JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF ENERGY AND ENERGY INDUSTRIES,
THE REPUBLIC OF TRINIDAD AND TOBAGO

THE STUDY ON POLLUTION PREVENTION AND CONTROL WITHIN THE PETROLEUM SECTOR IN THE REPUBLIC OF TRINIDAD AND TOBAGO

(SUMMARY)

JANUARY 1995

TECHNO CONSULTANTS, INC.
COSMO OIL CO., LTD.

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Preface

In response to a request from the Government of the Republic of Trinidad and Tobago, the Government of Japan decided to conduct a study on Pollution Prevention and Control within the Petroleum Sector in the Republic of Trinidad and Tobago and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Trinidad and Tobago a study team headed by Mr. Koji Tanaka, Techno Consultants, Inc. four times between September 1993 and December 1994.

The team held discussions with the officials concerned of the Government of the Republic of Trinidad and Tobago, and conducted field surveys in the study area. After the study team returned to Japan, further studies were conducted and the present report was prepared.

I hope that this report will contribute to the Pollution Prevention and Control within the Petroleum Sector in Trinidad and Tobago and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Trinidad and Tobago for their close cooperation extended to the study team.

January 1995

Kimio Fujita

Kimio Fujita
President
Japan International Cooperation Agency

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List of Abbreviations

ACA	Activated Carbon Adsorption
API	American Petroleum Institute
ATOC	AMOCO Trinidad Oil Company Limited
BBL	Barrel, a unit of volume equivalent to 159 liters
bbls	Barrels
BCF	Billion cubic feet
Bls	Barrels
BOD	Biological oxygen demand
BOPD	Barrels of oil per day, bpd
bpcd	Barrels per calendar day
BPD	Barrels per day
bpsd	Barrels per stream day
BM	Breakdown maintenance
CARICOM	Caribbean Community
CARIRI	The Caribbean Industrial Research Institute
CNG	Compressed natural gas
CODcr	Chemical oxygen demand by potassium bichomate method
CODmn	Chemical oxygen demand by potassium permanganate method
CPI	Corrugated plates interceptor
CTC	Carbon tetrachloride
DAF	Dissolved air flotation
DCF	Discounted cash flow
DCR	Dispersion by chemical reaction
DCS	Distributed digital control system
DEA	Diethanolamine
DRI	Direct reduction iron
EL	Elevation
EMA	Environmental Management Agency
EOR	Enhanced oil recovery
FRP	Fiber-reinforced plastics
GC	Gas chromatography
GC/MS	Gas chromatography/mass spectrometer
GDP	Gross Domestic Products

GIS	Geographical information system
hr	Hour
IADB	Inter-American Development Bank
JICA	Japan International Cooperation Agency
JIS	Japanese Industrial Standards
kcal	Kilocalories
kl	Kiloliters
kWatts	KiloWatts
KWh	KiloWatt-hours
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MBD	Thousand barrels per day
MMCFD	Million cubic feet per day
MMSCFD	Million standard cubic feet per day
MOEEI	Ministry of Energy and Energy Industries
MTBE	Methyl tertiary butyl ether
MTPY	Metric ton per year
NGC	Natural Gas Company of Trinidad and Tobago Limited
NGL	Natural gas liquids
NOx	Nitrogen oxides
NPMC	National Petroleum Marketing Company
NPV	Net present value
PAC	Poly aluminum chloride
OECD	Organization for Economic Cooperation and Development
PCOL	Premier Consolidated Oilfields Ltd.
PECOL	Same as PCOL
Petrotrin	Petroleum Company of Trinidad and Tobago Limited
pH	Measure of acidity with 7 indicating neutrality
PM	Preventive maintenance
PPGPL	Phoenix Park Gas Processors Limited
PPI	Parallel plates interceptor
ppm	Parts per million
psia	Pounds per square inch absolute, a unit of pressure
psig	Pounds per square inch gauge, a unit of pressure
SCFD	Standard cubic feet per day
SCF	Standard cubic feet

SIM	Selected ion monitoring method
SOx	Sulfur oxides
sq.	Square
SS	Suspended solids
TCL	Trinidad Cement Limited
TDS	Total dissolved solids in ppm
Trintoc	Trinidad and Tobago Oil Company, Limited
Trintopec	Trinidad and Tobago Petroleum Company, Limited
TSS	Total suspended solids in ppm
TT	Trinidad and Tobago
TOC	Total oxygen consumption
VGO	Vacuum gas oil

Chapter 1 Introduction

This is a summary version of the report on the STUDY ON POLLUTION PREVENTION AND CONTROL WITHIN THE PETROLEUM SECTOR IN THE REPUBLIC OF TRINIDAD AND TOBAGO conducted in accordance with the Scope of Work agreed upon in Port of Spain on February 8, 1993 by the representatives of the Ministry of Energy and Energy Industries of the Republic of Trinidad and Tobago and the Preparatory Study Team of the Japan International Cooperation Agency (JICA). A consortium of TECHNO CONSULTANTS, INC. and COSMO OIL CO., LTD. of Japan has executed this study under contract to JICA. This report summarizes the contents of the main report submitted concurrently with this report to the Ministry. For details reference should be made to the main report.

The study team, of which names and assignments of the members are given at the end of this chapter, commenced the study in September 1993 and completed it in January 1995. During this period the study team conducted three field surveys in the Republic each lasting about a month, from September to October 1993, from February to March 1994 and from July to August 1994, one draft report presentation and a seminar in December 1994.

The Scope of Work defines the objective of the study as quoted below, "The objective of this study is to review the present conditions of petroleum pollution and to formulate a program for minimizing the pollution within the petroleum sector in the Republic of Trinidad and Tobago, thereby contributing to the region's sound industrial development and environmental protection in the following refinery and facilities:

1. Refinery (Pointe-a-Pierre)
2. Onshore petroleum fields
3. Petroleum storage and pipeline."

The onshore petroleum fields and petroleum storage and pipeline are further defined by the Scope of Work and the Minutes of Meeting attached to it. Details of the scope of study are explained in Chapter 3 of the main report. The scope of study consists mainly in developing a program to achieve the target oil content in effluent water streams from the onshore petroleum facilities. The target is defined as 50 ppm on a monthly average or 75 ppm on a daily maximum. It should be noted that the scope of study does not include assessment of impact on the environment of the effluent water.

The study team achieved the above objectives by accomplishing this study. The study encompasses various aspects of petroleum pollution relating to the above three facilities. The study team encountered many difficulties, of which water produced in association with crude oil presented the most serious challenge. The effort made by the study team to discover its true nature and to develop a recommendable method for treating it led to the most important conclusions and recommendations of this study.

The water is found to be in the form of a very stable oil-in-water emulsion in which very fine oil particles, ranging in diameter from less than one micron to a maximum of ten microns, are thoroughly dispersed in the water phase. This emulsion is very stable by nature and does not separate into water and oil by conventional gravity-induced separators such as API separator, PPI, or CPI. After a series of experiments, the dissolved air flotation with coagulation has been selected for breaking the emulsion and eliminating oil particles from the water.

A hidden problem emerged when the dissolved air flotation with coagulation proved to be suited to the treatment of this water. The water after being rid of oil particles was found in many cases to contain more than 50 ppm, the target set for this study, of what may be recognized as "oil and grease" by the ASTM standard testing method. The two most extensively adopted processes for similar purposes, biological treatment and activated carbon adsorption, were tested as the most promising candidates for treating this water. On the basis of the results of the experiments, the study team recommends a combination of dissolved air flotation with coagulation and activated carbon adsorption for treating water for the onshore petroleum fields/main storage and dissolved air flotation with coagulation alone for Pointe-a-Pierre Refinery. By this the target level, 50 ppm on monthly average and 75 ppm on a daily maximum, can be achieved.

Other aspects of this study include review of the socio-economic background, effects of the climatic and geographical conditions on water pollution, treatment of oil-containing wastes, review of laws and regulations, air pollution by the refinery and service stations, recommendations for better maintenance, and measures to cope with accidental pollution.

This study has developed a comprehensive program for prevention and control of oil pollution, evaluates the program, and presents conclusions and recommendations. The core of the program is facilities recommended for Bernstein Main Storage and Pointe-a-Pierre Refinery, the dissolved air flotation with coagulation plus activated carbon adsorption for the former and the dissolved air flotation alone for the latter.

The study team consists of the following eleven members:

Name	Assignment and association
Koji TANAKA	Study team leader, TECHNO CONSULTANTS, INC. (TCI)
Yoshitaka IMAEDA	Industrial and environmental policies, TCI
Mahbub A. K. M. REZA	Climatic and hydrometric study, SANYU CONSULTANTS INC.
Toshio SASAKI	Oil production, TCI
Muneteru YOSHIZAWA	Transportation and storage, TCI
Akira ISHIYAMA	Refining processes, COSMO OIL CO., LTD. (COC)
Tomoo UESUGI	Operation and maintenance, COC
Takeshi HIHARA	Oil water separation-1, TOHO CHEMICAL INDUSTRY CO., LTD.
Shinsuke SATOU	Oil water separation-2, TCI
Makoto NATORI	Effluent water treatment, TCI
Yoshikazu SATOU	Wastes disposal, COC.

Chapter 2 Summary of Major Conclusions and Recommendations

This chapter summarizes the major conclusions and recommendations of the study.

1. **Proposed Program**

   To achieve the 50 ppm target, a waste water treating system with dissolved air flotation with coagulation (DAF) plus activated carbon adsorption (ACA) is proposed for Bernstein Main Storage, and one with DAF alone for Pointe-a-Pierre Refinery.

   Their cost is estimated at 16,300 and 3,377 thousand U.S. Dollars in 1994 Trinidad Tobago prices, respectively. The annual economic operation cost is estimated at 4,769 thousand U.S. Dollars, or 0.22 U.S. Dollars per barrel of crude oil. This report justifies this cost.

2. **Dams and catches**

   Expansions of dams and catches installed on the rivers to prevent the accumulated oil from being washed away are not recommended.

3. **Water Produced with Crude Oil, Oil-in-water Emulsion**

   Water produced with crude oil is in the form of very stable oil-in-water emulsion. This emulsion has been identified as the most serious cause of oil pollution. The conventional gravity-induced separators are ineffective to this emulsion. DAF was found to be effective and applicable to the actual waste water streams. By this method, the treated water becomes crystal clean.

4. **Water after treatment by DAF**

   Water produced with crude oil needs to be further treated by ACA after DAF treatment because of the dissolved substances. Therefore, a system having both DAF and ACA is proposed for Bernstein Main Storage.

5. **Project scheme**

   The following project schemes are proposed for Pointe-a-Pierre Refinery and Bernstein Main Storage.

	Bernstein Main Storage	Pointe-a-Pierre Refinery
Design conditions for DAF and ACA Units		
Flow rate, cubic meters per hour:	440/400	250
Oil content of water, mg/liter		
Inlet	1,000	400
Treated water	50	50
Waste treatment system,	to be included	to be included
Schedule, year		
Preparation	1	1
Construction	1	1

The waste water from Los Bajos Main Storage is sent to Bernstein Main Storage.

6. Evaluation

These facilities cost 4,769 thousand U.S. Dollars a year to operate, corresponding to 0.22 U.S. Dollars per barrel. This cost is justifiable in terms of comparison with some economic indicators, percentage on the earnings from petroleum exports, net economic value generation versus economic cost, importance of pollution control and expected socio-economic benefits.

7. Recommendations

Execution of the program defined as project scheme is recommended to achieve the 50 ppm target. The inefficient oil wells that disproportionately produce large amounts of water per barrel of oil increase the total treating cost. A study similar to that done by the study team should be done on more comprehensive data. Suspension of operation of the inefficient wells should be studied to reduce the amount of foul water and to reduce the treating cost.

Safety of substances dissolved in water to aquatic organisms is not established. The government and Petrotrin should therefore monitor on a long-term basis accumulation of such substances in the bodies of aquatic organisms that live in the contaminated areas and their effects.

It is also recommended that good practices of operation and maintenance should be implemented to the extent the budget of Petrotrin permits. Use of earthen pits should be abandoned. Preventive maintenance should be done on facilities that can cause a major accidental pollution.

Chapter 3 Background of the Study

3-1 History and Environment of the Study

Many of the onshore wells of Trinidad and Tobago are superannuated. Enhanced oil recovery by steam injection is extensively practiced to squeeze out the remaining oil. With steam injection, crude oil being produced is accompanied by water which contains emulsified oil. This water, or an oil-in-water emulsion to be exact, can contain oil at concentrations exceeding 10,000 ppm. Such emulsified oil in the water cannot be separated by the commonly used gravity-induced oil separators. Consequently, such water containing oil at very high concentrations is discharged to the rivers.

No substantial measures have been taken to regulate environmental damage by oil, although the Petroleum Act established in 1969 contains regulations on the prevention of oil pollution. In 1989, a guideline was issued for the control of oil and grease in the effluent water from the petroleum sector. However, the guideline has not been rigorously enforced, because of technical and economical difficulties associated the enforcement.

