UPDATE

EVALUATION OF TECHNOLOGY FOR THE TREATMENT OF WASTE SLUDGE AND SOLIDS CONTAMINATED WITH SALT, METALS, AND HYDROCARBONS

Prepared For

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DISCLAIMER

EXECUTIVE SUMMARY

The Canadian Petroleum Association (CPA), with the support of Environment Canada, has embarked upon a study to identify treatment technologies capable of treating sludges and solids contaminated with fine particles, salt, oil, and heavy metals generated by conventional oil production operations. The initial study, completed by CH2M Hill Engineering Ltd. and summarized in the CPA's report entitled "Evaluation of Technology for the Treatment of Waste Sludge and Solids Contaminated with Salt, Metals, and Hydrocarbons," Phase 1 Report, in 1989, included an assessment of treatment technologies capable of handling these wastes within the provincial and federal regulatory framework.

In light of other waste characterization and technology assessment work carried out by the CPA recently, the CPA and Environment Canada decided that a revisit to the initial 1989 technology assessment work would be appropriate to ensure that the recent information was taken into consideration in identifying and assessing suitable treatment technologies.

This update of the Phase 1 Report assesses those technologies which were identified in Monenco Consultants Limited's report to the CPA entitled "Evaluation of New Technologies For Clean up of Produced Oily Solids From Heavy Oil Operation," July 1990 and which may have potential application in treating the wastes addressed in the Phase 1 Report. This update also reviews additional waste characterization data which was collected by the CPA subsequent to CH2M Hill's Phase 1 work.

The detailed review of the additional information regarding chemical and physical composition of waste sludge/solids indicated that the waste characterization basis used for the initial technology assessment study was generally accurate and realistic. The wastes contain a significant portion of fine material (silt and clay), as well as coarse sands and contain variable amounts of oil, salt and heavy metals.

Using the Kepner-Tregoe (K-T) approach previously established in the Phase 1 Report, this study assesses an additional twenty two processes for potential suitability to treat wastes exhibiting the characteristics described above. After preliminary screening of the additional twenty two processes, eight processes were selected for detailed evaluation using the criteria previously established in the Phase 1 Report and then rated with the processes in the Phase 1 Report.

This current assessment resulted in a revision to the original short-lists developed in the Phase 1 Report.

For the small-scale, local plant scenario, simpler and less costly processes based on aqueous extraction/leaching technologies (ASTCO-STS Process and RTR/Gulf Process) using heat, chemicals and gravity/mechanical separation devices together with landfill/landfarming and subsurface disposal (disposal wells) for final solid and liquid residue are preferred.

The top four rated processes for the small-scale, local plant scenario are:

1. ASTCO-STS Process
2. RTR/Gulf Process
3. Aqua-Guard Thermal Oxidizer
4. B.E.S.T. Process

For the large commercial-scale plant scenario, more complex, high technology based options such as solvent extraction (B.E.S.T. and BP Oil Process) and thermal treatment processes become more attractive. It is anticipated that current low technology options such as disposal wells, landfill/landfarm, etc. will still be required for final residue disposal even in this scenario.

The top rated processes for the large regional plant concept are:

1. B.E.S.T. Process
2. Aqua-Guard Thermal Oxidizer
3. BP Oil Solvent Extraction
4. ASTCO-STS
5. Taciuk Processor

The results of this technology assessment work show that there could be some overlap in potential treatment processes suitable for conventional production waste sludges and solids and other oil and gas production wastes such as heavy oil produced sands.

At least one process, ASTCO-STS, is rated highly for both treatment of conventional production waste sludges and treatment of heavy oil produced sands. Other treatment processes such as Aqua-Guard Thermal Oxidizer and Taciuk which are based on thermal treatment technologies are rated quite highly in both applications and have potential to handle both types of waste material.

The current status of the treatment technology assessment work being carried out by CPA and Environment Canada has reached a point where a "focussing" step is necessary to review the work that has been done to date and to determine what should be done in the future. The future work program might include the following:

- Completion of any outstanding technology assessment studies such as CPA's recently initiated gas plant sludge treatment/disposal investigation.

- A "focussing" phase to review past and current technology assessment projects, prioritize wastes generated by the oil and gas production industry and to agree on the processes which are most applicable to the range of waste(s) needing treatment.

- A program development and bench-scale/laboratory testing phase in which basic chemistry, process design and cost of selected processes are defined in some detail, field pilot testing requirements and costs are identified and a test plan prepared.

- A demonstration testing phase to field test the selected processes on actual waste material.

It is anticipated that future work will include processes suitable for both local, small-scale operations and large-scale, commercial operations since both types of operations will be required by industry to handle the various waste materials accumulating in the field.

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1. INTRODUCTION

1.1 BACKGROUND

In December 1989, the Canadian Petroleum Association (CPA), with the support of Environment Canada completed the first phase of a study of treatment technology for waste sludge and solids generated during oil production activities. The summary report, prepared by CH2M Hill Engineering Ltd. entitled "Evaluation of Technology for the Treatment of Waste Sludge and Solids Contaminated with Salt, Metals, and Hydrocarbons" Phase 1 Report was published by the CPA in December 1989. This study included a survey and evaluation of existing and developing treatment processes and technologies and ranked them for potential application in treating waste sludges and solids exhibiting a wide range of characteristics and containing a variety of contaminants.

Subsequent to the completion of this initial study in December 1989, additional information regarding the characteristics of waste sludge and solids addressed in the study was obtained by the CPA and is presented in the report "Physical and Chemical Characteristics of Oilfield Production Facility Waste Sludges and Solids", September 1990 prepared by David Bromley Engineering 1983 Ltd., (DBEL).

Also, since completion of the initial treatment technology study, additional work has been carried out by the CPA, Sask-Alta Waste Disposal Co-op and AOSTRA evaluating technologies for clean-up of produced oily solids generated by heavy oil operations. The results of that work, carried out by Monenco Consultants Limited (MCL), have been summarized in a report published by the CPA in July, 1990 entitled "Evaluation of New Technologies For Clean up of Produced Oily Solids From Heavy Oil Operations". MCL's study focused on the treatment and disposal of coarse sands (i.e. typically greater than 60 micron) produced by heavy oil operations in western Canada. Therefore the treatment/disposal approach would be somewhat different than with wastes containing a significant fraction of fine material (silt and clay) as well as some coarse material which was the focus of the Phase 1 Report mentioned above (conventional oil production oily waste).

In light of the additional information available through the studies referenced above, the CPA and Environment Canada decided that a revisit to the Phase 1 Report technology assessment was appropriate to ensure that the recent information was taken into consideration in identifying and assessing suitable treatment processes/technologies.

This update of CH2M Hill Engineering Ltd.'s initial study reviews the additional chemical and physical waste characteristic data obtained by DBEL and evaluates the suitability of those technologies identified in MCL's Report for application in the treatment of oil production waste sludges and solids contaminated with salt, metals, and hydrocarbons and containing a significant portion of fine material (clay and silt). A list of all of the processes/technologies that were considered in this update is presented in Table B.1, Appendix B. This list of processes/technologies includes those evaluated by CH2M Hill Engineering Ltd. in the Phase 1 Report and by Monenco Consultants Limited in their study of treatment and disposal of heavy oil produced sands.

This report summarizes the results of the updated technology evaluation.

1.2 OBJECTIVES AND METHODOLOGY

The overall objective of this study was to prepare a revised short list of applicable technologies capable of treating and disposing of various hydrocarbon -, metal -, and/or salt-contaminated solids and sludges generated by oil producers, which updates the 1989 CPA report entitled "Evaluation of Technology For the Treatment of Waste Sludge and Solids Contaminated With Salt, Metals, and Hydrocarbons." Technologies would be suitable for implementation in either a large, regional, central plant or a small, local plant scenario.

To achieve the overall objective, a series of tasks was completed as follows:

1. Review the additional physical and chemical waste characteristic data collected by DBEL and review the technologies identified in MCL's Report and assess their potential application to treat the range of wastes considered in the previous assessment.

2. Show how the results of the revised assessment change the short-list of technologies identified in the 1989 CPA/Environment Canada Phase 1 Report.

3. Review the current overall status of technology demonstration work under CPA/Environment Canada for oil and gas production wastes and prepare a conceptual implementation plan for future work.

2. REVIEW OF REPORTS

The first task in this update of CH2M Hill Engineering Ltd.'s initial treatment technology study was to review, in some detail previous work pertaining to characterization and treatment of oil production waste sludge and solids which have been summarized in the various CPA published reports listed below.

2.1 CH2M HILL ENGINEERING LTD. - "EVALUATION OF TECHNOLOGY FOR THE TREATMENT OF WASTE SLUDGE AND SOLIDS CONTAMINATED WITH SALT, METALS, AND HYDROCARBONS", PHASE 1 REPORT, DECEMBER 1989

CH2M Hill's treatment technology study investigated a total of 32 treatment processes/technologies which had potential application to the types of oilfield wastes. A short-list of processes was generated for both a small-scale local plant scenario and a large commercial-scale plant scenario using a Kepner-Tregoe (K-T) assessment approach. The study concluded that emerging high technology processes will be required to handle the entire range of wastes contaminated with oil, salt, and heavy metals and with a significant fraction of fine material of less than 60 microns. Certain classes of generic treatment technologies such as solvent extraction and aqueous leaching/extraction are likely candidates for future consideration.

Also, it was concluded that these emerging high-technology-based processes will most likely have to be used in combination with existing low technology disposal methods to provide a solution for final residual solids disposal.

2.2 DAVID BROMLEY ENGINEERING (1983) LTD. - PHYSICAL AND CHEMICAL CHARACTERISTICS OF OILFIELD PRODUCTION FACILITY WASTE SLUDGES AND SOLIDS, SEPTEMBER 1990

The primary objective of the characterization work carried out by DBEL was to obtain supplementary data regarding the physical and chemical characteristics of six sludge/solid waste streams common to upstream oil production operations. The six streams included:

- Process pond sludge

- Flare knockout drum sludge
- Flare pit sludge
- Treater bottom sludge
- Tank bottom sludge
- Spill material

The supplementary data will assist in the evaluation of treatment technology options for these waste materials. A comprehensive field sampling program was carried out with three samples of each type of waste collected from different production facilities.

The DBEL Report concluded that:

1. In general, the quality of the data base generated is acceptable for the evaluation of treatment technologies.

2. Laboratory analytical procedures used to analyze selected parameters in sludges/solids were generally acceptable.

3. All six sludge/solid wastes could potentially be classified as hazardous based on the Alberta Hazardous Waste Regulation.

4. Leachates generated from all samples did not contain concentrations of metals, cyanides, and nitrate/nitrite which exceed the limits of a TDGR 9.3 dangerous material.

The following conclusions are derived from a review and assessment of the analytical data in DBEL's Report:

- The DBEL report confirms that the study basis regarding waste composition/characteristics used by CH2M Hill in the Phase 1 Report was realistic. Wastes are contaminated with salt, metals, and oil in varying amounts and all of the wastes contain a significant portion of fine material less than 60 micron in size. Some of the wastes contain as much as six percent salt.

- Leachate analysis indicated that heavy metal concentrations in leachate do not exceed limits of TDGR 9.3. Metals tend to remain with the solids, although it should be noted that leachate analysis was carried out on waste samples "as is". Future work will need to investigate leachate quality after treatment to determine the degree of immobilization of metals/organics in the solid residue.

