**COURSE OUTCOMES:**

* Know the nature of petroleum, and describe the oil and gas supply chain. –
* Know the concepts of petroleum geology and basic rock properties, and the mechanisms of the “Petroleum System”.
* Describe drilling operations, equipment, and the general basic drilling techniques and systems.
* Know the composition, functions, and nature of rotary drilling fluids.
* Know the well completion methods, casing strings, tubing and packer.
* Know the general coring methods, core type, equipment and operational procedures. Handling the sampling of core recovery.
* Know well logging basic concept and purpose, types and the miscellaneous logging devices.
* Be able to know what causes the formation damage and well treatment.
* Know the geologic types of reservoirs and their drive mechanisms.
* To be able to estimate the hydrocarbon in place and reserves.
* Differentiate between Petroleum fiscal systems and have an introductory understanding of the Lebanese Petroleum Fiscal System.

**NOTES:**

* Sedimentary rocks are the most common reservoir rocks because they are more porous than igneous and metamorphic rocks. Also, sedimentary rocks form under temperatures and pressures at which hydrocarbons may be preserved.
* Porosity = (total rock volume – rock grain volume) / total rock volume. It is the fraction of the rock’s volume that consists of pores.
* Permeability is a measure of the ease at which a fluid can flow through a rock.
* Petroleum is a mixture of many hydrocarbons (paraffin hydrocarbons, cycloparaffins, aromatic hydrocarbons, polynuclear hydrocarbons + S,N,O,Metals as impurities).
* Fluid Mixture can be vapor, liquid or two-phase (both).
* Compressing gas produces liquid. Expanding liquid produces gas.
* Bubble Point: point at which first bubble of gas appears.
* Dew Point: point at which first drop of liquid appears.
* Fluids (black oil, volatile oil, wet gas, dry gas, gas condensate).
* Pressure decreases as we move through the production system (Reservoir, wellbore, separator).
* Oil comes from:

Liquid: free oil

Vapor: vaporized oil

* Gas comes from:

Liquid: dissolved gas

Vapor: free gas

* Hydrocarbon pathway: EXPLORATION (Explore – Appraise) – DEVELOPMENT (Concept – Design – Execute) – PRODUCTION (Execute – Optimize)
* Exploration: How do we make economically sound decisions about where to drill? How do you predict the presence of petroleum? Where does petroleum come from?
* Appraisal/Delineation: How much oil or gas is there?
* Development: Select and execute optimal development plan/How much could we produce? / How much is feasible to produce?
* Operation and Production Optimization: Field Management, Stimulation and Enhanced oil recovery.
* Upstream: Onshore/offshore rig
* Mid-stream: Transportation
* Downstream: Refineries
* First phase: We invest a lot of money and we pay a lot. Second phase: we start earning money.
* Pre-production (Exploration/Appraisal/Delineation) – Build Up (development) – Plateau (Reservoir management/Production operations/Primary recovery) – Decline (Enhanced recovery/Secondary recovery/Tertiary recovery) – Abandonment.
* Storage facilities are important to control supply and demand and to maintain the quality of the produced hydrocarbons.
* OIL: Production (drilling, extraction and recovery) – Storage – Export – Transport – Refine – Terminal - Sell.
* GAS: Processing Plant – Regasification – Underground Storage – Fractionator – Liquification – Export.
* Theories on the origin of oil and gas:

1. Inorganic Theory (abiogenic)
2. Organic Theory (biogenic)

* Oil and gas are lighter than water. They are pushed upwards onto the surface by the water.
* Reservoir rocks are usually sandstone or limestone.
* A conventional Petroleum System requires four components:

1. Source rock
2. Reservoir rock
3. Trap
4. Seal

* A conventional Petroleum System requires two processes:

1. Petroleum generation
2. Petroleum migration

* Timing between petroleum migration and creation of the reservoir, trap and seal is critical.
* Structural Traps: Anticlines – Faults.
* Stratigraphic Traps: Angular unconformities – Reefs – Pinchout.
* Salt domes
* Organic Matter in Sedimentary rocks is either “Bitumen” (organic constituent of fine-grained sedimentary rocks that is fusible and soluble in common organic solvents) or “Kerogen” (organic constituent of sedimentary rocks that is not soluble in common organic solvents).
* Petroleum System Maturity is the state of the source rock with respect to its ability to generate oil or gas.
* An oil-prone source rock matures to produce heavy 🡺 medium 🡺 light oils.
* At T > 100 degrees C 🡺 dry gas
* The generation of hydrocarbons in source rocks is controlled by the temperature as kerogen transforms from reactive to dead carbon.
* Diagenesis (gas), Catagenesis (oil and gas), Metagenesis (any remaining oil + simpler forms of dry gas). Process varies with the type of kerogen.
* 65 degrees C for oil generation, above 150 degrees C we only have natural gas, above 250 degrees C we get carbon.
* The temperature should not be too low (no generation) or too high (carbonized).
* Trap should form before generation, migration and accumulation. Critical moment could be halfway through generation, migration and accumulation.
* Nonhydrocarbon gases 🡺 Oil 🡺 Wet gas 🡺 Dry gas
* Primary Migration: expulsion of newly generated hydrocarbons from a source rock.
* Secondary Migration: movement of hydrocarbons into reservoir rock in a trap or other area of accumulation.
* When late generation occurs, gas displaces oil and the displaced oil accumulates in one area.
* Sandstones have high permeability thus allow fluid flow easily.
* Migrating hydrocarbons can either find their way to the surface and create seeps or become trapped in porous reservoir rock. Because of migration, oil and gas end up accumulating far from their source.
* Source System 🡺 Carrier System 🡺 Reservoir System
* Trap must be available before or during migration.
* Thermal maturation of kerogen depends linearly on time and exponentially on temperature.
* Source rock: continuously expels petroleum when active (could be active, inactive or spent). Should be fine-grained and rich with organic matter. Amount of HC released depends on the rock volume and thermal maturity.
* Reservoir rock: permits the migration and accumulation of petroleum under adequate trap conditions.
* Seal/Trap: can withstand capillary pressure and prevents the further migration of hydrocarbons in the subsurface.
* Overburden rock: overlies the source rock and contributes to its thermal maturation.
* High Hydrogen/Carbon ratio 🡺 Oil / Low Hydrogen/Carbon ratio 🡺 Gas
* The amount of HC generated depends on the kerogen type and the heating rate.
* Biodegradation (biogenic/abiogenic) affects crude oil quality. Occurs at T < 80 degrees C at oil-water contacts.
* Types of rock: Igneous (Molten materials; Crystallization) – Sedimentary (Weathering and erosion of rocks at the surface; Sedimentation, Burial and lithification) – Metamorphic (Rocks under high T and P; Recrystallization due to heat, pressure or chemically active fluids).
* Sedimentary rocks are the most important rocks for the oil industry. They can be clastic (from erosion) or chemical (through chemical or biological processes).
* Clastic Rocks: Sand – Silt – Clay. The difference lies in the size of the grain.
* Depositional Environments can be Marine (sea) / Lake / Continental / Shallow or deep water.
* Grains from carbonate rocks are deposited close to where they formed. On the other hand, grains from sand and silt travel far away from their source before they deposit.
* Porosity of Carbonate Rocks: Connected – Vugs – Fracture Porosity
* Oil can adhere to the surface of carbonate rocks because of wettability (thus harder to produce).
* Most carbonate reservoirs are believed to have mixed wettability or be oil-wet. Sandstone are only water-wet.
* Carbonates exhibit highly variant properties (porosity, permeability, flow mechanisms) within small sections of the reservoir. This makes them difficult to characterize.
* Anticlines, faults and salt domes give evidence of the presence of hydrocarbons.
* Wellbore data: Information gathered from wells that have been already drilled.
* Cuttings: emerge as the well is drilled. These can be analyzed to obtain important information.
* Logging: lower a tool down into the well to take electrical and other kinds of measurements (porosity, permeability and absence/presence of hydrocarbons and quantity).
* Gravity Method: sense the difference in gravitational pull due to change in density of the rocks.
* Magnetic Method: detects changes in magnetic field.
* Seismic Method: generates an acoustic pulse at the surface using a source such as a vibrator truck, explosives or an air gun (in marine seismic).
* Basin: Large geographic area that may contain multiple hydrocarbon systems.
* Play: Regionally – extensive unit with a single hydrocarbon system. Defined by geologic boundaries.
* Effective porosity: connected porosity that can contribute to production.
* Wettability: Tendency of a fluid to spread on or to adhere to a solid surface in the presence of other immiscible fluids.
* Surface Tension: Interaction between hydrocarbons and water depends on the surface tension between them. It is the film that separates two immiscible fluids.
* Capillary pressure is a function of surface tension and the radius of the pore throats in the rock.
* Capillary pressure/surface tension forces increase as:

1. The grains get smaller
2. The pore network is more tortuous
3. The more clay coats the grains
4. All these factors increase the surface area of the rock.
5. Swirr increases and the reservoir quality gets worse.

