Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/petroleum-coal
Petroleum & Coal 56(3) 206-221, 2014

SHALE GAS AND TIGHT OIL, UNCONVENTIONAL FOSSIL FUELS

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Received March 14, 2014, Accepted May 30, 2014

Abstract

This paper deals with reviewing on the application of unconventional fossil fuels such, as shale gas and tight oils. After a brief introduction covering some frequently asked questions, key topics, glossary and terminology of shale gas and tight oils, an overview of the work performed to date in the field is given.

On the supply side, the most noticable phenomenon remains the American shale revolution 2012 the US recorded the larges oil and natural gas production increases in the world, and saw the largest gain in oil production in its history.

World primary energy production is expansion across all types of energy forms play in an increasingly significant role. Renewables, shale gas, tight oil and other new fuel sources in aggregate grow at 6,2 % p.a. and contribute 43 % of the increment in energy production to 2035.

The total recoverable shale gas in the United states, was revised downward to 18,6 trillion cubic metres in 2013. Recoverable shale gas in Canada was revised upward to 16,1 TCM.

Although the prospects for shale gas production are promising, there remains considerable uncertainty regarding the size and economics of this resource. Many shale formations are so large that only portion of the entire formation has been extensively production-tested. Most of the shale gas wells have been drilled in the last few years, so there is considerable uncertainty regarding their long-term productivity. Another uncertainty is the future development of well drilling and completion technology that could substantially increase well productivity and reduction production cost.

Tight oil is conventional oil that is found within reservoirs with very low permeability. The oil contained within this reservoir rock typically will not flow the wellbore at economic rates without assistance from technologically advanced drilling and completion process. Commonly, horizontal drilling coupled with multi-stage fracturing is used to access these difficult to produce reservoirs.

Keywords: Shale gas; shale oil; tight oil; unconventional fossil fuels; energy in 2012; energy outlook 2035; horizontal drilling; hydraulic fracturing; fracking.

1. Introduction

Unconventional natural gas and oil resources are considerable. At the present time, they are only produced marginally, ouring to the technical and ecological difficulties and production costs.

The production cost of the shale gas and shale oil varies with the gas and oil content per unit volume of the reservoir rock. The production cost is the highest for shale gas and oil from deep aquifers, for which the gas and oil content is particularly low.

The most important developments can therefore be anticipated in the twenty-first century. Their velocity will depend both on the scale of shale gas and shale oil demands and on the technical breakthroughs, that wil been achieved to lower costs.

2. Energy in 2012

The year 2012 saw a slowdown in the growth of energy consumption globaly, partly as a result of the economic slowdown but also beacause individuals and businesses have responded to high proces by becoming more efficient in thei use of energy. At the same time the supply of energy is coming from an increasing diversity of sources as the world's energy market continues to adapt, innovate and evolve [10].

On the supply side, the most noticeable phenomenon remains the American shale revolution 2012 the US recorded the larges oil and natural gas production increases in the world, and saw the largest gain in oil production in its history. World primary energy consumption grew by 18 % in 2012, well below the 10-year average of 26 %. Global oil consumption grew by 121.396 tonnes per day (t/d), or 0,9 %, below the historical average. Oil had the weakest global growth rate among fossil fuels for the third consecutive year.

World natural gas consumption grew by 2,2, below the historical average of 2,7 %. Consumption growth was above average in South&Central America, Africa and North America, where the US (+4,1 %) recorded the largest increment in the world. Global natural gas production grew by 1,9 %. The US (+4,7 %) once again recorded the largest volumetric increase and remained the world`s largest producer. Coal consumption grew by 2,5 % in 2012, well below the 10 year average of 4,4 % but still the fastest-growing fossil fuel.

Global nuclear output fell by 6,9 %, the largest decline on record for a second consecutive year. Renewable energy sources saw mixed results in 2012. Global biofuels production recorded the first decline since 2000 (-0,4 %, or –0,1 mtoe), due to a decline in the US (-4,3 % or –1,2 mtoe) [10].

Table 1 World consumption fuels in 2012 (milion tonnes oil equivalent)

Oil	4130.5	33.1 %
Natural gas	2987.1	23.9 %
Coal	3730.1	29.9 %
Nuclear energy	560.4	4.5 %
Hydroelectricity	831.1	6,7 %
Renewables	237.4	1.9 %
Total	12 476.6	100.0 %

3. Energy outlook 2035

World primary energy production grows at 1.5 % p.a. from 2012 to 2035, matching consumption growth. Growth is concentrated in the non-OECD, which accounts for almost 80 % of the volume increment. There is growth in all regions except Europe. Asia Pacific shows both the fastest rate of growth (2.1 % p.a.) and the largest increment, providing 47 % of the increase in global energy production. The Middle East and North America are the next largest sources of growth, and North Amerika remains the second largest regional energy producer [11].

There is expansion across all types of energy, with new energy forms playing an increasingly significant role. Renewables, shale gas, tight oil and other new fuel sources in aggregate grow at 6.2 % p.a. and contribute 43 % of the increment in energy production to 2035. The growth of new energy forms is enabled by the development of technology and underpinned by large-scale investments.

By 2035 growth of tight oil (0,78 Mt/d), biofuels (0,26 Mt/d), and oil sands (0,45 Mt/d) alone will have accounted for 60 % of global growth and all of the net increase in non-OPEC production. Tight oil will account for 7 % of global supplies in 2035 while biofuels and oil sands obtain market shares of 3 % and 5 %, respectively. North America will dominante the expansion in unconventionals with 65 % of global tight oil and with Canada responsible for all the world´s oil sands production. In the US, the increase in tight oil production coupled with declining demand will continue the dramatic shift in import dependence. Imports are set to decline from a peak of well over (1.63 Mt/d), or 60 % of demand, in 2005 to just (0.136 Mt/d), or less than 10 % demand in 2035.

Global gas supply is expected to grow by 1.9 % p.a. or 4.82 Bm^3/d over the outlook period, reaching a total of 13.92 Bm^3/d by 2035. Shale gas is the fastest growing source of supply (6.5 % p.a.), providing nearly half of the growth in global gas. Gas supply growth is concentrated in the non-OECD (3.53 Bm^3 or 2.1 % p.a.) accounting for 73 % of global growth. Almost 80 % of non-OECD growth is from non-shale sources. OECD supply growth (1.5 % p.a.) comes exclusively from shale gas (5.1 % p.a.), which provides nearly half of OECD gas production by 2035.

Shale gas supply is dominated by Nort America, which accounts for 99 % of shale gas supply until 2016 and for 70 % by 2035. However, shale gas growth outside North America accelerates and by 2027 will overtake North American growth. China is the most promising country for shale growth outside North America , accounting for 13 % of world shale gas growth; together, China and North America wil account for 81 % of shale gas by 2035.