- It was noted that some of the analytical data presented was not consistent with the physical make-up of the wastes (e.g. Higher Heating Value versus sample oil/water/solids fractions). This could be a result of a limitation of the analytical procedures employed. Further analytical work is required to check these inconsistencies in the data.

- The hydrocarbons present in the wastes are comprised of primarily aliphatics and asphaltenes with a smaller amount of aromatics.

2.3 MONENCO CONSULTANTS LIMITED - "EVALUATION OF NEW TECHNOLOGIES FOR CLEAN UP OF PRODUCED OILY SOLIDS FROM HEAVY OIL OPERATIONS", JULY 1990

The primary objective of MCL's study was to identify and evaluate processes/technologies which could clean-up and dispose of oily solids produced by heavy oil operations. The wastes addressed were coarse (typically greater than 60 micron material) heavy oil produced sands. Other study objectives included the acquisition of a produced oily solids characterization database and the formulation of a field demonstration program for selected technologies.

The approach used by MCL involved solicitation of treatment/disposal technologies from various proponents through a national advertisement campaign.

The conclusions of MCL's study were:

1. Technologies are available which may be suitable for cradle-to-grave clean-up and disposal of produced oily solids with costs ranging from $\$105/m^3$ to $\$136/m^3$. These technologies include Fluid Bed Combustion, ASTCO-STS Extraction Process and Halliburton Hydraulic Fracturing Sub-surface Disposal.

2. Field testing to evaluate viability and to optimize process and scale-up would be required for several of these technologies.

3. Road surfacing is one of the most effective methods of oily solids disposal and is currently practised by Esso Resources Canada Ltd. Cost of disposal by this method is $75/m^3.

MCL's study focused on the treatment and disposal of coarse sands. Technologies such as re-injection, road surfacing and gravity separation processes were deemed to be suitable for this type of waste. The wastes considered in the CH2M Hill Phase 1 Report contain both coarse sand and a large fraction of fine silt and clay and therefore are not as well suited to some of those technologies highly rated in MCL's assessment. However, it is recognized that some of the treatment processes such as thermal treatment may be suitable to handle both types of wastes. A review of MCL's report indicated that several proponent technologies considered in their assessment were also included in the original Phase 1 Report. These were:

- Taciuk Processor
- RTR/Gulf Process
- Agloflotation Process
- Kruyer Process
- Clark Hot Water Process

Other treatment processes included in MCL's list such as Pacific Fluid Bed Combustor, Fujibeton Solidification, etc., were not specifically addressed in the Phase 1 Report, although their corresponding generic categories (i.e. fluidized bed combustion, solidification/fixation) were considered.

A review of MCL's report also provides additional technology information which was not available at the time of the Phase 1 Report and which is taken into consideration in this update:

1. Recent information and/or test experience has shown that certain treatment technologies such as solvent extraction may have difficulty with fine material in the solvent recovery step. Fines tend to absorb

solvent which can only be recovered with additional treatment stages adding to cost and complexity of the system.

2. Recent information has indicated that thermal treatment methods are being developed, tested, and used commercially to treat similar wastes once permitting/approvals, delays and hurdles have been overcome. Thermal treatment processes are being coupled with current methods such as landfill, landfarming and landspreading for final residue disposal and gravity separation of oil/water/solids for pretreatment of waste feed.

3. SUMMARY OF APPLICABLE PROCESSES

This section summarizes and compares individual treatment processes identified in MCL's report and which were not addressed previously in the CH2M Hill 1989 Phase 1 Report and classifies them under each of the general categories developed in the Phase 1 Report. A technology which was not included in either previous report, the Aqua-Guard Thermal Oxidizer, is also evaluated in this update report.

As previously stated in the Phase 1 Report, the ideal treatment technology or combination of technologies is one that is low cost, simple to operate, capable of treating wastes containing a significant portion of fine particles, capable of separating oil/water from fine solids, and capable of generating a residual solid which is dewatered, desalted, and heavy metals removed and/or immobilized. No one single process/technology is able to achieve all of the treatment objectives stated above for a waste containing the wide range of contaminants and exhibiting the varied characteristics of the oilfield wastes in this study. More realistically, high-technology based options coupled with simpler, less costly, low-technology processes likely offers the best solution.

Each of the treatment processes/technologies identified in MCL's report were considered in this update and build on the list of technologies assessed in the CH2M Hill Phase 1 Report. The complete list of processes/technologies investigated which may have potential application for the treatment of oily waste sludge/solids is shown in Table B.1, Appendix B.

3.1 COMPARISON OF PROCESSES

This section is presented in a table format (Tables 3.1 to 3.4) and summarizes the information regarding individual processes presented by MCL in their 1990 report and also the information on the Aqua-Guard Thermal Oxidizer. Appendix C contains detailed vendor information on the Aqua-Guard process.

The information provided in this section, together with the detailed information presented in MCL's 1990 report and CH2M Hill's Phase 1 Report forms the basis for the assessment of treatment processes in Section 4.

Table 3.1 Solvent Extraction Treatment Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
SESA Process		
The Solvent Extraction Spherical Agglomeration (SESA) Process was developed by NRC and is currently marketed by Terra Energy Ltd. The process combines extraction, agglomeration, and solvent recovery steps.	o High recovery of hydrocarbon possible o Considerable backing of NRC available	o Process has only been bench-tested o No economics are available o Fine material in wastes may result in difficulty in solvent recovery step o Process requires diluent addition o Development cost would be substantial

Table 3.2 Aqueous Extraction and Leaching Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Trans, Couillard, Rouleau Process		
Process developed specifically for removal of heavy oil from tank bottom petroleum sludges. Process is based on treatment in a flotation device.	o Process is not patented o Process can be expanded and additional stages added to treat different wastes o Simple operation o Cost competitive	o Will not accommodate either coarse or fine material easily o Has not been pilot tested yet (Bench tests only)
Cold Lake Oily Sludge Process		
This is a hot water extraction process using the same concepts as the proven Clark Hot Water Process on a much smaller scale. Process has been developed by Esso Resources Limited.	o Pilot tested on ecology pit wastes o Can be modular construction and totally portable	o Information on process lacking at this time o Fine material may be problem in process
Suncor Oily Sludge Cleanup Process		
This process was developed by Suncor Inc. for use on bitumen rich pond bottom sludges at its Fort McMurray facility. The process is based on conditioning in tumblers, froth flotation to recover hydrocarbons and residue dewatering using a centrifuge.	o Considerable experience in treatment of oil sands/bitumen tailings and sludges/residues o Cost competitive process	o May not be suitable for wastes containing a lot of fines o Limited experience with material other than oil sand tailings

Table 3.2 Aqueous Extraction and Leaching Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
STS Process		
This hot water extraction process employing agitation, coalescing and gravity separation was developed by Alberta Solids Treatment Company (ASTCO).	o Commercial unit available o Successfully tested for hydrocarbon recovery and oil/water/solids separation on oily sludges o Low capital and operating costs o Simple operation	o Process is separation only. Does not remove contaminants (i.e. salt, heavy metals) from the various phases

Table 3.3 Thermal Treatment Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Superburn Incinerator This process, designed and supplied by Canadian Waste Management is based on a revolving fluidized bed combustion concept. The fluidized sand bed is maintained at 600-700 degrees C.	o Can achieve excellent temp. control resulting in low NOx emission o Commercial experience with other waste materials o Can treat a variety of wastes o Various size ranges available	o Need supplemental fuel (oil or gas) o Dolomite or limestone required to neutralize o Noise suppression equipment may be required o Capital costs likely high due to system complexity o Ash needs to be disposed of
Dolen Burner This is a mobile burner supplied by Environment Protection Company and is specifically designed to eliminate hydrocarbon in sand, gravel, clay and sludges.	o Completely mobile - can be taken to waste site o Capacities as high as 20 tph o Reduces oil to <0.8% and eliminates all water from wastes o Can treat a wide variety of wastes o Simple to operate	o Products of combustion (solid residue) concentrated with metals, salts still need disposal o Propane is required as primary fuel for burner and afterburner o Potential difficulty in permitting/approvals due to air emissions o Elaborate air pollution control equipment may be required o Residual heat produced

Table 3.3 Thermal Treatment Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Lurgi-Ruhrgas Process This is a direct retorting process using a circulation/ reaction chamber. It has been commercially proven for cracking naphtha, crude oil and coal and has been in operation since the 1950's.	o Can accept a wide variety of liquid & solid feeds o Experience with heavy oil, tar sands and oil impregnated diatomite o Long history of operating experience o Reputable company backing	o High water content in feed will require pre-drying equipment o Coke is produced as a by-product of the process o Large number of mechanical components (complex process) o High capital costs o Flue gas treatment required o Sour water generated in process which will require treatment prior to disposal
Aqua-Guard Thermal Oxidizer This thermal treatment unit is based on a rotary kiln plus secondary combustion process and is a transportable and self-contained unit. It can be erected/assembled in 3-5 days.	o Experience in treating similar wastes o Transportable - can be taken to remote waste sites if necessary o Process has been demonstrated on a commercial basis at several sites	o Requires scrubber and baghouse to control air emissions which increases capital cost of the unit o Permitting/approval of process could be a problem depending on the site

Table 3.3 Thermal Treatment Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Anachemia Pyrolytical Process		
This is a licensable process developed by Anachemia Solvents Limited which blends oily sludge/ solids with a solvent and burns the gas pyrolytically in a spouted bed pyrolytic reactor.	o More efficient than conventional incineration for some wastes with less emissions o Enables recovery of solvents from still-bottom residues in a solvent recovery plant o Demonstrated on paint sludge containing up to 50% solvent concentration	o System is mechanically complex o Many components required to treat gaseous emissions and to recover hydrocarbon fraction o Likely high cost o Process uses new technology for main reactor o Residual heat is produced which requires a heat sink o Limestone required to neutralize flue gas
Fluid Bed Combustor (FBC)		
This unit provided by Pacific Environment System Inc. is a retort type fluid bed combustor operating at 1900 degrees F.	o Experience in treating oily solids (oil-soaked clays) o Portable units available o Flexibility in handling a variety of wastes. Allows combustion of wastes with high moisture o Demonstration plant available for testing o Technology used commercially in other waste applications	o Salt content in waste material could be a problem in bed (melting & fusion) if provisions are not provided to overcome this o In-bed limestone required to control acid gas emissions

Table 3.3 Thermal Treatment Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Fluid Bed Combustor (continued)	o Can be shutdown on weekends/ overnite and restarted with little or no preheating	o Particulate control equipment required for flue gas o Solid waste must be sized to be relatively uniform and less than 1/2" size o Requires sand make-up o Ash generated is wet. If dry ash is required, clarifier/thickener or other dewatering equip. is required.

