International Conf. on Water Resources & Arid Environment (2004)

Treatment Techniques of Oil-Contaminated Soil and Water Aquifers

Mohammed M. Amro

Petroleum Engineering Department, King Saud University,
P.O. Box 800, Riyadh 11421, Saudi Arabia, E-mail: mamro@ksu.edu.sa

Abstract

Many operations in the petroleum exploration, production and transportation have the potential to affect the environment in different degrees. Leakages from pipelines, oil wells, underground storage tanks of gas stations, improper disposal of petroleum wastes and stranded oil spills are the major sources of surface and groundwater contamination. The removal of hydrocarbons from contaminated soil and water aquifer is an essential practice because of environmental and health concerns, and in order to avoid further contamination of surface and groundwater. There are different methods applied to remove the hydrocarbons from the soil and water environment including commercially oil and gas technologies such as vertical and horizontal wells.

However, the efficiency of these methods depends on several factors, such as the amount of spilled oil and the penetration depth of the oil into the soil, the type of oil and polluted soil and the age and degree of contamination. Contamination of groundwater resources can result from migration of hydrocarbon through sedimental soil and watercourses, therefore, surface spill or subsurface leakage of petroleum products has been of concern to many industries and governments.

The objectives of this study are to highlight the importance of the oil removal from contaminated sites and to present different approaches and techniques applied to treat the oil-contaminated soil and water aquifers and their applications as well as limitations.

Introduction

Crude oil is a naturally liquid with a complex mixture of organic molecules, mostly hydrocarbon with varied chemical and physical properties. A precise description of the chemical composition of crude oil is not practicable because of its complexity.

More than 50% of crude oil produced in the world comes from the Arabian Gulf area from onshore and offshore wells.

Number of oil spills reported in the Arabian Gulf area was 550 oil spill incidents with a total of 14,000 barrels in the period 1995 to 1999 and 11,000 barrels was spilled in the period 2000 to 2003 [1].

There are different response methods to remove the oil from sea surface and to prevent the oil from contaminating the shoreline, such as mechanical recovery and application of dispersants. However, the purpose of conducting any oil spill response is to minimize the amount of damage in the sea and prevent the oil to come in contact with the shoreline. For that reason, the response must be made extremely rapidly to remove the oil from sea surface as fast as possible [2]. When oil spill reaches and penetrates into the shoreline substrate, the effects of the oil spill will be apparent for long period of time, thus the oil spill that reaches a shore quickly will be more toxic [3]. However, one barrel of crude oil can make one million barrels of water undrinkable [4, 5].

There are different operations in the petroleum industry in the onshore as well as in the offshore that can cause soil pollution and aquifer contamination with petroleum products, such as drilling operations, leakages from wellheads and pipelines and overflows at gathering stations, improper disposal of petroleum wastes and leakage from underground storage tanks.

Aquifer contamination can result from migration of crude oil through the porous media. Oil can migrate through porous media and can adsorb on rock surface. The penetration depth depends on the oil mobility in term of viscosity and on the rock properties in terms of porosity and permeability. Rainfall may help the spreading of hydrocarbon contaminates into the agricultural land and into the groundwater.

Oil pollution associated with groundwater contamination is a growing problem especially in arid countries due to limited water resources.

Remediation Technologies

Crude oil released to land or marine environment is immediately subject to a verity of physical, chemical and biological changes [6, 7]. At sea, crude oil, which is usually lighter than water, will spread over the water surface area. After a short time the thickness of the oil film on the water surface will amount to less than 1 mm. The velocity of propagation of the oil on water surface depends on the type of oil, water temperature, and weathering processes such as; atmospheric temperature, wind and tide. The evaporation of the light components will take place immediately and up to around 40 % of a crude oil may evaporate during a short period of time [8]. This process will lead to an increase in the viscosity of the spilled oil. Another part of the oil will be loaded into the water, since some volatile hydrocarbon components, such as benzene, toluene, and the xylenes have some water solubility in the range of 150-1800 mg/l and are toxic [7]. Thus, the removal of the hydrocarbon from soil and from water surface is an essential practice to prevent groundwater contamination. Any remained portion of crude oil in the ground acts as a permanent source of contamination.

