A STRATEGY FOR SUSTAINABLE WASTE MANAGEMENT IN OIL AND GAS INDUSTRY

by

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ABSTRACT

Oil and gas industries unavoidably generate huge quantity of waste during their activities including exploration, production, storage, gathering, processing, transmission, distribution or combination of these. Most of wastes produced from oil and gas industries are categorized as hazardous and toxic waste that should be handled safely and wisely and should comply with Government Regulation No. 85/1999. Waste oil, solvent, and Oily Sludge are the waste profiles that may damage the environment, if traditional way to handle these wastes is applied.

The strategy for sustainable waste management is related to waste management hierarchy in which the strategy should make moving up the waste management hierarchy. Indeed, recovery (recycling, composting, and energy) and reuse are the Best Practicable Environmental Option (BPEO) for handling most wastes produced from oil and gas industry.

The role of stakeholder in the implementation of the strategy is likely to be a key factor for doing sustainable waste management successfully. Central government plays an important role in preparing the Government Regulation and National Policies on Waste Management. Local governments will have responsibility for implementing the policies in the region by working together with the Environmental Impact Management Agency. Finally oil and gas industries, being a major producer of waste, have important responsibility for ensuring that their waste management practices are consistent with sustainable development.

I. INTRODUCTION

Oil and gas industries are well-known as high capital and high risk industry due to advanced technology used in their activities. During oil and gas production activities, it is of course produced side product in form of wastes which may be categorized as hazardous and toxic wastes (HTW) in accordance with the Government Regulation (PP; Peraturan Pemerintah) Number 18 of 1999 that has been modified in the PP No. 85 of 1999. The HTW should be environmentally friendly handled starting from collecting, storing, treating, transporting and disposing of.

In order to incorporate safely in handling the HTW, the oil and gas industries should have a standard operating procedure (SOP) for handling the HTW, otherwise, they will meet some problems to continue their businesses. The problem that may arise is how to synchronize the SOP with the regulation, especially since the regional autonomy era has been started. The local government is not ready yet to implement the integrated waste management scheme due to waste treatment facilities have not been built yet in the region. In Indonesia, there is so far only one HTW treatment facility which is located in West Java, while the oil and gas industries are mostly located outside of Java Island. Moreover, it is costly to send the HTW produced by the oil and gas industries to West Java, although the capacity of waste treatment facility is enough to receive the HTW from outside of Java Island.

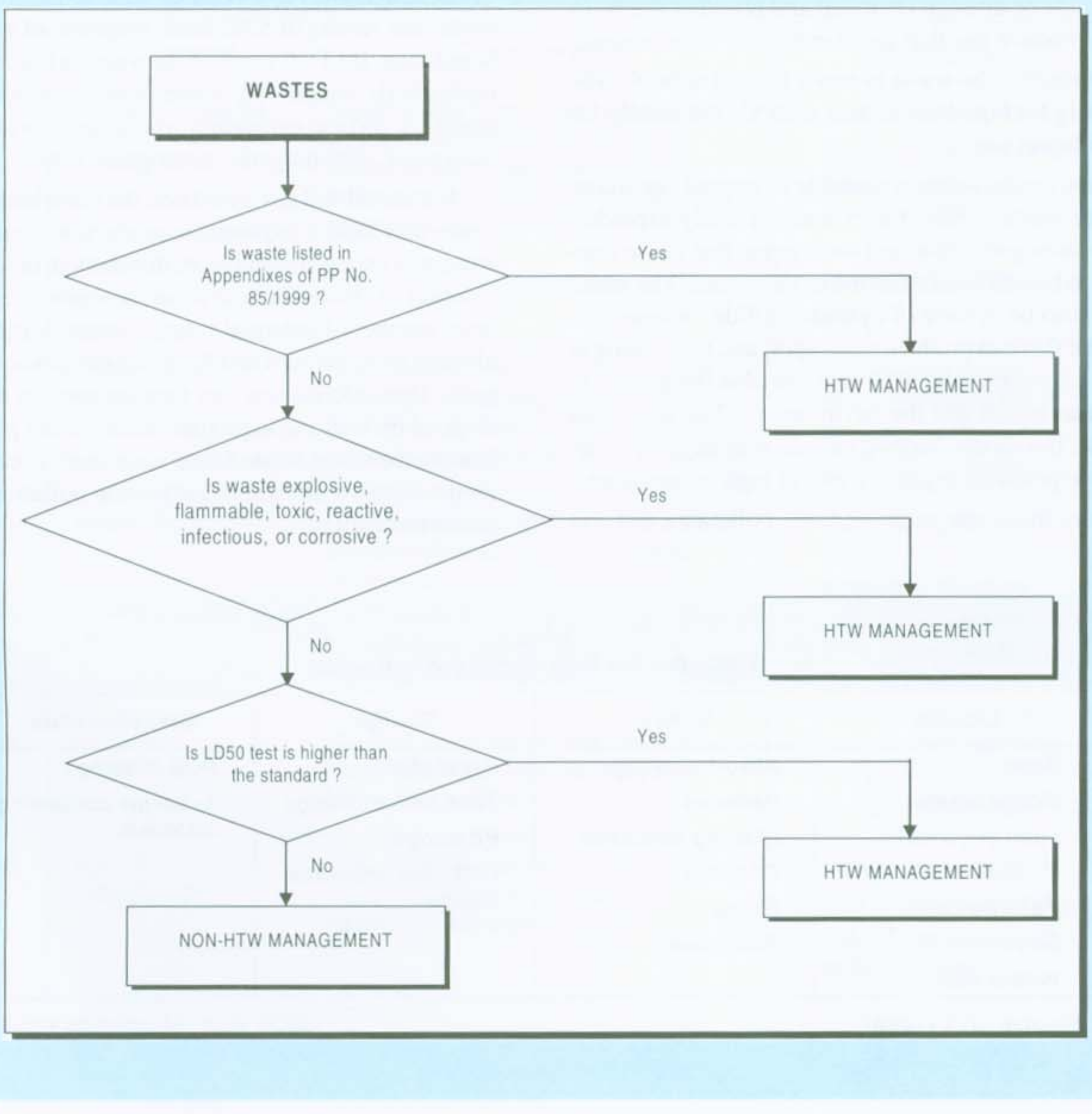
The most important is that the oil and gas industries should manage the wastes in a sustainable way, which means that the oil and gas industries need to reduce the amount of waste they generate, and to take greater care of that which they do produce. Only by taking more responsibility for their wastes can they ensure that the environment is protected both now and for future generations. This message is in line with the principle of sustainable development: promoting development which meets the needs of the present without compromising the ability of future generations to meet their own needs.

