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Review Article

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Hydrocarbon Exploration and Production- a Balance between Benefits to the Society and Impact on the Environment

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Abstract

There is an increasing concern for alternate source of fuel due largely to the environmental impacts of hydrocarbon exploration, production and usage. Global warming and marine pollution is the top on the list. However, the efforts and achievements of the industry over the years towards safer operations and greener environment seem to be ignored or unacknowledged. In this paper, effort is made to review the environmental effects of oil exploration and production and the role and achievements of the oil industry in mitigating these impacts. It is argued here that the dependence of man and society on hydrocarbon goes beyond just burning hydrocarbon for fuel but also cuts across hydrocarbon usage in various aspects of our social, technological and medical lives. Finally, we emphasized that the need for a balance between exploration and production of hydrocarbon and environmental integrity will be a reality only if parties involve step up synergy towards a safer operation.

Keywords: Oil; Gas; Environment; Benefits; Oil industry; Greening; Man

Introduction

The exploration and usage of petroleum started much earlier than the modern history we are familiar with. According to the literature, petroleum exploration, drilling, production and refining started more than 4000 years ago. Petroleum related activities in Babylon, Roman province, Iraq, and China and the use of petroleum products (tar and asphalts) in construction, lamp oil and medicine are well documented. Modern history of petroleum began in the 19th century which marks the birth of petroleum industry in Poland, Romania, Russia, United States and Canada. The demand for petroleum for fuel rose at this period resulting in oil boom. By early 20th century, major oil fields were discovered in Canada, Mexico, Persia, and Venezuela and by 1950s, the invention of internal combustion engine marked the rise in importance of petroleum. By mid-20th century, oil rapidly replaced coal as a source of fuel. Today petroleum is an important part of politics, society and technology [1]. According to the 1993 estimates of United States Geological Survey, the world ultimate crude oil reserves is in the range of 2.1-2.8 trillion barrels [2] while total global oil consumption per day is about 89.9 million barrels [3].

Just as the societal demand and consumption of petroleum have grown exponentially, so is its impact on the environment. In the old era of petroleum, environmental effects of petroleum operations were insignificant probably because of the small population, very small scale of production, utilization of simple tools and low petroleum usage. Petroleum was then a good mineral resource without adverse consequences. Today, petroleum exploration, production, transportation and usage result in adverse effects to the marine lives, land, atmosphere and humans. This is obviously due to the role of petroleum in our society today. It is the economic drive of many petroleum rich countries. It fuels the most important aspects of human society- the military, transportation, Agriculture, and electricity. By, October 31, 2011, the world population will reach 7 billion [4] and its major source of fuel is petroleum, hence petroleum supply must measure with human need. To be able to meet this demand, high technology tools and materials have been deployed which on one hand have significantly improved exploration and production activities and on the other hand have resulted in severe environmental consequences. Cao et al. [5] pointed out that such environmental consequences are primarily due to unsustainable usage of the new technologies and materials, and also unsustainable usage of natural resources (petroleum) which eventually result in the overstretch of the environmental carrying capacity of our society. Example of such technology is the use of complex drilling fluids containing toxic chemical components detrimental to health of oil workers and to the lives of marine fauna and flora (where the cuttings smeared with drilling fluids are usually dumped). Also the need and use of large tankers for large scale and long distance transportation of petroleum products from one region of the world to another is not without repercussions to the marine environments that serve as the transport routes. Furthermore, large scale burning of fossil fuel (in which petroleum is a significant part) is believed by many to be the cause of the increase in concentration of atmospheric greenhouse gas. Thanks to the environmentalists that brought the attention of the oil industry to the consequences of their activities. This paper reviews the impacts of petroleum and its exploration and production to man and his society. The economic, industrial, technological and social benefits of petroleum are first presented followed by a review of the health, economic, environmental and social consequences of petroleum operations to man and its environment. The concerns of the environmentalists and public is also brought to light and juxtaposed with the response of government agencies and the petroleum industry

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towards a safer industry practices. Finally, the need for a synergy between environmentalists, government agencies and the industry is hereby emphasized and preferred over a call for alternate energy source or restrictions to petroleum exploration and production.

