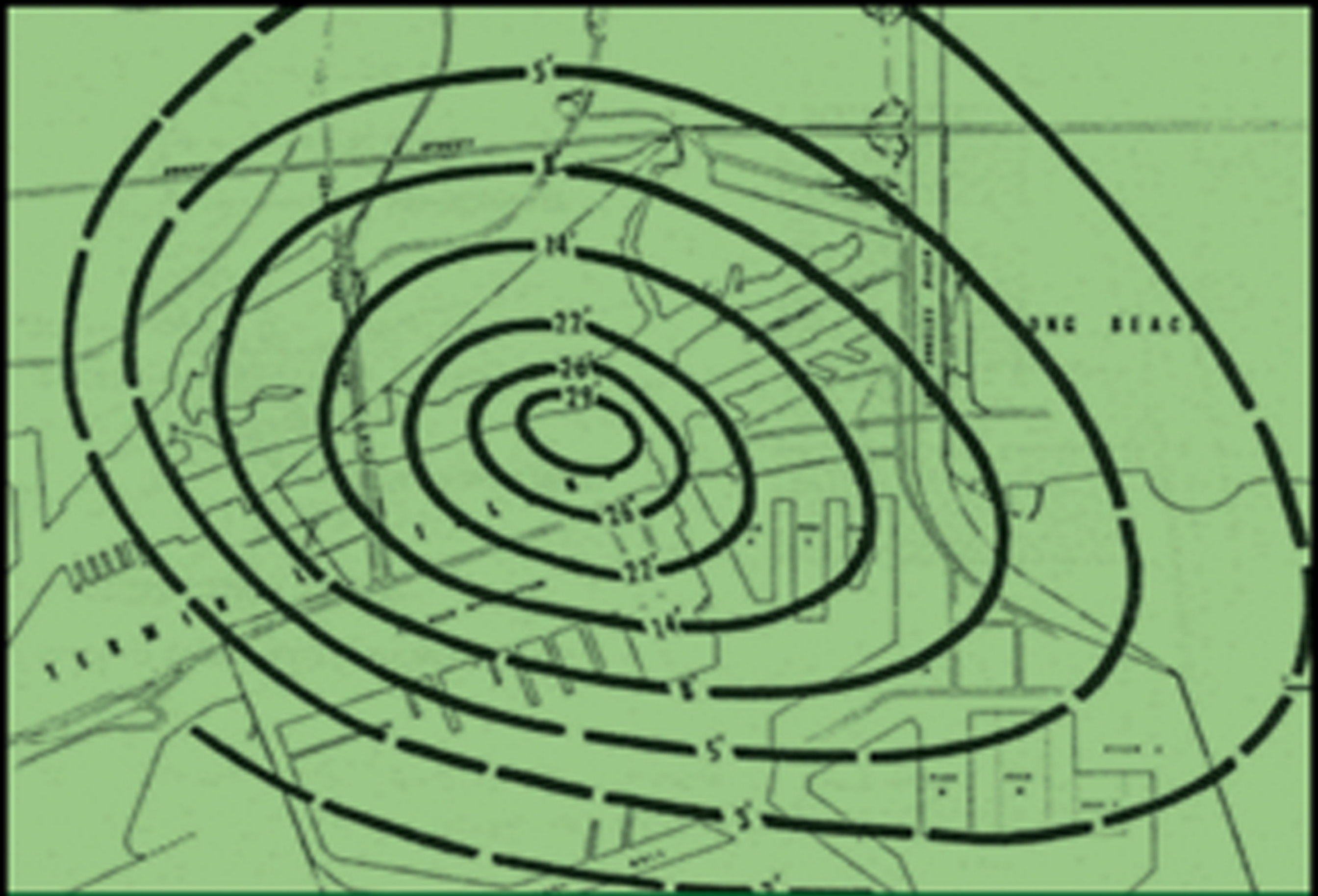

ENVIRONMENTAL ASPECTS OF OIL AND GAS PRODUCTION

John O. Robertson
and George V. Chilingar

Scrivener Publishing

WILEY

Environmental Aspects of Oil and Gas Production

Scrivener Publishing
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Beverly, MA 01915-6106

