

Oilfield Scales Treatment and Managerial Measures in the Fight for Sustainable Production

By

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Abstract

Formation of oilfield scale is recognised as one of the major problems associated with oil and gas production. It poses a lot of serious threat in field production and it is a menace to production flow assurance, which in turn reduces the production flow resulting in production losses. Scale mitigation and management strategies are considered as a new development in the field to face the challenges. The mitigation strategies are considered as simple routine job when a fast and effective technique is employed to clean up the scale deposits or preventing further scale formation and the threat that might arise.

Keywords: Scales, Inhibitor, precipitate, production facilities, water, oilfield, production

Introduction

Oil and gas production generally contains water. This could be seawater, formation water and or injection water with which under some conditions can lead to precipitations and deposition of mineral scale, such as calcium carbonate ($CaCO_3$) and sulphates of barium, strontium, and calcium¹. This scaling can develop in the formation pores near well bore, leading to reduction formation porosity and permeability; it can also block flow by forming thick lining on the production pipe and or coat and damage down holes completion equipment. This makes the fluid flow to become worse, diminishing its ability and excellent performance, thus leading to plugging of tubing, valves, transport facilities, and surface equipment. (Fig. 1)



Figure 1: Severity of scale deposits in oilfield equipment before inhibitions treatment²

Most of the scales found in an oilfield were either as a result of water, naturally contained in a reservoir rock leading to direct precipitation or as component of produced water, which normally become oversaturated with scale as a result of two incompatible water mixtures.

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¹ Cowan, J.C. and Weintritt, D.J.: Water Formed Scale Deposit, Gulf publishing Co., Houston, Texas, USA (1976)

² Krishnam U.R; Keshabananda N.B; Nashi M.O; and Faisal G.A, Proactive scale mitigation strategies for simple to complex multilateral producers in a Saudi Arabian carbonate field, Saudi Aramco Journal of Technology Summer 2011

Generally there are possibilities for formation of scale, whenever seawater is injected to enhance oil recovery or when an oil well produces water.

In some areas such as the North Sea and Canada where the region is prone to scale, it is recognised as one of the major production menace. When scale is formed, it affects the well productivity and the facilities integrity. Thus, it is necessary to remove it or adopt a scale strategy to avoid and prevent further occurrence.

The formation of oilfield scale is recognised as one of the major problems associated with oil and gas production and considered as a serious threat in field production especially when scale mitigation strategies are under developed. However, with the recent development in the field, scale mitigation is considered a simple routine job, although it is still a challenge for complex wells³.

Effect of scale can be drastic and immediate, causing a lot of loss. For example, in one of the North Sea wells “miller field” engineers revealed that production fell from 30,000 B/D (4770 m³/d) to zero in just 24 hour as a result of scale formation⁴ which was a great shock and highly dramatic.

Scale mitigations cost the oil and gas industry a lot of money in millions of dollars. When scale is formed, a fast and effective technique is required for its removal. These techniques involve both chemical and mechanical approaches depending on the location of the scale formed and or its physical properties. Most often, mineral scale are treated base on their types. Some can be dissolved by acid treatment such as in the case of $CaCO_3$, while others cannot and sometimes the scales would have been coated with waxy hydrocarbons protecting them from chemical dissolvers.

Chemical and or mechanical techniques are employed traditionally to cut through the scale blockages. Nevertheless, some hard scales such as $CaSO_4$, show tendency to resist both mechanical and chemical treatments. Before the recent development in scale management, oilfield with hard scale in their productions are normally treated by moving work over rigs to pull the damaged tubing out of the well and either treated the scale at the surface ground or replaced the tubing by another one⁵.

Generally, scale inhibition is carried out purposely to clean up scale deposit and or to prevent further formation or any threat that might arise in other to achieve profitable smooth flow assurance.

What are Scales?

The hard deposit formed from inorganic mineral constituents of water is known as scale. Scale may adhere to the metal or other surfaces in the oil and gas production system or it may be deposited as sludge. Adhering scale presents the worst problems; deposits may consist of several different mineral scales along with other materials such as sand and hydrocarbon residue.

³ Lynn, J.D.: Development of the Ghawar Scale Squeeze Simulation Model, Using core Analysis to Evaluate Treatment Chemicals, SPE paper 25589, presented at Middle east oil show, Bahrain (1993) pp 3-6

⁴ Brown, M.: Full Scale Attack; BP Technology Magazine, Review 30, (1998) pp 30-32

⁵ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; Oil Field Review, Autumn (1999)

Scale deposition is a complex crystallization process. Most natural waters contain significant quantities of dissolved impurities, which are present as ions. Combinations of some of these ions form compounds that have low solubility in water. When the solubility limit for these compounds is exceeded (supersaturation), the compounds can precipitate as solids. The extent of the supersaturation can be thought of as the thermodynamic driving force for precipitation.