Considering the present situation in which environmental conservation is becoming a matter of global concern, pollution prevention is an indispensable step impossible to circumvent, before the nation can further develop its petroleum industry. Trinidad and Tobago plans to modernize and expand Pointe-a-Pierre Refinery by using funds from an international financing institution. A condition attached to the finance requires that Trinidad and Tobago take appropriate measures to prevent and control oil pollution on its own territory and on the surrounding Caribbean Sea.

In order for the government to effectively implement environmental protection measures, which do not by nature generate prompt profits, proper guidance by the government by means of right legal and administrative measures is very important. The government emphasizes environmental conservation in the Medium Term Policy Framework. The Environmental Management Agency (EMA) will be established soon as a concrete step toward better environmental management. With the assistance of the World Bank and in association with other concerned organizations, EMA will draft environmental regulations and standards.

3-2 Natural, Social and Economic Conditions of the Nation

The climate is tropical with a small seasonal variation. Rain falls in all seasons, but the wettest season is from June to December. The precipitation varies with the region, ranging from 1,500 to 3,000 millimeters. Heavy rains which sometimes fall during the rainy season exacerbate the petroleum pollution.

The economy of Trinidad and Tobago is dependent chiefly on exports of petroleum and petroleum products. Since the mid 1980s, the importance of the petroleum sector has been gradually fading as prices and production declined. To offset such a trend to some extent, natural gas has been making an increasing contribution to the national economy. The economic structure depending on export of energy-based commodities has remained unchanged.

The petroleum sector provides about 25 percent of the GDP. Other industries of this country are heavily dependent on the petroleum sector, and therefore the real contribution by the petroleum sector to the national economy is larger than it may appear from this figure.

The trade balance has been substantially in surplus by virtue of the export of petroleum, petroleum products and petrochemical products. However, the service account has been continuously recording heavy deficits due to the repatriated dividends of foreign petroleum companies, and both current and total accounts have been continuously negative.

Crude oil, petroleum products, ammonia, urea and methanol, and direct reduction iron, all derived from the country's hydrocarbon resources, have been the major export products. In 1991, for example, export earnings of crude oil and petroleum products amounted to 64.5 percent of the total exports. If the chemical products made from natural gas are added, the share of the energy sector in the total export exceeded 85 percent.

3-3 Industrial Development Policy

The petroleum sector is very important in the economy of Trinidad and Tobago. However, excessive dependence on the petroleum sector is a structural weakness of the country's economy. In recognition of this, the government has been implementing several policy measures to diversify the economy as well as to revitalize the petroleum sector. The basic strategy for implementing the above policy is to encourage investment by the private sector, especially by foreign companies. Industries using natural gas as feedstock and/or fuel are candidates for promotion.

3-4 Production and Trade of Petroleum and Petroleum Products

Petrotrin virtually monopolizes onshore oil production. Petrotrin's onshore crude is sent entirely to the domestic two refineries while its offshore crude is exported. TRINMAR is producing oil in the Gulf of Paria. TRINMAR's production in 1992 was 32,000 BPD, or equivalent to 23 percent of the total production. TRINMAR's crude oil is sold entirely to Petrotrin, and dividends are paid to TEXACO, the shareholder of the company.

Roughly half the crude oil produced locally is exported; the balance is refined. In 1982, 31.72 million barrels of crude oil, equivalent to 49 percent of total production, was exported. In 1992, 26.89 million barrels of oil, equivalent to 51 percent of total production, was refined and the 49 percent balance was exported. It should be noted, however, that about 90 percent of the country's oil is exported, because local consumption of petroleum products is around five million barrels, or 10 percent of total oil production.

Since 1959 when gas began to be used as feed for ammonia production, the consumption of gas has been rapidly increasing in diverse uses. At present, the largest consumer of natural gas in the country is the gas-based petrochemical industry, which now consumes more than 300 million SCFD as feed and fuel for producing ammonia, urea and methanol. More than 90 percent of these chemicals are exported. The domestic consumption is very small. The utilization of gas for power generation comes next to the petrochemical industry. All three power stations on the Island of Trinidad use natural gas as fuel, together consuming 140 MMSCFD. Gas is also extensively used as fuel by industries like the steel mill for example.

3-5 Present Situation of Environmental protection

Petroleum pollution on the Island of Trinidad is evident mainly in rivers, sea and soils. Rivers located near the sources of pollution are most seriously affected. Black oil is seen floating on rivers running through the oil producing areas. The banks are smeared black with oil. Besides, the color of those rivers, to which the water produced in association with crude oil is discharged, is a light brown. This phenomenon seems particularly noticeable if the effluent water comes from wells operated under steam enhancement. What makes water light brown is not suspended silt particles as is the case with many rivers but oil-in-water emulsions that come from underground with crude oil. The oil contents of river water were from 20 to more than 1,000 ppm according to the analysis done as part of this study.

On the sea, pollution in the Gulf of Paria is most serious. In the southern part of the gulf near the oil producing area, sea water is light brown like polluted rivers as far as hundreds of meters from the coast. Evidently, such emulsions flow into the sea without being separated or decomposed. The causes of the serious pollution in the Gulf of Paria are as follows:

- Many rivers running through the oil producing area flow into the gulf.
- Two refineries are located in this area.
- Ports for loading and unloading crude oil and petroleum products are located in this area.
- The gulf is a semi-closed system.

Currently, soil pollution by oil is not regarded as very serious, because the effects are rather confined. However, the risk of secondary environmental pollution such as ground water contamination is pointed out.

The major sources of petroleum pollution are the onshore oil fields, tank farms and refineries. Particularly, the emulsions separated from the crude oil produced with steam injection cause the most serious pollution.

The government emphasizes the conservation and safeguarding of the environment in the Medium Term Policy Framework. As the first step of the government's principal strategy for environmental conservation, the Environmental Management Agency (EMA) responsible for overall environmental administration will soon be established. The establishment of the EMA will improve the current complicated environmental management system.

Presently, in Trinidad and Tobago, there is no regulation for air pollution, water pollution, no definition of hazardous wastes. In the petroleum sector, the Ministry of Energy and Energy Industries prepared draft guideline on oil and grease in 1989, which specifies a monthly average of 50 ppm and daily maximum of 75 ppm for effluent water from oil fields and refineries. The proposed standard of 50 ppm maximum oil and grease was prepared under the assistance of the Environmental Protection Agency of the United States and with reference to the standards of neighboring oil producing countries. The proposed standard was scheduled to be enforced in 1990. However, it has not been rigorously enforced yet, because Trintoc and Trintopec, now merged into Petrotrin, the state-owned oil companies, did not agree with the 50 ppm standard on the ground of technical difficulties. AMOCO and TRINMAR reportedly said that they would be able to comply with the standard, because the crude oils they produced were relatively easy to separate from water.

Formulation of environmental regulations and standards will be a priority mission of the EMA. This work will start this year under the World Bank's financial assistance (Business Expansion and Industrial Restructuring Loan). The establishment of a monitoring system is also an important task of the EMA. The monitoring system will be a cooperative undertaking led by the EMA, but involving other governmental organizations and the industrial sector due to the limitation on the budget and manpower of the EMA, while its details are yet to be disclosed.

3-6 Petroleum Sector Policy, Projects and Programs

Petroleum and natural gas have been critically important in the economy of the nation and will be so for many years to come. The basic policies for the petroleum and natural gas sector are to revitalize the exploration and production activities and to promote utilization of the natural gas resources. The basic strategy for implementation of the above policies is to encourage foreign investment and to reduce the country's direct investments in high-risk capital intensive activities such as off-shore exploration and petrochemical production. In this context, several important reforms including a new petroleum taxation regime have been introduced.

The biggest project in the energy sector is the proposed construction of a 400-million-cubic-feet-per-day (MMCFD) liquefied natural gas (LNG) plant, intended to export gas to the Northeastern United States. It is still in a preliminary feasibility study stage. The principal gas source for this project will be the reservoirs in the east coast marine area. The investment cost is estimated to be US$ one billion. This project will contribute not only to securing stable foreign currency earnings but also to increasing employment opportunities. The government expects that this project could provide 3,000 jobs in construction at peak, and 300 direct permanent jobs on completion.

In the transportation sector, replacement of gasoline by compressed natural gas (CNG) has been investigated. Right now, a very small amount of CNG is used as automobile fuel, because only 10 CNG filling stations have been set up. However, there is a tremendous opportunity for foreign currency earning by exporting replaced gasoline if the majority of vehicles are switched to CNG. Further, CNG has an advantage in that it is by far the cleaner and environmentally more desirable fuel.

In addition to the above, there is a plan to produce MTBE from methanol and iso-butylene. However, at present, it is questioned whether this project is realistic due to supply limitation of iso-butylene.

As for environmental protection, the government has a plan to phase down the lead content of gasoline.

Chapter 4 Key Issues and Approaches

4-1 Key Issues

Throughout the entire study there are issues of critical importance on which decisions must be made among possible alternatives. The purpose of this chapter is to review and summarize these important issues and to indicate the decisions the study team has made, with rationales for supporting them.

4-2 General

4-2-1 Definition of the Target Oil Content in the Effluent Streams

The target quality of effluent water streams from the petroleum facilities is 50 ppm oil content on a monthly average and 75 ppm on a daily maximum; 50 and 75 ppm should be interpreted as 50 and 75 milligrams per liter of oil and grease as measured by the ASTM Testing Method D-4281, Freon Extraction Method.

4-2-2 Effect of the Target Level on the Environment

The oil content of 50 ppm is still very high when its effects on the ecological environment are considered. Notwithstanding, its effects on the environment are beyond the scope of this study.

4-3 Oil Wells, Main Storage, Tank Farms

4-3-1 Representative Production Facility

As the representative production facility, Bernstein Main Storage has been selected. Bernstein Main Storage has all the attributes of tank farms to qualify it as representative of all the main storages. It is the largest of all tank farms; it treats waste water from both thermal and non-thermal crudes; it will become the crude oil gathering and storage center of the onshore oilfields. Therefore, a central water treatment system is planned for Bernstein Main Storage.

4-3-2 Treatment of Water Produced with Crude Oil

The water produced with crude oil is in the form of very stable oil-in-water emulsion. Such emulsions are discharged to the rivers flowing through the oilfields in the study area. The treatment of such an emulsion is the central issue to achieve the 50 ppm target.

4-3-3 Dissolved Air Flotation with Coagulation

After having confirmed that such emulsions are not amenable to gravity-induced separators and that emulsifiers are either only partially effective or ineffective, the study team has decided that dissolved air flotation with the use of (a) coagulant(s) is the only method that can effectively collect emulsified oil particles and separate them from water.

4-3-4 Treatment of Water after Dissolved Air Flotation

The study team discovered that the water after treatment by dissolved air flotation can contain dissolved substances at higher than 50 ppm. The results of tests by gas chromatography mass-spectrometry indicate that these substances are most likely naturally-occurring organic acids combined with alkaline metallic ions. Based on the results of such experiments, the study team recommends a combination of dissolved air flotation with coagulation (DAF) and activated carbon adsorption (ACA) as the only practical means of treating water produced with crude oil. By this the target of oil content in water less than 50 ppm can be achieved.

4-3-5 Oil Leaks from Facilities

Many of the existing petroleum facilities are very old. The study team does not believe that all these facilities should be maintained in the best condition regardless of cost. It is important that all the facilities be properly maintained so that major accidents may be prevented, and that leaks may be manageable. It is also very important that the leaking oil should not be allowed to escape the spot where the leak takes place but be contained and collected. Under present conditions, in which leaks are sporadically found, one or two vacuum cars should go around and collect oil before it pollutes the environment.

4-3-6 Separation of Storm Water from Oily Water

Storm water should be prevented from entering the oily water treating system so that the load on the water treating system is minimized.

4-3-7 Review of Oil Production under Enhanced Oil Recovery

Some of the most inefficient wells under intensive steam enhancement produce several times more water than oil. The oil produced by such wells accounts for 10 to 20 percent of the total production. Suspension of operation of such inefficient wells could greatly reduce the amount of water to be treated. The benefits and costs of operating such wells should be studied.

4-4 Dams and Catches

4-4-1 Results of the Climatic and Hydrometric Study

The climatic and hydrometric study done as part of this study indicates that all the dams and catches in the scope of the study cannot accommodate flow rates under flood conditions.

4-4-2 Roles of Dams and Catches in Pollution Prevention

The whole system of prevention and control of petroleum pollution becomes very large and consequently expensive if the system attempts to accommodate the storm water. Besides, the dams and catches cannot stop the most serious cause of petroleum pollution, the oil-in-water emulsion produced with crude oil and discharged to the rivers, whether they are expanded or not. Expansion of dams and catches is therefore meaningless.

4-4-3 Oil and Debris Floating against the Dams and Catches

Presently, oil and debris are floating against the weirs of the dams and catches. The moment they are found, the emergency squad should be mobilized to collect them; the party responsible for leaking oil or dumping debris should be identified and warned against their operations. The habit of regarding oil or debris floating on public water as an extremely abnormal and intolerable condition should be established.

4-5 Pointe-a-Pierre Refinery

4-5-1 Capacities and Performances of the Existing Separators

The throughputs of water to the existing four API separators and guard basins far exceed their design capacities due to inflows of large volumes of non-oily water; namely storm water and once-through cooling water. Effluent water from all four API separators contains oil far exceeding 50 ppm, more than 1,000 ppm in many cases. The study team does not recommend that the existing facilities be expanded but that a new system with dissolved air flotation be installed to treat oily waste water, and that the existing system be converted into one which treats non-only waste water.