The removal efficiency of crude oil from contaminated sites requires information about the composition of the crude oil and the type of soil. For instance, the heavy crude oil does not readily penetrate porous media and its density may be near that of water. The toxicity of this class of oil is low. However, the cleanup of such type of oil is very difficult. The weathering or evaporation of volatiles may produce solid or tarry oil. The average or medium crude oil is more toxic than the heavy crude oil and has the tendency to penetrate into porous media. The light crude oil (volatile oil) spreads rapidly on solid or water surface and penetrates porous surface. This type of oil is usually highly toxic.

Saudi Arabian crude oil falls between the light and medium crude oil and has a relatively high API gravity [6].

In the last decade, several treatment technologies have been proposed for treating petroleum hydrocarbon contaminated sites. These treatment methods can be performed by two basic processes: *in-situ* and *ex-situ* treatment using different cleaning technologies, such as thermal treatment, biological treatment, chemical extraction and soil washing, and aerated accumulation techniques [5,9,10-13]. However, no universal method can be devised for the removal of oil from contaminated sites.

***In situ* Treatment Methods**

The application of the *in-situ* processes requires that the contamination in the subsoil must not be excavated or scraped. Treatment is carried out in the subsoil (*in-situ*) either by biological means such as oil degradation by microorganisms, or chemical-physical processes such as incineration, air sparging, and soil air suction extraction or through combinations of the two processes, depending on the spectrum of contaminants. To conduct an *in-situ* treatment, available oil and gas drilling technologies and equipment can be applied including vertical and horizontal drilling. However, the *in-situ* techniques are more effective on sandy soils than in soils contain clay.

***In situ* bioremediation**

Bioremediation method has gained acceptance worldwide as an *in situ* treatment of contaminated sites. Bioremediation can be also applied with the help of spreading units in case the contamination occurs at the surface. However, the degradation of oil in the *in-situ* process requires availability of sufficient amount of oxygen. Therefore, the selection of any method of this technique depends also on the penetration depth of the hydrocarbon into the soil and on the nature of the soil if it is groundwater saturated or unsaturated and if the contaminants in the subsoil are biodegradable. Figure 1 shows an example, in which nutrients and oxygen are injected into the contaminated area to stimulate the indigenous bacteria to break down the hydrocarbons as a nutrient source. Feeding oxygen and nutrients into the soil can accelerate the process of clean up. This method is suitable to treat contaminated sites of petrol stations and refinery sites as well as to treat areas, where the water table is close to the surface [6,7,10,11]. Figure 2 shows the growth of microorganisms on soil surface in present of oil and water phases [14].

