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New Tool Determines Reserves of Mature Oil & Gas Fields

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Oil has been produced worldwide for well over a century and more than 40 thousand oil fields have been discovered so far[1,2,3]. Of the known discovered reserves of these fields – estimated at 2.4 trillion barrels – 94% are concentrated in fewer than 1,500 major fields defined as those with more than 100 million barrels of reserves. For the US, the tally is over 30 thousand oil fields of which roughly 300 are majors with 80% of the total US reserves. The North Sea has a total of about 265 oil fields of which 90 are major fields which account for 80% of total reserves. Saudi Arabia has 96 oil fields altogether. Worldwide, the top 100 oil fields account for 50% of current production and 65% of reserves. More than 90% of the world's oil fields are classified as small and hold just 3% of reserves. A small oil field is defined as one with less than 25 million barrels of reserves.

The tally of gas fields discovered is not as straightforward as it is for oil since gas comes from multiple sources: fields of non-associated gas only, fields with both non-associated gas and oil reservoirs, unconventional (CBM and shale gas) 'fields', and gas associated with all oil fields. Associated gas accounts for a significant 16% of total output; this percentage varies considerably from about 10% in Russia, 25% in the US to almost 100% in Saudi Arabia, Venezuela and elsewhere. With the exception of the US, production and reserves statistics do not differentiate source details. Estimates of the global number of non-associated gas fields are in the range of 28 thousand. There are about 365 giant non-associated gas fields compared with 370 giant oil fields. Giant gas fields account for roughly 75% of the total ultimate reserves discovered of 13.8 quadrillion cubic feet (qcf) or 2.3 trillion barrels of oil equivalent; giant oil fields account for a similar percentage.

A giant oil or gas field is one with more than 500 million barrels of oil equivalent reserves – that is roughly 3.5 trillion cubic feet (tcf) of gas. More than 90% of the world's gas fields are classified as small and hold 12% of total reserves. A small gas field is defined as one with less than 0.25 tcf of reserves. The tally of US gas fields is around 24 thousand of which roughly 300 are major fields with reserves greater than 1 tcf.

In 2000-2008 on average worldwide 214 oil fields and 58 gas fields have been discovered annually. The average size of these fields is 28 million barrels and 1.7 tcf, respectively.

The Big Three oil producers – the US, Russia and Saudi Arabia – together hold 600 billion barrels of ultimate reserves or one-quarter of the total oil reserves discovered globally to date. They have all past their peak production[4] and it is estimated that 80% of their oil production

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[1] "World Energy Outlook", IEA, 2008..
[2] "Largest US oil and gas fields", EIA, Aug. 1993
[3] Ivanhoe, L.F. and G. C. Leckie, "Global oil, gas fields, sizes tallied, analyzed", O&GJ, Feb. 15, 1993
[4] Sandrea, R., "An In-Depth View of Future World Oil & Gas Supply – *A Quantitative Model*", Oil & Gas Journal Online Research Center, Jan. 2009.
http://www.pennenergy.com/index/resourcecenter/reports/new_future_global.html

today comes from mature fields – that is fields that have past their peak. Time to peak varies with the size of the field (Equation 4). It would normally occur as early as 2 years after production start-up in a field with 100 million barrels of reserves or as late as 28 years in a 100 billion barrel field akin to Ghawar. Real peak times are usually longer, however, as conservation, economics and policy considerations alter the field's natural production profile.

There are many reasons – economic, pre-audits, strategic planning for EOR, among others – that call for the size or ultimate reserves of a field. Fundamentally, there are three ways to estimate reserves and two of these – volumetric and material balance – require sensitive geologic and engineering data at the reservoir level that are highly proprietary to the operators. A field may consist of several reservoirs, varying from about 3 in Saudi Arabia to 15 in Venezuela, grouped in the same geological structure, each of which has to be evaluated individually for its reserves and then summed together for the field.

The only method of directly estimating reserves for the entire field is decline analysis. Although this methodology only requires knowledge of the field's production history, this information is also proprietary and therefore sparsely available.

The huge number of mature fields – the IEA estimates the figure at half of the total oil fields – calls for an agile method for estimating reserves. This article develops a model that would provide an estimate of reserves based only on the peak production rate of an oil or gas field. Some unexpected physical variations in the behavior of oil and gas fields are brought to light.

The Model

In earlier articles[5,6] the following power relationship between peak production and field size was firmly established with real data from both oil and gas fields:

$$q_{peak} = a\,K^{b} \qquad (1)$$

q is the field peak production rate and K its ultimate recoverable reserves; a and b are constants specific to oil or gas fields. The power relationship is derived from the familiar logistic production decline model.

The algorithm for oil fields is:

$$K = 11 \bullet 10^{-5} \bullet (q_{peak})^{\mathbf{1.6}} \qquad (2)$$

with a correlation coefficient (r^2) of 0.996. The units for q_{peak} and K are thousand barrels a day (kb/d) and billion barrels of oil (Bbo), respectively.