* For the same porosity, we can have various permutabilities.
* Rotary drilling is the method of drilling that uses a sharp, rotating drill bit to dig down through the Earth’s crust.
* The spinning of the drill bit allows the penetration of even the hardest rock.
* Drilling System Components:

1. Drilling Rig (machine used to drill)
2. Drill String (mechanical linkage connecting the drill bit to the rotary drive system).

It transmits and supports axial/torsional loads and hydraulics to clean the hole and cool the bit.

1. Drill pipe
2. Bottom Hole Assembly (BHA) (Provides the force for the drill bit to break through the rocks).
3. Drill Bit (It is the part that allows drilling).
4. Drilling Fluid
5. Well Head (surface foundation on which the well is built up during the drilling operations).

* Drilling Rig Sub-Systems:

1. Power generation system (to generate power for rig operation)
2. Hoisting system (large pulley to run and pull drilling equipment into and out of the well).
3. Well control system (Prevents a blowout).
4. Rotary system (Essential for rotary drilling; rotates drill string and drill bit at the bottom of the borehole).
5. Circulating system (To control the flow of drilling fluids).

* Offshore drilling rigs: Fixed Platform – Jack-up Rig – Compliant Tower – Floating Production System – Tension-leg Platform – Spar Platform.
* The Well Design describes the final state of the well.
* The drilling program advises how to achieve the well design safely and cost effectively.
* Directional Drilling: Procedure of deviating a wellbore to reach a specific point in the subsurface.
* Inclination: Angle between the axis of the well and a vertical line passing through the said point.
* Azimuth: Angle between the axis of the well and the North/South axis of a Geographic coordinates system.
* Measured depth: real length of the well drilled. No projections needed.
* True Vertical Depth (TVD): vertical distance from the bottom of the well to the surface. For a vertical well, TVD = MD.
* Well Types: Wildcat – Exploration – Delineation – Production.
* We set casing to:

1. Consolidate the hole already drilled (protect sensitive formations, water sources…).
2. Provide pressure control integrity to drill ahead (can safely handle a kick).

* Cement is placed in the annular gap between the borehole and the casing. The role of cement is:

1. Provide total zonal isolation in the annulus.
2. Provide casing protection
3. Support the borehole
4. Provide casing support
5. Support axial load of casing strings to be run later

* Conductor casing 🡺 Surface casing 🡺Wellhead housing 🡺 BOP 🡺 Intermediate casing 🡺 Production casing 🡺 Evaluation (if economical, continue) 🡺 Perforation
* Drilling Fluid Functions:

1. Remove cuttings from the well
2. Control formation pressures
3. Suspend and release cuttings
4. Seal permeable formations
5. Maintain wellbore stability
6. Minimize formation damage
7. Cool, lubricate and support the bit and drilling assembly.
8. Ensure adequate formation evaluation
9. Minimize impact on the environment

* Pore Pressure (PP): Pressure acting on the fluids in the pore spaces of the rock. It is related to fluid salinity.
* Normal Pore Pressure is equal to the hydrostatic pressure of a column of formation fluid extending from the surface to the subsurface formation.
* Overburden Pressure: is the pressure exerted by the total weight of overlying formations above the point of interest. It is a function of: Matrix density – Porosity – Connate fluids density.
* Fracture Gradient (FG): Pressure at which formation break down occurs. Least principle stress must be overcome to initiate fracture (fracture can be horizontal or vertical).
* How to deal with risk:

1. Identify risks.
2. Assess exposure.
3. Record risk register
4. Reduce exposure
5. Manage remaining risk

* Hydrocarbon volume depends on:

1. Thickness
2. Porosity
3. Hydrocarbon saturation

* Hydrocarbon producibility depends on:

1. Thickness
2. Permeability

* Formation Evaluation is the analysis of formation and fluid properties through examination of fluid cuttings or using tools (integrated into the Bottom Hole Assembly while drilling, or conveyed on wireline or drill pipe after the borehole has been drilled).
* Formation evaluation guides wellsite decisions (reservoir development and production planning…).
* Petrophysical Data and Sources:

1. Mud Logs
2. Cores
3. Open Hole Logs
4. Cased Hole Logs
5. Borehole seismic

* Fluids: contacts and saturation
* Rock: Porosity, permeability and lithology.
* Open Hole Logs: measure rock properties