Benefits of Petroleum to the Society

Economic drive of society

Petroleum (also called crude oil) is the most traded commodity in the international market and economic drive of many countries [6]. Apart from its primary use as a source of energy, crude oil is considered the mother of all commodities because it is an important raw material for wide varieties of materials [7]. Though lately, there is a concern that the world will run out of oil but there are also optimistic views by analysts that the world will be oil richer [2,8-11]. Crude oil normally co-exists with natural gas in the underground reservoirs at high pressure and temperature. When the crud arrives at the surface, and after refining, it yields variety of products in gaseous, liquid, and highly viscous states. These products are normally referred to as petroleum products such as natural gases, gasoline, kerosene, naphthalene, lubricants, asphalts, etc.

A source of important natural gases

Natural gas is a potential source of hydrogen, carbon monoxide-hydrogen, formaldehyde, acetylene and other important gases used all over the world in our homes as cooking gases and fuel for room heaters, in the industries as source of fuel for machineries and equipment, and in the hospitals for treatment, and so on.

Petrochemical industry

Petroleum or crude oil is a source of raw materials for the wide variety of chemicals available today. It is a major source of benzene and benzene is a source of many important chemical compounds such as toluene, phenol (used to make resins and adhesives), aniline, naphthalene, styrene (used to make polymers and plastics) and anthracene. In the 1950s, increase demand of benzene especially from the growing plastic industry necessitated the production of benzene from petroleum (a larger source than coal) and today, most benzene come from petroleum. Small quantity of benzene is used to manufacture drugs, rubbers, lubricants, detergents, dyes, explosives, pesticides and napalm [12,13].

Alkenes/Olefins are other components of crude oil that is widely used in the petrochemical industry. Their hydration and oxygenation yield alcohol and important group of solvents. Polymerization of alkenes also yields plastics (polypropylene and polyethylene) which are of high industrial value [14]. Ethylene reacts with hypochlorous acids to yield chlorohydrin (a chemical used in the production of non-freezing explosives). Hydrolysis of chlorohydrin yields Ethylene oxide-a useful insecticide [15].

Agriculture

Herbicides: Crude oil has been used as herbicides in the past. Though in the 1950s, it was discovered in Great Britain that toxicity of oil is related to the aromatic components of oil. Hence mixtures of different oil fractions with low (safe) aromatic content were successfully used as herbicides for controlling weeds at greatly reduced cost and minimal toxicity to the crops. For example, in USA and Australia, kerosene type fraction was used in selective destruction of weeds in carrot crops. Other light fractions with lower toxicity used were white spirit, Stoddard solvents. In the Great Britain, oil herbicides were successfully applied to parsnips and cornifer seed beds in forest nurseries. Heavier oil fractions like diesel oil were used as total weed killers. The major advantage of petroleum herbicides is that they kill annual grasses and dicotyledonous weeds [16]. Today, industrial farmers rely heavily on pesticides, herbicides and fertilizers to supply commercial quantity of food to the society [17].

Fertilizer: There was necessity to reduce the wastage associated with the conventional fertilizers particularly at the time (1966) when US spent over $325 million in fertilizer aid abroad and an expected shipment of $1 billion worth of fertilizers yearly until 1970 in order to combat food crisis in Africa, Asia and Latin America. The conventional fertilizers are soluble in water and not all the nitrogen in solution is available for plant uptake. A significant percentage (25–50%) is lost to the deeper soil through leaching, a situation prominent during heavy rainfall or heavy irrigation. Improved fertilizers were developed such as urea-formaldehyde condensation product (Urea form) produced from reaction of urea and formaldehyde and has a nitrogen content of 38%. Soil microorganisms slowly convert U-F nitrogen to nitrates and nitrogen is released to the soil. Fertilizers are also coated with tars, pitches, asphaltic substances and others to control nitrogen release to the soil. In the late 1960s, petroleum wax combined with urea asphalt and oxidized wood rosins were also used as fertilizers because of its ability to release nitrogen nutrients into to the soil in a controllable manner [18].

Petroleum mulches: The use of bituminous oil fractions to prevent soil erosion is an old agricultural practice. They have also been used as a sealants/impervious coatings to direct water runoffs to selected areas (in watershed). They are also applied to soil to give it the favourable moisture and temperature needed to promote plant early growth. Petroleum mulch were successfully applied to many crops (including carrot, pea, potatoes, lettuce, spinach, melons, onions, beans, cucumbers, peppers, rice, sugar beets, celery, asparagus, leeks and radish) in many countries around the world and increase yields were observed [19].