To help achieve the objectives of sustainable waste management, this paper discusses the profile of the wastes produced from the oil and gas industries. From this information, the different waste management options can be ranked and chosen in line with BPEO principle. This paper will also highlight the role of the stakeholders in implementing integrated waste management scheme. The conclusion will be the last part of the paper that will conclude the strategy for sustainable waste management that should be considered by the stakeholders.

II. WASTE PROFILES PRODUCED FROM OIL AND GAS INDUSTRIES

The waste produced from the oil and gas industries can be classified as non-HTW and HTW. The waste is classified as HTW if the waste contains hazardous and toxic substances that is due to its amount, properties, and concentration which can directly and indirectly pollute the environment and present threat to public health and, in a wider sense, environmental quality. PP No 18/1999 and 85/1999 have provided a guideline for deciding whether the waste produced is classified as HTW or not as illustrated in Figure 1.

Figure 1
Diagram of determining HTW category (PP No. 18/1999 and 85/1999)



From the figure, it can be recognized that there are several tools that can be used for identifying HTW including:

1. Appendixes of PP No. 18/1999 and PP No. 85/1999

a. Appendix I consists of three tables of HTW from non-specific sources, specific sources, and wastes from expired chemical substances, residue spills and off specification products.

b. Appendix II consists of TCLP (Toxicity Characteristic Leaching Procedure) standard of pollutants in the wastes for determining toxic properties.

c. Appendix III consists of list of chronic pollutants in the wastes

2. HTW's characteristics test:

a. Explosive; at 25°C, 760 mmHg the wastes can easily explode or through chemical and physical reactions can produce gas that can damage the environment.

b. Flammable; the waste is easily flamed at 60°C, 760 mmHg for liquid waste, and at 25°C, 760 mmHg for non-liquid waste.

c. Reactive; the waste is unstable in normal condition. If the waste is mixed with water, it easily explodes, produces gas, vapor and toxic smog that cause danger to human health and the environment. The waste can also be in form of cyanide, sulfide, or ammonia waste that can produce gas, vapor, and toxic smog at pH between 2 and 12.5 that are also dangerous to human health and the environment. The waste can make fire on discharging or receiving oxygen or unstable peroxide organic waste at high temperature.

d. Toxic; the waste contains toxic pollutants that can cause harm to human health and the environment. For determining toxicity of the waste, one can use TCLP standard for organic and inorganic matters in the waste. If the result is below TCLP standard, it is then continued by toxicology test.

e. Infectious; the waste that has been infected by microbe may cause infection to human body. As a result, the community that lives near waste disposal area may get hepatitis and cholera diseases.

f. Corrosive; the waste may cause irritation of skin, or accelerate iron rust (SAE 1020) with corrosion rate of 6.35 mm/year at 55°C. pH of the waste is usually equal or less than 2 for acid waste, and equal or higher than 12.5 for alkali waste.

