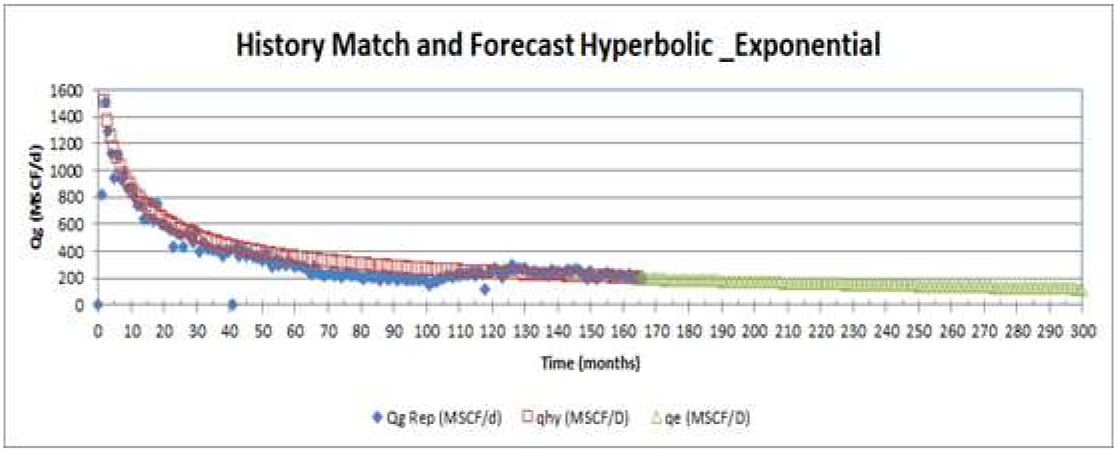
CHAPTER 9 ADDITIONAL NOTES AND ANNEXES

Engineering Economics Topics in Hydrocarbon Subsurface_ a Bibliographical Review Handbook



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Engineering Economics Topics in Hydrocarbon Subsurface _a Bibliographical Review Handbook

Chapter 9 Additional Notes and Annexes

Along previous chapters the importance of the reserves issue was indicated, also in Chapter 5 and more specifically in the section Hydrocarbon Reserves Estimates Risk the use of Decline Curve Analysis (DCA) was mentioned as a procedure to estimate reserves.

As DCA is a common method ***Annex 1*** includes a summary of the theory and equations pertaining to production forecasting, based on Decline Curve Analysis (DCA) and normalized curves for shale gas and oil. It also presents a spreadsheet to estimate production profiles based on DCA.

Annex 2 is a summary of some Oil and Gas Rights Concepts applicable in the United States as a complement of the topics presented in Chapter 8.

Annex 1 Decline Curve Analysis

Decline Curves are one of the oldest and most common means of forecasting production because:

- They are easy to plot
- Yield results on a timely basis
- Are easy to analyze

Decline curves are a plot of production or production rate versus time. The equations that will be used on the associated spreadsheet are the following and the additional comments apply in each case.

Exponential Decline

When the logarithm of a producing rate is plotted versus linear time, a straight line often results. This behavior is referred to as "exponential decline" or "constant percentage decline." The equation corresponding to this situation can be written as follows:

$$q = q_i \, e^{(-D\ t)}$$

$$D = \left[\ln\left(\frac{q_i}{q}\right)\right]/t$$

$$H_p = \frac{q_i - q}{D}$$

Where:

q = producing rate at time t, vol/unit time

q_i = producing rate at time 0, vol/unit time

D = nominal exponential decline rate, 1/time

t = time

e = basis of natural logarithms, (2,71828…..)

D*t = has to be dimensionless to use any system of units

q and q_i are expressed in the same units

H_p = hydrocarbon cumulative production

i.e., Oil (N_p) or Gas (G_p

Any set of units can be used if time cancels out

Hyperbolic Decline

Often the data will not plot as a straight line on semi-log scale, but instead will be concave upward. This situation, in which the decline rate continuously decreases with time, can be modeled with a hyperbolic equation. A special case of hyperbolic decline is known as ***harmonic*** decline. The equation, which is most useful for decline curves, follows:

$$q = q_i \, (1 + b \, D_i \, t)^{-1/b}$$

$$H_p = \frac{q_i^b}{\langle 1-b \rangle \, D_i} \left[q_i^{(1-b)} - q^{(1-b)} \right] \quad \text{For b < 1}$$

$$H_p = \frac{q_i}{D_i} \, ln \frac{q_i}{q} \quad \text{For b =1 or } \textbf{\textit{harmonic}}$$

Where:

q = producing rate at time t, vol/unit time

q_i = producing rate at time 0, vol/unit time

D_i = initial nominal exponential decline rate (t = 0), 1/time

b = hyperbolic exponent

t = time

H_p = hydrocarbon cumulative production

i.e., Oil (N_p) or Gas (G_p).

Any set of units can be used if time cancels out

When:

- b is equal to zero, this representation is the same as the ***exponential decline***
- b is equal to 1.0 the decline is called ***harmonic***

Therefore, in a way situations the real decline data is hyperbolic, with exponential and harmonic being special cases.

As **b** increases the life of the production and the remaining reserves also increase.

Spreadsheet for Production Decline

As the main idea of this work is not the arithmetic but the concepts, it was included a spreadsheet that handles the equations already presented. The proposed spreadsheet for calculation follows.

