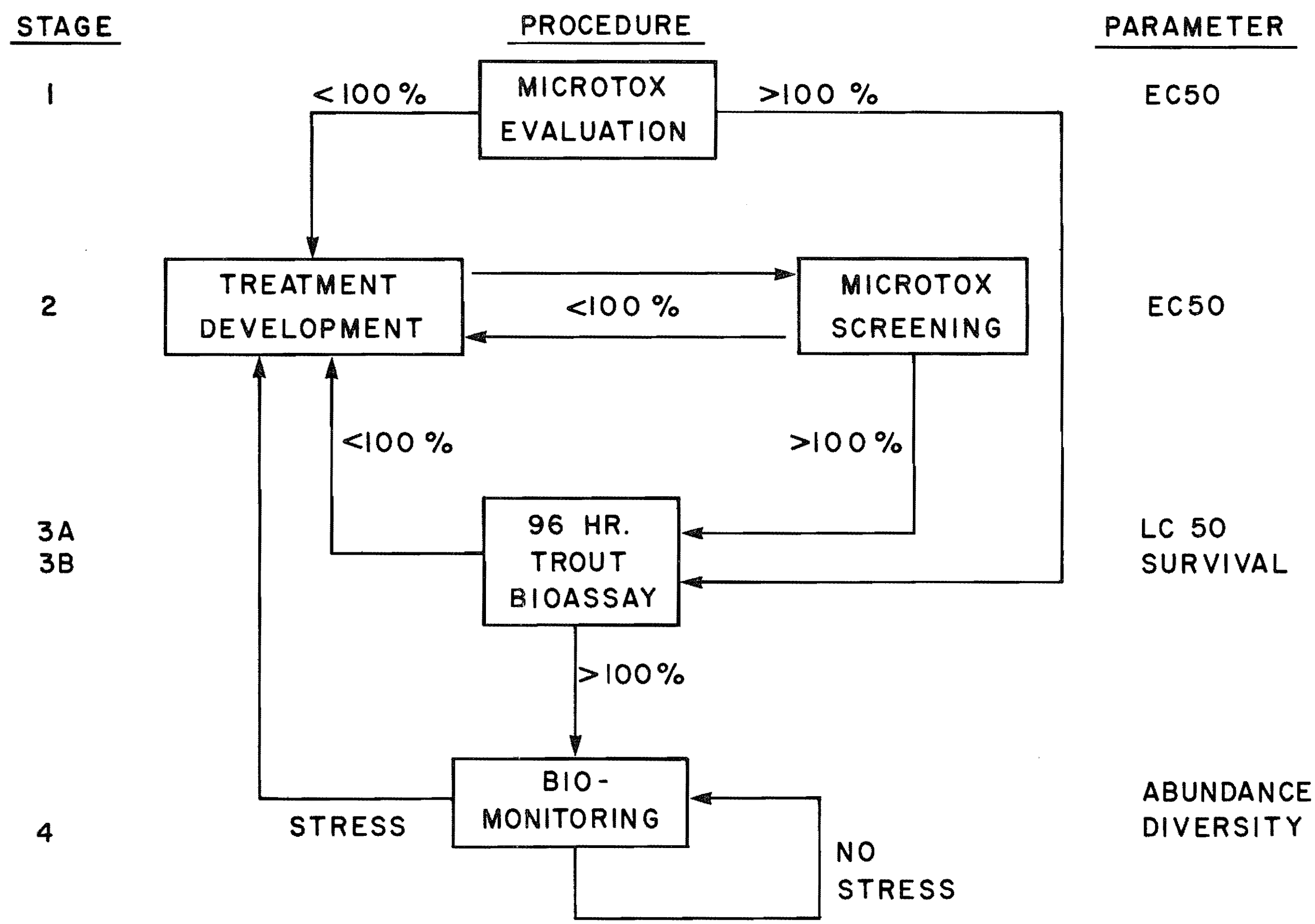

Figure 7. Schematic representation of the sequential toxicity testing procedure for wastewaters. The right-hand column lists the parameters measured at each stage. See text for details.

value in less than 100% the wastewater is classified as unacceptable by regulatory agencies (Environment Canada 1974). It should be noted that an LC_{50} value of 100% indicates that 50% of the fish die in a full strength sample of the test solution during the 96-hour exposure period. In Stage 3B we go a step further and try to achieve 100% survival of trout in the full-strength test solution of tailings pond water. Currently, this level of detoxification of tailings pond water can be achieved with chemical treatment and we are close to achieving it with a 16-month storage period.

Once Stage 3B is achieved, further work would focus on design and cost engineering, obtaining approval from the required regulatory agencies, and construction of the treatment facility. During this time, a biomonitoring program would be developed as indicated in Stage 4. This involves surveys of the receiving water prior to discharge to establish baseline conditions both upstream and downstream of the proposed discharge point. Species abundance and diveristy are the two most commonly used test parameters. Additional surveys would be conducted at regular intervals after initiation of discharge in order to assess the environmental impact of the effluent. Further information regarding the design of biomonitoring programs can be found in Hellawell (1978) and Green (1979).

ACKNOWLEDGEMENTS

We like to thank Mr. Bill Benson and Mr. James Doyle, Syncrude Canada Ltd., for their expert technical assistance with sample collection and preparation and data analysis. Water analyses were done by Chemex Laboratories, Calgary, trout bioassays by Chemical and Geological Laboratories, Edmonton, and *Daphnia* bioassays by E.V.S. Consultants, Vancouver.

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LIST OF FIGURES

ENVIRONMENTAL ASPECTS OF WASTE WATER MANAGEMENT AT AN OIL SANDS DEVELOPMENT IN NORTHERN ALBERTA

M.D. MacKinnon
Syncrude Canda Ltd.

1. INTRODUCTION

Syncrude produces synthetic crude oil from the Athabasca oil sands deposit in Northeastern Alberta. Bitumen is extracted from oil sands using a caustic hot water method and then upgraded to a synthetic crude oil by coking and hydrotreating. In these processes, large quantities of water are required (about 1.5 m^3 per T of oil sand feed). Since 1978, Syncrude has produced over 200 x 10^6 barrels of synthetic crude oil and annual production is projected to be 50 x 10^6 barrels. Over 100 x 10^6 T of oil sand will be mined and waste water volumes will be greater than 120 x 10^6 m^3 per year.

Syncrude follow a "zero discharge" policy and all process-affected waters are retained within a tailings pond. The tailings pond has been built along the Beaver Creek Valley in the northern part of the Lease 17 **(Figure 1)**. The pond is enclosed by dykes constructed of compacted tailings sands that are delivered as slurry of about 50 to 60% tailings solids. About 70% of the plant water requirements are recycled from the low solids (less than 1%) surface zone of the tailings pond. Remaining water needs, mainly for utilities and steam generation, are drawn from the Athabasca River. The tailings pond has been growing at about 25 x 10^6 m^3 per year. Syncrude is required to obtain the necessary information for the eventual reclamation of the tailings pond to a viable land surface or a waterbody that will not need long term maintenance. Reclamation will require the treatment of pond waters to environmentally acceptable levels for either abandonment as a waterbody or discharge with no negative impact on the aquatic systems of the area.

Since 1980, the chemical and physical properties of the tailings pond have been followed. In **Table 1**, some of the differences in general composition of surface zone tailings pond waters and Athabasca River water are compared. Tailings pond waters are high in particulate and dissolved solids and petroleum related organic materials. Also, these waters are acutely toxic

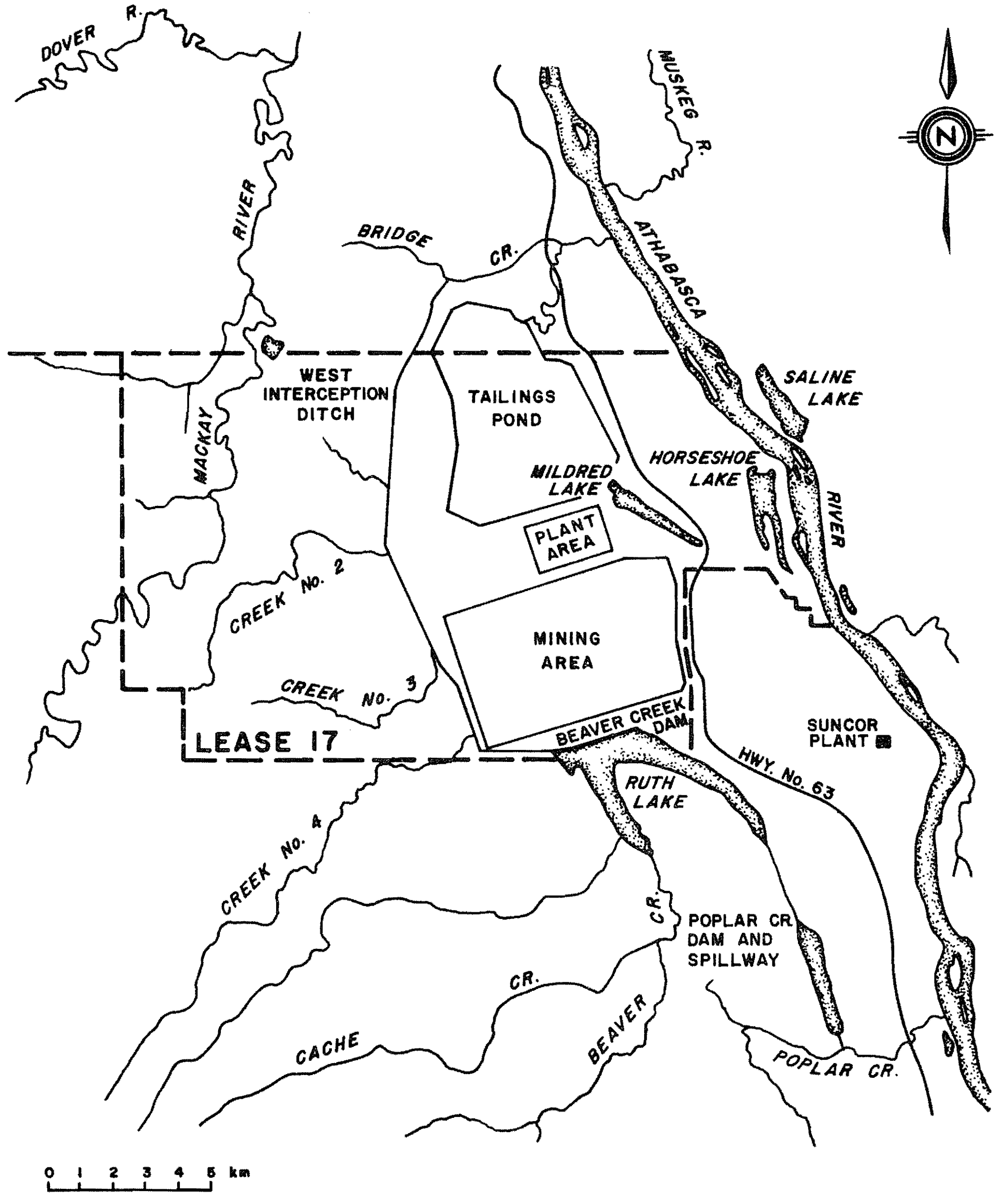

Figure 1. Location of Syncrude's oil sands plant on Lease 17 in Northeastern Alberta.

Table 1: Comparison of chemical, physical and toxicological properties of Athabasca River Water and tailings pond water in 1984. Unless otherwise indicated, units are $mg.l^{-1}$.

Variable	Tailings Pond Water[1]	Athabasca River Water Upstream[2]	Athabasca River Water Downstream[3]
pH	8.1	8.0	7.9
Conductivity ($uS\ cm^{-1}$)	1780	250	210
Dissolved Solids	1200	200	220
Suspended Solids	800	60	120
Odour (units)	4.0	2.0	2.0
Colour (units)	1000	150	125
Turbidity (NTU)	680	140	100
B.O.D.	32	2.5	2.2
C.O.D.	422	35	35
Dissolved Oxygen	2.5	10.0	9.5
Cyanide	.95	.002	.005
Dissolved Organic Carbon ($mg.C.l^{-1}$)	42.5	5.5	5.5
Kjeldahl Nitrogen ($mg.N.l^{-1}$)	7.08	.80	.65
Surfactants (MBAS)	2.00	.1	.10
Tannin and Lignin	9.0	1.3	1.1
Oil and Grease	20.0	1.5	0.5
Phenols	0.15	0.004	0.002
Nutrients			
$NO_2 + NO_3$ ($mg.N.l^{-1}$)	.02	.03	.03
PO_4 ($mg.P.l^{-1}$)	.070	.18	.14
NH_3 ($mg.N.l^{-1}$)	3.00	.05	.08
Major Ions ($mg.l^{-1}$)			
Na	440	5.0	6.5
K	10	0.9	0.9
Ca	7.0	27	27
Mg	4.4	7.3	7.9
F	2.5	.05	.06
Cl	126	1.5	3.3
SO_4	228	19	20
HCO_3	580	115	115
Trace Elements (detection limits in brackets)*			
Ag (.001)	.001**	**	**
Al (.01)	.14	.85	.75
As (.002)	.01	.001	.001
Ba (.01)	.23	.09	.07
B (.02)	1.68	.05	.08
Cd (.001)	.001	**	**
Cr (.001)	**	.002	**
Co (.001)	**	.002	.002
Cu (.001)	**	.005	.005
Fe (.01)	.39	2.0	2.2
Hg (.0001)	.0001	.0001	**
Mn (.004)	.04	.17	.12
Mo (.001)	.08	**	**
Ni (.001)	.01	.003	.002
Pb (.002)	**	.003	.002
Sb (.0002)	.012	**	**
Se (.002)	.011	.0002	.0002
Si (.02)	4.5	4.0	4.2
Ti (.01)	.06	**	**
V (.001)	.020	.004	.003
Zn (.001)	**	.0007	.01
Toxicity			
Fish LC_{50} (%)	LT10	GT100	GT100
Microtox EC_{50} (%)	LT30	GT 100	GT100

*as determined with Atomic Absorption methods. Pond waters were filtered through 0.45 um.
**Below detection limits.
LT - less than; GT - greater than

1. Surface zone tailings pond water.
2. Taken from R.L.L. (1985) upstream of Syncrude at Poplar Creek.
3. Taken from R.L.L. (1985), downstream of Syncrude at MacKay River.

with LC_{50} for trout and *Daphnia* of less than 10% and EC_{50} for bacteria (as measured with the Beckman Microtox Toxicity Analyzer) of less than 30%. Trace element concentrations are higher in the process affected waters but still relatively low. In studies being conducted by Syncrude, various treatment methods for the clarification and detoxification of tailings pond waters have been examined and will be discussed in this paper (MacKinnon and Retallack 1982, Boerger et al. 1985).

Environmental Concerns of Wastewater Storage

Various aspects of the tailings pond operation have been considered potential environmental concerns. To the present stage of its development, the tailings pond has posed little direct environmental impact. Features such as floating bitumen on the pond surface are a hazard to waterfowl of the area. However, through booming and recovery operations, the area covered by bitumen mats has been minimized. Also, an ongoing bird deterrent program has successfully made the pond unattractive to local or migrating waterfowl (Syncrude, 1984). Since the tailings pond is built above grade and is contained by compacted sand dykes, there is a potential of seepage into groundwater or surface waters in the vicinity of the pond. Monitoring of the area with a system of piezometers has not identified any significant intrusion of process affected waters from the pond. With time and as the hydrostatic head of the pond increases, the possibility of seepage into these areas will be closely monitored.

The chemical and biological quality of the waters retained in the tailings pond are poor in relation to natural waters of the area. The present and projected characteristics of these tailings pond waters have received much attention by Syncrude since these waters must eventually be reclaimed. Successful reclamation of the tailings pond will require the production of environmentally acceptable waters. Some of the testing procedures which Syncrude is applying to the evaluation of the effectiveness of treatments for detoxification and removal of toxic effect of tailings pond water will be outlined.

2. METHODS

Surveys of the distribution of tailings pond properties with depth (up to 34 m) and area have been conducted at least four times annually during the open water period since 1980. An outline of the field and laboratory analyses is given in Figure 2. Water and sludge samples are analyzed for conductivity, pH, total solids, suspended solids, bitumen, major cations (Na, K, Mg, Ca), major anions (Cl, SO_4, HCO_3), nutrients, (NO_2, NO_3, PO_4, NH_3), dissolved organic carbon, and minor elements. Most methods are standard procedures described by Alberta Environment (1977).

The acute toxicity of treated and untreated tailings pond water was tested using various bioassay methods. Routine testing was run on the Beckman 15-minute static bioassay using a bioluminescent bacterium (Photobacterium phosphoreum) following the method described by Beckman. The acute toxicity was taken as the concentration of sample required to produce a 20% (EC_{20}) or 50% (EC_{50}) decrease of the light produced by the bacteria (Bulich et al. 1981). Fish bioassays (96-hour static bioassays) using 5 or 10 rainbow trout (Salmo gairdneri) of 0.5 to 1.0 gm in 20 to 25 L were conducted by Chemical and Geological Labs Ltd. (Edmonton) following the method described by Alberta Environment (1978). Each test used 5 effluent concentrations plus control. Ninety-six hour static acute bioassay tests with Daphnia (Daphnia pulex) were conducted by E.V.S. Consultants Ltd. (Vancouver) at 5 concentrations. Three replicates of 5 animals per 100 ml of each concentration were run.