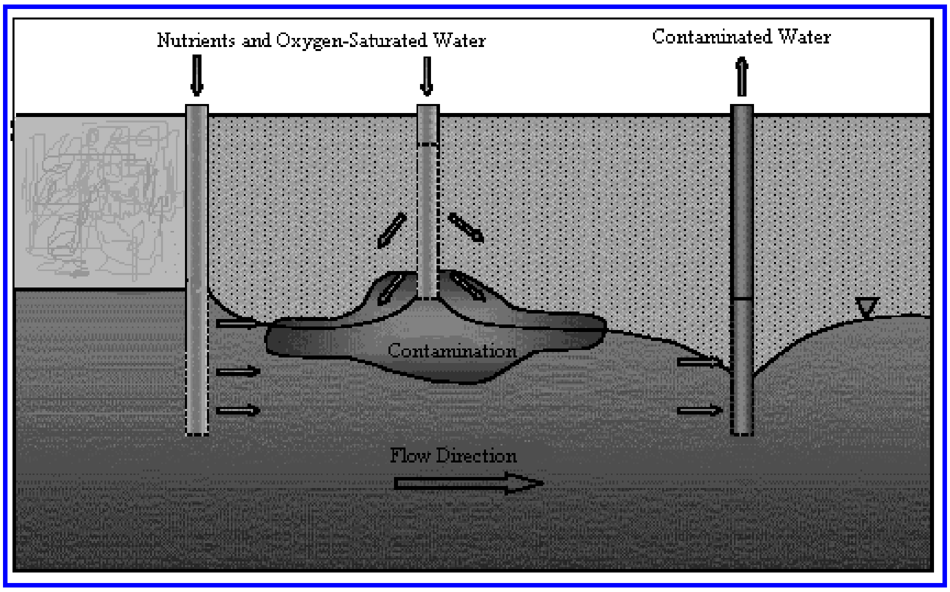

Fig. 1: Stimulation of indigenous bacteria by injection of air and nutrients

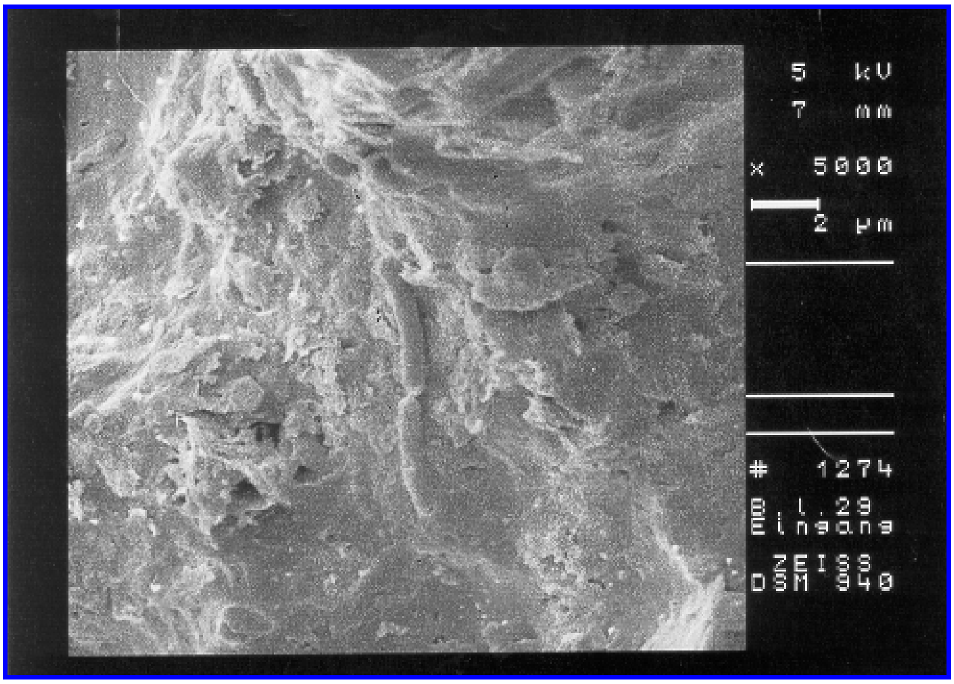

Fig. 2: Screening electronic microscopy (SEM) showing microorganisms on sample surface

Air sparging

Air sparging is referred as soil venting (volatilisation) and can be applied to extract the contaminants from soil as well as from groundwater-saturated soil by mobilization of the volatile compound. Air sparging accelerates also the growth of aerobic bacteria in the contaminated area by oxygen feeding. Figure 3a presents the air injection into the contaminated soil, to mobilize the volatile compounds and to promote the growth of bacteria. However, if oil contamination occurs in the groundwater, air sparging can be also conducted below the water table to extract the volatile compounds to unsaturated zone or to the surface by evacuation or extraction wells. Figure 3b shows schematically the treatment of groundwater-saturated zone by air sparging below the water table using two extraction wells.

