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Overview of Scale Treatment in Oilfield Environments from a Technical Viewpoint

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مراجعة عامة لمعالجة الرواسب القشرية في بيئات حقل نفط من الناحية التقنية

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تنعكس التحديات المستمرة التي فرضت نفسها بسبب تزايد المشاكل الناتجة من الرواسب القشرية بالحقول النفطية في استمرارية الجهود البحثية المبذولة عالميا والمسخرة في تطوير تقنيات أفضل وأكثر حداثة في مجالي التقليل منه والتحكم فيه.

تتناول هذه الورقة بوجه عام مراجعة الطرق الكفيلة والمستخدمة للحد من مشاكل القشور المترسبة في المعدات النفطية السطحية والأخرى بداخل الآبار المنتجة مع التركيز على سلسلة مختارة من مضادات الترسب القشري المتطورة والمصممة لضمان تدفق النفط باستخدام تقنية بديلة عن التقنيات التقليدية.

لقد تم التعرض للاجابة على الأسئلة المتعلقة بمتى يجب أن تتم المعالجة وبماذا ، خاصة عندما تكون كمية المياه المصاحبة للنفط قليلة وكذلك متى يوقف ضخ مضادات الترسب القشري في عمق البئر وبما يمكن التحكم في الحالات الصعبة (مثل الآبار التي بها تشققات بالصخور الحاوية للنفط أو التي تعطي ضغطا منخفضا عند القاع).

Abstract: *The continuing challenge posed by oilfield scale is most clearly reflected in the significant ongoing global research effort dedicated to developing newer and better technologies for its mitigation and control. This paper provides an overview of the current status of topside and downhole oilfield scale control methodologies, and focuses on a selected series of anti-scaling developments that are designed to provide the oilfield flow assurance engineer with much needed alternatives to 'conventional technologies'. The question of – 'when to squeeze-treat', and 'with what' is addressed with respect to low watercut wells and also, two non-squeeze downhole anti-scaling options are described that can provide scale control in difficult well situations (i.e. fractured completions and wells exhibiting low downhole pressure).*

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INTRODUCTION

Oilfield scaling is ranked amongst the top three key flow assurance concerns in oil and gas production. If left unchecked, inorganic scale deposition can result in a myriad of production/process problems that often require time consuming and costly intervention to correct[1]. Oilfield operations commonly affected by scaling include;

(i) Drilling and Completions.
(ii) Water Injection (including produced water re-injection).
(iii) Hydrocarbon drainage.
(iv) Process operations.

Scale 'prevention' by means of chemical scale inhibitor application is now the preferred mechanism adopted by the oil industry to address mineral scaling issues. A number of 'Fluid' and 'Flow' modification technologies such as desulphation, filtration/ coagulation and water shut-off have been used by the industry for reducing scale problems, however they invariably involve chemical scale inhibitor use at some stage during their specific action to ensure complete control of scale[2,3]. Scale inhibitor application is widely regarded as the most cost-effective solution to the majority of oilfield scaling problems with continuous chemical injection and batch squeeze treatment considered as standard for managing scale in 'topsides' and 'downhole' process scenarios respectively.

The oil industry has become increasingly technologically sophisticated in its pursuit and exploitation of hydrocarbons globally, and this is most clearly demonstrated by the renewed interest in reserves that have hitherto been regarded as potentially geographically and/or geologically challenging[2,4,5]. Much effort has been directed towards the engineering and mechanistic aspects of the hydrocarbon recovery process, particularly towards the latter half of the 20th century. By contrast, it is only relatively recently that the same focus and effort has been accorded to flow assurance challenges associated with brines co-produced during hydrocarbon recovery. Scale related technology has therefore needed to develop quickly to 'catch-up' and meet the increasing demands posed by the rapidly expanding oil industry. The importance of scale technology to the success of the oil industry cannot be overstated particularly for the new generation of challenging well ventures.

This paper discusses general scaling control strategies and touches upon current trends in topsides scaling control. However, the majority of the overview concentrates on downhole scale control using chemical scale inhibitors. The question of – 'when to squeeze-treat', and 'with what' is briefly discussed with respect to low watercut wells in simple well scenarios.

Examples of alternative non-squeeze options are also discussed which are applicable to difficult well situations *i.e.* fractured completions and wells exhibiting low downhole pressure.