For crystallization of a compound to occur from water, three conditions must be fulfilled at the same time:

- 1) Supersaturation
- 2) Nucleation
- 3) Crystal growth (figures 2 and 3)

In an oilfield scale, water is primarily important, since scale occurs if water is produced, because water is a universal solvent and good solvent for many material, as such carry large quantities of scaling materials. This gave rise to complex fluid, rich in ions with which some are at saturated limit. Seawater tends to be rich with ions that are by-products from the activities of sea marine, decay of aquatic animals and water evaporations near surface. Ground water is chemically different from deep sub-surface water normally associated with oil and gas. Alteration in sedimentary material enriches deep surface water with ions, where by water in carbonate and calcite cemented stone reservoirs contains divalent ions such as Ca^{2+} and Mg^{2+} while sand stone formation fluid contains ions such as Ba^{2+} and Sr^{2+} ⁶. Examples of common oilfield scales include:

Acid insoluble scale:

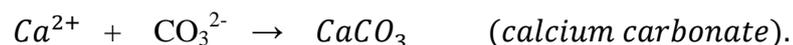
These are sulphate compounds of Barium, Strontium, or Calcium. The sulphate ion (SO_4^{2-}) normally found in the seawater reacts with these ions (Ba^{2+} , Sr^{2+} and or Ca^{2+}), which are naturally found in the formation water depending on the fields geological history.



These compounds are also mildly soluble in water and as a result they subsequently precipitate out and form solid solutions. At 25 °C temperature, $BaSO_4$ is only 2.3 mg/l soluble in water, while $SrSO_4$ and $CaSO_4$ are 114 mg/l and 2,000 mg/l respectively⁷. Thus, cannot be dissolve by water.

Acid soluble scale:

These are carbonate compounds of mostly Ca^{2+} ion; example of the most common carbonate scale is $CaCO_3$.

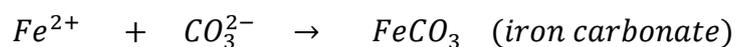


Examples of other oilfield scales are:

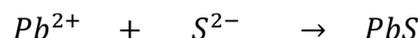
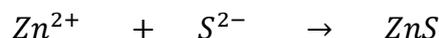
⁶ Cowan, J.C. and Weintritt, D.J.: Water Formed Scale Deposit, Gulf publisher Co., Houston, Texas, USA (1976)

⁷ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; oil field review, autumn (1999)

Iron scale: such as iron carbonate and iron sulphide.



Exotic scale: such as zinc sulphide and lead sulphide.



These compounds are all form as a result of corrosion. Others include silicate scale; associated with injection water and Halite scale such as *NaCl* associated with injection of *CH₃OH* into formation water.

Scale begins to form when the solubility limit of one or more component is exceeded from the mixing fluid which has a complicated dependence upon temperature, pressure and salinity of the fluid. Typically, increase in temperature increase solubility. Similarly, decrease in pressure decreases solubility while background salinity of fluid sometimes gives it discomfort to its typical temperature trend.

For example:

1. *CaCO₃* Solubility in water increase with increase temperature, but showed inverse trend with decrease temperature.
2. *BaSO₄* Solubility in water increase by a factor of two at temperature ranging between 25 °C-100 °C and decrease by same factor as the temperature approaches 200 °C.

In addition, carbonate mineral solubility increases as the fluid acidity increases. Thus, *CO₂* or *H₂S* presence at high pressure creates significant acidity and consequently, formation water in contact with carbonate rock and acid gases can be enriched with dissolved carbonated ions depending on the temperature and pressure of the gas above the liquid phase. Generally, *CO₂* leaves the water phase as the pressure falls thereby causing the pH to rise leading to formation of calcite scale.

Scale Formation

Temperature and pressure change are the driving force in formation of scale. Although pH change, gassing or incompatible water contact may produce over saturated water but these do not always produce scale⁸. For a scale to be formed, it must grow from solution which is the first development from a saturated fluid forming unstable clusters of atom. This process is referred to as homogeneous nucleation (Fig 2).