4-5-2 Concept of Proposed Water Treating System

(1) Separation of Non-only Water from Oily Water

Non-oily water, cooling water and storm water for example, should be separated from oily water streams.

(2) Water Treatment

The study team recommends that an new independent oily water treating system be installed. The existing water treating system should be converted into a non-only water treating system. The proposed oily water treating systems will collect all oily water from the plant areas and tank sites and deliver the oily water by above-ground piping to an appropriate place where the water treating system will be installed. The water treating system will consist of separators, dissolved air flotation plus coagulation and associated facilities. It must be accepted that no combination of gravity-induced separators alone will be capable of bringing the oil content down to the 50 ppm target, and that the proposed system is the only conceivable and also the least expensive way to achieve the target.

4-5-3 Ongoing Upgrading Project

As part of the upgrading project financed by IADB, a project to separate non-oily water from oily water is underway. This is part of Petrotrin's plan to reduce the oil content in the effluent water to 150 ppm. The present upgrading project, only capable of achieving about 150 ppm oil in water, is worth implementing as an intermediate measure. When the recommendations by this study are done, the facilities installed and the modifications done in the present upgrading project will be used for the treatment of non-oily water.

4-6 Oil-containing Wastes

The sludges produced from cleaning of tanks and oil-water separators, slop oil or a water-in-oil emulsion to be exact, and spent lubricating oil recovered at service stations and car maintenance shops are major oil-containing wastes. The study team supports Petrotrin's plan to bio-remediate the sludges and to expand the present program to recover the spent lubricating oil. This study recommends incineration of the slop oil in the proposed waste treatment centers. At the request of the study team, Trinidad Cement Limited (TCL), has begun studying an alternative possibility of burning slop oil as fuel for cement manufacturing. If this proves to be feasible, this alternative should be considered.

Commissioning of dissolved air flotation will generate an oil-containing scum. The study team recommends that the scum be rid of water and incinerated. Likewise, TCL is studying the possibility of feeding scum to the cement plant. If TCL finds it possible, this alternative should be considered.

4-6-1 Rehabilitation of Soils

The study team believes that the present practice of dumping oil-containing wastes in open earthen pits should be abandoned. Soils that have already been stained with oil -- banks of rivers to which oil is discharged, soils of earthen pits, soils contaminated with oil leaking from pipes and other facilities -- should be rehabilitated or not is a question to which the answers will be different for different cases. Abolition of the practice of dumping oil in open earthen pits and establishment of a practice of recovering oil that has leaked to the environment will ameliorate the problem of soil contamination.

4-6-2 Concept of Waste Treatment Center

The study team proposes a concept of waste treatment centers, one to be located in the premises of Pointe-a-Pierre Refinery and the other in Bernstein Main Storage. The waste treatment centers will have incinerators to burn slop oil and scum to be generated from the dissolved air flotation units.

Chapter 5 Emulsions and Wastes, their Natures and Treatments

5-1 Emulsions

As is repeatedly mentioned, water produced with crude oil, or oil-in-water emulsion, and slop oil, or water-in-oil emulsion are two major causes of petroleum pollution in Trinidad and Tobago. The study on the emulsions is summarized as below.

1. The liquids generated from oil wells form a crude oil/water mix, actually an emulsion of crude oil and water. Normally, the maximum water content of this emulsion is less than 30 to 40 percent. That from the Forest Reserve primary crude oil, for example, is about 30 percent and forms a homogeneous water-in-oil emulsion. The crude oil/water mix from the thermal wells contains water at higher contents and separates into a water-in-oil and an oil-in-water emulsions before reaching ground level. In the case of the Bernstein thermal oil, the fluid contains about 85 percent water.

2. The water phase separated from crude oil/water mix forms an oil-in-water emulsion. In such emulsions, fine particles of oil ranging in diameter from less than one micron to several tens microns are dispersed. The oil content ranges from several hundred to several ten thousands mg/liter. Emulsions of this type from thermal oil wells are very stable and resemble ordinary brown muddy river water. The emulsions can contain more than 10,000 mg/liter of oil.

3. One of the major sources of oil pollution in Trinidad and Tobago is such oil-in-water emulsions. They are discharged to public waters without effective treatment.

4. The diameters of oil particles in such oil-in-water emulsions are distributed from less than 0.1 microns to 10 microns, with the average diameter at about 2.5 microns. Under a microscope it may be observed that the perfectly spherical oil droplets are dispersed uniformly in the water. There is no indication that the oil droplets are being stabilized by fine inorganic matter adsorbed on the surfaces of the droplets. The emulsions are conceivably stabilized by some non-solid natural stabilizers.

5. The diameters are therefore considered too small to be treated by gravity-induced oil separators such as API separators or CPI. In order to separate the contained oil from the

water, breaking of the emulsion and association and coagulation of oil droplets are required.

6. One method of treating oil-in-water emulsions lies in adding (a) suitable reverse emulsion breaker(s) to separate the emulsions into oil and clear water.

7. Several reverse emulsion breakers are found to be effective. Cationic high molecular and polyamide coagulants are especially effective. Among the inorganic coagulants tested, calcium chloride is effective.

8. It may be considered from the above that reverse emulsion breakers are effective in breaking the oil-in-water emulsions into oil and water.

9. Generally, coagulation is considered effective in treating oil-in-water emulsions. A combination of reverse emulsion breakers and dissolved air flotation can remove nearly all dispersed oil particles. Normally, water thus treated contains less than 10 mg/liter oil.

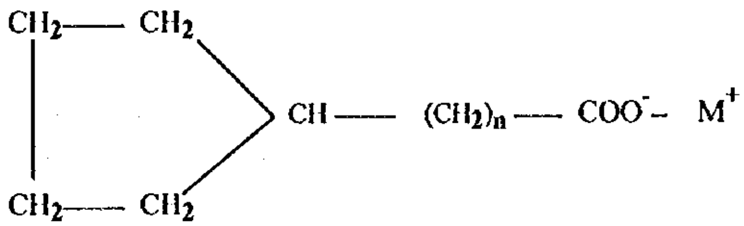
The water experimentally obtained after treatment by a combination of reverse emulsion breakers and dissolved air flotation is visually clear, indicating that dispersed oil particles have been completely removed. However this water is found to contain oil in concentration between 60 and 139 mg/liter in terms of normal hexane solubles, or carbon tetrachloride extraction plus infrared rays absorption. This indicates that the apparently clear water contains substances soluble in these solvents and measured as oil. To achieve the target oil content of 50 ppm, information on such substances is necessary. The GC/MS tests were done to examine these substances.

10. Prior to the GC/MS tests, organic substances were qualitatively analyzed by the TIC method. The TIC method is sensitive to all organic substances with a molecular weight smaller than about 1,000 and is therefore capable of qualitatively analyzing organic substances present in a few 10 ppm range. By this method no single substance was found to be present in high concentration; however, the presence of organic substances which increase the measured oil content was confirmed. These are compared with a standard sample of naphthenic acid obtained in Japan; the substances in question and the Japanese naphthenic acids show similar mass spectra although retention time differs somewhat between them. There is also similarity in the pattern of chromatograms between them. Further, quantitative analyses were done on paraffins, naphthenic acids,

phenols and aliphatics by the SIM method. Paraffins, phenols and aliphatics are found to be present at only one mg/liter or less. In contrast, naphthenic acids show concentrations from 15 to 60 mg/liter.

11. The analytical results obtained on the same samples by the GC/MS method, normal hexane solubles, and carbon tetrachloride extraction plus infrared rays absorption method were compared. The latter two methods tend to yield higher values than the former but all are of the same order. In consideration of the difference in method, use of the Japanese standard naphthenic acids that are not exactly the same as those in question, and exhibition of one large hilly peak by the GC/MS method that may be regarded as one single peak, the difference shown by these three methods is not decisive. The organic substances measured as oil by normal hexane solubles and carbon tetrachloride extraction plus infrared rays absorption presumably consist mainly of naphthenic acids and their derivatives.

12. The naphthenic acids in the oil-in-water emulsion may be considered to form salts with sodium and potassium. Naphthenic acids react with sodium or potassium compounds under the influence of the high temperature of the steam injected into the formation. The structure of salts formed between sodium or potassium and cyclopentane-based naphthenic acid, for example, is shown below.



(M^+ : Na^+, K^+, etc)

13. The salts of naphthenic acids are surfactants and soluble in water. Therefore, the presence of such salts in the oil-in-water emulsion separated from the crude oil/water mix helps stabilize the emulsion. The naphthenic acid salts may be contributing greatly to stabilizing the oil-in-water emulsion from the thermal crude oil even at such a high content of oil. The breakage of such oil-in-water emulsions by addition of acids may be attributed to suppression of the ability of the naphthenic acid salts to dissociate oil particles. Naphthenic acid salts are soluble in water and therefore not removable by

dissolved air flotation. Treatments of a higher grade, like adsorption by activated carbon, are needed to remove naphthenic acids.

14. Overall, the results of the study in this chapter may be summarized as follows:

1. Various inorganic and organic reverse emulsion breakers, coagulants, were tested on oil-in-water separated from the crude oil/water mixes. Normally, these coagulants are used for dissolved air flotation. In the case of this study, use of aluminum sulfate as inorganic coagulant and polymer coagulants as organic coagulants is proposed.

2. Salts of naphthenic acids are considered to be formed underground by reactions with sodium and potassium existing there under the influence of the injected steam. These naphthenic acid salts act as surfactants and help stabilize the emulsions. The naphthenic acids exist in solution in the emulsions and are therefore not removable by dissolved air flotation. They are measured as oil by the tests using normal hexane or freon. Accordingly, the dissolved air flotation alone is not enough to reduce oil content to 50 mg/liter and adsorption by activated carbon is required.

3. The thick water-in-oil emulsions, both components being in the range of 30 to 70 percent, are not broken into oil and water by any chemicals under ambient conditions. They are called slop, intermediate emulsion, middle layer emulsion; whatever their naming, they are difficult to deal with and not properly dispose of. Among them, those not properly treated into oil and water eventually end up being discharged to the environment. There seems no alternative but to incinerate them.

5-2 Wastes

The oil-containing wastes that cause petroleum pollution in Trinidad and Tobago are: (1) slop oil, or sludge sometimes alternatively called, (2) sludge recovered from cleaning of tanks and oil-water separators, and (3) spent lubricating oil. In addition, an oil-containing scum will be produced on commissioning of the proposed dissolved air flotation units.

In the absence of a proper method of treatment, much of the slop oil is discharged to the environment. The slop oil is a water-in-oil emulsion. The study team recommends that the slop oil be incinerated in the proposed waste treatment centers. At the request of the study team, Trinidad Cement Limited (TCL) is studying possibility of effectively using this as an auxiliary fuel. If it proves to be feasible, this would be an ideal way of disposing of the slop oil.

The sludges recovered from cleaning of tanks and oil-water separators are stored in open earthen pits. Such a practice often causes pollution when oil escapes from the pits. The study team recommends that these sludges be treated by Petrotrin's expanded bio-remediation program. The study team also considers it best that Petrotrin expands nationwide their present program of collecting and regenerating the spent lubricating oil.

The study team recommends that the scum produced from the proposed dissolved air flotation units be incinerated by the proposed waste treatment centers. TCL is also studying the possibility of feeding the scum to the cement kilns as an auxiliary raw material. If it is found feasible, this would be a better way of disposing of the scum.

Chapter 6 Effects of Climatic Conditions on the Pollution

Table 6-1 shows that for all the catches and dam, either of the river cross section or baffle, or both, is not capable of carrying the peak runoff volume. This means that if oil is present at the catches, oil will be washed away when it pours very heavily. Although the catches and dams are found inadequate and not capable of performing their intended purposes of stopping floating oil in the case of heavy downpours, the study team would not recommend re-designs, modifications or expansions of any of these catches and dams. The measures to control and prevent oil pollution should be made to be unaffected by the climatic or weather conditions, by such appropriate measures as separating oily water and storm water, rather than being designed to absorb fluctuations of load that may occur if storm water is allowed to enter the water treating facilities. Instead, the study team recommends that the very idea of stopping and collecting oil by the catches and dams on the public streams should be abandoned, because this is not the right way to control petroleum pollution.

First and foremost, there should never be oil floating on the public streams before discussing the capacity of catches and dams to stop oil that has escaped to the public streams. Second, catches and dams, designed to stop the floating oil, are utterly ineffective against the water-miscible oil-in-water emulsion produced with crude oil, the most serious source of oil pollution in the study area of Trinidad and Tobago, now being discharged from the production facilities to the public water streams and freely flowing down the rivers through the catches and dams to the sea.

The project scheme the study team recommends would ensure prevention of floating oil from entering the public stream and reduction of oil content in effluent water to lower than 50 ppm, either in the form of floating oil, in the form of water-miscible oil-in-water solution, or dissolved form. After the implementation of the recommendations there should never be oil floating at the catches and dams as long as normal operating conditions are maintained. If floating oil appears at the catches or dams on account of an accidental discharge of oil, such a situation should be regarded as an emergency. Emergency personnel and equipment should be mobilized immediately and oil should be collected promptly.