Mechanized farming: Agriculture productivity has significantly increased since the 1940s due to the use of diesel engine tractors to cultivate, harvest and process farm produce. Also mechanized farming (fuelled by fossil fuel mainly gasoline or diesel) allows the farmers to produce large food stuff much easier than 50 years ago [17]. Gasoline fuelled trucks have also been used to transport food products to the markets across cities, nations and continents.

Space exploration

Kerosene has been used as rocket propellant for many years. Poly-nuclear aromatics are the most resistant of all organic compounds and will withstand radiation in the order of 109 to 1010 rad before undergoing 25% change in viscosity. Hence, they are used as heat transfer fluid in space application because of their thermal and radiation stability, freedom of corrosion, wide liquidous range and some lubricating properties. Hydrocarbon plastics and elastomers such as polystyrene are used in space for similar reason to encapsulate solar cells and batteries used to provide electricity for satellites and space probes [20]. Furthermore, light weight composites and carbon fibres have been used to make aircraft lighter and travel faster [21].

Construction

Asphalt (also called bitumen) is a heavy residue of petroleum distillation. It is largely used in road construction where it is used as glue mixed with aggregate particles to form asphalt concrete. It is used to construct motor way, airport runway, streets, parking lots, sports area, canal linings, reservoirs, and in coastal protection. Out of the total bitumen used globally, 85% is used as pavement asphalt (for road construction), 10% for roofing and the remaining 5% for other uses [22]. More than 90% of the 5.2 million kilometres paved roads and high ways in Europe was constructed with Asphalt [23]. In the United States, 85% of asphalt usage is in road construction. A significant percentage of asphalt is also used for roofing shingles, fence post treatments, water proofing for fabrics [24]. Of the 4 million kilometres paved roads and high ways in US, 92% is constructed with asphalt [23]. Also, in China, road construction accounts for three-quarter (75%) of total asphalt consumption. As of 2003, asphalt has been used to construct 30, 000 km of China's national high ways and it will continue to be used for the next three decades to construct 85,000 km national high ways. Similarly, asphalt consumption in roofing is significant and the demand will continue to rise as well [25]. China demand for asphalt for road construction and maintenance is 16 million tons in 2010 and expected to increase [26]. According to Bubshait [27], the total length of asphalt-paved road in Saudi Arabia is 44, 000 km which is among the longest and most developed road network in the Middle East. The increasing demand for asphalt can be attributed to increasing economic activity in developing countries in Africa, Asia, and Middle East where massive road and building construction in rural and urban areas is expected [28].

Electricity generation

The main sources or fuel for electricity generation are hydro, coal, nuclear, wind, oil, and natural gas. The demand for electricity has been increasing with rise in world population. According to the OECD 2010 fact book [29], world electricity consumption increased at an annual rate of 3.8% between 1971 to 2007. As of 2010, natural gas constitutes 20.9% (the second largest after coal and peat which constitute 41.6%) source of world electricity while Oil constitutes 5.6 % making total petroleum contribution to electricity generation 26.4%. In its revised estimates in 2012 [30], natural gas contribution to electricity generation increased to 21.4% while coal/peat reduced to 40.5% and oil also dropped to 5.1%. It therefore appears that the percentage share of natural gas in electricity generation would increase with time. According to the EIA [31], the percentage of coal will drop from 49% in 2010 to 39% by 2035 while that of gas will increase from 24% to 27% within same period. This is due to the need to comply with new environmental regulations (cutting generation from coal), more completion of natural gas and renewable energy plants [32].

Adverse Effect of Petroleum Exploration and Production on the Environment

Environmental issues has become a major source of concern in oil and gas exploration and production because of current exploration and production practices and the use of modern technology and materials (toxic in nature) in the discovery and exploitation of oil reserves. The following subsections elaborate more on the impact of petroleum exploration and production to the environment.

