

ENPE 241

Introduction to Petroleum Engineering

Assignment No. 2: Fall 2013
Due Date: 2:00 PM on October 10, 2013 (Thursday)

The Midale carbonate formation in southeast Saskatchewan was discovered in 1953, while water injection was initiated in 1964 for the purpose of implementing pressure maintenance. It is assumed that there were many forms of microscopic plankton and algae living in the oxygenated near-surface waters of the oceans in this area hundreds of million years ago.

- 1) Describe how these living organisms could be converted into oil and/or gas which is accumulated in the Midale reservoir.

Solution:

- **Origin of Oil**

- The only organisms with enough mass to possibly account for so much oil and gas are the many forms of microscopic plankton and algae living in the oxygenated near-surface waters of the oceans.
- Two conditions should be met prior to generation of oil:
 - (1). Wholesale death is necessary to provide sufficient volume for commercial development.
 - (2). Rapid burial of the dying organisms is necessary to prevent bacteria from consuming them.

- **Generation of Oil**

- The only organisms with enough mass to possibly account for so much oil and gas are the many forms of microscopic plankton and algae living in the oxygenated near-surface waters of the oceans. First, wholesale death is necessary to provide sufficient volume for commercial development. Second, rapid burial of the dying organisms is necessary to prevent bacteria from consuming them.
- The virgin of oil in freshly deposited organic material is chemically quite different from the crude oil that is later produced. This transformation, called diagenesis, is caused by the high temperatures encountered by the organics as they are buried deeper and deeper in a sedimentary basin.
- A minimum temperature of about 150°F (65°C) is necessary for oil generation under average sedimentary basin conditions. The up limit temperature for oil generation is 300°F (150°C), under which gas will be generated.
- The deeper the burial, the higher the temperature and the greater the diagenic effects. Organics that were not buried very deeply or for very long yield tarlike heavy oils. The deeper and longer the burial, the greater the maturation of the oil. That is, it becomes progressively lighter oil, which means it has lower viscosity, greater volatility, and is lighter in color as well.

- **Migration of Oil**
 - Oil and gas generated in the source rock can be expelled from the impermeable rock by two methods. As the source rock is buried deeper, increasing pressure compacts the rock, thus decreasing the pore space and squeezing out some of the fluids. Secondly, the generation of a liquid (crude oil) or gas from a solid (organic matter) causes a large increase in volume. This generates stress on the source rock and fractures the rock. The hydrocarbons escape upward through the fractures. After the pressure is released, the fractures close. The vertical and lateral flow of the petroleum from the source rock is called migration.
- **Accumulation/Entrapment**
 - Once the oil and gas migrate into the trap, they separate according to density. To complete the accumulation, the reservoir rock must be overlain by a caprock or seal. A caprock or seal is an impermeable rock layer that does not allow fluids to flow through it. Without a caprock or seal, the oil and gas would leak into the surface. Two common caprocks are shales and salt layers.
- **Conditions of A Petroleum Accumulation**
 - There must be an organic-rich source rock to generate the oil and/or gas.
 - The source rock must have been heated sufficiently to yield its petroleum.
 - There must be a reservoir to contain the expelled hydrocarbons. This reservoir must have porosity, to contain the oil and/or gas, and permeability, to permit fluid flow.
 - The reservoir must be sealed by an impermeable cap rock to prevent the upward escape of petroleum to the earth's surface.
 - Source, reservoir, and seal must be arranged in such a way as to trap the petroleum.

2) Describe the general process of how the Midale carbonate rock is formed.

Solution:

The Midale carbonate rock is a kind of sedimentary rock. The formation of the sedimentary rock is composed of the following four processes: weathering, erosion, deposition, and lithification:

- **Weathering:** Any of the chemical or mechanical processes by which rocks exposed to the weather undergo changes in character and break down.
 - Frost wedging: the single most effective mechanism in the breakdown of mountains. This process begins with ground waters penetrating minute fractures in the rock. The weather then turns cold and freezes the water in the fractures. As the water changes to ice, it expands slightly, but with a force great enough to shatter the rock. Water is essential to the chemical weathering of rocks.
 - Chemical weathering: It is a process by which rocks are decomposed, dissolved, or loosen by chemical processes to form residual materials. Water encountering CO₂ in the atmosphere forms carbonic acid. The limestone rock can be dissolved by contacting with the dilute carbonic acid. This mechanism also can convert impervious limestone rocks into porous and permeable rocks suitable for petroleum reservoirs.

- **Erosion:** General term for the processes by which the surface of the earth is constantly being worn away.
 - The high rainfall on mountain tops, combined with the steep slopes, sends streams coursing downward laden with the rubble from weathering. As the rubble tumbles in the fast-moving waters, it breaks into smaller and smaller pieces. Chunks of rock also impact the streambed, gouging out additional pieces of rocks as the stream cuts its channel deeper. Erosion transports weathered material from higher altitudes and deposits it at lower altitudes.
- **Deposition:** Also known as **sedimentation**, is the geological process whereby material is added to a landform.
 - A stream tumbling down a mountain transports a heavy load of solid material. However, as it approaches the lowlands and its velocity decreases, the larger particles start to drop out of suspension, with progressively smaller particles following.
- **Lithification:** Conversion of unconsolidated sediments into sedimentary rocks by compaction and cementation.
 - As deposition proceeds, earlier sediments are buried deeper and deeper. This increasing overburden squeezes out water, compacting the sediments until individual particles come into contact. After the geometry is fixed by compaction, cementation by calcium carbonate or silica precipitating from circulating waters may glue the rock grains together.