MINERAL SCALING

Mixed salt solutions or 'brines' are commonly associated with hydrocarbon bearing formations and will, regardless of the total dissolved salt content, be clear and continuous under the equilibrium conditions existing in the undisturbed reservoir. On first contact and throughout subsequent development and exploitation, the brine equilibrium will change, resulting in an increased potential for the more sparingly soluble salts to destabilise and phase separate out of solution. The increased scaling potential is largely dependent upon the formation waters salt loading and the physical changes that the system has experienced. In the majority of formation water self-scaling cases, calcite ($CaCO_3$) is usually the dominant scaling species, and can occur from downhole to topside depending upon the bubble point of the system.

Ingress and co-production of a sulphate rich brine-seawater with reservoir formation water during hydrocarbon recovery can result in formation sulphate scales of alkaline earth metals. The most commonly encountered scales are. barite ($BaSO_4$), celestite ($SrSO_4$), anhydrite ($CaSO_4$) or gypsum ($CaSO_4.2H_2O$). Sulphate scales present greater challenges as their sparingly soluble nature makes them more difficult to control and remove once formed compared to carbonate scales. Barite scale is regarded as being particularly difficult because of its tendency to form rapidly at most temperatures, and once formed, is extremely difficult to remove[6]. In complex brine mixtures; no single scale type occurs exclusively, and therefore, multiple scaling potentials have to be considered. Scale precipitation is promoted by the relative abundance of nucleation sites. The sites do not necessarily need to be scale crystals and can be formation fines, asphaltene or corrosion particulates.

Although oilfield scale is generally thought of as primarily carbonates and/or sulphates of the alkaline earth metals calcium, strontium and barium, complex salts of iron such as the sulphides, hydrous oxides and carbonates may also form as solid deposits, resulting in similar fouling problems for oilfield operating systems[7].

SCALE CONTROL

Prevention is better than cure' is particularly relevant to inorganic scaling in the oilfield environment. At the forefront of prevention are scale inhibitors chemicals[8]. Scale inhibitors fall into two basic categories, the organophosphonates such as DTPMPA and water-soluble polymers such as PCA. New inhibitors include sophisticated molecules that exhibit anti-scaling properties common to both generic types[9]. Inorganic phosphates are also used by the industry and are considered effective for calcium carbonate scale inhibition. Their use is however limited by their tendency to hydrolyse in aqueous media to form orthophosphates that effectively have no appreciable anti-scaling capability.

Scale inhibitors function by interfering with scale crystal growth. Some molecules act primarily as crystal nucleation inhibitors where endothermic adsorption on nucleating crystal embryos causes an increase in the crystal radius required for further crystallisation and hence inhibition of the process. Others irreversibly adsorb at active crystal growth sites that effectively 'snuffs-out' further growth at these locations on the growing scale crystal resulting in growth inhibition. Inhibitors act in non-stoichometric proportions compared to the concentration of scaling ions present. Successful inhibitors are those that maintain crystal growth suppression when present even at very low concentration for extended periods of time and across the targeted physical conditions. The number and diversity of unique oilfield scaling scenarios is most clearly demonstrated by the large number of commercially available scale inhibitors.

Topsides

Topside facilities receive raw unprocessed well fluids from a number of sources that are firstly merged before entering the topsides system for processing. Scaling occurs when brines co-produced with hydrocarbons experience changes in fluid composition (through mixing), pH, temperature and pressure. Topsides processing systems, because of their very function, are prone to scaling and therefore require continuous scale inhibitor chemical application to ensure control across the plant. Although the mechanical action of process systems can create scaling hotspots throughout the system, topsides scale is generally regarded as being simpler to control than downhole scale, mainly because of the high accessibility offered by the majority of surface installations.

Prior to deployment, topside scale inhibitor is required to fulfil certain selection criteria;

(i) The chemical should be effective at low concentration for the control of water based scales specific to that system and its operational conditions.

(ii) The chemical should be benign to the system, its flowing components and any other process chemical additives used in the process.

(iii) The chemical should be readily monitorable via simple yet robust analytical techniques.

(iv) The chemical should be environmentally friendly.

Topsides Continuous Injection

In the simplest case, an onshore or offshore production installation manifolds received fluids prior to primary dehydration for bulk water removal. Incoming waters may contain scale inhibitor from. upstream squeeze operations, however additional dosing of topside inhibitor is usually necessary to provide complete control across the process system. Dosing is usually performed at the 'christmas tree' of source wells to allow sufficient mixing time prior to dosed stream merging with other fluid streams in the production manifold. In some cases additional scale inhibitor dosing is required upstream of scaling 'hotspots' where an increased scaling tendency is evident, usually caused by a specific process system action *i.e* heating/cooling of the fluid stream, low or stagnant flow regimes and also degassification systems.