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Publishing

WILEY

This edition first published 2017 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA
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Library of Congress Cataloging-in-Publication Data
ISBN 978-1-119-11737-7

Cover image: Provided by John O. Roberston and George V. Chilingar
Cover design by Kris Hackerott

Set in size of 11pt and Minion Pro by Exeter Premedia Services Private Ltd., Chennai, India

Printed in

10 9 8 7 6 5 4 3 2 1

This book is dedicated to the custodian of the Two Holy Mosques, His Majesty King ***Salman bin Abdul-Aziz Al Saud*** *in recognition of his support of all branches of Engineering and Sciences in order to improve the well-being of humankind.*

This book is also dedicated to the following:

Professor S, W. Golomb,

hailed as the father of modern digital communications – from deep space communications -- to the internet –- to cell phones. A man known for his recreational and discrete mathematics – and for his support of the University of Southern California.

Dr. John Mork,

president of "The Energy Corporation of America" for his support of the University of Southern California and his outstanding contributions to the Petroleum Industry.

Nina and Henry Chuang,

for their continuous support of graduate students at the University of Southern California and for Dr. Chuang's outstanding contributions to the petroleum Industry.

Contents

Acknowledgments

The present book is the result of the work of many contributors whose research has enabled the writers to build on their work. The authors have attempted to give credit for the many ideas and research of many previous investigators. Without their ideas, this book would have been impossible. Science is an accumulation of ideas that slowly grows over time. Understanding of the present is only accomplished by understanding the past. Tomorrow, additional knowledge will modify our thoughts of today.

The writers owe a special thanks to the publisher, Phil Carmical, and his staff who made everything presented a little – and sometimes at lot – better.

Academician John O. Robertson owes a special thanks to the fellow staff and professors at **ITT-Tech**, National City, CA, for their support. Especial acknowledgment goes to his wife, Karen Marie Robertson, for her support and the hours she spent helping proof this text; and also his son Jerry John Robertson, for his important contributions.

Professor, Academician George V. Chilingar acknowledges the moral support and encouragement given by his wife Yelba Maria Chilingar, and his children Eleanor Elizabeth, Modesto George and Mark Steven.

1

Environmental Concerns

1.1 Introduction

This book is a systematic evaluation of surface and subsurface environmental hazards that can occur due to the production of hydrocarbons and how these problems can be avoided. The importance of such a study is dramatized by recent examples that have occurred within the Los Angeles Basin, CA:

1. ***In the early 1960s***, a portion of the Montebello Oilfield developed in the 1920s was converted to the Montebello Gas Storage Project, under the City of Montebello (a city within Los Angeles County). A minimal amount of work was done on the older wells to prepare the wells for repressurization. In the early 1980s, significant gas seepages were discovered alongside and under homes from several prior abandoned wells. Homes were torn down to allow a drilling rig to reabandon the leaking wellbores which were endangering the community with migrating gas. These home sites were then converted to mini-parks so that future casing leaks could be resealed if necessary. These problems led to the abandonment of the gas storage project in 2000.
2. ***On December 14, 1963***, water burst through the foundation of the earthen dam of the Baldwin Hills Reservoir, CA, a hilltop water storage facility which had been weakened by differential subsidence. This facility was located in a square-mile of metropolitan Los Angeles, CA, consisting of a large number of homes, of which 277 were damaged by moving water and inundated with mud and debris, or destroyed.

Hamilton and Meehan (1971) noted that differential subsidence was a result of fluid withdrawal from the Inglewood Oilfield and the subsequent reinjection of water into the producing formation (for secondary oil recovery and waste water disposal). This resulted in the differential subsidence that was responsible for the ultimate demise of the earthen dam (see Chapter 3).