	Fill out the following cells on the next tabs		
	Delta t		Time increment to complete Column B
	q abndn (SCF/D)		Economic limit rae to end the forecast
	Set time format		Select if the time format will be days, months, or years
For the Harmonic and Hyperbolic			
	Di		Adjust Di acoordingly to time format selected
	b		
For the exponential case			
	time	**qe (SCF/D)**	
	0		fill the rate for the first two time periods
	1		
For the Harmonic and Hyperbolic			
	time	**$q_{hy\ or\ ha}$ (SCF/D)**	
	0		fill the rate for the first time periods

Description	**Exponential**	**Hyperbolic**	**Harmonic**
Declination b	0	>0, NO=1	1
Rate	q = qi*e^(-D*t)	q = qi*(1+b*Di*t)^(-1/b)	q = (qi)/(1+Di*t)
Cumulative Production	Gp = (qi-q)/D	Gp = ((qi^b)/(Di*(1-b)))*(qi^(1-b)-q^(1-b)	Gp = (qi/Di)*Ln(qi/q)*t
Nominal Decline Rate	De = (qi-q)/qi	De = (qi-q)/qi	Di = Dei/(1-Dei)
Efective Decline Rate	De = 1-e^(-D)	De = 1-e^(-D)	Dei = (qi-q)/qi
Life	t = (Ln(qi/q))/D	t = (((qi/q)^b)-1)/(b*Di)	t = ((qi/q)-1)/Di

	Adjust Di acoordingly to time format	
Di	0,500	1/years
b	0,1	
Delta t	1	

	Exponential					**Hyperbolic**		**Harmonic**	
	q abndn (SCF/D)	8,00	**t abndn**	**years**	15,5	**t abndn**	5,7	**t abndn**	23,0
Set time format	**years**	**q_{ex} (SCF/D)**	**D_{exp} (SCF/D)/time**	**De (SCF/D)/time**	**Gp_e (SCF)**	**q_{hy} (SCF/D)**	**Gp_{hy} (SCF)**	**q_{ha} (SCF/D)**	**Gp_{ha} (SCF)**
	0	100,00				100,00		100,00	
	1	85,00	0,162519	0,150000	33688	61,39	28826	66,67	29599
	2	72,25		0,277500	62324	38,55	46712	50,00	50600
	3	61,41		0,385875	86663	24,72	58054	40,00	66889
	4	52,20		0,477994	107352	16,15	65391	33,33	80199
	5	44,37		0,556295	124938	10,74	70225	28,57	91452
	6	37,71		0,622850	139886	7,25	73462	25,00	101199

TABLE 172 Data Input and Output _ The Spreadsheet to Calculate Gas Production Decline

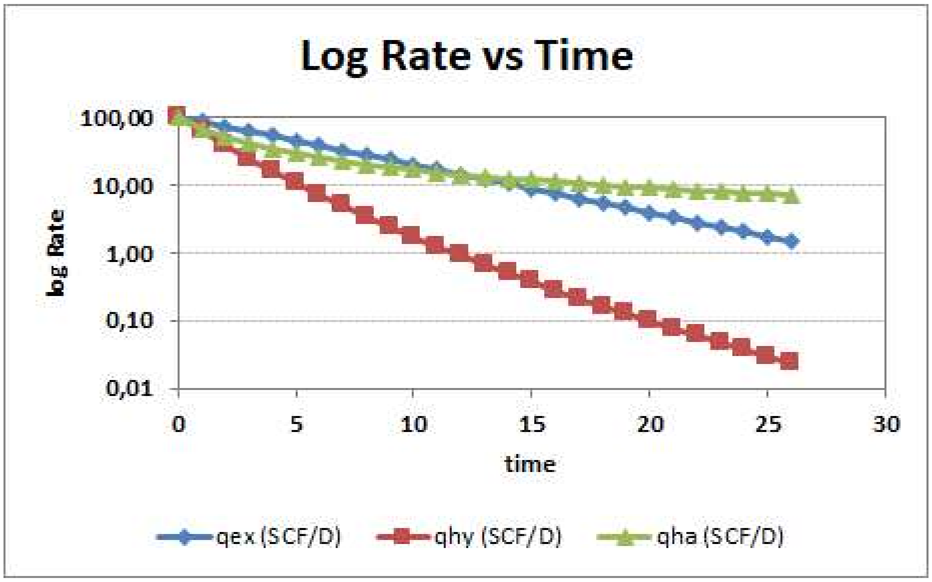


FIGURE 74 OUTPUT FROM THE SPREADSHEET TO CALCULATE PRODUCTION DECLINE

						Adjust Di acoordingly to time format			
					Di	0,500	1/years		
					b	0,5			
Delta t	1								
	Exponential					Hyperbolic		Harmonic	
	q abndn (STB/D)	8,00	t abndn	years	5,2	t abndn	10,1	t abndn	23,0
Set time format	years	qe (STB/D)	Dexp (STB/D) /time	De (STB/D) /time	Npe (STB)	qhy (STB/D)	Nphy (STB)	qha (STB/D)	Npha (STB)
	0	100,00				100,00		100,00	
	1	61,27	0,489880	0,387300	28857	64,00	29200	66,67	29599
	2	37,54		0,624599	46538	44,44	48667	50,00	50600
	3	23,00		0,769992	57371	32,65	62571	40,00	66889
	4	14,09		0,859074	64008	25,00	73000	33,33	80199
	5	8,63		0,913655	68075	19,75	81111	28,57	91452
	6	5,29		0,947096	70566	16,00	87600	25,00	101199

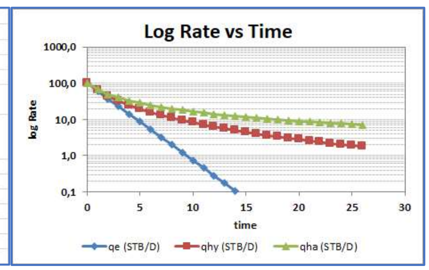


FIGURE 75 DATA INPUT AND OUTPUT _ THE SPREADSHEET TO CALCULATE OIL PRODUCTION DECLINE

DCA and Normalized Curves for Shale Gas _ Special Case

The initial production (**IP**) rate measures how many barrels of oil or standard cubic feet gas a day is produced by a new well. It is used as a proxy or an indication for the future productivity of such a well. The initial production rate is important because it is used to extrapolate to obtain an estimate of the total production of a well, its peak production level, and the rate at which production will decline, using decline curve analysis (DCA).