3. LD 50 test

Lethal Dose Fifty (LD50) test is the dose of the waste that results in 50% death response of guinea pig population. If LD50 value of the waste is higher than 50 mg/kg body weight, the waste is then continued to be tested for chronic evaluation which consists of toxicity, mutagenic,, carcinogenic, teratogenic tests.

For the oil and gas industries, the main business processes may include exploration, production, storage, gathering, processing, transmission, distribution, or some combination of these. Such diverse operations represent a large number of potential waste sources. It is helpful to identify these sources and the processes associated with each. This information can then be used to determine disposal options and to prepare management procedures in advance of the waste being generated. It can also be used to assess waste minimization and pollution prevention opportunities.

Table 1
Waste profiles from oil and gas industries

Liquids	Solids	Sludge	Miscellaneous
- *Brine* - *Condensates* - *Lube oil (used)* - *Oil/water mixtures* - *Paint thinners* - *Solvents* - *Waste water*	- *Absorbents/rags* - *Batteries* - *Blasting abrasives* - *Coatings* - *Filters* - *Soil/gravel*	- *Pig sludge* - *Tank bottom sludge* - *Pit sludge* - *Oil/Water separator sludge*	- *PCB Wastes* - *Asbestos containing materials*

Source: IGT (1996)

In general there are four main categories that can be used to put the profiles of the waste produced from the oil and gas industries as shown in Table 1 [3].

Mulyono, M., et al. (2002) has further identified HTW's characteristics produced from the oil and gas industries as seen in Table 2 [7].

Liquid waste and oily sludge are abundantly produced by the oil and gas industries. Both of them may contain poly aromatic hydrocarbons (PAHs) which is the major oil component. Some PAHs such as benzo(a)pyrene, benzo(a)anthracene, 3-methylcholanthrene, 1-nitropyrene may be classified as HTW because they are carcinogenic and bacterial mutagenic. Moreover, both wastes also contain heavy metals which is harmful to human health.

Oil refineries unavoidably generate huge quantity of oily sludge during refining of crude oil or removing impurities from crude oil. Oily sludge is a hazardous hydrocarbon waste, which constitutes a major task of sludge management. Sources of oily sludge in refinery include crude oil tank bottoms, intermediate and product tank bottoms, wastewater sludge such as API separator bottoms, settlements in ponds, basins and lagoons, contami-

Table 2
Hazardous and toxic wastes

No	Category	Characteristics	Examples
1.	Inorganic aqueous wastes	Liquid waste composed primarily of water but containing acids/alkalis and/or concentrated solutions of inorganic hazardous substances (e.g. heavy metals, cyanide)	- spent sulfuric acid - spent caustic baths - washings of reactors and formulation tanks - rinse water from pesticide containers - etc.
2.	Organic aqueous wastes	Liquid waste composed primarily of water but containing admixtures or dilute concentrations of organic hazardous substances (e.g. pesticide)	- washings of reactors and formulation tanks - rinse water from pesticide containers
3.	Organic liquids	Liquid waste containing admixture or concentrated solutions of organic hazardous subtances	- spent halogenated solvent - distillation residues
4.	Oils	Liquid waste comprised primarily of petroleum-derived oils	- used lubricating oils - used cutting oils
5.	Inorganic sludges/solids	Sludges, dust, solids and other non-liquid wastes containing inorganic hazardous substances	- wastewater treatment sludge - fly ash, bottom ash
6.	Organic sludge/solids	Tars, sludges, solids and other non-liquid wastes containing organic hazardous substances	- sludges from oil tanks - slop oil emulsion solids - soil contaminated with spilled solvent

Source Mulyono, M., et al. (2002)

nated soil etc. The crude oil tank bottom is the oiliest of all the sludge generated in refineries.

When crude oil remains in a cold storage tank, a heavy residue forms that, over time, accumulates at the bottom of the tank and reduces usable tank volume. This residue includes heavy paraffin waxes and asphaltnes that solidify in crystalline form. The residue is extremely difficult to remove from tanks and presents a very difficult disposal problem since it has great potential to leach and become persistent in soil and water.

Liquid waste covers all of liquid waste generated from refinery processes activity and produced water. There is no data on the quantity of liquid waste produced by Indonesia's natural oil and gas industry. One of oil and gas company in East Kalimantan, for example, generates 150,000 barrels of produced water per day. Another company in West Java, produces 130 m^3 wastewater per hour after applying a pipe approach in the management of their waste. The quantity of liquid waste is strongly associated with its oil production. Barina field of Venezuela for example generates 362,000 barrels produced water 144,000 barrels oil per day (a ratio of 2.5:1 of barrel water:barrel oil) [1].

