Institution: Edinburgh Research Partnership in Engineering – ERPE (Heriot-Watt/Edinburgh)

Unit of Assessment: B15: General Engineering

Title of case study: Oilfield Mineral Scale Management

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

One of the major problems experienced in the oil production industry is the formation of mineral scale deposited downhole within an oil reservoir and topside. The scale creates a blockage causing a detrimental effect to the productivity of the well. ERPE Research in scale management has led to the following impacts in the REF2014 period:

- Helped Shell save £3M per well per year by reducing the frequency of scale inhibiting treatments i.e. squeezes, from a treatment every six months to a yearly treatment.
- All scale service companies are required to demonstrate competence in ERPE written SQUEEZE software within tender processes. For a single contractor (Nalco Champion) in 2012 this resulted in an addition $3.5M (£2.3M) of revenue.
- [text removed for publication]

2. Underpinning research (indicative maximum 500 words)

The ERPE team of Mackay (Prof), Sorbie (Prof), Todd (Prof) have been on staff throughout the REF2014 period.

Overall, the most important outputs from the ERPE research were:

- Demonstration of the importance of reservoir mineralogy in determining how scale inhibitors are retained in reservoirs.
- The modelling of adsorption and precipitation scale inhibitor squeeze treatments in North Sea fields.
- The development of the methodology to assess the scale risk in fields at the Front End Engineering and Design stage of a project.

One of the major problems experienced in the oil production industry is the formation of mineral scale. Scale is deposited downhole within an oil reservoir and topside, throughout the water production lifecycle of a producer well. This creates formation damage (restriction / blockage within the rock matrix) and blockage of the production tubing, reducing the productivity of the well. Various forms of inorganic scales can be found in the North Sea and elsewhere and these are normally prevented using a process known as a "squeeze" treatment, where scale inhibitor chemicals are applied to the rock formation to stop scale deposition in the pipelines and to protect the wellbore area, or by continual chemical injection, which treats the topside precipitated calcium carbonate and barium sulphate scale.

Scaling problems arise in high pressure, high temperature (HP/HT) fields in the North Sea and around the World, and also in systems where low temperatures are prevalent such as long line tie-backs. In order to treat the scale that is formed under such severe conditions as these, a solid, scientifically-based understanding of the chemical processes leading to scale formation is required.

Since 1993, ERPE has developed a detailed predictive understanding of the way in which scale forms and can be treated in a wide variety of operating environments. ERPE has achieved this understanding through manufacture of specialised laboratory equipment, field condition experiments (up to 200 C and 1500 bar), and development of computer software that can model scale at the level of pore, core, well and field.

To give some context for the amount of data that ERPE has generated and analysed, our industrial partners, (e.g. BP, Petrobras, Shell, Total, Statoil, Talisman, etc), have provided water compositional analysis data and samples of core taken from numerous wells in their fields; ERPE has received 65,000 lines of 8-12 ion field brine analysis data from operators and undertaken reservoir simulation studies on 40 offshore fields for 16 companies and over 100 reservoir

condition corefloods. The data has been used to investigate the fundamental mechanisms by which generic chemicals inhibit various scales and how they are retained on various mineral substrates. [1,2,3] The work has been carried out under a wide range of conditions leading to a widespread applicability of the results of the research.

ERPE's SQUEEZE software encapsulates the results of 20 years of detailed laboratory experiments and experience in upscaling laboratory measurements to field conditions. The SQUEEZE software enabled ERPE researchers to conduct appropriate experiments to study field problems, often iterating with modelling to ensure requisite data are collected and analysed [4]. These predictions were then compared with observed field data, and the models further refined as necessary. Knowledge gained from analysis of produced water compositions and reservoir simulation calculations regarding brine displacement through the reservoir, and the impact this has on production conditions, is also used to inform recommendations for field practice [5], a process that is now routinely carried out by industry during the Front End Engineering and Design (FEED) phase of projects

3. References to the research (indicative maximum of six references)
The references identified with * are the ones which best indicate the quality of the underpinning research.

[1] * Jordan, M.M., Sorbie, K.S., Jiang, P., Yuan, M., Todd, A.C. and Taylor, K.: "Mineralogical Controls on Inhibitor Adsorption/Desorption in Brent Group Sandstone and Their Importance in Predicting and Extending Field Squeeze Lifetimes", Society of Petroleum Engineers European Production Operations Conference and Exhibition, 15-17 March 1994, Aberdeen, DOI: 10.2118/27607-MS 12 Google Scholar (GS) citations.
This paper showed that the one of the main factors determining how scale inhibitors are retained in reservoirs is the reservoir mineralogy.

[2] Neville, A., Bepoix, M., Graham, G. , and Morizot, A.P.: "Assessing the Potential of Atomic Force Microscopy to Study the Formation of Electrodeposited Calcareous Scales in Uninhibited and Inhibited Conditions", Society of Petroleum Engineers International Symposium on Oilfield Scale, 30-31 January 2002, Aberdeen, DOI: 10.2118/74653-MS
This work identified the nature of crystal growth in oilfield environments, and as a result that chemicals need not function by preventing growth across the entire crystal surface area, but just need to target the active growth site on the crystal, reducing the volumes of chemical required for inhibition.