Table 3.4 Other Treatment Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Salt Cavern Disposal		
This is a disposal technology developed by NewAlta Environmental Services Corp. in which oily solids would be injected into previously mined salt caverns after removal of the water phase.	o network of collection/ transportation set-up and in-place o Approvals process well underway o Provides permanent disposal	o Process is not mobile o Transportation of wastes required o Salt water requires disposal or evaporation step o Disposal costs not available at this time
Mobil Oil Sand Injection		
This is an injection process, developed by Mobil Oil to dispose of sand and fluids in disposal wells.	o Provides permanent disposal o Simple operation	o Only limited information available at this time o Requires a disposal well o Permitting/approval for a disposal well may be a problem o Transportation of wastes to disposal well required
Neutralysis		
This process developed by Energy Consulting Inc. utilizes pulverized municipal solid waste mixed with oily sludge and an extrusion/ drying process to produce a light weight aggregate.	o Produces a useable/saleable by-product o Disposes municipal solid waste at the same time o Full-scale demonstration plant in operation	o Needs a market for the product o Large number of components in the process-costly process o Requires air pollution control equipment to control air emissions o Probably only suited for large-scale central processing concept

Table 3.4 Other Treatment Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Ekopor V-DZ Ekopor is a chemical that is added to oily waste to separate oil and solids from water. Absorbed solids are then used as a fuel.		o Application is primarily for oil spill cleanup
Citri-Solve CitriSolve supplied by Envirodyne International is a chemical spray applied to oil spills to digest the oil.		o Main application is for oil spill control
O.S. Sep. Process This process utilizes proprietary chemicals to treat emulsions and facilitate separation of hydrocarbons from solids & water and uses commercially available mineral processing equipment.	o Bench and pilot demonstration test work completed o Process tested on a variety of oilfield wastes	o Process is primarily for hydrocarbon recovery o Solids residue and salt water still need disposal
Shell Process Shell Canada has developed a process to clean-up oil sludges/solids based on conditioning, gravity separation and dewatering steps.	o Extensive testing done on heavy oil produced sands o Simple process o Cost competitive	o Process may have difficulty in handling fine material since gravity methods are used in the process

Table 3.4 Other Treatment Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Fujibeton Solidification		
This solidification process available from Canadian Waste Management Inc. mixes wastes, proprietary inorganic polymers and Portland cement to produce a concrete.	o Extensive overseas experience o Process can accommodate any volume of waste material o Simple operation o Process produces a useable/ saleable product (similar to concrete) o Can treat wastes containing fines	o Product generated by the process needs a market o Very little experience with types of wastes considered in this study o Long term effects of treated product not known
Voest-Alpine Montage (VAM)		
This solidification process treats wastes with calcium oxide and water to produce calcium hydroxide, a water repellant powder which is compacted to make a product suitable for road construction.	o Simple operation o Mobile unit o Commercial experience with other wastes such as oil sludges & drilling muds	o Product generated by the process needs a market o Particulate emissions from the process require control equipment
Halliburton Re-Injection		
This waste disposal technology is based on re-injection of oily solids/fluids into disposal wells at hydro-fracturing pressures.	o Proven process commercially o Provides permanent disposal	o Needs a disposal well (i.e. converted production well) o Waste material transportation required o Permitting/Approval for disposal well could be a problem in the future

Table 3.4 Other Treatment Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Guinard Centrifugation Process This process uses a disc nozzle centrifuge together with heat and chemicals to separate hydrocarbon and water from solids.	o Accepts wide range of waste types and solids content o Process produces a pelletable sediment o Hydrocarbon recovery is good	o Process requires water, steam, power o Process provides de-watering only o Salt water requires disposal o Fines could be a problem o Mechanical equipment subject to high wear
Bird Centrifugation Process This sludge clean-up process developed by Bird Machine of Canada uses a combination of heat, primary solid bowl centrifuge and secondary disc nozzle centrifuge to separate hydrocarbons and water from solids.		o Process requires water, steam, power o Process provides de-watering only o Salt water requires disposal o Residual solids requires disposal o Fines could be a problem o Mechanical equipment subject to high wear

Table 3.4 Other Treatment Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Filtration		
Process using a media filter to remove solids and hydrocarbons from water phase.		o Filtration (on its own) not suitable for oily wastes with fines considered in this study
Esso/Road Surfacing		
This is a road surfacing technique, developed by Esso Resources Canada to apply oily sand material for road construction.	o Simple operation o Cost competitive o Considerable experience built up with technology	o Time and volume constraints o Long term environmental effects not known. o Mixture must be just right - otherwise problems o Experience only with coarse material (sand & clay) from heavy oil operations o Fluid must be drained off and disposed of separately

4. ASSESSMENT OF TREATMENT PROCESSES

The second objective of this update of the initial technology assessment study is to show how the results of this additional technology evaluation change the short-list of technologies previously generated in the Phase 1 Report.

4.1 APPROACH

The treatment process assessment is based on a Kepner-Tregoe (K-T) approach with preliminary screening and detailed evaluation steps.

As in the previous Phase 1 Report, two scenarios of treatment plant configuration are considered:

1. A small/local plant that serves batteries within an operating field with one or more operating companies. It is expected that this facility would receive wastes within a narrower feed range and, therefore, may by more suitable to simpler, low technology options or simpler variations of a high technology process.

2. A large/central plant that serves a region of many batteries and operating companies. The wastes received at a central facility exhibit a wide range of characteristics and such a treatment facility would most likely involve either a developing high technology process or a combination of emerging high technology processes and existing low technology methods.

Potential treatment technologies would, either on their own or in a combination with other processes, have to be capable of treating wastes having a significant portion of fine particles (silt and clay), separating oil/water from solids, dewatering and desalting solids, and removing or immobilizing metals in solids.

Technical evaluation criteria by which the treatment processes have been assessed are the same ones previously developed in CH2M Hill's Phase 1 Report. As before, the evaluation is divided into two steps: preliminary screening and detailed evaluation.

4.2 PRELIMINARY SCREENING

In the preliminary screening, each of the processes listed in MCL's report and not previously covered in the Phase 1 Report are evaluated against the K-T "Must" criteria. These are:

1. The treatment process must have successfully been demonstrated at pilot scale to have the capability to treat at least one of the waste types considered in the Phase 1 Report.

2. The treatment process must have the capability to treat fines of down to 2-micron diameter efficiently. This "Must" is identified since this study focuses on treatment and/or disposal of waste having a significant portion of fine particles (silt and clay).

These criteria must be satisfied in order for the process to be considered further.

Each treatment process described in Section 3 was evaluated against the above K-T "Musts". The results of the preliminary screening are presented in Table 4.1.

4.3 DETAILED EVALUATION

The processes/technologies identified in MCL's Report to the CPA, July 1990 were reviewed to assess their potential application to treat the range of wastes considered in the Phase 1 Report. The processes/technologies which met the "Musts" in Section 4.1 were re-evaluated against the processes/technologies previously evaluated in the Phase 1 Report using the same K-T "Want" criteria listed below:

1. **Operability** - The operability criterion relates to the reliability, simplicity, and stability of a system. Relatively simple systems with high service factors (low downtime), minimal pretreatment, and low operating and maintenance requirements that are easy to control are

TABLE 4.1. PRELIMINARY SCREENING

Process/Technology	K-T MUSTS Demonstrated at Pilot-Scale*	Treats Fines (2 microns)	Go/NoGo
Thermal			
• Superburn Incinerator	Yes	Yes	Go
• Dolen Burner	No	Yes	No Go
• Lurgi-Ruhrgas	No	Yes	No Go
• Aqua-Guard Thermal Oxidizer	Yes	Yes	Go
• Anachemia Pyrolytical Process	No	Yes	No Go
• Pacific Environment System - Fluid Bed Combustor (PES-FBC)	Yes	Yes	Go
Aqueous Extraction & Leaching			
• Trans,Couillard, Rouleau Process	No	No	No Go
• Cold Lake Oily Sludge Process	Yes	No	No Go
• Suncor Oily Sludge Cleanup Process**	No	Not Likely	No Go
• ASTCO-STS Process	Yes	Yes****	Go
Solvent Extraction			
• SESA Process	No	Questionable	No Go
Other Treatment/Disposal Methods			
• NewAlta Salt Cavern Disposal	Yes	Yes	Go
• Re-Injection (Haliburton, Mobil)	Yes	Yes	Go
• Neutralysis	No	Yes	No Go
• Ekopor V-DZ	No	Yes	No Go
• Fujibeton Solidification	No	Yes	No Go
• VAM	Yes	Yes	Go
• Citri-Solve	No	Yes	No Go
• O.S. Sep. Process	Yes	Yes	Go
• Guinard Centrifugation	Yes	No	No Go
• Bird Centrifugation	Yes	No	No Go
• Filtration	Yes	No	No Go
• Road Surfacing***	Yes	No	No Go
• Shell Process	No	Questionable	No Go

* Demonstrated at pilot-scale level to treat at least one of the waste types considered.
** Process developed by Suncor primarily for recovery of bitumen from tar sands using diluent, heat, mechanical, separation. Not likely to be effective on material containing significant fraction of fines.
*** Esso road surfacing procedures developed specifically to use coarse sand material from heavy oil operations after dewatering. Unlikely candidate for material containing significant fraction of fines.
**** Capability to treat fines to be confirmed.

considered most desirable.

2. **Performance** - A system's performance is its ability to treat the waste with high recovery/destruction/removal efficiencies and good turndown capability while yielding a product that meets or exceeds the outlet quality requirements by a reasonable margin of safety and a residue that is low in volume and readily disposed of in an acceptable manner.

3. **Portability** - A mobile unit is the most portable. Skid-mounted units are more transportable than fixed plants.

4. **Potential for commercialization** - Those technologies with the least anticipated scale-up problems and the least need for additional pilot testing have the highest potential for commercialization.

5. **Flexibility of process to handle varying feed** - Those technologies that have demonstrated the flexibility to handle a wide range of feed characteristics (i.e., particle size, oil/water/solids composition) are considered most desirable.

6. **Field experience in similar applications** - Those technologies that have demonstrated actual field experience with similar waste types and environmental conditions are most desirable.

7. **Expandability** - Module-type construction using existing, well proven pieces of equipment are least expensive to expand.

8. **Technology builds on or enhances current practices** - Technologies that are similar to current oilfield practices (e.g. physical and chemical/thermal enhanced

separation) are easier to adopt by existing operating and maintenance staff.

9. **Operational safety risk** - Technologies operating in low temperature, low pressure environments using nontoxic substances have a lower safety risk to operators than technologies operating in high temperature, high pressure environments using toxic substances.

10. **Relative cost** - In general, physical treatment processes cost less than physical/chemical or biological processes; physical/chemical or biological processes cost less than thermal treatment processes.

As some criteria were considered to be of greater or less importance than others, weighting is assigned to each criterion. The more important the criterion, the higher the weighting.

Detailed Evaluation Criteria	Small/Local Plant Weighting Factors	Large/Central Plant/Weighting Factors
Operability	140	100
Performance	130	140
Portability	100	50
Potential for commercialization	50	120
Flexibility of process to handle varying feed	120	130
Field experience in similar applications	100	100
Expandability	50	90

Technology builds on or enhances current practice	90	50
Operational safety risk	110	80
Relative cost	110	140

Each process was evaluated relative to the others and assigned a rating of 1 to 10 (with 10 being the rating given the best-fitting process) under each of the criteria. The product of the weighting times the rating gives a weighted score for each criterion. The sum of these for all criteria then gives a total weighted SCORE for each alternative, with the highest total SCORE theoretically assigned to the process that best satisfies the detailed evaluation criteria. The maximum possible score is 10,000. It is important to recognize that the scoring is done purely on a relative basis for the case being examined. Detailed evaluation worksheets are presented in Appendix A.