3. GENERAL DESCRIPTION OF SYNCRUDE'S TAILINGS POND

By the end of 1984, the water surface area of the tailings pond was about 13 km^2 and had an elevation of 317.5 m (depths to about 35 m). The volume of water and sludge in the pond was about 170 x 10^6 m^3 (Table 2). The pond is projected to increase to an elevation of 349 m, with a volume of about 450 x 10^6 m^3.

The primary inputs to the pond are tailings from extraction and raw water drawn from the Athabasca River. In Figure 3, a schematic showing current water balances around the pond is given. About 70% of the plant water requirements are taken from the surface zone of the tailings pond, with raw water accounting for about 30% of the water needs. Other water inputs (mine drainage, oil sand feed, and precipitation) are balanced by water losses on the site (steam losses, evaporation).

SAMPLING AND ANALYTICAL SCHEME FOR TAILINGS POND WATERS

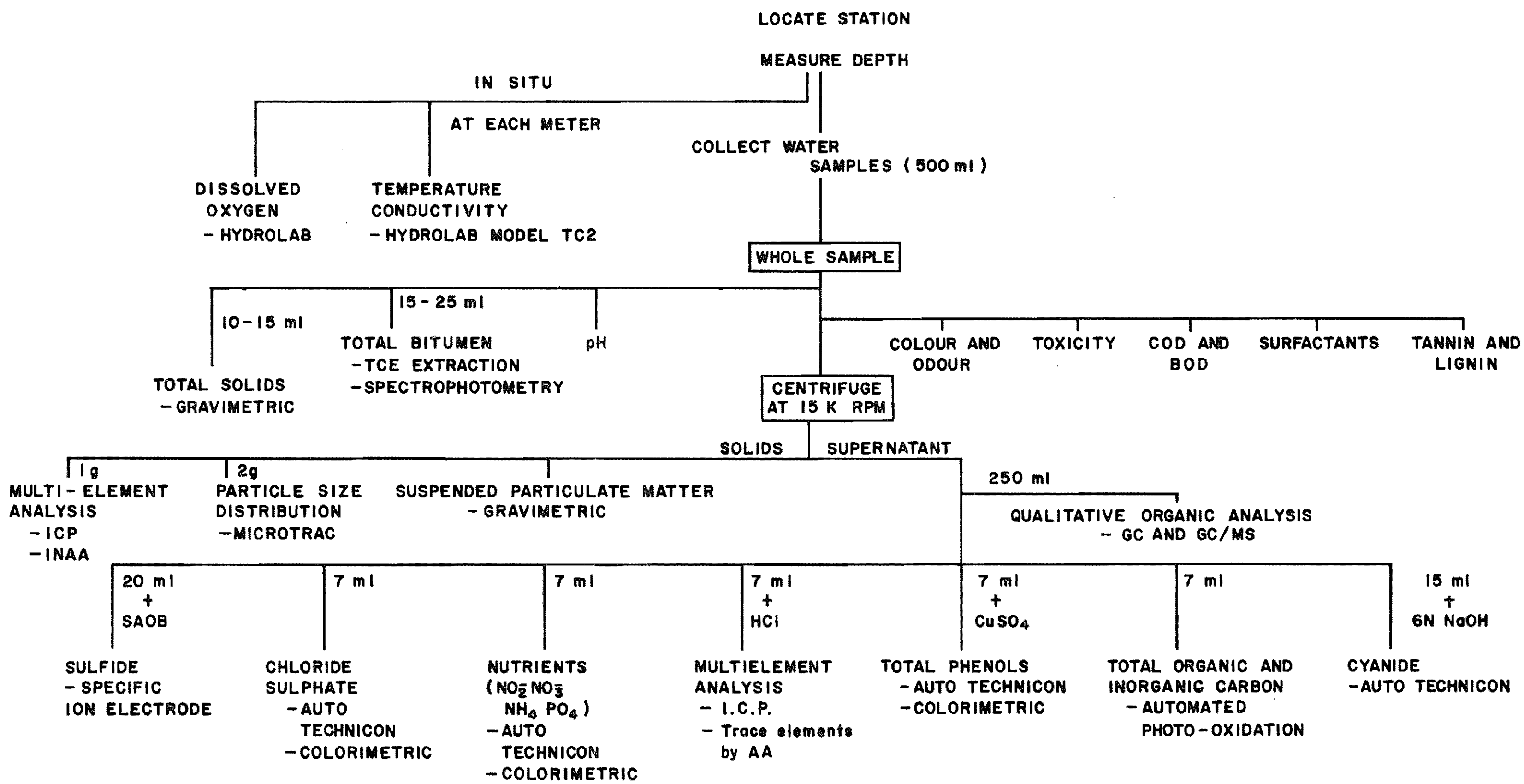

Figure 2. Outline of sampling and analytical methods used to analyse tailings pond waters.

Table 2. General physical characteristics in tailings pond for 1980 - 1984 and for projected levels.

	1980 - 1984*	Projected
Water elevation of Pond (m)	317.5	349
Water surface area (km^2)	13.5	17
Average annual volume of Tailings water delivered to pond (x 10^6 m^3)	110	130 - 150
Average oil sand feed per year (x 10^6 T)	70	100
Recycle water drawn from tailings pond per year (x 10^6 m^3)	75	100
Raw water intake from Athabasca River		
a) Average volume per year	32	26
b) Average m^3 per T of oil sand feed	.44	.26
Other Water to the site per year[1] (x 10^6 m^3)	5.0	6.0
Tailings to Pond to 1984		
a) Solids (x 10^6 T) per year		
i) Coarse (greater than 22 um)	50	80
ii) "Sludge formers" (less than 22 um)	5	8
b) Unrecovered Bitumen (x 10^6 T) per year	.9	.6
Mass of Solids Present in Pond (x 10^6 T)		
a) Coarse fraction (greater than 22 um)	2.0	--
b) "Sludge formers" (less than 22 um)	15.5	--
Pond water volume (x 10^6 m^3)		
a) Total	170	450
b) Low solids zone[2]	105	100
c) Sludge zone[3]	65	350

*Annual average of values for 1980 to 1984.

1. Estimated mine drainage water, site drainage and water in oil sand feed.
2. SPM less than 2%.
3. SPM content more than 3%.

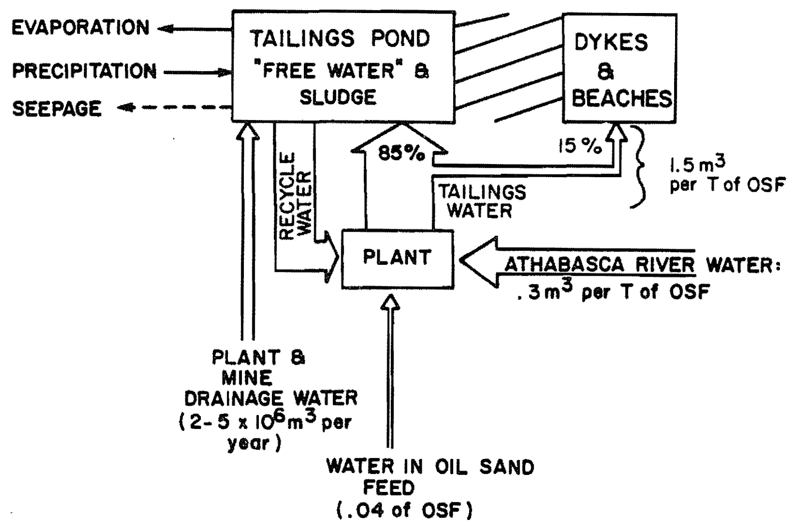

Figure 3. Outline of water balances at Syncrude's oil sands plant, 1984.

Through the input of Athabasca River water, mine and site drainage waters, process chemicals and oil sand tailings, the mass and concentrations of many of the dissolved and particulate components of the pond have increased steadily since 1980 **(Table 3)**. In Table 3, the average concentrations of selected variables from a surface zone (0 to 8 m) and sludge zone (13 to 25 m) for the period 1980 to 1984 are summarized. Comparison of changes within the sludge zone for 1980 and 1981 are limited because there were few samples collected below 16 m. Within the 9 to 11 m depth interval, the thermocline and pycnocline are located and dramatic changes in most variable values are observed. In each year, differences in the solids and bitumen content between the surface and sludge zones are large. Concentrations of dissolved components generally show a smaller difference between the two zones.

During 1980 to 1984, the particulate content of the surface zone has descreased from above .5% to less than .1% (Table 3). Since 1980, over 350 x 10^6 m^3 of the surface zone tailings pond water have been recycled for plant water needs (Table 2). Over 95% of the water used for the extraction process is recycled water. In the sludge zone, the solids fraction has increased with time. Suspended solids content shows a steady increase with depth: below 25 m, total solids content is 40 to 50%. Initial settling of the tailings solids input to the pond to levels of 15 to 20% occurs rapidly (several weeks) (Yong et al. 1983). Consolidation beyond the 20% is slower. In the mass balances of the solids and bitumen components of the tailings pond, the extraction tailings account for most of the material added to the pond **(Figure 4a and b)**. However, with the loss of the solids and bitumen fractions during dyke and beach building around the pond and settling and adsorption to sediments, only a small fraction of the tailings solids (about 5%) and the bitumen in the tailings (about 15%) are actually suspended within the tailings pond (Table 2). In **Figure 5**, the average distribution of solids in 1984 showed an increase in the particulate fraction with depth to values over 40%. However, the relative proportion of the coarse solids content (greater than 22 um) increases with depth, from less than 10% at 15 m to over 30% at 25 to 30 m. The concentration of the "sludge-forming" solids (less than 22 um) and clay (less than 2.8 um) shows little change over depth below Table 3.

Table 3: Comparison of averaged variable levels in tailings pond for the period 1980 - 1984. Standard deviation and range are given.

	For Depth Zone = 0 - 8 m					For Depth Zone = 13 - 25 m				
	YEAR					YEAR				
Variable	1980	1981	1982	1983	1984	1980	1981	1982	1983	1984
pH	8.12 ± .18 7.53 - 8.53	8.00 ± .12 7.50 - 8.40	8.01 ± .12 7.50 - 8.40	8.08 ± .04 8.00 - 8.10	8.18 ± .13 8.00 - 8.45	8.3 ± .2 8.0 - 8.7	8.2 ± .3 7.3 - 8.6	8.4 ± .2 7.9 - 8.6	8.4 ± .1 8.3 - 8.5	8.4 ± .1 8.2 - 8.6
Conductivity (uS.cm^{-1})	1150 ± 218 240 - 1533	1560 ± 89 1380 - 1750	1510 ± 213 1120 - 1780	1760 ± 78 1630 - 1840	1740 ± 56 1600 - 1820	1120 ± 120 870 - 1360	1130 ± 120 800 - 1400	1080 ± 160 750 - 1400	1240 ± 90 1060 - 1420	1260 ± 50 1180 - 1400
Total Solids (%)	.77 ± .26 .56 - 2.15	.32 ± .06 .20 - .65	.20 ± .03 .12 - .37	.20 ± .02 .17 - .23	.18 ± .02 .16 - .21	7.9 ± 1.0 2.4 - 38.5	16.8 ± 5.5 1.3 - 23.3	24.4 ± 5.7 14 - 36	27.5 ± 5 19 - 39	27.0 ± 6 15 - 40
Bitumen (mg.l^{-1})	349 ± 220 113 - 2000	80 ± 37 1 - 250	37 ± 30 1 - 207	47 ± 17 20 - 86	29 ± 21 1 - 81	.7 ± 1.3 .1 - 7	1.2 ± 1.0 .1 - 6	2.0 ± 1.4 .2 - 7	2.7 ± 1.5 .2 - 7	1.6 ± 1.5 .1 - 6
TOC (mg.Cl^{-1})	48 ± 8.3 36.0 - 80.0	47 ± 7 39 - 68	43 ± 8 30 - 80	43 ± 5 33 - 53	45 ± 3 40 - 53	54 ± 13 37 - 88	70 ± 20 43 - 150	54 ± 13 30 - 130	56 ± 12 36 - 100	48 ± 3 40 - 56
Major Ions (mg.l^{-1})										
Na	282 ± 17 224 - 338	318 ± 24 221 - 371	390 ± 21 350 - 430	407 ± 15 350 - 440	444 ± 14 406 - 484	270 ± 23 201 - 316	276 ± 35 203 - 350	347 ± 27 248 - 407	357 ± 23 292 - 410	398 ± 27 336 - 465
K	14.3 ± 6.1 5.5 - 26.2	11.8 ± 3.7 5.1 - 18.8	8.5 ± 1.5 3.8 - 12.9	6.7 ± 1.7 1.5 - 11.3	9.9 ± 1.2 8.1 - 12.7	23 ± 13 7 - 56	25 ± 15 9 - 67	9 ± 2 3 - 16	9 ± 2 4 - 15	12 ± 2 8 - 17
Ca	6.2 ± .7 4.1 - 8.1	5.8 ± .6 3.6 - 8.1	6.8 ± .6 5.5 - 8.3	6.1 ± .3 5.6 - 6.9	6.9 ± .4 6.2 - 7.8	4.5 ± .6 4 - 7	5.7 ± 1.7 4 - 10	4.5 ± .6 3 - 6	4.6 ± .6 4 - 8	4.6 ± .5 3 - 6
Mg	4.5 ± .6 3.2 - 8.0	3.7 ± 7 2.5 - 8.4	3.9 ± .3 2.6 - 4.7	3.9 ± .2 3.6 - 4.5	4.4 ± .2 4.0 - 4.8	5.3 ± 2 3 - 11.5	6.8 ± 4 3 - 21	2.7 ± .3 2 - 3.6	2.8 ± .4 2 - 5	2.9 ± .3 2 - 4
Cl	78 ± 6 59 - 95	96 ± 6 87 - 110	107 ± 5 94 - 119	111 ± 7 99 - 128	126 ± 5 118 - 140	72 ± 8 50 - 95	78 ± 14 53 - 110	91 ± 10 61 - 110	94 ± 10 73 - 110	106 ± 8 91 - 123
SO_4	194 ± 16 125 - 255	202 ± 13 160 - 243	214 ± 7 187 - 238	226 ± 10 104 - 250	228 ± 8 213 - 143	111 ± 40 3 - 190	56 ± 56 10 - 190	40 ± 30 6 - 160	21 ± 11 2 - 54	38 ± 17 13 - 91
HCO_3	454 ± 37 305 - 534	535 ± 17 503 - 604	536 ± 35 467 - 589	594 ± 30 503 - 660	583 ± 57 457 - 675	504 ± 42 410 - 610	600 ± 80 490 - 900	665 ± 56 530 - 790	720 ± 50 510 - 810	733 ± 62 520 - 850
Total Ions (meq.l^{-1})	26.6 ± 1.5 21.5 - 31.9	27.1 ± 3.3 21.7 - 34.7	33.9 ± 1.4 30.8 - 35.9	35.9 ± 1.1 32.7 - 37.8	37.9 ± 1.1 35.3 - 41.2	25 ± 2 19 - 29	16 ± 4 20 - 35	30 ± 2 25 - 34	31 ± 2 24 - 34	34 ± 2 30 - 37
Na/Cl (meq./meq.)	5.6 ± .3 4.6 - 6.6	5.4 ± .6 4.2 - 7.3	5.6 ± .4 4.7 - 6.7	5.7 ± .3 4.8 - 6.4	5.4 ± .3 4.7 - 6.0	5.8 ± .5 4.3 - 6.5	5.6 ± .6 4.5 - 7.3	6.0 ± .5 4.5 - 7.5	5.9 ± .3 5.1 - 6.7	5.8 ± .4 5.0 - 6.6
Nutrients										
NO_2 + NO_3 (mg.N.l^{-1})	.06 ± .06 .01 - .22	.02 ± .03 .0 - .24	.01 ± .01 .0 - .02	.02 ± .02 .0 - .11	.02 ± .01 .0 - .04	.08 ± .08 .02 - .4	.24 ± .21 .02 - .7	.13 ± .1 .02 - .5	.07 ± .06 .0 - .4	.05 ± .01 .02 - .1
NH_3 (mg.N.l^{-1}	.	3.83 ± 1.3 .4 - 5.4	3.72 ± 1.0 2.5 - 6.9	3.74 ± .6 3.0 - 4.7	3.1 ± .3 2.5 - 3.4	.	4.4 ± 2 2 - 10	4.9 ± .8 3 - 7	5.8 ± .6 4 - 7	5.9 ± 1.3 4 - 8
PO_4 (mg.P.l^{-1})	.13 ± .12 .03 - .70	.08 ± .05 .03 - .33	.05 ± .02 .02 - .16	.04 ± .02 .02 - .09	.06 ± .04 .02 - .14	.21 ± .16 .1 - .9	.7 ± 1.0 .1 - 1.5	.15 ± .1 .0 - .3	.24 ± .10 .0 - .4	.21 ± .1 .1 - .3

