Decline Curve Analysis and Production Forecast Studies for Oil Well Performance Prediction.

Abstract:

This report is focused on the study of reservoir fundamentals, reservoir drive mechanisms, and future production rate using decline curve analysis. Decline curves are one of the most extensively used forms of data analysis employed in evaluating reserves and predicting future production. The decline-curve analysis technique is based on the assumption that past production trends and their controlling factors will continue in the future. The theory was followed by several examples question from Book "Reservoir Engineering by Tarek Ahmed" used for the practical demonstration, standard curves were generated on python using exponential, hyperbolic and harmonic decline model equations from which comparative study of production decline rate trend analysis was carried out. Further the focused is to define the application of those graph that can predict the future decision.

Introduction.

Petroleum Engineers face the difficult task of predicting the future life of producing wells in a petroleum reservoir and more significantly estimating recoverable oil and gas reserves. This has been a major challenge in the oil and gas industry over years. For this, oil and gas productions and reserves have to be properly forecasted. Wrong forecast of oil and gas productions can lead to insignificant cost and failure of various oil recovery techniques. Several techniques have been adopted in literature to predict the amount of oil and or gas production rate with time. These include the material balance, decline curve analysis, volumetric calculations, pressure transient analysis and reservoir simulation, among others. However, decline curve analysis has proved to be one of the most commonly method for determining the most probable future life of wells and estimation of its future production when there is available and sufficient production history data. [1] [2]

Theoretical Background:

Naturally occurring hydrocarbon systems found in petroleum reservoirs are mixtures of organic compounds that exhibit multiphase behavior over wide ranges of pressures and temperatures. These hydrocarbon accumulations may occur in the gaseous state, the liquid state, the solid state, or in various combinations of oil, liquid, and solid. These differences in phase behavior, coupled with the physical properties of reservoir rock that determine the relative ease with which gas and liquid are transmitted or retained, result in many diverse types of hydrocarbon reservoirs with complex behaviors.

The ability of a reservoir to store and transmit fluids is governed by its fundamental properties such as porosity, permeability, fluid saturation, and pressure. Porosity determines the storage capacity of the reservoir, while permeability controls the ease with which fluids can flow through the rock.

Frequently, petroleum engineers have the task to study the behavior and characteristics of a petroleum reservoir and to determine the course of future development and production that would maximize the profit. [2]

Method and Data Used.

The study was conducted using a structured methodology combining theoretical learning, data analysis, and practical implementation. Initially, reservoir engineering fundamentals and decline curve theory were studied using *Reservoir Engineering Handbook* by Tarek Ahmed.

Decline curve model such as exponential, hyperbolic, and harmonic were applied to the example data using Python programming. Python (using NumPy, Pandas, Matplotlib, and SciPy) was used for curve fitting, parameter estimation, and automated forecasting. The results from different decline models were compared to evaluate their applicability under varying reservoir conditions. [2]

Model Equations: [3]

$$q_t = \frac{q_i}{(1 + bD_i t)^{1/b}}$$

$$D = -\frac{d(\ln q)}{dt} = -\frac{1}{q}\frac{dq}{dt}$$

where q_t = gas flow rate at time t, MMscf/day
q_i = initial gas flow rate, MMscf/day
t = time, days
D_i = initial decline rate, day $^{-1}$
b = Arps' decline-curve exponent

<u>So</u>

Exponential	$b = 0$	$q_t = q_i \exp(-D_i t)$
Hyperbolic	$0 < b < 1$	$q_t = \dfrac{q_i}{(1 + bD_i t)^{1/b}}$
Harmonic	$b = 1$	$q_t = \dfrac{q_i}{(1 + D_i t)}$

<u>For Cumulative Production Rate</u>:

$$G_p = \int_{t_1}^{t_2} q_t \, dt$$

Exponential b = 0: $$G_{p(t)} = \frac{(q_i - q_t)}{D_i}$$

Hyperbolic 0 < b < 1: $$G_{p(t)} = \left[\frac{(q_i)}{D_i(1-b)}\right]\left[1 - \left(\frac{q_t}{q_i}\right)^{1-b}\right]$$

Harmonic b = 1: $$G_{p(t)} = \left(\frac{q_i}{D_i}\right)\ln\left(\frac{q_i}{q_t}\right)$$

The following production data are available from a dry gas field:

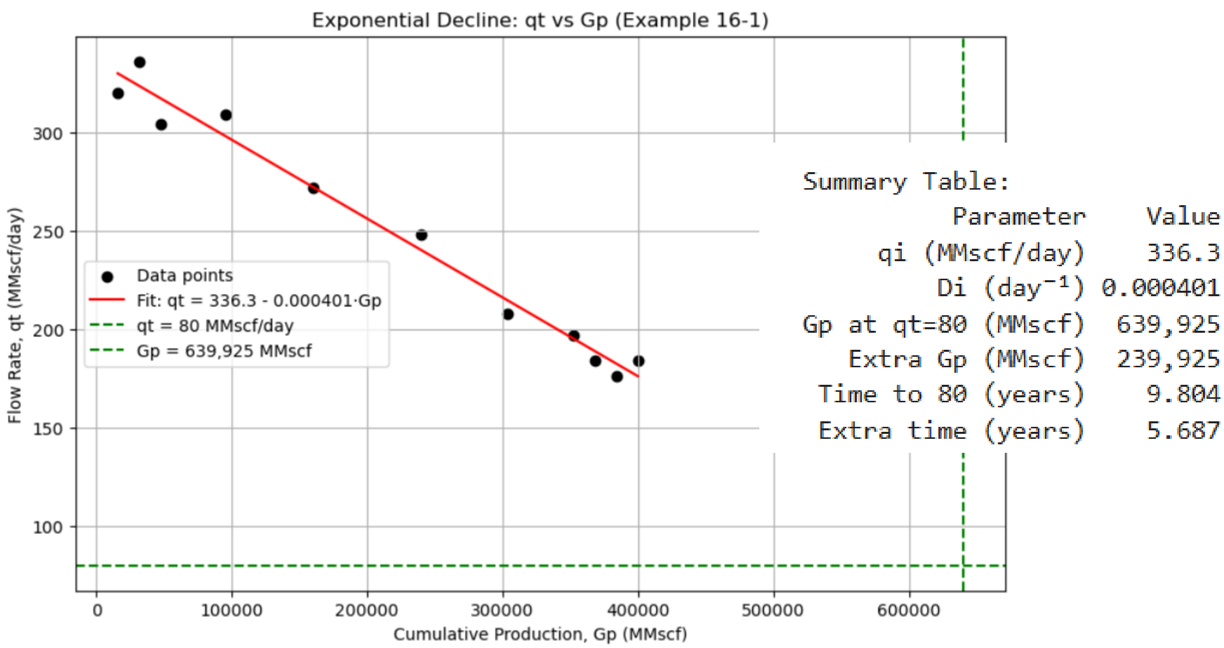
q_t, MMscf/day	G_p, MMscf	q_t, MMscf/day	G_p, MMscf
320	16,000	208	304,000
336	32,000	197	352,000
304	48,000	184	368,000
309	96,000	176	384,000
272	160,000	184	400,000
248	240,000		

Estimate

(a) The future cumulative gas production when the gas flow rate reaches 80 MMscf/day

[2] (b) *Extra* time to reach 80 MMscf/day

This is the example of Exponential Decline Model:



<u>Application in Project Decision Making</u>:

*A 'b' factor of 0 often suggests that the reservoir has strong, constant pressure support. This is typically indicative of a **strong water drive** or a **very large gas cap** that maintains constant pressure in the production zone. Engineers interpret this to mean that the decline is predictable and not rapidly accelerating due to pressure depletion, which influences confidence in long-term forecasts. By plotting the rate verses cumulative production and extrapolating the straight line to an economic limit (80 MMscf/day), we can predict the total volume of oil the field will produce over its life cycle. This large-scale reserve estimate of approximately **578,947 MMscf** allows management to determine the overall commercial viability of the entire field, report reserves to regulatory bodies and investors, and value the asset for potential sale. The calculation that it will take an extra **1,829 days** (or 5 years) to reach the abandonment rate of 80 MMscf/day provides a clear timeline for the operations team. They can use this timeframe to for Budgeting and Resource management. This constant decline rate enables accurate forecasting of future revenue streams, which is crucial for Investment Planning and economic Limit.* [4] [3]

Example 16-3

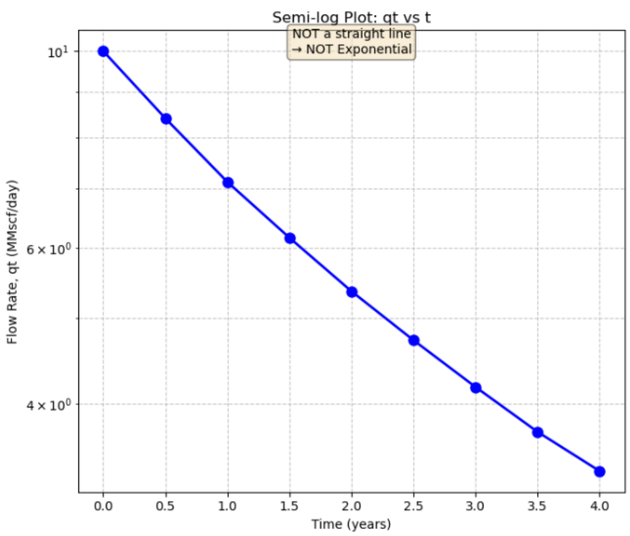
The following production data were reported by Ikoku (1984) for a gas well:

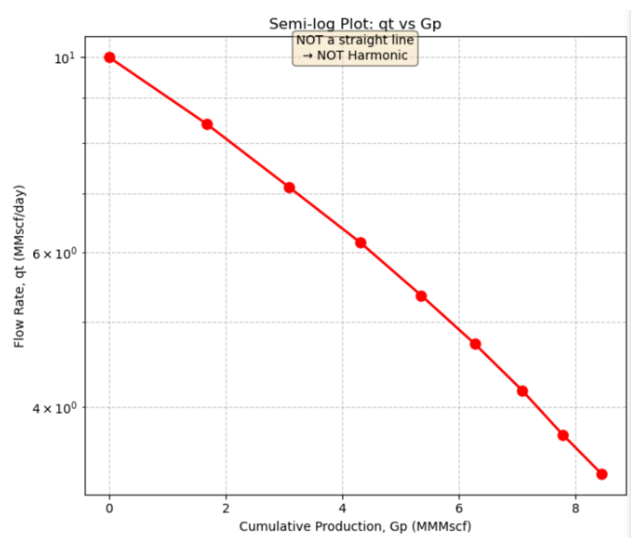
Date	Time, years	q_t, MMscf/day	$G_{p(t)}$, MMscf
Jan 1, 1979	0.0	10.00	0.00
Jul 1, 1979	0.5	8.40	1.67
Jan 1, 1980	1.0	7.12	3.08
Jul 1, 1980	1.5	6.16	4.30
Jan 1, 1981	2.0	5.36	5.35
Jul 1, 1981	2.5	4.72	6.27
Jan 1, 1982	3.0	4.18	7.08
Jul 1, 1982	3.5	3.72	7.78
Jan 1, 1983	4.0	3.36	8.44

Estimate the future production performance for the next 16 years.

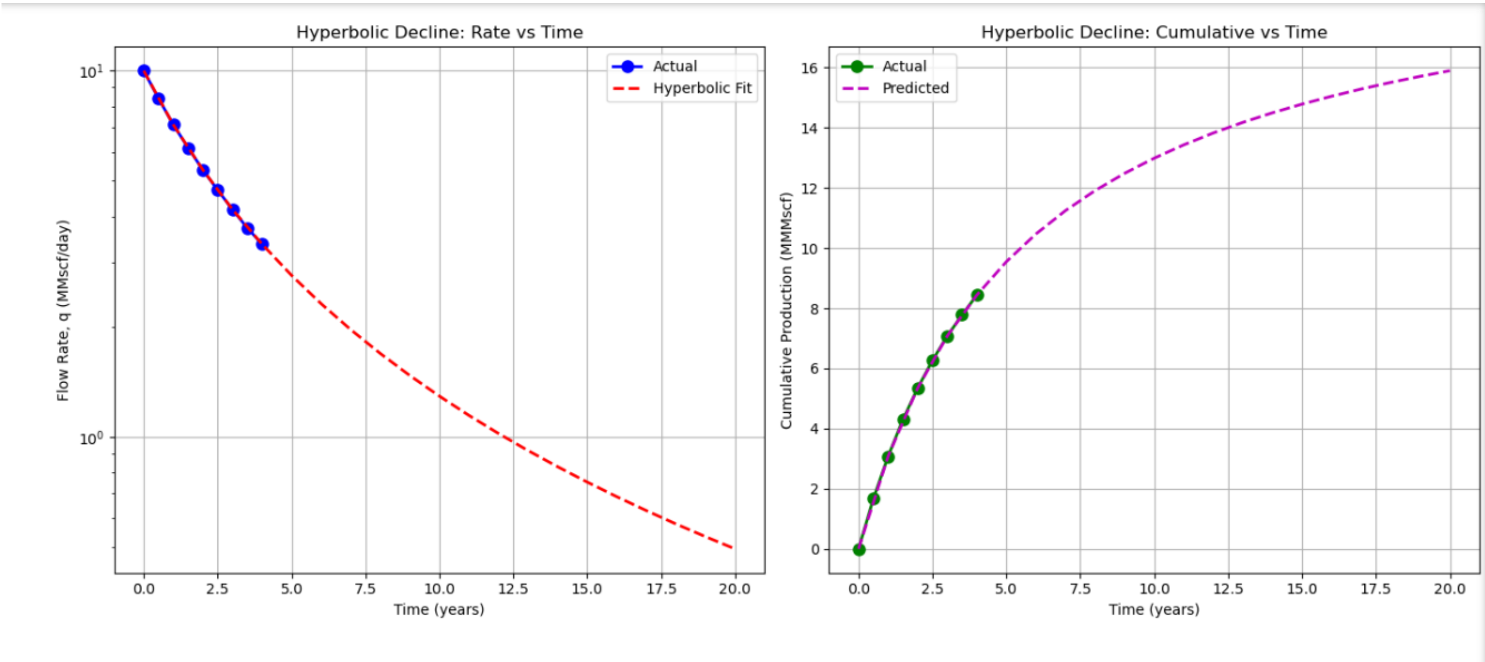
[2]

Solution: Checking which curve is this.





so, it is hyperbolic decline curve.