4.4 DISCUSSION OF RESULTS

It should be noted that the various components of a treatment system have to perform specific functions such as oil removal, dewatering, and immobilization of salt and metals. Few processes exist that would perform all of these functions cost effectively.

Solidification/fixation (VAM Process), in situ biological treatment and soil slurry biodegradation consistently rank lower in relation to other processes for criteria such as operability, performance, flexibility to handle varying feeds, and similar field experience. Also, these processes are very different from current practices and would require significant adjustment of the technical skills possessed by typical oilfield operators.

Although thermal treatment processes such as the Aqua-Guard Thermal Oxidizer and the Taciuk Processor scored relatively high on performance, potential for commercialization, and flexibility to handle varying feed criteria, they typically require external auxiliary systems such as feed preparation, air pollution control, and wastewater and ash treatment that add a significant complexity and overall cost to the basic process. They are also quite different from current practices.

Landfilling and landfarming used to be relatively simple and inexpensive to initiate and operate. Recent regulations are making these processes more difficult and complicated. To apply these processes would require either numerous small operations over a wide area or extensive transportation of potentially hazardous material. Also, the requirements for monitoring and testing before site development, during operation, and after site closure would likely result in high operating costs. Since the contaminants in the wastes are neither destroyed nor recovered, long-term liability remains.

Likewise subsurface disposal using disposal wells or caverns has drawbacks. Permitting/approval for such facilities are becoming more difficult and, as in the land application methods, transportation of waste material to the disposal well and/or cavern site would be required. Maintenance requirements for a disposal well or cavern to avoid well plugging, corrosion, etc., would likely be quite high.

Other processes such as Hot Toluene Fluid Extraction, Oleophilic Sieve, Aglofloat, CF Systems and Colt Treater are either in a very early stage of development or limited to a very narrow range of feed application. The Aglofloat process also requires a coal co-feed.

The results of the detailed evaluations for a small-scale local plant and a large regional plant are presented in Tables 4.2 and 4.3 respectively.

4.5 SMALL-SCALE LOCAL PLANT TECHNOLOGY EVALUATION

The top four processes for a small-scale local plant are:

1. ASTCO-STS
2. RTR/Gulf
3. Aqua-Guard Thermal Oxidizer
4. B.E.S.T.

The two top ranked processes both scored over 6,000 points and are based on aqueous extraction/leaching technologies. The third and fourth ranked processes followed fairly closely in the scoring and are thermal treatment and solvent extraction technologies respectively.

The results of the evaluation indicate that less complex, easy to operate and well demonstrated processes are preferred for treating wastes on a small-scale local plant scenario.

TABLE 4.2 **SMALL PLANT K–T EVALUATION RESULTS**

RANK	PROCESS	SCORE
1	ASTCO–STS	6150
2	RTR/Gulf	6080
3	Aqua–Guard Thermal Oxidizer	5910
4	B.E.S.T.	5900
5	USEPA Soil Washer	5610
6	Re–Injection	5570
7	PES–FBC	5450
8	Salt Cavern	5420
9	O.S. Sep.	5390
10	Taciuk Processor	5360
11	Superburn Incinerator	5250
12	BP Oil Solvent Extraction	5100
13	Industrial Landfill	4850
14	Land Farming	4790
15	CF Systems	4770
16	Colt Treater	4680
17	Hot Toluene Extraction	4560
18	VAM	4340
19	Oleophilic Sieve	4190
20	Aglofloat	3920
21	In Situ Biolog. Treatment	3450
22	Soil Slurry Biodegradation	3420

TABLE 4.3 **LARGE PLANT K–T EVALUATION RESULTS**

RANK	PROCESS	SCORE
1	B.E.S.T	6320
2	Aqua–Guard Thermal Oxidizer	6240
3	BP Oil Solvent Extraction	6050
4	ASTCO–STS	6030
5	Taciuk Processor	6010
6	PES–FBC	5930
6	RTR/Gulf	5930
7	Superburn Incinerator	5830
8	Salt Cavern	5630
9	USEPA Soil Washer	5610
10	Re–Injection	5540
11	O.S. Sep	5280
12	CF Systems	5110
13	Industrial Landfill	5090
14	Land Farming	5010
15	Colt Treater	4920
16	Hot Toluene Extraction	4900
17	VAM	4320
18	Oleophilic Sieve	4240
19	Aglofloat	4210
20	In Situ Biolog. Treatment	3710
21	Soil Slurry Biodegradation	3670

All four processes have experience treating similar types of waste and were assessed to be able to handle fine material adequately either as is or with slight process modifications. Of the short-listed processes above, thermal treatment (i.e. Aqua-Guard Thermal Oxidizer) and the RTR/Gulf Process will accept wastes with fines as the process now stands. The RTR/Gulf Process has been previously tested on waste material containing a significant fraction of small particles and found that fines did not present a significant problem. A solvent extraction process such as B.E.S.T. may have some difficulty in the solvent recovery step if fines are present. Fines tend to absorb to solvent and separation is difficult. The ASTCO-STS process is based primarily on gravity separation and therefore may be susceptible to fines carryover in either the hydrocarbon or water streams. Further modifications may have to be made to this process depending on the degree of carryover.

Both the ASTCO-STS process and Aqua-Guard Thermal Oxidizer have commercial units available now.

Each of the four processes listed above would require a low technology process such as landfill or landfarming to dispose of final residual solids.

4.6 LARGE REGIONAL PLANT TECHNOLOGY EVALUATION

In the evaluation of processes for the large regional plant concept, the top five rated processes, all scoring over 6,000 points, are:

1. B.E.S.T.
2. Aqua-Guard Thermal Oxidizer
3. BP Oil Solvent Extraction
4. ASTCO-STS
5. Taciuk Processor

In this evaluation, the top five rated processes are all closely rated with the difference between the first and fifth being only five percent.

It is apparent that high-technology options such as solvent extraction and thermal treatment become more attractive for the large regional plant scenario than at the local small plant scale.

The top ranked process, B.E.S.T. Solvent Extraction, is expected to be able to generate a residual solids fraction which meets disposal requirements and to handle fines adequately albeit with some potential modifications/additions to the solvent recovery section of the process. Existing low technology disposal options such as landfill or landfarming can be combined with the B.E.S.T. Process to provide a suitable means of final residue disposal. The nature of the final residue will have to be determined in future bench-scale or pilot-scale testing using actual waste material from field locations. Also the ability of the process to handle fines would have to be verified. The process is expected to be able to treat coarse contaminated solids as well.

A thermal treatment based process such as Aqua-Guard Thermal Oxidizer or Taciuk Processor could be an alternative on the large plant scale even though permitting/approvals may be more lengthy and more of an obstacle than with either solvent extraction or aqueous extraction/leaching based technologies. The Aqua-Guard Incineration process has been developed to the stage where commercial facilities are available. A Taciuk demonstration unit is currently being constructed specifically for oily waste material.

4.7 TREATMENT COST

Preliminary order-of-magnitude cost information was obtained from the literature and from discussions with process vendors/licensors for the top rated processes. Cost information for the BP Oil Process was not available due to the vendor's confidentiality requirements.

The treatment costs presented in Table 4.4 are based on a wide range of plant capacities and vary widely with regard to what is included in the published cost information. Some processes include major cost items such as site development, field construction, permitting/approvals/licensing, utilities, etc. while others do not. Also the specific factors for calculating the annualized capital cost portion of the blended cost, such as payback period, interest rate, depreciation, etc., differ from case to case.

If individual companies/operators choose to pursue any of these potential treatment processes/technologies on their own, a verification of costs is first recommended. These costs are presented for preliminary comparison purposes only and will have to be refined and confirmed for the specific processes and applications in future phases of the project.

TABLE 4.4. TREATMENT COSTS

	B.E.S.T.	*BP Oil*	*RTR/Gulf*	*Taciuk Processor*	*ASTCO-STS*	*Aqua-Guard Thermal Oxidizer*
Treatment Cost in $ CDN/tonne (Blended capital and operating)	65-132	N/A	50-75	100-150 (See comment)	75-85 (See comment)	150-200 (This cost is obtained from published literature and covers incineration cost only)
Plant Capacity Basis	91 t/d		1.5 t/h	240 t/d	120 t/d	240 t/d
Qualifications re: Cost	Not included are: -residue disposal -permits -utilities -sampling/analysis -taxes/licences -transportation -field construction -site development		Not included are: -residue disposal -waste storage and auxillary facilities -permitting -sampling/analysis	Not included are: -residue disposal -permitting -sampling/analysis	Not included are: -residue disposal to CL II LF -heat source -material handling and storage external to STS unit -storage of treated water, oil & solids -field set-up/ commissioning	Not included are: -residue disposal -permitting -sampling/analysis
Comments		Cost info. not available due to vendor's confiden-tiality requirement.		For a smaller unit (i.e. 1 t/h) treatment costs on $/tonne basis would be much higher by a factor of several times.	Cost does not include cost of residue disposal to a CL II landfill.	Capital cost of a 10 t/h incineration unit quoted at 1.9 million Cdn 4Q1990.

5. FUTURE WORK PROGRAM

5.1 INTRODUCTION

The third objective of this update study was to review the current overall status of technology demonstration work undertaken by the CPA and Environment Canada pertaining to oil and gas production oily wastes and to prepare a conceptual implementation plan for future work.

To date, the CPA has completed technology assessment studies for the treatment and disposal of heavy oil produced sands and conventional production waste sludge and solids contaminated with salt, metals, and hydrocarbons. Also, studies to characterize conventional production waste sludge and solids and gas plant waste sludges have now been completed by the CPA. A treatment technology assessment study for gas plant sludges has been initiated by the CPA and Environment Canada. Gas plant sludges are expected to be somewhat different in terms of treatment technology than either heavy oil produced sands or conventional production waste sludge/solids. They are expected to contain considerably more volatile and semi-volatile organics, sulphur compounds, and phosphorous and nitrogen compounds. As a result, the processes identified in this work may or may not be quite suitable and will have to be combined with other treatment processes/technologies to handle the different contaminants in gas plant sludges. However, some of the technologies such as solvent extraction, biodegradation and thermal treatment could well be applicable for these wastes, as well.

Upon completion of the gas plant sludge treatment technology assessment, the CPA and Environment Canada will be in a better position to select technology to treat upstream oil and gas industry residual oily wastes.

5.2 FUTURE WORK PHASES

Based on the current status and conclusions of the various waste treatment assessment and characterization studies completed by the CPA, the future work program will most likely consist of several phases with an ultimate objective of field demonstrating selected treatment processes or combinations of processes. The overall program can be executed in a 14 to 16 month timeframe and could be phased as indicated in Figure 5.1.

FIGURE 5.1

FUTURE WORK
CONCEPTUAL IMPLEMENTATION PLAN

PHASE I (a)
FOCUSING

1. REVIEW CONCLUSIONS OF CPA'S PREVIOUS TECHNOLOGY ASSESSMENT WORK.
2. REVIEW CHARACTERISTICS, SOURCE, TYPE, QUANTITY, etc... OF WASTE MATERIALS & PRIORITIZE (if necessary).
3. AGREE ON PROCESSES WHICH ARE MOST APPLICABLE TO RANGE OF WASTE NEEDING TREATMENT.(RE: HO sands, conventional production, gas plant sludges)
4. PREPARE TECHNICAL MEMORANDUM DOCUMENTING DECISIONS/ JUSTIFICATION.