Producing wells (oil or gas) typically have an initial production rate that is fairly small compared to peak production, because (for example) oil production follows a bell curve shape. However, shale oil and gas wells decline much more rapidly after the initial surge.

In the case of unconventional shale gas the production from the wells declines continuously and rapidly within a month or two of initial production (IP). Gas rate can fall to 50-85% of the IP rate within a year, to less than 10% of their IP rate after three years. In some other cases the production declines 50-60% within one year and around 73% over the first two years. Higher rates of production decline mean shorter production life and a lower ultimate recovery.

For conventional hydrocarbons with only 2-3 years of production history, it is difficult to know whether production will continue to decline at the same rate or whether the rate of decline will slow down as a future hyperbolic decline curve, which has a rate of decline that diminishes over time. In the hyperbolic model the production rate declines with time according to the following relationship:

$$q = \mathrm{q}_i \frac{1}{(1 + b\, D_i\, t)^{1/b}}$$

Where:

q is the time-varying production rate

q_i is the initial production rate parameter

b is the hyperbolic decline exponent parameter 0 < b < 1

D_i is the initial decline rate parameter

Integration of this equation leads to an expression for the estimated cumulative gas production (Gp) (or the cumulative oil production (Np)).

$$Gp\ (or\ Np) = \frac{q_i^b}{D_i\,(1-b)}\,(q_{(i)}^{(1-b)} - q_{(t)}^{(1-b)})$$

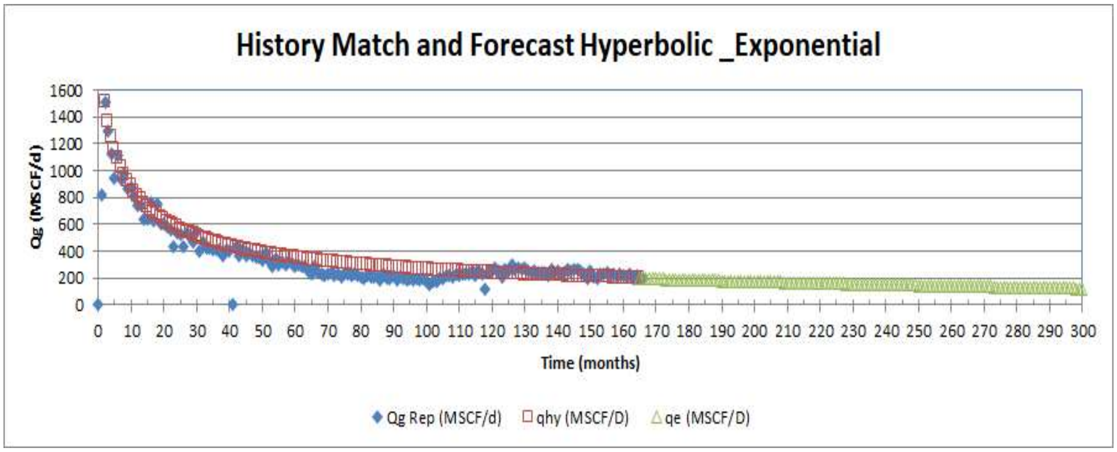
Estimating the rate of production decline is therefore essential to both forecasting production and assessing the Estimated Ultimate Recovery (**EUR**) of the well. This is the main determinant of project profitability. For these cases, the simplest methodologies for forecasting future decline rates and EUR go under the heading of Decline Curve Analysis (DCA).

Analysis of production decline for shale gas wells using hyperbolic equations typically results in a best-fit value of greater than unity for the decline exponent parameter, b. This will usually be the result when data from the transient-flow period are used to fit the entire period including boundary-dominated flow. The use of b values > 1 leads to the physically unrealistic result that cumulative production becomes unbounded as time increases. To overcome this situation, the exponential equation is used in sequence after the hyperbolic equation.

The equation for exponential decline is:

$$q_t = q_{ie}\, e^{(-D_s\, t)}$$

DD_s, which is the decline rate at the point (to be defined) where production shifts from hyperbolic to the exponential tail and q_{ie} is the rate at the end of the hyperbolic period.



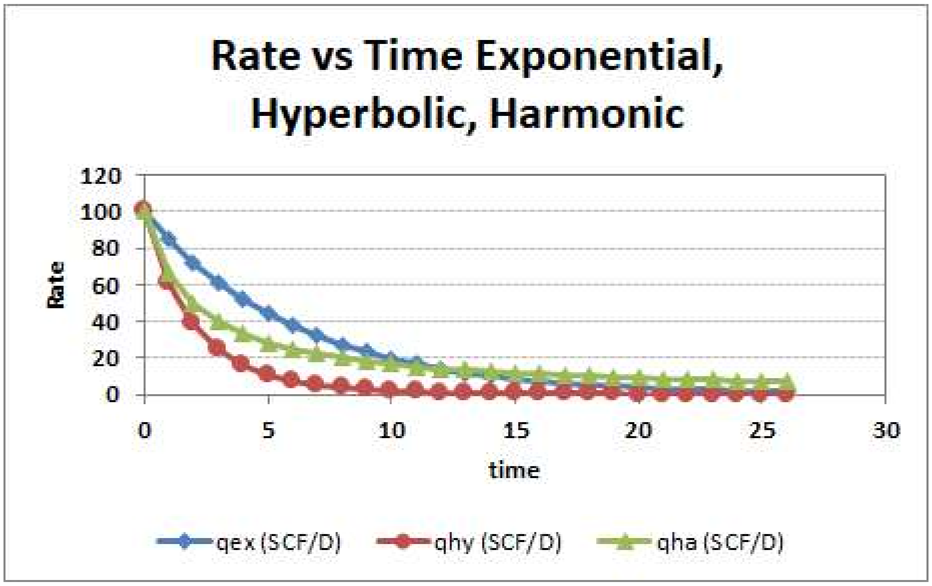
Di	0,110	1/months	
b	1,68		
Dexp	0,003524	Mscf/month	After month 165