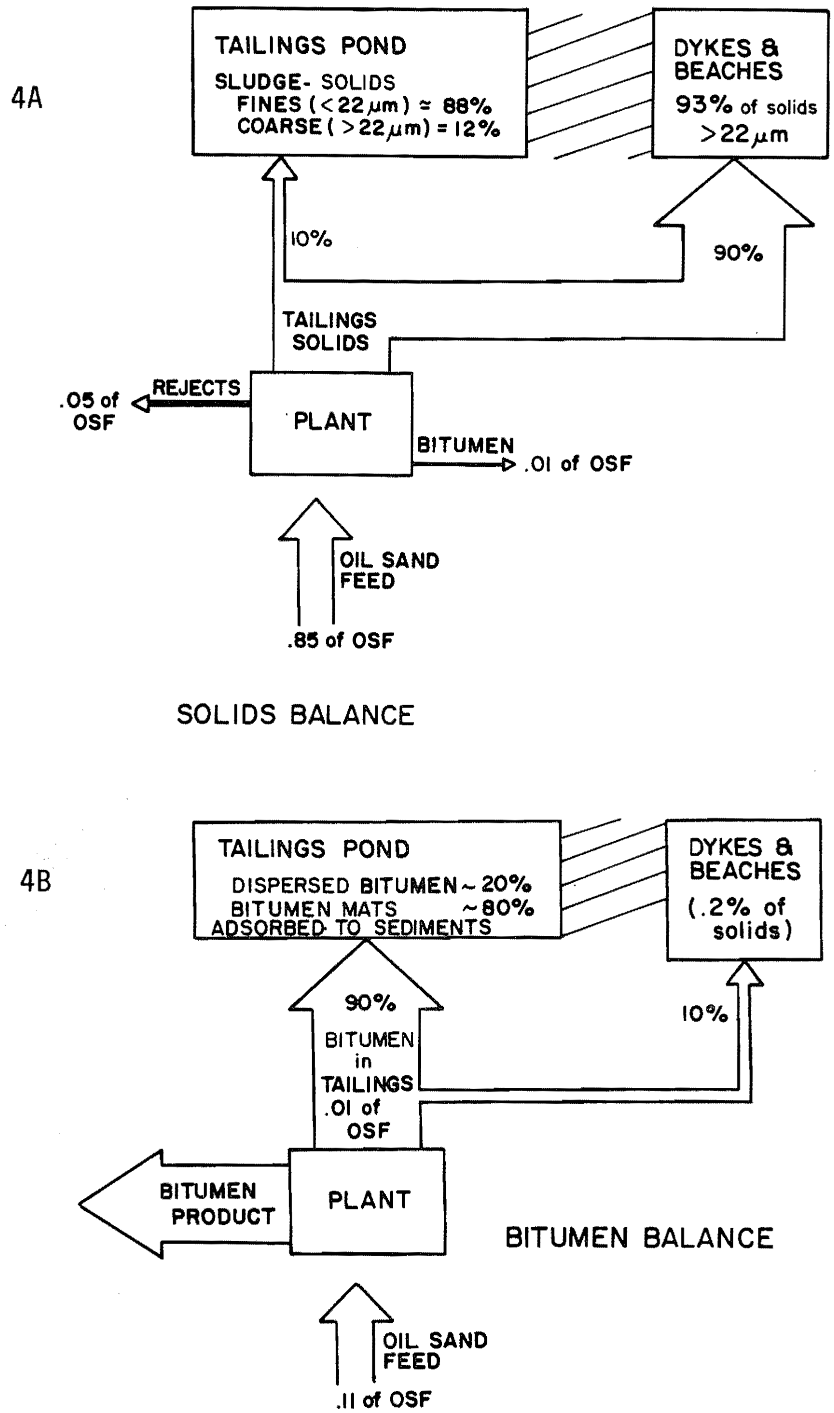

Figure 4. Outline of solids and bitumen balances at Syncrude's oil sands plant, 1984.

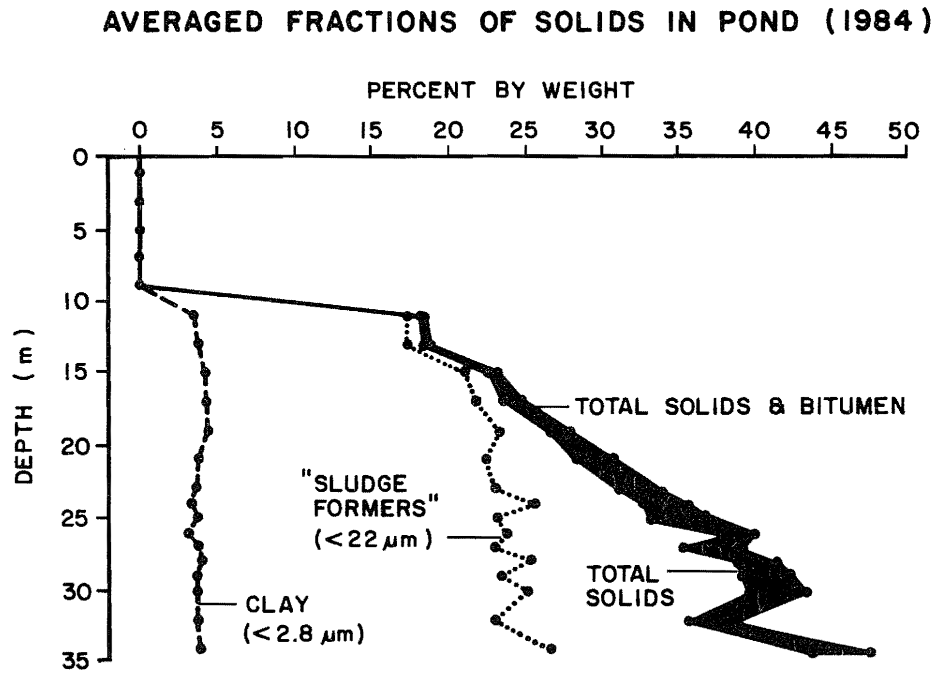

Figure 5. Depth profile of averaged total bitumen and solids content (weight percent) with the "sludge-former" (less than 22 um) and clay (less than 2.8 um) fractions in tailings pond in 1984.

20 m. Bitumen contents in the sludge zone averaged about 8% of the solids. Since operations began, about 5.6 x 10^6T of unrecovered bitumen have been lost to tailings. About 10 to 15% has been captured in dykes and beaches, about 15% is dispersed throughout the pond water column, while the remainder is present in floating surface and subsurface bitumen mats or been bound to sediment interfaces (Figure 4b).

The dissolved solids content in the tailings pond has increased about 35% since 1980 (Table 3). In 1984, the sum of the total ion equivalents of the major ions in the surface zone of the pond was about 35 to 41 meq.l^{-1}, about 15% higher than that calculated in the sludge zone. Other dissolved components include the dissolved organic matter and minor elements. The main inputs of dissolved solids are derived from extraction chemicals, oil sand leachate, saline and surface water drainage, and waste waters. A schematic of the mass balance of dissolved components is shown in Figure 6. The relative distributions of the major ions at various depth zones are shown in Figure 7. At all depths, sodium is the dominant cation: Na represents about 90 to 95% of the total cations, while K, Mg and Ca account for only about 5 to 10%. Most of the sodium is added to the pond from the caustic used in extraction and utilities. The ratio of equivalents of relatively conservative ions of sodium and chloride is high (5 to 6) and changes little with depth or time (Table 3). Bicarbonate is the dominant anion and accounts for 50 to 75% of the total anion equivalents. There is little change in the relative distribution of cations with depth. However, the relative makeup of total anion components varies with depth: dramatic drop of SO_4 levels in sludge zone, slight drop of Cl with depth, increase of bicarbonate concentration with depth (Figure 7). Other dissolved components in the pond waters such as dissolved organic carbon, nutrients and minor elements, have changed little since 1980 (Table 3). Some of the concentrations changes measured with depth or time probably result from sample preparation: colloidal solids of less than 0.45 um may have remained in the sample even after high speed centrifugation (15 K RPM for 30 minutes) and filtration (0.45 um Millipore). The trace metal levels in the filtered samples are quite low and have shown no indications of concentration buildup over time.

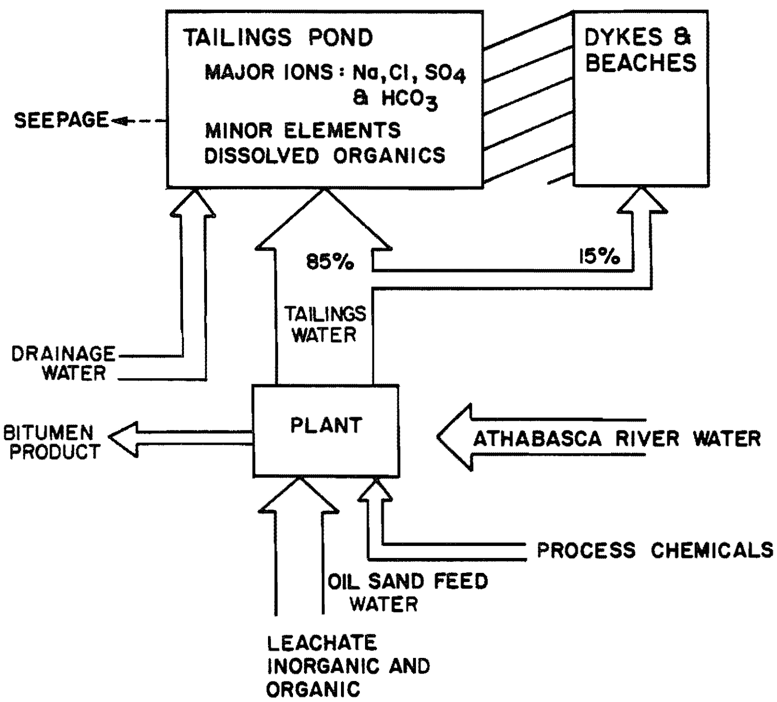

Figure 6. Schematic of balance of dissolved solids at Syncrude's oil sands plant, 1984.

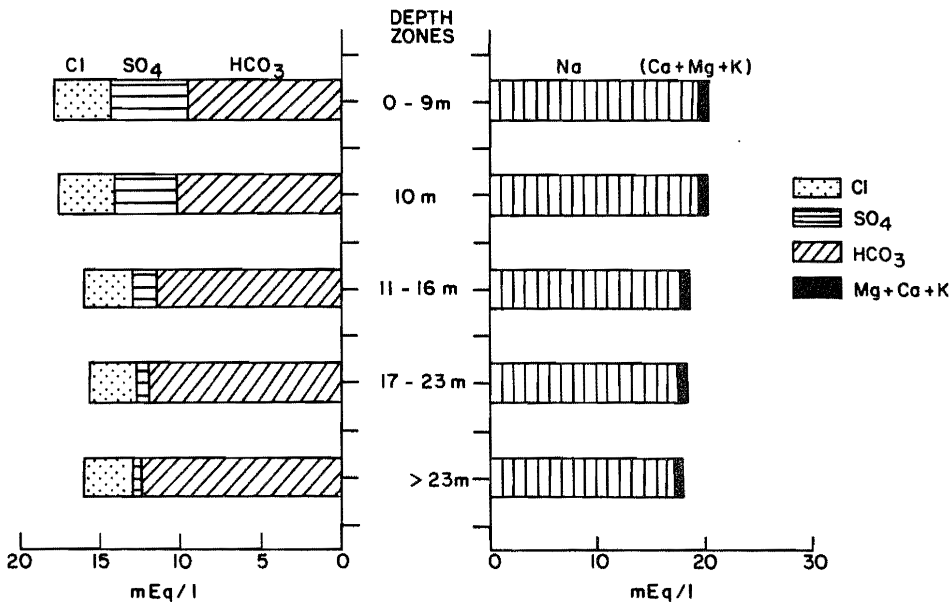

Figure 7. Relative distribution of major anion and cation concentrations (meq. l^{-1}) at various depth zones in tailings pond, 1984.

The waters in the tailings pond are acutely toxic (LC_{50} for fish and Daphnia of less than 10%) The high suspended solids and bitumen levels are probably partially responsible for this toxic effect. Most of the toxic character of the pond water has been isolated in the polar acidic organic fraction. These components are probably derived primarily as a dissolved organic leachate of the bitumen during extraction with the caustic hot water process. This will be discussed in more detail later.

Summary of Tailings Pond Structure

Based on the pond surveys, the structure of the pond can be simplified into two density zones: 0 to 10 m, low solids, low density well mixed surface zone, and below 11 m, high solids sludge zone with little active mixing where solids content and density steadily increase with depth. The interface between the zones has remained relatively constant at between 10 to 11 m depth. This interface is very sharp, with a change from less than .1% to over 10% solids in less than 30 cm. At present, the surface zone of the pond contains about 2/3 of the waste water volume (Table 2). Treatment methods have been developed for both the rapid clarification and detoxification of this water using chemical methods (MacKinnon and Retallack, 1982) and a slower natural process using aging and biological degradation of toxic components contained in the pond waters (Boerger and Aleksiuk, 1985). These methods must be evaluated for their potential application to the eventual reclamation of the tailings pond.

4. RECLAMATION OF TAILINGS POND WATER BY TREATMENT

The effectiveness of selected physical and chemical methods for detoxification and clarification of the low solids surface zone of tailings pond waters was reported by MacKinnon and Retallack (1982). The most successful treatments involved coagulation through adjustment of pH to less than 5 followed by flocculation with an anionic polyelectrolyte. The treatment procedures and methods used for evaluating the rate of clarification and toxicity of produced water are outlined in **Figure 8.** The properties of the water, turbidity, acute toxicity (Microtox bioassay) and general water chemistry were determined prior to and after treatments.

Greater than 95% of the suspended solids in surface pond water are in the fine silt fraction less than 22 um (MacKinnon et al. 1985). In the oil sand deposit, the solids are classed as being "water wet", which means that the solids are surrounded by a layer of water. This water layer is maintained during the caustic hot water extraction and in the tailings solids added to the tailings pond. Settling of these "water wet" fines is very slow (Camp, 1977). The addition of a coagulant aid such as acid (H_2SO_4) or alum ($Al_2(SO_4)_3$) destabilizes and breaks down this water layer so that the fines are brought together and agglomerate to fine flocs (Stage 1, **Figure** 8). Synthetic polyelectrolytes, such as the medium charge density and molecular weight, anionic polyacrylamide polymers (CFA30 from Crossfield Polyelectrolytes), aggregate these fine flocs to larger flocs which settle rapidly from solution (Stage 2 and 3). After the coagulation step, the solids are surface active and will absorb hydrophobic species in the treated water. With acid as the coagulant aid, the organics absorbed will be primarily the acid-neutrals. With alum treatment, it will be mainly neutral components, while with alkaline treatment, the base-neutrals should be removed. In the earlier study by MacKinnon and Retallack (1982), the acute toxicity of the pond water produced by treatments using high pH conditions (pH greater than 10) was not reduced. However, treatment under low pH conditions produced waters with no acute toxicity by fish (trout and fathead minnows), Daphnia, and bacteria (Microtox) with LC_{50} or EC_{50} levels of greater than 100%.

The effect of three chemical treatments on the chemical and toxic properties of surface zone tailings pond water confirmed that acidification as a coagulant aid results in detoxification of the pond water (Table 4). The procedure outlined in Figure 8 was followed. Treatment 1 (T1) and Treatment 2 (T2) used acidification as the coagulant: T1, pH adjustment to 4.5 with H_2SO_4, T2, pH adjustment to 4.5 with H_2SO_4 plus 5 $mg.l^{-1}$ of an anionic polyelectrolyte (CFA30). In Treatment 3 (T3) alum ($Al_2(SO_4)_3$) at 100 $mg.l^{-1}$ was used as the coagulant aid with 5 $mg.l^{-1}$ of the anionic polyelectrolyte, CFA30. After treatment, the samples were allowed to settle undisturbed for 24 hours.

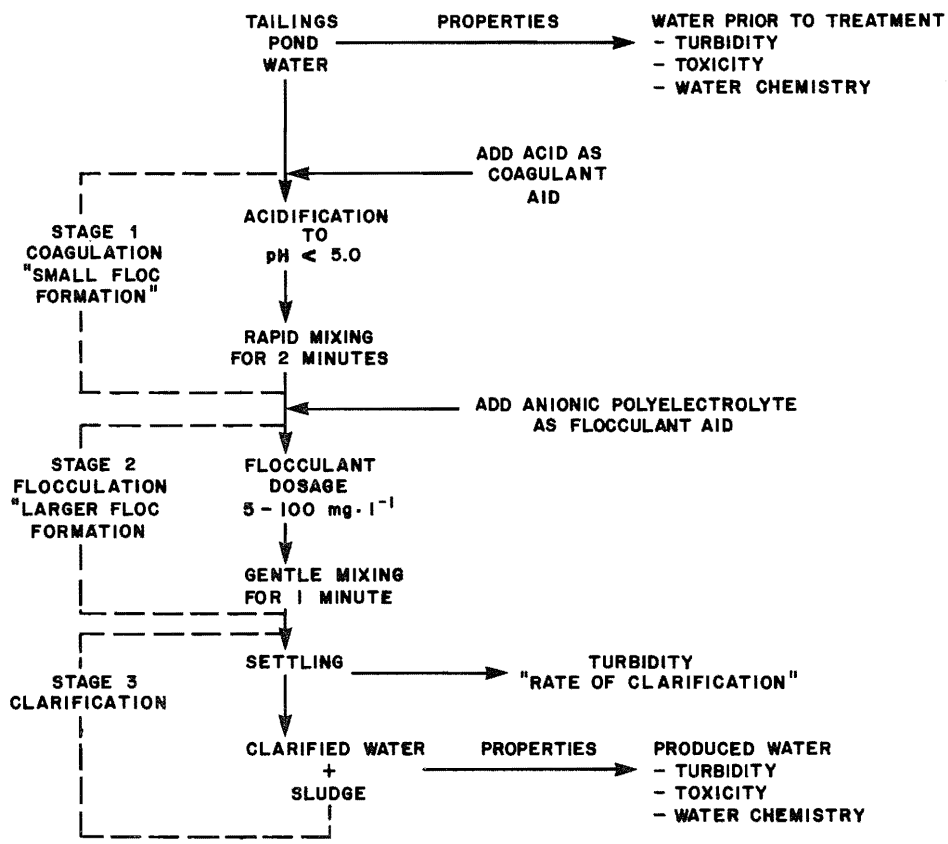

Figure 8. Outline of treatment for clarification and detoxification of tailings pond water using coagulation and flocculation.