⁸ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; oil field review, autumn (1999)

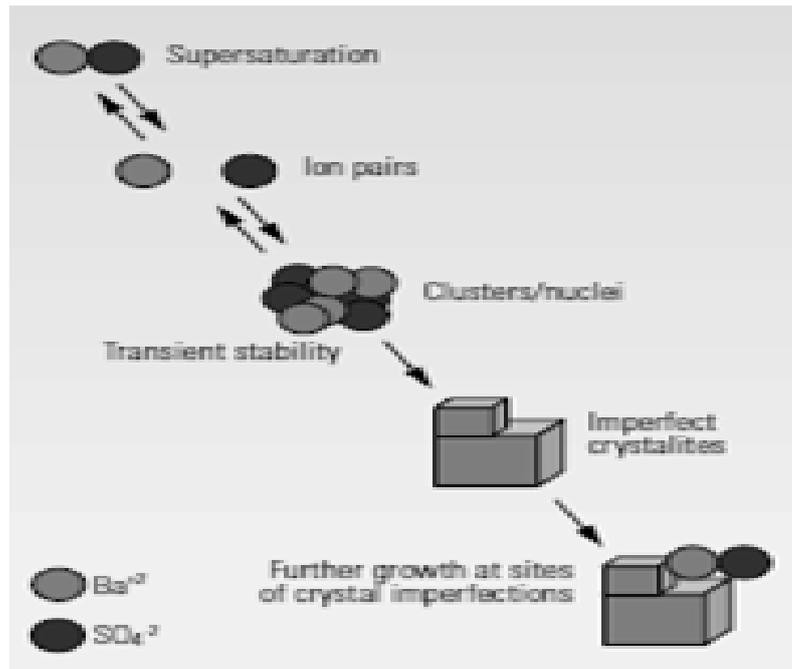


Figure 2: Homogeneous Nucleation process; (scale growth starting in supersaturated solution with ions pairs forming single crystals in the solution)

In figure 2 above, the atom cluster initiates the equilibrium ion concentration in the super saturated solution; this then grows by ions adsorption onto imperfect crystallites extending the crystal size which is driven by reduction in free energy of the seed crystal. However, this shows that large crystal will favour further growth while smaller crystal may re-dissolve back in the solution⁹. As a result, this leads to a larger crystal with enough degree of super saturation thereby encouraging more scale growth.

In a pre-existing fluid boundary, crystal growth also tends to be triggered in a process called heterogeneous nucleation (Fig. 3). The nucleation causes defect in pipes such as surface roughness and production of liner perforation. A scale deposit can occur due to high degree of turbulence. Thus, scale accumulation can occur at the position of the bubble point pressure in the flowing system.

⁹ Richardson, S.M. and McSween, H.Y.: Geochemistry Pathways and Process, Englewood cliffs, New Jersey, USA (1989).

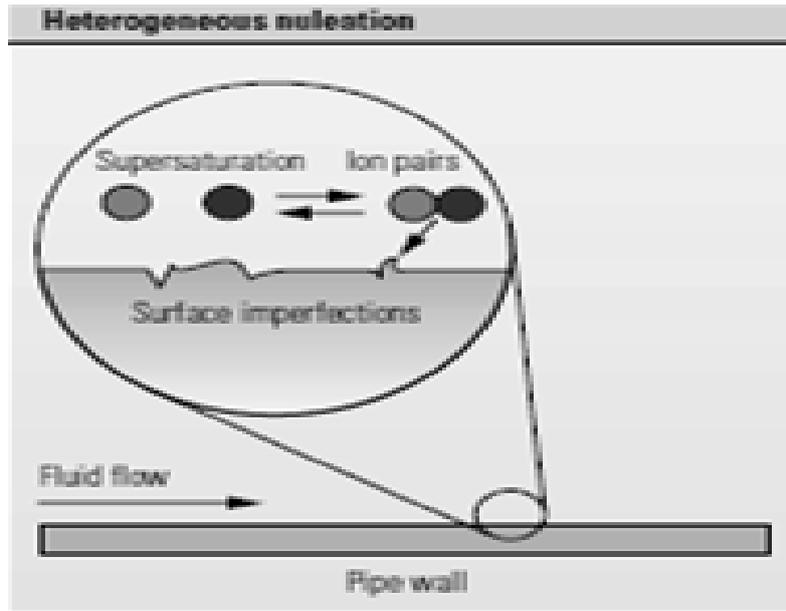


Figure 3: Heterogeneous nucleation process¹⁰; (scale grow on pre-existing surface defect, such as rough spots on the liquid tubing surface)

This in fact explains more on why scale deposit may rapidly build on down-hole completion equipment. Upon understanding the concept of scale nucleation, inhibition has been developed which are chemically designed, specifically to poison the nucleation and stop the growth stages of the scale formation which will also reduce the rate at which this scale is formed.

