Institution: Imperial College London

Unit of Assessment: 12 Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Title of case study: 9. Putting pressure information into sharp focus: the use of deconvolution to boost oilfield reserves

1. Summary of the impact (indicative maximum 100 words)

Like using glasses to improve eyesight, or the corrective lens of the Hubble telescope, the development of a stable deconvolution algorithm for oil well pressure data has increased the amount of information that can be extracted from well test analyses. The method specifically allows the volume of the reservoir connected to the well to be determined. Several oil and gas companies attest to an increase in their estimates of reserves by more than 20% using deconvolution, with one company indicating a doubling of reserves. The research has led to better design of recovery, better financial planning and more informed investment decisions in the oil and gas industry.

2. Underpinning research (indicative maximum 500 words)

Measurements of pressure and fluid production in oil, gas and water wells are used in the oil industry and in groundwater hydrogeology to determine the production capacity of wells and to describe heterogeneities and connected volume in porous fluid-bearing formations. Analysis has traditionally assumed an ideal, constant rate. The main limitation of this approach is that the durations of constant rate periods are usually small compared with the total production time. Therefore it provides only limited information on the well-reservoir system. In particular, the reservoir volume connected to the well is significantly under-estimated, often leading to the unnecessary and expensive drilling of additional wells to access the whole field. Production also has to be halted for such measurements, resulting in lost revenue.

The problem of taking all the data gathered over long production times was solved by Prof Gringarten, Dr Von Schroeter and Dr Hoellander from 2000 to 2003 in the Department of Earth Science and Engineering of Imperial College. The approach used deconvolution to correct for the effects of variable – and often uncertain – flow rates on the pressure response. Deconvolution transforms variable-rate pressure data into a constant-rate initial drawdown with a duration equal to the total duration of the test and directly yields the corresponding pressure derivative. This derivative is free from the distortions caused from errors introduced by incomplete or truncated rate histories. This deconvolved derivative is the sharp-focus pressure response from which the true behaviour of the reservoir can be identified.

Previous attempts to solve this problem only worked for the rare cases when the pressure and rates were known with virtual certainty – the equivalent of only being able to design glasses if the structure of cornea of the patient is known precisely. Prof. Gringarten and his team introduced a new method which reformulates deconvolution as a nonlinear Total Least Squares (TLSD) problem. The two main improvements are (1) a nonlinear encoding of the reservoir response which makes explicit sign constraints obsolete and (2) a modified error model which accounts for errors in both pressure and rate data. The new method is capable of deconvolving smooth, interpretable response functions from uncertain data [3]. This was the first stable and practical deconvolutoion algorithm in the literature: the equivalent of developing an eye test and glasses for pressure data.

This research was performed under an industry-funded project on “Alternative Methods for Testing Oil and Gas Wells to Eliminate Emissions” sponsored by BP, Conoco, NorskHydro, and Schlumberger. This algorithm was published initially in 2001 [1], with a follow-up paper in 2002 [2] and a peer-reviewed paper in 2004 combining the previous two [3]. This publication received the Carl Ferguson Award from the Society of Petroleum Engineers (SPE) in 2005 for the best paper published in 2004 by an author aged under 33 (Dr Hoellander).

3. References to the research (indicative maximum of six references)
* References that best indicate quality of underpinning research.

*[1] T. von Schroeter, F. Hoellander, A. C. Gringarten, "Deconvolution of Well test Data as a Non-linear Total Least Square Problem", in Proc. 2001 SPE Ann. Tech. Conf. Exh., Soc. Pet. Eng., New Orleans, Louisiana, (2001) Document ID: SPE 71574 DOI : 10.2118/71574-MS

*[2] T. von Schroeter, F. Hoellander, A. C. Gringarten, "Analysis of Well Test Data From Permanent Downhole Gauges by Deconvolution", in Proc. 2002 SPE Annual Technical Conference and Exhibition, Society of Petroleum Engineers, San Antonio, (2002) Document ID: SPE 77688 DOI: 10.2118/77688-MS

*[3] T. von Schroeter, F. Hoellander, and A. C. Gringarten, "Deconvolution of Well test Data as a Non-linear Total Least Square Problem", SPE Journal, Volume 9, Issue 4, pp. 375, (Dec 2004) http://dx.doi.org/10.2118/77688-PA

4. Details of the impact (indicative maximum 750 words)

The development of the Imperial deconvolution algorithm represents a major milestone in well test analysis, and the first game-changing development since the introduction of pressure derivatives in 1983. It allows better identification of reservoir characteristics and a better, more confident evaluation of reserves.

The Imperial algorithm was implemented by BP in 2004 in their well test analysis software product (PIE) which they share with Total. It was subsequently implemented in commercial software packages such as Saphir from Kappa Engineering (2007), Pan-Systems from Weatherford (who purchased the algorithm from Imperial in 2007 and implemented it in 2008), FAST from Fekete (2009). The availability of deconvolution in commercial software made it easier for operators to incorporate it in their well test analysis process.