Perhaps the most dramatic adjustments to shale gas are seen in trade flows. The US is set to shift from a net importer of gas today to a net exporter in 2018, with net exports reaching 0.30 Bm^3/d by 2035. It will become a net LNG exporter from 2016, reaching a total net LNG export volume of 0.31 Bm^3/d by 2035.

US domestic gas production has been revitalized by the shale gas ´revolution´. US shale gas output by 2029 will exceed the highest level ever achieved by conventional gas production in the US. By 2035, shale gas production will be just short of US total gas output in 2012. How does the market accommodate this shale gas ´shock´? All the elements of the supply and demand balance adjust, responding to relative price movements. Conventional supply declines faster than it would have done in the absence of shale; gas gains share in the various segments of US energy markets, in competition with other fuels; and US gas gains share in the international market in competition with other suppliers.

US shale gas output will grow by 4.3 % p.a. between 2012 and 2035, enabling US gas production to rise by 45 %. This is causing a series of adjustments in energy markets; some already evident, others developing over time. Next, gas will gain market share in the industrial sector, from 39 % in 2012 to 42 % by 2035. And finally, gas will start to penetrate the transport sector. Gas is the fastest growing fuel (18 % p.a.) in a sector where overall demand is falling (-0.9 % p.a.) By 2035 gas wil account for 8 % of US transport sector fuels, almost matching biofuels [11].

4. Shale gas

Natural gas is playing a growing energy role. The scale of its reserves and its environmental advantages favor its use, for fast growing activities such as the precision industries and generation of electricity. Although the shale gas potential of many nations is being, as of 2013, only the US, Canada, and China produce shale gas in commercial quantities, and only the US and Canada have significant shale gas producion [12].

The table 2 is based on data collected by the Energy Information Administration agency of the United States Department of Energy [13]. Numbers for the estimated amount of recoverable shale gas resource are provided alongside numbers for provensource are provided alongside numbers for proven natural gas reserves.

Table 2 Shale gas by country

Country	Estimated recoverable shale gas [trillion cubic metres]	Proven natural gas reserves of all types [trillion cubic metres]
China	31.22	3.47
Argentina	22.46	0.34
Algeria	19.80	4.45
United States	18.62	8.90
Canada	16.07	1.90
Mexico	15.26	0.48
South Africa	13.58	-
Australia	12.24	1.20
Russia	7.98	47.26
Brazil	6.86	0.39

The US EIA had made an earlier estimate of total recoverable shale gas in various countries in 2011, which for some countries differed significantly from the 2013 estimates [14]. The total recoverable shale gas in the United States, which was estimated at 24,14 trillion cubic metres in 2011, was revised downward to 18,62 trillion cubic metres in 2013. Recoverable shale gas in Canada, vhich was estimated to be 10,86 TCM in 2011, was revised upward to 16,07 TCM in 2013.

Shale gas is found in shale „plays", vhich are shale formations containing significant accumulations of natural gas, and which share similar geologic and geographic properties.

A decade of production has come from the Barnett Shale play in Texas. Experience and information gained from developing the Barnett Shale have improved the efficiency of shale gas development the country. Another important play is the Marcellus Shale in the eastern. United States geophysicists and geologists identify suitable well locations in areas with potential for economical gas production by using surface and subsurface geology techniques and seismic techniques to generated maps of the subsurface [2].

Conventional gas reservoirs are created when natural gas migrates toward the Earth´s surface from organic-rich source formation into highly permeable reservoir rock, where it is trapped by an overlying layer of impermeable rock in contrast, shale gas resources form within the organic-rich shale source rock. The low permeability of the shale greatly inhibits the gas from migrating to more permeable reservoir rocks. Without horizontal drilling and hydraulic fracturing shale gas production would not be economically feasible because the natural gas would not flow from the formation at high enough rates to justify the cost drilling.

Shale gas was first extracted as a resource in Fredonia, New York, in 1821 [15-16], in shallow, low-pressure fractures. Horizontal drilling began in the 1930s, and in 1947 a well was first fracked in the US [17]. George P. Mitchell is regarded as the father of the shale gas industry, by making it commercialy viable in the Barnett Shale by getting costs down to $ 4 per million British Thermal Units [18]. Mitchell Energy archieved the first economical shale fracture in 1998 using slick-water fracturing [19-21]. Since then, natural gas from shale has been the fastest growing contributor to total primary energy in the United States, and has led many other countries to pursue shale deposits. According to the IEA, shale gas could increase technically recoverable natural gas resorces by almost 50 % [22].

4.1 Geology

Because shales ordinarily have insufficient permeability to allow significant fluid flow to a well bore, most shales are not commercial sources of natural gas. Shale gas is one of a number of unconventional sources of natural gas; others include coalbed methane, tight sandstones, and methane hydrates. Shale gas areas are often know as resource plays [24] (as opposed to exploration plays). The geological risk of not finding gas is low in resource plays, but the potential profits per successful well are usually also lower [23].

Shale has low matrix permeability, so gas production in commercial quantities requires fractures to provide permeability. Shale gas has been produced for years from shales with natural fractures; the shale gas boom in recent years has been due to modern technology in hydraulic fracturing (fracking) to create extensive artificial fractures around well bores [23].

Horizontal drilling is often used with shale gas wells, with lateral lengths up to 3000 m within the shale to create maximum borehole surface area in contact with the shale (Fig. 1) [23].