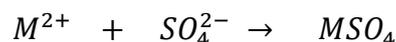
Scaling Potentials

The presence of high pressure reservoir with combined amount of dissolved acid gas (CO_2 and H_2S), at 5-20% means there will be no scaling formation at this stage normally at the tubing bottom. However, as the production fluid moves up, the pressure decrease and these dissolve acid gases tend to flash out of the fluid and as a result the pH of the fluid increase due to loss of CO_2 and H_2S which shift the thermodynamic balance toward super saturation of the produce water. At this time the scale formation is favoured due to nucleation and kinetics of the crystal growth.



Thus, equilibrium shifts to the carbonate precipitation.

Also, for a hypothetical equation:



Where $M^{2+} = Ba^{2+}, Sr^{2+}$ or Ca^{2+}

¹⁰ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; oil field review, autumn (1999)

The precipitation of scale can be detected via solubility product K_{sp} , for a hypothetical equilibrium equation;



Also, K_{sp} is expressed as:

$$K_{sp} = m_{Ae} m_{Be} \cdot \gamma^A \gamma^B = a_{Ai}^n a_{Bi}^m \text{ (at equilibrium)}$$

Where; $m_{Ae} m_{Be}$ = molarities of ions A^{2+} and B^{2+} at equilibrium
 $\gamma^A \gamma^B$ = activity coefficients of A^{2+} and B^{2+}

Saturation ratio (SR) calculated as $a_{Ai}^n a_{Bi}^m / K_{sp}$ is used to predict precipitation of scales. When $SR > 1$ precipitation will occur.

SR value can be changed depending on the type of the scale and the temperature at which it occurs; for example, SR as large as 5 may be required for $CaCO_3$ precipitation at 80 °C and 2.7 at 120 °C.

How Can Scale be Identified?

The first step in designing a scale mitigation program is by identifying a scale location and its composition.

Surface and Tubing Production equipment

In tubing, scale occurs as a thick solid layer adhering to the wall with a crystal growth of up to 1 cm or even longer¹¹ (Fig. 4). Scale growth in tubing cause lower rate of production due to increase in roughness of the pipe and reduction of the diameter of the pipe; thereby reducing the fluid flow rate. As the scale grows, it increases the driving pressure and the production goes down. Consequently, access to the lower part of the well will become difficult and impossible. There by blocking the production flowing through the tubing.

¹¹ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; oil field review, autumn (1999)

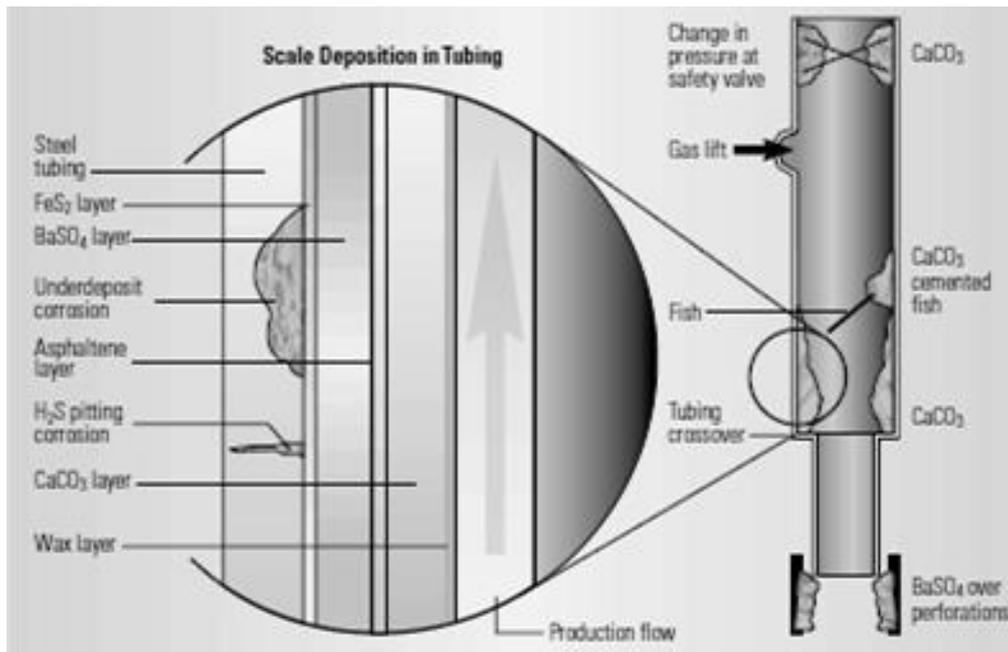


Figure 4: Scale depositions in tubing. (It varies from down-hole perforations to the surface where it constrains due to tubing restrictions and sometimes the scales are covered by asphaltenes, corrosion and pitting can occur due to bacterial activities and sour gas diminishing the pipe integrity).