The rate of clarification for each of the treatments was followed by measuring the suspended solids content with time (Figure 9). Over the 24-hr period, the untreated pond water sample (Reference sample) showed little decrease in the suspended solids content while all three treatments show greater than 85% removal. The produced water from the acid treatment (T1) settled more slowly than those treated with the anionic polyelectrolyte (T2 and T3). The flocculant greatly accelerated the rate of settling and most of the solids (greater than 95%) were removed within the initial 10 minutes (Figure 9).

The waters produced by all three treatments were similar except for those changes resulting from the addition of reagent chemicals (Table 4). In all three treatments, the water showed lower levels of suspended solids, oil, colour, BOD, COD, tannin and lignin, and some of the minor elements than those in the untreated pond water (Table 4). The levels of minor elements were not greatly affected by the treatments. Generally, there were increases in the V and Zn concentrations and decreases in the Ba and Ti levels. With the acid treatments (T1 and T2), levels of Fe, Mn, and Mo increased, while Al and Sb decreased. With alum treatment (T3), Fe was effectively removed from the sample while Al showed a slight increase. In the treatments using acidification, addition of reagents such as H_2SO_4 and NaOH had the effect of increasing the dissolved solids levels. While the chemical and physical composition of the waters produced by the treatments described in Table 4 were similar, it was only the treatments using pH adjustment to less than 5 that showed a significant decrease in the toxicity of the produced waters (Table 4). With acidification (T1 and T2), the toxicity of the untreated tailings pond water (EC_{50} = 43%, LC_{50} less than 10%) was reduced: LC_{50} with fish and Daphnia bioassays and EC_{50} with bacteria (Microtox) bioassay were greater than 100%. Little reduction in the toxicity with the fish or bacterial bioassays was found with the alum treatment (T3) (an improvement in the Daphnia LC_{50} from 2 to 38% probably resulted from the solids removal, MacKinnon and Retallack 1982). In the treatment involving acidification to pH of 4.5 (T1 and T2), the fish bioassay showed no mortality or even stress after 96 hours.

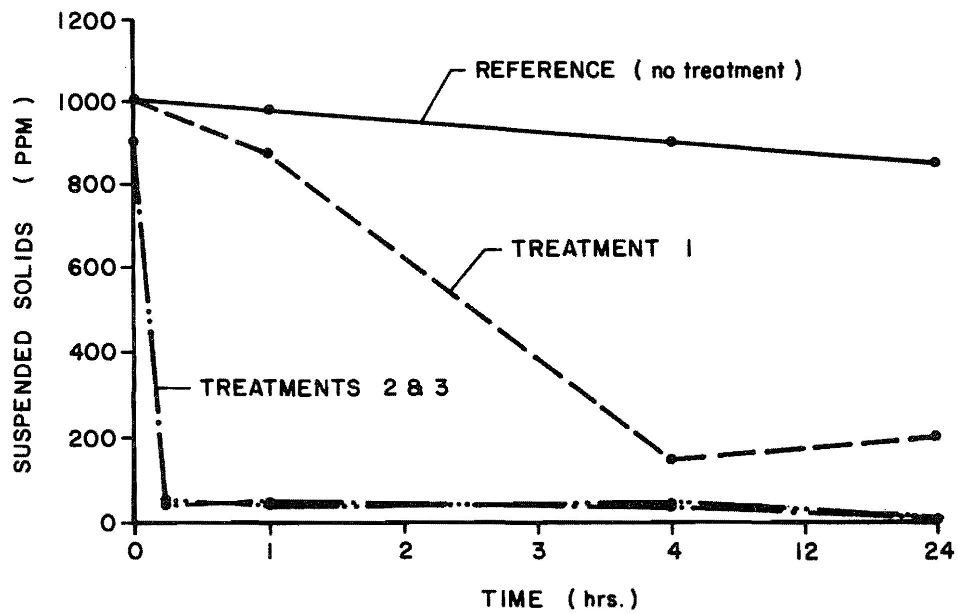

Figure 9. Rate of suspended soilds removal in surface tailings pond water and without treatments, as described in Table 4.

Table 4: Comparison of physical, chemical and toxicological properties of water from Syncrude's Tailings Pond (TP), as well as that obtained by treatment of tailings pond water with acid (TI), with acid and flocculant (T2), with alum and flocculant (T3). GT = greater than, LT = less than

Parameter	Units	Untreated Tailings Pond Water (TP)	Treated Tailings Pond Water: Acid Alone T1*	Treated Tailings Pond Water: Acid + Anionic Polyelectrolyte T2*	Treated Tailings Pond Water: Alum + Anionic Polyelectrolyte T3
General Parameters					
pH	pH units	8.1	8.3	8.4	8.3
Conductivity	uS/cm	1410	1900	1790	1350
Dissolved solids	mg/l	1191	1750	1570	1300
Suspended solids	mg/l	1007	160	20	20
Turbidity	NTU	680	78	34	32
Color	TCU	1000	300	200	200
BOD	mg/l	32	19	12	15
COD	mg/l	422	189	299	289
Tannin + Lignin	mg/l	9.0	4.5	3.5	3.5
Dissolved oxygen	mg/l	2.0	8.0	8.0	8.0
Oil + grease	mg/l	19.0	5.0	2.9	12.0
Surfactants (MBAS)	mg/l	2.00	1.95	1.90	2.05
Phenols	mg/l	0.150	0.145	0.125	0.007
Cyanide	mg/l	0.950	0.920	0.920	0.950
Major Ions					
Sodium	mg/l	395	540	525	390
Potassium	mg/l	9.0	8.5	9.1	8.5
Magnesium	mg/l	3.3	3.4	3.4	3.5
Calcium	mg/l	8.1	7.3	7.3	6.7
Chloride	mg/l	117	114	116	114
Sulphate	mg/l	215	605	595	250
Bicarbonate	mg/l	661	429	393	620
Fluoride	mg/l	2.50	2.50	2.12	2.12
Nutrients					
Total Organic	mg C/l	42.5	40.0	42.5	43.5
Total Kjeldahl	mg N/l	7.1	5.0	6.6	6.6
Nitrite + Nitrate	mg N/l	0.02	0.04	0.08	0.12
Ammonia	mg N/l	2.87	2.57	2.82	2.20
Phosphate	mg P/l	0.070	0.030	0.020	0.200
Minor Elements (Dissolved)					
Aluminium (10)**	ug/l	140	130	90	160
Antimony (0.2)	ug/l	12.0	12.0	6.5	12.0
Arsenic (0.1)	ug/l	7.1	9.4	10.5	4.7
Barium (10)	ug/l	230	180	130	90
Boron (20)	ug/l	1680	1740	1720	1720
Cadmium (1)	ug/l	LT1	LT1	LT1	LT1
Chromium (1)	ug/l	4	1	LT1	LT1
Cobalt (1)	ug/l	LT1	3	LT1	LT1
Copper (1)	ug/l	2	LT1	LT1	LT1
Iron (10)	ug/l	390	510	760	10
Lead (2)	ug/l	LT2	LT2	LT2	LT2
Manganese (4)	ug/l	41	95	57	44
Mercury (0.10)	ug/l	0.16	LT0.10	0.10	0.10
Molybdenum (1)	ug/l	63	110	110	62
Nickel (1)	ug/l	14	15	14	15
Selenium (0.2)	ug/l	10.6	9.5	12.2	9.7
Silica (as SiO_2 (20)	ug/l	4500	5250	4520	4500
Silver (1)	ug/l	LT1	LT1	LT1	LT1
Titanium (10)	ug/l	60	LT10	LT10	LT10
Vanadium (1)	ug/l	24	100	136	34
Zinc (1)	ug/l	1	19	19	8
Toxicity					
Trout	LC_{50} (%)	7	GT100 (100% survival after 96 hours)	GT100 (100% survival after 96 hours)	7
Daphnia	LC_{50} (%)	2	93	GT100 (100% survival after 96 hours)	38
Microtox	EC_{50} (%)	43	GT100	GT100	45
	EC_{20} (%)	9	20	20	11

*pH of treated waters readjusted to about pH 8 with NaOH prior to analysis.
**Numbers in brackets are detection limits in $ug.l^{-1}$. Samples were filtered through 0.45 um Millipore.
LT = less than

Daphnia results were very similar and essentially showed no mortality in the produced water after 96 hours. The acute toxicity levels with the alum treatments showed little change from the results obtained with the untreated sample (Table 4). The level of survival of the fish and *Daphnia* in the water produced by the alum treatment was low. As discussed by MacKinnon and Retallack (1982), there is effective removal of toxicity under reduced pH conditions, but no significant reduction in acute toxicity under neutral or alkaline conditions (Table 4). The main toxic components in tailings pond waters appear to be organic compounds in the polar acidic fraction. Within this fraction, components with properties consistent with naphthenic acids have been tentatively identified (Zenon 1984). These lower molecular weight polar organic acids are natural surfactants which are derived from the caustic extraction of petroleum products (Schramm et al. 1984). With the caustic hot water extraction of oil sands, the leaching of these organic acids would be enhanced and this would lead to their high levels in the tailings pond waters. Under natural leaching conditions of the oil sands in the McMurray Formation, some input into the surface waters of this region is to be expected. The naphthenic acids are quite toxic, with an EC_{50} of about 8 mg/L^{-1} (EC_{20} about 3.7 mg/L^{-1}) (Zenon 1984). If a major fraction of the tailings pond water toxicity were the result of these polar, carboxylic acid surfactants, then those treatments where pH is adjusted to less than 5 would likely lead to their adsorption onto surface active particles during coagulation and destabilization of the fines. The settling of the coagulated fines would sweep these toxic organics from the system and leave non-toxic, clarified water. The efficiency of the removal is dependent on the suspended solids levels in the sample (MacKinnon, et al. in prep.). The carboxylate surfactants have been found to be labile under natural conditions, so it is expected that some degradation will occur during storage of waste waters (Schramm et al. 1984). Besides the loss of these natural surfactants, other toxic components present in tailings pond waters are expected to readily mineralize.

Over 90% of the low molecular weight phenols in tailings pond waters were found to be lost during only 48 hours storage at 4°C with no preservative

(Hargesheimer et al. 1984). The natural microbial population in tailings pond waters have been shown to mineralize over 50% of C^{14}-labelled organic compounds such as phenol, glycolic acid, and glutamic acid in only four days at 15°C (Foght et al. 1985). Also, the mineralization of hexadecane and phenantherene were reported but the rates were slower. Under natural conditions in large shallow pits with good levels of aeration, a dramatic decrease in the concentration of components such as phenols (to less than 10 ppb), cyanide (to about 10 ppb), ammonia (over 50%), COD (over 50%), solids (over 90%) and acute Microtox toxicity (to EC_{50} greater than 100%) was observed over a 1 to 2 year period (Boerger, 1984). It appears that given sufficient time under aerobic conditions, the concentration of many compounds in tailings water will be reduced significantly. This would complement the rapid chemical detoxification treatments described earlier (Table 4). Even without this process, the water produced by acidification as the coagulant aid showed no toxic effects on the fish and Daphnia during the 96 hour static bioassays. Also, long-term survival (up to 44 days) of many organisms indigenous to the area in these treated waters has been shown by Boerger (1984).

5. BIOASSAY TESTING PROCEDURE

In the evaluation of waters produced by various clarification and detoxification treatments of tailings pond waters, a variety of toxicity tests have been applied. This has been based on a hierarchial approach, where the results from a bioassay using one specific test organism are used to decide what next test in the sequence should be applied. For testing of these treated waters, this sequential procedure has been extremely valuable and has aided in the development of successful treatment methods (Boerger et al. 1985). The testing procedure as applied by Syncrude consists of four stages. It is centered on the Beckman Microtox bioassay, the 96-hour static trout bioassay and conventional biomonitoring techniques of the receiving water (Figure 10).

For both treated and untreated tailings pond waters, good correlations between the fish and Microtox bioassays have been found (MacKinnon and

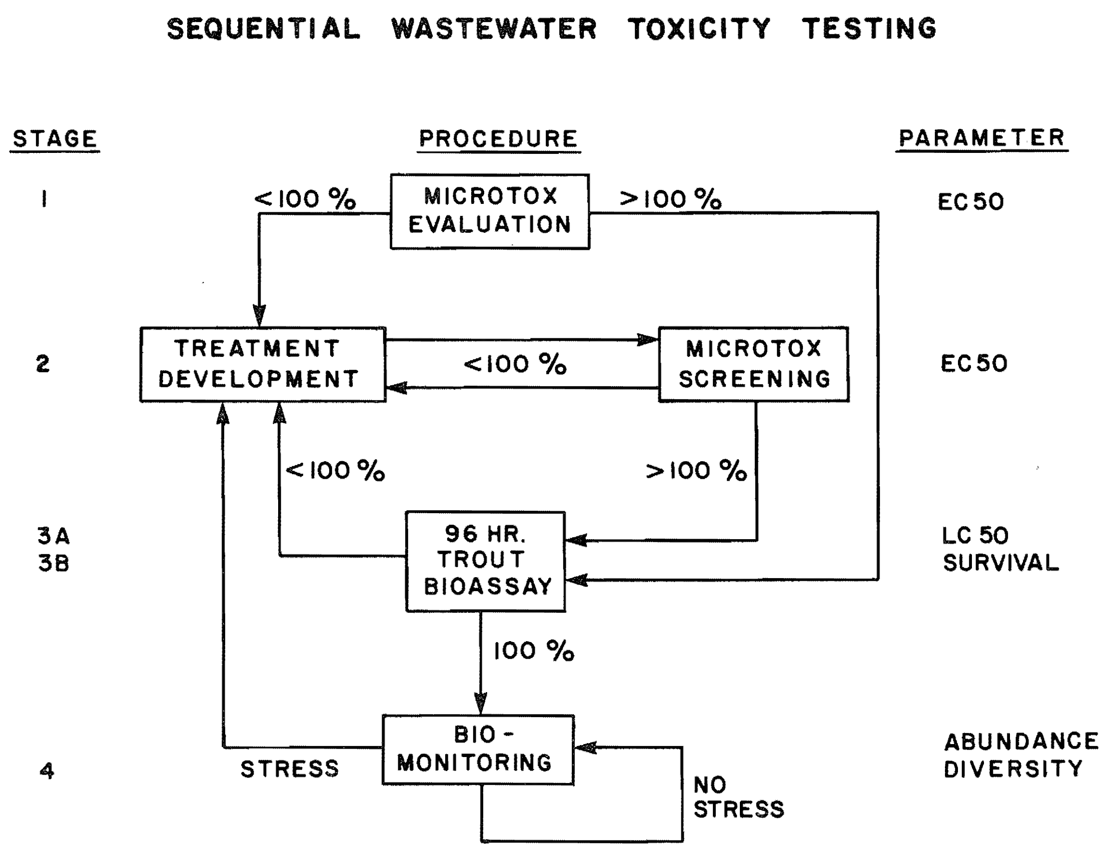

Figure 10. Outline of sequential wastewater toxicity test using a hierarchial approach. Parameters are indicators of toxic response.

Retallack 1982). In Table 4, the EC_{50} and LC_{50} values were similar. For this hierarchial system to be successful, the results of the various bioassay tests must be comparable. Strosher (1983) showed a high correlation ("r" value greater than 0.85) between the bacterial and fish bioassays for waste drilling fluids. Qureshi et al. (1982) examined pure and complex materials and reported comparable results of various bioassays with the Microtox.

In the first stage of the sequential testing procedure, the acute toxicity of the test waters is evaluated by the Microtox bacterial bioassay (EC_{50}). If the Microtox EC_{50} is greater than 100%, then the water is tested using a 96-hour static trout bioassay (Stage 3). If EC_{50} is less than 100%, the water goes to Stage 2, where treatment methods are applied or developed (Figure 10). At this stage, the Microtox is used to screen the effectiveness of various treatment methods. The Microtox bioassay is used at this stage as the bioassay test for routine screening since it is fast (about 15 minutes), uses small volumes of water (about 5 mL), is inexpensive to operate (less than $10 per test) and gives reproducible results with a fairly high degree of precision ($\pm$ 20%). When the treated waters show an EC_{50} of greater than 100%, the water is then evaluated by the fish bioassay (LC_{50}).

In Stage 3, the Microtox results are confirmed with the trout bioassay. The LC_{50} is used to determine toxicity of water. If the LC_{50} value is less than 100%, the wastewater is classified as unacceptable (Environment Canada 1974). An LC_{50} value of 100% indicates only that 50% of the fish die in a full strength sample of the test solution during the 96-hour exposure period. A further requirement in Stage 3 is to achieve 100% survival of the trout over 96 hours in the full-strength solution of the test water (Figure 10). At present, the chemical treatments using acidification of tailings pond water has produced water of a quality which attains this level of detoxification (100% survival of trout over 96 hours in 100% produced water).