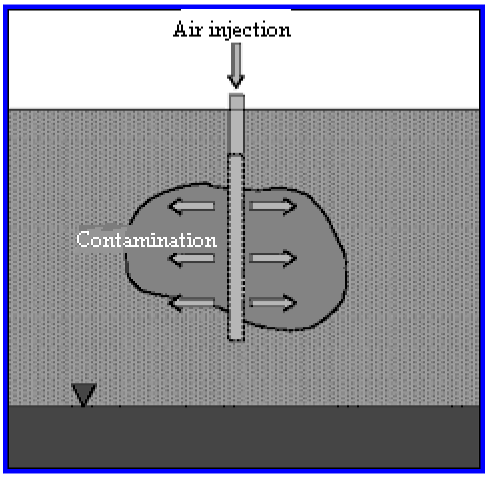

Fig. 3a: Air sparging in contaminated soil

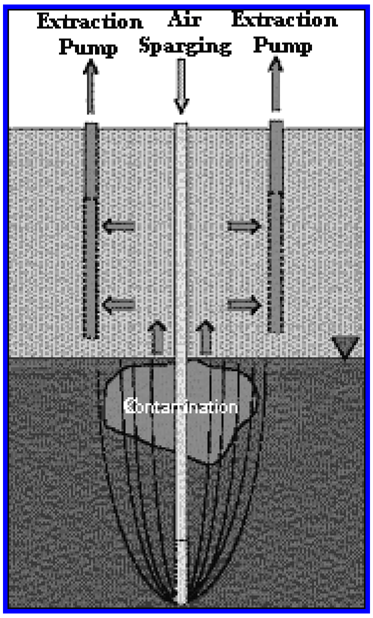

Fig. 3b: Air sparging applied in groundwater contamination

Slurping

In this process, special well completion is required to extract the oil by means of vacuum. This method is preferred, if the oil contamination occurs in boundary area between groundwater-saturated and groundwater-unsaturated soils. This method is also effective in aquifers with low permeability (figure 4).

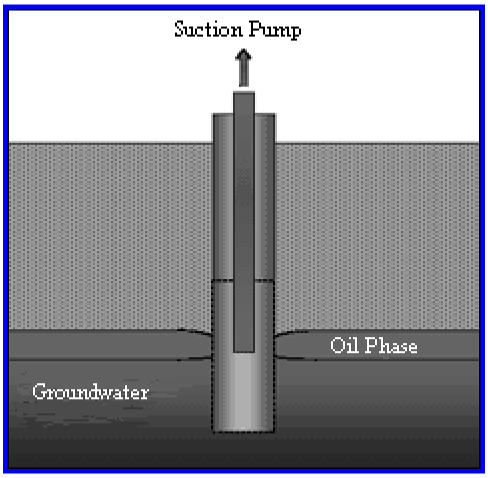

Fig. 4: Sketch of slurping remediation method

Soil air suction

This method is referred to suction extraction of contaminated soil air by means of vacuum to remove the volatile hydrocarbon from contaminated area. This remediation method is more effective if it is accompanied with *in situ* steam injection to enhance the removal of volatile compounds. Figure 5 presents schematically the soil air suction method.

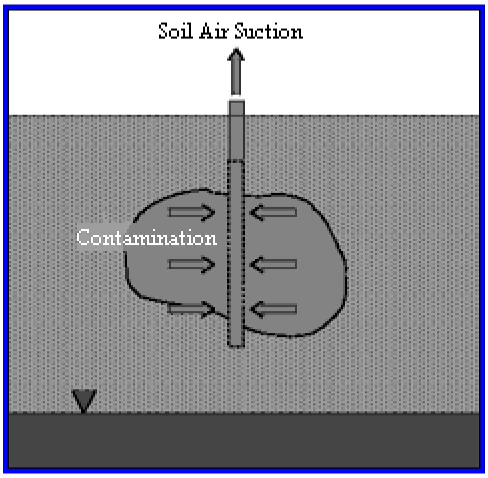

Fig. 5: Soil air suction method

In situ steam injection

In situ steam injection is one of the thermal treatment methods that can be applied to remove the volatile organic compound from contaminated soil. In this method, steam at high temperature and compressed air are injected into the contaminated soil. The temperature of the injected steam should be higher than the boiling points 220 °C of the volatile compounds. With the help of this process, the contaminants can be easily converted to the gaseous or volatile phase. The air, vapor and the released hydrocarbon compounds are removed by extraction wells.