Downhole Continuous Injection

Topsides scale protection can also be provided by downhole chemical injection. Although expensive to install and maintain, the downhole injection system will provide scale cover for all tubing and upstream equipment (xmas trees, safety valves, gas-lift interfaces) as well as the topsides process system tubing and interfaces. The most frequently encountered issue with downhole chemical injection systems is system failure caused by a blocked or crimped umbilical or fouled inoperable injection nozzle. Remedial interventions to correct downwell faults are expensive and can be technically challenging due to the relative inaccessibility of the downwell environment. An alternative route to deploying scale inhibitor downhole is via the well gas-lift system. For wells that have gas-lift but no downhole chemical injection system installed, this can provide a cost-effective method of deploying scale inhibitor into tubing without the expense of retro-fitting injection equipment. Gas-lift scale inhibitors are specially formulated to exist unaffected within the unique conditions that exist within the gas-lift environment[10].

Deep Downhole Continuous Injection

Deep downhole chemical injection allows scale inhibitor to be deployed at the near wellbore perforation face for scale control in situations where conventional near-wellbore scale protection methods are impractical *i.e* squeeze treating high demand wells[11]. Deep application technology is still in its infancy but may offer a realistic alternative to some of the more technically challenging scaling environments.

Downhole

Downhole scaling presents by far the greatest scaling challenges within the oil industry because of,

(i) Wellbores and near wellbore areas are relatively inaccessible.

(ii) Wellbore formations are usually complex and petrophysically heterogeneous in nature.

(iii) Routine wellbore surveillance tends to be given low status on the list of well intervention priorities.

(iv) Downhole conditions are usually significantly harsher than those experienced in any other part of the production system.

SCALE SQUEEZE INHIBITORS

Scale inhibitor chemicals are routinely used downhole wherever the risk of scale damage is predicted or suspected (from a field history perspective). For downhole application, scale inhibitors are routinely batch deployed via 'squeeze-treatment' into the near wellbore formation of the target well to achieve control of scale across the near-wellbore perforations upwards. Squeeze designs are optimised to achieve the longest 'safe' squeeze lifetime whilst minimising the well downtime. Squeeze chemicals therefore have to be retained within the reservoir and then returned at sufficient concentration within the normal produced fluids to prevent scale – for as long a time period as possible. Squeeze treatments have historically relied upon the scale inhibitor chemicals ability to interact with the formation surface through adsorption to enable the chemical to be retained within the reservoir. Precipitation type squeeze treatments provide an alternative method of retaining aqueous treatments within the reservoir by the controlled phase separation of an inhibitor-salt complex within the near wellbore formation. The precipitation squeezes can provide squeeze lifetime extension of up to three times depending upon the system anti-scaling requirements compared to its conventional adsorption squeeze analogue. Squeeze lifetime extension can be improved for both adsorption and precipitation type treatments by application of squeeze lifetime extension chemicals as part of the squeeze treatment package[12].

Squeeze Treatments

A squeeze treatment generally involves stopping production from the well concerned, followed by application of a concentrated solution of scale inhibitor that is pumped into the well and oveflushed out from the wellbore 5-25ft depending upon the perforated interval. After a shut-in period of 6-24 hours, production is resumed and the scale inhibitor leaches back into produced fluids, providing protection against scale formation until the scale inhibitor is exhausted. The performance of the squeeze treatment is usually performed via monitoring for scaling ions and scale inhibitor residuals in returning well fluids. Successful treatments are those regarded as achieving their designed lifetimes.

Squeeze Design Optimisation

In order to optimise the field performance of a squeeze chemical, the inhibitor must first be deployed correctly in the field, or coreflood tested under field conditions. Collected inhibitor residuals return data can then be used to derive a mathematical algorithm based upon conventional fluid-surface isotherms which can be used to model and sense-test new squeeze treatment designs.

Low Watercut Wells -When to Squeeze?

Low watercut wells pose unique scaling problems when their waters exhibit a significant scaling potential.

Conventional aqueous treatments are to be avoided because of the increased risk of water related formation damage, therefore non-aqueous alternatives have to be considered to avoid unwanted emulsification, wettability and water stimulation problems[13,14]. Low-watercut is commonly regarded as <5% of total production, however this interpretation can be very much operator specific. Equally important is the total produced fluid volume; if this is low *i.e.* 500bfpd then the potential precipitating mass will be restricted by the low volume of aqueous fluid, see Table 1. Ideally, scale protection should be available at first production to minimise the possibility of any scale deposition and build-up occurring downhole. This can be achieved by pre-emptively squeezing the 'dry' well with a suitable non-aqueous scale inhibitor, or by deploying non-squeezing scale inhibition options in the well if its completion permits.