Oil and gas pollution to the environment

According to [33], "Pollution can be defined as contamination of the earth's environment with materials that interfere with health, quality of life, or the natural functioning of ecosystems (living organisms and their physical surroundings)". Based on this definition, oil and gas pollution occurs when any or all of these take place: (i) drilled rock cuttings (contaminated with toxic drilling fluid) is discharged into the seas or lands, (ii) Produced water (contaminated with crude oil or gas) is discharged into the seas, lands, or injected in underground formation, (iii) seismic operations that disturb human and marine lives, (iv) hydrocarbon discharge or spillage in the sea or land in the course of hydrocarbon production and transportation, which can be either accidental or planned discharges, (iv) burning of hydrocarbon oil (in cars, trucks, trains, and planes), and (v) flaring of hydrocarbon gas. Accidental discharges can be as a result of vessels collision with rock or ice, explosion, a blowout of an offshore well, or pipeline leakages. The largest volume of wastes during exploration is drilling muds and cuttings [34] while the largest volume of production waste is produced water. In the US produced water constitutes 98% of total

Source of Wastes	Contaminants	Source of contaminants
Produced water	Dissolved solids (salts and heavy metals), hydrocarbons, gases (H_2S, CO_2), Natural occurring radioactive materials (NORM), Formation solids, chemical additives (e.g. corrosion inhibitors, scale inhibitors, emulsion breakers, dispersants, acids, surfactants, Oxygen scavengers, etc.)	Formation drilled, chemical additives from water flood projects,
Drill wastes (Drill cuttings and drilling fluids)	Deflocculants (such as chromolignosulphonate or lignite), lubricants, caustic (NaOH), corrosion inhibitors, lost circulation materials, heavy metals (barites, chromium, cadmium, mercury and lead),	Chemical additives, base fluids, drilled formations
Associated wastes	Sludges, workover wastes, waste from dehydration and sweetening of natural gas, waste from power plants etc.	Surface equipment, tank bottoms, scrubber, workover (acidizing, fracturing) activities,

Table 1: Sources of Contaminants in Drilling and Production Wastes.

waste volume generated by petroleum industry in the US while drilling wastes account for about 2% [35]. Table 1 summarizes the types of E&P waste, contaminant and their source.

Environmental effect of drilling fluid: Concerns about the environmental effects of drilling fluid arise because of discharge of unspent, spent drill fluid and associated rock cuttings onto the sea beds, and also because of the effect of the toxic components on the health of oil worker. Drilling mud started earlier as a simple mixture of clay and water to form mud slurry. The objectives of the slurry was simply to cool, lubricate drill bits and transport drill cuttings from the bottom of well to the surface. With passage of time, oil wells grew deeper and the required functions of drilled fluids advanced. Earlier simple mud composition did not work well at deep depth and as a result a variety of ingredients were added so that they function efficiently under a variety of bottom hole conditions [34]. Today, drilling fluids are composed of variety of such chemical ingredients or additives (toxic in nature) so that they can perform optimum functions at bottom hole conditions. Examples of such toxic additives include barites, haematites, petroleum hydrocarbon, emulsifiers, lingo-sulphates, and thinners. Oil Based Muds (OBM) have refined petroleum products (usually diesel fuel or a low aromatic mineral oil) as a continuous phase in which water, weighting materials, emulsifiers and other additives are dispersed [36] while water based mud (Water Based Mud, WBM) are basically made of clay, barite (barium sulphate), and water. Water is the continuous phase and constitutes about 90% by volume of the mixture. Although, Water based mud are considered to be the safest of the different types of drilling fluid, however, sometimes they also contain concentration of some of the toxic substances such as diesel oil to add lubrication to the mud. More discussion about toxicity of the petroleum hydrocarbon content is discussed in the next subsection. Water based mud is usually the preferred mud type because of environmental integrity but they are unsuitable for drilling conditions, OBM or Synthetic Based Mud (SBM) are used instead. The rock cuttings generated during drilling are transported from down hole up to the surface where they are either discharged to the sea or reinjected in another subsurface formation. The cuttings are normally smeared with the drilling fluids. Piles of mud cuttings can be found to contain barium (from mud barites), and other toxic chemicals such as Chromium, lead, and zinc [36]. These compounds in drilling fluids affect man in different ways. Drilling fluids Lost in wells during drilling operations can filter into underground aquifer or their disposal at well sites can reach the aquifers or drain down to surface and sea waters [37]. Today, as part of the response of the oil industry to the need to preserve the environmental, cuttings and spent mud are now re-injected into underground rock formation or transported to the shores for proper treatment or recycling before dumping into the seas. More discussion on this is in section on "The Role of the oil industry in Mitigating Oil Pollution".