Scale found in tubing varies in chemical composition depending on the layer of the scale and the well history. Scale may often include waxes and asphaltenes and those layers that are close to the tubing may include iron sulphide due to corrosion products.

Near well bore

Scales formed in near wellbore are typically carbonate or sulphate based with fine particle size in order of microns, which can block gravel packs, screen, and also matrix pores. It is normally formed after long well shut-in due to mixed incompatible water from different layers as a result of cross flow.

Injector wells

Incompatible mixing can occur near well bore due to injection water contact with formation water or completion brine. Scales formed, damage the injection well and can decrease permeability of formation thereby reducing the effectiveness of the water flood strategy. This is caused usually by temperature activated auto scaling from the injection water.

Scale Detection Methods

X-rays

Bamforth et al. (1996) reported the use of Gamma ray interpretation from tubing scale sample which indicates barium sulphate scale. This is because radium Ra^{226} radioactive element precipitated with this scale¹². According to his experiment, increase in gamma ray activities as much as 500 API give scale background.

¹² Bamforth, S. Besson, C. Stephenson, K. Whittaker, C. Brown, G. Catala, G. Rouault, G. Theeron, B. Conout, G. Lenn, C. and Roscoe, B.: Revitalizing Production Logging Oilfield, review 8, (4) 1996 pp 40-60

NODAL analysis

Nodal analysis indicates scale in matrix by identifying increase in reservoir constrain in productions. This is done to indicate tubing scale in the well especially when the well starts to demonstrate constrain that were not seen in early production but cannot distinguish formation damages from.

Water chemistry

Operators normally track the water chemistry by knowing the characteristics of the ions present in the produce water. Changes in the concentration of the scaling ions such as Ba^{2+} or SO_4^{2-} are notified. When the scaling ions coincide at a concentration prone to precipitation, oil production will reduce and water cut increases thereby signifying broken-in of injection water and therefore scale begins to form.

Therefore, permanent monitoring analysis should be employed to detect the changes in the water chemistry for early scaling condition and predictions. Sensors are used to help detect the concentration changes of scaling ions and regulate chemical dosage for scale control¹³

Chemical modelling

Phase equilibrium is used to detect the scaling potentials using the history of thermodynamics principle and geo-chemical data of a field. However, it depends on the parameters such as ions concentration, pressure, temperature, and gas phase composition. The program is used to predict incompatible mixing or changes in temperature and pressure.

Nowadays, the process is now available as domain software designed to simulate fluid and chemical transport in porous formation¹⁴.

Scale prediction program (scale soft pitzer – SSP) from Rice University and (OKSCALE) from Oklahoma University are used to predict scaling tendency of produce brine¹⁵. Results produced are classified as high, moderate, low or no scaling potential.

Scaling Scenarios

Incompatible mixing

Mixing injection and formation water incompatibly can cause scaling. Injection water, typically the seawater is injected into production well for enhanced oil recovery is rich in SO_4^{2-} ions with significant concentration¹⁶, while production water contains Ca^{2+} and or Ba^{2+} . Therefore, mixing them produces a fluid with both ions concentration for which are above solubility limit for sulphate mineral. Thus, $BaSO_4$ and $SrSO_4$ scale are formed from sandstone formation and $CaSO_4$ from limestone formation.

Gas flood scaling

Carbon (IV) oxide is also injected into the well for enhanced oil recovery and as a result the CO_2 dissolve in the water thereby making the water acidic.



¹³ Snieckus, D.: Tipping the Scales Forms and How to predict it, Offshore Engineer (1999) pp117

¹⁴ Oddo, J.E. and Tomson, M.B.: Why Scale Forms and How to Predict it, SPE Production and Facilities 9, (1) 1994 pp 47-54

¹⁵ Atkinson, G. Raju, K. and howell, R.W.: The Thermodynamics of Scale Prediction, SPE paper 21021, presented at SPE International Symposium on Oil Field Chemistry, Anaheim, California. (1991) pp 20-22

¹⁶ Austad, T., Strand S., Madland, M.V, Puntervold, T., and Korsnes, R.I.: Seawater in Chalk, and EOR and compaction Fluid. SPE Res Eval & Eng11 (4): 648-654.