Waste oil is also liquid waste that refers to fuel oil and lubricating oils that have gone through their intended use cycle and must be either disposed of or treated and re-used. When this is disposed of incorrectly, usually by throwing it down the drain, and enters watercourses, it can result in significant damage to the environment. Other liquid waste is organic solvents which are widely used across industrial and service sectors as degreasing and cleaning agents, propellants for aerosols, etc.

III. WASTE MANAGEMENT OPTIONS

In order to achieve the objectives of sustainable waste management, the different waste management options can be ranked in a hierarchy which broadly shows their relative environmental costs and benefits. The hierarchy, as shown in Figure 2, illustrates the waste management order that should be considered by the government in order to make a strategy for sustainable waste management.

Although all waste management options involve risks of pollution, landfill, which is currently used to dispose of more than 70% of waste, poses significant potential for pollution, for instance from methane. Methane is the sec-

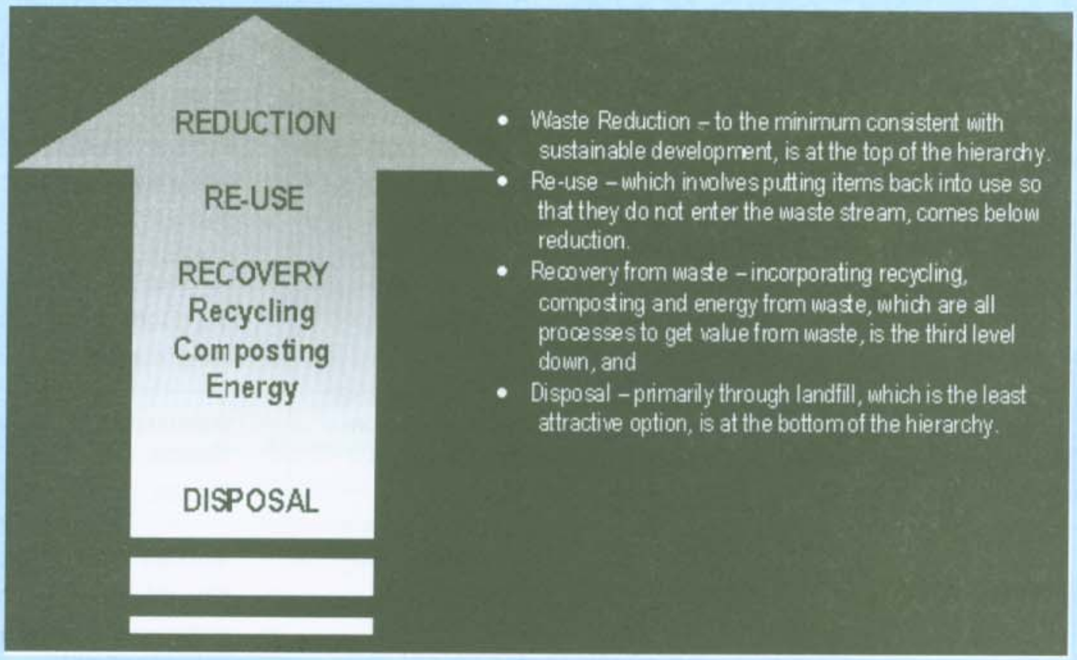
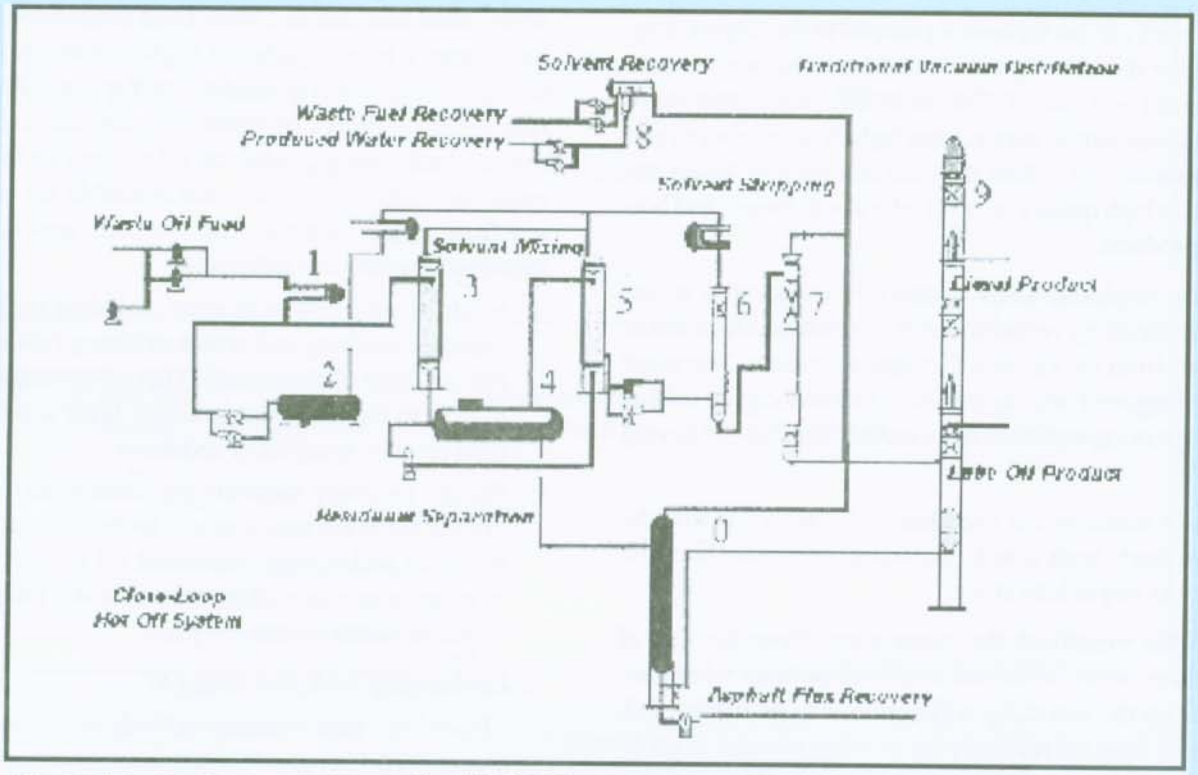