The acute testing stages (Stage 1 to 3) may be followed with a biomonitoring program to follow properties such as species abundance and diversity (Boerger et al. 1985). This would assess the potential impact of treated water on the aquatic environment.

6. CONCLUSION

Large quantities of waste water are produced during the processing of synthetic crude oil from oil sand deposits. The water quality is poor in relation to natural waters and will require some degree of treatment for reclamation. In this paper, the present quality of the tailings pond water, the mass balances of major components and changes during the development of the tailings pond have been described. Methods for the rapid clarification and detoxification of these waters using physical-chemical methods of coagulation and flocculation have been developed. Within Syncrude, the evaluation of the environmental acceptability is based on the water quality properties and the assessment of the waters by a sequential bioassay testing procedure. The water produced by the chemical treatments which use acidification to pH less than 5 is of good quality, with no acute toxicity, and high rates of aquatic organism survival over long periods.

7. ACKNOWLEDGEMENTS

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REVIEW OF RELATED R & D

R.R. Germain
Alberta OIl Sands Technology and Research Authority

The following is a brief overview of those areas in which the Authority is involved in the development of technology related to wastewater treatment.

1. **Dry in Kiln Desulfurization - UMATAC**

Negotiations are currently underway with Nova Husky Research to conduct an 18-month study into the use of calcium additives to the oil and sand feed of the Taciuk processor. An earlier study has indicated that the use of calcium additives may provide for complete desulfurization of the flue gases in the combustion zone of the processor with the attendant elimination of capital intensive, downstream, wet, flue gas desulfurization, and its associated waste disposal problems.

2. **Genotoxicity of Process Streams from Alberta Pilots**

The Authority has undertaken a number of studies aimed at assessing the toxicity of various process streams from Alberta pilots. Primarily aimed at produced fluids from in situ operations, samples of condensed connate and sour waters from the Taciuk process are also being examined. These studies are being conducted at the following locations:

* Kananaskis Centre for Environmental Research;
* University of Alberta; and
* B.C. Cancer Research Institute.

3. **Produced Water Treatment**

The Authority has been extensively involved in the development of technology for the treatment and reuse of produced waters from in situ heavy oil and bitumen recovery operations. The following studies have been carried out:

* Walden, a division of Abcor Inc. -- a series of field trails to examine the application of ultrafiltration and reverse osmosis for treatment of produced water.
* Geo Chem Laboratories (Canada) Ltd., Gemini Biochemical Research Ltd. -- a study to investigate the use of micro-organisms to remove hydrocarbons from produced water.
* University of Calgary -- a Ph.D. thesis to investigate the use of reverse osmosis for produced water treatment.
* Hankin Environmental Systems Inc. -- a two-phase study to investigate and optimize Hankin's patented treatment system which includes aeration, dissolved gas flotation, filtration, ozonation, activated carbon adsorption, electrodialysis, and reverse osmosis.
* AOSTRA/Industry Produced Water Treatment Project -- a three-phase study to identify and evaluate existing and potentially applicable processes and systems for the treatment and reuse of produced water.

A REVIEW OF FEDERAL GOVERNMENT RESEARCH DIRECTED TOWARDS TAR SANDS PLANT TAILINGS ISSUES

K. Karr
Environment Canada

FEDERAL GOVERNMENT ENERGY RESEARCH AND DEVELOPMENT FUNDING AGENCIES

The following agencies represent the Federal Government Energy Research and Development funding:

1. National Research Council;
2. Health & Welfare Canada;
3. National Sciences & Engineering Research Council;
4. Energy, Mines and Resources Canada; and
5. Environment Canada.

National Research Council

The major centre for oil sands/heavy oil research and development is the Chemisty Division (Colloid and Clathrate Chemistry Section).

Chemistry division

This division has developed a solvent extraction spherical agglomeration technology (SESA).

Achievements to date include:

1. In collaboration with Petro-Canada, major process modifications to the SESA process are giving improved capability for handling different grades of oil sands.
2. A series of tests, carried out in collaboration with an equipment manufacturer, has demonstrated the technical viability of large scale recovery of residual solvent from agglomerated, solvent extracted oil sand.
3. As a result of successful technical demonstration, a financial agreement has been reached between AOSTRA and NRC to pursue development of the SESA process to pilot plant design stage.

4. Bench scale-tests on centrifuge tailings and pond sludge have achieved over 90% oil recovery efficiencies. This work is being conducted in collaboration with the Alberta Research Council.

NRC Research support programs

There are two research funding programs available through NRC that can aid tailings pond research; they are:

1. Industrial Research Assistance Program (IRAP); and
2. Program for Industry Laboratory Projects (PILP).

Industrial research assistance program

The objective of IRAP is to increase the cabibre and scope of industrial research in Canada in situations where it leads to high business effectiveness with economic and/or social benefit to Canada. The program provides financial assistance towards salaries and fringe benefits paid by a company to scientific and technical staff engaged in approved industrial research projects.

An estimated $1 million was directed towards oil and gas developments in 1984/85 but none of this was for tailings pond research.

Program for industry laboratory projects

The objective of the program is to assist Canadian companies in developing and transferring technology within government laboratories to a more developed stage towards commercial development. PILP supports projects from conceptual stages through prototype and pilot-plant development. A financial contribution arrangement is made with the company.

In 1984/85 approximately $220K was directed towards oil ponds research and development.

A PILP application was approved to use the spherical agglomeration technology developed by NRC and ARC to upgrade low quality feed material (tailings pond sludge) to recover additional bitumen. The proponent later declined the assistance.

Health & Welfare Canada

This department has conducted R&D related to the industrial health aspects of oil sands and heavy oil industries.

Funding 1984/85 - $130 K (PERD)

Achievements:

A critical review of the literature and the current state of knowledge of hazardous chemical substances produced as a result of extraction and processing of oil sands/heavy oil was assessed.

National Sciences and Engineering Research Council (NSERC)

This council is the principal funding source for university R&D.

NSERC strategic grants of $615K in 1984/85 were provided for research in oil sands and heavy oil development ($130K environmental, $485K extraction and processing).

No significant work was conducted in tar sands tailings ponds.

Energy, Mines and Resources

Energy, Mines and Resources R&D in the oil sands is carried out by the Canada Centre for Mineral and Energy Technology (CANMET). CANMET programs are concerned with four district areas of technology, specifically:

1. Bitumen extraction from mined oil sands;
2. Upgrading of bitumen and heavy oil;
3. In situ recovery of bitumen and heavy oil; and
4. Treatment of wellhead emulsions from in situ recovery operations.

Improved environmental compatibility is among the program objectives. Program areas one and two would have some impact on the tailings pond issue.

Office of Energy Research and Development (OERD)

The OERD appears when the Department of Energy, Mines and Resources administers an interdepartmental Panel on Energy Research and Development (PERD). PERD is one of the primary funding mechanisms for energy-related R&D. The total budget for PERD research in 1984/85 was approximately $170 million (includes 311 person years).

The research areas are divided into tasks as per Figure 1. Task 2 covers research directed towards oils sands heavy oil and coal development.

Task 2 is divided into committees as follows (refer Figure 2):

Committee 2.1 - Oil Sands and Heavy Oils
2.2 - Coal Supply
2.3 - Coal Combustion
2.4 - Environment

The Oil Sands and Heavy Oil Committee 2.1 in 1984-85 had funding allocations of $8.5 million (25 person years).

The Environment Committee 2.4 in 1984-85 had funding allocations of $1.2 million (1 person year).

Following a project review and approval process funds are allocated to the various government departments who administer the research projects.

Environment Canada

Environment Canada receives its funds for R&D on tar sands plant environmental issues (including tailings ponds) from Task 2 of PERD.

The Western and Northern Region, Scientific Programs Branch in Edmonton, and the Oil, Gas and Energy Division in Ottawa are the groups initiating or managing research directed towards tailings pond issues.

Two research projects have been funded to date, directed towards tar sands plant tailing pond issues. These projects are:

1. Lime Coagulation of Whole Tailings;
2. Novel Methods for Characterization and Treatment of Toxic Oil Sands Wastewater.

Novel Methods for Characterization and Treatment of Toxic Oil Sands Wastewater

Project objectives:

The ultimate objective of the project is to develop cost-effective treatment methods for tar sands tailings pond water. More specific objectives for project phases are:

Phase I:

i) Characterize tar sands tailings pond water and identify toxic components;

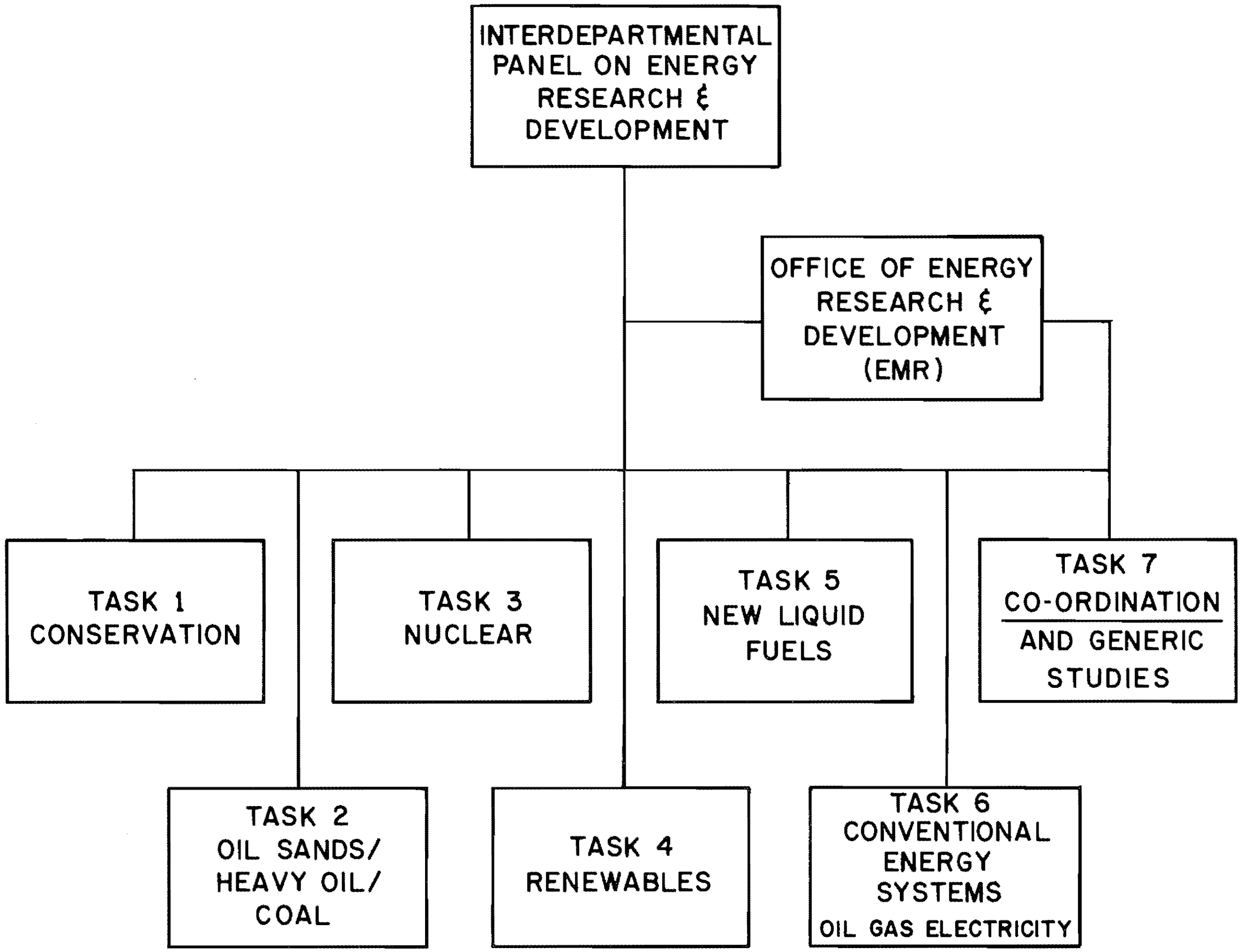

Figure 1. Federal energy research and development co-ordinating structure.

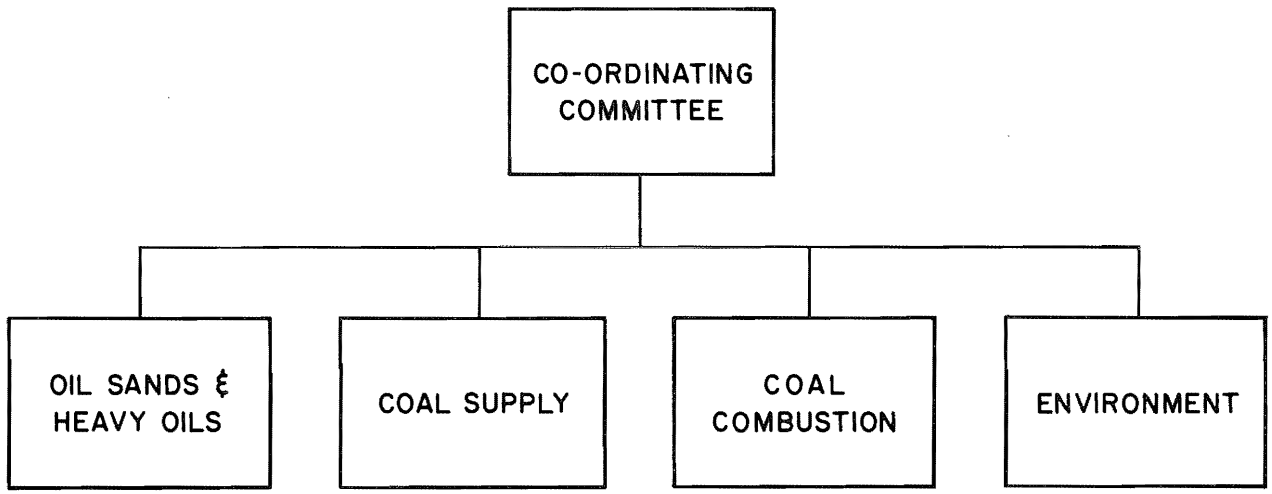

Figure 2. Oil sands/heavy oil/coal task committee structure.

Phase II: Step 1

i) Identify promising treatment alternatives, through laboratory-based bench-scale screening studies; and

ii) Carry out preliminary economic analyses of the most promising alternatives, to assist in selecting the most cost-effective options for further study.

Rationale

The tar sands plants in Alberta have large tailings ponds that contain a pond water that is highly toxic to aquatic organisms. Because of the pond water toxicity, discharge is not permitted. Consequently, the tailings pond water must be contained within large dykes. As the surface level of the pond water is significantly higher than the surrounding area, the dykes must be maintained at a substantial cost.

If a cost-effective treatment technology could be developed so that the pond water could be safely discharged to a river, then problems associated with long-term maintenance of the dykes could be eliminated.

Progress/Findings to date:

Phase I:

1. Toxic pond water was chemically characterized;
2. Chemical separation and analyses in conjunction with Microtox toxicity testing revealed that the acid extractable organics accounted for essentially all of the tailings pond recycle water toxicity. The predominant organics identified were a complex series of carboxylic acids. (Tar Sands Acids) - more specifically - napthenic acids; and
3. A specific analytical method suitable for quantification of the tar sands acid was developed.

Phase II:

Several treatment processes were evaluated for effectiveness and cost.

Reverse osmosis

Provides effective treatment - results in a non-toxic effluent.

Approximate Cost - $\$680/10^3M^3$

Carbon adsorption

Provides effective treatment - results in a non-toxic effluent.

Approximate Cost - $\$630/10^3M^3$

Ultrafiltration

Provides effective treatment and produces water suitable as boiler feed water.

Approximate Cost - $\$270/10^3M^3$

Biological treatment

Provides "significant" toxicity reductions but did not result in a non-toxic effluent. Worthy of further research.

Approximate Cost - Not determined.

Anticipated completion date

1. The Phase I report was completed in 1984.
2. The Phase II - Step 1 final report was received from Zenon on 1986 January 28.
3. The Phase I and Phase II - Step 1 reports will be combined and published as an EPS manuscript series report by the end of April 1986.
4. The project has now been completed by the contractor.

Delays/Problems

The Project Review Committee was informed by Syncrude in Spring of 1985 that they were getting some promising experimental results using an acidification/flocculation process to detoxify the tailings pond water. As a result, Zenon, EPS and Syncrude labs conducted a bench-scale experiment following Syncrude's protocol for acidification/flocculation of tailings pond sludge.

This additional work on acidification caused delays in the program.

The acidification/flocculation process achieved significant reductions in tailings pond toxicity. However, the pond water was not rendered completely non-toxic. With limited experimental work and criteria defining an acceptable treatment level, differences in interpreting the significance of the acidification/flocculation process results have arisen.

Funding:

	1983/84 exp.	1984/85 exp.	1985/86 exp.	Total exp.
Phase I	149	-	-	149
Phase II	-	116.3	30	146.3
Total				295.3

Tables 1, 2, and 3 (from Zenon Phase II Step 1 report) show the results of the "acidification treatment study" conducted by Zenon, EPS and Syncrude labs.

Lime Coagulation of whole tar sands tailings

Project objectives:

1. Develop a commercially economical process to treat whole fresh tar sands plant tailings to yield a trafficable and reclaimable solid fraction and ideally a non-toxic filtrate; and
2. Using laboratory, bench scale experiments, develop a process to treat whole tailings to create a geotechnically suitable material. Evaluate geotechnical properties of the solid portion, the toxicity of the liquid portion and the economics of the proposed process.