This dissolves the calcite in the formation rock. Subsequently, pressure drops which cause CO_2 to break out and cause carbonate scale to precipitate as previously explained.



Others includes; AUTO SCALE occurring as a result of changes in reservoir fluids due to temperature and pressure, EVAPORATION-INDUCED SCALING, occurring as a result of hot brine evaporation due to simultaneous production of formation and hydrocarbon gases (wet gases).

Scale Control Strategies

Fluid modifications

As discussed earlier; seawater is enriched with ions that are by-products from the activities of sea marines, decays of aquatic animal and water vaporization near surface and ground water. Also as mentioned previously, the seawater is injected in a well for enhanced oil recovery. Consequently, the ions presence such as SO_4^{2-} signifies scale potential. Thus, some changes have to be made to remove these sulphate ions from the water thereby reducing the sulphate content, minimizing and or mitigating against sulphate scale. This is becoming more important for high cost subsea and deep water well. For example; in Grrassol Angola, water treatment plant is constructed on the production platform to remove sulphate ions from the sea water thereby mitigating sulphate scaling (Fig. 5)



Figure 5: Grrasol Angola; Water treatment to mitigate sulphate scaling.

Nano-filtration process is adopted which is non-reverse osmosis, to remove large sulphate ions (Fig. 6)

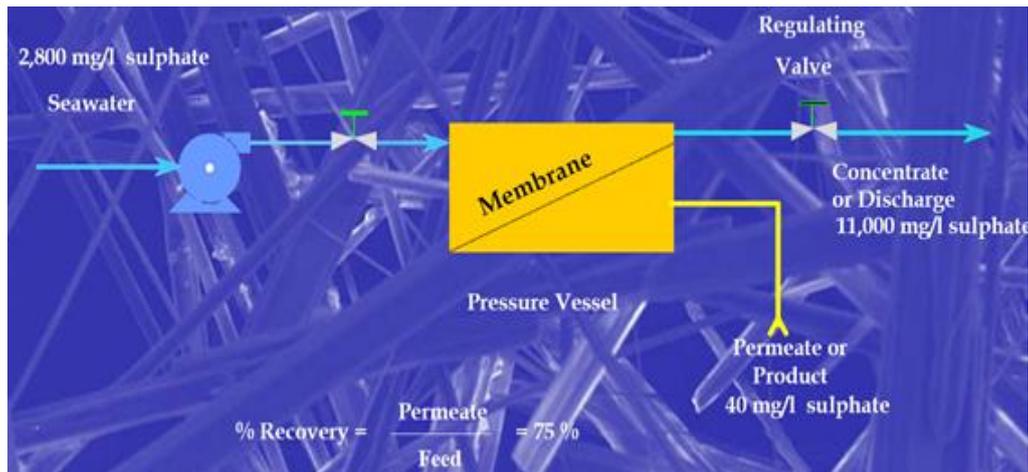


Figure 6: Process to remove sulphate ions from sea water

In Figure 6, 2,800 mg/l seawater sulphate content is passed through a membrane in a pressure vessel filtering large sulphate ions and produce sea water that contains only 40mg/l sulphate. This process significantly reduces the sulphate content of the sea water for injection and as such reduces scale potentials

Another process is by re-injection of produce water thereby significantly reducing the issue of chemical compatibility and as well as brine compatibility, thus, reducing the scale potentials.

Flow modification

A production field is designed based on the geochemical history of the place to modified fluid flow. Water may be shut-off in down-hole separator to minimize the scale potentials when mixed with injection water.

Scale removal and inhibitions

Techniques used in scale removal must be technically quick and non-destructive to the wellbore, tubing, and production facilities. A poor choice of technique for scale removal can lead to the scale re-occurrence and as a result a good method should be adopted by knowing the scale composition and texture. Also, choice of scale removal method depends on the type of the scale. For example, pure barium sulphate is hard and of low porosity¹⁷ and thus not permitting penetration of treatment chemicals. Therefore, only mechanical technique is proposed to remove it. Mixture of scale such as $BaSO_4$ and or $SrSO_4$, $CaSO_4$ and even $CaCO_3$ may need variety of removal techniques, both chemical and mechanical.