I. Base fluids: The oil phase is mostly petroleum oil which can have mixtures of different chemical compounds such as Volatile Organic Compounds (VOC), BTEX (Benzene, Toluene, Ethyl benzene, and Xylenes), PCB (Poly chlorinated Biphenyl), PAH (Polycyclic Aromatic Hydrocarbons like Naphthalene), Mercury, Iron, Nickel and Chromium. Though, these hydrocarbon compounds are biodegradable but their presence in any biotic environment threatens the lives there. They are known to be harmful to the central nervous system, carcinogenic, and pose other harmful effects on quality of life. Hence special care and properly trained rig crew members are needed to handle oil based mud [38]. The unspent drill fluid and waste generated must also be properly treated and disposed. The toxicity of aromatic hydrocarbons is much higher than that of straight chain hydrocarbons such as paraffin. LC50 of BETEX is in order of 10 ppm [35].

II. Heavy metals: Also present in the drilling fluids are inorganic substances used as additives to perform technical functions. However, these substances constitute environmental pollutants and as such great source of environmental concerns. Heavy metals like Barites and hematite are inorganic substances often used to give drilling fluids the required density. Barite and hematite are inert solids and are insoluble in water. Although, barites are said to be non-toxic in barite form because of their insolubility in water, weak acid and alcohol [39], however, barium ions are very toxic [40] and are found in piles of drilled cutting contaminated with drilling fluid [36]. Their concentration in a living organism continues to pile up until a fatal consequence is reached. They interfere with actions of enzymes such that the biochemical processes in cells are disturbed or stopped leading to fatal health issues like liver damage to the kidney, liver, reproductive systems, circulatory and nervous systems [40].

III. Inorganic pollutants: Other inorganic pollutants found in the drilling fluids are Potassium, acids and salts. Potassium is a good nutrient for algal growth on the sea. An uncontrollable presence of algae on water surface can hamper penetration of sunlight to sea beds needed for plant photosynthesis and also reduces oxygen level below sea level leading to eutrophication. Most living thing needs only little salts to carry out chemical processes. Too much salt can have negative impact on plants and living organisms [41]. Plants will begin to show signs of drought (yellowish leaves, stunted growth) even with adequate water supply [42]. The effects on organisms include hydration and growth deformation. This is due to Osmosis.

Environmental effect of produced water: Another source of pollution is water produced together with oil from oil wells. The produced water is separated from oil and either discharged to the sea after treatment or circulated back for enhanced oil recovery projects. Typical produced water consists of dissolved salts in the range of 50,000 and 150,000 ppm much more than sea salt concentration. Typical sea water has about 35,000 ppm salt concentration. Injected water for enhanced oil recovery is often treated with various chemicals such as

Chemical type	LC50 (ppm)
Scale inhibitor	1200-12,000
Biocides	0.2-1000
Reverse Emulsion breakers	0.2-15,000
Surfactants cleaners	0.5-429
Corrosion inhibitors	0.2-1000
Emulsion breakers	4-40
Paraffin inhibitors	1.5-44

Table 2: Toxicity of Production Chemicals.

Metals	Concentration (mg/L)
Cadmium	0.027
Chromium	0.186
Copper	0.104
Lead	0.315
Nickel	0.192
Silver	0.063
Zinc	0.17

Table 3: Toxicity of dissolved heavy Metals in produced water.

inhibitors (to inhibit corrosion, scale formation, paraffin) and other useful chemicals of varying toxicity (see Table 2 adapted from Reis [35]) that enhance water flooding projects. Typical produced water also contains dissolved heavy metals in varying concentration (Table 3-adapted from Reis [35]).

Environmental effect of seismic activities: The seas host treasures beneath their sea beds inviting human search for them through sophisticated and noisy exploratory and production activities disturbing to the marine flora and fauna. Example of such offshore and onshore noise pollution is seismic waves used to locate oil and gas deposits. They can harm sea mammals and disorientate whales leading to mass beaching [43,44]. As at 2010, over 320 active offshore rigs exist on different sea waters around the world [45] and the number is likely to increase as energy demand heightens.

Environmental effect of discharged oil or gas into the seas: Most oil exploration, production and transportation activities exist on water making the sea the largest receiving body of oil pollution. The seas are important part of human existence. Half of the world's population lives within 100 miles of the coastline [46]. The sea is our source of food (fishes, oysters, crabs etc.) for domestic consumptions and the food industry; means of transportation of humans and goods; source of water for drinking and factories; sea shores or beaches are also used for relaxation and tourism. Diving birds, millions of sea creatures and wild animals also depend on them for survival. For example, the United States Environmental Protection Agency estimates that US coastal waters provides over 28 million jobs and $54 billion worth of goods and services yearly. Also 180 million people visit the coasts every year [46].