FIGURE 76 HISTORY MATCH FORECAST HYPERBOLIC EXPONENTIAL

The parameters for these curves are usually derived by statistically fitting such curves to historical production data, with the key parameter being determined is the “b constant.” Larger values of b imply slower rate of decline of production and higher ultimate recovery.

The exponential decline curve exhibits a constant rate of decline, D (i.e., the percentage of change in production between time t and time t+1 is constant), and a plot of the natural log of production versus time takes the form of a straight line.

In contrast, the hyperbolic decline curve exhibits a reducing decline rate over time, so that a plot of production rate versus time takes the form of a curve. The b constant represents the rate at which that decline rate decreases.



e = exponential hy = hyperbolic ha = harmonic

FIGURE 77 RATE VERSUS TIME EXPONENTIAL, HYPERBOLIC, AND HARMONIC DECLINE

While the exponential decline curve is simpler, the hyperbolic curve is often found to provide a more accurate representation or model of conventional oil and gas fields, since the rate of production decline typically slows rather than remain constant.

Production from ***conventional*** gas wells typically declines less than 40% per year in the early stages, but production from ***shale-gas*** wells declines much faster, more than 60% per year. Rather than focusing on the initial rate of decline, which is apparent after only a few months of production, the key is how quickly and by how much will these decline rates reduce.

The debate has sometimes been characterized as an argument between hyperbolic and exponential decline. However, exponential decline can be viewed as a special case of hyperbolic decline, where b=0. Therefore, the key is finding the appropriate value of **b**.

The theoretical basis for a hyperbolic decline curve assumes 'boundary-dominated flow' - where the influence of the reservoir boundaries affects the flow rate behavior. In 1973 a study (Fetkovich) showed that exponential decline is the long-time solution to the diffusivity equation under conditions of constant wellbore pressure.

In normal circumstances, **b** is generally found to be between 0 and 1. However, shale-gas and other unconventional gas resources exhibit more "transient" or heterogeneous flow rates, and it is possible to fit curves with b constants higher than 1.0.

Data on shale gas decline rates is sparse, given the commercial sensitivity of this real data, but **b** constants between 1.4 and 1.6 have been used by shale gas companies currently active in the United States. However, using a b constant of 0.5 would more accurately reflect for investors the uncertainty associated to such production. This difference significantly affects the EUR/well: a **b** constant of 1.1 results typically in an estimate of 6.5 MMMSCF/well, while a value of 0.5 results in only 3.0 MMMSCF/well (billion cubic feet cumulative production). The latter is a more frequently attained value.

Guidelines from the Society of Petroleum Engineers (SPE) identify a possible range for the **b** constant of values between 0 and 1.5 for shale gas, but suggest that a conservative decline rate (lower b) be used to report proved reserve volumes. A more optimistic decline rate (higher b) may be used for proved plus probable (2P) reserves. Another approach is used by some authors with a cut-off production rate of 133 MCF/d which results in an estimated ultimate recoverable resource (EUR) of about 1.4-2.7 billion cubic feet and a well life time of 11-29 years.

On average, for the shale gas wells, the initial cumulative production before the peak rate accounts for about 7% of total well production, which means the decline curves capture most of the production. The production of such a shale-gas well usually peaks shortly after being brought on-stream, and the decline curve describes the decline phase after the peak. Thus, the highest production before the onset of decline is denoted “Initial Production (IP)”

Normalized Curves

Another way to characterize decline curves for shale gas wells has been labeled the normalized value approach. It allows many different wells to be compared directly. The production data are normalized in the sense that the maximum initial production is set to a value of 1.0, and the following monthly production figures are displayed as a fraction of this maximum rate from the initial production period ($Q_g = Q_{gi}/Q_{gMax}$).

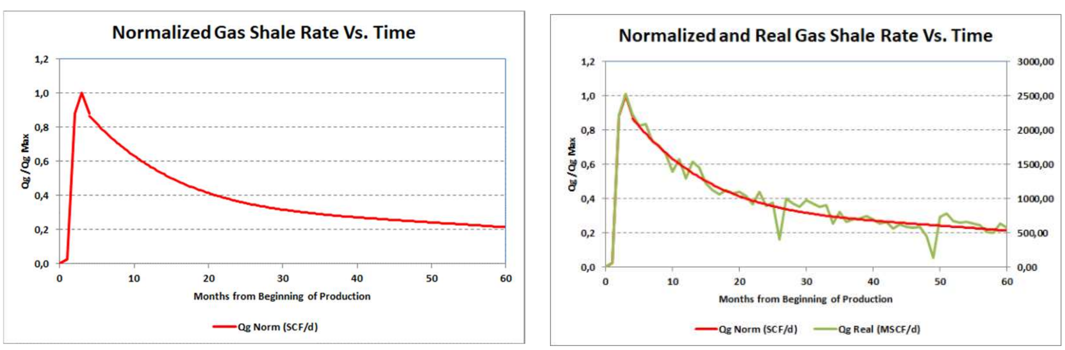


FIGURE 78 GAS RATE NORMALIZED VS. MONTHS FROM BEGINNING OF PRODUCTION

The production profile of typical shale gas wells entails a rather sharp initial decline in the production rate and, after a few months, a much slower rate of decline. This becomes very important in determining the profitability of shale gas wells versus conventional gas wells. Production in the initial several years of the well’s productive life declines hyperbolically, and at some point, the production decline levels off, reflecting an exponential (constant annual percentage) decline rate.