PHASE I (b)
PROGRAM DEVELOPMENT &
BENCH-SCALE/LAB TESTING

1. RESOLVE ANY OUTSTANDING ISSUES (eg. cost sharing amongst participants, confidentiality req'ts, etc.)
2. HOLD DISCUSSIONS WITH PROCESS VENDORS & (if necessary) CARRY OUT BENCH SCALE / LABORATORY WORK TO ESTABLISH BASIC CHEMISTRY, PROCESS DESIGN & COST OF SELECTED PROCESSES; REVIEW EXISTING PILOTS.
3. COLLECT VENDOR/PROCESS INFORMATION TO DETERMINE TYPE OF PILOT EQUIPMENT, OPERATIONS AND SELECT LOCATION(S).
4. DETERMINE PERMITTING/APPROVAL REQUIREMENTS AND PREPARE NECESSARY INFO PACKAGE.
5. PREPARE DETAILED TEST PLAN & SCHEDULE OF ACTIVITIES.
6. PREPARE DETAILED COST ESTIMATES.

PHASE II
FIELD DEMONSTRATION
TESTING

1. MOBILIZE,PROCURE MATERIALS & SET-UP/HOOK-UP FIELD PILOT(S).
2. OPERATE FIELD PILOT(S) AND COLLECT DATA.
3. DEMOBILIZE.
4. ANALYZE DATA & PREPARE SUMMARY REPORT.
5. MANAGE FIELD PROGRAM.

SCHEDULE & COST

Phase I (a)	Phase I (b)		Phase II
2 MONTHS	5 MONTHS	1 MONTH	6-8 MONTHS
$20k - $25k	$125k - $175k		$500k - $1500k (THIS WILL DEPEND ON No. & TYPE OF PROCESSES TESTED).

The phases of the future work program might include:

- Phase I(a) - Focussing
- Phase I(b) - Program Development/Bench and Laboratory Testing
- Phase II - Field Demonstration Testing

Phase I(a) - Focussing

In this segment of work, all previous CPA technology assessment and characterization studies will be reviewed in detail.

The characteristics of the various oil and gas production waste materials (including conventional production sludge/solids, heavy oil sands and gas plant sludges) will be reviewed and a brief priority assessment will be carried out based on their composition, volume, location, operating environment, and applicable regulatory requirement.

The priority assessment conclusions will be integrated with the technology assessment conclusions and agreement will be reached as to which processes are most applicable to the range of wastes needing treatment.

This work could be completed within a period of two months at a cost of approximately $20,000 - $25,000.

Phase I(b) - Program Development and Bench-Scale/Laboratory Testing

Once the most applicable processes have been selected, additional process testing requirements necessary to establish basic chemistry, process design and cost data will be determined. For this, a detailed experimental program will be developed and subsequently carried out. Tasks could include:

- Resolution of major issues such as cost sharing arrangement, waste material classification, definition of treatment efficiency, etc, amongst study participants.
- Discussions with each process vendor/licensor to determine if bench/laboratory testing is required to establish basic chemistry,

process design and cost information. For some processes which have been used commercially or semi-commercially in similar applications, it is expected that only limited bench/laboratory work may be required.

- If bench and/or laboratory testing is required, identification of the nature of testing and development of a test plan. A test plan will typically address the following items:

  - Location of tests (i.e. vendor/licensor facilities or other location).
  - Test protocols to ensure that results can be compared and that the results can be used to improve the assessment of process performance, pretreatment requirements and costs.
  - Schedule.
  - Costs.

- Carry out necessary bench and/or laboratory testing work.
- Discussions with other operators using the same processes/technologies being tested and review of existing performance and cost data (if available).
- Once the basic chemistry and process design have been established for the processes being considered, a field test plan will be developed in detail. The plan will typically include:

  - Definition of pilot equipment requirements and operational aspects and selection of testing location(s)
  - Monitoring/analytical testing requirements
  - Permitting/approvals requirements
  - Vendor/licensor confidentiality agreements and/or requirements
  - Field hook-up and tie-in details
  - Detailed test plan/schedule
  - Detailed estimate of costs

This phase of the program is expected to take five months to complete with an estimated cost of $125,000 - $175,000.

Phase II - Field Demonstration

Phase II will include the actual demonstration testing of selected processes at specific field location(s). This phase is expected to be six to eight months in duration and the cost will vary anywhere from $500,000 to $1,500,000 depending on the number and type of processes tested. Typically, field testing of new processes/technologies involving multiple processes is most cost effective when execution is based on an intense compressed schedule as opposed to a prolonged schedule.

For the purposes of this report it has been assumed that three processes/technologies will be tested simultaneously at one field location. It has also been assumed that field test units will be available on either a rental or lease basis from the selected process vendors/licensors.

Major tasks in a field demonstration testing phase would typically include:

- Mobilization and procurement
- Field set up/hook-ups/tie-ins
- Operator training/familiarization
- Operation and data collection
- Demobilization
- Data processing and summary report to the CPA
- Program management

5.3 INDIVIDUAL COMPANY INITIATIVES

Individual initiatives undertaken by a company for testing a single or a number of potentially suitable treatment technologies at a specific site would generally follow the conceptual implementation plan outlined in Figure 5.1 with some modification.

An individual company initiative would most likely combine Phase 1(a) and Phase 1(b) and complete this task in a much shorter timeframe and for less cost. Depending on the treatment process(es) selected for field demonstration testing, Phase II could also be executed in a shorter period of time and for less cost.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The CPA and Environment Canada are studying treatment technology available for treating and disposing of various hydrocarbon -, metal -, and salt-contaminated solids generated by conventional oil production activities. CH2M Hill's Phase I Report, December 1989 was a global assessment of existing and developing processes/technologies for handling wastes containing a wide range of contaminants and exhibiting a wide range of characteristics. Subsequent to issue of the Phase I Report a technology assessment study (Monenco Consultants Limited) was carried out by the CPA, Sask-Alta Waste Disposal Co-op and AOSTRA to address treatment and disposal of heavy oil produced sands and a number of treatment processes having potential application were identified.

This update assessment evaluates the suitability of those additional processes/technologies identified in Monenco's Study along with an additional technology (Aqua-Guard Thermal Oxidizer) for treating hydrocarbon -, metal -, and salt-contaminated solids using the same assessment methodology and criteria as CH2M Hill's Phase I Report.

The conclusions of this update assessment are:

1. Additional characterization work has been completed by the CPA/Environment Canada to determine the chemical and physical characteristics of oilfield production facility waste sludges and solids (David Bromley Engineering Ltd., 1990). A review of the analytical data resulted in the following conclusions:

   - The analytical data confirm that the waste characterization basis used in CH2M Hill's Phase 1 Report was accurate and realistic.

   - Leachate analysis indicated that heavy metals do not leach and tend to remain with the solids. Future work will be required to investigate leachate quality after treatment of solids to determine the degree of immobilization of metals/organics in the "treated" solid residue.

- Some of the analytical data presented was not consistent with the physical make-up of the wastes shown (e.g. Higher Heating Value versus sample oil/water/solids fractions). This could be a result of a limitation of the analytical procedures employed and future work is required to check some of the physical and chemical parameters of oily waste samples.

2. The results of the technology assessment herein show that there is some overlap in potential treatment processes suitable for conventional production waste sludges and solids and heavy oil produced sands which was the focus of MCL's study.

   At least one process, ASTCO-STS is rated highly for both treatment of conventional production waste sludges and solids and treatment of heavy oil produced sands. Other treatment processes such as Aqua-Guard Thermal Oxidizer and Taciuk which are based on thermal treatment technologies are rated quite highly in both assessments and have potential to handle both types of waste material.

   Processes based on solvent extraction technology such as B.E.S.T. are preferred for the large plant scenario. This process should be able to handle the coarse heavy oil produced sands, as well.

3. On a small-scale, local plant scenario, simpler and less costly processes based on aqueous extraction and leaching technologies such as ASTCO-STS Process and RTR/Gulf Process using heat, chemicals and gravity/mechanical separation devices together with landfill/landfarming and subsurface disposal (disposal wells) for final solid and liquid residue are preferred.

   On a large-scale, central plant scenario, more complex, high technology based options such as solvent extraction

(B.E.S.T. and BP Oil) and thermal treatment processes become more attractive. It is anticipated that current low technology options such as disposal wells, landfill/landfarm etc., will still be required for final residue disposal.

4. Some of the technologies which were highly rated for heavy oil produced sands such as road surfacing and re-injection may not, on their own, be suitable for conventional problematic oil and gas wastes due to certain characteristics of these wastes (i.e. fines, salt, etc). However, re-injection may be an acceptable, viable alternative for final disposal of conventional waste liquid residuals after treatment.

   Similarly, current methods such as landfill and landfarming may have potential application for final solid residue disposal of conventional problematic oil and gas wastes after treatment.

5. The cost information regarding treatment costs presented in this report are order-of-magnitude costs and were obtained for comparative purposes only. As such, they should not be used for any other purpose such as budgeting, project authorization, etc.

6.2 RECOMMENDATIONS

1. The results of another study recently initiated by the CPA to address treatment and disposal of gas plant waste sludges should be reviewed to determine if there is any overlap in treatment processes/technologies with those identified in this report.

2. Because Federal and Provincial environmental regulations are being constantly revised and updated, (e.g. Alberta Environmental Protection and Enhancement Legislation, June 1990 and Federal Canadian Environmental Protection Act Priority Substances List), future work should include a review of all proposed regulations since these changes may have a direct effect on the way oil and gas production wastes are managed in the future.

3. The treatment cost information for potentially suitable processes needs to be developed in greater detail to generate more accurate cost data for the various treatment processes.

4. The current status of the treatment technology assessment work being carried out by CPA and Environment Canada has reached a point where a "focussing" step is necessary to review what has been done and to determine what should be done in the future. An outline of a conceptual implementation plan for future work is presented in Section 5 and it is recommended that future work develop along these lines.

   The overall scope of the future work program might include the following:

   - A focussing phase to review past and current technology assessment projects, prioritize wastes generated by the oil and gas production industry and agree on the processes which are most applicable to the range of waste needing treatment.

- A program development and bench-scale/laboratory testing phase in which basic chemistry, process design and cost of selected processes are defined in detail, field pilot testing requirements and costs are identified and a field test plan prepared.

- A demonstration testing phase to field test the selected processes on actual waste material.

Future work should include processes suitable for local, small-scale operations and for large-scale centralized operations since it is anticipated that both types of operation will be required by operators in the future.