Other methods could be beneficial for the *in situ* remediation process such as, dry soil barrier and horizontal drilling technology.

Dry soil barrier involves an injection of air below the contaminated area to create a dry layer by vaporization of the water in the soil. Thus, no liquid will flow through the dried layer until the critical saturation is reached. In case of oil leakage, the dried soil layer would retain the oil that would move forward to water aquifer and would prevent a contamination with the water source.

Horizontal drilling technology is nowadays widely used in oil and gas drilling and can be applied to enhance the removal affectivity of the most *in situ* remediation methods by the placing of a longer horizontal section into the contaminated area as it can provide greater exposure into the area of interest. This would enhance the removal of contaminated water or to improve the injectivity of air, steam, bacteria or any other chemicals, which can accelerate the treatment of contaminated area. Figure 6 shows schematic of horizontal well that is placed perpendicular to the direction of fluid flow in the contaminated area.

Ex situ Treatment Methods

With the ex-situ processes the contaminated soil must be removed to an off site remediation facility. This method can be applied if the amount of contaminated soil is small or if the oil contamination occurred at the surface in residential areas or industrial estates, in which an in-situ treatment is not possible. Ex-situ treatment of contaminated sites leads in many cases to a greater degree of remediation as compared to in-situ treatment due to controllability of many factors (moisture, temperature, salinity, pH).

The soil can be combusted in incinerating plants or chemical extraction or soil washing using surfactants can be undertaken to remove the hydrocarbon components.

The most important *ex situ* cleaning techniques are thermal methods including steam stripping and combustion, extraction methods, and biological methods.

The chemical extraction involves the usage of different solvents, where the contaminants are disassociated from the soil, dissolved or suspended in the solvents [15,16]. The advantage of this method is its applicability for different types of crude oils and soil, but it is more suitable for soil with low clay content. It can also be performed either *in-situ* or *ex-situ*. In the *ex-situ* process (excavated contaminated soil) the removal efficiency can be better controlled and the cleanup period is relatively short

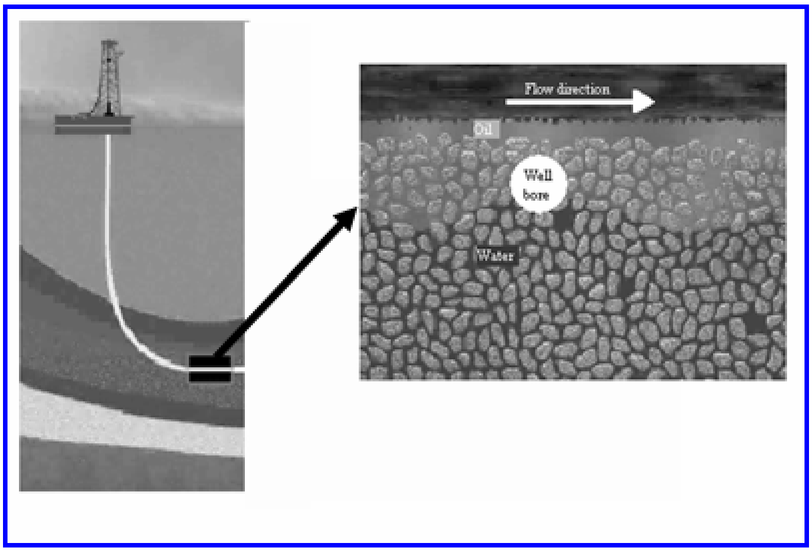

Fig. 6: Horizontal drilling technology applied to enhance remediation process

The appropriate chemical solvents can be selected depending on the compounds in the crude oil. Surfactant can be applied as soil washing as an *ex situ* or *in situ* process.

Conclusion

Some of the hydrocarbon components in crude oil have certain degree of water solubility and are toxic. Therefore, the removal of hydrocarbon from soil and from water surface is an essential practice to prevent contamination of water aquifers.