No. 1 API Separator is the only one that has enough capacity to handle the peak runoff volume. If the hydraulic by-pass works properly the load will further decrease.

In the case of No. 2 API Separator, if the hydraulic by-pass works well the load would decrease substantially. Flooding would occur if it pours very heavily. Therefore, in order to make the system completely flood-free, diversion of some runoff and installation of a hydraulic by-pass with an appropriate cross section are recommended.

The inlet channel of No. 3 API Separator has only 50 percent capacity. A larger channel cross section and an appropriate hydraulic by-pass may solve the problem. Considering the large peak runoff volume, segregation of storm water from the effluent water would be the best option as a permanent solution.

Apart from the huge runoff volume, the low elevation is also a problem in the case of the Oil-stock Sump. Even if appropriate inlet channel dimensions are provided, the severe flooding problem would remain unsolved unless the level of the sump is raised. Therefore, elevation of the level and expansion of the inlet channel dimensions are recommended.

Table 6-1 summarizes the results of calculations.

Table 6-1 Results of the Calculations

Oil-catches				
Item	Peak runoff m^3/s	Capacity m^3/s		Remarks
		River	Baffle	
Techier	25.96	20.23	3.50	Neither river cross sections nor baffle sections are capable of carrying peak runoff volumes.
F20	5.50	0.134	0.902	Same as above
TB33	26.38	29.64	1.972	River cross section is capable of carrying the peak runoff volume but the baffle is not.
Vance	17.0	53.29	5.648	Same as above
Cocoa	36.25	--	16.159	The baffle does not have enough capacity to carry peak runoff volume.
Arrow-head	40.30	--	34.74	Same as above
John	17.72	28.143	10.236	River cross section is capable of

				carrying the peak runoff volume but the baffle is not.
TRINMAR	1.29	0.12 (Flow over weir)	0.075	Channel does not have enough capacity for peak runoff volume.

API Separators

Item	Peak runoff m^3/s	Inlet channel Cap. m^3/s	Remarks
No. 1	4.20	5.511	The separator has enough capacity to carry the peak runoffvolume.
No. 2	3.89	1.45	The separator is not capable of carrying the peak runoff volume.
No. 3	7.56	3.931	Same as above
Oil stock sump	9.78	5.74	Same as above

Chapter 7 Project Scheme for Pollution Prevention

This chapter presents the project scheme. The project scheme is defined as a proposed program for installation of new facilities and modifications of the existing ones necessary to achieve the 50 ppm oil target in the most economical and efficient way, based on the outcomes of all the preceding work as explained in the previous chapters. Discussions on the key issues in Chapter 4 and the results of the experiments given in Chapter 19 of the Main Report, in particular, are instrumental to the development of the proposed project scheme.

Establishment of the project scheme was the most important objective of the third field survey conducted from July to August 1994. The study team presented the Interim Report before arrival of the team in Port of Spain. The counterpart and the study team fully discussed the Interim Report, Chapter 18 in particular, "Key Issues in Pollution and Pollution Prevention." During the third field survey, the counterpart and the study team frequently discussed various key issues and the whole program, or the project scheme. At the closing stage of the third field survey, the study team presented a progress report which explained, among other things, the project scheme on which the counterpart and the study team agreed.

The project scheme has remained basically unchanged except that the amount of oily waste water in Pointe-a-Pierre Refinery has changed from the agreed 200 to 250 cubic meters per hour on the basis of more detailed estimates.

7-1 Definition of the 50 ppm Target

The 50 ppm target is not the concentration of pure hydrocarbons dissolved in the water effluent from the petroleum facilities but 50 milligrams per liter of oil and grease as measured by the ASTM Testing Method D-4281, Freon Extraction Method. The oil and grease content indicated by the ASTM method could include substances other than pure hydrocarbons soluble in freon. This definition is very significant in the development of the project scheme, because the effluent stream of the dissolved air flotation facility proposed at Bernstein would not have to be treated by activated carbon if the target level were defined as pure hydrocarbons contained in water having less than 50 ppm.

7-2 Waste Water Treatment in Pointe-a-Pierre Refinery

The main features of the proposed program for Pointe-a-Pierre Refinery are as follows:

1. Oily water flows and non-only water flows should be separated in principle. However, upon thorough inspection of the sites, it has been found difficult in certain areas to prevent storm water from flowing into the oily water streams with the existing facilities duly taken into consideration. Therefore, the waste water treating system must accept a marginal amount of storm water and hence needs a slight marginal capacity in excess of the estimated oily water flow rate.

2. The amount of oily water after the planned upgrading project is estimated at 250 tons per hour. This figure does not include water from the barometric condensers at the vacuum distillation units for the lubricating oil complex. The amount of this water alone is estimated at more than 200 tons per hour, which would put a heavy load on the planned water treating system. The project scheme specified replacement of these barometric condensers by surface condensers.

3. Oily water is collected from a large number of places of origin by two above-ground piping systems, one for plain oily water and the other for chemical oily water, which converge to the central water treating system. Pits and pumps are installed as required to collect, store and inject oily water into the piping systems. Oily water includes: water bled from tanks, desalter effluent, overhead condensed water from distillation columns, water carrying oil leaking from stuffing boxes of pumps, water leg occasionally drained from processing facilities, water collected within areas enclosed by spill walls, etc. Non-oily water includes: storm water, cooling water for tubular coolers and condensers, discharge from the cooling towers, etc.

4. The central waste water treating system will have four buffer tanks, one CPI, one dissolved air flotation unit, and will be designed to meet the target 50 ppm on a monthly average and 75 ppm on a daily maximum. Provisions will be made to tide over troubles with pumps and other key machines with the necessary inventory of spares. However, a standby train to cope with total failure of the system will not be provided in view of the very remote possibility of such a case.

5. The existing water treating systems -- oil sumps, API separators and guard basins -- are

used for treatment of non-oily water streams. The non-oily streams will carry down the oil trapped in the sewage system for a while after non-oily flows have been completely separated from the oily water streams. Eventually, non-oily streams will become free from oil.

6. The basic design conditions of the central waste water treating system are:

(1)	Flow rate, cubic meters per hour:	250
(2)	Oil content of water at CPI inlet, mg/liter:	500
(3)	Oil content of water at DAF inlet, mg/liter:	400
(4)	Oil content of water at DAF outlet, mg/liter:	<50
(5)	Oil content of water at the outlet, mg/liter:	<50

Note: DAF stands for dissolved air flotation unit.

7-3 Waste Water Treatment at Bernstein Main Storage

Bernstein Main Storage is selected as the representative production facility mentioned in the scope of work as having all features of the production facilities in the study area. The proposed program for Bernstein Main Storage is as follows:

1. A waste water treatment system consisting of one train of dissolved air flotation with coagulation unit and activated carbon adsorption unit will be installed. In view of the very remote possibility of total failure of the system, a standby train will not be provided.

2. The capacity of the waste water treating system is 400 cubic meters per hour.

3. The waste water from Los Bajos Main Storage is sent to Bernstein Main Storage over a distance of 12 kilometers, by a water pipeline of 8 inches diameter.

4. The basic design conditions of the waste water treatment system in Bernstein Main Storage are as follows:

(1)	Flow rate, cubic meters per hour:	400
(2)	Oil content of water at inlet, mg/liter:	1,675
(3)	Oil content of water at DAF inlet, mg/liter:	1,000
(4)	Oil content of water at ACA outlet, mg/liter:	<50

Note: ACA stands for activated carbon adsorption unit.

7-4 Dams and Catches

The dams and catches will not be expanded to accommodate storm conditions for the reasons explained in Chapter 4.

7-5 Waste Treatment Centers

Two waste treatment centers are proposed, one in Pointe-a-Pierre Refinery and the other in Bernstein Main Storage. The waste treatment centers will vary both in scale and configuration depending upon whether Trinidad Cement Limited accepts either of the middle-layer emulsion or scums, or both or none. Whatever decision TCL may make, this study needs to develop its own program for disposing of all oil-containing wastes.

The basic design conditions of the waste treatment centers are as follows:

Pointe-a-Pierre Refinery:

(1)	Scum (moisture 91 wt.%), tons per hour	2.0
(2)	Middle-layer emulsions, barrels per day	33
(3)	Water/oil ratio of the middle-layer emulsions	35/65.

Bernstein Main Storage:

(1)	Scum (moisture 97.9 wt.%), tons per hour	32.2
(2)	Middle-layer emulsions, barrels per day	75
(3)	Water/oil ratio of the middle-layer emulsions	35/65.

It is a pre-requisite of the designs that the sludges from cleaning of tanks and separators will not be dumped in earthen pits but will be treated in Petrotrin's expanded bio-remediation project.

7-6 Schedule of Implementation

The schedule of implementation may be considered as follows assuming that each step proceeds efficiently. Considering the present condition of petroleum pollution, each step must be expedited.

		Months
First year		
1.	Study of this report	2
2.	Approval by the government	3
3.	Negotiation with financiers	6
4.	Application for finances	1
Second year		
5.	Selection of consultants	2
6.	Basic engineering	4
7.	Preparation of BID documents	2
8.	Invitation for BID	1
9.	Evaluation of tenders	1
10.	Contract with the contractor	2
Third year		
11.	Engineering, design, construction	12
Fourth year and on		
12.	Operation	

Much of the technical work can be done by Petrotrin. Petrotrin's active participation can expedite each step.

Chapter 8 Conceptual Design

Although the design work done in this study is conceptual, the process of development is no different from detailed design of a process plant and follows the universal standard procedure, starting from material balance/energy balance, preparation of process specification, mechanical specification, construction study, etc.

8-1 Material Balance

8-1-1 Basis for the Material Balance

(1) Pointe-a-Pierre Refinery

1. The oily waste water stream after being separated from the storm water stream is rated at 250 kiloliters per hour, or 37,736 barrels per day. This flow rate includes effluents which contain acids and alkalis. The oil content of the oily waste water stream is 3,000 ppm.

2. The oil contents of the oily water stream at the inlet of the treating facilities are as follows:

CPI, ppm	500
Dissolved Air Flotation with Coagulation (DAF), ppm	400

3. The amount of alum, the inorganic coagulant used for DAF, used is 3.5 times the oil at the inlet of DAF.

4. On the basis of the results of experiment, the amount of scum to be generated is 0.013 kiloliters/kiloliter of oily waste water.

5. The density of the scum is 0.62 grams/milliliter, based also on the results of experiment.

6. Accordingly, the amount of scum generated is calculated as follows:
   0.62 (gr/ml) x 0.013 (kl/kl) = 8 kg/kl oil-containing scum

7. The floating oil recovered from the buffer tanks and CPI is supposed to contain 26 percent water and 20 percent emulsion, the latter in turn contains 35 percent water.

8. The solid matter of the scum exists as $Al(OH)_3$ and trapped oil. The former is formed from the added alum, or $Al_2(SO_4)_3 18H_2O$.

9. The cake of scum formed after dehydration by vacuum filtration contains 70 percent moisture.

(2) Bernstein Main Storage

1. The oily waste water stream is rated at 220 kiloliters per hour, or 33,500 barrels per day. This flow rate includes that which will be added in the future upon implementation of the firm projects. The oil content is supposed to be 8,496 ppm.

2. The oily waste water stream from Los Bajos Main Storage is rated at 180 kiloliters per hour, or 26,500 barrels per day. The oil content is supposed to be 282 ppm.

3. The oil contents of the oily water stream at the inlet of the treating facilities are as follows:

Los Bajos API Separator Outlet, ppm	270
Skimmer Pit Outlet, ppm	3,000
Oil Separator Outlet, ppm	1,500
DAF Inlet, ppm	1,000

4. The amount of alum, the inorganic coagulant used for DAF, used is 3.5 times the oil at the inlet of DAF.

5. On the basis of the results of the experiment, the amount of scum to be generated is 0.13 kiloliters/kiloliter of oily waste water.

6. The density of the scum is 0.62 grams/milliliter, based also on the results of experiment.

7. Accordingly, the amount of the scum generated is calculated as follows:

$0.62 \text{ (gr/ml)} \times 0.13 \text{ (kl/kl)} = 81 \text{ kg/kl}$ oil-containing scum

8. The floating oil recovered from the skimmer pit and CPI is supposed to contain 33 percent water and 20 percent emulsion; the latter in turn contains 35 percent water.

9. The solid matter of the scum exists as $Al(OH)_3$ and trapped oil. The former is formed from the added alum, or $Al_2(SO_4)_3 18H_2O$.

10. The cake of scum formed after dehydration by vacuum filtration contains 70 percent moisture.

8-2 Basic Concepts for the Conceptual Design

8-2-1 Pointe-a-Pierre Refinery

(1) Overall Design Philosophy for Waste Water Treating System

1) General Strategy

Initially when the refinery was constructed, storm water streams and oil water streams were not separated but used common sewers, API separators and guard basins. The two streams are being separated in the Upgrading Project in the tank yard area. In the process areas, however, these two streams are not separated.