Characteristic decline curves can also be studied at either the average aggregate or individual well level. The “average aggregate decline curve” is fitted to the average monthly production of several wells, smoothing fluctuations and representing an average behavior for a collection of wells.

As any other production forecast entails risk that is translated to the reserves estimates and to the economic analysis of the project.

Comments on Decline Curve Analysis

The decline curves are not just academic exercises. This sort of analysis is used to help determine whether specific hydrocarbon energy development projects are likely (or not-likely) to pay off. The high initial production rate and steep initial decline is characteristic of unconventional gas wells (and is different from the slower decline in many conventional gas wells). This implies that most of a project’s revenue – sometimes as high as 80% of total project lifetime well revenues – can be accrued over the first five to seven years of the well’s producing life.

To correct for the anomaly of decline curves suggesting is some cases infinite production time, an economic “cut-off or truncation economic point” must be assumed, where the value of produced hydrocarbon drops below some assumed cost of operation. The well is then assumed to be no longer profitable, and is “shut-in.” Such calculations require assumptions about the capital and operating cost of the well, the expected price of hydrocarbon over the well lifetime and the period over which these costs should be amortized. Another way to stop a forecast is based on a hydrocarbon price, so wells are no longer profitable when producing below an economic hydrocarbon rate.

Annex 2 Oil and Gas Rights Definitions in the United States

These concepts are not intended to be the basis for legal advice. Rather, the objective is to present examples of fundamentals definitions so that non-experts can begin to familiarize with the option of participating in hydrocarbon industry-related investment projects in the USA.

Interested parties normally obtain the right to explore for and extract oil and gas by leasing that right from the owner of the mineral rights of a piece of property. The hydrocarbon interest may or may not be owned by the same person who owns the surface rights.

When the mineral rights are bought and sold separately from the surface rights, the minerals are called "***severed***." In cases where the hydrocarbon interest is sold, this may be done forever or only for a specific period.

Assets

It is an item or group of items, or a resource (mineral or otherwise) to which a value can be assigned. It could be equipment, a project, or a human resources functional group.

Authorization for Expenditure (AFE)

This is typically a standard form of presenting a financial estimation of all funds required to execute a job, for example, drill and complete a well. The estimates for AFE's are usually obtained from experience of recent expenditures in the same area where the operation will occur, drilling contractors, services companies, current catalogs, and/or a combination of all the above, etc.

Bond

This is a financial instrument for long-term debt financing. The bond is a promissory note, where the borrower agrees to repay the principal amount of the bond at a specific future date, while paying a certain amount (interest rate on the borrowed amount). Thus, bonds are characterized by a face value, a coupon rate (the interest rate applied to the face value paid to the lender), and a maturity date (when the principal amount or face value will be repaid). Bonds provide fixed income to the bond purchasers but the exchange value of the bond (buy/sell price at any time before maturity) will change continuously and in the opposite direction to the market interest rate.

Joint Ventures

It relates to the pooling of resources by two or more firms for the purpose of exploring, developing or expanding existing operations. Joint ventures can operate through anyone of a variety of business forms, but overall managerial control usually resides in a Board of Directors, or Management Committee including representatives from each venture in proportion to that partner's ownership share in the organization. Joint Ventures are particularly attractive for large capital projects in high-risk environments.

Landowner

This term is often used to mean the owner of the material interest. A landowner having the mineral rights may grant or retain the following interests associated with the mineral:

A MINERAL INTEREST

The ***holder*** of a mineral interest owns the mineral rights (or a portion of them) under a piece of property.

Whether the mineral interest holder owns the surface or not, the holder has the right to reasonable access to develop the hydrocarbons.

The holder must compensate the surface owner for any damage caused by the operations to explore for or produce the hydrocarbons.

The ***mineral interest owner*** may own all the minerals at the subsurface or may only own certain minerals like coal, oil or gas.

The owner of the mineral interest may grant a leasehold interest. In that instance, the mineral interest owner becomes the ***lessor*** and the owner of the leasehold interest is the ***lessee***. The lessor usually retains a royalty interest as compensation for allowing someone else to extract the minerals in place.

A LEASEHOLD INTEREST

A leasehold interest is conveyed or transferred by the mineral interest owner (lessor) to the lessee.

The leasehold interest owner, or working interest owner, has the right to explore for and produce minerals.

A 100% ***working interest (WI)*** owner would pay all the costs to develop and produce the mineral and would receive all the revenues minus any royalty interest retained by the mineral interest owner in the leasing transaction.