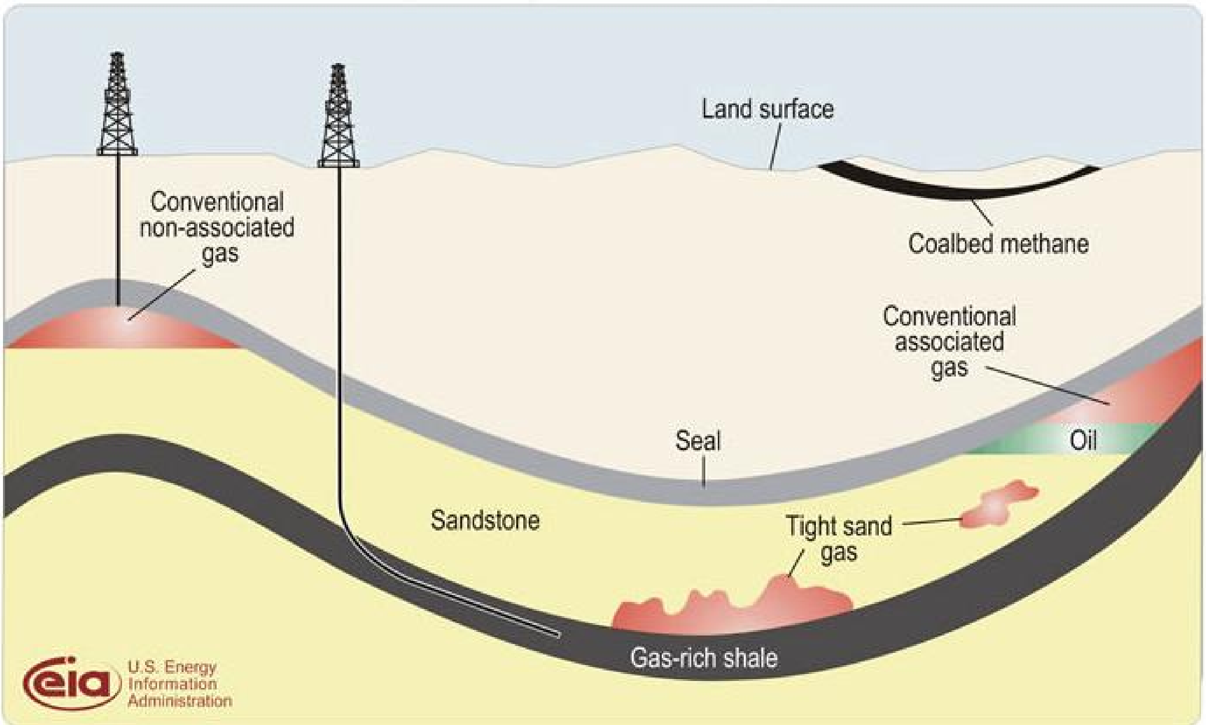

Figure 1. Schematic geology of natural gas resources [23]

Shales that host economic quantities of gas have a number of common properties. They are rich in organic material (0, 5 % to 25 %) [25] and are usually mature petroleum source rocks in the thermogenic gas window, where high heat and pressure have converted petroleum to natural gas. They are sufficiently brittle and rigid enough to maintain open fractures.

Some of the gas produced is held in natural fractures, some in pore spaces, and some is adsorbed onto the organic material. The gas in the fractures is produced immediately; the gas adsorbed onto organic material is realeased as the formation pressure is drawn down by the well [23].

4.2. Formation of natural gas reservoirs

4.2.1 General

A natural gas reservoir occupies the integranular porosity or the cracks of a rock that is called a reservoir rock or simply a reservoir. The permeability of this rock must be sufficient to obtain a gas flow enabling profitable production. Gas reservoirs are classed as „conventional" and „unconventional" reservoirs. The former, resulting from large gas accumulations, can be exploited using current techniques. In the latter, the gas is stored under specific conditions and requires special and costly techniques to be produced.

The reservoir that contains the gas also contains water, a fluid that is omnipresent in the sediments, and very frequently oil. All or part of the gas may be dissolved in the water or the oil, depending on the thermodynamic conditions prevailing in the reservoir and the chemical species present. If a gas phase is present, its density is lower than that of the water or the oil, and it tends to move upward as a result of buoyancy. Hence it can only remain in the reservoir if prevented from escaping by a barrier [26].

This barrier is either a permeability barrier, usually consisting of shale or salt, or a hydrodynamic barrier, in which case the movement of water counteracts the buoyancy. The reservoir-barrier combination constitutes a trap (Fig. 2).

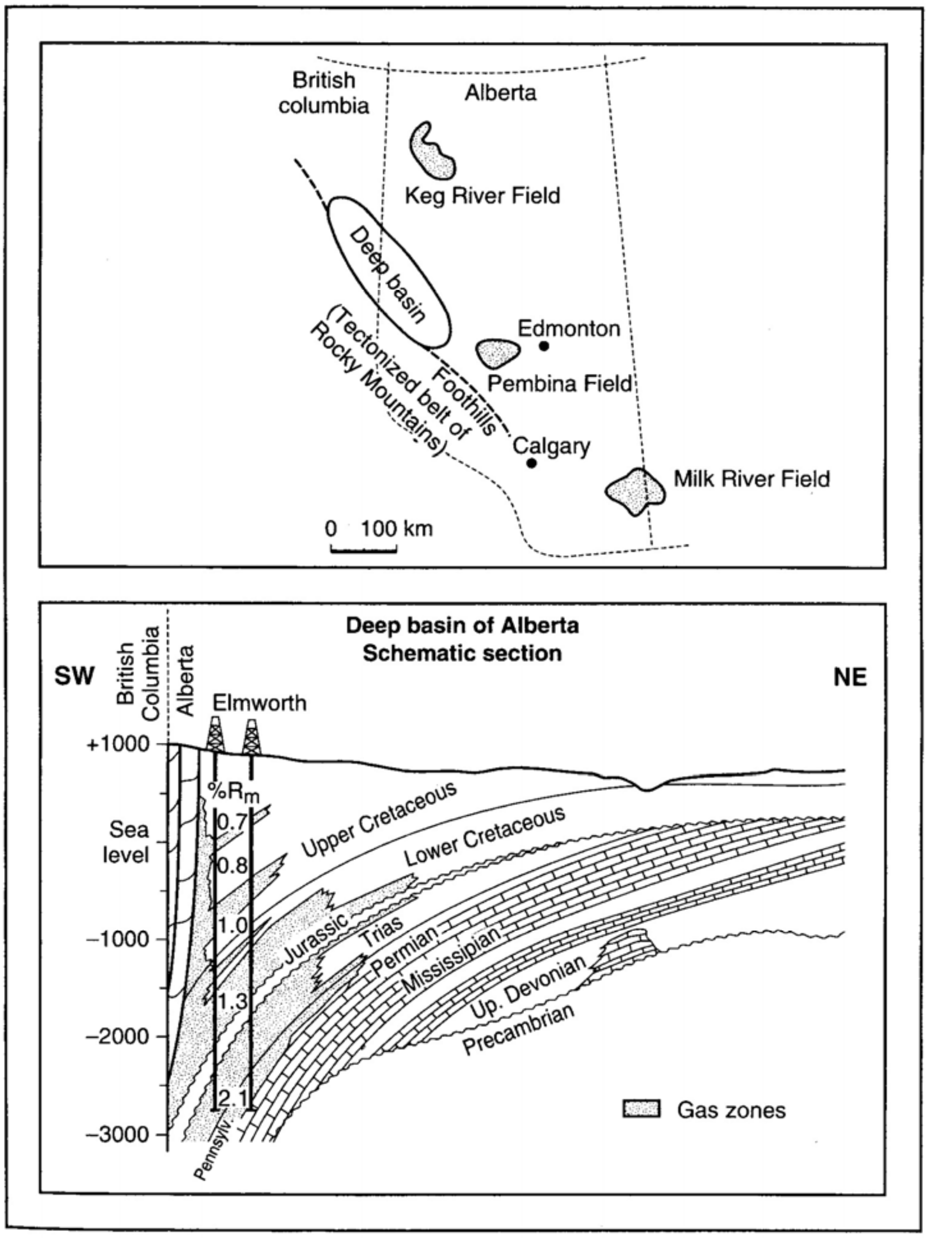

Figure 2. Deep-basin gas reservoir in Alberta (CAN) [26].