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APPENDIX A

DETAILED EVALUATION OF PROCESSES

TABLE A.1a ASSESSMENT OF TREATMENT PROCESSES – K–T WORKSHEET

PROCESS		OPER–ABILITY	PERFORM–ANCE	PORT–ABILITY	POTENTIAL FOR COMMER–CIALIZATION	FLEXIBILITY OF PROCESS TO HANDLE VARYING FEEDS	FIELD EXPERIENCE IN SIMILAR APPLICATION	EXPAND–ABILITY	TECHNOLOGY BUILDS ON OR ENHANCES CURRENT PRACTICE	OPERATIONAL SAFETY RISK	RELATIVE COST	TOTAL
		SMALL PLANT DETAILED EVALUATION CRITERIA										
WEIGHTING		*140*	*130*	*100*	*50*	*120*	*100*	*50*	*90*	*110*	*110*	
CF Systems	Rating	3	6	6	7	6	5	8	5	2	3	
	Score	420	780	600	350	720	500	400	450	220	330	4770
B.E.S.T.	Rating	4	8	6	8	8	7	8	4	4	4	
	Score	560	1040	600	400	960	700	400	360	440	440	5900
Hot Toluene Fluid Extraction	Rating	3	5	6	7	6	4	8	4	3	3	
	Score	420	650	600	350	720	400	400	360	330	330	4560
BP Oil Solvent Extraction	Rating	4	6	6	7	6	6	8	6	2	3	
	Score	560	780	600	350	720	600	400	540	220	330	5100
USEPA Soil Washer	Rating	5	5	9	6	3	5	9	6	5	6	
	Score	700	650	900	300	360	500	450	540	550	660	5610
RTF/Sulf	Rating	7	4	7	5	5	6	7	6	7	7	
	Score	980	520	700	250	600	600	350	540	770	770	6080
Taciuk Processor	Rating	4	9	3	9	8	10	6	2	2	2	
	Score	560	1170	300	450	960	1000	300	180	220	220	5360
Soil Slurry Biodegradation	Rating	3	3	2	4	3	3	5	1	6	5	
	Score	420	390	200	200	360	300	250	90	660	550	3420
Land Farming	Rating	4	3	1	9	3	6	4	9	7	5	
	Score	560	390	100	450	360	600	200	810	770	550	4790
In Situ Biolog. Treatment	Rating	3	3	1	4	3	2	6	3	6	5	
	Score	420	390	100	200	360	200	300	270	660	550	3450
Industrial Landfill	Rating	6	1	1	9	8	1	5	9	6	5	
	Score	840	130	100	450	960	100	250	810	660	550	4850
Agiofloat	Rating	2	4	4	5	5	4	6	2	5	4	
	Score	280	520	400	250	600	400	300	180	550	440	3920
Cott Treater	Rating	6	3	3	10	2	2	6	9	5	5	
	Score	840	390	300	500	240	200	300	810	550	550	4680
Oleophilic Sieve	Rating	5	1	7	6	2	2	7	4	5	6	
	Score	700	130	700	300	240	200	350	360	550	660	4190
PES–FBC	Rating	5	9	7	9	8	8	5	1	2	1	
	Score	700	1170	700	450	960	800	250	90	220	110	5450
Superburn Incinerator	Rating	5	9	6	9	8	7	5	1	2	1	
	Score	700	1170	600	450	960	700	250	90	220	110	5250
Aqua–Guard Thermal Oxidize	Rating	6	10	7	9	10	8	4	1	2	1	
	Score	840	1300	700	450	1200	800	200	90	220	110	5910
ASTCO–STS	Rating	6	3	9	10	2	7	9	9	9	3	
	Score	840	390	900	500	240	700	450	810	990	330	6150
OS. Sep.	Rating	5	3	5	6	2	4	8	9	9	6	
	Score	700	390	500	300	240	400	400	810	990	660	5390
VAM	Rating	3	2	9	6	2	3	7	4	6	5	
	Score	420	260	900	300	240	300	350	360	660	550	4340
Salt Cavern	Rating	5	5	0	6	10	6	4	5	8	4	
	Score	700	650	0	300	1200	600	200	450	880	440	5420
Re–Injection	Rating	5	5	0	7	10	6	1	9	8	3	
	Score	700	650	0	350	1200	600	50	810	880	330	5570
COMMENTS					10=Commercial unit available			Assume scale of expansion is 2X,not 10X				

TABLE A.1b ASSESSMENT OF TREATMENT PROCESSES – K–T WORKSHEET

LARGE PLANT DETAILED EVALUATION CRITERIA												
PROCESS		OPER-ABILITY	PERFORM-ANCE	PORT-ABILITY	POTENTIAL FOR COMMER-CIALIZATION	FLEXIBILITY OF PROCESS TO HANDLE VARYING FEEDS	FIELD EXPERIENCE IN SIMILAR APPLICATION	EXPAND-ABILITY	TECHNOLOGY BUILDS ON OR ENHANCES CURRENT PRACTICE	OPERATIONAL SAFETY RISK	RELATIVE COST	TOTAL
WEIGHTING		*100*	*140*	*50*	*120*	*130*	*100*	*90*	*50*	*80*	*140*	
CF Systems	Rating	3	6	6	7	6	5	8	5	2	3	
	Score	300	840	300	840	780	500	720	250	160	420	5110
B.E.S.T.	Rating	4	8	6	8	8	7	8	4	4	4	
	Score	400	1120	300	960	1040	700	720	200	320	560	6320
Hot Toluene Fluid Extraction	Rating	3	5	6	7	6	4	8	4	3	3	
	Score	300	700	300	840	780	400	720	200	240	420	4900
BP Oil Solvent Extraction	Rating	4	7	6	8	7	6	8	6	4	4	
	Score	400	980	300	960	910	600	720	300	320	560	6050
USEPA Soil Washer	Rating	5	5	9	6	3	5	9	6	5	6	
	Score	500	700	450	720	390	500	810	300	400	840	5610
RTI/Gulf	Rating	7	4	7	5	5	6	7	6	7	7	
	Score	700	560	350	600	650	600	630	300	560	980	5930
Taciuk Processor	Rating	4	9	3	9	8	10	6	2	2	2	
	Score	400	1260	150	1080	1040	1000	540	100	160	280	6010
Soil Slurry Biodegradation	Rating	3	3	2	4	3	3	5	1	6	5	
	Score	300	420	100	480	390	300	450	50	480	700	3670
Land Farming	Rating	4	3	1	9	3	6	4	9	7	5	
	Score	400	420	50	1080	390	600	360	450	560	700	5010
In Situ Biolog. Treatment	Rating	3	3	1	4	3	2	6	3	6	5	
	Score	300	420	50	480	390	200	540	150	480	700	3710
Industrial Landfill	Rating	6	1	1	9	8	1	5	9	6	5	
	Score	600	140	50	1080	1040	100	450	450	480	700	5090
Aglofloat	Rating	2	4	4	5	5	4	6	2	5	4	
	Score	200	560	200	600	650	400	540	100	400	560	4210
Cott Treater	Rating	6	3	3	10	2	2	6	9	5	5	
	Score	600	420	150	1200	260	200	540	450	400	700	4920
Oleophilic Sieve	Rating	5	1	7	6	2	2	7	4	5	6	
	Score	500	140	350	720	260	200	630	200	400	840	4240
PES-FBC	Rating	5	9	9	9	8	8	5	1	2	1	
	Score	500	1260	450	1080	1040	800	450	50	160	140	5930
Superburn Incinerator	Rating	5	9	9	9	8	7	5	1	2	1	
	Score	500	1260	450	1080	1040	700	450	50	160	140	5830
Aqua–Guard Thermal Oxidize	Rating	6	10	7	9	10	8	4	1	2	1	
	Score	600	1400	350	1080	1300	800	360	50	160	140	6240
ASTCO–STS	Rating	6	3	9	10	2	7	9	9	9	3	
	Score	600	420	450	1200	260	700	810	450	720	420	6030
OS. Sep.	Rating	5	3	5	6	2	4	8	9	9	6	
	Score	500	420	250	720	260	400	720	450	720	840	5280
VAM	Rating	3	2	9	6	2	3	7	4	6	5	
	Score	300	280	450	720	260	300	630	200	480	700	4320
Salt Cavern	Rating	5	5	0	6	10	6	4	5	8	4	
	Score	500	700	0	720	1300	600	360	250	640	560	5830
Re–Injection	Rating	5	5	0	7	10	6	1	9	8	3	
	Score	500	700	0	840	1300	600	90	450	640	420	5540
COMMENTS					10 = Commercial unit available			Assume scale of expansion is 2X, not 10X				

A. DETAILED EVALUATION OF PROCESSES

The following discussion summarizes and describes in general terms the rationale for the rating/assessment of processes presented in Tables A.la and A.lb.

A.1 OPERABILITY

The operability criterion relates to the reliability, simplicity, and stability of a process or system. No one process was found to be outstanding as defined by this criterion. Of the processes listed, the RTR/Gulf Process was rated the highest in terms of being a relatively simple system with high service factor, minimal pretreatment requirement, and low operating and maintenance requirements. This was followed closely in the rating by the ASTCO-STS Process, Colt Treater, industrial landfill, and Aqua-Guard Thermal Oxidizer. Solvent-extraction-based processes such as CF Systems, B.E.S.T., Hot Toluene Fluid Extraction, and BP Oil Solvent Extraction were downrated in this category because of their complexity and higher maintenance requirements. Fluidized-bed combustion processes, the Taciuk Process and landfarming were also deemed to be processes requiring high maintenance. Re-injection methods were downrated because of the maintenance required for the subsurface disposal well and/or cavern. The lowest-rated processes scoring only 2 or 3 points are quite complex processes, requiring high maintenance, offering low service factors, and requiring more pretreatment in this application.

For the small plant evaluation the rating for the individual processes is the same as in the large plant evaluation. The importance of operability, however, becomes more pronounced for the small plant evaluation and this is reflected in its increased weighting for the small plant scenario.

A.2 PERFORMANCE

A system's performance is its ability to treat the waste with high recovery, destruction, or removal efficiencies and good turndown capability while yielding a product that meets or exceeds the outlet quality requirements by a reasonable margin of safety and a residue that is low in volume and readily disposed of in an acceptable manner.

Thermal treatment processes using rotary kiln or fluidized-bed concepts and the Taciuk Processor score the highest relative to the others. In many cases, thermal treatment is the most efficient method for destruction of organics. It also significantly reduces the volume of inorganics such as metal and salt, and reduces their mobility so that the residue can be effectively disposed of. Physical and chemical processes such as B.E.S.T., BP Oil and CF Systems are expected to have relatively good recovery/removal efficiencies as demonstrated by limited published results. However, to date these technologies have not been as well established as thermal treatment methods. Other processes evaluated such as Aglofloat, in situ biological treatment, soil slurry biodegradation, U.S. EPA Soil Washer and the RTR/Gulf Process are still in their development/piloting stage and their performances are not sufficiently defined. The ASTCO-STS Process, while demonstrated on other wastes, has limited experience with the specific waste types and therefore because of the lack of data has been downrated somewhat in this category. Solidification/fixation technologies such as VAM, and industrial landfill scored low because they neither destroy nor remove contaminants. The Colt Treater is only applicable to a very narrow range of wastes considered in this study. The performance of the Oleophilic Sieve was reported to be poor for the type of wastes considered in this study.

The performance criterion is only slightly less important for the small plant scenario than it is in the large plant scenario.