Figure 2
Waste management hierarchy



Source: Interline Resources Corporation (1996) [2]

Figure 3
Flow diagram of used oil refinery technology

ond most important greenhouse gas after carbon dioxide and is produced from the breakdown of the wastes at a landfill site.

It is only through an integrated approach to waste management that high recovery levels can be achieved. "Making waste work" is wisely statement that sets an ambitious target of recovering value from the waste. The Government should have a policy to make the waste management practices move up the waste hierarchy. However, the choice of option for a particular waste stream needs to take into account both the environmental and economics costs of different options.

In line with the waste management options, the following description will give good explanation to handle special wastes produced from oil and gas industries.

Waste Oil and Solvent Management

Used oil that is collected can be recycled by refining process which removes contaminants and additives from used oil. There are existing processes to remove these materials, but these methods require high capital and operating costs. Therefore profitable use of oil refining has not become widespread. However, after years, one company in the United States of America (USA) has completed a used oil refinery technology that will revolutionize the oil recycling industry. Used lubricating oil is recycled to its highest and best use-clean lubricating oils. Moreover, the technology also reduces the cost of building refineries to a fraction of the cost of traditionally used oil refineries, and the operating costs are indeed lower. The technology is developed by Interline Resources Corporation of the United States.

A flow scheme in Figure 3 illustrates the configuration of the interline process. First, raw used lube oil is mixed with a solvent. This solvent has distinct properties for recycling used oil because it has a high selectivity of hydrocarbons and rejects metals and other contaminants. The metals and other contaminants are retained in an asphalt residuum. The extraction process takes place at ambient conditions, which eliminates coking and corrosion that accompany traditional used oil distillation processes.

The oil/solvent mixture is pumped to the solvent stripper where the solvent is removed from the oil, and then condensed and reused. The oil is then flashed at atmospheric pressure to remove the light hydrocarbons, and the remaining oil is then distilled in a vacuum tower, resulting in high quality base oil lube stock, diesel, and bottoms products.

The residuum/water mixture is transferred to the asphalt-blending vessel where it is combined with tower bottoms from the vacuum distillation column. The water is then removed and the resulting mixture can be sold as flux for roofing asphalt or as an asphalt modifier for paving asphalt.

As a result of the used lube oil refinery is that the end product, with a mild finishing step, has the same quality as virgin lube stock.

In the meantime the move away from the use of used lube oil to waste management options which are further up the hierarchy will continue to be market-led, and used lube oil recovery by refining process is probably the BPEO for most used lube oil. However, for used lube oil that contains a significant amount of contaminants refining process is not suitable.

Oily Sludge Management

Traditional way to handle this type of waste is to dump the sludge into pits, but possible seepage of the oily sludge from the pits over a period of time cannot be ruled out, therefore, environment-friendly technologies are increasing in demand by petroleum industry to manage oily sludge.

Indian refineries have been exploring for better methods and have also implemented improved techniques for waste minimization and oil recovery from oily sludge. Many of these techniques have shown promising results. However significant progress has been achieved in recycling, reuse, recovery and treatment of HTW by refineries in the USA and some other countries.

Some of the significant management practices adapted by various refineries are discussed in this section. The efforts have been in the area of waste minimization, oil recovery, biotreatment and secured disposal as oily sludge from oil and gas industry contains mainly petroleum hydrocarbon. Petroleum hydrocarbon is a mixture of aliphatic, aromatic, policyclic hydrocarbon ranging from short C3 to much longer carbon chains.