Figure 2 gives an example of an unconventional trap in which the gas, formed in the deep parts of a basin (Alberta Basin, Canada), advances upward due to the buoyancy. However, the permeability of the formation in which the gas advances is low, and the movement of the gas is extremely slow due to the existence of high capillarity forces that oppose its motion. In this figure, the scale marked in % R_m corresponds to the increase in the vitrine reflectance as a function of depth. It is assumed that the gas begins to be formed in significant quantities from an R_m of 1.3 %. The gas located above this limit was therefore most likely a gas formed deeper in the basin.

Most barriers, except for salt, are incapable of completely stopping the upward movement of the gas. This gives rise to leaks, the process being called dysmigration. Naturally, dysmigration is rarely perceptible on the human timescale. At the geological timescale, however, a gas reservoir appears as a temporary underground repository which only lasts as long as it is replenished at a higher rate than its losses.

The reservoir rock participates in the geological evolution of the basin. It may be dragged deeper by subsidence or rise towards the surface because of the erosion of the overlying sediments, causing a change in the thermodynamic conditions prevailing therein. It may also be deformed by tectonics, cemented by mineral recrystallization, or even destroyed by erosion if it reaches the surface. Natural gas reservoirs are therefore complex objects. Each of them has its own individual history [26].

4.2.2 Unconventional reservoir

Unconventional reservoirs are not distinguished by any particular configuration, and their formation is based on the same principles. They include the following types:

a) Reservoirs of **tight sandstones** or relatively impermeable sandstones: the permeability of these sandstones is so low as to make it impossible to obtain a sufficient gas flow by simple drilling. The largest tight sandstone reservoirs, found in the United States, contain gas without associated oil.

b) **Fractured shales**: these are shales containing millimetric cracks that are filled with gas. The craks are supplied by the surrounding shale, but at a very low rate on the human timescale. These shales are in fact source rocks still containing a part of the gas formed therein. A classic example is provided by the Albany Shales in the United States. These reservoirs also contain gas without associated oil.

c) **Coal mine gas**: it is well known that gas or "firedamp" is found in many coal seams. This gas is rich in methane and often contains high proportions of carbon dioxide and nitrogen. It is formed during the burial of the coal, which is its source rock, and where it remains trapped. It is liberated by the decompression caused by mining operations. It is generally removed by ventilation, but its recovery is sometimes profitable.

d) **Deep aquifer gas**: in these reservoirs, the gas is found dissolved in water. One example is provided by the deep aquifers of the Mexican Gulf coast in the United States already mentioned. The gas is pure methane, and the quantities dissolved range from 10 to 20 N_m^3 per m^3 of water. This region features projects for the geothermal tapping of deep aquifers, and the recovery of the methane present in the water is considered to be an important factor for the profitability of the operation.

This main unconventional sources of natural gas are [26]:

(a) Low- permeability sandstone reservoirs.
(b) Fractured shales.
(c) Coal-bed methane.
(d) Methane dissolved in geopressurized aquifers.
(e) Hydrate reservoirs.

Unconventional sources of natural gas are considerable, but have been tapped very litlle so far for economic reasons.

The assumption of the presence of large quantities of methane of inorganic origin in the deep layers of the Earth´s crust was postulated by Gold and Sauter [27-28]. Tests performed to detect deep methane failed to yield positive results, and it has already been reported in [26] that Gold´s theory appears highly speculative today. However, as pointed out by Nederlof [29], even if the organic origin of the oil and gas reservoirs discovered so far in the sedimentary basins has been fully established, this does not necessarily mean that methane of a different origin cannot be found in the far deeper zones of the Earth´s crust or the mantle.

4.2.3 Low-permeability gas reservoirs

4.2.3.1 Sandstone reservoirs

Large amounts of natural gas exist in tight sandstone reservoirs, characterized by a permeability lower than 30 μD and low porosity (7 to 12 %). The gas saturation of the porous medium is generally low, about 50 % instead of about 80 % in the usual reservoirs

The combination of these factors implies low well productivity. A similar situation is found when the pressure in the reservoir is relatively low (3 to 4 MPa), with the permeability ranging between 30 and 100 μD [26].

Low permeability may stem from two different factors:

a. The mineralogical composition of the porous medium: thus the presence of a mixture of shales and fine sediments leads to the formation of a dense, nonporous medium.
b. The depth of the reservoir which causes compaction of the porous medium.

The stability of methane at the temperature and pressure conditions implied by extreme depth was investigated by Takach *et al.* [30]. He concluded that methane remains stable up to a depth of at least 12 km, but that, in the presence of carbonates and water, the carbon dioxide content may increase.

The production of tight reservoirs requires the application of relatively complex and costly methods. The depth of some reservoirs raises another problem and increases the cost of drilling operations.

The main solution employed to improve productivity is hydraulic fracturing. This helps to fracture the porous medium and thus to boost the productivity of the wells which communicate with the fractures created.

Another promising technique for improving well productivity is horizontal drilling. This substantially increases the length of the drain and thus boosts the production of the well by a factor of up to 4 or 5 in favorable situations.

4.2.3.2 Fractured shales

Shale formations containing gas

Shales aire usually considered impervious, and can form a cap rock for a gas reservoir.

In some shales, however, relatively high contents of organic matter originally present have led to the formation of natural gas contained in natural fractures of the rock.

The Devonian shales in the eastern United States are the best known. These shales were formed from sediments deposited 350 million years ago in a shallow sea which covered a large portion of the eastern United States. The kerogen present in the rock was transformed during its burial into methane and bitumen. The gas accumulated in the formation fractures [31].

Reservoirs of the same type very probably exist in the rest of the world. For them to contain natural gas, it is first necessary for the geological conditions allowing the formation of methane from kerogen to be satisfied. The tectonic evolution of the formation should also have created sufficient porosity by natural fracturing of the rock.

Gas production from fractured shales

Natural gas production from fractured shales raises tremendous problems. As in the case of tight sandstone reservoirs, horizontal drilling and hydraulic fracturing are the most promising techniques to improve the productivity of these reservoirs.

Hydraulic fracturing has the disadvantage of creating an essentially unidirectional fracture. This is why another fracturing method, based on the use of a slow action explosive has been investigated. It generates a set of radial fractures, ensuring better communication between the well and the natural fractures in the rock.