3. ***On March 24, 1985***, migrating subsurface gas filled the Ross Dress for Less department store in the Fairfax area of Los Angeles. There was an explosion followed by a fire, due to a spark in the basement of the store. Over 23 people were injured and an entire shopping center was destroyed. The area around this center had to be closed down as migrating gas continued to flow into the area, burning for several days through cracks in sidewalks and around the foundations. This site was located directly over a producing oilfield containing many abandoned and improperly completed wells (see Chapter 2).
4. ***On October 23, 2015,*** massive volumes of escaping methane gas from a well (SS-25) in the Aliso Canyon Underground Storage facility reservoir flowed out and spread over the surrounding community of Porter Ranch, Los Angeles County, CA (Curwen, 2016). Engineers suspected that the escaping gas was coming from a hole in the 7-in casing about 500 ft below the surface. Therolf *et al.* (2016) reported the concerns of California Regulators to delay plans to capture and burn the leaking gas that had sickened and displaced thousands of Porter Ranch residents. The Aliso Oilfield was developed in the late 1930s and a portion of this oilfield was converted to a gas storage reservoir. The oilfield had previous fires from leaking wellbores that were put out by Paul "Red" Adair in 1968 and 1975 (Curwen, 2016). The escaping gas flowed into the nearby community for over 3 months, endangering the residents with health, fire and possible explosion hazards. At the time of writing of this book, the well has not been repaired.

Unfortunately, many oilfields located in urban settings similar to that of the Los Angeles Basin, CA, have been managed by catastrophe rather than through preventative management.

The objective of this book is to identify the environmental problems associated with the handling of hydrocarbons and suggest procedures and standards for safer operation of oilfields in urban environments.

This book is intended to help evaluate hydrocarbon production operations by looking at specific environmental problems, such as migrating gas and subsidence. The writers recommend a systems analysis approach that is supported by a monitoring program. Today there are many wells over 50 years of age and some over 100 years. The capability of these older wells to isolate and contain hydrocarbons decreases with time as the cement sheath deteriorates and the well casing corrodes. Chapter 3 describes the breakdown process of the cement in the wellbore with respect to time, resulting in the decrease of the ability for cement to isolate the reservoir fluids. Chapter 6 reviews the corrosion that can result in gas leaking holes in the casing. Thus, increased pressure by water injection, at a later date in the life of an oilfield, can create an environmental hazard in areas that contain wells with weakened cement and corroded steel casing, or inadequately abandoned coreholes and oilwells.

The intent of the writers is also to identify and establish procedures and standards for safer drilling and production of oilfields within the urban community. A necessary adjunct to these procedures is the establishment of a monitoring program that permits detection of environmental problems before occurrence of serious property damage or personal injury. This includes the following:

1. Monitoring of wells for surface seepage of gas.
2. Monitoring for surface subsidence.
3. Recognition of the oilfield geologic characteristics, including fault planes and potential areas and zones for gas migration to the surface.
4. Establishing procedures for the systematic evaluation of the integrity of both producing and abandoned oilwells and coreholes.
5. Monitoring of distribution pipelines and frequent testing for corrosion leaks.

1.2 Evaluation Approach

This evaluation approach requires development of a functional model for each oilfield operation. This approach should identify the basic hydrocarbon drive mechanism that is responsible for the movement of hydrocarbons in the reservoir. Particular attention should be given to faults and the caprock of the reservoirs.

Emphasis should be placed on the individual well production history, i.e., gas/oil ratio, water production and pressure history. Frequent surface soil gas tests should be made for all wells 50 years of age and older.

In gravity drainage pools, oil moves downdip and gas moves updip. As the gas/oil ratio of updip wells increases, these wells are shut-in. Most of the production occurs at practically zero pressure in gravity drainage pools. Freed gas, which accumulates at the top of the structure and is no longer held in solution becomes available for migration. If there is a pathway for its migration toward the surface or if such an avenue is created, it will migrate to adjacent areas of lower pressure working its way to the surface. The freeing of solution gas substantially increases the volume of gas available for migration.