Contractor

C-H Synfuels Ltd., Calgary, Alberta

Rationale

The accumulation of tailings pond sludge and a toxic pond water may pose as an environmental problem for many years to come. Construction and long term maintenance of the tailings pond dykes are expensive propositions. A process that could produce a trafficable or geotechnically acceptable material and eliminate the sludge problem is highly desirable. A process that can reduce the toxicity of the water fraction of the whole tailings would also be very attractive.

Progress

A process was developed that included:

1. The addition of lime (optimum dose approx. 990 mg/L) to the whole tailings at the plant end of the tailings pond slurry

TABLE 1

ACIDIFICATION TREATMENT STUDY : CHARACTERIZATION OF PRETREATED TAILING POND WATER

	ZENON	EPS	SYNCRUDE	AVERAGE
GENERAL				
pH	7.55			7.55
total solids (mg/L)	2840	2685		2762.5
total suspended solids (mg/L)	1130	1285	1440	1285
total dissolved solids (0.45u)(mg/L)	1068	1395	1371	1278
turbidity (NTU)	2050	690		1370
ORGANIC				
dissolved organic carbon (0.45u)(mg/L)	183	231		207
dissolved tar sands acid (0.45u)(mg/L)	73	70	51	65
phenol (ug/L)			180	180
TOXICITY				
rainbow trout LD50-96h	8	5.8	7.2	7.0
Microtox EC50 (15,15)	15	25	28	23
Microtox EC20 (15,15)	6.4	6.9	9	7.4
INORGANIC				
Metals (mg/L)				
beryllium	L0.005			L0.005
molybdenum	0.11			0.11
calcium	5.9	4.88		5.39
vanadium	0.005			0.005
aluminum	1.16			1.16
magnesium	5.1	3.87		4.5
barium	0.08			0.08
potassium	10.3	7.94		9.1
strontium	0.22			0.22
sodium	430	396		413.2
zinc	0.005			0.005
cadmium	L0.005			L0.005
manganese	0.04			0.04
cobalt	L0.005			L0.005
copper	0.005			0.005
silver	L0.01			L0.01
iron	0.2			0.2
lead	L0.01			L0.01
chromium	L0.01			L0.01
nickel	0.03			0.03
Anions (mg/L)				
fluoride	3.7			3.7
chloride	150			150
nitrite-N	L1			L1
O-phosphate-P	L0.1			L0.1
bromide	0.1			0.1
nitrate-N	L0.1			L0.1
sulphate	240	208		224
carbonate		17.5		17.5

TABLE -2

ACIDIFICATION TREATMENT STUDY : CHARACTERIZATION OF TREATED TAILING POND WATER

	ZENON	EPS	SYNCRUDE	AVERAGE
GENERAL				
pH	4.5			4.5
total solids (mg/L)	1497	1590		1544
total suspended solids (mg/L)	87	155	L20	87
total dissolved solids (0.45u)(mg/L)	1410	1435	1438	1428
turbidity (NTU)	96	77.5		87
ORGANIC				
dissolved organic carbon (0.45u)(mg/L)	124	63	40	76
dissolved tar sands acid (0.45u)(mg/L)	28	26	32	29
phenol (ug/L)			110	110
TOXICITY				
rainbow trout LD50-96h	62	G100	G100	87
Microtox EC50 (15,15)	79	116	G100	98
Microtox EC20 (15,15)	26	29	31	29
INORGANIC				
Metals (mg/L)				
beryllium	L0.005			L0.005
molybdenum	0.08			0.1
calcium	6.4	5.92		6.2
vanadium	0.005			0.005
aluminum	0.3			0.3
magnesium	4.9	4.26		4.6
barium	0.11			0.1
potassium	10	7.25		8.6
strontium	0.23			0.2
sodium	490	391		440.5
zinc	0.15			0.2
cadmium	L0.005			L0.005
manganese	0.11			0.1
cobalt	0.005			0.005
copper	0.25			0.3
silver	L0.01			L0.01
iron	0.1			0.1
lead	L0.01			L0.01
chromium	L0.01			L0.01
nickel	0.07			0.1
Anions (mg/L)				
fluoride	3.4			3.4
chloride	136			136
nitrite-N	L1			L1
O-phosphate-P	0.1			0.1
bromide	0.5			0.5
nitrate-N	0.1			0.1
sulphate	770	743		757
carbonate		123		123
cyanide			0.4	0.4
amonium			2.5	2.5

TABLE 3

ACIDIFICATION TREATMENT STUDY : TREATMENT REMOVAL EFFECTIVENESS

	ZENON	EPS	SYNCRUDE	AVERAGE
GENERAL				
pH				
total solids (mg/L)	47%	41%		44%
total suspended solids (mg/L)	92%	88%	99%	93%
total dissolved solids (0.45u)(mg/L)	(32%)	(3%)	(5%)	(12%)
turbidity (NTU)	95%	89%		94%
ORGANIC				
dissolved organic carbon (0.45u)(mg/L)	32%	73%		63%
dissolved tar sands acid (0.45u)(mg/L)	62%	63%	37%	56%
phenol (ug/L)			39%	39%
TOXICITY				
rainbow trout LD50-96h				
Microtox EC50 (15,15)				
Microtox EC20 (15,15)				
INORGANIC				
Metals (mg/L)				
beryllium	0%			0%
molybdenum	27%			27%
calcium	(8%)	(21%)		(14%)
vanadium	0%			0%
aluminum	74%			74%
magnesium	4%	(10%)		(2%)
barium	(38%)			(36%)
potassium	3%	9%		5%
strontium	(5%)			(5%)
sodium	(14%)	1%		(7%)
zinc	(2900%)			(2900%)
cadmium	0%			0%
manganese	(175%)			(175%)
cobalt	0%			0%
copper	(4900%)			(4900%)
silver	0%			0%
iron	50%			50%
lead	0%			0%
chromium	0%			0%
nickel	(133%)			(133%)
Anions (mg/L)				
fluoride	8%			8%
chloride	9%			9%
nitrite-N	0%			0%
O-phosphate-P	0%			0%
bromide	(400%)			(400%)
nitrate-N	0%			0%
sulphate	(221%)	(257%)		(238%)
carbonate				
cyanide				
amonium				

line. Addition of lime at the plant end provides the required mixing/reaction time and prevents slurry segregation. (Reduces pipeline erosion);.

2. The addition of a polyelectrolyte at the lime addition point (optimum dosage approx. 8 mg/L); and
3. The proposed treated schemes are attached as Figure 3 (from Appendix "A" Dry Tailings Disposal from Oil Sands Mining).

Problems

1. Industry reviewed the final report and did not show any interest in proceeding further.
2. The geotechnical properties of the resulting solid portion were considered unacceptable.
3. The industry felt that the costs of the proposed process would be considerably higher than the project by C-H Synfuels.
4. Industry was involved in their own research projects concerning different processes and simply did not show sufficient interest to justify further work. Consequently, further work was terminated.

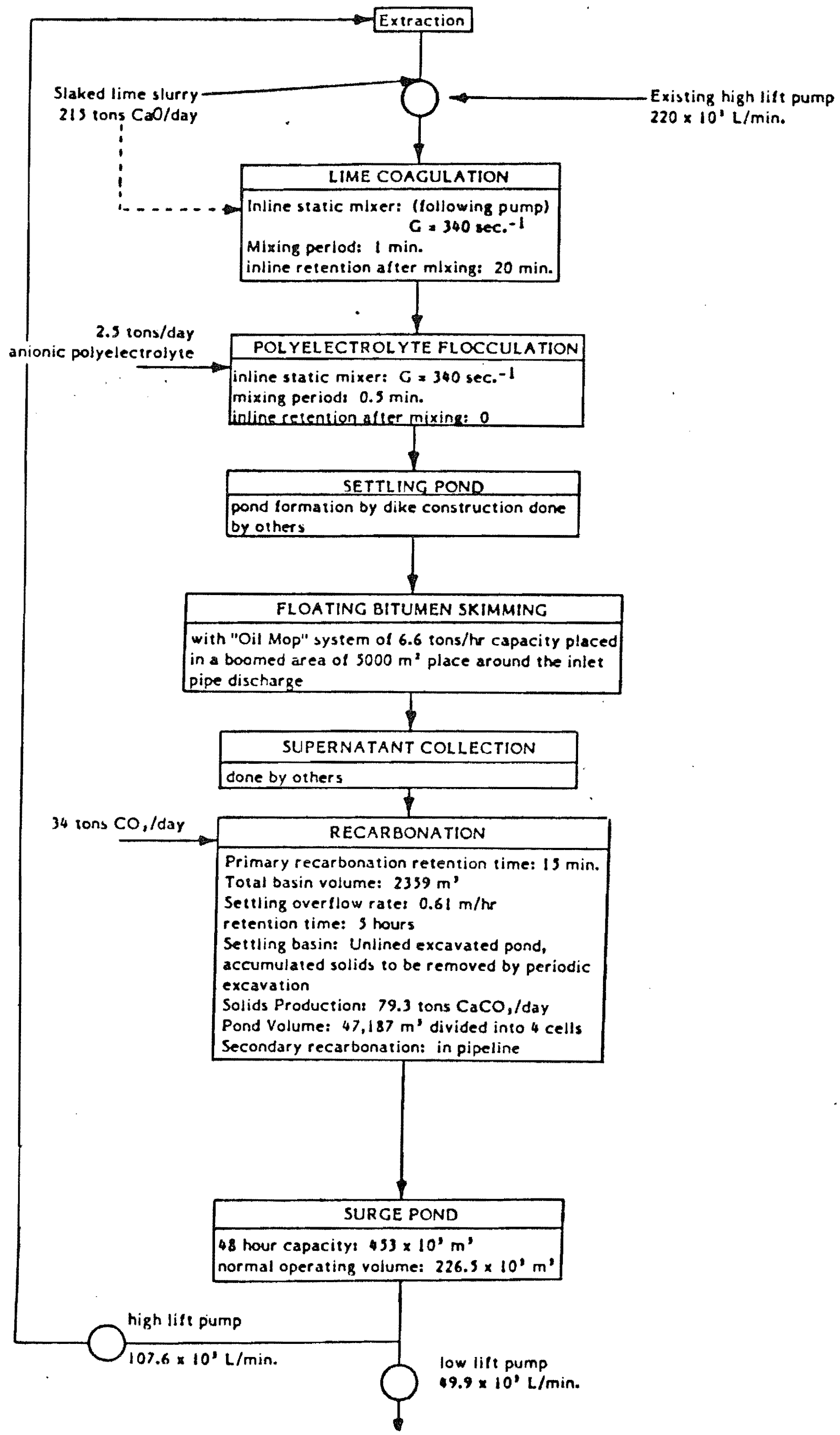

Figure 3. Design specifications of the proposed tar sands tailings treatment scheme.

ENVIRONMENTAL PROTECTION IN ALBERTA

R.C. Orr - EPS
Environment Canada

Shared Juridiction

In Canada, the responsibility and juridiction for environmental protection is shared between the provinces and the federal government. Constitutionally, under the terms of the BNA, the land and resources became provincially owned while economic areas such as commerce, fisheries, navigation, remained under the juridiction of the federal government. Since fisheries is a federal responsibility, and the water resource a provincial one, protection of water is a joint responsibility of both levels of government. In Alberta, two main pieces of legislation are available to protect water quality. Section 33 of the federal Fisheries Act makes it an offence to discharge deleterious substances to waters inhabited by fish. The Alberta Clean Water Act protects water quality through licensing of effluent discharges to water bodies in the province.

The duality of jurisdiction and responsibility could lead to conflict between the two levels of government and could also cause uncertainy for industry if they were required to meet different conditions from separate regulators. In practise this does not occur since agreement between the two levels of government allows for a "one window" approach in terms of regulation of industry.

Environmental Accord

The Canada/Alberta Environmental Accord provides a framework for co-operation between the two levels of governments. It provides for Alberta to be the direct regulator of industry, while allowing for information exchange and cooperation between the two governments to ensure the federal minister is able to meet his responsibilities.

Federal Role

Even though direct regulatory responsibility has, in most cases, been passed to the province, there still remains a responsibility and role for the federal department. These responsibilities include:

1. Development of national standards, guidelines, and codes of practise;
2. Support for technology development for various industry sectors;
3. Promotion of information exchange on a national basis; and
4. Ensuring consistent enforcement of regulations, on a national basis.

Messages and Signals

Although the Accord provides guidance on how each jurisdiction should carry out its responsibilities, other messages are being received which help define roles of both governments. Surveys of the public consistently show that the public puts a very high priority on environmental quality. Although economic development is welcomed, the surveys suggest that it should not be achieved at a price of environmental degradation.

The MacDonald Commission, the Pearse Report and the Conservative Speech from the Throne all emphasize the need for economic development but only in association with good environmental protection. The MacDonald Commission and the Pearse report also detail the continuing federal responsibility in ensuring that Canada's environment is protected.

In light of these messages, Environment Canada, and especially EPS, is reviewing its roles and responsibilities to ensure that it is carrying out its mandate in an appropriate manner. One area presently being reviewed is the compliance and enforcement policy of EPS.

Compliance and Enforcement Policy

In terms of the regulatory role, EPS is carrying out a comprehensive evaluation of its enforcement and compliance policy. This evaluation may bring changes in the way in which EPS operates. For instance, to date, enforcement under Section 33 of the Fisheries Act is not pursued for technical violations by unregulated industry as long as the "spirit" of the Act is met. It is no longer felt that such a practise can be continued. Options are needed for bringing about compliance from both a technical standpoint as well as in the spirit of the Act. Some of these options include:

1. Regulation of all industry sectors;
2. Utilization of Section 33.13 (f) which would allow authorizations for specific facilities; and

3. Designation of provincial officials who could issue authorizations under 33.13 (f), which would allow discharges under prescribed conditions. (This designation could be used to make the terms of the provincial licence the same as the authorization under the federal act.).

EPS is also examining its ultimate role regarding regulation and enforcement. One such role which has not previously been played is that of an auditor of enforcement to ensure consistency and fairness on a national basis.

Advocacy

One role that clearly is an EPS responsibility is that of advocate for environmental protection. EPS has carried this role in a number of ways: first, is the setting of national standards, objectives and guidelines; second, is the "in-house" research program which aims to develop better technology to clean up industrial problems; third, is the provision of funding for environmental research through programs such as the Panel on Energy Research and Development (PERD).

One of the reasons for the workshop, from a federal standpoint, is to try to ensure that PERD funding is directed in a cost-effective way toward solving the environmental problems of the energy industry. I hope our workshop identifies where research should be undertaken in the oil sands area. I further hope that the workshop can foster the spirit of cooperation between the two governments and the industry, which will allow cooperative research programs to proceed and which will truly address some of the environmental problems of the oil sand industry.

REGULATORY ASPECTS FOR SYNCRUDE

P. Shewchuk
Alberta Environment

A document named "Syncrude Criteria, January 1973" published by Alberta Environment formed the basis for the approval of the Ft. McMurray oil sands plant.

Under the Clean Water Act, the concept of best practicable technology was the criterion applied to establish acceptable liquid effluent treatment standards. On this basis, the operator would have been expected to treat the wastewater originating from the bitumen upgrading facilities prior to any release to the surrounding watershed area, and would have been expected to utilize a tailings pond to discharge wastewater from the extraction plant and to recycle a portion of this wastewater back to the extraction plant. However, Syncrude management decided to utilize a tailings pond for all of its wastewater from extraction and upgrading and thereby eliminated the direct discharge of process wastewater to the surrounding watershed area.

Due to an ever increasing inventory of tailings pond water and projected accumulation over the life of the plant, Syncrude personnel are considering means of treatment and detoxification of the tailings pond wastewater for a possible future discharge into the Athabasca River. From a regulatory agency point of view, we have to establish safe effluent concentrations for various parameters to ensure the safety of aquatic life in the Athabasca River and to maintain the quality of the river for its many beneficial uses. This necessitates characterization of the tailings pond wastewater, and conducting bench and pilot scale experimentation to establish effective treatment technology.

NATURAL DETOXIFICATION AND COLONIZATION OF OIL SANDS TAILINGS WATER IN EXPERIMENTAL PITS

H. Boerger and M. Aleksiuk
Syncrude Canada Ltd.

INTRODUCTION

Syncrude Canada Ltd. produces over 40 x 10^6 barrels of synthetic crude oil annually from the Athabasca Oil Sands in northeastern Alberta, Canada. This process, involving the extraction of bitumen from oil sand and the subsequent upgrading of the bitumen to synthetic crude oil, results in the annual production of over 100 x 10^6 m^3 of waste water which is stored in a tailings pond. About 70% of the waste water is recycled back to the plant, resulting in a net annual accumulation of 20 to 30 x 10^6 m^3 of water. In 1983, the tailings pond contained 160 x 10^6 m^3 of water and sludge, covered an area of 14 km^2, and had a maximum depth of 32 m (Figure 1). The pond consists of an upper zone of "free" water in which the concentration of solids is less than 1%. Below a depth of 10 m the pond is filled with sludge. Present projections suggest that there may eventually be as much as 400 x 10^6 m^3 of water in the tailings pond with as much as half present in the free water surface zone.