Equipped only with gravity-induced separators, it is hardly possible to attain less than 150 ppm oil level, to say nothing of the 50 ppm target level. The results of the experiment done by the study team indicate that it is possible to reduce the oil content of the effluent water from the refinery to less than 50 ppm by the introduction of DAF. A system with DAF as the core facility is proposed.

To obtain the expected performance from the proposed facility, it is essential that the flow be stabilized within the design limits. For this purpose, the storm water should be completely separated from the oily waste water. It is also necessary to separate chemical oily waste water containing caustics and amines from the oily waste water stream, in consideration of COD control expected in the future.

An incinerator will be necessary to incinerate the scum generated at the DAF unit. If the study being done by Trinidad Cement Limited (TCL) on the possibility of feeding the scum comes up with an affirmative result, the scum could be handed over to TCL and the incinerator could be dispensed with. With the result of the study still pending, this study proposes installation of an incinerator in the waste treatment center.

1. Separate buffer tanks will be prepared for oily waste water and chemical oily waste water. These tanks provide storage capacity and help stabilize the feed rates to the treating facilities.

2. A system consisting of a CPI, DAF, guard basin and their associated facilities will be installed downstream of the buffer tanks.

3. Two separate pipelines will be installed traversing the refinery, one for oily waste water and the other for chemical oily waste water. The pipelines will run above ground on the existing pipe racks.

4. Each process unit will have its own separate pits for oily waste water and chemical oily waste water. The areas which may be contaminated by oil will be enclosed by spill walls to keep rain water out. These pits are connected with the oily pipelines.

5. These pits will have automatic level-controlling pumps to keep the liquid level in the pits constant. The fluids are discharged to the oily waste water and chemical oily waste pipelines, and sent to the buffer tanks.

6. A closed bleeding system will be employed for bleeding the bottom water from tanks. This system has already been adopted by Pointe-a-Pierre Refinery. The levels of bottom water are measured by a measuring tape covered with coloring paint before and after bleeding. Tanks are grouped according to their locations, and pipes connected with bleeding valves of these tanks converge to a pit installed for each group. These pits will have automatic level-controlling pumps. The oily waste water is sent to buffer tanks while keeping the liquid levels of the pits constant.

7. The waste treatment center will have a conveyer for the scum, dehydration unit, cake transporting system, incinerator and ashes storage facility.

8. The refinery is now implementing a program for modernizing the instrumentation as part of the upgrading project. The program consists in installation of a central control room and conversion of the existing system of instrumentation into a Distributed Control System (DCS). This program will provide surveillance of the entire refinery operation at the central control room.

At the request of Petrotrin, the proposed system will be controllable from the central control room. However, the incinerator needs to be controlled locally from the standpoint of safety of operation. It should be closely attended to by local personnel; un-attended operation controlled only remotely would not be practical. Likewise, the DAF unit needs to be closely attended to. Two operators will take care of both DAF and incinerator round-the-clock in shift. The following items will be monitored and controlled by the DCS system.

1. Buffer tanks
   Level indicators and flow rate controllers of the water discharged from the tanks

2. Levels of the suction pits for pumps with automatic startup device and high-level alarms
   Process area: 14 points
   Tank yard: 16 points
   Buffer tanks, CPI, guard basin: 3 points.

3. DAF unit
   (1) Flow indication and controlling of the feed water and pressurized water
   (2) Pressure indication of pressurized water tank
   (3) Level alarms for the feed water tanks, scum tank, alum solution tank, and polymer solution tank

A cable will be laid to the nearest satellite center of DCS to transmit signals. Transmission of signals will ride on the signal highway that will be laid from the satellite center to the central control room as part of the upgrading project. The proposed system does not include that portion of the cable.

2) Reliability of the Waste Water Treating System

The waste water treating system will have one train. The target oil content of the effluent streams from the petroleum facilities to the public water, 50 ppm on a monthly average and 75 on a daily maximum, is an uncompromising condition which must always be met. As a provision for repair work, spares will be provided for such pieces of equipment which are considered to be subject to breakdown.

The operation of the system also emphasizes reliability of operation.

The following practices should be observed.

1. The levels of the buffer tanks should always be maintained low. In case of trouble with the waste water treating system, the buffer tanks could hold two days' equivalent of effluent water. The operation should be watched carefully to discover troubles before they develop into major ones. A system of maintenance which can quickly respond to a call should be established.

2. An inventory of adequate size should be maintained for various types and sizes of mechanical seals of rotating equipment and other parts liable to break down.

3. Cleaning, that of CPI for example, should be well scheduled to be done within the holding capacity of the buffer tanks.

(2) Design Conditions of Facilities of Waste Water Treating System

1) Estimation of Waste Water Flows

Table 8-1 gives estimated flow rates of oily effluent water from the process units. The amounts of water from the units with asterisk are used for the design with some allowance.

Table 8-1 Estimation of Waste Water Discharges

(Unit: cubic meters per hour)

Processing unit	Throughput (Bls/day)	Petrotrin's estimate (Bls/day)		Design
No. 8 Topping unit*	135,000	6,750	45	40
No. 4 Vacuum distillation unit*	106,000	7,340	49	49

No. 3 Vacuum distillation Unit	18,000	159,000	1,053	30
FCC/GC*	30,000	5,608	37	40
Alkylation unit	3,000	-	-	-
No. 1 Vacuum distillation unit	18,000	39,600	262	30
D3 column*	3,000	4,100	27	30
No. 1 Reformer/Unifiner*	10,000	450	3	5
No. 2 Reformer/Unifiner*	15,000	510	3	5
No. 1 Hydrodesulfurization unit*	20,000	1,950	13	15
New visbreaker*	32,000	850	6	6
New sulfur recovery unit*	180 t/d	920	6	6
No. 2 Hydrodesulfurization unit*	55,000	2,670	18	20

8-3 Specifications of Facilities

Based on the process specifications given in the previous section, this section presents mechanical specifications of the proposed facilities.

8-3-1 Pointe-a-Pierre Refinery

(1) Waste Water Treating System

Table 8-2 summarized the process design specifications of the waste water treating system at Pointe-a-Pierre Refinery.

Table 8-2 Process Design Specifications of the Waste Water Treating System at Pointe-a-Pierre Refinery

Fluid flow rates, m^3/hour	
Total inflow to the buffer tanks	250
Total effluent from the buffer tanks	250
Charge to CPI	250
Charge to DAF	250
Effluent from DAF	250
Inflow to the guard basin	250
Effluent to the Guaracara River	250
Oil and grease content, mg/liter	
Weighted average at the inlet of buffer tanks	3,000
Charge to CPI, ppm	500
Charge to DAF, ppm	400
Effluent from DAF	50 max.
Effluent to the Guaracara River	50 max.
pH value of untreated water, range	7 to 8
pH value of treated water, range	7 to 8

Source: Study team

Note: 1. The amount of oil on the flow rate is negligible.

Four idle tanks will be converted into buffer tanks. These are:

Buffer tanks for waste water	
NP No. 19, kiloliters	5,000
NP No. 20, kiloliters	4,150
NP No. 21, kiloliters	4,150
Their combined holding time is about 1.5 days.	
Buffer tank for chemical waste water	
NP No. 26, kiloliters	3,000
Its holding time is 4.5 days.	

The waste water and chemical waste water piping system, with pits, pumps and spill walls, will be installed traversing the refinery. These will follow the specifications given in 8-2, "Basic Concept for the Conceptual Design."

(2) Waste Treatment Center

Table 8-3 summarized process design specifications of the waste treatment center at Pointe-a-Pierre Refinery.

Table 8-3 Process Design Specifications of Waste Treatment Center at Pointe-a-Pierre Refinery

Wet scum from DAF	
Production, kilograms/hour	2,000
Water content, weight percent	91
Middle-layer emulsion	
Production, cubic meters/hour	0.2
Calorific value	5,800
Oil content, volume percent	65
Water content, volume percent	35
Dewatering facility	
Feed	Wet scum from DAF
Dewatered scum	
Water, weight percent	70
Oil, weight percent	16
Aluminum hydroxide, weight percent	14
Calorific value, kcal/kilogram	1,200

Source: Study team

(3) Instrumentation

The operation and monitoring of the waste water treating system will be done by a Distributed

Control System which is connected by an optical fiber cable via a satellite center to the central control room to be installed as part of the refinery upgrading program.

8-3-2 Bernstein Main Storage

(1) Waste Water Treating System

Table 8-4 summarizes the process design specifications of the waste water treating system at Bernstein Main Storage.

Table 8-4 Process Design Specifications of the Waste Water Treating System at Bernstein Main Storage

Fluid flow rates, m^3/hour	
Waste water from BMS API Separator	220
Waste water transported from Los Bajos Tank Farm	180
Combined waste water	400
Total inflow to the oil separator	400
Total effluent from the oil separator	400
Charge to CPI	400
Charge to DAF	440
Charge to DAF	440
Charge to ACA	400
Effluent to the Silver Stream River	400
Oil and grease content, mg/liter	
Skimmer Pit outlet	3,000
Oil Separator inlet	1,675
Oil Separator outlet,	1,500
Charge to DAF, ppm	1,000
Effluent from DAF, inlet to ACA	100
Effluent from ACA	50 max.
Effluent to the Silver Stream River	50 max.
pH value of untreated water, range	7 to 8
pH value of treated water, range	7 to 8

Source: Study team
Note: 1. The amount of oil is negligible on the flow rates

A slop tank with a capacity of 1,000 kiloliters will be installed.

(2) Waste Treatment Center

Table 8-5 summarizes process design specifications of the waste treatment center proposed for Bernstein Main Storage.

(3) Instrumentation

The instrumentation will be of locally controlling type.

(4) Pipeline from Los Bajos to Bernstein Main Storage

A new pipeline will be installed between Los Bajos Tank Farm and Bernstein Main Storage to transport waste water from the former to the latter. An 8-inch pipeline will be laid along the road over the distance of 12 kilometers. A pump will be installed at Los Bajos Tank Farm.

Table 8-5 Process Design Specifications of Waste Treatment Center at Bernstein Main Storage

Wet scum from DAF	
Production, kilograms/hour	32,200
Water content, weight percent	97.9
Middle-layer emulsion	
Production, cubic meters/hour	0.5
Calorific value	5,800
Oil content, volume percent	65
Water content, volume percent	35
Dewatering facility	
Feed Wet scum from DAF	
Dewatered scum	
Water, weight percent	70
Oil, weight percent	16
Aluminum hydroxide, oxide, weight percent	14
Calorific value, kcal/kilogram	1,200

Source: Study team

8-4 Design of Facilities

Based on the process specifications, conceptual designs of the relevant facilities are developed. Reference should be made to Chapter 21 of the Main Report.

Chapter 9 Costs

9-1 Basis of Cost Estimation

This chapter shows investment costs and operation costs of the proposed facilities based on the design specifications developed in Chapter 21 of the Main Report. The costs were developed according to the following principle.

1. The costs are all Trinidad and Tobago costs, estimated based on the information on the local costs collected during the field survey and also on the information provided by Petrotrin after the third field survey. Although the consultants are based in Japan, the Japanese costs, which are higher than the Trinidad and Tobago costs in almost all cost items, are used only for references.

2. The year for the cost estimation is 1994.

3. The conversion rate to U.S. Dollars is 5.4 TT Dollars/U.S. Dollar.

4. Each plant cost is the installed cost including the import duty and value-added tax.

5. Estimation of the cost is based on the conceptual design of Chapter 21 of the Main Report.

9-2 Investment Cost

Tables 9-1 and 9-2 give estimated installed costs of the proposed facilities and modifications in Pointe-a-Pierre Refinery and Bernstein Main Storage, respectively.

Table 9-1 Installed Cost of Facilities and Modifications at Pointe-a-Pierre Refinery

(Unit: thousand U.S Dollars)

	Civil Works	Equip-ment	Instal-lation	Total
CPI	45	5	13	63
DAF	120	260	50	430
Guard basin	30	5	10	45
Vacuum filter	20	221	5	246
Incinerator	100	409	172	681
Surface condensers	178	384	142	704
Tanks	40.	17	6	63
Pipes	43	284	35	362
Pumps	28	181	19	228
Pits, ditches, spill walls	19	19	7	45
DCS	98	344	68	510
Total	721	2,129	527	3,377

Source: Study team

Table 9-2 Installed Cost of Facilities and Modifications at Bernstein Main Storage

(Unit: thousand U.S Dollars)

	Civil Works	Equip-ment	Instal-lation	Total
Oil separator	316	4	18	338
CPI	73	5	16	94
DAF	150	325	63	538
ACA unit	680	10,531	732	11,943
Vacuum filter	30	832	5	867
Incinerator	150	1,230	212	1,592
Pipes	40	307	25	372
Pumps, pits	12	86	8	106
Slop tank	120	300	30	450
Total	1,571	13,620	1,109	16,300

Source: Study team

9-3 Operation Costs

The operation cost consists of variable operation cost and fixed operation cost; the former is considered to vary in proportion to the throughput while the latter is independent of the throughput. The variable costs are expressed in terms of U.S. Dollars per cubic meter of waste water treated.

The fixed operation cost normally includes maintenance cost, insurance cost, fixed assets tax, and labor and salary.