1. Crude Oil Tank Bottom Desludging

Since sludge consists of a mixture of hydrocarbons, water, sand rust, ash and other solid constituents, efforts have largely been to achieve higher recovery of water to achieve reduction in residue for disposal. Other criterion in development of advanced methods has been to reduce tank outage, enhance safety and reduce VOC emissions. Several methods are available for oil recovery from crude oil tank. The methods applied can be broadly classified into following:

a. In situ oil recovery techniques including hot gas oil or distillate washing and steam stripping (with or without addition of chemicals). This allows entrapped oil to float to the top of the sediment layer and be recovered prior to removal of sediment;

b. Ex situ recovery methods are usually performed by contractor at the tank site and include filtration, centrifuging and setting. Separated oil is recycled back to process or slope oil tanks, and water phase is sent to waste water treatment plant.

2. Desludging with Hot Gas Oil

Traditional tank cleaning methods use a combination of heat (60-70°C or greater) and mechanical agitation to force the oil trapped in sediment back into solution. Hot gas oil is frequently used as a diluent and circulated in the tank that will be cleaned up. By maintaining temperature and circulation for a period of time depending on circulation rate, with changeover of gas oil in between, it is possible to recover major portion of free oil and emulsified oil trapped in upper layers. However, it has following drawbacks:

- Tremendous amount of energy is required to circulate and heat large volumes of oil;
- Time taken to clean tank ranges from 3-4 months putting tanks out of service.

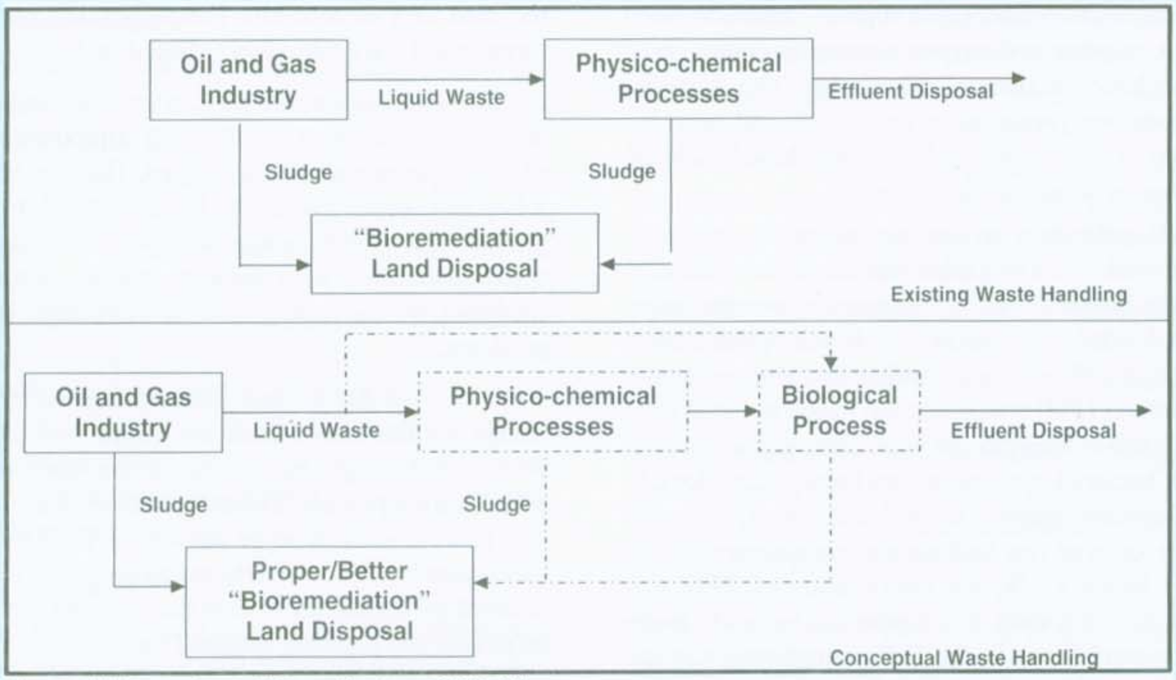
3. Chemical Desludging

Many chemicals have been developed to aid the process of desludging. In general the chemical is added along with solvent and circulated, normally at higher temperatures. The oil recovery is faster compared to use of only hot gas oil. The chemical added performs one or more of following function:

a. Converts wax in the oil from crystalline to an amorphous material;

b. Disperses the amorphous material into diluent solvent;

c. Acts as demulsifier which separates water present;



Source: Wisjnuprapto and Edwan Kardena (2000) [9]

Figure 5
Existing and conceptual waste handling

d. Acts as degreaser;

e. Acts as a pour point depressant.

Various refineries have carried out trials with different chemicals. The technique ensures better hydrocarbon recovery and reduced outage of crude tank.