Its use typically increases the verifiable estimate of reserves by 20%, and by more than 50% in the case of BG Group in the Santos Basin, offshore Brazil. In the latter case, the increase of the aggregate of proved and probable reserves plus discovered resources and risked exploration, that can be credited in part to deconvolution, was estimated at 3 billion barrels of oil equivalent (boe), with a value of approximately USD 300 billion [A].

In addition to benefitting oil and gas operating companies [A-D], the Imperial deconvolution algorithm has been adopted by software and consulting companies in the oil and gas sector, strengthening their market position and increasing revenues [E,F].

The following companies have provided testimonies on the impact of deconvolution on their business:

<u>Oil and gas operating companies</u>
BG indicated a 50% increase in reserves in their share of the Santos Basin, offshore Brazil, due to deconvolution combined with other interpretation techniques [Ai] and they state "*This research was instrumental in solving the deconvolution problem and the paper by von Shroeter, Hollaender and Gringarten (SPE 77688) is the industry reference…. we now use deconvolution as standard practice*."[Aii]

BP's published evaluation of the algorithm states "*We have found deconvolution analysis to be extremely useful for early detection of closed reservoir behavior. Pressure/rate deconvolution also opens new opportunities for analysis of permanent gauge pressure data. It is a valuable addition to the suite of techniques used in well-test analysis.*" [B]

Shell uses deconvolution to support de-risking of major gas developments in Europe. [C]

Petro SA were able to book additional reserves by applying deconvolution to the E-M highly compartmentalized gas condensate field in South Africa The project economics indicated an NPV of $300MM. they state "*Based on the success of the 2 wells, the financial impact was huge for the organisation because additional reserves were booked and the positive NPV is being realised…. Due to new knowledge, we could history match the models better, and predict well performance. This allowed us to plan better and estimate reserves better*." [D]

Software vendors

Kappa Engineering is a petroleum software company that holds approximately 70% of the market share in Pressure Transient Analysis, with over 10,000 users worldwide. Responding to clients' requests, they were the first to integrate the Imperial algorithm in the software in 2006 in a Beta version with an official release in 2007. They state "*it proved to be a very efficient tool combining successive build-ups into a larger equivalent test period…. As long as the engineer understands the limitations of the process, substantial engineer time can be saved for an overall analysis that is compatible with the long term behavior of the well in its drainage area. In the past, only very experienced engineers could reproduce, with a lot of trial and error, the diagnostic process that is now provided within a few seconds using the deconvolution…. It is now part of our users' day-to-day work. As the Managing Director of KAPPA Engineering I confirm that this work has been, to my opinion, by far the most important methodology development in PTA in the past twenty years*." [E]

Fekete Associates Inc state "*Alain Gringarten and his team (von Schroeter) at Imperial College overcame this problem by developing a stable Deconvolution algorithm. Since then, all the major software vendors, including ourselves, have implemented an adaptation of that algorithm….While there are still some issues with data quality, which can result in false analyses, the value of the von Schroeter-Gringarten algorithm is unquestionable. It has resulted in a better interpretation of reservoirs and quantification of reserves. Because it extends the interpretation to encompass the "total" flow duration rather than a "specific" flow period, it often translates into increased proven reserves (equivalent to 100's of millions of dollars)…..Of all the attempts at Deconvolution since the 1970's, the von Schroeter-Gringarten implementation is the only successful one, and the authors deserve the full credit and recognition by the industry, and all the encouragement to continue development in this field of knowledge*." [F]

5. Sources to corroborate the impact (indicative maximum of 10 references.)

[Ai] BG Group plc "BG Group raises Santos Basin net potential to 8 billion barrels of oil equivalent" (2011) www.bg-group.com/MediaCentre/PressArchive/2011/Pages/30June2011.aspx (Archived at https://www.imperial.ac.uk/ref/webarchive/hrf on 5th September, 2013); Pressure Transient Analyst, BG Group.

[Aii] Group Technical Authority- Pressure Transient Analysis, BG Group, to confirm the use of the research to enable deconvolution to become a standard practice.

[B] M Levitan, "Practical Application of Pressure/Rate Deconvolution to Analysis of Real Well Tests," SPE Reservoir Evaluation and Engineering, **8**(2) 113-121 (2005). DOI; 10.2118/84290-PA

[C] Chief Reservoir Engineer, Shell U.K. Limited, to confirm the use of deconvolution by Shell

[D] Acting Vice President, Petro SA to confirm the additional reserves booked due to deconvolution by Petro SA.

[E] Managing Director, KAPPA Engineering to confirm the use of the Imperial algorithm.

[F] Chairman, Fekete Associates Ltd to confirm adaption of the algorithm by oil and gas software vendors.