The sea is also a transport route for large oil tankers. Most oil transported around the world travel by sea carried by small, large and ultra large tankers between point of production, refining and point of consumption across Europe, Africa, Asia and Middle East. A 2008 estimate showed that 7.2 million tons of oil were transported daily around the world making a total of 2.6 billion tonnes in 2008 alone compared to 500 thousand and 100 thousand tonnes in 1960 and 1935 respectively [47].

During these activities, hydrocarbon can be discharged in the sea through various ways as mentioned in the section on "Oil and Gas Pollution to the Environment" The seas for example have suffered serious hazards from oil rig explosion, oil tanker accidents (resulting in oil spills) in the past such as: the wrecking of the Torrey canyon in 1967; the Santa Barbara channel platform blow out in 1969; the Gulf of Mexico rig incidents in 1970 and 1971; the grounding of super tanker AMOCO Cadiz in 1978; and the deliberate discharge of a large quantity of oil into the Arabian Gulf in 1991 during operation desert storm [48,49]. Others are in 1989 Exxon Valdez Alaska; 1999 in Erika in France; Prestige in Spain, 2002; and recently the 2010 BP rig blow out in the Gulf of Mexico 2010. Prior to the April 2010 Gulf of Mexico spill, of the billions of oil transported in the US waters, only 0.001 per cent is spilled [44].

The impact of these discharges on the seas cannot be overemphasized. Oil Spills affect marine lives such as marine birds, shell fishes, whales, and many other marine fauna and flora. In most cases, chemical dispersant are used to break up the thick oil slicks into tiny chunks that can easily be scattered and taken away by sea motion. However, the effects of these chemicals are even more harmful and results in killings of fishes. Furthermore, hydrocarbon spills contaminate beaches and shoreline boats [50]. Furthermore, Poly Aromatic Hydrocarbons (PAHs) compounds in oil affect the hearts of pacific herring and Pink Salmon embryos as research into effect of the Exxon Valdez Spill of 1989 revealed. This poses a serious threat to the health of people such as respiratory, nervous system, liver, kidney and blood disorders. The fisheries and food industry could thus be severely hit [51].

The Role of States' Governments in Mitigating Petroleum Hydrocarbon Pollution

Government agencies, environmentalists and wild life and environment conservation voluntary groups have continued to show concern to protect marine water and lives. Stricter environmental regulations are being imposed by government agencies. Many countries have regulations or laws in place that force oil companies involved in hydrocarbon pollution (such as oil spillage) to take full responsibility for spill clean-up and compensation for people who incurred loss or damage as a result of the spill. The laws also make the companies to pay strict fines whose magnitude depends on the sensitivity of the spillage area and the cause of spillage. Such laws have been implemented in the past such as the $3.5 billion fines [52] on Exxon Valdez for the 1989 spill supported by the US oil pollution act 1990 (ITOPF, 2010), $60 million Sea Empress spill in 1996 in the UK [53] and most recently, $20 billion BP oil spill in 2010 in US [54]. There is no doubt that these strict laws have significantly reduced frequency of oil spillage in the seas over the decades despite the increase in seaborne petroleum trade. The number of spills in the 70s is 3 times those in the 80s and 90s and 6 times those in last decade, i.e. 2000-2010 [55]. If however, laws are not enforced, and the government shows no strictness in implementing the laws, then some irresponsible oil companies may take advantage of such situation. Hence, government role which is a key role in promoting safe oil exploration and production is wanting. The best example is Nigeria where some oil companies have continuously eluded the gas re-injection act 99 of 1979 which requires all oil companies to stop flaring by 1984. Oil corporations operating in Nigeria have continued to flare gas even after the dead line and up till today only to pay meagre fines which the companies find cheaper and easier than implementing the law [56]. The government has also continued to extend the deadline from years to years and as at 2010, the national house of assembly was proposing a 2012 deadline to stop gas flaring. Inefficient usage or burning of hydrocarbons or fossil fuels has been identified to be another factor responsible for the increase in adverse environmental effect of petroleum or fossil fuel. Cao et al. [5] in their paper are of the opinion that low prices of fuel or any resource that has adverse environmental impact is responsible for its inefficient use or overuse by members of the community. They therefore suggest that a fairly increase in price of fuel can be a good incentive for efficient usage of fuel. This idea sounds good and in this case then, petroleum price regulatory agencies and states' governments can be instrumental in implementing the idea so as to curtail petroleum users' excesses. State governments can also encourage and promote the use of manual bikes and large transit buses within cities (particularly large cities) so as to cut down sources of greenhouse gases as already began in some countries like China. Finally, in agreement with Guan et al. [57] recommendations, government and policy makers can help by making laws allowing establishment of independent environmental monitoring agencies and giving such agencies the freedom and power

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to monitor environmental degradation resulting from government and industry activities, and the government must be ready to accept and respond to criticism arising from the agencies.