4. Biological Treatment

The most popular disposal option for residues from oily sludge world wide has been landfill. It was after the land ban regulations in USA that biological treatment ceased to be importance for hazardous oily sludge. Other developments include land treatment with or without addition or microbes. Biological treatment is one method for treatment of oily sludge to meet land disposal requirements. Figure 5 shows the existing and conceptual waste handling system for oily sludge.

Land treatment has been the preferred option for oily sludge in several countries and API reported significant quantities being disposed of by this method (survey in 1992). Contaminated sludges are applied at appropriate loading rates to an available area and the natural biological degradation processes are used to enhance and degrade the contaminants present. The process typically uses indigenous microorganisms to degrade contaminants in the soils. Biodegradation conditions are enhanced by the addition of nutrients and water. Land treatment has a significant history of use and performance and has been successfully demonstrated for the application of sludges from refineries.

Although biodegradation of petroleum hydrocarbon can be performed in anaerobic conditions, however aerobic biodegradation seems to be more effective. Thus in order to bio-treat oily sludge, the presence or supply of oxygen is a very important factor to the success of the treatment. Biodegradation process, also called "bioremediation technique", which includes biopile, landfarming and composting will be more effective if oxygen supply is not limited. Since the technique uses microorganisms, microbial diversity in the site is important. Produced water may already contain microorganism such as bacteria that could survive and has great potential to be able to utilize oil as their carbon and energy sources. The bacteria can be screened further to obtained a consortium capable of degrading oil.

An indigenous bacterial consortium was developed by assembling five bacterial strains (3 strain

Acinetobacter baumannii, one strain *Burkholdia cepacia*, one strain *Pseudomonos* sp.) Developed bacterial consortium could degrade aliphatic, aromatic, NSO (nitrogen, sulphur, and oxygen containing compounds) and asphaltene fractions of oily sludge. This bacterial consortium was produced in mass scale and immobilized onto a carrier material. The carrier based bacterial consortium is designated as oilzapper.

A full-scale study on bioremediation of oily sludge contaminated land using oilzapper was conducted at an oil refinery. Based on contamination levels, bioremediation site was divided into four blocks. Block A was treated with oilzapper plus nutrient resulted that total petroleum hydrocarbon (TPH) contamination in soil reduced from 134 mg/g soil to 5mg/gin one year. Similarly, with application of bacterial consortium and nutrients in Block B, the TPH contamination in soil reduced from 43 mg/g soil to 4 mg/g soil in an year indicating a degradation of 90.6% TPH. In Block C, 90.3% degradation of TPH was achieved by application of oilzapper and nutrients. However, in control Block D, the TPH contamination in soil reduced from 132 mg/g soil to 113 mg/g soil in one year indicating a reduction of only 14.3%.

Similarly, bioremedaiton of oily sludge with application of oilzapper was conducted at Indian Oil Corporation Ltd., Barauni Refinery, Digboi Refinery, Guwahati Refinery, Bharat Petroleum Corporation Ltd. Refinery, Mumbai, Hindustan Petroleum Corporation Ltd., Vishakhapatnam refinery and Oil Indian Ltd., Duliajan. More than 5000 metric tons of oily sludge has been biodegraded at these sites.

5. Recycle/Reuse Options for Oily Sludge

Recycling is the most desired option environmentally to handle oily sludge. API has been carrying out survey on Management of Refinery Residuals since 1987. These surveys present the column of waste generated for each type, treatment and disposal methods utilized, recycling and reuse methods etc. These surveys provide wealth of information on residuals management.

Many other recycling/reuse options for environmental friendly handling of hazardous wastes have been developed and are used. Of these, the two options of importance are discussed below. These are recycling to Cement Kiln and gasification to produce power.

A preferred method for off-site recycling of hazardous waste is incorporation of waste into waste derived alternative fuel for recycling in cement kilns. In USA this activity is highly regulated and monitored and the recycling of hazardous material has to be in permitted facilities. The United Kingdom has also initiated a program "CEMFUEL" for this purpose. Refinery waste recycled to a cement kiln generally takes one of two forms, solid (oily cake) fuel or liquid fuel.

The gasification process converts any carbon containing material into a synthesis gas composed primarily of carbon monoxide and hydrogen. This can be used as a fuel to generate electricity building block for a large number of uses in the petrochemical and refining industries. Gasification adds value to low or negative value feedstock by converting them to marketable fuels and products.

Other suitable method for recycling and reuse oily sludge is solidification treatment that process oily sludge into solid. Lemigas has conducted the study regarding solidification process. The study showed that solidification process is likely to be suitable method for treating oily sludge [6]. Moreover, the technology used is a proven technology which can process the oily sludge to be used as paving and patching material for road.