1. Mud Logging
2. Wireline Logging
3. Logging While Drilling (LWD)

* Cased Hole Logs: measure properties of producing fluids, casing and formation

1. Production Logs
2. Cement Evaluation
3. Formation Evaluation (Neutron, Sonic, etc.…).

* Wireline logs are made by lowering a tool to the deepest point in the well and then recording data while raising the tool to the surface. (ROCK PROPERTIES)
* Mud Logging: Fluid is continuously circulated down the inside of the drill pipe, through the bottom of the drill bit and back to the annular space. The drilling mud carries broken rock fragments (cuttings) to the surface. These rocks are analyzed to provide information about lithology, texture and presence of HCs. The air above th drill mud is analyzed for its content. (ROCK PROPERTIES)
* Core Sample: Formation geological sample. This sample is obtained either via drill string or wireline.

1. Drill string coring is done using special drill bits that can be joined in multiples (for increased core recovery). The outer barrel rotates pushing the rocks into the inner barrel which remains stationary.
2. Wireline logging coring uses a tool that is pushed down into the formation and this tool acquires a representative sample of the formation fluid. This sample is analyzed to obtain data.

* Core Analysis gives information related to Geology – Petrophysics – Reservoir Engineering – Production Engineering.
* Open Hole Logging: Provides the most important data for well evaluation. It consists of lowering a set of sensors into the well to record formation properties as a function of depth.

1. Wireline Logging (after the well is drilled)
2. Logging While Drilling (LWD) (while the well is being drilled)

* In highly – deviated and horizontal wells, tools for logging cannot be lowered through the well by their own gravity. Instead, the tools are attached to the end of the drill pipe which is lowered through the borehole (Tough Logging Conditions; TLC).
* Logging While Drilling (LWD) is common in deviated, extended reach and horizontal wells.
* Depth of investigation of a log is the distance away from the borehole that a logging tool can measure.
* Resolution of a logging tool is defined by its ability to distinguish thin beds.
* Hydrostatic pressure of the mud column is greater than the pore pressure of the formation drilled through.
* The drilling mud invades the formation pores and expels water/formation fluids. The invasion process stops when enough solids accumulate at the borehole walls and create an impermeable barrier.
* Invaded Zone 🡺 (further away) 🡺 Transition Zone 🡺 (further away) Uninvaded Zone
* Transition Zone mostly contains formation water and usually drilling mud doesn’t reach that zone a lot.
* Borehole Seismic: acquired by firing the seismic source on the surface and recording the seismic signal with a detector positioned downhole within the wireline tool. The data can be acquired in open hole or cased hole (it is possible to obtain the data while the well is being drilled). Could be a simple checkShot survey or a complex 3D-VSP acquisition.
* Lithology Identification: (porosity and other parameters)

1. Gamma Ray: Reflects the clay or shale content, causing a high GR log reading. Sandstone and limestone have a very low level of radioactivity and thus a low GR log reading.
2. Spontaneous Potential: Measuring difference between the electrical potential of a movable electrode in the borehole and the electrical potential of a fixed surface electrode. This difference is due to the difference in salinity between the mud filtrate and the formation water. The SP log cannot be recorded when a well is drilled using oil-based mud. Shale zones 🡺 Straight line / Sand zones 🡺 Not straight line. SP log deflects to left in sand and to the right in shale

* Check-Shot survey is used to determine the depth to time relationship.
* Surface seismic data suffers due to low resolution.
* Vertical Seismic Profile (VSP) is used to improve the resolution of surface seismic.
* Porosity:

1. Sonic: measures formation slowness. Can be converted to porosity if matrix and fluid slowness are known. Consists of a sound pulse and a receiver. These waves are transformed to graphs as they impinge on the borehole wall. Records vs depth of the time needed for the sound wave to travel 1ft of the formation. (shales cause computed porosity to read high due to pressure of bound water / Oil and water have little effect / gas causes the interval transit time to read too high).
2. Density: Measures bulk density. Can be converted to porosity if matrix and fluid densities are known. Consists of chemical gamma ray emitter and detector. Measures gamma rays and their energy levels at a given distance from the source (this gives the electron density of the formation). The electron density is directly related to the true bulk density and results in a formation bulk density log. Used in sand containing shale since shale has little effect. (Shale has little effect / Residual oil causes the bulk density to read lower and gas causes it to read much lower).
3. Neutron: Measures hydrogen index. Output is apparent porosity unit. Consists of chemical or electronic high energy neutron emitter and neutron detector. Some of the thermal neutrons get absorbed by the atoms in the formation while other reach the detector. (Shale causes porosity to read too high / residual oil causes porosity to read slightly lower / gas causes porosity to read much lower).