The Role of the oil industry in Mitigating Oil Pollution

Pressure build up from environmental concerns have received concerns of equal magnitude and response from the oil industry. Many innovative ideas, techniques and best practices have been sought with the goal to reduce the adverse effects of the oil exploration and production to acceptable and safe limits. Hence sustainable exploration and production of oil becomes the regular rhythm in oil industry meetings, conferences and workshops.

There has been long time effort to reduce toxicity of drilling fluids by reducing their toxic components and replacing them with non-toxic ones without compromising their optimum performance. Synthetic based mud (SBM) is an example of such innovations. Other innovative muds are newer OBM with organic oils such as vegetable oils as substitutes for diesel, kerosene or fuel oils.

Operators have also embraced newer technologies, strategies and management plans that help them comply with environmental regulations, and reduce waste streams generated during drilling and production processes. The strategies and techniques are discussed below.

Adoption of reduction, re-use, reclaim, recycle and residue (5 R's) policy

The adoption of (5 R's) scheme- waste reduction, re-use, reclaim, recycle and residue (depicted by Figure 1) has been helpful and effective. Highest level of waste reduction is the reduction at the source, followed by re-using the waste components in their original state and then recycling of components for other purposes other than originally utilized [58].

Waste minimization:

I. Reduction of drilling wastes from source: Many other technologies have been deployed and are still under examination that helped reduced volumes of cuttings generated such as slim hole drilling technology, horizontal and multilateral drilling [59]. A well with diameter below 6 inches is generally referred to as slim hole or well. The advantage of such type of well in addition to reduced volume of drill cuttings is reduced cost of drilling a well since lesser volume of drilling mud, and also smaller casings and tubing strings are required. Moreover, less expensive rigs can be used. Drilling many wells from a single platform has also reduced the environmental effects of drilling operations since there is no need to move drilling platform from one location to the other (in other to drill more wells) which normally result into duplicates in marine disturbance and contamination.

II. Reuse/ recycling: Re-injection (or reuse) of produced water for water flooding projects is a good example of reusing. It helped to reduce the volume of produced water discharged into the seas. Water treatment plants are also used on the rig site to process produced water before disposal into seas. Use ofsw produced water as wash water on Rig floor is an example of recycling practice that helps minimize oil rig waste. Also the use of tank bottoms, emulsions, and contaminated soil in road construction is a welcome recycling practice.

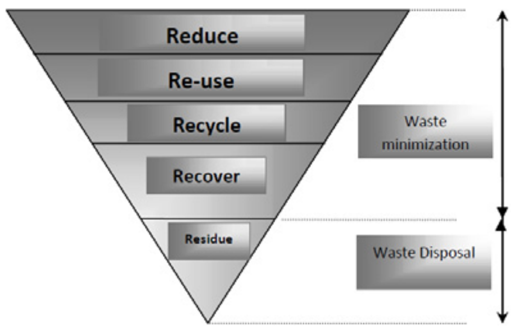

Figure 1: Waste Management 5 R's Policy.

Million barrels per year	1995	1985
Produced water Drill Waste Associated Wastes	17, 910.7 148.7 20.6	21,000 361 12
Total	18, 080	21, 373

Table 4: Comparison of waste generated in 1985 and 1995 in the US.

Produced water disposal method	% produced water disposed by method 1985	% produced water disposed by method 1995
Inject for enhanced oil recovery (EOR) Injected for disposal NPDES Discharge Reuse Other (percolation, evaporation, public treatment works)	62 30 6 0 2	71 21 3 2 3*
Total	100	100

Table 5: Comparison of Produced Water Disposal Methods in 1985 and 1995.