The water in the surface zone is very turbid due to the presence of suspended clay (Table 1). Concentrations of dissolved solids are substantially higher than in the Athabasca River, with the major ions being sodium, chloride, sulphate and bicarbonate. Dissolved oxygen is always low due to the high biochemical and chemical oxygen demands. Concentrations of potentially toxic substances (oil and grease, phenols, cyanide, surfactants and ammonia) are 10 to 1000 times higher than in the Athabasca River. The water is acutely toxic, with the 96-hr LC_{50} (median lethal concentration) for trout and Daphnia being less than 10%. Currently, only bacteria inhabit the tailings pond. Because the volume of fresh toxic tailings which is being pumped continuously into the pond is large (100 x 10^6 m^3/yr.) relative to the volume of the free water zone (105 x 10^6 m^3), there has been no reduction in toxicity since water started to be stored in the pond in 1979.

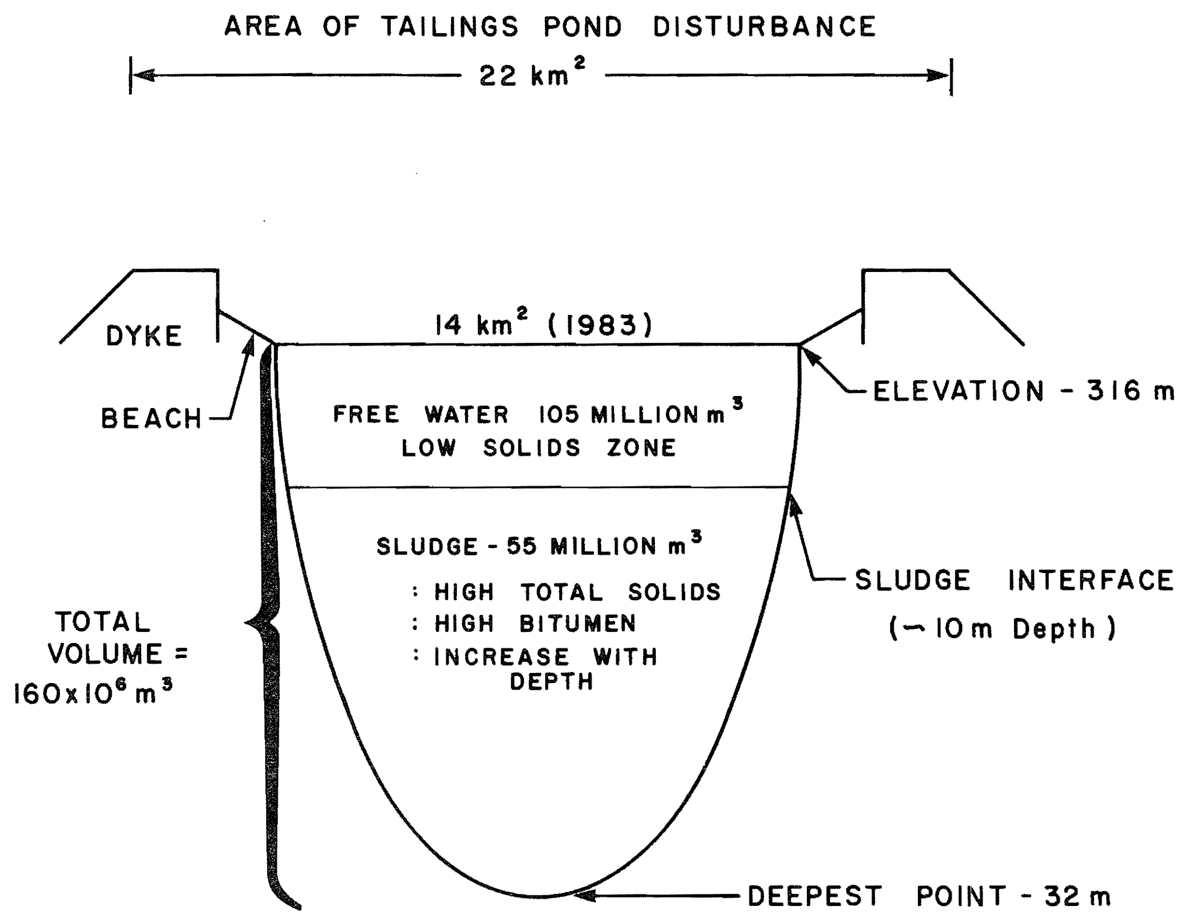

Figure 1. Schematic diagram of Syncrude's tailings pond in 1983.

Table 1. Chemical composition of fresh and 10-month period aged tailings pond water compared with water from the Athabasca River at the Syncrude Canada Ltd. pump house. All samples were collected 1984 May 03 from a depth of 0.5 m. LT = less than.

Parameter	Unit	Tailings Pond Water: Fresh	Tailings Pond Water: 10-month Storage	Athabasca River
pH	units	8.1	8.4	8.4
Conductivity	uS/cm	1410	860	270
Dissolved Solids	mg/L	1191	659	134
Non-filterable residue	mg/L	1007	154	55
Turbidity	NTU	680	66	8
Oil and grease	mg/L	19.0	5.4	0.9
Dissolved oxygen	mg/L	2.0	9.0	9.0
5-day BOD	mg/L	32.0	2.0	2.2
COD	mg/L	422	120	16
Phenols	mg/L	0.15	0.007	0.001
Cyanide	mg/L	0.95	0.013	0.001
Surfactant (MBAS)	mg/L	2.00	1.40	0.12
Ammonia nitrogen	mg/L	2.87	1.24	0.05
Sodium	mg/L	395	232	13
Chloride	mg/L	117	69	7
Sulphate	mg/L	215	158	26
Bicarbonate	mg/L	541	264	154
Nickel	ug/L	14	9	LT1
Vanadium	ug/L	24	183	10
Mercury	ug/L	0.16	0.25	LT0.1
Lead	ug/L	LT2	LT2	LT2
Copper	ug/L	2	1	1
Cadmium	ug/L	LT1	LT1	LT1
Zinc	ug/L	1	2	4
Arsenic	ug/L	7	7	1
Toxicity (96-hr trout survival)	percent survival	0	100	100

Various methods for detoxifying tailings pond water have been examined (MacKinnon and Retallack 1982). The only method found so far which both clarifies and detoxified the water involves acidification to pH 4.5, followed by flocculation with anionic polyelectrolytes and neutralization of the decanted clarified water. Such a treatment results in water in which trout can survive for 96 hours without mortality. However, such chemical treatment is costly (about $0.25/m^3$), especially considering the volumes of water which may eventually have to be treated.

Various studies on other waste waters have shown that naturally-occurring physical, chemical and biological processes can also result in the removal of toxic substances such as hydrocarbons (Jordan and Payne 1980), surfactants (Cooper 1980), ammonia (Focht and Verstraeti 1977) and cyanide (Leduc and co-workers 1982), as well as lead to flocculation of clay suspensions (Hocking 1977; Avnimelech and Menzel 1984). It is possible, therefore, that tailings water may detoxify and clarify naturally once it is removed from the constant input of fresh, toxic tailings. If natural processes prove to be sufficiently rapid and reliable, storage of excess tailings water in shallow lagoons could decrease the cost of, or completely eliminate, chemical treatment.

This paper describes the results obtained during the first year of an ongoing study on the physical, chemical and biological changes of tailings water stored in 300 m^3 experimental pits. In particular, we were interested in the rate and extent of detoxification of the tailings water and its colonization by aquatic biota.

Procedure

a) Construction and Filling of Pits

Two experimental pits were excavated adjacent to the tailings pond. Each pit measured 13 m by 13 m at the surface, had walls with a 1:1 slope, a maximum depth of 3 m in the central area, and a volume of 300 m^3. Each pit was lined with a 10 mil sheet of woven polyethylene. On 1983 June 30, the pits were filled with water from the surface zone of the tailings pond.

b) Chemical Analysis

The chemistry and toxicity of the water in the experimental pits, as well as the abundance and diversity of aquatic biota was measured at 1 to 3 month intervals at each of 3 depths: 25 cm below the surface, mid-depth, and 25 cm above the bottom. Chemical parameters were determined using standard methods and have been previously described (MacKinnon and Retallack, 1982).

c) Measurement of Toxicity

The Beckman Microtox method was used for routine measurement of toxicity. This is essentially a 15-minute static bioassay using a bioluminescent bacterium as the assay species.

The amount of light produced by the bacteria, as measured with a luminometer, is inversely proportional to the toxicity of the solution being tested (Bulich and co-workers 1981). Values of EC_{50} (median effective concentration, or concentration of sample which reduces light output by the bacteria by 50%) never varied by more than 10% in duplicate samples. After 10 months (1984 May 03), the toxicity of the water in the experimental pits was also measured by determining the percent survival of trout and Daphnia (a small, common freshwater crustacean) kept for four days in water from the experimental pits.

d) Measurement of Microbial Phenol Degradation

The ability of the bacteria in the tailings pond water to degrade phenol was examined by Dr. D.W.S. Westlake and co-workers, Dept. of Microbiology, University of Alberta, Edmonton. Samples of tailings pond water were placed in flasks, innoculated with ^{14}C-labelled phenol, sealed airtight and incubated on a rotary shaker. Control flasks contained tailings pond water which had been heat sterilized by autoclaving for 45 minutes prior to the addition of the ^{14}C-labelled phenol. Periodically, samples of the gas above the water in the flasks were analyzed for $^{14}CO_2$ by gas chromatography. An estimate of the rate and extent of the microbial degradation can then be determined by comparing the amount of $^{14}CO_2$ produced relative to the ^{14}C-phenol added to the tailings water at the start. Further details are described by Fedorak and co-workers (1982).

e) Enumeration of Aquatic Biota

The abundance of microplankton (aquatic plants and animals measuring 10 to 60 u) was determined by microscopic examination of 25 uL of water. Larger plankton (60 to 1000 u) was enumerated after filtering 10 L of water through a net having a mesh size of 60 u. Even larger aquatic organisms were sampled by sweeping through the water and across the bottom with a net having a mesh size of 1 mm.

RESULTS AND DISCUSSION

a) Changes in Water Chemistry

The following results are based on the period July 1983 to June 1984. After filling, the concentration of chloride in the pits was 100 mg/L (Figure 2). Since dissolved solids are excluded for the most part during freezing, the chloride content of the water under the ice rose to about 200 mg/L (i.e., about half of the water in the pits was frozen). Following ice melt, the chloride content of the water returned to 110 mg/L. Seasonal changes in the concentration of other major constitutents (sulphate, total inorganic and organic carbon, sodium) were similar to those of chloride. Since the surface area of the pits (169 m^2) was large relative to the depth (3 m), mixing by wind prevented vertical stratification in summer. Even under the ice, differences in the concentration of chemical constituents between top and bottom of the water never exceeded 10%.

After filling, the concentration of dissolved oxygen in the pits varied between 2.5 to 3.5 mg/L (25 to 34% saturation) and was similar to that in the recycle pond (Figure 3). Within four months, dissolved oxygen had risen to 10 to 12 mg/L (100% saturation). During the winter the dissolved oxygen decreased to 1 to 2 mg/L (8 to 15% saturation). By May 1984, it had returned to 100% saturation.

Comparison of toxic substances such as oil and grease, ammonia, phenols and cyanide in the tailings pond with those in the water stored in the experimental pits for 10 months shows that the concentrations of these were substantially reduced (Table 1). Except for sodium, ammonia, vanadium and mercury, concentrations of chemicals in the 10-month stored tailings pond water were within an order of magnitude of those in the Athabasca River.

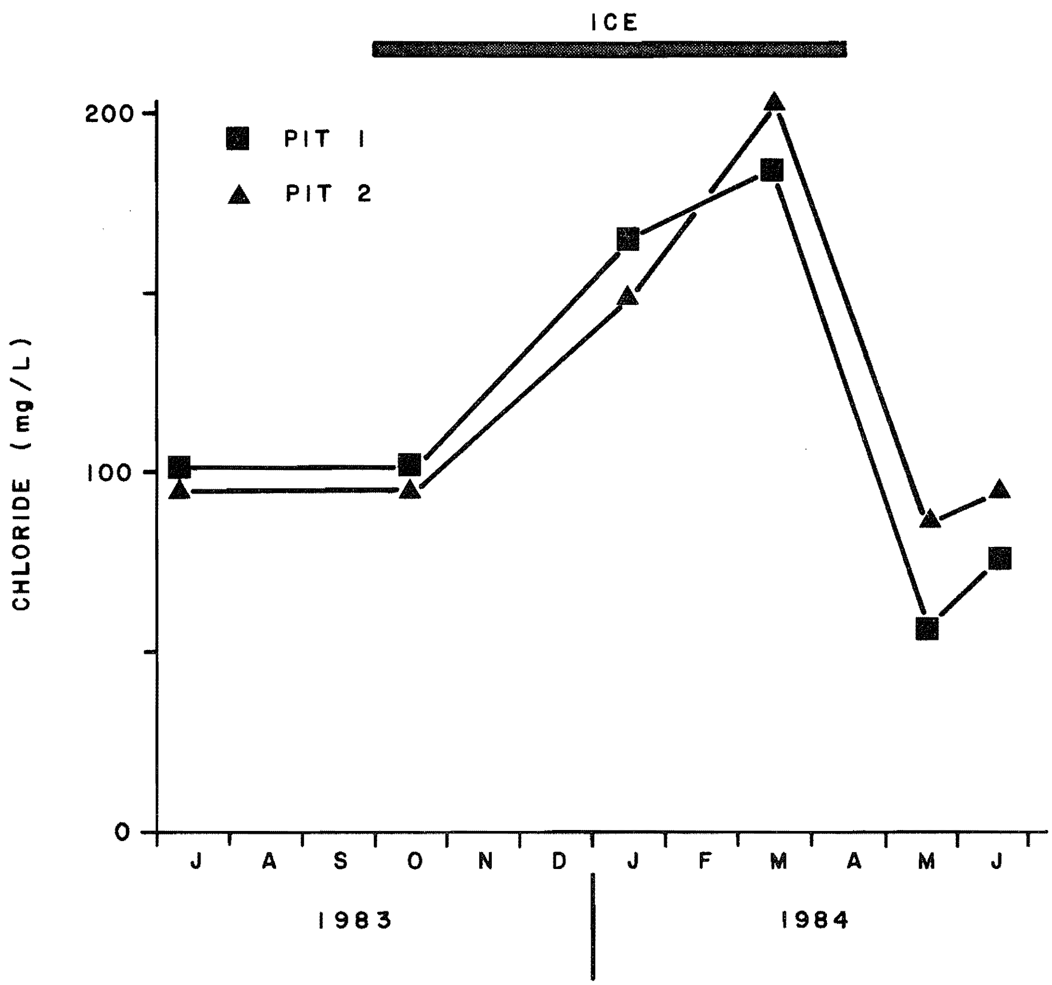

Figure 2. Temporal changes in concentration of chloride in experimental pits 1 and 2. All samples collected from a depth of 25 cm.

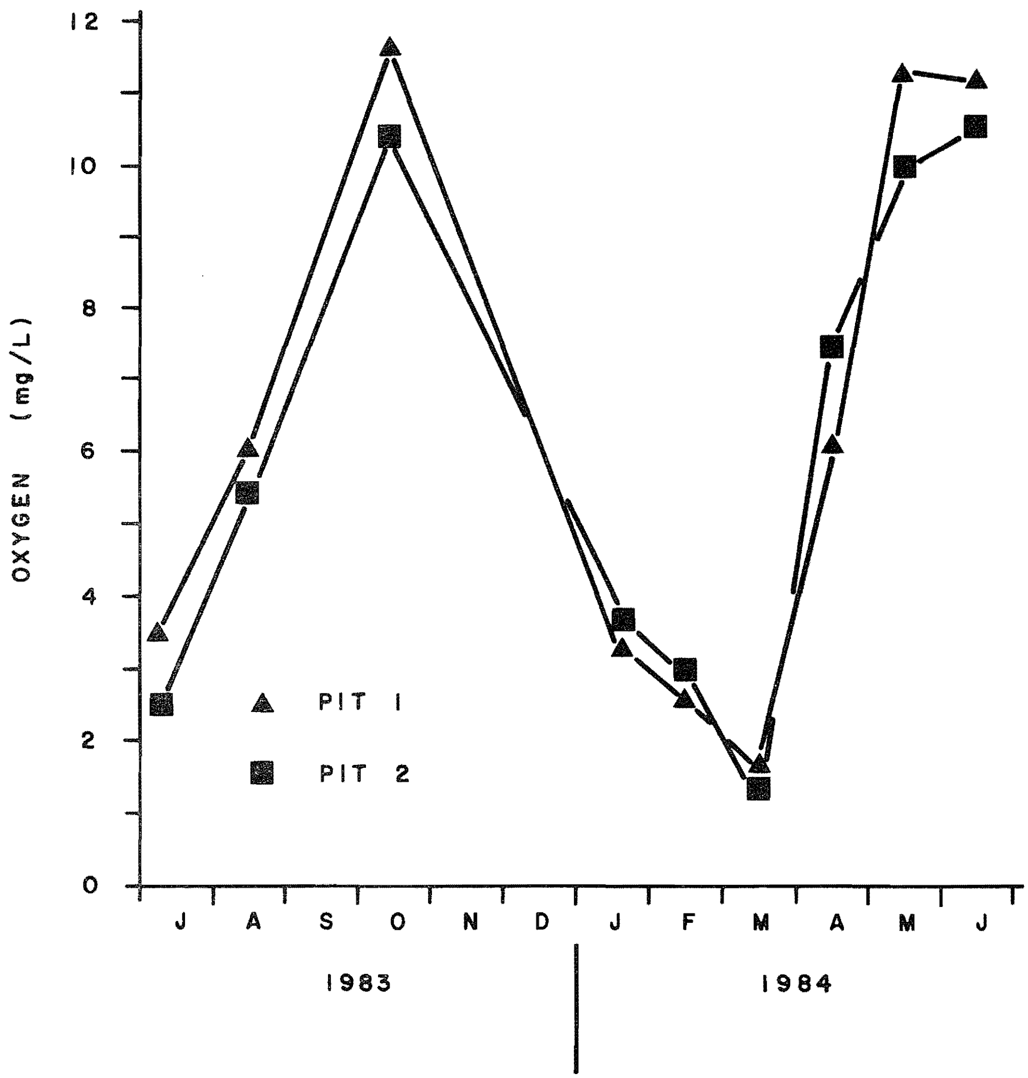

Figure 3. Temporal changes in concentration of dissolved oxygen in experimental pits 1 and 2. All samples collected from a depth of 25 cm.

b) Changes in Toxicity

Toxicity of the tailings pond water, as measured with the Microtox Test, was reduced substantially (Figure 4). After one year, the EC_{50} (concentration of water which causes a 50% reduction in light produced by the bioluminescent bacteria used in the test) increased from 35% to 100%. Detoxification occurred at about the same rate in winter as in summer, suggesting that the process is not influenced by changes in temperature from 4^{o} to $15^{o}C$, by changes in dissolved oxygen from 8% to 100% saturation, or by changes in chloride from 100 mg/L to 200 mg/L.