The explosive helps to produce a very short pressure peak. Multiple fractures appear if the pressure buildup takes place in a time interval between 0.05 and 5 ms, depending on the diameter of the well, and the shortest times correspond to the smallest diameters [32].

Horizontal drilling also helps to improve well productivity. Horizontal drilling tests have been conducted in a shale formation with positive results, and this technique appears to be promising for these reservoirs [29]. Horizontal drilling can also be combined with hydraulic fracturing [33].

5. Tight oil

Crude oil, also known as petroleum or fossil fuel, is found in some rock formations deep below the earth´s surface. Crude oil forms the foundation for the petroleum industry and is relied upon for fuels as wel as feed stocks for the petrochemical industry [8].

Oil is commonly defined as either heavy or medium-to-light grade dependent on the density of the hydrocarbon and its ability to flow. Heavy oil generally refers to crude oil that is too viscous for pipeline transport without dilution, or oil that is mined in the oil sands in Northern Alberta. Conventional oil, which is referred to as light or medium in grade, is found in reservoir rocks which have enough permeability (the ability for a fluid to move through a rock formation) to allow the oil to flow to a vertical or horizontal well.

Tight oil is conventional oil that is found within reservoirs with very low permeability. The oil contained within these reservoir rocks typically will not flow to the wellbore at economic rates without assistance from technologically advanced drilling and completion processes. Commonly, horizontal drilling coupled with multi-stage fracturing is used to access these difficult to produce reservoirs.

Oil is trapped within the open spaces in the rock (called porosity). This porosity may be in the form of the smoll spaces between grains in a sandstone or as small, open vugs, or cavities, within carbonates (limestone or dolomite type rocks). For the reservoir to flow oil to a wellbore, the rock must have some form of permeability either in interconnected pathways between pore spaces or in natural fractures found in the rock. The percentage of pore volume, or void space, within the rock is generally less than 30 % and in tight oil reservoirs is commonly less than 10 %. The amount of oil stored within a reservoir is directly related to the porosity of the reservoir and other geological characteristics.

Crude oil has a number of characteristics or properties that allow it to be classified into different types. One of the main properties of oil is its density. The higher the density, the more resistant it to flowing in the reservoir. A measure of a fluids resistance to flow is termed viscosity. Most tight oil produced is of the medium to light variety, with a lower viscosity.

The world has relied extensively on the production of oil for many years and continues to be dependent on it as the primary source of transportation fuels. As countries continue to produce oil resources, there is a natural decline in production as the easy to access resources are depleted.

Extensive oil and gas resources are known to be present in tight oil reservoirs, however, they require additional technology to enable them to be produced. Tight oil is of high quality but commonly found in regions where reservoir properties inhibit production using conventional drilling and completion techniques. The oil itself requires very little refinement and, in many cases, existing surface infrastructure can often be utilized, reducing both surface impact and capital investment [8].

Industry and Government often report the Original Oil in Place (OOIP) resource for regions or geological formations that are believed to have, or are proven to contain, oil and gas potential. The OOIP is simply the amount of oil that is trapped within the reservoir underground. This amount is often many times larger than the actual amount of oil industry is capable of recovering. With the application of horizontal drilling and multi-stage hyraulic fracturing, industry is successfully extracting additional oil from these reservoirs.

Tight oil is found throughout Canada´s known oil-producing regions as well as numerous basins in the United States.

The industry has explored for and developed conventional oil reservoirs for many years. As these resources for many years. As these resources have diminished, companies have expanded their search to look at new sources of oil, such as shale oil and other tight oil reservoirs. Drilling and completion technologies used to produce unconventional resources are also being applied to increase oil production from some conventional oil reservoirs where recovery has been low [Fig 3].

5.1 Types of tight oil plays

In the oil and gas industry, the types of oil and gas deposits are generally classified into different categories called „ Plays". Plays are differentiated based on geology and the technology required to produce the oil. There are numerous play types associated with tight oil: conventional oil play unconventional oil play

In some existing oil fields, the fringe regions, or halos, surrounding the areas of historical production, are know to contain oil. The reservoir properties in the halo are not as favorable as those within the previously developed area. Applying new technologies, such as horizontal drilling, allows oil to be recovered from the halo or fringe regions. Examples of this type of play are the Cardium and Vikong Formations in Western Canada.

Geo-stratigraphic play

This type of play describes a geological formation known to contain significant oil resources over a large geographic region. This type of play also requires the use of advanced technology to yied economic oil production. The Middle Bakken Formation, wich occurs in parts of Saskatchewan, Nort Dakota and Montana, is an example of this type of play. It contains oil that has been sourced from the overlying and underlying organic rich shale units [8].