The leasehold interest is created by a legal agreement (a lease). It is subject to any provisions contained in the agreement. Common lease provisions are:

- The primary term: Leases area usually in effect for a period of one to ten years (called the primary term)
- Lease bonus: The lessee pays a "sign-up" bonus to the lessor to induce him to sign
- Delay rentals: Unless operations are commenced on or before one year from the effective date of the lease, the lease terminates unless the lessee pays a delay rental

- Shut-in gas well provisions: A lessee can hold the lease beyond the primary term by paying an amount equal to the annual delay rental if there is a completed gas well on the lease which is shut in
- Cessation of production clause: Leases normally provide that if a well becomes incapable of production, the lessee must commence reworking or drilling operations within 60 days or lose the lease if the primary term has expired
- Pooling clause: Pooling applies to the *aggregation* of small areas of land necessary to form a drilling unit (acreage needed for one well)
- Unitization clause: Unitized area includes the entire reservoir. Without specific pooling or unitization terms in the lease agreement the lessee may not commit the leased acreage to a unit or pool without the consent of the royalty owner

A Royalty interests

In addition to the bonus, the lessee agrees to pay the lessor a certain percentage of the money received from the sales of hydrocarbons. The lessor does not have to pay any of the costs of drilling and equipment of the wells or the costs of treating the hydrocarbons. The lessor pays the severance, ad-valorem, and windfall profit tax.

Assigned Rights

The owner of the leasehold interest or working interest owner may convey or assign rights provided for the lease agreements. These rights terminate when the lease expires. Some rights are:

- Overriding Royalty Interest: This is like a landowner's royalty. The holder of an override receives a portion of the production fee clear of all costs. An override is created from the share of the leasehold revenue
- Revisionary Interest or Back-in: This happens when an override reverts to working interest at some specific moment e.g., at payout
- Carried interest: This is an interest which is not responsible for any costs and does not receive any revenue until a certain condition is met
- Net Profit Interest: It receives a portion of the net proceeds from a well after all costs have been paid. The net profits interest is different from the carried interest, because the latter shares in the costs and receipts after a set of specified conditions have been met while a net profit interest continues for the duration of the production. On an unsuccessful well, a working interest will lose money while a net profit interest will not share in the losses
- Production Payment: This is a share of the hydrocarbon produced from a lease, free and clear of costs of production, terminating when a given amount of oil and/or gas has been produced or when a given amount of money from the sale of those hydrocarbons has been realized

Non-operating Interest

In taxation language, this term refers to royalty, overriding royalty, and net profits interest. This is an interest that is not burdened with the cost to find, develop and produce the minerals. In some other cases, the non-operating interest is the working interest of owners that are not responsible for the day-to-day operational decisions that the operator must make. Working interest owners are loaded with the cost of finding, developing, and producing the minerals.

Operating Agreement

It is a necessary component to any hydrocarbon deal, because several entities could share the cost and revenues associated with an oil and gas lease. Some examples clauses in an operating agreement (OA) could be:

- Cost and Revenue Sharing: Identify the working interest (WI) and net revenue interest (NRI) from each party. The working interest (WI) of players is their fractional share of 100% of the costs, and the net revenue interest (NRI) of the players is their fractional share of 100% of the revenues. These concepts might be different for land and legal departments.
- Operator Responsibility: The operator is required to conduct the operations in a professional manner. Any operation done must be undertaken on a competitive basis; even if the operations are performed using equipment owned by the operator, the charges must be competitive
- Expenditure Limits: The OA limits the amount that the operator can spend on a single project before prior approval is required from all parties. Any major operation requires the consent of all parties subject to certain non-consent clauses
- Non-Consent Clause: When all the parties do not consent to a proposed job, a provision of the OA should specify how the costs and revenues are to be shared if the job is undertaken
- Accounting Procedures: The accounting procedure to be used should address how direct costs, overhead, and pricing of material purchases, transfer, and dispositions will be handled

Operating Interest

For the Internal Revenue Service (IRS) of the United States federal government, the operating interest is any interest in minerals in place that is burdened with the cost of development and operation of the property.

Operator of an Asset

This is the entity which is responsible for the day-to-day management activities. Operators get approvals for their activities and are reimbursed for their costs by the non-operators. An operator must be designed to carry out the terms and obligations of the lease for the parties. The operator's specific activities and limitations should be clearly specified in an Operating Agreement.

Partnerships

This is the formalized relationship between two or more persons or corporations who join to carry on a trade or business. A drawback under this business format is that each partner is individually liable for the acts of every other partner made in the name of the firm.