* Archie’s experiment: Equation allows to estimate water saturation using the water resistivity, cube resistivity and porosity.

1. When the cube is filled with water (no rock), porosity is 100% (and water saturation is 100%) and cube resistivity = water resistivity.
2. If sand is added to the cube so that porosity becomes 70%, water saturation remains 100% since there are no hydrocarbons. Resistivity of the cube becomes higher than that of the water because the water has been replaced by rock.
3. Adding oil does not change the porosity. The water saturation decreases to 50% since half of the pore space is occupied by oil. (Water saturation is how much of the pore space is occupied by water). Resistivity of the cube in this case is higher than the resistivity in (ii) because half of the water was replaced with oil.
4. Adding salt to increase the salinity changes the water resistivity and porosity remains the same. Resistivity of the cube is proportional to the resistivity of the water.

* Saturation measurements must be made in the virgin zone since the invasion process of the drilling mud changes the fluid saturation in the invaded zone.
* The main tools for determining hydrocarbon saturation in the open hole are the Resistivity tools and they are designed such that they can read deep in the formation (Resistivity Log).
* The gas causes the porosity obtained from density log to increase and porosity from neutron log to decrease, causing a high density-neutron separation. However, shales in the formation can mask this separation.
* Quick-Look/Evaluation: Identify Reservoir Interval 🡺 Identify Hydrocarbon Zones 🡺 Differentiate Oil and Gas 🡺 Evaluate porosity in water, oil and gas zones 🡺 calculate water resistivity from water zone 🡺 calculate water saturation using the water resistivity in the water zone.
* Cased hole logging: lowering a set of sensors or a perforating gun after the well has been cased (Applications: cement evaluation - perforating – reservoir monitoring – production logging – corrosion evaluation).

1. Cement evaluation: acoustic sensors are lowered into the well. This signal travels through the borehole and cement and goes back to the receiver. The elapsed time is recorded.
2. Reservoir monitoring: determination of petrophysical parameters after initial conditions have been disturbed by production. This is a dynamic process. We monitor the movement of fluid interfaces and saturation. Pulsed neutron tools are used.
3. Production logging: provides information about the behavior of fluids in the well during production or injection. The objective is to cross check or fine tune the results of reservoir modeling. Sensors are used.

* Drill stem testing: To determine productive capacity, pressure, permeability or extent of a hydrocarbon reservoir.

1. Isolate the zone of interest with temporary packers
2. One or more valves are opened to produce the reservoir fluids through the drill pipe and allow the well to flow for a period.
3. Operator kills the well, closes the valves. Removes the packers and trips the tools out of the hole.

* Wireline Formation Testing: formation pressure, formation fluid samples, permeability, productivity assessment, in-situ and minifrac testing. The wireline formation tester can obtain vertical pressure profiles which are used to define fluid type within the reservoir and locate fluid contacts in thick and relatively high permeability virgin zones.

1. The wireline formation tester carries fluid samples to be analyzed on the surface (site or laboratories).
2. Drilling mud contamination could pose challenges.
3. The wireline formation tester creates a pressure pulse in the formation by withdrawing 20 cc of fluid from the formation via the probe module. The pressure pulse is analyzed to obtain a value of the mobility of the fluid in the formation.

* Lithology: grain size, texture, color of rocks.
* The pressure continuously drops through the production system (Drainage boundary, Wellbore, Wellhead & choke, separator, stock tank).
* Overburden Pressure (OP): total pressure at any depth resulting from the combined weight of the formation rock and fluids, whether water, oil or gas (rock pressure RP + fluid pressure FP).
* Over-pressurized pore pressure: any pore pressure greater than the hydrostatic pressure of the formation water occupying the pore space.
* Under-pressurized pore pressure: any pore pressure less than the pore fluid hydrostatic pressure.
* The heat flow outwards through the earth’s crust generates a geothermal gradient.
* In reservoir conditions: hydrocarbon vapor and hydrocarbon liquid. In surface conditions: oil and gas.
* Specific gravity of a gas: ratio of density of that gas to the density of dry air at the same temperature and pressure.
* Bubble point pressure is the pressure at which the first bubble of gas appears in a single-phase oil.
* Dew point pressure is the pressure at which the first drop of liquid appears in a single-phase gas.
* Oil and gas volume formation factor: measures how much saturated oil shrinks when it reaches the surface (Voil @ reservoir / Voil @ STB or Vgas @ reservoir / Voil @ STB).
* Gas-Oil Ratio (GOR): Volume of tank Gas / Volume of Stock Tank Oil (Standard Conditions).
* Hydrocarbon Reservoir Fluid Types: Black Oil – Volatile Oil – Gas Condensate – Wet Gas – Dry Gas.
* It’s necessary to have a positive pressure differential acting from the wellbore into the formation to prevent inflow of the reservoir fluids. Particles suspended in the mud partially block the pore spaces, reducing the permeability and creating a damaged zone near the wellbore.
* Effective permeability: permeability to a fluid (when the rock pore spaces contain more than one fluid).
* Relative permeability: ratio of effective permeability to a fluid at a given saturation to a base permeability (effective permeability to a fluid at a 100% saturation).
* Relative permeability to a phase depends on:

1. Saturation
2. Wettability
3. Pore size distribution

* Irreducible water saturation – critical water saturation – residual oil saturation to water – residual oil saturation to gas – critical gas saturation.
* Irreducible water saturation can be expressed in terms of rock quality which in turn is a function of porosity and permeability.
* Imbibition: wetting phase displacing non-wetting phase (water injection).
* Drainage: Non-wetting phase displaces wetting phase (migration of a hydrocarbon into the reservoir during a filling process).
* Capillary pressure: force manifested by sticking/wetting phenomenon (sticking of wetting phase on rocks).
* Capillary pressure measurement:

1. Mercury injection (Air/Mercury)
2. Porous Plate (Air/Brine or Oil/Brine)
3. Centrifuge (Oil/Brine)

* Drive mechanism: source of energy for driving the reservoir fluids out of the wellbore (not necessarily the energy needed to lift the fluids onto the surface).

1. Depletion Drive Reservoir (reservoir is not in contact with a large aquifer; enclosed by porous media and all energy comes from the reservoir itself)
2. Solution Gas Drive (expanding gas provides the force to drive the oil)
3. Gas Cap Drive (there is a gas cap at the top of the reservoir so the bottom hole pressure is close to the bubble point pressure, so solution gas drive occurs).
4. Water Drive Reservoir
5. Compaction Drive Reservoir
6. Pressure Maintenance
7. Water Injection
8. Gas Injection

* Recovery Mechanisms:

1. Primary: relies on the reservoir’s energy
2. Secondary: water injection/immiscible gas injection
3. Tertiary: miscible gas injection/chemical injection/steam injection.

* Reservoir Analysis:

1. Material Balance (amount left = amount initial - amount removed).
2. Decline Curve Analysis

* A Well Test is a tool for reservoir characterization and evaluation.

1. Investigates a much larger volume of the reservoir than cores or logs
2. Provides estimates of permeability under in-situ conditions.
3. Provides estimates of near-wellbore conditions.
4. Provides estimates of distances to boundaries.

* Types of Well Tests:

1. Drawdown Test: produce a well at constant rate and measure the pressure response
2. Buildup Test: shut in a well that has been producing and measure the pressure response
3. Injection Test: inject fluid into a well at constant rate and measure the pressure response.
4. Injection-falloff Test: shut in an injection well and measure the pressure response.
5. Interference test: produce a well at constant rate and measure the pressure response at one or more offset wells.
6. Pulse Test: Alternately produce and shut in one well and measure the pressure response at one or more offset wells.

* Well completion: hardware used to optimize hydrocarbon production from the well.

This may be a simple packer, a system of mechanical filtering outside of the perforated pipe or a fully automated measurement and control system that optimizes reservoir economics without human intervention.

* Well completion must be consistent with

1. The expected production from the reservoir
2. The way the reservoir is used over its lifetime
3. Bottom hole orientation
4. Completion fluids
5. Logging and testing requirements

* Well completion impacts or is impacted by:

1. Borehole stability
2. Characteristics of fluids exposed to the reservoir
3. Depth of filtrate invasion
4. Hardware (casings, cementing and completion equipment).