[3] * Yuan, Ming Dong, Sorbie, K.S., Todd, A.C., Atkinson, L.M., Riley, H, Gurden, S. "The Modelling of Adsorption and Precipitation Scale Inhibitor Squeeze Treatments in North Sea Fields" Society of Petroleum Engineers International Symposium on Oilfield Chemistry, 1993, New OrleansSPE Journal, 25613 (1993) DOI: 10.2118/25163-MS 27 GS citations
The research that led to this paper established the SQUEEZE model as the standard tool for assessing scale inhibitor core floods, which are used by industry every time a new chemical is introduced to a field for scale control.

[4] Mackay, E.J., Matharu, A.P., Sorbie, K.S., Jordan, M.M., and Tomlins, R.: "Modelling Scale-Inhibitor Treatments in Horizontal Wells: Application to the Alba Field", *SPE Production & Facilities* (May 2000) 15 (2) 107-114. DOI: 10.2118/63013-PA 48 GS citations
This paper was the first to describe how to design scale inhibitor squeeze treatments in an existing horizontal well using reservoir modelling, and has been the basis on which all subsequent modelling of scale squeezes in horizontal wells has been carried out since.

[5]* Sorbie, K.S. and Mackay, E.J.: "Mixing of Injected, Connate and Aquifer Brines in Waterflooding and its Relevance to Oilfield Scaling" Journal of Petroleum Science and Engineering (July 2000) 27 (1-2) 85-106. DOI: 10.1016/S0920-4105(00)00050-4 108 GS citations.
This paper established the methodology now used by operating companies to assess the

scale risk in fields at the Front End Engineering and Design stage of a project.

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

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In the REF2014 period Shell has used SQUEEZE software to go from a treatment every six months to a treatment every 12 months, saving £3M per well per annum. A partial list of the wells for which this OPEX reduction has been achieved is Pierce B1, Guillemot P3, and some Bittern wells, leading to savings well in excess of £10M per year. [S4]

As a result of ERPE research, service companies tendering for work are required to demonstrate expertise in designing field treatment programmes using the SQUEEZE software. In the last three years, 102 industry representatives have undergone SQUEEZE training at our Edinburgh campus and at industry offices in Aberdeen, Norway, Dubai, Malaysia and USA. As examples of service company use of SQUEEZE software, we provide two quotes: Clariant Oil state that they *"use the most recently updated version of the SQUEEZE modelling software (currently SQUEEZE 8) to plan all the scale inhibitor squeeze operations that we manage for our clients. Across the global organization this equates to approximately 300 squeezes per year and protects over 500,000,000 barrels of produced water resulting in many billions of dollars of protected oil production."* [S1]

Nalco Champion *"…use the latest version of the SQUEEZE software for all our squeeze designs, which annually numbers approximately 250 squeeze treatments. Along with our current customer contracts we are required by operators to demonstrate expertise in the use of the SQUEEZE software in tendering for chemical squeeze business. In the past 12 months Nalco Champion has been able to secure contracts worth over $3,000,000 based on our ability to use the current version of this ERPE developed software."* [S2]

Prevention by inhibition is by far more cost effective than cure taking into account typical workover costs in the UK N Sea of ca. £25 M/well excluding the associated loss of production.
ERPE is a recognized world leader JIP supporting the industry in terms of learning on this key scale management area. A Production Chemistry Team Leader at Talisman Sinopec Energy UK Ltd commented that *"All the scale management activity in the North Sea that our company undertakes is impacted by the research that has been undertaken by ERPE over the past decade….Talisman-Sinopec Energy UK Limited has some fifty four wells under active scale squeeze management protecting 36,798 barrels of oil production per day. This production typically equates to a significant portion of the company's annual production and revenue.*" [S5]

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

[S1] Senior Manager within Application Development Team, Clariant Oil will advise that their company uses the SQUEEZE (Version 8) modelling software to plan all scale inhibitor squeeze operations that we manage for our clients.

[S2] Consultant, Oil Field Chemicals Team, Nalco Champion, an Ecolab Company will corroborate that they use SQUEEZE (Version 8) software for all squeeze designs, annually approximately 250 squeeze treatments. They must demonstrate expertise in the use of SQUEEZE software in tendering for chemical squeeze business.

[S3] Scale Specialist, Total will confirm that they undertook some modelling of squeeze treatments for a specific well at ERPE. The value of production of gas condensate from this well was approximately £1million daily. A 90 day shut in to install a chemical injection capillary was the alternative. Total decided to model the treatments using SQUEEZE software.

[S4] Production Chemist Shell, will confirm that ERPE's work with Shell has shown that squeezes in some of their fields cost £3million, and they have used the SQUEEZE software to go from a treatment every six months to a treatment every 12 months, saving £3m per well per annum in those fields.

[S5]	Senior member of staff within the Production Chemistry Team, Talisman Sinopec Energy UK Ltd The company has 54 wells under active scale squeeze management protecting 36,798 barrels of oil production per day. Prevention by inhibition is more cost effective than cure taking into account typical workover costs in the UK N Sea of ca. £25 millions/well excluding the associated loss of production.