If this migrating gas encounters a fault (natural path) or a wellbore (man-made path), it can then move toward the surface. As also pointed out in Chapter 2, as the wells age the casing corrodes and the cement fractures enlarge. The reason that cement ages and develops fractures with time is hydration of the cement. The cement does not have the same capability to isolate the hydrocarbons that it did when first put in place. This is contrary to a mistaken belief by many, that the risk of gas seepage is reduced over time as the reservoir pressure declines through fluid production. There are many older wells, drilled and completed 50 to 100 years ago within urban settings that leak.

1.3 Gas Migration

The existence of oil and gas seeps in oil-producing regions of the world has been recognized for a long time. For example, Link (1952), then the Chief Geologist of Standard

Oil Company (NJ), wrote a comprehensive article on the significance of oil and gas seeps in oil exploration. In this publication, he documented oil and gas seeps located throughout the world. Although the primary purpose of Link's paper was to identify the importance of surface oil and gas seeps in the exploration and location of oil and gas, it is of no less importance in identifying the hazards associated with the seepage or migration of hydrocarbons to the surface.

Various state agencies have published maps identifying seepage of oil and gas. For example, the Division of Oil and Gas of the State of California has published a detailed listing of seepages located throughout the state of California (Hodgson, 1987).

Many of these seeps are located in or near the immediate vicinity of producing or abandoned oilfields. As pressure drops, gas comes out of solution, allowing the freed gas to migrate toward the surface.

About 90% of all oil and gas seeps in the world are associated with faults, which provide natural pathways for migration of gas. Man-made pathways (wellbores) may be also present.

1.3.1 Paths of Migration for Gas

Fault planes and wellbores can serve as conduits for migration of gas from the oil/gas reservoirs to the surface (see Chapman, 1983; Doligez, 1987). Consensus of opinion, up to the mid-1960s, was that faults generally act as barriers to petroleum or water migration. Obviously faults acted as traps for oil/gas accumulations. The authors believe that, at best, faults are "leaky" barriers and that at a minimal differential pressure of 100–300 psi there is a flow of fluids across the fault planes. Thus, evaluation of fluid flow along (and across) fault planes is an important consideration, especially when monitoring for surface seepage.

The identification of potential paths of migration (fault planes and/or wellbores) within the geologic setting of any oil or gas field is essential in establishing the surface locations where seepage monitoring stations ought to be established. Also of importance are those locations where subsurface fault planes intersect water aquifers. Jones and Drozd (1983) pointed out that there is little doubt that faults can provide permeable avenues for hydrocarbon migration.

It is important to establish sampling intervals for a gas seepage monitoring program. When the flow of fluids is variable, a continuous monitoring system is required to obtain valid results. If only isolated samples are sporadically collected, the result may be a failure to detect a hazardous condition.

Usually, fluid movement along the faults increases their permeability. Following the San Fernando, CA, earthquake of February 9, 1971, it was recognized that seismic activity could not only damage wells, but also "*trigger*" the migration of oil and gas to the surface (Clifton *et al.*, 1971). In conclusion, the mapping of surface faults is essential.

1.3.2 Monitoring of Migrating Gases

Measurement instrumentation and gas sampling procedures need to be considered for the reliable determination of gas seepage hazards. The objectives to be achieved are: (1) gas identification and source determination, (2) seepage pattern characterization, and (3) long-term gas sensing for detection and warning.

That distinction is important because the instrumentation and measurement techniques are different for each of the above functional areas. Natural gas found in an oilfield environment contains primarily methane and small amounts of ethane, propane, isobutene and other higher-molecular-weight hydrocarbons. The mere presence of these higher-MW hydrocarbons establishes that the gas is of a thermo- or petrogenic origin rather than a biogenic, or decomposition origin. Additionally, the relative percentages of the respective higher-MW hydrocarbons are sometimes used to identify the origin of the gas. If the gas has migrated through thousands of feet of geologic strata in reaching the surface (where the sample has been gathered), substantial changes often occur in the relative percentages of the gas constituents due to selective absorption of various hydrocarbons and mixing of the thermogenic gases with biogenic gases that occur near the surface (Khilyuk *et al.*, 2000).