A.3 PORTABILITY

A mobile unit is considered the most portable. Skid-mounted units are more transportable than fixed plants. The U.S. EPA Soil Washer and ASTCO-STS Process are mobile units and thus scored the highest in this category. Some of the thermal treatment units such as PES-Fluid Bed Combustor and Aqua-Guard Thermal Oxidizer are transportable systems requiring only 3-5 days of field assembly time and therefore rated fairly high. The RTR/Gulf, Aglofloat, Oleophilic Sieve, CF Systems, B.E.S.T., Hot Toluene Fluid Extraction, and BP Oil Solvent Extraction have either mobile units available or are reported to be compact in size and readily transportable in modules. The Taciuk Processor, and soil slurry biodegradation technologies generally require many interconnected process units or large vessels and therefore are difficult to move. Landfarming, solidification/fixation, in situ biological treatment, and industrial landfills are site specific treatment processes. Re-injection methods requiring disposal wells and/or sub-surface cavern were not considered to be at all portable.

The portability criterion is much more important in a small plant scenario than in a large plant. In the small plant scenario, it is reasonable to assume that, because of economics, the treatment unit would be brought to the waste sites on a rotational basis. In contrast, wastes generated within a regional boundary would be brought to a central treatment facility in the large plant scenario. This philosophy is reflected in the portability weighting for small plants being twice the weighting for large plants.

A.4 POTENTIAL FOR COMMERCIALIZATION

Under this criterion, those technologies with the least anticipated scale-up problems and the least need for additional pilot testing have the highest potential for commercialization. A number of technologies investigated here have demonstrated full-scale application. These include the various thermal treatment processes (PES, Superburn, Aqua-Guard and Taciuk), ASTCO-STS Process, and the Colt Treater. Others that have been fully demonstrated in pilot scale and are readily approaching commercialization are the B.E.S.T. Process, BP Oil, and CF Systems. The RTR/Gulf Process and U.S. EPA Soil Washer will probably require further pilot testing before commercialization, although scale-up problems are not expected for these processes. Landfarming and industrial landfill, although commercially used for other wastes will have some testing etc., specifically with the waste types involved. Some technologies score relatively low in this category because they are in very early stages of development. These include soil slurry biodegradation, in situ biological treatment, and Aglofloat. It should be noted that the opinions stated above are based on information received at the time of writing. Some of the developing technologies may be rapidly advancing to commercial stage.

The importance of this criterion is related to the size of the operation. For small investments (i.e. small plants) the stake is small and therefore a higher risk of investment loss is generally acceptable. For large plants with substantial investment, this risk is generally minimized by adapting well-proven and demonstrated, commercially available technologies.

A.5 FLEXIBILITY OF PROCESS TO HANDLE VARYING FEEDS

Under this criterion, those technologies that have demonstrated the flexibility to handle a wide range of feed characteristics (i.e., particle size, oil/water/solid composition) scored higher. This criterion is probably the most difficult one to meet for all the technologies investigated since they all have limitations regarding feed specifications. In general, however, subsurface re-injection and thermal processes have demonstrated the capability to treat a wider range of waste feed than processes such as solvent extraction, aqueous extraction/leaching, biological treatment, and physical separation. For example, aqueous extraction/leaching technologies such as ASTCO-STS, O.S. Sep.Process, and U.S. EPA Soil Washer are generally more expensive when the feed consists of significant amounts of fines that are less than 60 microns in diameter. Recovery of the solvent fraction becomes more difficult if fines are present in the waste material in solvent extraction based technologies. Toxic constituents such as some heavy metals are detrimental to biological treatment. The amounts of free water and hydrocarbon in the feed have major implications on solidification/fixation processes such as VAM and physical separation processes such as Oleophilic Sieve and Colt Treater.

The flexibility of a process to handle the varying feed criterion is weighted slightly higher for the large plant scenario. The rationale is that a large central plant would be required to handle a wide range of feed material brought in from various fields while small plants could be designed to handle specific types of wastes.

A.6 FIELD EXPERIENCE IN SIMILAR APPLICATIONS

Under this criterion, those technologies that have demonstrated actual field experience with similar waste types and environmental conditions scored higher. The Taciuk Processor was assessed to meet this criterion the best. Technologies having some field experience or having demonstrated field experience but under different environmental conditions are PES-Fluid Bed Combustor, Superburn Thermal Oxidizer, Aqua-Guard Thermal Oxidizer, B.E.S.T. and ASTCO-STS. These are followed in rating by processes having pilot test experience on a lesser scale. These include BP Oil, RTR/Gulf, U.S. EPA, Landfarming, and CF Systems. Re-injection methods while demonstrated in actual field operation with other materials (i.e. water, sand/water, oil/water, brine) has only limited experience with the types of wastes in this study. Technologies still in their developmental stage with very limited field experience with the waste types considered are VAM, in situ biological treatment, industrial landfill, Colt Treater, Hot Toluene Fluid Extraction, and the Oleophilic Sieve.

It is felt that field experience in similar applications is as important for the large plant scenario as for the small plant and equal weightings have been assigned to both categories.

A.7 EXPANDABILITY

Under this criterion, modular type construction using existing, well-proven pieces of equipment are expected to be the least expensive to expand. A number of the technologies investigated scored fairly high in this category. Many of the technologies make use of vessels, tanks, pumps, screens, centrifuges, heat exchangers, dryers, decanters, and other material-handling equipment that are well proven in chemical processing and other industries. Exceptions are landfarming and industrial landfill, because of the potential difficulty in acquiring suitable land, and soil slurry biodegradation due to the large tankage involved. Re-injection methods are downrated substantially here because expansion would mean the development of an additional disposal well and/or cavern. Thermal treatment processes are downrated slightly because of the larger and more complicated components involved in their technologies.

A higher weighting is assigned to the large plant scenario because of the potential cost saving due to economy of scale. It would also be more economical to build a large central plant than to expand smaller local plants.

A.8 TECHNOLOGY BUILDS ON OR ENHANCES CURRENT PRACTICE

Under this criterion, those technologies that are similar to current oilfield practices scored higher because they are easier to adopt by existing operating and maintenance staff. Current practices include gravity separation with or without heat input, use of waste material for road construction, deep well disposal, and landfarming or landspreading. It is apparent that several of the technologies summarized in this document are generally much more complex than most current practices. In order to conduct a meaningful assessment, the scope of current practices was expanded to include typical operation of a production battery such as free water knockout, treaters, dehydration, and desanding. These operations are basically physical/chemical processes applied to the product stream.

Technologies that scored highest under this criterion are re-injection, landfarming and industrial landfill and processes such as Colt Treater, ASTCO-STS, O.S. Sep. Process which are similar to current oilfield practices. Some of the physical/chemical processes scored fairly well and this includes solvent extraction technologies (BP Oil, CF Systems), and aqueous extraction/leaching processes such as US EPA and RTR/Gulf. Thermal treatment processes were rated low in this category as was soil slurry biodegradation because of their unique nature.

The weighting for this criterion was assigned a higher value for the small plant scenario than for the large plant. The rationale follows that in a small plant environment, technical resources are limited to operate and maintain a high-tech system.

A.9 OPERATIONAL SAFETY RISK

Under this criterion, technologies operating in low temperature, low pressure environments using nontoxic substances have a lower safety risk to operators and thus scored higher than technologies operating in high temperature, high pressure environments using toxic substances.

Technologies that scored relatively higher under this criterion are the RTR/Gulf Process, ASTCO-STS and O. S. Sep. Process.

Technologies such as solidification/fixation (VAM), land application, and biological also scored fairly high because of their low pressure and temperature operating environment. Solvent extraction and thermal treatment processes scored the lowest due to their high pressure/temperature or toxic substances requirements.

A higher weighting is assigned to the small plant scenario. The rationale follows that current technology exists to allow appropriate safety features to be incorporated into plant design. The impact is higher cost. A large central plant is better able to absorb this cost than a smaller plant.

A.10 RELATIVE COST

Treatment technologies with lower relative cost scored higher under this criterion. In general, physical treatment processes cost less than physical/chemical or biological processes; physical/chemical or biological processes cost less than thermal treatment processes.

For the technologies investigated O.S. Sep. Process and RTR/Gulf are expected to have the lowest relative cost. Although the ASTCO-STS Process is a relatively low cost process, the residual disposal associated with this process requires a Class II landfill and this results in a downgrading for this process. This has far more impact on the large plant scenario where a larger quantity of waste material is treated and therefore greater volume of residual is produced which requires Class II landfill disposal.

The environmental downsides/risks of the various thermal treatment technologies and their associated elaborate air emissions control requirements are reflected in the cost category. Solvent extraction processes are generally less expensive than thermal treatment processes.

A higher weighting is assigned to the large plant scenario. The rationale follows that cost effectiveness is often the deciding factor for the construction of a large, full-scale commercial facility, whereas in some cases, other reasons such as research and development, may be the driving force behind the implementation of a small-scale pilot project.

APPENDIX B

LIST OF TREATMENT PROCESSES/TECHNOLOGIES

Table B.1 Treatment Processes/Technologies

Solvent Extraction Treatment	Aqueous Extraction/ Leaching	Thermal Treatment	Biodegradation Treatment	In Situ Treatment	Other Treatment Disposal Technologies
- CF Systems	- U.S. EPA Soil Washer	- Rotary Kiln	- Soil Slurry Bio.	- Radio Frequency	- Industrial Landfill
- B.E.S.T.	- HWZ Soil Washing	- High Temp. Slagging Incineration	- Landfarming/ Land Treatment	- Vitrification	- Hot-Mix Asphalt
- Hot Toluene Fluid Extraction	- Heidemij Soil Washing	- Fluidized Bed	- Composting	- Solidification/ Fixation	- Aglofloat
- BP Oil	- Oil CREP	- Molten Salt		- Biological	- Colt Treater
- SESA	- Harbauer Soil Washing	- Infrared			- Oleophilic Sieve
	- MTA Soil Washing	- Tacluk Processor			- Gravity Separation
	- Hot Water Extraction	- Electric Pyrolyzer			- VAM
	- RTR/Gulf	- Pacific Environ.- FBC			- Fujibeton Solidification
	- Suncor Oily Sludge	- Dolen Burner			- Esso Road Surfacing
	- ASTCO-STS	- Anachemia Incineration			- NewAlta Salt Cavern Disposal
	- Trans, Couillard, Rouleau Process	- Lurgi-Ruhrgas			- Reinjection
	- Cold Lake Oily Sludge Process	- Superburn Incinerator			- Neutralysis
		- Aqua-Guard Thermal Oxidizer			- Citri-Solve
					- Ekopor
					- Guinard Centrifugation
					- Bird Centrifugation
					- Filtration
					- O.S. Sep. Process
					- Shell Process

APPENDIX C

SUPPLEMENTAL PROCESS TECHNOLOGY INFORMATION

FOR THE AQUA-GUARD THERMAL OXIDIZER

AQUA-GUARD THERMAL OXIDIZER

TECHNICAL INFORMATION

AND

COST SUMMARY

November 1990

Produced by:

Aqua-Guard Technologies Inc.
Vancouver, B.C.
Canada

THE BENNETT ENVIRONMENTAL GROUP FORMS NEW SOILS REMEDIATION COMPANY.

Bennett Remediation Services Ltd. (BRS ltd)., is a newly formed company designed to operate hydrocarbon and hazardous materials incineration systems across Canada.

BRS ltd., will be using Aqua-Guard incinerators to set up services in the Canada's three western provinces. Aqua-Guard Technologies Inc., have had units operating on a commercial basis since 1982. Newer models have been operating commercially, primarily for major oil companies, since early 1989.