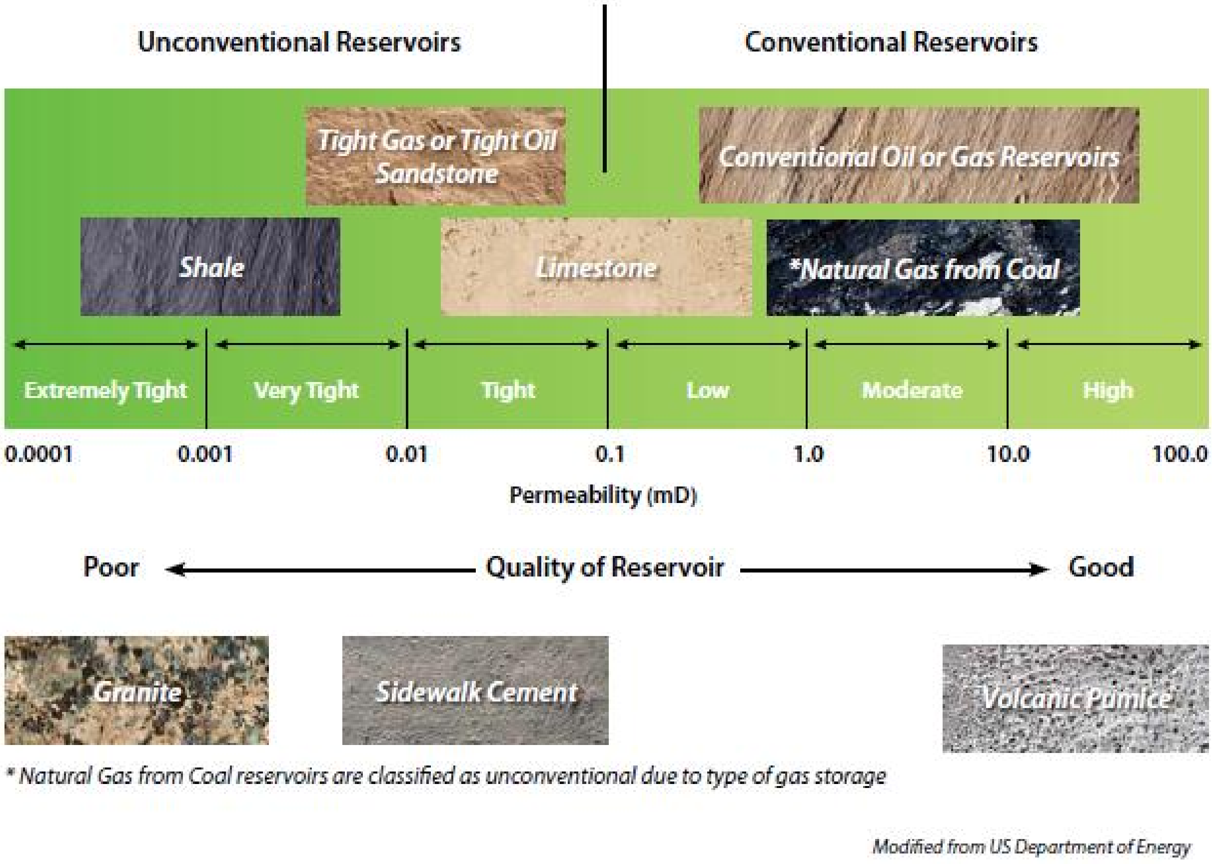

Figure 3. Conventional and unconvetional resveirs [8]

Shale oil play

In shale oil plays, the rock material is predominantly organic-rich shale which contains oil. The rock is not only the source of the oil but also the reservoir. Shale reservoir tend to have „tighter" permeability than sand or carbonate tight oil reservoirs and may require a different type of completion technique. An example of a shale oil reservoir with potential to produce would be the Exshaw Formation in southern Alberta [8].

5.2 Technologies used to recover tigth oil

The oil which is produced or extrated from tight reservoirs is the same type of oil which can be produced from conventional reservoirs. It is the application of advanced technologies which make these developments unconventional. Different technologies are used for different plays but the most common methods used today are horizontal drilling and multi-stage hydraulic fracturing.

Horizontal drilling

The purpose of drilling a horizontal well is to increase the contact between the reservoir and the wellbore. Wells are drilled vertically to a predetermined depth (typically 1000m to 3000m below the surface depending on location) above the tight oil reservoir. The well is then „kicked off" (turned) at an increasing angle until it runs parallel within the reservoir. Once horizontal, the well is drilled to a selected length which can extend up to 3-4 km. This portion of the well is called the horizontal leg (Fig. 4).

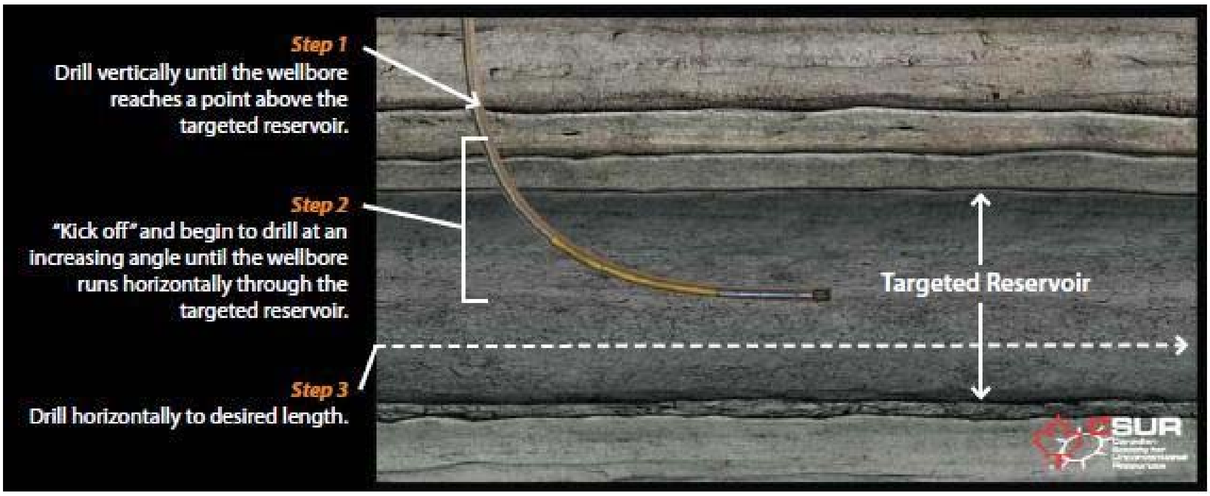

Figure 4. Horizontal drilling [8]

Hydraulic fracturing

Tight oil reservoirs require some form of stimulation once the well has been drilled. The most common type of stimulation used by the oil and gas industry is referred to as hydraulic fracturing or fracking. This process applies pressure by pumping fluids into the wellbore which opens existing, or creates new fractures or pathways in the reservoir through which the oil can flow to the wellbore. In conventional oil reservoirs the reservoir permeability is sufficient that hydraulic fracturing may not be needed to achieve economic production rates.

In unconventional oil, the reservoir permeability is typically very low and additional pathways must be created to enable the flow of hydrocarbons.

To create the fractures, fluids are pumped under pressure from surface into the reservoir, many hundreds to thousands of meters below ground. The type of fracture fluids used will vary depending on the reservoir characteristics. Commonly, water is used as a base fluid. Generally, three to twelve a additives are added to the water, based on the characteristics of the source water and also of the formation to be fractured. These additives represent 0,5 % to 2 % of the total fracturing fluid volume. Their purpose is to reduce friction, prevent microorganism growth/biofouling and prevent corrosion [8].

As part of the stimulation process, once the fractures have been created, sand or ceramic beads (proppants) are pumped into these small openings to hold open the fractures created. The volume of fracture fluid and proppant used for each hydraulic fracture varies dependent upon the anticipated production rates following the treatment.

In tight oil wells, the hydraulic fracturing process typically involves multiple stages along the well bore. Each stage is isolated using packers or plugs to contain the fracturing fluids and ensure that the fracture grows in the direction and distance that was planned [34].

5.3. Micro-seismic

Magnitude

A seismic event may occur from natural or man-made (induced) causes that create sound waves in the earth. A seismic event may be caused by an event ranging from a devastating earthquake to something as common as dropping an object from your hand. Micro-seismic events, as the name suggests, are approximately 1 million times smaller than any tremor that may be felt by a human. Micro-seismic events associated with hydraulic fracturing are man-made events generated during the process which creates pathways for hydrocarbons to flow to the wellbore. These micro-seismic events are very small; they release energy roughly equivalent to a gallon of milk falling from a kitchen counter and their detection, as explained below, requires sensitive and sophisticated equipment. The fractures, or cracks, are generally only wide enough to allow a grain of sand or small ceramic bead to become lodged within these cracks; providing the path for hydrocarbon flow.