9-3-1 Pointe-a-Pierre Refinery

(1) Variable Operation Costs

The dissolved air flotation unit, vacuum filter, incinerator, and waste water gathering pipeline system have variable operation cost items. Table 9-3 gives the total variable operation cost for Pointe-a-Pierre Refinery.

Table 9-3 Total Variable Operation Cost for Pointe-a-Pierre Refinery

(Unit: US Dollars/cubic meter of waste water)

Dissolved air flotation unit	0.097
Vacuum filter	0.002
Incinerator	0.025
Waste water gathering pipeline system	0.014
Total	0.138
Total, thousand U.S. Dollars/year	302

Source: Study team

(2) Fixed Operation Costs

In calculating the fixed operation cost, the combined cost of the maintenance, insurance and fixed assets tax is assumed to be five percent of the initial plant cost. The labor and salary cost is calculated by the number of persons assigned times TT Dollars 4,500/month/head. Ten persons are assigned to form a shift of two persons to attend to the entire system.

Table 9-4 gives the total fixed operation cost for the facilities and modifications proposed for Pointe-a-Pierre Refinery.

Table 9-4 Total Fixed Operation Cost for Pointe-a-Pierre Refinery

(Unit: thousand US Dollars per year)

	Maintenance Insurance Tax	Labor and Salary	Total
CPI	3.2	N.A.	3.2
DAF unit	23.75	N.A.	23.75
Vacuum filter	12.3	N.A.	12.3
Incinerator	34.05	N.A.	34.05
Gathering system, pumps, surface condenser, pits	70.10	N.A.	70.10
DCS	25.50	N.A.	25.50
Total	169	100	269

Source: Study team

9-3-2 Bernstein Main Storage

(1) Variable Operation Costs

The dissolved air flotation unit, activated carbon adsorption unit, vacuum filter, incinerator, and pipeline system have variable operation cost items. Table 9-5 gives the total variable operation cost for Bernstein Main Storage.

Table 9-5 Total Variable Operation Cost for Bernstein Main Storage

(Unit: US Dollars/cubic meter of waste water)

Dissolved air flotation unit	0.227
Activated carbon adsorption unit	0.194
Vacuum filter	0.009
Incinerator	0.039
Waste water gathering pipeline system	0.023
Total	0.492
Total, thousand U.S. Dollars/year	1,724

Source: Study team

(2) Fixed Operation Costs

In calculating the fixed operation cost, the combined cost of the maintenance, insurance and fixed assets tax is assumed to be five percent of the initial plant cost. The labor and salary cost is calculated by the number of persons assigned times TT Dollars 4,500/month/head. Ten persons are assigned to form a shift of two persons to attend to the entire system. Table 9-6 gives the total fixed operation cost for the facilities and modifications proposed for Bernstein Main Storage.

Table 9-6 Total Fixed Operation Cost for Bernstein Main Storage

(Unit: thousand US Dollars per year)

	Maintenance Insurance Tax	Labor and Salary	Total
CPI	21.60	N.A.	21.60
DAF unit	26.90	N.A.	26.90
ACA unit	597.15	N.A.	597.17
Vacuum filter	43.35	N.A.	43.35
Incinerator	79.6	N.A.	79.6
Pipes, pumps, pits slop tank	46.40	N.A.	46.40
Total	815	100	915

Source: Study team

9-4 Miscellaneous Costs

An expansion in facility and operation always incurs unaccounted-for costs. These are increases in telephone calls, clerical work, managerial work, labor cost in other departments or sections, social insurances, consumption of stationery supply, etc. These are collectively called "overhead." As is customary with expansions of process plants, incremental overhead cost is assumed to be 50 percent of the labor and salary cost. This incremental cost is reflected in the economic evaluation of this project.

9-5 Consultancy Fee for Basic Design and Contractors Selection

Before the government of Trinidad and Tobago enters into contract for engineering and construction of the waste water treating systems and waste disposal centers, the government may need to retain consultants for assisting the government in basic design, preparation of BID documents, tendering, negotiations with candidate contractors and selection of the successful contractors. The consultancy fee varies very widely depending upon how much of these work the government can do for itself, whether the design and construction works will be done on a lump-sum contract or a cost-reimbursable one. The study team estimates the consultancy fee at 350 thousand 1994 U.S. Dollar price on the assumptions that the government will do a minimum of technical work and that the design and construction will be done on a lump-sum contract. The estimated consultancy fee does not include supervision on the design and construction works.

Chapter 10 Evaluation

This chapter evaluates the proposed program for achieving the 50 ppm target in terms of economic benefits and costs.

10-1 Basis Premises

The following premises, on which the counterpart and the study team agreed and recorded in the Progress Report for the third field survey, are used for evaluation of the program.

1.	Project year	20
2.	Social discount rate, percent/year	10
3.	Fund source, percent loan	100
4.	Interest rate, percent/year	5.0
5.	Repayment of loan, percent of principal/year	10
6.	Construction period, year	1
7.	Operation period, year	19
8.	Shadow price factor	not used

10-2 Total Capital Requirements

10-2-1 Installed Plant Costs

Chapter 9 gave the following costs:

	Thousand U.S. Dollars
Pointe-a-Pierre Refinery	3,377
Bernstein Main Storage	16,300
Total installed cost	19,677

10-2-2 Calculation of Total Capital Requirements

Table 10-1 shows calculation of the total capital requirements for the proposed programs for Pointe-a-Pierre Refinery and Bernstein Main Storage.

Table 10-1 Total Capital Requirements

(Unit: thousand U.S. Dollars)

1. Plant cost

	Plant cost	IDC	Pre-operation cost	Total capital req'ment
Pointe-a-Pierre Refinery	3,377	84	10	3,471
Bernstein Main Storage	16,300	408	10	16,718
Total	19,677	492	20	20,189

Note:
1. IDC stands for interest during construction. IDC's are 0.5 years' interests on the loan for the plant costs plus calculated
2. Pre-operation costs are assumed to be 10 percent of annual salary and labor.

2. Consultancy fee

	Consul-tancy fee	IDC	Pre-operation cost	Total capital req'ment
Pointe-a-Pierre Refinery	60	4.5	N.A.	64
Bernstein Main Storage	290	22	N.A.	312
Total	350	26	N.A.	376

Note:
1. The consultancy fee is prorated to Pointe-a-Pierre Refinery and Bernstein Main Storage according to the plant costs.
2. IDC's are 1.5 years' interests.

3. Total cost

	Plant cost	IDC	Pre-operation cost	Total capital req'ment
Pointe-a-Pierre Refinery	3,437	88	10	3,535
Bernstein Main Storage	16,590	430	10	17,030
Total	20,027	518	20	20,565

10-3 Working Capital

It is assumed that spareparts equivalent to one percent of the installed plant cost and 25 percent of the annual requirements of consumables except for diesel fuel will be purchased before startup. Table 10-2 calculates investments in working capital.

Table 10-2 Working Capital

(Unit: thousand U.S. Dollars)

Pointe-a-Pierre Refinery	
Spareparts	35
Consumables	
Aluminum sulfate	46
Polymer flocculant	3
Total	94
Bernstein Main Storage	
Spareparts	170
Consumables	
Aluminum sulfate	198
Polymer flocculant	11
Nitrogen	5
HCl	Negligible
NaOH	1
Activated carbon	105
Total	490
Total 584	

10-4 Economic Costs

10-4-1 Initial Economic Costs

Chapter 9 gave estimated the plant costs. The total capital requirement and working capital are calculated as shown above. These costs are not economic costs but financial costs; the former and the latter are rigorously distinguished in the economic evaluation of investment programs. Usually, financial costs are calculated first and economic costs are calculated by deducting transfer cost items from the financial costs. Cost represents in monetary terms the amounts of material or human resources consumed. The transfer cost items are paid but not for consumption of resources, but are transferred from the investment program to other sectors within the country. In the case of this study, the taxes and duties fall into the transfer cost item which will be transferred from the petroleum sector to the government sector.

The equipment costs shown in Tables 9-1 and 9-2 include about 15 percent duty and 15 percent the value-added tax (VAT); therefore, the economic costs of equipment are estimated by removing them, or by dividing the financial equipment costs by 1.30. Likewise, the costs of civil works and installation include 15 percent VAT; therefore, their economic costs are estimated by removing them, or by dividing their financial costs by 1.15. The economic cost of the consultancy fee is assumed to be equal to its financial cost. Items constituting working capital are imported goods, therefore, their economic value is assumed to be equal to the above working capital divided by 1.3. Table 10-3 summarizes initial economic cost items.

Table 10-3 Economic Costs of the Program

(Unit: thousand U.S. Dollars)

Installed cost	
Pointe-a-Pierre Refinery	2,723
Bernstein Main Storage	12,807
Total	15,530
Consultancy fee	
Pointe-a-Pierre Refinery	60
Bernstein Main Storage	290
Total	350
IDC	
Plant cost	
Pointe-a-Pierre Refinery	68
Bernstein Main Storage	320
Total	388
Consultancy fee	
Pointe-a-Pierre Refinery	4
Bernstein Main Storage	22
Total	26

Pre-operation cost	
Pointe-a-Pierre Refinery	10
Bernstein Main Storage	10
Total	20
Working capital	
Pointe-a-Pierre Refinery	72
Bernstein Main Storage	377
Total	449

Source: Study team

10-4-2 Economic Operation Costs

The economic operation costs are estimated by removing the transfer cost items from the financial operation costs. Table 10-4 summarizes economic operation costs.

Table 10-4 Economic Operation Costs

(Unit: thousand U.S. Dollars per year)

Pointe-a-Pierre Refinery	
Variable operation cost	263
Fixed operation cost	230
Total operation cost	493
Bernstein Main Storage	
Variable operation cost	1,499
Fixed operation cost	727
Total operation cost	2,226
Total	
Variable operation cost	1,762
Total fixed cost	957
Total	2,719

Source: Study team

Note: 1. Economic variable operation costs are obtained by dividing the financial variable operation costs by 1.15.

2. Economic fixed operation costs are obtained by dividing the financial MIT cost by 1.3 plus financial labor and salary cost.

10-5 Economic Burden of the Program

Using the above figures the economic costs are calculated to be 0.04, 0.35 and 0.22 U.S. Dollars per barrel for Pointe-a-Pierre Refinery, Bernstein Main Storage, and the total, respectively. The total annual cost is 4,769 thousand U.S. Dollars per year.

10-6 Evaluation of the Economic Burden

Against the seriousness of the petroleum pollution and urgency of measures to meet the 50 ppm target, the cost of 4,769 thousand dollars per year, or 0.22 U.S. Dollars per barrel of crude oil, is justifiable for the following reasons.

10-6-1 Significance of the Economic Burden

The annual economic burden of the waste water treatment, 4,769 thousand U.S. Dollars, represents the following numbers in terms of the economic indicators of Trinidad and Tobago.

- 0.13 percent of GDP; GDP is about 20,000 million TT dollars.
- 0.54 percent of the petroleum sector's contribution to GDP; the petroleum sector's contribution to GDP is about 25 percent.
- 0.45 percent of the government revenue; the government revenue is about 6,000 TT million dollars.
- 4.00 U.S. Dollars per capita per year; the population is 1.24 million. It is also 0.13 percent of GDP per capita, 3,043 U.S. Dollars.
- 0.38 percent of the export earnings; the export earnings are about 7,000 TT million dollars.
- 0.58 percent of the export earnings of crude oil and petroleum products; the export earnings by crude oil and petroleum products account for about 65 percent of the total export earnings.

Granted that, in view of the seriousness of the present petroleum pollution, onshore petroleum production cannot continue without satisfying the 50 ppm target, the question is whether to sustain such a cost in one way or another or to terminate onshore petroleum production. With the small incremental economic burden, 0.22 U.S. Dollars per barrel, termination of the onshore petroleum production would be out of the question. The export earnings of crude oil and petroleum products appear to be the most likely sources of funds for the waste water treating cost.

The percentage, 0.58, is never too large to be diverted to the cause of pollution prevention and control within its own sector. An incremental cost corresponding only to 0.58 percent of the earnings from petroleum export does not harm the competitiveness of Trinidad and Tobago in the international petroleum market.

10-6-2 Economic Cost versus Economic Value of Crude Oil

The economic value of crude oil that comes to Bernstein Main Storage is calculated and compared with the economic treating cost of 0.22 U.S. Dollars per barrel. The facilities are mostly old and depreciated; the economic cost of the crude oil is for the most part that of steam. Assuming water produced with crude oil to be generated only from steam, 2.0 tons of steam is consumed per ton of oil, or per 6.3 barrels of oil (400 tons per hour of steam versus 30,000 bpcd of crude oil). To produce 2.0 tons of steam, heat equivalent to about one barrel of oil is consumed. In other words, economic value corresponding to one barrel of oil is consumed to produce 6.3 barrels of oil. Actually, excess associated gas is burned to generate steam; however, the associated gas should have an intrinsic economic value commensurate with its heating value, or with one barrel of oil. Assuming the economic value of the crude oil to be equal to the current posted price of a Venezuelan crude oil of similar quality, 12 U.S. Dollars per barrel, the economic steam cost is 1.90 U.S. Dollars per barrel of oil produced. Other economic costs of crude oil such as electric power, manpower, and maintenance cost should be much lower than the economic cost of the steam; their combined economic costs should not exceed two U.S. Dollar for the subject onshore fields. The onshore oilfields that send crude oil to Bernstein Main Storage are generate an economic value of 12 U.S. Dollars per barrel of oil at an economic cost of about four U.S. Dollars. By balance, the onshore fields are generating an economic value of about eight U.S. Dollars per one barrel of oil produced. Against such economic value generation, this sector should be able to bear the 0.35 U.S. Dollars per barrel incremental economic burden.