(a) Chemical techniques

This is an approach used for scale removal especially when conventional removal method is not accessible. Acids are used to dissolve scales such as carbonate minerals. For example, hydrochloric acid is used to remove $CaCO_3$ scales while those that cannot be dissolved by acid such as hard sulphate scale because of their low solubility in acid, are treated with strong

¹⁷ Krishnam U.R; Keshabananda N.B; Nashi M.O; and Faisal G.A, Proactive scale mitigation strategies for simple to complex multilateral producers in a saudi arabian carbonate field, Saudi Aramco Journal of Technology Summer 2011

chelating agents in the formation matrix, so that they can break the acid resisting bond by locking up the scale metallic ions with their close ring-like structure¹⁸.

Chemical techniques are controlled based on how the applied chemical has access to the scale surfaces, which is an important parameter for efficient removal process (surface area).

In tubing, scales have small surface area, so as to make chemical treatment a practical removal method.

Dissolvers and pre-flushes chemicals contain viscoelastic surfactants with high viscous gel with brine composition, but which completely break down in oil or hydrocarbons and become water-like are used. They therefore help in channelling the scale dissolver into productive oil saturated zone thereby avoiding non-productive water saturated zone.

Note:

Rapid acid reaction may hide a problem, because spent acid solution are good initiators for scale reformation. For example, evaluating a well production history; the matrix stimulations with acid help in interpretation of declining production rate¹⁹. (Fig 7)

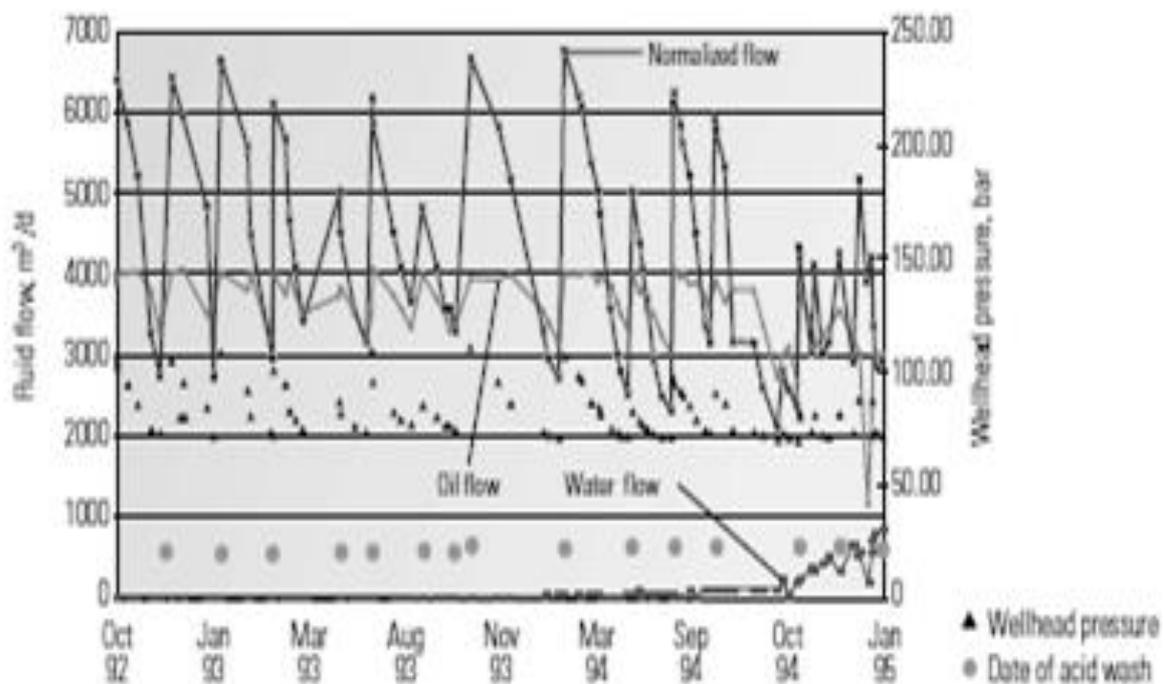


Figure 7: Production Profile in Gullfaks field showing cyclic production impairment²⁰.

Chemicals that dissolve and chelate can stop re-precipitation cycle. Ethylene Diamine tetra acetic acid (EDTA) is used for improved chemical scale removal. Treatment with EDTA is slower than with hydrochloric acid and more expensive but it works very well. Variation in

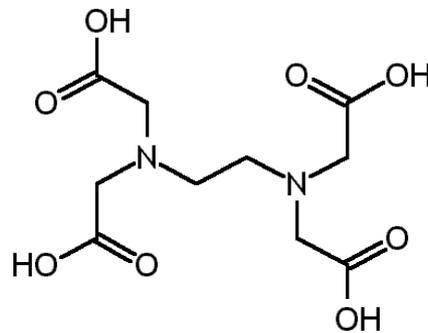
¹⁸ Martel, A.E. and Calvin, M.: Chemistry of Metal Chelate Compounds, New York USA (1999).