Monitoring

During fracture stimulation operations, it is important to know where the fractures are being created in the resevoir. Monitoring of the fracturing process in real time can be accomplished using a variety of techniques. Pressure responses and micro-seismic monitoring are two such techniques.

Measuring micro-seismic events that are occurring as the fracture stimulation takes place provides industry professionals with visual evidence that fractures are being developed both vertically and horizontally. Because these micro-seismic events are measured in real time, immediate adjustments can be made during the operation to ensure that the fractures created stay within the zone that has production potential. The magnitude of seismic events created using hydraulic fracturing techniques is many times smaller than events which can be felt at surface.

Following completion of fracturing operations, the micro-seismic model can be used to define the limit and reach of each fracture stimulation in the wellbore(s). The horizontal and vertical model is also used to define recoverable resources, areas of insufficient stimulation and a visual assurance that potencial groundwater sources are protected.

Initial production

Once pathways have been created within the tight oil reservoir, allowing the oil to flow to the wellbore, conventional methods are used to produce the well. These can include pump jacks which lift the oil to the surface, storage tank facilities (commonly referred to as batteries) and pipelines and trucks used for transport. Well production is commonly robust in the early stages of production but will decline over time.

Infill drilling

In many cases, tight oil development is used to increase the overall recovery of oil from an existing field. Infill wells are located amongst existing coventional wells. The purpose of these wells is to extract additional oil which has not been recovered using conventional production technology. In contrast, Halo wells are located on the fringes of the existing field and rely upon the utilization of new technology to expand the boundaries of the productive zone or „sweet spot" within the oil bearing formation.

Wellbore construction and groundwater protection

Proper well construction isolates the wellbore; a critical step taken by the oil and gas industry to protect potencial groundwater sources which may be encountered during the drilling process. There are typically three different sets of steel casing which are individually cemented into the wellbore to provide barriers which isolate wellbore fluids from the rock intervals.

After each string of casing is installed in the well, cement is pumped down the center of the casing (surface, intermediate or production) and circulates back to the surface in the space outside of the casing. This space is commonly referred to as the annulus. After each of these steps are completed, the cement is allowed to set prior to the continuation of drilling and, in some places, a „cement bond" geophysical log is run to determine the integrity of the cement that surrounds the casing. This extra measure is taken to ensure that the wellbore is adequately cemented and capable of withstanding the pressures associated with hydraulic fracturing. Prior to stimulation, the well is pressure tested to ensure the integrity of the casing system that has been installed in the ground.

Minimizing footprint

Economical production of oil from low permeability reservoirs has been made commercially viable through the application of technologies such as horizontal drilling and multi-stage hydraulic fracturing. Companies are striving to reduce enviromental impacts and to minimize costs associated with tight oil development. The application of multiple wells from a single pad has been recognized as an opportunity to achieve both of these objectives. While the size of a multi-well pad is slightly bigger than a regular oil and gas lease, the comulative footprint for a tight oil field development is much smaller than it would be using vertical wells.Fewer access roadse required and the concentration of facilities and pipelines within the pad minimizes surface disturbance.

During the drilling and completion of the well, there is a significant space requirement for the equipment used. Once the well has been completed and commercial production initiated, the lease site requirements are typically reduced by as much as 50 %. The space, which had been required for drilling and completions activities, is reclaimed to the condition that is was found prior to industry activity.

5. Environment

The extraction and use of shale gas can affect the environment through the leaking of extraction chemicals and waste into water supplies, the leaking of greenhouse gases during extraction, and the pollution caused by the improper processing of natural gas. A challenge to preventing pollution is that shale gas extractions varies widely in this regard, even between different wells in the same project; the processes that reduce pollution sufficiently in one extraction may not be enough in another [17].

Several studies which have estimated lifecycle methane leakage from shale gas development and production have found a wide range of leakage rates, from less than 1 % of total production to nearly 8 % [25]. Using data from the Environmental Protection Agency´s most recent Greenhouse Gas Inventory [37] yields a methane leakage rate of about 1.4 %, down from 2.3 % from the EPA´s previous Inventory [35].

In April 2013 the U.S. Environmental Protection Agency dramatically lowered its estimate of how much methane leaks from wells, pipelines and other facilities during production and delivery of natural gas by 20 percent. According to the Associated Press, the EPA report on greenhouse emissions credited tighter pollution controls instituted by the industry for cutting an average of 41.6 million metric tons of methane emissions annually from 1990 trough 2010, A reduction of more than 850 million metric tons overall. The AP noted, „The EPA revisions came even though natural gas production has grown by nearly 40 percent since 1990" [36].

Water and air quality

Chemicals are added to the water to facilitate the underground fracturing process that releases natural gas. Fracturing fluid is primarily water and approximately 0.5 % chemical additives (friction reducer, agents countering rust, agents killing microorganism). Since (depending on the size of the area) millions of liters of water are used, this means that hundreds of thousands liters of chemicals are often injected into the subsurface [38]. About 50 % to 70 % of the injected volume of contaminated water is recovered and stored in above-ground ponds to await removal by tanker. The remaining volume remains in the subsurface; hydraulic fracturing opponents fear that in can lead to contamination of groundwater aquifers, though the industry deems this „highly unlikely". However the wastewater from such operations often lead to foul-smelling odors and heavy metals contaminating the local water supply above-ground [39].

Besides using water and chemicals however, it is also possible to frack shale gas with only liquified propane gas. This reduces the environmental degradation considerably. The method was inveted by GasFrac, of Alberta, Canada [40].

Earthquakes

Hydraulic fracturing routinely produces microseismic events much too small to be detected except by sensitive instruments. These microseismic events are often used to map the horizontal and vertical extent of the fracturing [41]. However, as of late 2012, there have been three instances of hydraulic fracturing, through induced seismicity, triggering quakes large enough to be felt by people; one each in the United States, Canada, and England; all were too small to cause damage [42].

7. Conclusion

Shale gas is natural gas that is found trapped within shale formations. Shale gas has become an increasingly importants source of natural gas in the United States since the start of this century, and interest has spread to potential gas shales in the rest of the world. Information Administration predicts that by 2035, 43 % of the United States´ natural gas supply will come from shale gas. Although the shale gas in potential of many nations is being, as of 2013, only the US, Canada, and China produce shale gas in commercional quantities, and only the US and Canada have significant shale gas production. The US administration believes that increased shale gas development wil help reduce greenhouse gas emissions.

Some studies have alleged in the release of more greenhouse gases than conventional natural gas.