- 3) A cylindrical core plug (length: 12 cm and radius: 3 cm) is drilled out from a core sample that is taken out from a well in the Midale formation, then it is cleaned, dried and weighted to be 430 g. After 100% saturating it with a brine of specific gravity of 1.08, the new weight is 467 g. Calculate the porosity of the rock sample. Is this absolute porosity or effective porosity? Provide your justification.

Solution:

$$V_{bulk} = A \cdot L = \pi r^2 \cdot L = 3.14 \times 3^2 \times 12 = 339.12 \text{ cm}^3$$

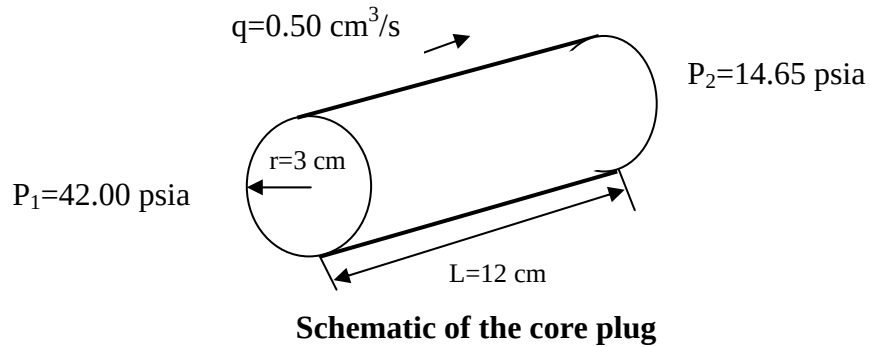
$$V_{pore} = V_{brine} = \frac{m_{brine}}{\rho_{brine}} = \frac{467 - 430}{1.08} = 34.26 \text{ cm}^3$$

$$\phi = \frac{V_{pore}}{V_{bulk}} = \frac{34.26}{339.12} \times 100\% = 10.1\%$$

It is effective porosity. The pore structure of the real core sample is complex. It consists of “isolated” or “noninterconnected” pores or voids dispersed over the medium. Such pores cannot be saturated by brine. In addition, there are several “dead-end” or “blind” pores that are interconnected only from one side. It is difficult to completely saturate these blind pores. Therefore, the measured porosity is effective porosity.

- 4) If the brine is used as flowing fluid with viscosity of $\mu = 1.00 \text{ cp}$ to measure the permeability. During the experiment, pressure at the inlet of the core plug is $p_1 = 42.00 \text{ psia}$, while the outlet is exposed to the atmospheric pressure of $p_2 = 14.65 \text{ psia}$. Calculate the permeability (mD) of the core plug if the flow rate is $q = 0.5 \text{ cm}^3/\text{s}$.

Solution:



According to Darcy's law, we have

$$q = \frac{kA\Delta p}{\mu L} \quad (1)$$

Then this equation can be rewritten as

$$k = \frac{q\mu L}{A\Delta p} \quad (2)$$

$$k = \frac{(0.50 \text{ cm}^3/\text{s})(1.00 \text{ cp})(12.0 \text{ cm})}{\pi \times (3 \text{ cm})^2 (42.00 \text{ psi} - 14.65 \text{ psi})(0.068 \text{ atm}/\text{psi})} = 0.1029 \text{ Darcy} = 102.9 \text{ mD}$$

- 5) The Midale formation is schematically shown in **Figure 1**. Design a process to identify the hydrocarbon and the subsurface structures including folds and faults by using the three geophysical techniques.

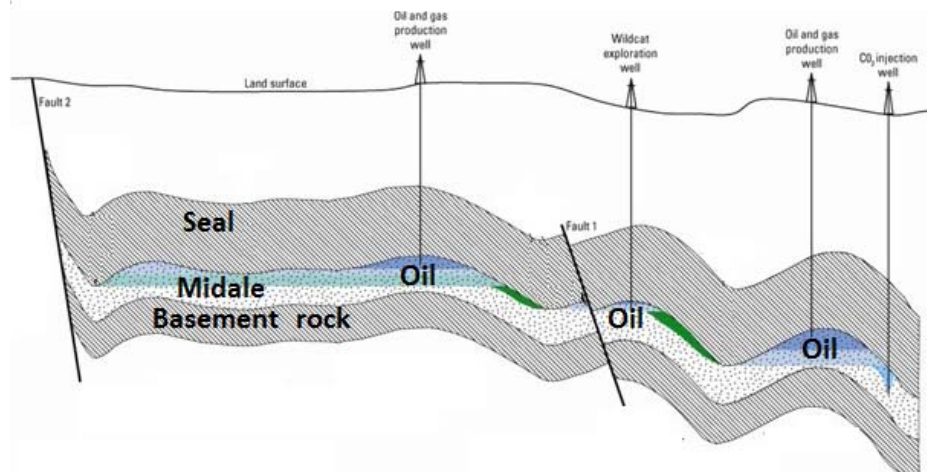


Figure 1 Schematic of Midale formation.