There are many remediation techniques available to treat the oil-contaminated sites in offshore as well as onshore; however, the removal efficiency of these methods depends on the type of oil, type of soil, weather conditions, penetration depth, sensitivity of the location and the toxicity of the chemicals. As there is no universal method can be generally applied to completely remove the oil from contaminated sites, thus, the preventing oil spills or leakages should be the first concern. However, if oil spills or leakages occur, response should be taken immediately to minimize the potential environmental consequences.

Oil and Gas drilling technologies, such as horizontal drilling can be applied to accelerate the *in situ* remediation process. *Ex situ* treatment methods can be applied if the oil contamination occurred at the surface in residential or industrial areas.

Finally, it is important to install observation wells (shallow wells) to monitor the surface water and contaminates in areas with potential oil leakages, such as underground storage oil tanks especially of petrol stations.

References

Saudi Aramco,. 2001. *Guidelines for the Use of Oil Spill Dispersants in the Gulf Area*, Gulf Area Oil Companies Mutual Aid Organisation (CAOCMAO)**.**

I., Singsaas, M. Reed, P.S. Daling 2000. *SPE Paper 61117,* presented at the *SPE int. conf. on health, safety and the environment in oil and gas exploration and production,* Stavanger, (Norway), 26-28 June.

O.M. Ghazaly, E. Sayed. 2000, *SPE Paper 61464*, presented at the *SPE int. conf. on health, safety and the environment in oil and gas exploration and production*, Stavanger, (Norway), 26-28 June.

Petroleum Review, 1998. “Bacterial bugs beat oil pollution”, September, pp. 31-33.

E.E. Galvez, ***et. al.*****, 2001.** *SPE Paper 69445*, presented at the *SPE Latin American and Caribbean Petroleum Engineering Conf.*, Buenos Aires, Argentina, 25-28 March.

S.E. Whiteside, 1993. *SPE Paper 26399*, presented at the *68th Ann. Conf. and Exhibition of Society of Petroleum Engineers*, Texas, 3-9 October.

K. Aminian, and S. Ameri, 2000. “Evaluation of the petroleum technology-based dry soil barrier”, Journal of Petroleum Science & Engineering, 26, Elsevier Science,**.**

J.N. Hokstad, L.G. Faksness, P.S. Daling, **2000.** *SPE Paper 61468*, presented at *SPE Int. Conf. on Health, Safety & Environment in Oil & Gas Exploration & Production*, Stavanger, Norway, 26-28 June.

H. Neumann-Hensel, B. Onken, W. Ahlf, 1999. *Erdoel, Erdgas, Kohle* 115 (6), (Germany), , 309-310.

R.H. De Pagter, D.J. Whiddon, 1994. *SPE Paper 27173* , presented at the *2nd Int. Conf. on Health, Safety & Environment in Oil & Gas Exploration & Production*, Jakarta, Indonesia, 25-27 January.

M.D. Ratliff, 1994. *SPE Paper 27170*, presented at the *2nd Int. Conf. on Health, Safety & Environment in Oil & Gas Exploration & Production*, Jakarta, Indonesia, 25-27 January,.

K. Yrum, T. Pekdemir, and M Copur, 2004. "Surfactents treatment of crude oil contaminated soils", Journal of Colloid and Interface Science 276, 456-464, Elsevier Science.

J. D. Childs, *et. al.*, 2004. "Improving the extraction of tetrachloroethylene from soil columns using surfactant gradient systems", Journal of Contaminant Hydrology 71, 27-45, Elsevier Science**.**

M. M. Amro, 1994. "Microbial enhanced oil recovery", PhD Thesis, Technical University of Clausthal, Germany.

M. M. Amro, 2004. "Factors affecting chemical remediation of oil contaminated water-wetted soil", Chemical Engineering and Technology, 27, No. 8**.**

M.M. Amro, M.N. Al-Awad, 2002. presented at the *Symposium on Maritime Disaster Management*, KFUPM, Saudi Arabia, 19-23 Jan., 69-79.