Oil recovered from shale and other low-permeability formations is known as „tight oil", often shale or light sandstone. Economic production from tight oil formations requires the same hydrautic fracturing and often uses the same horizontal well techology used in the production of shale gas. It should not be confused with oil shale, which is shale rich in kerogen.

Natural gas production from fractured shales raises tremendous problems. As in the case of tight sandstone reservois, horizontal drilling and hydraulic fracturing are the most promising techniques to improve the productisity of these reservoirs. The composition of natural gas reservoir varies considerably. The thermal mode leads to the formation of „thermal gas" from the organic watter present in some sedimentary levels. This organic matter is incorportad in the sediments at the time of deposition. Debris from organisms which accumulate at the water sediment interface are degraded by living organisms. In an anaerobic enviroment, degradation is slow and incomplete. The residues accumulate in the sediments in the form complex macromolecular structures and debris that have resistent biodegradation. The overall mass is insolable in organic solvents and constitutes kerogen.

The accumulation of kerogen takes place nearly exclusively in fine-grained sediments, especially clays, for two reasons. First, the hydrodynamic properties of the organic debris are similar to those of fine-grained minerals. Secondly, it is easy to create anaerobic conditions in these sediments.

Frequently asked questions (key topics include) *[1]:*

- What is „shale gas" or „shale oil"?
- What is „tight shale gas" or „tight shale oil"?
- What is „tight shale gas" or „shale gas"?
- What is „tight light oil" or „tight oil shale"?
- What is the difference between shale gas and oil shale?
- What is the difference between tight light oil and oil shale?
- How are shale gas and shale oil produced?
- Where is shale gas found in North America?
- Tight & shale gas environmental concerns
- European shale developments: an update on UK, Poland, Slovakia and Ukraine
- The effect of shale gas on other industries
- Unconventional gas operators' experiences
- New developments & drilling technologies

Glossary and terminology [8]

Shale gas *refers to natural gas that is trapped within shale formations. Shales are fine-grained sedimentary rocks, that can be rich sources of petroleum and natural gas. Over the past decade, the combination of horizontal drilling and hydraulic fracturing has allowed access to large volumes of shale gas, that were uneconomical to produce. The production of natural from shale formations has rejuvenated the natural gas industry in the United States. Unconventional natural gas deposits are difficult to characterize overall, but in general are often lower in resource concentration more dispersed over large areas and require stimulation or some other extraction or conversion technology. Extremme large natural gas in-place volumes are represented by these resources, and the US has produced only a fraction of their ultimate potential.*

Shale gas is defined as natural gas from shale formations. The shale acts as both the source and the reservoir for the natural gas. Older shale gas wells were vertical, while more recent are primarily horizontal and need artificial stimulation, like hydraulic fracturing to produce. Only shale formation with certain characteristics will produce gas. The most significant trend in US natural gas production is the rapid rise in production from shale formations. In large measure this is attributable to significant advances in the use of horizontal drilling and well stimulation technologies and refinenment in the cost-effectiveness of these technologies. Hydraulic fracturing is the most significant of these [2-7].

Shale oil *(also known as **tight oil** or **light tight oil**) is a petroleum play, that consist of light crude oil contained in petroleum – bearing formations of low permeability, often shale or tight sandstone. Economic production from tight oil formations requires the same hydraulic fracturing and often uses the same horizontal well technology used in the production of shale gas. It should not be confused with oil shale, which is shale rich in kerogen.*

Tight oil shale formation are heterogeneous, they vary widely over relatively short distances, thus even in a single horizontal drill hole the amount recovered may vary, as may recovery within a field, or even between adjacent wells.This makes evaluation of plays decisions regarding the profitability of wells on a particular lease difficult. Production of oil requires some natural gas, oil cannot be produced from a portion of a formation, which contains *only oil. Formation, which formed under marine conditions contain less clay and are more brittle, and thus more suitable for fracking than formations in fresh water, which may contain more clay. Formations with more quartz and carbonate are more brittle [8-9].*

Annulus: *The space between two concentric objects, such as between the wellbore and casing or between casing and tubing, where fluid can flow.*

Aquifer: *The sub-surface layer of rock or unconsolidated material that allow water to flow within it. Aquifers can act as sources of groundwater, both usable fresh water and unusable saline water.*

Casing: *Steel pipe placed in a well and cemented in place to isolate water, gas and oil from other formations and maintain hole stability.*

Carbonates: *Sedimentary rocks, that are rich in calcium or magnesium carbonate such as limestone or dolomite. The dissolution spaces (vugs) associated with these types of rock can contain oil or gas.*

Completion: *The activities and methods of preparing a well for the production of oil and gas.*

Flowback: *The flow of fracture fluid back to the wellbore after the hydraulic fracturing treatment is completed.*

Formation: *A formation consists of a number of rock units that have a comparable lithology, facies or other similar properties. Formations are not defined on the thickness of the rock units they consist of and the thickness of different formations can therefore vary widely.*

Horizontal drilling: *A drilling procedure in which the wellbore is drilled vertically to a kick-off depth above the target formation and then angled through a wide 90 degree arc such that the producing portion of the well extends horizontally through the target formation.*

Hydraulic fracturing (aka ´fracking´): *A method of improving the permeability of a reservoir by pumping fluids such as water, carbon dioxide, nitrogen or propane into the reservoir at sufficient pressure to crack or fracture the rock. The opening of natural fractures or the creation of artificial fractures to create pathways by which the oil can flow to the wellbore.*

Multi-stage fracturing: *The process of undertaking multiple fracture stimulations in the reservoir section where parts of the reservoir are isolated and fractured separately.*

Permeability: *The ability of the rock to pass fluids or oil through it. The higher the permeability number, the greater the amount of fluid or oil that can flow trough the rock. Permeability is measured in a unit called Darcies. Conventional reservoirs may have permeabilities in the 10´s to 100´s of milliDarcies or occasionally Darcy range. Unconventional or tight reservoirs usually have permeabilities in the micro to nanoDarcy (one millionth of a milliDarcy) range.*

Play: *The extent of a petroleum-bearing unit within a formation.*

Porosity: *The free space within the fine grained rock that can store hydrocarbons.*

Propping agents/proppants: *Non-compressible material, usually sand or ceramic beads, that is added to the fracture fluid and pumped into the open fractures to prop them open once the fracturing pressures are removed.*

Reservoir: *The rock that contains potentially economic amounts of hydrocarbons.*

Reclamation: *The act of restoring something to a state suitable for use.*

Stimulation: *Any process undertaken to improve the productivity of the hydrocarbon bearing zone (e.g., formation fracturing).*

Sweet spot: *The specific area within the reservoir where a large amount of gas is accessible.*

Vug: *A small cavern or cavity within a carbonate rock.*

Acknowledgment

This work was supported by the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences, grant No 1/0228/12.

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