Aqua-Guard's first MK I unit was designed and built in early 1982 and was tested and used to dispose of hydrocarbon contaminated soil. Over the next 6 years, design and rigorous testing took place with the assistance of a major oil company and the Canadian Government. In 1988 a second (MK II) more technically advanced unit was built, tested and leased to a major oil company to remediate over 30,000 tonnes of hydrocarbon contaminated waste. Due to the success of this unit a third MK III unit was purchased by a large U.S. oil company and installed in July of 1990. In the fourth quarter of 1990 BRS Ltd. will be establishing oily waste disposal facilities using the Aqua-Guard machines in the three western Canadian provinces (B.C., Alberta & Saskatchewan). The need for this technology in the petroleum and hazardous waste industries is essential.

Aqua-Guard's track record:

1982: *Prototype unit purchased, tested and operated by Esso Resourses Ltd. in Cold Lake, Alberta, Canada for the treatment of hydrocarbon wastes. Throughput 5 tonnes/hour.*

1989: *Commercial unit designed, built and tested in Vancouver, B.C., Canada and then leased to Esso Petroleum Canada in Regina, Saskatchewan. Throughput 10 tonnes/hour. Total material processed was over 30,000 tonnes of hydrocarbon contaminated soils.*

1990: *Commercial unit purchased by Exxon U.S.A. for installation at site in Caribbean. Unit was designed, built and tested in May of 1990 in Vancouver, B.C. and installed for Exxon in the Caribbean in late July and operating in August. The unit will be remediating over 250,000 tonnes of hydrocarbon contaminated soils, with a throughput rate of 10 tonnes of material per hour.*

1990: *BRS LTD. will be establishing an oily waste disposal facility in northern B.C. in the fourth quarter of 1990.*

1991: *A commercial hazardous waste treatment facility will be established by BRS LTD. in Vancouver, B.C. in the first quarter of 1991.*

1991: *BRS LTD will purchase two further units for similar oily waste disposal services to be established in the provinces of Alberta and Saskatchewan in early 1991.*

For release Sept 5, 1990.

THERMAL OXIDIZER

Bennett Environmental Consultants, along with its manufacturing division, Aqua-Guard, recognized in the early 1980's that the problem of disposing of oily waste materials was increasing along with industrial growth. Oily waste materials are not welcome at landfill disposal sites which are often far from the location where the wastes were generated. Transporting inflammable waste materials over long distances is dangerous and expensive. Because of these considerations, waste disposal near the waste generation site is desirable, even though few generators produce a sufficient volume of waste to justify permanently established disposal facilities. An efficient transportable disposal system must be able to be moved easily and quickly from location to location to dispose of oily waste materials effectively, safely and economically. In 1982, Aqua-Guard Technologies Inc. was awarded a contract by the Canadian Government to design, build and test a road transportable incinerator (Rotary Kiln) to meet these criteria. This unit was satisfactorily tested by Esso Resources Ltd. and the Canadian Petroleum Association in 1986.

In 1988 Aqua-Guard Technologies built a "second generation" larger and more technically advanced transportable rotary kiln incinerator for the disposal of oily waste materials.

The new full scale commercial model of the kiln is designed to handle up to 20 tonnes/hr of contaminated oily waste materials, including sorbents (i.e.pads and booms), as well as contaminated soils, or sand, containing up to 20% hydrocarbons and up to 25% water. The waste material is fed into the rotary kiln through a hopper into the primary rotary pyrolysis unit by means of a large auger/feed pipe conveying system. The main rotary kiln unit operates at 700 to 870 degrees C., where hydrocarbons are vaporized and react under starved oxygen conditions to produce combustible gases. The gases then enter through the cyclone section of the afterburner where air is injected and oxidation takes place at 1000-1220 degrees C.

The combined throughput time for the gases in the pyrolysis and oxidation sections is 3-4 seconds. The throughput time for the solid material is 5-15 minutes, depending on the volume of input and speed of kiln rotation.

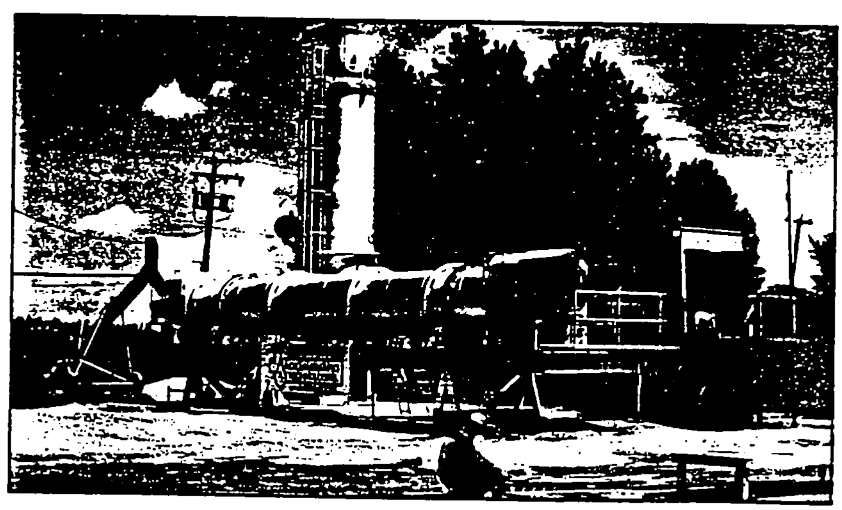
The afterburner can be easily fitted with an optional scrubbing system designed to customer specifications. In order to achieve a high material throughput, complete combustion, and a low overall weight acceptable for road transport, new concepts were developed and incorporated into the Aqua-Guard kiln which separate it from conventionally designed stationary oily waste incinerators. As a result, the new Aqua-Guard rotary kiln is versatile, mobile and offers a realistic solution to cost effective control.

In 1989, Aqua-Guard supplied two incinerators to ESSO Petroleum - one in Regina, Canada, where the incinerator was used to dispose of over 30,000 tonnes of hydrocarbon contaminated soil and the other, in the Caribbean where a MKIII machine will be disposing of approximately 250,000 tonnes of hydrocarbon contaminated soil over a three year period.

The 1990 purchase price for the MKIII Thermal Oxidizer ranges from $0.800 M (U.S.) without a gas scrubber to $1 M (U.S.) with a scrubber. Delivery time and cost will vary with capacity and design specifications.

The Aqua-Guard Thermal Oxidizer can be used in various situations. If you have an oily or hazardous waste disposal problem, please contact us. We can help.

FOR FURTHER INFORMATION CALL BEC COLLECT (604) 681-8828 or (604) 681-3373



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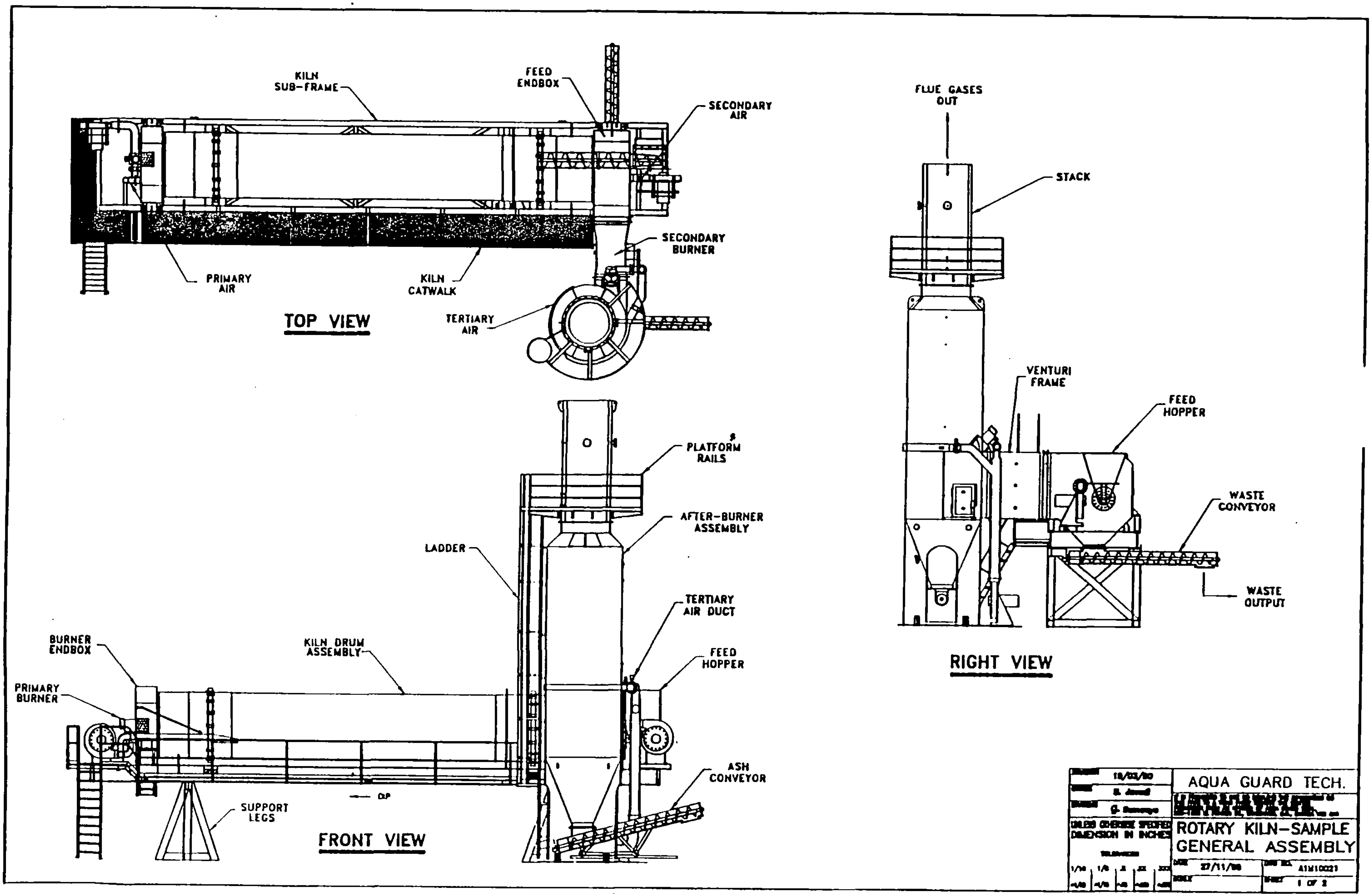
AQUA-GUARD TECHNOLOGIES


KILN SUB-FRAME
FEED ENDBOX
SECONDARY AIR
SECONDARY BURNER
PRIMARY AIR
KILN CATWALK
TERTIARY AIR
TOP VIEW
FLUE GASES OUT
STACK
VENTURI FRAME
FEED HOPPER
WASTE CONVEYOR
WASTE OUTPUT
RIGHT VIEW
PLATFORM RAILS
AFTER-BURNER ASSEMBLY
LADDER
TERTIARY AIR DUCT
FEED HOPPER
ASH CONVEYOR
BURNER ENDBOX
PRIMARY BURNER
KILN DRUM ASSEMBLY
SUPPORT LEGS
FRONT VIEW
AQUA GUARD TECH.
UNLESS OTHERWISE SPECIFIED DIMENSION IN INCHES
ROTARY KILN-SAMPLE GENERAL ASSEMBLY
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