10-6-3 Effect on Consumer Prices of Petroleum Products

It is not recommended to pass the economic burden on to domestic consumers by increasing retail prices of petroleum products. Usually, the cost of pollution prevention and control in a particular industry is passed on to its end users by inclusion of such costs in the prices of the commodities. Trinidad and Tobago, however, represents a special case. Large fractions of crude oil and petroleum products are exported; domestic consumption is about five million barrels per year, about one tenth of the crude oil production. If the economic burden of waste water treatment, 4,769 thousand U.S. Dollars, is charged to domestic consumers, it amounts to 0.033 TT dollars per liter on average for all petroleum products. This is too much to add to the present average retail price of about 0.4 to 0.5 TT dollars per liter.

10-6-4 Comparison with Other Countries

The Tenth World Petroleum Congress held in 1979 perhaps represented the petroleum industry of the time when it had to meet stricter water quality standards. The American Institute of Petroleum, perhaps one of the most reliable sources of information, presented to the congress estimated annualized cost ranging from 0.29 and 0.39 U.S. Dollars per barrel in 1985 price to meet ever stricter standards for waste water. The cost of this program, 0.22 U.S. Dollars per barrel in 1994 prices, compares very favorably with the above estimates.

10-7 Socio-economic Benefit

The socio-economic benefits that could be brought about by this project are very versatile but not quantifiable. The following benefits are expected.

1. Benefits to agriculture and fishery
2. Reduction of health hazard
3. Favorable environment for the petroleum sector
4. Business opportunities and introduction of new technology
5. Public awareness of environmental conservation
6. Preservation of bio-diversity

10-8 Benefits versus Costs

Benefits can only be expressed qualitatively, while costs are quantifiable. Benefits and costs cannot be compared in equal terms. Present conditions of petroleum pollution are not tolerable by any standard, given the fact that waste water discharged from the production facilities is an oil-in-water emulsion that can contain oil in thousands of ppm, and the emulsion mixes uniformly with river water and sea water, affecting the entire body of water from the surface to the bottom. Survival of the onshore petroleum industry should be considered to hinge upon elimination of such oil-in-water emulsion and achievement of the 50 ppm target, to say nothing of further expansion of the petroleum sector. If the choice is to be between termination of onshore petroleum production and implementation of the proposed program, the former option to save 4,769 thousand U.S. Dollars per year, corresponding only to 0.58 percent of the export earnings of crude oil and petroleum products, and corresponding to about three percent of the economic value generation in Bernstein Main Storage, would be unreasonable.

10-9 Alternative Case Study

10-9-1 Barometric Condenser versus Surface Condenser

During the third field survey the study team recommended that the barometric condensers of the vacuum distillation units be replaced by surface condensers to reduce the large amount of oily water that is being discharged by them. Petrotrin, being concerned about the cost of replacement, said that the barometric condensers should remain and the water effluent from them can be treated by No. 4 API Separator which will have enough capacity for treating the effluent after oily and non-oily water streams are separated. It was agreed that the project scheme would stipulate replacement of the barometric condensers as base case, but the case in which barometric condensers remain would be studied as a sensitivity case.

The effluent water from the barometric condensers is vigorously agitated with condensing oil vapor and becomes oily; therefore, treatment with CPI and DAF would be needed. The required additional capacity is assumed to be 262 tons per hour.

The calculation shows that, if the barometric condensers remain, the annual cost increases from 885 to 1,251 thousand U.S. Dollars, or from 0.04 to 0.06 U.S. Dollars per barrel.

10-9-2 Effects of Inefficient Oil Wells

As was said before, the first step toward better waste water management is to reduce the amount of foul water. This principle can also apply to Bernstein Main Storage. The average design water rate is two tons of water per ton of oil, or per 6.3 barrels of oil. Crude oils come from a large number of wells, which differ greatly in the rate of water production, or efficiency.

Now, a question emerges whether the operation of inefficient wells should be suspended to substantially reduce the amount of foul water, thereby reducing the cost of waste water treatment, or they should be operated to increase crude oil production. A case study is done to answer this question on the following premises.

1. Treating cost per unit volume of waste water treating system at Bernstein Main

Storage varies in proportion to 0.8th power of the capacity of the system.

2. One barrel of crude oil has an economic value of 12.0 U.S. Dollars.
3. Water produced in association with crude oil comes from the injected steam.
4. One barrel of water consumes 0.08 barrel crude oil equivalent of fuel, or 0.96 U.S. Dollars.

Table 10-5 compares economic value generation for 25,000, 27,500 and 30,000 barrel-per-day throughputs of crude oil at Bernstein Main Storage. Waste water to be treated for these three cases are 13,000, 24,000 and 60,000 barrels per day.

Table 10-5 Case Study of Economic Value Generation for Waste Water Treating Capacity at Bernstein Main Storage

(Unit: thousand U.S. Dollars per day)

Crude oil production, bpd	25,000	27,500	30,000
Waste water generation, bpd	13,000	24,000	60,000
Ratio	0.217	0.400	1.000
Ratio raised to 0.8th power	0.295	0.480	1.000
Economic value generation	300	330	360
Increment	0.000	30.000	30.000
Economic value consumption			
Waste water treating system	3.139	5.108	10.641*
Steam	12.480	23.040	57.600
Total	15.619	28.148	68.241
Increment	0.000	12.529	40.093
Net economic value	284	302	292

Note: * Treating cost at Bernstein Main Storage
Source: Study team

Note that net economic value generation decreases when the throughput increases from 27,500 to 30,000 barrels per day, because the incremental economic value generation is more than offset by the incremental economic cost of steam. The incremental 2,500 barrels per day of crude oil produced by tail-end inefficient wells need large amounts of steam, and produce large amounts of foul water. By comparison with the incremental steam cost, the incremental economic cost of the waste water treating system is marginal. Net economic value generation is almost the same for the above three cases. Under such a condition, suspension of the operation of the tail-end most inefficient wells is worth studying. The reduction of foul water has a number of advantages: reduction of pollutants discharged to the environment, reduction in the size of waste water treating facility, reduction in the initial capital outlay.

If the economic cost of steam is disregarded as it is now on the ground that otherwise useless associated gas is burned to generate steam, it is natural that the consumption of steam, and generation of waste water as well, should not draw much attention. However, the associated gas should have legitimate uses and should have an economic value commensurate with its heating value. In the light of that also, suspension of the operation of inefficient wells should be studied.

10-10 Life of Oil Field

All these studies are based on the assumption that the subject area will continue to produce oil for some 20 years. The study team did not conduct reservoir analysis of its own. The study team has been informed that Trinidad and Tobago is fairly confident of the future oil-producing potential of this area, and continues exploration and test drillings, and that there are untapped large reservoirs deeper in this area which enable this area to continue production for some tens of years.

Chapter 11 Conclusions and Recommendations

11-1 Conclusions

The government of Trinidad and Tobago intends to diversify its economy, by reducing dependence on petroleum and encouraging other industries. However, the petroleum industry seems to be the only industry that can provide prompt return. Serious petroleum pollution is a factor which can impede further development of the petroleum industry. The government is very concerned about the seriousness of petroleum pollution. Recently, the government has set up the Environmental Management Agency (EMA), as a concrete step toward better environmental management. EMA will draft environmental standards and regulations. There is no legalized pollution standard for oil content in the effluent water from petroleum facilities. The only standard is the draft guideline that has been issued by the Ministry of Energy and Energy Industries specifying that oil and grease discharges from refineries and land based petroleum facilities shall not normally exceed 50 ppm on monthly average or 75 ppm on a daily maximum. This draft guideline is the target of this study.

Petroleum pollution in the study area, the southwestern oil-producing area of the Island of Trinidad, is serious and needs immediate remedial measures. Of air, water and soil pollution, water pollution is the most serious. Oil is being discharged with effluent waste water streams to rivers and sea from petroleum facilities. Water in the rivers and sea in this area shows very high oil content, sometimes as high as thousands of ppm. Oil is accumulated at dams and catches installed on the rivers in this area. The most serious petroleum pollution is caused by two types of emulsion.

First, water produced in association with crude oil is in the form of an oil-in-water emulsion. This water contains thoroughly dispersed oil particles ranging in diameter from less than one to a maximum of about 10 microns. The particles are so small that the emulsion is very stable and does not separate into oil and water by gravity-induced separators, the only type of separators installed in the study area. The oil content can be as high as tens of thousand ppm. This water resembles normal silt-containing brown-colored river water and is not visibly recognizable as containing oil. This water, oil-in-water emulsions, is discharged from producing facilities to the rivers in the study area and goes to the Gulf of Paria, mixed thoroughly with water, polluting the entire body of water from surface to bottom. Though not visible, pollution by this type of emulsion is very serious.

The other type of emulsion, water-in-oil emulsion, is very sticky and viscous like heavy oil. This type of emulsion is also very stable and hard to break into oil and water. It is seen floating on water in the separators. It is skimmed and returned to tanks. As it accumulates in the tanks and separators, it escapes to the environment and contaminates rivers, sea and soil. Unlike pollution by the former type of emulsion, pollution by this type of emulsion is visible.

Soil is contaminated with oil at places where oil has leaked from petroleum facilities, and where there are open earthen pits holding oil-containing wastes.

Technically, solution of these three pollution problems is the central objective of this study. Based largely on comprehensive experiments done by the study team, this report proposes solutions to these problems: dissolved air flotation with coagulation plus activated carbon adsorption for the oil-in-water emulsion, incineration for the water-in-oil emulsion, and abandonment of the practice of using earthen pits and bio-remediation undertaken by Petrotrin for oil-containing wastes.

The study team proposes installation of waste water treating systems at Pointe-a-Pierre Refinery and Bernstein Main Storage. Their cost is estimated at 3,377 and 16,300 thousand U.S. Dollars in 1994 Trinidad Tobago prices, respectively. The annual economic operation cost is estimated at 4,769 thousand U.S. Dollars, or 0.22 U.S. Dollars per barrel of crude oil. This report justifies this cost.

The major conclusions the study team has drawn from this study are as follows.

1. **Pollution Condition**

   Petroleum pollution in the study area is very serious. The most serious is water pollution, caused mainly by two types of emulsion: oil-in-water emulsion and water-in-oil emulsion. Oil content of water in the rivers and sea is very high. It can rise to thousands of ppm, a far cry from the 50 ppm target.

2. **Government Policy**

   The government regards the present pollution conditions as very serious and as a factor that can impede the social and economic development of the nation. Immediate remedial measures are desired. As a concrete step toward better environmental management, EMA has been set up to assume overall responsibility of environmental management.

3. **Dams and catches**

The climate of Trinidad and Tobago is divided into a dry season and a wet season; the former from January to May and the latter from June to December. During the wet season there are occasional heavy rains. In heavy rain, swollen river streams overflow the dams and catches installed on the rivers, washing down the oil and debris that have accumulated, polluting the downstream areas. The study team conducted hydrometeorological studies on these dams and catches and concluded that all these dams and catches are overloaded in heavy rain. However, the study team has concluded that expansion of these dams and catches would be useless and therefore is not recommended. Instead, the study team concludes that the waste water treating system should be designed not to be affected by climatic conditions rather than to absorb their fluctuations.

4. **Water Produced with Crude Oil, Oil-in-water Emulsion**

The study team has identified the water produced in association with crude oil as an oil-in-water emulsion under close observations under a microscope. The suspended minute oil globules give the water a brown color which makes the water resemble normal river water containing silt. It has also been confirmed by microscopic observations that the water essentially does not contain solid particles like those of silt. Size distribution was measured on several samples by the well-known Coulter counter method; the median globule diameter was found to be about 2.5 microns.

The globules are so small that the emulsion is very stable, and does not separate by gravity; therefore, it is not amenable to gravity-induced separators like API separators, CPI, or guard basins, the only type of separators installed in the study area. Economical and practical methods of breaking the emulsion into oil and water were sought. Effects of pH, temperature, emulsion breakers, extraction of oil globules by kerosene, and aqueous solutions of electrolytes were tested. Some of them were found to be partly effective in laboratory conditions; but none was found to be applicable in the field.

Finally, dissolved air flotation (DAF) using alum and a polymer as coagulant was found to be effective and applicable to the actual waste water streams. By this method, the treated water becomes crystal clean, indicating no trace of oil globules remaining in the treated water. In a DAF unit, flocs are generated in the waste water from alum and are coagulated by the polymer. The flocs float to the surface, catching oil globules. Finite air bubbles generated from the pre-pressurized water fed to the unit assist flotation of the flocs. Oil-containing flocs are removed by skimming, dewatered, and incinerated according to the proposed scheme.