For gas fields, the corresponding algorithm is:

$$K = 0.012 \bullet (q_{peak})^{\mathbf{0.951}} \qquad (3)$$

with a correlation coefficient (r^2) of 0.994. For the purpose of this analysis, the units for q and K are in oil equivalent, kboe/d and Bboe, respectively. The original field units in cubic feet (cf) were converted to barrels of oil equivalent using a factor of 6,000 cf per barrel.

[5] Sandrea, R., "Estimating new field production potential could assist in quantifying supply trends", Oil & Gas Journal, May 22, 2006

[6] Sandrea, R., "Equation aids early estimation of gas field production potential", Oil & Gas Journal, Feb. 9, 2009

Results

Five oil fields and six gas fields covering a spectrum of oil provinces were used to establish the correlations shown in Fig. 1. The ultimate reserves of each field were determined by production decline analysis – considered the standard; the peak production rates are actual field values. The basic data is summarized in Table 1. For the oil fields, the mean deviation between the reserves obtained by the model algorithm (Equation 2) and the decline standard was 5.3%. For the gas fields, the mean deviation was 3.3 % for the values estimated with Equation 3.

Contrary to intuitive expectation that the trend lines for oil and gas fields would be parallel, it turns out that they intersect each other at about K= 10 Bboe or 60 tcf. This indicates that the production potential of the vast majority (99%) of gas fields – those smaller that 60 tcf – is lower than that of oil fields of comparable size. On the other hand, the production potential of supergiant gas fields – those larger than 60 tcf – is much higher than that of oil fields of equivalent size. The dissimilarity in the slopes of the two correlations is apparently not due to the lithology of the reservoir. This premise was tested using a mix of carbonate and sandstone oil and gas fields.

The model was applied to a diverse set of 17 oil and gas fields from around the globe for which reliable data on their size and field peak production rate is available. Table 1 summarizes the recoverable reserves values obtained using Equations 2 and 3 which are compared with the standard values. The average deviation for the oil fields is 4.6%, and for the gas fields, 3.3%. This is extraordinary that the ultimate reserves of an oil or gas field can be estimated with a reliability of 95% based on a single parameter – its peak production rate.

The model was then used to estimate the ultimate reserves of Ghawar, a number that has been elusive with approximations ranging from 75–95 billion barrels. According to the recent IEA Outlook, Ghawar peaked at 5,588 thousand b/d, 29 years after production start-up in 1951. These two facts can now be used to obtain a fresh estimate of its reserves. Equation 2 indicates that Ghawar's reserves are about 110 billion barrels. This value can now be used to check its time to peak using the following algorithm[4]:

$$t_{peak} = 5 \bullet K^{\mathbf{0.37}} \qquad (4)$$

The calculated value of 28 years is evidently a good match with the known field peak time of 29 years. The units of t and K are years and billion barrels of oil, respectively.

The model algorithm depends on a single factor – field peak rate. While this simplicity enhances its versatility it also limits its applicability in fields subject to practices/conditions that compromise the attainment of the field's natural peak rate, such as, conservation, capacity caps on production and pipeline facilities, and policy considerations. The latter affects many important fields in the Persian Gulf. Ghawar was an exception. It peaked prior to its first major shut-in in 1981/82. The Snorre field in the North Sea is a good example of the effect of production caps. When the field was first appraised estimates of its oil reserves were 1.4 billion barrels. These reserves have a production potential of 367 kb/d according to Equation 2. Development plans for the field called for installing an initial production capacity of 186 kb/d with subsequent upgrades to 245 kb/d and 360 kb/d. The latter expansion was never realized. The field went on-stream in 1992 and evidently could never produce beyond 245 kbd; its decline began after 2003. A cursory glimpse of its production history would show that the field 'peaked'

[4] Sandrea, R., "An In-Depth View of Future World Oil & Gas Supply – *A Quantitative Model*", Oil & Gas Journal Online Research Center, Jan. 2009.
http://www.pennenergy.com/index/resourcecenter/reports/new_future_global.html

at 245 kb/d which, according to the model-Equation 2, would indicate reserves of 730 million barrels or roughly half of its real value.
Finally, it should be pointed out that the model is applicable only to single fields and not to a cluster of several fields like, for instance, the Cantarell complex; grouping distorts the production profile.
In regard to gas fields, it was difficult to obtain data for major fields other than those used in the correlation; auspiciously, the resulting correlation is first-rate in that 4 of the 6 fields used, showed no deviation between the estimated reserves and the standard decline values (see Table 1). In fact, for fields with reserves less than 30 tcf – this covers 99% of all gas fields – the model algorithm, Equation 3, reduces to a simple linear expression:

$$K = 10 \cdot q_{peak} \qquad (5)$$

with units of tcf and bcfd, respectively. This algorithm can also be used inversely to estimate the production capacity of newly discovered reserves.

Final Comments

- A model was developed to provide a quick estimate of the reserves of mature oil and gas fields based on a single parameter – the peak production rate of the field. The model provides estimates with a 95% confidence level and is applicable to individual fields which were produced without any operational limitations that ultimately repress their true peak rate. The method is particularly useful because it obviates the need for decline analysis which requires the complete production history of the field and may not be always available.
- For the majority of gas fields – those smaller than 30 tcf – a simple rule-of-thumb applies: the size of the field is 10 times its peak production rate. Conversely, for newly discovered gas fields: the production potential of the field is one-tenth of its reserves.