The reduction in toxicity was also confirmed in tests with trout and Daphnia. No specimens tested could survive for 4 days in undiluted tailings pond water. However, after 10 months of storage, survival rate was 60% for trout and 80% for Daphnia. The Microtox test cannot be run without dilution of the water being tested. One can, however, make the Microtox data more comparable to the trout and Daphnia values by calculating the concentration of test solution which causes a 20% rather than a 50% reduction in light output by the bacteria. It requires only a 9% solution of fresh tailings pond water in non-toxic diluent to cause a 20% reduction in light output. However, after ten months storage in the experimental pits such a reduction did not occur until the concentration reached 59%.

c) Detoxification Processes

The relative role of various physical, chemical and biological processes in the removal of the various toxic components is not yet clear. Tailings pond water kept in open containers in the laboratory lost 25 to 30% of its toxicity within one week. This was almost certainly due to the evaporation of volatile components since the time period also corresponded to the disappearance of any detectable odour from the water. The experiments with ^{14}C-phenols showed that bacteria in the tailings water can degrade 50% of the phenol in one week under laboratory conditions (Figure 5). The microbial nature of the degradation process is indicated by the lack of any $^{14}CO_2$ in the control flask prior to day 9. The control flasks were handled in exactly the same manner as the test flasks, the only difference being that the tailings pond water in the control flasks had been sterilized

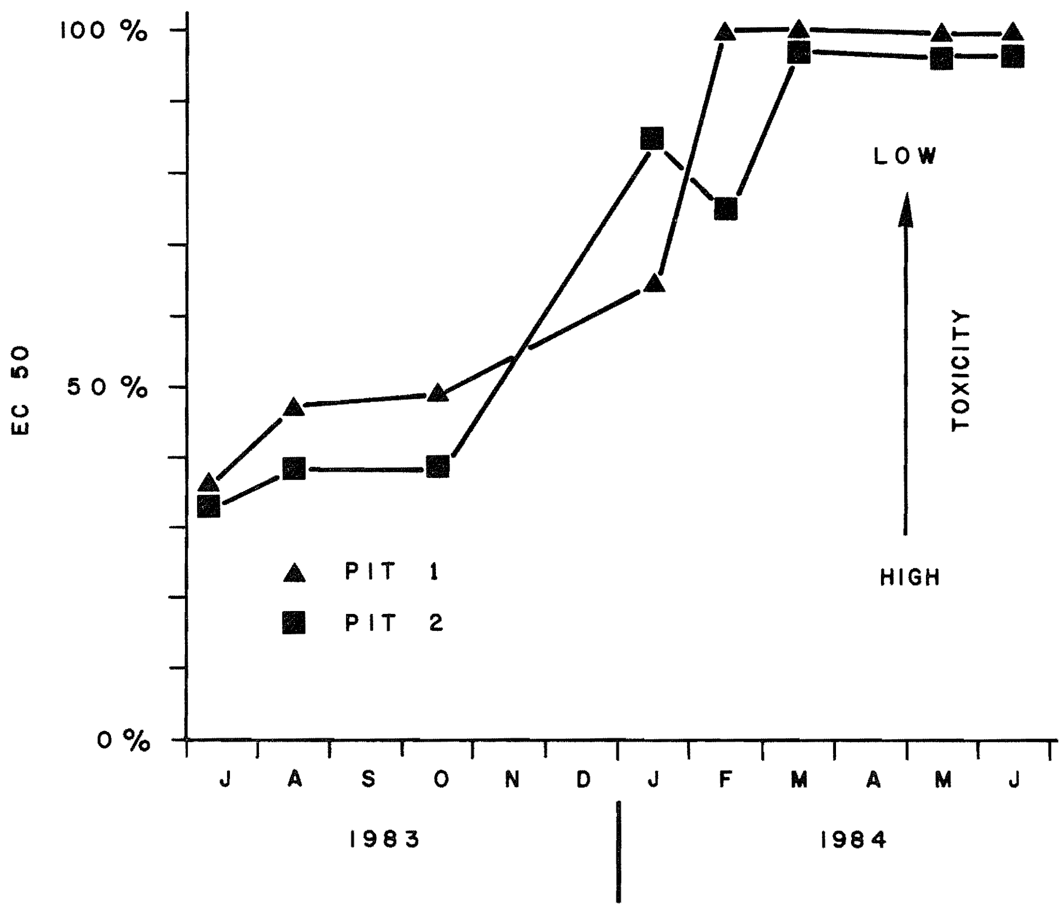

Figure 4. Changes in toxicity of water in experimental pit 1 and 2 as measured with the Beckman Microtox technique. ER_{50} is the median effective concentration of water which causes light emission by the bioluminescent bacteria to be reduced by 50%.

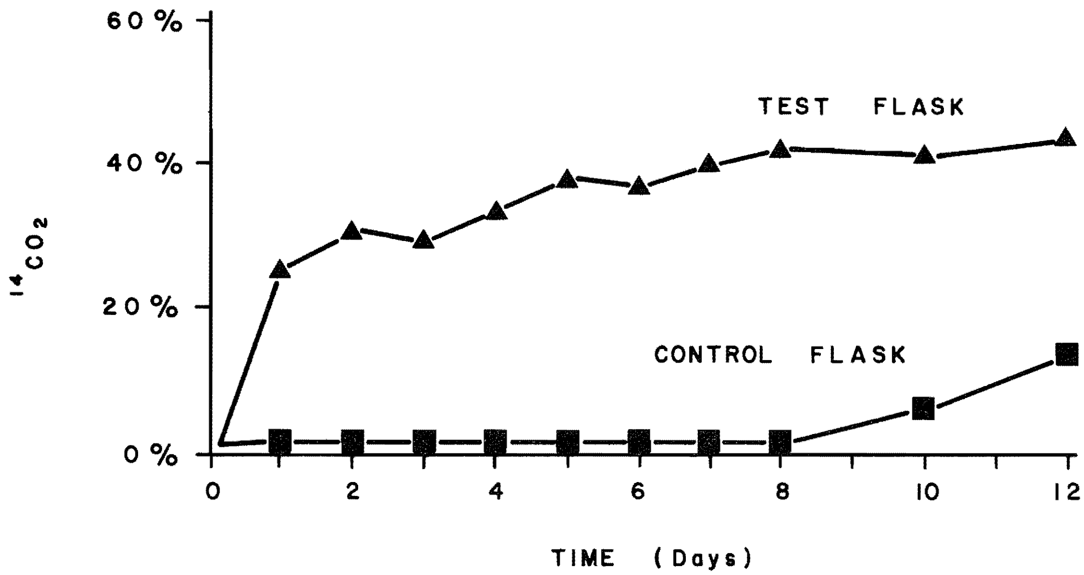

Figure 5. Percent of ^{14}C-phenol degraded to $^{14}CO_2$ in tailings pond water collected 1983 September 18, from a depth of 0.5 m. Water in control flask was autoclaved to stop bacterial activity.

prior to the addition of labelled phenol. In previous laboratory experiments, Forrester and co-workers (1983) showed that bacteria from the tailings pond can degrade 42% to 74% of the bitumen added to cultures within a two-week incubation period. Yield of $^{14}CO_2$ appeared to reach an assymptote at about 50%. In experiments with ^{14}C-labelled glycolic acid we have obtained 80 to 90% yields of labelled carbon as $^{14}CO_2$ (Foght and co-workers 1985). It is possible that phenol mineralization was nutrient limited.

The rate of detoxification appeared to be relatively independent of water temperature, occurring at about the same rate in winter as summer (Figure 4). High winter rates could suggest that detoxification is primarily physical, possibly involving adsorption onto suspended particulate matter and the settling out of this material during the period of ice cover. However, microbial processes could also be important during the winter since low temperatures do not appear to limit metabolic processes of acclimated populations (Tramer and Sirving 1983).

d) Colonization by Aquatic Organisms

Tailings pond water contains high numbers of bacteria (10^6 - 10^8 cells/ml) belonging to eight species. The most common genera are *Alcaligenes* and *Acinetabacter*.

At the start, bacteria were the only organisms present in the experimental pits. Within two months, seven species of one-celled (size less than 60 u) planktonic plants (phytoflagellates) and animals (ciliates) had colonized the pits and had reached densities of 10^3 cells/mL (Figure 6). After reaching a maximum abundance of 8 x 10^3 cells/mL in October, the plankton declined to less than 10^3 cells/mL during the period of ice cover. Abundance increased again in May 1984. Such a seasonal cycle is common for microplankton of natural lakes. While the adunance was similar to that in natural lakes, the number of species was only about one-twentieth.

So far we have found no net plankton (size range 60 to 1000 u). This group is very abundant in natural lakes and includes groups such as cladocerans, copepods, rotifers and diatoms.

Aquatic organisms larger than 1 mm in size were observed for the first time in May, 1984, and included three species of aquatic insects: adult water

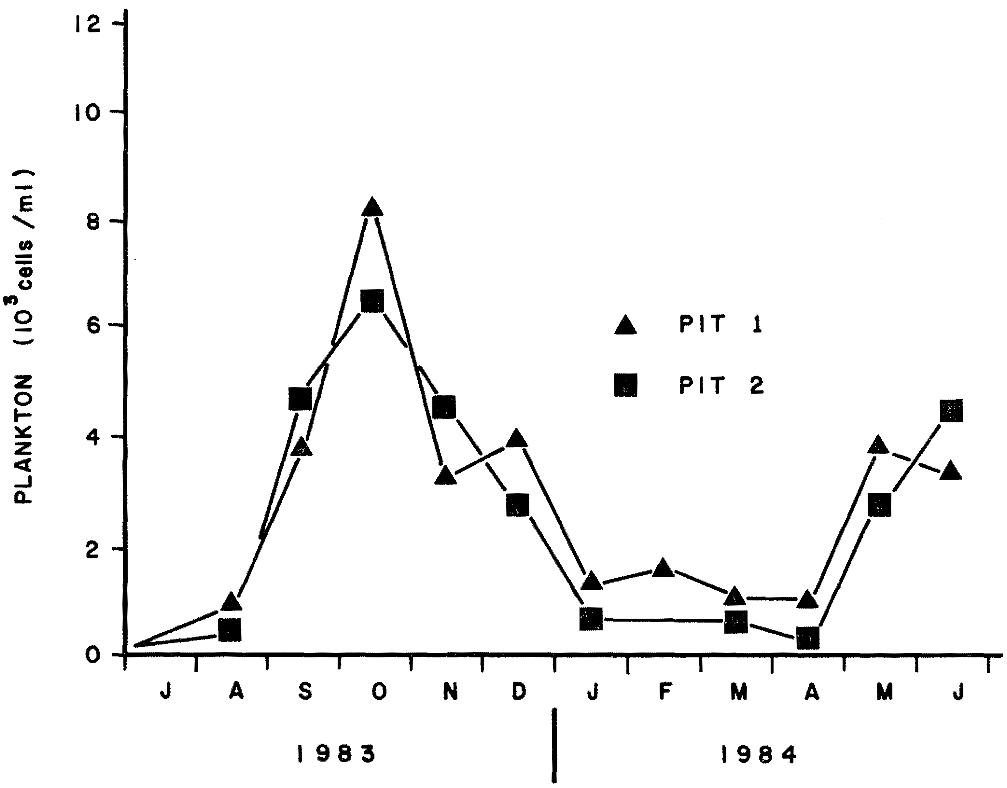

Figure 6. Temporal changes in the concentration of microplankton (10 to 60 u) in experimental pits 1 and 2. Samples collected from a depth of 25 cm.

detoxification, reservoir size would be substantially decreased if the time required for detoxification could be reduced to less than two years. We are currently examining if small amounts of ferilizer will increase the rate of naturally-occurring detoxification.

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LIST OF FIGURES

PARTICIPANTS

ALBERTA OIL SANDS TAILINGS WASTEWATER
TREATMENT TECHNOLOGY WORKSHOP
MILDRED LAKE, ALBERTA
1985 OCTOBER 29-30

M. (Mike) Aleksiuk
Environmental Affairs Department
Syncrude Canada Ltd.
Edmonton, Alberta

E.G. (Earle) Baddaloo
Research Management Division
Alberta Environment
Edmonton, Alberta

T.J. (Theo) Beukeboom
Research Management Division
Alberta Environment
Edmontonton, Alberta

P. (Peter) Blackall
Scientific Programs Branch
Environmental Protection Service
Edmonton, Alberta

H. (Hans) Boerger
Environmental Affairs Department
Syncrude Canada Ltd.
Edmonton, Alberta

B. (Bart) Bolwyn
Alberta Environmental Centre
Alberta Environment

R. (Bob) Coppock
Alberta Environmental Centre
Alberta Environment
Vegreville, Alberta

C. (Cam) Edwards
Industrial Programs
Environmental Protection Service

R. (Rob) Germain
Alberta Oil Sands Technology and Research Authority
Edmonton, Alberta

B.R. (Brian) Hammond
Research Management Division
Alberta Environment
Edmonton, Alberta

R. (Richard) Houlihan
Energy Resources Conservation Board
Calgary, Alberta

B. (Bruce) Jank
Wastewater Technology Centre
Environmental Protection Services
Burlington, Ontario

R. (Richard) Johnson
Alberta Environmental Centre
Alberta Environment
Vegreville, Alberta

K. (Kelly) Karr
Oil and Gas Production
Environmental Protection Service
Environment Canada
Ottawa, Ontario

M. (Merle) Korchinski
Alberta Environmental Centre
Alberta Environment

B. (Boyd) Lampman
Utilities
CanStar Oil Sands Ltd.
Calgary, Alberta

G. (George) Lesko
Environmental Affairs Department
Syncrude Canada
Edmonton, Alberta

I. (Ian) Mackenzie
Research Management Division
Alberta Environment
Edmonton, Alberta

M. (Mike) MacKinnon
Environmental Affairs Department
Syncrude Canada Ltd.
Edmonton, Alberta

B. (Bob) Martin
Environmental Affairs
Suncor Oil Sands Group
Fort McMurray, Alberta

A. (Akio) Masuda
Pollution Control Division
Alberta Environment
Edmonton, Alberta

D. (Douglas) Mead
Safety and Environmental Affairs
Shell Canada
Calgary, Alberta

J. (Jim) Moore
Alberta Environmental Centre
Alberta Environment
Vegreville, Alberta

R. (Ryan) Moore
Governmental Affairs
Suncor Oil Sands Group
Calgary, Alberta

J. (Jay) Nagendran
Standards and Approvals Division
Alberta Environment
Edmonton, Alberta

R. (Ray) Orr
Environmental Protection Service
Environment Canada
Edmonton, Alberta

J. (Joe) Price
Heavy Oil Department
Esso Resources Canada Ltd.
Calgary, Alberta

W. (Wayne) Richardson
Energy Research & Development
Environmental Protection Service
Environment Canada
Ottawa, Ontario

P. (Paul) Shewchuk
Standards and Approvals Division
Alberta Environment
Edmonton, Alberta

S. (Steff) Stephansson
Environmental Affairs
CanStar Oil Sands Ltd.
Calgary, Alberta

V. (Valerie) Stowell
Energy Conservation
Syncrude Canada Ltd.
Fort McMurray, Alberta

K. (Koichi) Takamura
Oil Sands Research Department
Alberta Research Council
Edmonton, Alberta

J. (Jack) Taylor
Alberta Environmental Centre
Alberta Environment
Vegreville, Alberta

D. (Dean) Wallace
Oil Sands Research Department
Alberta Research Council
Edmonton, Alberta

I. (Ivan) Weleschuk
Environmental Protection Department
Energy Resources Conservation Board
Calgary, Alberta

M. (Malcolm) Wilson
Alberta Environmental Centre
Alberta Environment
Vegreville, Alberta

R. (Roy) Wood
Environmental AFfairs
Suncor Oil Sands Group
Fort McMurray, Alberta