5. **Water after treatment by DAF**

A number of samples of waste water, those from Bernstein Main Storage in particular, that were treated by dissolved air flotation with coagulation were found to contain higher than 50 ppm oil. Here the definition of 50 ppm becomes important. To be exact, 50 ppm is interpreted as 50 milligrams per liter of sample water that is recognizable as oil and grease by ASTM Test Method D-4281, the freon extraction method, the method officially employed in Trinidad and Tobago. In this test freon dissolves not only oil, or pure hydrocarbons, but also a variety of organic compounds. If only pure hydrocarbons from crude oil were involved, DAF alone would suffice to reduce the oil content to below 50 ppm; this is not the case with the subject water. If aromatic and naphthenic carboxylic acids are present in the crude oil, these substances tend to be dissolved in water, because of their high solubilities in water, and measured as oil by the ASTM D-4281 Method. This is what actually happens to the water produced with crude oil. By Gas-Chromatography/Mass-Spectrometry (GC/MS), these substances are indicated to be naphthenic acids. Two promising methods for eliminating these substances, biological treatment and activated carbon adsorption, have been tested; adsorption by activated carbon proved to be very effective while biological treatment showed a negative result. On the basis of such a result, adsorption by activated carbon (ACA) is proposed after the DAF unit for treating water produced with crude oil.

6. **Project scheme**

The following project schemes are proposed for Pointe-a-Pierre Refinery and Bernstein Main Storage.

	Bernstein Main Storage	Pointe-a-Pierre Refinery
Design conditions for DAF and ACA Units		
Flow rate, cubic meters per hour:	440/400	250
Oil content of water, mg/liter		
Inlet	1,000	400
Outlet, maximum		50
ACA outlet, maximum	50	
Waste treatment center, with incinerator		
Scums, tons per hour	32	2.0

Emulsion, barrels per day	75	33
Water/oil ratio of emulsion	35/65	35/65
Schedule, year		
Preparation	1	1
Construction	1	1

The waste water from Los Bajos Main Storage is sent to Bernstein Main Storage by installing an eight-inch pipeline over a distance of 12 kilometers along the road, with a pump and electric facilities. Auxiliary facilities are also installed.

Complete separation between oily-water streams and non-oily water streams is also an essential element of the project scheme.

7. Conceptual design and estimation of costs

Based on the project scheme, material balances, process modification and installation plans, process specifications of facilities, mechanical specifications of facilities, and layout plans were developed. These are detailed in Chapter 21, "Conceptual Design" of the Main Report. The installed plant costs were developed. The operation costs were also developed. These costs are 1994 Trinidad and Tobago Price expressed in U.S. Dollars. Inflation is not incorporated. The estimated costs are 3,377 and 16,300 thousand U.S. Dollars for Pointe-a-Pierre Refinery and Bernstein Main Storage, respectively.

	Bernstein Main Storage	Pointe-a-Pierre Refinery
Installed plant cost, U.S. thousand Dollars	16,300	3,377
Operation cost, U.S. thousand Dollars/year		
Variable operation cost	1,724	302
Fixed operation cost	915	269
Total operation cost	2,639	571

8. Evaluation

Cash flows were developed over a period of 21 years, two years for construction and 19 years for operation. Annual fixed amounts of compensation that make the proposed water treating facility economically viable at a discount rate of 10 percent per year were calculated; a compensation of 4,769 thousand U.S. Dollars per year, or 0.22 U.S. Dollars per barrel, has been obtained. This compensation has the following significance against the economic indicators.

0.13 percent of GDP; GDP is about 20,000 TT million dollars.

0.54 percent of petroleum sector's contribution to GDP; petroleum sector's contribution to GDP is about 25 percent.

0.45 percent of government revenue; government revenue is about 6,000 million TT dollars.

4.00 U.S. Dollars per capita per year; the population is 1.24 million. It is also 0.13 percent of GDP per capita, 3,043 U.S. Dollars.

0.38 percent of export earnings; export earnings are about 7,000 million TT dollars.

0.58 percent of export earnings of crude oil and petroleum products; export earnings by crude oil and petroleum products account for about 65 percent of total export earnings.

In view of the seriousness of the present petroleum pollution, onshore petroleum production cannot continue without satisfying the 50 ppm target. The question is how to sustain the cost or whether to terminate onshore petroleum production. With the small incremental economic burden, 0.22 U.S. Dollars per barrel, termination of the onshore petroleum production is out of the question. Export earnings of crude oil and petroleum products appear to be the most reasonable source of funds for the waste water treating cost. The percentage, 0.58, is not too large to be diverted to the cause of pollution prevention and control within its own sector. An incremental cost corresponding only to 0.58 percent of the earnings from petroleum export does not harm the competitiveness of Trinidad and Tobago in the international petroleum market.

The economic cost of waste water treating was compared with the economic value of crude oil produced in the subject area. The result of calculation shows that one barrel of crude oil still bears an economic value of eight U.S. Dollars after paying the economic costs of water treatment and crude oil production. Against all these, the cost of waste water treatment is justifiable.

Domestic consumption of petroleum is very small compared with export. Under such a condition, it is not right to pass all the waste water treating cost on to domestic consumers. If the economic burden of 4,769 thousand U.S. Dollars is charged to domestic consumers, it amounts to 0.033 TT Dollars per liter on average for all petroleum products. This is too much to add to the present average retail price of about 0.4 to 0.5 TT Dollars per liter.

The proposed program will bring about a variety of socio-economic benefits, though these benefits are not quantifiable in monetary terms. Damage to agriculture and fishery will be reduced. Health hazards stemming from petroleum pollution will be reduced. An environment favorable to expansion and development of the petroleum sector will be created. The program will bring about business opportunities to local businesses and introduce new technologies. It will raise public awareness of the importance of environmental conservation. It will help preserve the biological diversity of Trinidad and Tobago.

The proposed program calls for replacement of the barometric condensers of the vacuum distillation units of Pointe-a-Pierre Refinery with surface condensers to reduce the amount of foul water. An economic sensitivity study was done for the case of continuous use of the barometric condensers. It is assumed that the effluent water from the barometric condensers has to be treated by an additional train of CPI and DAF units. The cost increases from 0.04 to 0.06 U.S. Dollars per barrel.

Some inefficient wells produce disproportionately large amounts of water per barrel of oil. A set of data on oil production and water production from all onshore wells that send crude oil to Bernstein Main Storage directly or via Los Bajos Main Storage were arranged in increasing order of water/oil production ratio. An analysis of these data shows that 78 percent of water is produced with the tail-end 17 percent of oil production, 60 percent of water with the tail-end 8.3 percent. Net economic value generation is compared at three points of oil production; namely, full production, 8.3 percent reduction and 17 percent reduction. The net economic value generation virtually does not increase from the 17 percent reduction point, because the incremental value generation by increase in oil production is offset by the incremental costs of steam and waste water treatment. Under such a condition, suspension of operation of the most inefficient wells is worth considering, because reduction of the amount of foul water has a number of advantages: reduction of the amount of pollutants discharged to the environment, reduction in the size of the waste water treating facility, reduction in the initial capital outlay.

9. Operation and maintenance

Operation and maintenance of the petroleum facilities in the study area are generally good. The technical level of Petrotrin is high in these respects. Presumably because of insufficient availability of necessary funds, manpower and also because of accepted practice, operation and maintenance of the petroleum facility leave something to be desired. The following are important points from the viewpoints of pollution control.

(1) Non-oily water intrusion to waste water treating system

Oily waste water streams and non-oily waste water streams are not separated in most petroleum facilities. Intrusion of rain water in the waste oil treating systems in the rainy season overloads the systems and greatly decreases their efficiency. This occurs frequently during the rainy season.

(2) Lack of adequate water treating facilities

Pointe-a-Pierre Refinery, main storages, tank farms and gathering stations do not have waste water treating facilities suited to the types of waste water.

(3) Use of earthen pits

Earthen pits are used to hold oil-containing wastes. This causes pollution of soil and underground water.

(4) Oil and emulsion accumulation on the surface of separators

Oil and water-in-oil emulsions, which are supposed to be collected, accumulate on the surfaces of API separators, guard basins, dams and catches.

(5) Oil remaining not recovered at sites of past leaks

Oil is seen not recovered at sites of past leaks. The contamination can spread to the surroundings.

(6) Breakdown maintenance

Breakdown maintenance is still done on important facilities that can cause a major accidental pollution.

(7) Obsolete facilities

Some of the facilities are obsolete and deteriorated, flow lines and pipelines for example. They need frequent inspection to forestall spills.

10. Legal and administrative measures

Trinidad and Tobago does not have a legal framework that enables the administration to properly act to control pollution. Emission standards have yet to be established. Pollution conditions are not properly monitored.

11-2 Recommendations

This report presents two types of recommendation: recommendations which need to be implemented in order to achieve the 50 ppm target, and recommendations for good operational practices. These two types of recommendations are distinguished and presented separately.

11-2-1 Recommendations to Achieve the 50 ppm Target

The program presented in Chapter 20, "Project Scheme" and defined in more detail in Chapter 21, "Conceptual Design" of the Main Report should be implemented as quickly as possible. In implementing the recommended program, the following are also recommended.

1. **Favorable financing**

   If Trinidad and Tobago needs financing for funding this project, finances on favorable terms should be sought. The possibility of financing on favorable terms from the international financing organizations and from bilateral institutional financial systems of the OECD member nations should be studied.

2. **Lump-sum contract versus cost-plus-fee contract**

   It would be better for Trinidad and Tobago to execute the design and construction work under one lump-sum contract, with performance guarantee, with one contractor of demonstrated capability and credibility. In this way, the entire project can be understood in advance in a clear perspective. The owner of the project is assured of execution at a fixed price. The owner can hold one contractor fully responsible for the entire work, and needs not talk with a number of suppliers. Public competitive tender on equal conditions is possible with a lump-sum contract. Evaluation of the tender is easier with a lump-sum contract than a cost-plus-fee contract.

3. **Bleeding of water upstream of Bernstein Main Storage**

   It is a pre-requisite to the recommended program that any facility or operation upstream of Bernstein Main Storage should not bleed even a drop of water to rivers or the environment. If this is not faithfully observed, the effect of the entire water treating system will be reduced. Education and training of all those concerned with operation of facilities upstream of Bernstein Main Storage must be properly done in this respect.

4. **Study on effects of inefficient oil wells**

While preparation is being made for implementation, a study on the effects of inefficient oil wells such as that presented in 23-9-2 of the Main Report should be done in more detail, based on data periodically collected in a manner specifically designed for this purpose over a span of six months or so. Only by such studies can the proper EOR and the right amount of waste water be established. The study should incorporate all associated issues which include potential unemployment if operation of inefficient wells is suspended. Such a study can be done by no one but the government. Based on the findings of such studies, the benefits and costs of pollution control should be reviewed. The benefits will be further improved vis-a-vis the costs.

5. **Disposal of water-in-oil emulsions and scum**

If Trinidad Cement Limited (TCL) finds it possible to feed scum from DAF to, and burn slop oil, or water-in-oil emulsion, at their kilns, this will represent effective utilization of wastes. In such a case, these should be supplied to TCL and the sizes of the proposed waste treatment systems should be reduced.

6. **Effects of the dissolved substances**

It must be remembered that the effluent of the waste water treating systems contains water soluble hydrocarbon derivatives to a maximum of 50 ppm. Safety of such substances to aquatic organisms is not established. The government and Petrotrin should therefore monitor accumulation of such substances in the bodies of aquatic organisms that live in the contaminated areas and their effects, on a long-term basis.

11-2-2 Recommendations for Good Operational Practice

1. **Maintenance of facilities**

It is recommended that a number of recommendations enumerated in Chapter 17, "Maintenance" be gradually implemented to the extent the budget of Petrotrin permits.

2. **Use of earthen pits**

The practice of using earthen pits to hold oil-containing wastes should be abandoned. Oil-containing wastes should be burned by the proposed waste treatment systems.

3. **Oil and emulsion accumulation on the surface of separators**

Oil and water-in-oil emulsions accumulated on the surfaces of API separators, guard basins, dams and catches, should be recovered. Finding of oil on dams and catches should be regarded as emergencies, and emergency squads should be mobilized to recover the oil. The source should be identified and corrective measures must be immediately taken to prevent recurrence of such incidents.

4. **Oil remaining unrecovered at sites of past leaks**

Oil remaining unrecovered at sites of past leaks should be recovered. The contaminated soil should be either re-mediated by the Petrotrin's planned bio-remediation project, or incinerated.

5. **Breakdown maintenance**

Preventive maintenance should be done without exception on all facilities such as tanks and major pipelines that can cause major accidental pollution.

6. **Obsolete facilities**

Some facilities are obsolete and deteriorated, flow lines and pipelines for example. They should be frequently inspected to prevent spills.

7. **Development of human resources for environmental control**

Human resources needed for better environmental control should be developed. Human resources are needed in the administrative as well as technical fields. Trinidad and Tobago should identify qualified individuals and take every possible opportunity to develop their abilities.

8. **Environmental monitoring**

Joint monitoring program by EMA, the Ministry of Energy and Energy Industry and Petrotrin should be promoted to monitor and accumulate data on petroleum pollution.

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