Use of subsurface depth probes and the selection of the depth from which the samples are collected are important in obtaining credible results. In general, the gas sample must have a sufficiently high concentration of natural gas, and must have been collected from a sufficient depth, i.e., below the near-surface clay caprocks, in order to prevent misinterpretation of the results (Khilyuk *et al.*, 2000).

Relatively inexpensive portable or semi-portable gas detectors allow determination of the percent composition in air of explosive gases, such as methane. These gas detectors can be used to efficiently characterize gas seepage patterns, and identify localized concentrations of explosive gases. They can also be utilized in monitoring soil gases near wellbores. Portable gas detectors can also be used for obtaining gas samples for isotopic analysis.

Continuous gas sensing and detection systems are often utilized throughout the basement and/or first floor areas of a building to detect the accumulation of natural gas. In this situation, a low-level alarm system can be established safely below any possible explosion level. Also, exhaust fans can be automatically activated by the system to purge accumulated gas from the building until the gas levels return to a safe level. A central control panel can be used to activate exhaust fans as well as to transmit a signal to an outside, central, 24-hr sentry station. This can be tied into the burglar alarm, fire protection, or other sentry systems to alert central control, especially if higher levels of explosive gas develop (high-level alarm). Although this type of system is practical for installation in new commercial construction or in retrofitting existing commercial structures, it is generally cost prohibitive for use in residential homes and small apartment houses.

Most U.S. states, for example, have established a regulatory agency to oversee the oil and gas production activities within the state, including certain safety aspects. However, none of these agencies have developed a systematic or comprehensive program for dealing with the hazards associated with oil and gas seepage, monitoring older wells (50 years or older) for gas seepage and land subsidence.

Clearly, there is a great need for a nationwide uniform set of procedures and guidelines to be established for the monitoring of dangerous levels of gas seepage and land subsidence, especially in urban areas where the surface dwellers usually have no idea of the hazard that underlies them (e.g., Porter Ranch, CA, gas well blowout).

1.3.3 Identification of Biological vs. Thermogenic Gases

One of the most important aspects of gas migration is proper identification of the source of the gas. Gas fingerprinting allows identification of the gas source (Coleman, 1987).

Identification involves the use of a variety of chemical and isotopic analyses for distinguishing gases from different sources (Coleman *et al.*, 1977, 1990). In Chapter 2, Table 2.1 lists most of the chemical compounds and the percent composition typically found in natural gas that is associated with oil and gas production. For example, the presence of significant quantities of ethane, propane, butane, etc., in a migrating gas indicates that the source of the gas is of thermogenic origin rather than a biological one. Thermogenic gases (petrogenic gases) are formed by thermal decomposition of buried organic material made up of the remains of plants and animals that lived millions of years ago, and buried to depths of many thousands of feet.

In contrast, microbial gases (biogenic gases) are formed by the bacterial decomposition of organic material in the near-surface subsoil. These gases are usually composed of almost pure methane.

Actually, the thermogenic gas samples collected at or near the surface have undergone compositional transformation as a result of migration through thick sections of geologic strata. During migration, the gas composition can become primarily methane as the heavier hydrocarbons are stripped out of the migrating gas, giving the appearance of microbial or biogenic gas. In addition, they could be mixed with the biogenic gases near the surface. (A detailed discussion of this is presented in Chapter 2.)

Schoell *et al.* (1993) studied the mixing of gases. Their isotopic analysis is based upon the following fundamental concepts: Isotopes are different forms of the same element, varying only in the number of neutrons within their nuclei and thus their mass. Carbon, for example, has three naturally occurring isotopes: carbon-12, carbon-13 and carbon-14. The two stable (nonradioactive) isotopes of carbon, carbon-12 and carbon-13, are present in all organic materials and have average abundances of 98.9% and 1.1%, respectively. These two isotopes of carbon undergo the same chemical reactions. Once methane is formed, its carbon isotopic composition is relatively unaffected by most natural processes.