Drill Waste Disposal Method	% Drill Wastes Disposed by Method	
	1985	1995
Evaporate Onsite Hauled Offsite Injection Buried Onsite Discharged to surface Land Spread Reuse for other Drilling Others (Solidification and Incineration)	29 28 13 12 10 7 0 1	47 2 13 21 1 7 7 2
Total	**100%**	**100%**

Table 6: Comparison of Waste Disposal Methods in 1985 and 1995.

Waste disposal:

I. Cuttings re-injection: Cuttings re-injection is a process of injecting drilled cuttings back to an underground depleted reservoir rock for the purpose of safe disposal. This technique has been extensively used to safely discharge solid wastes in Gulf of Mexico, western Canada, North Sea, West Africa, South America, Caspian Sea, Argentina, and Norwegian Sea and wastes injection volumes have increased from thousands of barrels in the 80's to over 20 million barrels in recent times [60-65].

II. Land spreading, land filling, land farming, composting: More effective waste disposal methods such as land spreading, land filling, land farming, composting are today important part of waste management in the oil industry. The volume of waste discharged (residue) is minimized by the practices discussed above. A comparison of the waste generated in the US in 1985 and in 1995 indicated a reduction in drill waste and produced water generated (Tables 4 and 5-adapted from Johnson et al. [66]) because of the increase in the use of these best practices (Table 6- also adapted from [66]).

Environment friendly spillage control

In response to oil spill, more environment friendly methods are being tested different from the historical usage of harmful chemicals like dispersants and adsorbents that contain toxic compounds harmful to aquatic fauna and flora. The ability of agriculture products to effectively sorb oil has been reported in the literature. Notable among them are natural products like Straws [66-68], Wool [67], Sugar Cane baggage [69], Cotton [66,67,70,71], Cotton grass fibre [72], Corn cobs [73]. Their use is however not extensively explored in the oil industry. Straws, cellulosic fibre, milkweed, and cotton fibre significantly sorb more oil than polypropylene (synthetic organic) materials used commercially [68,74,75].

To ensure oil transport safety, each oil company sets its quality, safety and security standards for ship owners to govern: condition and maintenance of tankers; design of tankers; recruitment, training and management of tanker crew members; and planning routes and journey. Specialized inspectors are also recruited to ensure compliance [47] between 1970s and the years 2000-2010 the number of major oil spills (i.e. over 700 tonnes) has decreased eight fold [76]. The amount of oil spilled has decreased significantly from 3.6 million barrels in 1970s to 500, 000 barrels in 1990s [43] and according to energy information agency [77], since 1975 to 2008, offshore drilling has had a 99.9 per cent safety record.

Synergy between Environmentalists, the Governments and the Oil Industry

Despite the improvement in best practices and efforts in sustaining a sustainable oil and gas operations by the oil industry, environmentalists are still not convinced that enough is done and call for alternative source of energy. Alarms from the environmentalists cannot be ignored as their alarms and efforts have over the years resulted in synergies between the industry and the environmentalists and also lead to safer petroleum operations. However, the later must realize that our society is faced with a choice of either protecting the numerous benefits of petroleum crude to man and the society (as discussed in the review) or sacrificing these values to protect the sea integrity and marine lives. A balance between the two, a call for more synergies between both parties, and more investment in research and development of better technology is a way forward and a much better advocacy than a call for alternative energy. The oil industry on the other hand must intensify its efforts in a safer and greener operation particularly with respect to spillage control which has recently bedevilled the industry. Researches should be intensified on how to replace oil based with less or nontoxic, biodegradable oil such as vegetable oil without the mud losing its technical functionalities.

Conclusion

Hydrocarbon has been of historical benefits to man andit is today, a backbone of our technological achievements. However, the environmental consequences of hydrocarbon exploration, production, and usage have been a cause of concern in modern times.A sustainable hydrocarbon operation becomescrucial if we must continue to benefit from hydrocarbon.However, realization of a sustainable hydrocarbon operation is highly challenging because of the need to maintain a balance between advanced technology driven petroleum operations and minimal environmental effects. Important sustainable practices currently adopted by the industry have been identified. Areas needing more attention have also been highlighted.The synergies among environmentalists, oil industries, and governments towards greener petroleum operations can significantly reduce environmental effect of the industry's up- and downstream operations as it tries to meet rising global energy demand. Hence, political leaders, environmental scientists and the oil industry must work hand in hand taking into consideration the adverse effects of petroleum as well as its benefits to the society. Such move will guide all parties in policy and decision making. Moreover, such synergy is a better option while the call to stop oil operations for alternative energy source is a distraction.

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