From environmental viewpoint, it is desirable to explore recycle and reuse options for application in Indonesia, otherwise disposal option for residues from oily sludge would be the last choice, but it should be followed by biological treatment.

IV. ACTORS AND PLAYERS

Working towards sustainable waste management is a wide-ranging task requiring the commitment of all the different groups of waste producers in society, in cooperation with the authorities responsible for regulating and controlling waste management. It is important that central and local government and industry are clear about their responsibilities for sustainable waste management.

It is also important to implement "polluter pays" principle for environmental damage and should be targeted at the right groups of people.

Central Government

Central government has a key role to play in achieving sustainable waste management. The strategy itself, by giving prominence to policies on the reduction, reuse and recycling of waste, and the advantages of recovering energy from it, represents a significant contribution to this goal. Central government will continue to further the objectives of the strategy:

1. Through regulation regarding waste management where appropriate;

2. Promoting responsible waste management within industry and local authorities;
3. By issuing guidance;
4. By producing a statutory waste strategy.

In addition, each Department should have a designated "Green Minister" to ensure that environmental considerations are reflected in his or her Department's policies. The Department of Environment together with the Department of Energy and Mineral Resources, the Department of Trade and Industry, and the Department of Health have to produce a strategy as a guide to enable other departments to ensure that their resource use practice takes full account of the need of the environment. In other words, Government department with a responsibility for major projects such as oil and gas industry should promote recycle and reuse of waste produced where feasible.

Local Authorities

Local Authorities will have an important role to play in helping to achieve the goal of sustainable waste management. They are responsible for implementing waste management policies in their duties as waste regulation authorities, waste disposal authorities and as waste collection authorities. Moreover, like central government, local governments need to ensure that their own operations take account of the requirements of sustainable waste management.

Local government should make waste regulation authorities for handling waste produced from oil and gas industry. These consider the need for waste facilities in the region, and need to take account of the strategy in drawing up their waste disposal plans. For implementing these facilities, it is possible for local government to work together with environmental consultants and contractors that may be private sector companies, wholly owned local authority waste disposal companies or other waste disposal companies in which the Local Authorities have an interest.

Competitive tendering for waste disposal contracts is intended to help encourage higher standards in the collection, treatment and disposal of waste. Tendering process may also be used to ensure that the local authority contracts play a constructive part in moving to a more sustainable approach to waste management.

There is now a wide range of publications giving advice to local authorities on how they can contribute to the goal of protecting and improving the environment. As part of its work on the promotion strategy associated with this waste strategy, the government may provide publications relating to waste management and environmental protection so that the messages of this strategy can be disseminated to the parties involved.

As part of local government, the Environmental Impact Management Agency (BAPEDAL) will bring together waste regulation responsibilities by providing a coordinated approach to assessing the best options for dealing with all the waste that arise in the region, and to produce a reasoned assessment for an integrated approach to waste management. The agency will be expected to operate to high standards, based on the best possible information about the environment and the process which affect.

The Agency will also take over the Department of Environment's role in sponsoring research, and issuing technical guidance, on waste management practices and their effects, becoming a centre of expertise. Consequently, the Agency will have a statutory role in providing formal advice on the content of the strategy to oil and gas industry in the regions.

Oil and Gas Industry

As a major producer of waste, industry has an important responsibility for ensuring that its waste management practices are consistent with sustainable development principle. The waste strategy contains two main messages for oil and gas industry:

1. industry can help itself by adopting waste reduction and management strategies which both save money and are good for sustainable development;
2. industry should ensure that its processes and products are designed taking into account the objective of sustainable waste management.

Industries should also consider changing their management and reporting arrangements so as to give recognition of waste costs. Moreover, the oil and gas industry should be involved actively in the program provided by the agency such as a cleaner production program, blue sky program, etc.

V. CONCLUSION

From a discussion above, it can be concluded that:

1. Oil and gas industries generate mostly special waste called hazardous and toxic waste (HTW) that should be handled wisely and should comply with the Government Regulation No. 85 of 1999.
2. The strategy for sustainable waste management should consider waste management hierarchy in

which the strategy should make the waste management hierarchy move up. However the choice of option for particular waste stream needs to take into account both the environment and economics costs.

3. Recovery (recycle, composting, and energy) and Reuse are probably the BPEO for most HTW produced from oil and gas industry. It means that there is an opportunity for the investor from private sector companies, wholly owned local authority waste disposal companies or other waste disposal companies to be involved in sustainable waste management scheme.
4. There are several waste management businesses that can be funded by the investor including incineration plant, combined heat and power waste to energy plant, commercialized microorganisms cultivation, pavement and brick fabrication, etc.
5. All stakeholders should be involved actively in the sustainable waste management scheme according to their roles. As a focal point, BAPEDAL should make good cooperation among the stakeholders.

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