The third naturally occurring isotope of carbon, carbon-14, is a radioactive isotope formed in the upper atmosphere by cosmic rays and has a natural abundance in atmospheric carbon dioxide of about 0.1%. Carbon-14, is the basis for the radiocarbon dating method and is present in all living things.

Hydrocarbon gases which are formed from the decomposition of organic materials have a carbon-14 concentration equivalent to that of the organic material from which they were formed. Biogenic or microbial gases formed from organic material that is less than 50,000 years old contain measurable quantities of carbon-14. Thermogenic (petroleum related) gases, on the other hand, are generally formed from materials that are millions of years old and thus contain no carbon-14. Thus, the presence of carbon-14 can be used to distinguish between thermogenic (petrogenic) and microbial (biogenic) gas.

Hydrogen also has two naturally occurring stable isotopes: (1) protium, more commonly referred to as hydrogen (H) and (2) deuterium (D). The hydrogen isotopic ratio

D/H is used as a fundamental gas distinguishing parameter. The hydrogen isotope analysis of methane can be used to elucidate the microbial pathway by which the gas was formed (Khilyuk *et al.*, 2000).

In summary, the isotopic analysis permits distinguishing between the various sources of gases:

1. **Producing or abandoned oil or gas wells**: If the seepage evaluation is made in the vicinity of a producing or an abandoned well, leakage from the producing wells, or from abandoned wells that have been improperly plugged, can result in near-surface accumulations of gas. Also, near-surface gas accumulations are frequently observed as a result of upward seepage of gas along faults or fissures in the rocks.
2. **Natural gas pipelines**: If the seepage problem is located in an area where buried gas lines exist, leakage from these pipelines can result in subsurface accumulations of gas.
3. **Underground gas storage reservoirs**: In many parts of the country, natural gas is stored underground, under pressure, in abandoned oilfields. If gas leaks from one of these reservoirs (through fractured caprocks, for example), it can migrate sometimes several miles along faults or through aquifers before it appears at the surface, e.g., Hutchinson, KS.
4. **Landfill gas**: Landfills containing decomposing organic material generate a substantial quantity of methane gas. Significant lateral migration of methane (for up to several miles) from landfills has been documented.
5. **Sewer gas**: Gas also originates within a sewer system. Sewage decomposes through microbial action and can result in the production of significant quantities of methane. Sewer gas can migrate over large distances from the sewer and then move along subsurface cracks and fissures.
6. **Coal beds**: Coal beds are also a potential source of natural gas, as coal beds contain coal gas, which is typically high in methane.

The isotopic analysis procedure detailed in Chapter 2 is a necessary element of any successful identification of migrating gas study effort.

1.4 Underground Gas Storage Facilities

The use of underground storage of natural gas is a well-developed technology widely used in many parts of the world. This method of storage is popular as the costs to contain the gas are far less than the cost of constructing surface facilities storing similar volumes of gas. As indicated in examples #1 and #4 at the beginning of the chapter, these gas storage reservoirs can present a major hazard to an urban community if not properly monitored.

The primary concern of the presence of a gas reservoir in an urban area is that most underground storage facilities were once oilfields containing abandoned wells and coreholes (man-made pathways for gas migration). Unfortunately, wells within the project are not always properly evaluated to determine if all wells and coreholes within the project were properly abandoned or capable of handling cycling of gas at higher pressures. The cost of properly reabandoning and recompleting the wells and coreholes within the project to today's standards are high and often not considered as a part of the project. Frequent problems resulting from gas migration and "leaking" gas from these storage facilities are often related to the failure of wells to contain the repressured gas at higher pressures.