Table 1. When to squeeze for low watercut wells

Water (%)	Scaling	BFPD tendency	Squeeze ?	Comments
< 5	Low	500	No	Monitor scaling ions for changes
< 5	Low	5000	No	Monitor scaling ions for changes
< 5	Medium	500	Yes	Monitor scaling ions for changes
< 5	Medium	5000	Yes	Consider pre-emptive squeeze
< 5	Harsh	500	Yes	Consider pre-emptive squeeze
< 5	Harsh	5000	Yes	Consider pre-emptive squeeze

A number of pre-emptive non-aqueous squeezing options are available, including oil soluble, oil miscible, oil dispersed and oil continuous scale inhibitors. Selection of a suitable chemical and deployment package for squeeze treating the wells is best performed by coreflood testing the candidate using representative field core under field conditions to assess for possible formation damage issues.

For watercuts >5%, the range of squeeze treatment technologies increases with the increasing level of water breakthrough. From 5-25%, alternative squeeze technologies such as emulsified scale inhibitors and tailored aqueous based treatments combined with wettability modifying agents can be deployed to provide scale control downhole while minimising the impact on production and the formation.

Squeezing – New Alternatives

Future oilfield developments are most likely to be located in the more remote challenging environments such as deep water developments, high temperature, high pressure formations and remote subsea completed wells. Scale inhibitor research and development is focussed on improving the efficiency of scale inhibitors and enhancing deployment technology to minimise the number of well interventions required to maintain scale control. The existing older technologies are constantly being optimised and improved while newer scale inhibitor technologies are under evaluation that are designed to optimise the placement of scale inhibitors in critical locations within the near wellbore formation to enhance the treatment lifetime.

Emulsified Squeeze Inhibitors

A number of emulsified scale inhibitors are currently available in the marketplace for use in squeeze treatments. Invert emulsions are generally water-in-oil emulsions where the water component contains the scale inhibitor. The emulsion package is considered as a non-aqueous package that allows oil continuity during treatment[15,16,17]. The emulsified chemicals are relatively benign to the formation whilst also achieving deeper penetration of the treatment into the formation to improve flowback character compared to their conventional aqueous based analogues. Improved retention within the formation has led to increased squeeze lifetimes.

OIL DISPERSED/OIL SOLUBLE/CRUDE OIL SOLUBLE SCALE INHIBITORS

Oil based scale inhibitors are directly applicable to low watercut wells that express significant scaling potential and also wells that suffer poor restart or that are water sensitive. The majority of commercial 'oil soluble/oil dispersed/oil continuous products still use aqueous based inhibitors in their formulation which makes them less amenable to deployment in formations that are known to be water sensitive[18,19,20]. More recently, new crude oil soluble inhibitor products have been made available that contain absolutely no aqueous based components in their formulation which should provide additional benefits when squeeze treating formations that are extremely water sensitive[21].

Impregnated Proppant

Well production can be stimulated through artificially fracturing the formation around the wellbore to increase the surface area through which hydrocarbons can enter the well.

Hydraulic fracturing is a temporary phenomenon that is maintained as long as the applied pressure is maintained. Small, strong ceramic beads or 'proppant' are injected during the hydraulic fracturing process to maintain the fracture after the well is returned to production. In most fracturing operations, large quantities of proppant are used per job, although not all proppant remains within the reservoir on back production. Ceramic proppant beads are porous and this porosity can be utilised to store solid scale inhibitor without impacting upon the mechanical integrity of the beads[22, 23].

Fractured wells are notoriously difficult to squeeze effectively, therefore application of impregnated proppant provides a useful alternative to squeeze treating wells to maintain scale control, see Figure 1. The entrapped solid scale inhibitor slowly dissolves into the aqueous phase across a long period of time, providing scale control in excess of that achievable through conventional aqueous based scale inhibitor squeeze chemistries and technologies. The technique is versatile and the nature of the scale inhibitor can be changed to reflect the demands of the targeted downhole scaling environment. The beads are pumped as a fraction of the normal proppant load (typically 5-20wt%) and start to release scale inhibitor when they come into in contact with well water. Impregnated proppant technology is particularly important for treating fractured low watercut wells as the inhibitor is in place and ready for the onset of water production. Scale control will ensue as long as the inhibitor releases above the required Minimum Inhibitory Concentration (MIC).

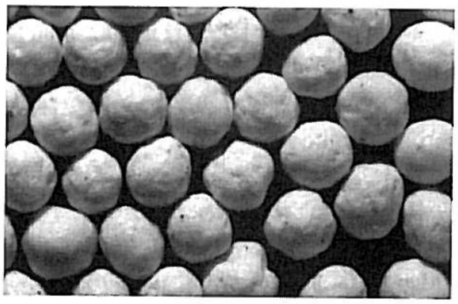

Fig. 1. Impregnated proppant beads.