Solution:

1). Gravity survey: Acceleration of the earth's gravity varies at different locations.

(1) Methodology

According to Newton's second law of motion, the acceleration a when a point, mass M_1 , is attracted to another point, mass M_2 , may be expressed as:

$$a = \frac{F}{M_1} = \frac{GM_2}{r^2}$$

where F is gravitational force between two point masses, M_1 and M_2 ; G is the universal gravitational constant, usually taken as $6.670 \times 10^{-11} \text{ m}^3/(\text{kg} \cdot \text{s}^2)$. If M_2 is considered to be the mass of the earth and r its radius, then a is the gravitational acceleration on the earth's surface (about 980.6 cm/s^2).

Unit: gals ($1 \text{ gal} = 1 \text{ cm/s}^2$).

(2) Application

Gravity meter is used to define

- (1). Limits and scale of sedimentary basins
- (2). Internal distribution of structural highs and lows.

2). Magnetic survey: The strength of the earth's magnetic field varies at different locations, depending on the magnetite containing in the basement rock.

(1) Methodology

The earth generates a magnetic field naturally. Lines of force radiate from one magnetic pole and converge to the other. The inclination of the magnetic field varies from vertical at the magnetic poles to horizontal at the magnetic equator. The force between two magnetic poles may be expressed as follows:

$$F = \frac{AM_1M_2}{r^2} \quad (1)$$

where F is force between two magnetic poles; A is a constant, generally unity; M_1 and M_2 are strengths of the respective poles; r is the distance between the two magnetic poles.

Unit: Gammas or oersted. $1 \text{ gamma} = 10^{-5} \text{ oersted}$.

(2) Application

Magnetometer is used to determine elevation of the basement rock.

In combination with the gravity survey or traditional seismic survey, the limits and scale of sedimentary basins as well as the internal distribution of structural highs and lows can be defined.

3). 3D seismic survey:

(1) Methodology

Consider a source of acoustic energy at a point on the earth's surface, the push (P) wave will be penetrated into the formation and reflected back to the surface. By knowing the transmitted time and velocity of the acoustic sound transmitted in the given media (e.g., rock or fluids), the corresponding depth of such formations or fluids will be determined.

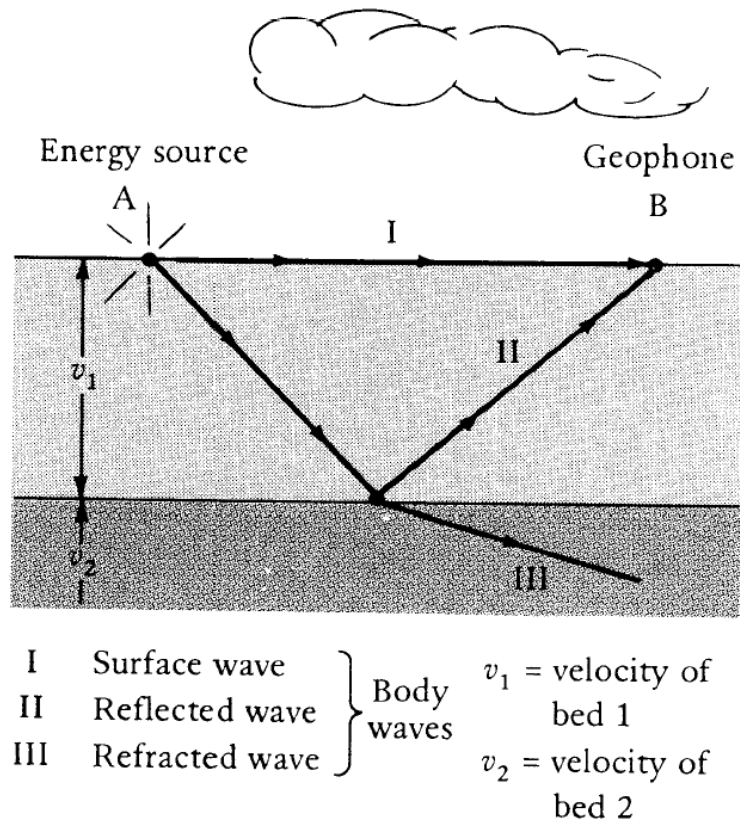


Figure 2 Cross-section illustrating various seismic wave path.

(2) Application

This is used to determine the types of rock, their depths, and whether a trap contains hydrocarbon or not.

3D seismic survey can be used to determine:

- 1) Types of rock
- 2) Their depths, and
- 3) Presence of hydrocarbons.