* Combining the information gained from logs with the objectives of the well allows us to design a good completion method. Information from: Hole profile – casing design – Offset wells – Mud logs – Drilling report – Drill stem tests – electric logs – Core analysis – Completion Design.
* Completion Fluid: a specific fluid added to the well after it has been drilled. The fluid remains there for the whole well completion period.
* After completing drilling operations, the drilling fluid is removed and completion fluid is added. A completion fluid:

1. Maintains well control
2. Effectively removes solids remaining after drilling was completed.

* The hydrostatic head of the fluid column should be greater than the static reservoir pressure to maintain well control.
* The differential pressure between the wellbore and the formation should be minimized to prevent excess loss of completion fluid to the formation.
* After the circulating completion fluid reaches the surface carrying solids, it is cleaned before being pumped down again. This will minimize solids-associated formation damage.
* Borehole orientation: vertical – horizontal – deviated
* Deviated wells increase well exposure area thus enhance productivity.
* Horizontal wells are used to exploit low permeability or thin reservoirs.
* Three basic ways to complete a well:

1. Open hole completion: the casing is set above the producing area. No pipe is placed or cemented across the formation. There is no control over production. Fluids are free to flow.
2. Liner completion:
3. Uncemented: a smaller diameter casing is set above the producing zone.
4. Cemented: A casing is set above the producing zone and liner is cemented into place.
5. Cemented casing/perforation completion: Production casing is run and cemented across the production zone. The casing is selectively perforated to produce the well. This is by far the most common type of completion.

* Cemented liner and cemented casing methods require a perforating gun to establish communication between the formation and the wellbore. Communication is established automatically in the case of the uncemented liner or open hole completion. After firing the gun and perforating the casing, fluids can enter the wellbore.
* Tubing: a completion equipment. Carries produced fluids to the surface or injectants to the desired intervals.
* Packer: a completion equipment. Protects the casing, controls fluid flow, supports tubing string and segregate intervals.
* Multiple zone wells require different completion designs.
* The size of the tubing needed for the anticipated flow rate impacts directly the size of the hole to be drilled.
* Many oil fields will undergo a secondary, or enhanced, recovery program to extend production beyond primary depletion.
* Enhanced Oil Recovery (EOR) requires the well to become an injection well. Injection wells are used to get rid of waste, extra water, miscible flood, gas… to improved recovery operations.
* Special Completions: Monobore completions – Multilateral completions – Intelligent completions.

1. Multilateral completions: two or more branches from a primary vertical wellbore.
2. Intelligent completions: allow to control subsurface components from the surface using electric power. These completions also constantly monitor downhole conditions such as temperature and pressure.

* The performance of a well is governed by two conditions:

1. The ability of the reservoir to pass fluids against downhole conditions (Inflow performance).
2. The ability of produced fluids to flow through the well conduit onto the surface (Outflow performance).

* Well outflow should match the expected inflow performance.
* The total pressure drop from the reservoir to the separator is the sum of the pressure drops in the 4 sections (reservoir, completion, wellbore, flowline).
* Nodal Analysis aims to calculate the flow rate knowing the reservoir and separator pressures.

1. Start from the separator and assume a flow rate 🡺 find pressure drop in the flowline to find the well head pressure 🡺 find the bottom hole pressure.
2. Start from the reservoir with reservoir pressure (known) and assume a flow rate 🡺 find pressure drop across the completion and bottom hole pressure.
3. Compare the two bottom hole pressures. If not equal, repeat.

* Outflow reservoir curve has positive slope. Inflow reservoir curve has negative slope.
* Inflow performance depends on:

1. Fluid properties:
2. Oil: viscosity – GOR – Bubble point – FVF – Density.
3. Gas: Z factor, compressibility – Density – Viscosity.
4. Well geometry (horizontal or vertical)
5. Formation properties (reservoir pressure, permeability, skin, net pay height).

* Outflow performance depends:

1. Fluid properties
2. Oil: viscosity – GOR – bubble point – FVF – density
3. Gas: Z, compressibility – Density – viscosity.
4. Friction
5. Completion Properties (tubing size, restriction, roughness).

* Size of the tubing is selected to maintain economical flow rate throughout the life of the reservoir.
* For high flow rate, low pressure loss and low fluid velocity 🡺 large tubing.
* For lower reservoir pressure and flowrate decline 🡺 smaller tubing.
* Nodal Analysis uses:

1. Skin
2. Permeability
3. Reservoir pressure

* Well stimulation: a treatment performed to enhance or restore production from a well.

1. Matrix Acidizing: Injected at a pumping rate below fracturing rate. The objective is to restore natural permeability. For sandstone, skin can be reduced to zero at best. For carbonates, we can get a negative skin (better).
2. A fluid that can dissolve the damage material (sandstone) or by-pass the damage material (carbonate) is used.
3. A set of fluids are usually used (to treat a single or multiple type(s) of damage).
4. The fluids mostly used are aromatic solvents and acids.
5. Fracturing: A negative skin is possible.