References

1. Contemporary Engineering Economics A Canadian Perspective. Chan S. Park, Kenneth C. Porteous, Kenneth F. Sadler, Ming J. Zuo. Addison Wesley Published Limited 1995
2. Oil Property Evaluation. John D. Wright Thompson-Wright Associates 1985
3. Weisstein, Eric W. "Triangular Distribution." From Math World--A Wolfram Web Resource. https://mathworld.wolfram.com/TriangularDistribution.html
4. Oil Sand Evaluation Project, Rolando García University of Alberta MENG625 assignment, 1996
5. Mine Investment Analysis D. W. Gentry, T. J. O'Neil Society of Mining Engineers 1984
6. The issues related to Shale Gas: from the estimation of reserves to the methods of development and production Jorge Manuel Portas-Basto. Masters thesis in Mining and Geological Engineering May 2014From gas shale bibliography
7. A Process to Evaluate Unconventional Resources. Phillip Chan, John R. Etherington and Roberto Aguilera. SPE 134602
8. Microsoft® Encarta® 2009. © 1993-2008 Microsoft Corporation
9. Ingeniería Económica. George Taylor 1990 Editorial Limusa
10. Statistics for Petroleum Engineers and Geoscientists. J. L. Jensen, L. W. Lake, P. W. Corbett, and D. J. Geoggin. Prentice Hall PTR 1997
11. Manual for Planning, Designing, Execution, and Evaluation of Hydraulic Fracturing Operations - A Systematic Approach. Martin Essenfeld and Rolando García Lugo. egep. 2020
12. Decline Curve Analysis Using Type Curves 1973 AIME SPE paper 4629. Fetkovich, M.J.
13. Roberto Aguilera, Naturally Fractured Reservoirs Second Edition, PenWell Books
14. Alvarado V, Manrique E. Enhanced Oil Recovery Field Planning and Development Startegies, Elsevier 2010
15. Petroleum Economics, Institute of Petroleum Engineering, Heriot-Watt University
16. https://www.investopedia.com/terms/e/equity.asp#:~:text=Equity%2C%20typically%20referred%20to%20as%20shareholders%27%20equity%20%28or,was%20paid%20off%20in%20the%20case%20of%20liquidation.
17. Contemporary Engineering Economics A Canadian Perspective Chan Park, Kenneth Porteous, Kenneth Sadler, Ming Zuo. Addison -Wesley Publisher Limited. 1995
18. Ownership and control of oil resources Feb 22, 2018 https://www.kaieteurnewsonline.com/2018/02/22/ownership-and-control-of-oil-resources/
19. Unitisation – the oil and gas industry's solution to one of geology's many conundrums. Hunton Andrews Kurth LLP https://www.lexology.com/library/detail.aspx?g=69912ce0-127d-447e-8a47-50f5d235dcfa
20. Oil and Gas Unitization: Specific Considerations for Cross-Border Unitization by Philip Weems and Nina Howell https://www.kslaw.com/blog-posts/oil-gas-unitization-specific-considerations-cross-border-unitization
21. An In-Depth Look At The Different Types of Crude Oil https://setxind.com/upstream/in-depth-look-at-crude-oil/#:~:text=%20When%20crude%20oil%20is%20classified%20based%20on,between%2022.2%20%C2%B0API%20and%2010%20%C2%B0API.%20More%20
22. Oil Markers: Useful Pricing Tools by Eugene M. KhartukovMay 5, 2019 https://oilmanmagazine.com/article/oil-markers-useful-pricing-tools/#:~:text=Generally%20speaking%2C%20three%20major%20markers%20used%20in%20pricing,used%20for%20Persian%20Gulf%20and%20the%20Asian%20markets.

23. Lease Financing: Types, Advantages and Disadvantages https://www.yourarticlelibrary.com/financial-management/lease-financing-types-advantages-and-disadvantages/43833
24. The renewable energy strategies of oil majors – From oil to energy? Author links open overlay panelMatthias J.Pickl https://www.sciencedirect.com/science/article/pii/S2211467X19300574
25. Historical Crude Oil Prices (Table) Oil Prices 1946-Present https://inflationdata.com/articles/inflation-adjusted-prices/historical-crude-oil-prices-table/
26. Statistics for Petroleum Engineers and Geoscientists. Jensen J. L., Lake L. W., Corbett P. W., Goggin D. J. Prentice Hall PTR 1997
27. Utility Theory https://saylordotorg.github.io/text_risk-management-for-enterprises-and-individuals/s07-01-utility-theory.html#:~:text=Any%20theory%2C%20which%20proposes%20to%20capture%20preferences%2C%20is%2C,is%20very%20important%20in%20the%20discipline%20of%20economics
28. Sea change: offshore safety and the legacy of Piper Alpha 20 Aug 2013 (Last Updated January 31st, 2020 07:55) https://www.offshore-technology.com/features/feature-piper-alpha-disaster-anniversary-offshore-safety/
29. Natgas.info Vivek Chandra, appeared in Vol. 17, No. 6 - 2020 of GeoExPro magazine. Gas Pricing http://www.natgas.info/gas-information/what-is-natural-gas/gas-pricing-contracts
30. Enhanced recovery Methods for Heavy Oil and Tar Sands. James G. Speight. University of Trinidad and Tobago. Gulf Publishing Company 2009
31. Managerial Finance in a Canadian Setting. Peter Lustig, Randall Morck, Bernard Schwab. 1994 John Wiley & Sons Canada Limited
32. Understanding normal distributions https://www.scribbr.com/statistics/normal-distribution/ Pritha Bhandari. Revised on January 19, 2021.
33. Oil and Gas Royalties Law and Legal Definition | USLegal, Inc. [McCullough v. Almach, 188 Okla. 434 (Okla. 1941)]
34. https://assets.kpmg/content/dam/kpmg/pdf/2015/03/A-Guide-to-Oil-and-Gas-Taxation-in-Canada-web.pdf
35. https://www.investopedia.com/terms/e/equity.asp#:~:text=Equity%2C%20typically%20referred%20to%20as%20shareholders%27%20equity%20%28or,was%20paid%20off%20in%20the%20case%20of%20liquidation.
36. Contemporary Engineering Economics A Canadian Perspective Chan Park, Kenneth Porteous, Kenneth Sadler, Ming Zuo. Addison -Wesley Publisher Limited. 1995
37. https://www.investopedia.com/terms/e/equity.asp#:~:text=Equity%2C%20typically%20referred%20to%20as%20shareholders%27%20equity%20%28or,was%20paid%20off%20in%20the%20case%20of%20liquidation.
38. https://www.investopedia.com/terms/e/equity.asp#:~:text=Equity%2C%20typically%20referred%20to%20as%20shareholders%27%20equity%20%28or,was%20paid%20off%20in%20the%20case%20of%20liquidation.
39. Contemporary Engineering Economics A Canadian Perspective Chan Park, Kenneth Porteous, Kenneth Sadler, Ming Zuo. Addison -Wesley Publisher Limited. 1995
40. Ownership and control of oil resources Feb 22, 2018 https://www.kaieteurnewsonline.com/2018/02/22/ownership-and-control-of-oil-resources/