Common failures of these storage facilities usually are: (1) existence of faults passing through the reservoir and caprock; (2) improperly abandoned coreholes, e.g., coreholes that were abandoned by filling with drilling fluids and not cement; and (3) active and abandoned wells incapable of handling the cycling of pressure stresses caused by increased/decreased pressure. Tek (1987) has shown that the typical life of a gas storage project is around 50 years; however, many such projects have a much shorter life due to geological and wellbore problems. If the gas storage project is located within an urban area, leaking gas may lead to health, fire and explosion problems. Thus, a much more careful evaluation and continuous monitoring must be made.

In October 1980, a serious gas leak developed in a storage field located in Mont Belvieu, Texas, a suburb of the greater Houston area. This migration of gas was first detected when an explosion ripped through the kitchen of a house when a dishwasher was started. More than 50 families were evacuated from their homes as a result of this gas leak. In this case, gas identification was important. For example, inasmuch as the gases were primarily a mixture of ethane and propane, it was possible to identify the gas coming from a nearby gas storage field. Again, this emphasizes the importance of monitoring gas storage fields on a continuous basis near urban areas.

The evaluation of the migration characteristics of the gas is also of considerable importance to the concerns herein, in that a primary objective is to establish appropriate monitoring procedures for locating seeping gas. For example, in the above instance, after the explosion, high concentrations of the gas were found around the foundations of the homes in the area.

Example No. 4 at the beginning of the chapter illustrates a recent serious problem occurring with the Aliso Canyon Gas Storage Project, which lies within the Los Angeles Basin, CA (Curwen, 2016). Gas containment of an older well broke down, exposing thousands of nearby residents to exposure of natural gas. Although the primary complaint of the residents was the odor of the gas, many residents also complained of health problems, e.g., nausea and bleeding noses. Because this gas storage project is in close contact with hundreds of homes, a primary objective must be the continuous monitoring of gas to insure that any leaking of gas may be quickly detected and stopped. This project demonstrates the unknown danger that gas storage reservoirs can present to a large number of people within an urban area.

In the Fairfax Explosion and then fire (Example No. 3 and discussed further in Chapter 2), after the initial explosion, high concentrations of the gas were found around the foundations of commercial and residential homes in the area. Migrating gas was also detected throughout the sewer lines, which acted as conduits for the gas. Again, no monitoring was made to detect migrating gas which could have alerted the residents of the potential danger.

1.5 Subsidence

Numerous studies have addressed the subject of surface subsidence due to fluid production (e.g., Poland, 1972; Chilingarian and Wolf, 1975, 1976). Classic oilfield subsidence cases are Wilmington, CA; Goose Creek, TX; and Lake Maracaibo, Venezuela. These studies focused primarily on developing procedures to arrest or ameliorate oilfield subsidence. This was largely accomplished by maintaining or replenishing underground pressure usually through water injection (waterflooding) [e.g., California Public Resources Code, Article 5.5. Subsidence, Section 3315(c) and Section 3316.4, Repressuring Operations Defined]. These studies, however, fail to address the increased hazards of displacing large volumes of freed gas in the reservoir resulting from the water injection. Typically, the water injection significantly increases pressures in the reservoir causing the freed gas (under higher pressures) from the reservoir to migrate toward the surface along paths of least resistance. This includes faults, fractures, abandoned wells, and producing and/or idle wells lacking mechanical integrity to hold the increased pressures.

The surface subsidence is usually caused by the production of fluid from the reservoir. This reduces the pore pressure supporting the layers of rock (strata) above the reservoir and increases effective (grain-to-grain) stress. Subsidence causes the formation of new fissures and faults and movement along preexisting faults. As a result of the decrease in pore pressure, some of dissolved (solution) gas is released as free gas, which is then free to migrate toward areas of lower pressure.

The problem of subsidence would be less severe if the settling of the surface were uniform; however, due to the heterogeneity of the rocks, the surface settles differentially, some areas settling greater distances than others. This results in the creation of cracks in roads, sidewalks and paved areas. Foundations of buildings when stressed by differential subsidence fail.