* Mud acid is used to acidize sandstone. It is a combination of HCl and HF.
* HCl is used to dissolve and by-pass carbonates.
* Hydraulic fracturing: fluid is pumped at a rate higher than the fracture rate to cause cracks in the rock. Used to deal with low natural permeability, natural production below economic potential, skin by-pass or higher permeability and soft formations, fracture for sand control.
* Objectives of well stimulation:

1. Increase production
2. Increase reservoir economic life
3. Increase reserves
4. Reduce or overcome near wellbore damage

* Production curve shifts to the right after stimulation.
* Artificial Lift: acquired when reservoir pressure is not sufficient to lift reservoir fluids onto the surface.

1. May be desired to increase production rates above natural flow rates.
2. Uses alternate sources to lift or lighten fluid column.

* Artificial Lift Methods:

1. Gas Lift
2. Electrical Submersible Pumps
3. Sucker Rod Pumps
4. Progressive Cavity Pump

* The choice of artificial lift depends on the reservoir data, fluid properties and production conditions.
* Well completion: process to enable safe and sufficient production from an oil or gas well.
* Present Value Concept: A dollar today is worth more than a dollar tomorrow. This dollar can be invested to earn money in the interim period.
* The higher the discount rate, the less the future dollar is worth today.
* Economic Evaluation Process consists of:

1. Inputs:

Costs (Capital cost estimate CAPEX – Operating cost estimate over the life of the project OPEX).

1. CAPEX: It is cash expenditures required to obtain the forecast benefits of a project (land, equipment, property, construction costs, development costs…)
2. OPEX: expenses directly attributed to the project’s operations: unrelated to the level of activity (maintenance, manpower…) or related to activity level (fuel, power, feedstock cost…). Overhead expenses are part of OPEX but not directly attributable to the project (research expenses, accounting…).
3. Outputs:
4. Production forecast: recoverable reserves – reservoir performance – optimum economic method of development – production profile – time schedule for future investment.
5. Price forecast: expecting future changes in prices.

* Net Present Value (NPV): economic value expected to be generated by the project at the time of measurement. Tends to favor large investments in ranking because of greater present value.
* Present Worth Index (PWI): measures the relative attractiveness of projects per dollar of investment. Ratio of cash inflows to cash outflows. This measure deals with the NPV limitation of preferring large investments over small ones.
* Present Worth Pay (PWP): Measures the time that the net investment will be at risk. The longer the payout period, the higher the chance for some unfavorable circumstance to occur.
* The Government wants:

1. Control of its HCs
2. Investment to allow extraction
3. A fair and reliable share of the value generated
4. Maximum economic recovery of HCs
5. Domestic security of supply

* What the Involvement of International Oil Companies (IOC) wants:

1. Access to reserves and to book as much as possible.
2. Consequent imperative to explore
3. Consequent need to cover costs of failed exploration from profits of successful explorations.
4. Stability

* Fiscal Model:

1. Concession Contract: contractor has exclusive rights to explore, develop, sell and export oil/gas from a specified area for a fixed period. Maximum control to contractor. Equity and Royalty & Tax structure.
2. Participation Joint Venture Agreement: Private foreign companies and NOC form a joint venture. Each JV partner pays/receives its share based on the participating interest.
3. Production Sharing Agreement: contract state enters a production sharing agreement with contractor for a specified period. Contractor finances exploration and development. If successful, contractor will recover its costs and earn a profit by receiving a share of production. Significant control to contractors but contractual state has control as well.
4. Service Contracts: contractor pays all exploration and development costs. Contractor works under government mandate and is paid for its work. Government maintains ownership and title of minerals. Most suitable for contractors for risk-free operations having producing assets.

* Lebanese Petroleum Sector

1. 1993: 2D Survey by Geo-Prakla
2. 2000/2002: Spectrum 2D Seismic Survey
3. 2006/2012: PGS 2D & 3D Seismic Surveys
4. 2013: Offshore 3D & Onshore 2D Seismic Surveys
5. 2004: Study to determine the hydrocarbon potential offshore Lebanon using 2D seismic acquired data.
6. 2011: Study to assess hydrocarbon proceptivity offshore Lebanon by interpreting and integrating 2D seismic profiles acquired and processed by Spectrum (2000/2002) and Petroleum Geo-Services (2008).
7. 2012: Study in which petroleum system modeling with testing of several scenarios was conducted in July 2012 using the acquired 2D seismic lines.
8. 2013: Study on 3D seismic offshore Lebanon.
9. 2015: Study to divide surveyed area.