41. Unitisation – the oil and gas industry's solution to one of geology's many conundrums. Hunton Andrews Kurth LLP https://www.lexology.com/library/detail.aspx?g=69912ce0-127d-447e-8a47-50f5d235dcfa
42. Oil and Gas Unitization: Specific Considerations for Cross-Border Unitization by Philip Weems and Nina Howell https://www.kslaw.com/blog-posts/oil-gas-unitization-specific-considerations-cross-border-unitization
43. https://www.investopedia.com/terms/e/equity.asp#:~:text=Equity%2C%20typically%20referred%20to%20as%20shareholders%27%20equity%20%28or,was%20paid%20off%20in%20the%20case%20of%20liquidation.
44. Contemporary Engineering Economics A Canadian Perspective Chan Park, Kenneth Porteous, Kenneth Sadler, Ming Zuo. Addison -Wesley Publisher Limited. 1995
45. Ownership and control of oil resources Feb 22, 2018 https://www.kaieteurnewsonline.com/2018/02/22/ownership-and-control-of-oil-resources/
46. Unitisation – the oil and gas industry's solution to one of geology's many conundrums. Hunton Andrews Kurth LLP https://www.lexology.com/library/detail.aspx?g=69912ce0-127d-447e-8a47-50f5d235dcfa
47. Oil and Gas Unitization: Specific Considerations for Cross-Border Unitization by Philip Weems and Nina Howell https://www.kslaw.com/blog-posts/oil-gas-unitization-specific-considerations-cross-border-unitization
48. An In-Depth Look At The Different Types of Crude Oil https://setxind.com/upstream/in-depth-look-at-crude-oil/#:~:text=%20When%20crude%20oil%20is%20classified%20based%20on,between%2022.2%20%C2%B0API%20and%2010%20%C2%B0API.%20More%20
49. Oil Markers: Useful Pricing Tools by Eugene M. KhartukovMay 5, 2019 https://oilmanmagazine.com/article/oil-markers-useful-pricing-tools/#:~:text=Generally%20speaking%2C%20three%20major%20markers%20used%20in%20pricing,used%20for%20Persian%20Gulf%20and%20the%20Asian%20markets.
50. Lease Financing: Types, Advantages and Disadvantages https://www.yourarticlelibrary.com/financial-management/lease-financing-types-advantages-and-disadvantages/43833
51. The renewable energy strategies of oil majors – From oil to energy? Author links open overlay panelMatthias J.Pickl https://www.sciencedirect.com/science/article/pii/S2211467X19300574
52. Historical Crude Oil Prices (Table) Oil Prices 1946-Present https://inflationdata.com/articles/inflation-adjusted-prices/historical-crude-oil-prices-table/
53. Statistics for Petroleum Engineers and Geoscientists. Jensen J. L., Lake L. W., Corbett P. W., Goggin D. J. Prentice Hall PTR 1997
54. Utility Theory https://saylordotorg.github.io/text_risk-management-for-enterprises-and-individuals/s07-01-utility-theory.html#:~:text=Any%20theory%2C%20which%20proposes%20to%20capture%20preferences%2C%20is%2C,is%20very%20important%20in%20the%20discipline%20of%20economics

55. Sea change: offshore safety and the legacy of Piper Alpha 20 Aug 2013 (Last Updated January 31st, 2020 07:55) https://www.offshore-technology.com/features/feature-piper-alpha-disaster-anniversary-offshore-safety/
56. Natgas.info Vivek Chandra, appeared in Vol. 17, No. 6 - 2020 of GeoExPro magazine. Gas Pricing http://www.natgas.info/gas-information/what-is-natural-gas/gas-pricing-contracts
57.
58. https://www.investopedia.com/terms/e/equity.asp#:~:text=Equity%2C%20typically%20referred%20to%20as%20shareholders%27%20equity%20%28or,was%20paid%20off%20in%20the%20case%20of%20liquidation.
59. Contemporary Engineering Economics A Canadian Perspective Chan Park, Kenneth Porteous, Kenneth Sadler, Ming Zuo. Addison -Wesley Publisher Limited. 1995
60. Ownership and control of oil resources Feb 22, 2018 https://www.kaieteurnewsonline.com/2018/02/22/ownership-and-control-of-oil-resources/
61. Unitisation – the oil and gas industry's solution to one of geology's many conundrums. Hunton Andrews Kurth LLP https://www.lexology.com/library/detail.aspx?g=69912ce0-127d-447e-8a47-50f5d235dcfa
62. Oil and Gas Unitization: Specific Considerations for Cross-Border Unitization by Philip Weems and Nina Howell https://www.kslaw.com/blog-posts/oil-gas-unitization-specific-considerations-cross-border-unitization
63. An In-Depth Look At The Different Types of Crude Oil https://setxind.com/upstream/in-depth-look-at-crude-oil/#:~:text=%20When%20crude%20oil%20is%20classified%20based%20on,between%2022.2%20%C2%B0API%20and%2010%20%C2%B0API.%20More%20
64. Oil Markers: Useful Pricing Tools by Eugene M. KhartukovMay 5, 2019 https://oilmanmagazine.com/article/oil-markers-useful-pricing-tools/#:~:text=Generally%20speaking%2C%20three%20major%20markers%20used%20in%20pricing,used%20for%20Persian%20Gulf%20and%20the%20Asian%20markets.
65. Lease Financing: Types, Advantages and Disadvantages https://www.yourarticlelibrary.com/financial-management/lease-financing-types-advantages-and-disadvantages/43833
66. https://www.britannica.com/science/statistics/Sample-survey-methods#ref367546
67. Thermal Recovery, Michael Prats, SPE 1982

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