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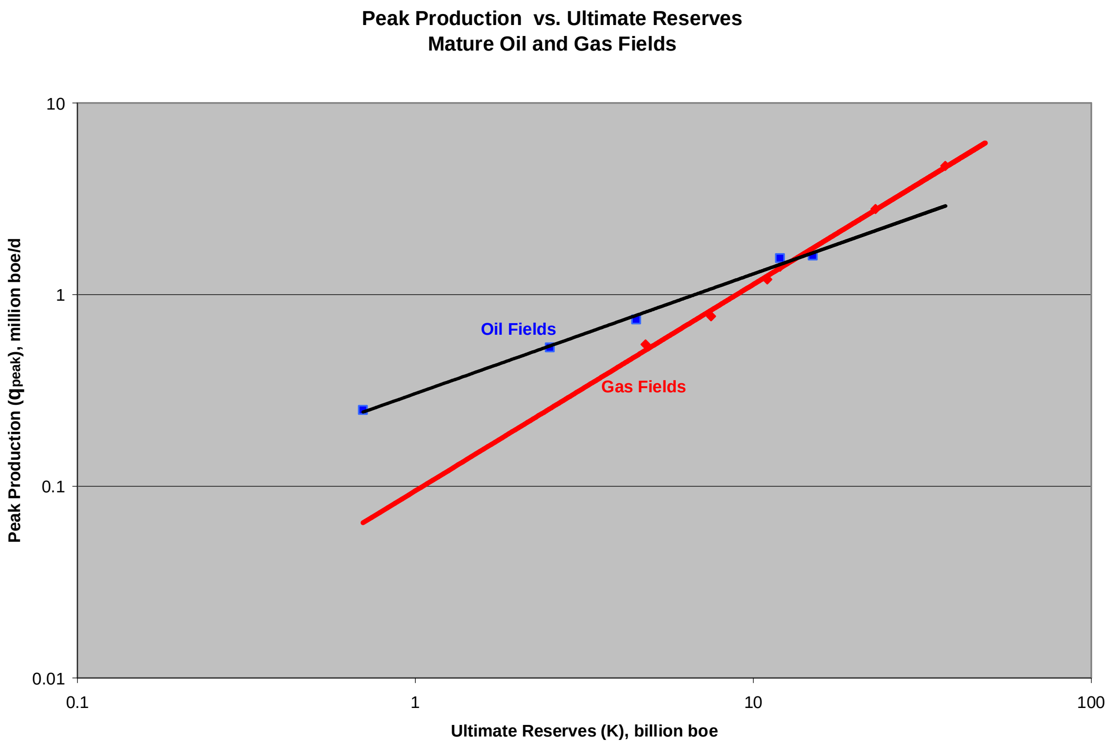
Table 1. Comparative Estimates of Ultimate Reserves for Selected Oil & Gas Fields

Field (Country)	Production Began Year	Peak Year	Field Peak Production kb/d	Ultimate Reserves, Bbo		% Difference
				Decline[1]	Model[2]	
Oil Fields						
Abkatun (Mexico)	1979	2004	548	2.4	2.6	8.3
Brent (UK)	1975	1984	483	2.0	2.1	5.0
•Cusiana (Colombia)	1992	1998	250	0.71	0.75	5.6
•Forties (UK)	1975	1979	523	2.5	2.4	4.0
Furrial (Venezuela)	1986	1998	454	2.0	2.0	0
Gulfaks (Norway)	1982	1994	530	2.5	2.5	0
Marlim (Brazil)	1991	2002	602	2.7	3.0	11.1
Oseberg (Norway)	1988	1994	503	2.3	2.3	0
•Prudhoe Bay (US)	1977	1988	1,500	12	13	8.3

•Romashkino (Russia)	1950	1972	1,645	16	15	6.2	
•Statfjord (Norway/UK)	1979	1991	641	3.5	3.4	2.8	
Gas Fields			kboe/d *bcfd*	Bboe *tcf*	Bboe *tcf*		
•Groningen (Netherlands)	1963	1977	1,400 *8.6*	12 *73*	12 *73*	0	
•Medvezhye (Russia)	1972	1983	1,200 *7.1*	11 *68*	10 *61*	9.0	
•Orenberg (Russia)	1971	1979	770 *4.6*	7.5 *45*	6.7 *40*	10.6	
•Shatlyk (Turkmenistan)	1973	1977	550 *3.3*	4.8 *29*	4.8 *29*	0	
•Urengoy (Russia)	1981	1987	4,700 *28*	37 *222*	37 *222*	0	
•Yamburg (Russia)	1985	1998	2,800 *17*	23 *138*	23 *138*	0	

Notes: • Fields used in the correlations in Fig. 1; [1]Values established by decline analysis; [2]Estimates using Equations 2 & 3.


Peak Production vs. Ultimate Reserves
Mature Oil and Gas Fields
10
1
0.1
0.01
0.1
1
10
100
Peak Production (qpeak), million boe/d
Ultimate Reserves (K), billion boe
Oil Fields
Gas Fields