The differential subsidence caused the failure of the earthen Baldwin Hills Dam, Los Angeles, CA (see Chapter 3 and example No. 2 at beginning of this chapter). On December 14, 1963, water burst through the foundation of the earth dam of the Baldwin Hills Reservoir, a hilltop water-storage facility located in metropolitan Los Angeles. The contents of the reservoir, some 250 million gallons of water, emptied within hours onto the urban communities below the dam, damaging or destroying 277 homes (Hamilton and Meehan, 1971). A detailed study of this disaster established that it was caused by fluids being withdrawn from the underlying Inglewood Oilfield. This was aggravated by water injection under high pressure into the highly faulted and subsidence-stressed subsurface, which triggered differential subsidence under the dam. Hamilton and Meehan (1971) concluded that “fault activation was a near-surface manifestation of stress-relief faulting triggered by fluid injection”(see Chapter 3 for additional details).

Monitoring programs related to waste water disposal (where waste water produced from oil production is routinely reinjected into the geological strata) need to be established. Waste water disposal can create special problems of distributing the natural pressure equilibrium existing in the area of water injection, usually causing gas to migrate from the area into lower-pressured areas in the upper geologic strata, increasing the hazard of surface seepage of gas.

Great care is required during acidizing of these disposal wells. Acidizing is frequently used to "*clear out*" or increase the pore space in the geologic strata where the water is being disposed. The acidizing process reduces the pressure requirements for water-disposal. Problems can arise when the acid is injected under high pressure and not only enlarges the pores around the wellbore but also causes fracturing of the rocks. This may create new avenues for the migration of gas.

A common practice in older oilfields is to utilize waterflooding for the purposes of enhancing oil recovery. By initiating a waterflood, one can literally double the quantity of oil produced from a dissolved-gas drive type reservoir. Waterflooding can also be used to decrease subsidence due to production of fluids. This technique, although often effective, frequently ignores the problems associated with gas migration. Crossflow often occurs between subzones, and cracks (fractures) formed during the waterflooding can form additional avenues for gas migration. Additional fractures may be formed by the rebound of the ground if large water-injection pressures are used during waterflooding in the subsiding areas.

Additionally, special precautions must be taken in areas where abandoned wells and older coreholes are located. The mechanical integrity (casing and the cement sheath) of all of the wells penetrating the reservoir must be assured.

Injection of fluids into the ground under high pressure for waste water disposal is also known to trigger faulting. A classic example of this was the Rangely Oilfield, in western Colorado. High pressure water injection was responsible for the 1962–1965 Denver earthquakes at the Rocky Mountain Arsenal and for generation of smaller earthquakes.

Problems of subsidence are compounded in areas that are subject to seismic activity, such as Southern California. Initially, the subsidence sets up stresses as a result of depletion of reservoir pressure (reduction in reservoir pressure due to fluid withdrawal), which can precipitate the movement along pre-existing faults and formation of new faults allowing gas to migrate to the surface.

The identification of the hazards associated with subsidence resulting from fluid withdrawal must be carefully evaluated as part of any prudent oilfield operation. This is best accomplished by establishing a systematic measurement of surface subsidence and gas seepage.

1.6 Emissions of Carbon Dioxide and Methane

It has been assumed by some that the content of carbon in the atmosphere (carbon dioxide and methane) affects global temperature. This concept was first attributed to a Swedish scientist, Syante Arrhenius, in 1898, who stated that global warming was driven by the carbon dioxide content in the atmosphere. It should be noted that he had no factual data to support his idea that methane and carbon dioxide (fossil fuel combustion) had any effect on the global warming of the atmosphere. Unfortunately, this unsupported concept has driven political and some scientific thought for the past few years.

In Chapter 4, a review of the historic cyclic earth temperatures shows a 100,000-year cyclic relationship between temperature versus time for the past 800,000 years. Also