Case #1

A North Sea oil well was producing 5700 bbl oil per day dry that dramatically reduced to 150 bbl per day after water breakthrough. The impairment was caused by the build up of mineral scale across the near wellbore perforations. Re-perforation did not provide the oil production increase that was expected, therefore a hydraulic fracture treatment was performed incorporating impregnated proppant to provide downhole scale control. Well production increased to 3072 BOPD, before averaging out at approximately 2600 BOPD nine months after fracturing.

Solid Encapsulated Scale Inhibitor System

Wells that have low operating pressure and/or water sensitive formations are notoriously difficult to treat using conventional scale mitigation technologies. Although non-aqueous and emulsified scale inhibitors can be used in some instances, it is considered preferable not to load the near wellbore formation with tons of injected cold fluid. If the well is fractured then repeat application with impregnated proppant should be considered, however for non fractured types or wells using submersible pumps, micro-encapsulated scale inhibitor solid particulates can be used[24,25]. The technique is most suited to vertical wells but can also be applied to deviated wells and deployed downhole in screens and inserts. The solid scale inhibitor material can also be deployed using hanging baskets or as pre-soak treatments for wash water. The weighted polymer composite comprises solid scale inhibitor (25-30wt%) encapsulated in a degradable matrix. The material acts on contact with aqueous fluid forming an inhibitor diffusion gradient from the sump to the closest water producing perforation. The well is effectively protected by the 'first-order' release of scale inhibitor into the flowing fluid stream.

Case #2

In 1999, a solid scale inhibitor treatment was targeted for a low-pressure oil producing well, where conventional aqueous squeeze treatment was considered impractical. The field had been producing oil since 1987, with seawater injection used for reservoir support since 1988. By 1999 the reservoir pressure had declined almost to an equilibrium level and no gas-lift system was in place to aid start-up and production.

The well hydrostatic head disallowed usage of conventional water based squeeze treatments to control a moderate calcium/strontium carbonate and

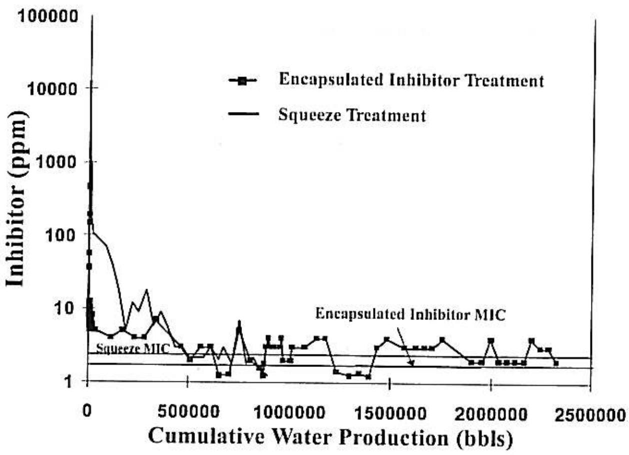

Fig. 2. Comparison of produced water volume treated by a micro- encapsulated particulate treatment and a conventional aqueous squeeze treatment performed on the same well.

barium sulphate scaling potential. Encapsulated scale inhibitor was deployed provided approximately three-times the conventional squeeze lifetime for the well with 2.5 MMbbls of water protected above MIC compared to 0.8MMbbls protected using conventional squeeze treatment technology, see Figure 2.

The encapsulated inhibitor deployment also provided significant additional benefits with respect well downtime and also ease of restarting post-treatment. From a gross costing perspective, the encapsulated treatment cost less than one third of the conventional treatment performed previously on the same well.

CONCLUSIONS

- Scale inhibitor technology has advanced rapidly over the last 15 years and is now matching the ever-increasing technical challenges posed by the oil and gas industry.
- The recognised industry standard method for scale control in oilfield systems is by application of chemical scale inhibitors.
- Many non-scale inhibitor technologies have been and are used in the industry to mitigate problems associated with scale, however in most cases scale-inhibitor application is needed to 'polish' the process.
- A range of alternative squeeze chemicals and technologies are available for controlling scale in routine and also non-routine down-well circumstances
- Low watercut wells often present significant unique challenges with respect to squeeze treatment selection and application.
- The issue of 'when to squeeze a well' can be answered by reviewing the potential risks to the well and by also reviewing the range of squeeze chemical candidates available for the conditions
- Newer alternative non-squeezing chemical options include Deep Down Chemical Injection, micro-encapsulated scale inhibitor particulates and impregnated proppant beads.

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