SUMMARY OF HYPERBOLIC DECLINE PARAMETERS

Parameter	Value
Initial rate (qi)	10.0 MMscf/day
Decline exponent (b)	0.527659
Initial decline rate (Di)	0.368608 $year^{-1}$
Di (monthly)	0.030717 $month^{-1}$
Di (daily)	0.001010 day^{-1}
Endpoint (t2, q2)	(4.0 years, 3.36 MMscf/day)
Midpoint (t1, q1)	(1.714 years, 5.797 MMscf/day)

Application in Project Decision Making:

*The value of the hyperbolic exponent **'b'** is a key diagnostic that informs about the reservoir's energy source (drive mechanism). A 'b' factor around 0.5 often indicates a **solution-gas drive** mechanism. This knowledge helps to decide on appropriate field development strategies, such as whether implementing secondary recovery methods (like water or oil injection) early might improve overall recovery efficiency. The calculated Estimated Ultimate Recovery of approx. **42.87 MMscf** is a vital figure for asset valuation, investment decisions, bank financing, and fulfilling regulatory reporting requirements. It provides confidence in the long-term value of the oil well. The forecast of an additional **34.43 MMscf** of production over the next 16 years helps in planning infrastructure needs. Operations teams can use this cumulative volume forecast to ensure existing pipelines, compression, and processing facilities are sufficient for the remaining life of the field, and to schedule eventual abandonment and decommissioning activities far in advance.* [4] [3]

CONCLUSION:

Decline curve analysis for both wells reveal varying reservoir characteristics and, therefore, management models. Well A corresponds to an exponentially declining conventional oil well, where oil is reduced at a uniform rate of 15.2% annually, ensuring 5.7 years of oil production and an additional 231,578 MMscf of oil reserves. In contrast, Well B portrays hyperbolic oil wells, common in unconventional oil fields, where oil is reduced at a steeper rate in the early years (b=0.52) but can be produced for more than 20 years. This requires continued investments in development, including in-fill wells and potential oil well retracting. Both models, therefore, stress the need for proper application of oil well models depending on oil well types, whether hyperbolic for development and in-fill wells in unconventional oil fields, where model updates are required periodically as additional oil production data is realized. [1] [4] [2]

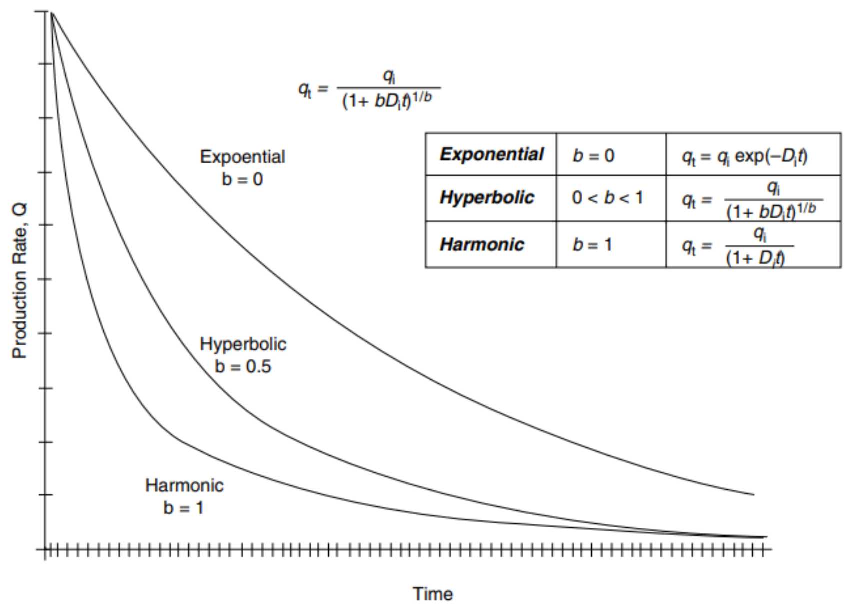


Figure 16-2. Decline curve-rate/time (*exponential, harmonic, hyperbolic*).

References

[1] A. E. Annan and Boah, *The International Journal of Engineering and Science (IJES)* .

[2] T. Ahmed, Reservoir Engineering Handbook.

[3] A. J.J, "Decline Curve Analysis," in *Reservoir Engineering Handbook*, 1945.

[4] A. W. ALQATTAN, "Application of Decline Curve Analysis," *The research repository at West Virginia University,* 2020.