¹⁹ Kotlar H.K., Karlstad S., Jobcosen S., and Vollen E., An integrated Approach for Evaluating Matrix Stimulation Effectiveness and Improving Future Design in the Gullfaks Field Paper SPE 506161, SPE European Petroleum Conference, Hague Netherlands, 20-22, 1998.

²⁰ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; oil field review, autumn (1999)

its chemical structure can also be used to remove non-carbonate scale such as calcium sulphate and calcium/barium sulphate. Examples:

- I. EDTA U105: used to dissolve $CaCO_3$, iron carbonate and or iron oxide.
- II. EDTA U104; used to dissolve wide variety of scale such as $CaSO_4$ and even mixed scale that is hard.



EDTA compound structure:

The EDTA chelate compounds are used to lock up the unwanted ions in solution. The molecule shares electrons from oxygen and nitrogen atoms with unwanted metal ions such as Ba^{2+} , forming a metal-EDTA chelate compound. This process can help to dissolve scale²¹.

U104 used in North Sea treatment was designed to pump against pressure into the formation radial average displacement of about 3ft but the treatment was over flushed with treated sea water and the well was shut in for 18hr for total soak. (Fig 8)

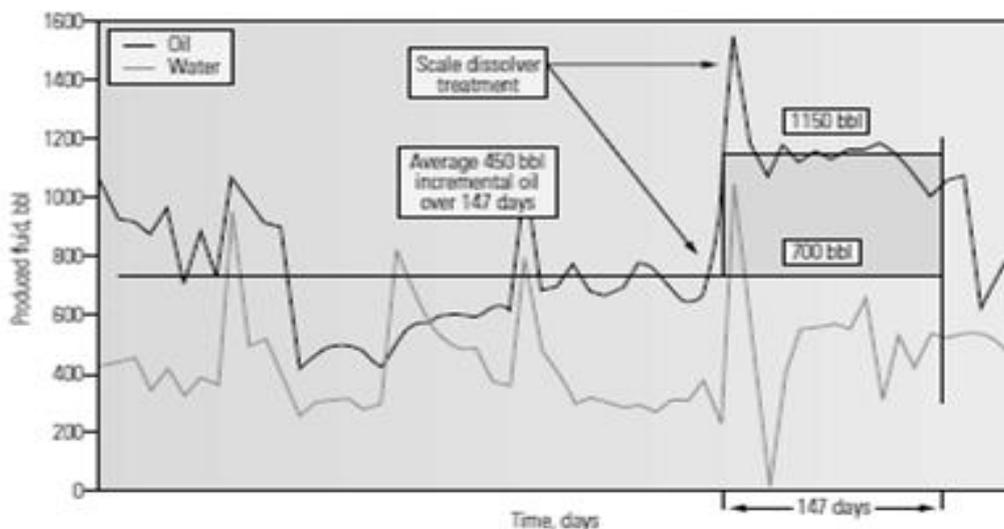


Figure 8: North sea well production history; (high damage in the well due to $BaSO_4$ and $CaCO_3$ scaling in the perforation and matrix near the wellbore and was successfully treated, resulting in 64% increase in oil production for more than 147 days)

When production was started over it increased to about $72 \text{ m}^3/\text{d}$ paying out all pumping and lost production cost in just 12 days²².

²¹ Martel, A.E. and Calvin, M.: Chemistry of Metal Chelate Compounds, New York USA (1999).

²² Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; Oil Field Review, Autumn (1999)

(a) Conventional mechanical method

This technique offers a wide range of tools, applicable depending on the areas of the scale deposits, but also provides some limitation of ranges applicability. Therefore, selecting the good method depends on the well position and the scale deposition. Mechanical methods are among the successful methods in scale removal in tubular. Earlier, explosives were used to rattle pipe and break the brittle scale, but can easily cause damage to the tubular and well cements. Very hard scale cannot be removed by explosive or penetrate by chemicals. Thus, conventional is the next alternative option, this is most used by engineering tools and machines.

Scale Inhibition

The cost of removing scale is very high and non-profitable and can be as high as 2.5 million dollars, while the cost of differed production is even higher²³. Just as medics said, “prevention is better than cure”, keeping a production healthy is for the betterment of the production. In most cases prevention of scale formation is preferable through chemical inhibitions to maintain good production. This can range from basic dilution method to more advanced methods of threshold inhibitions.

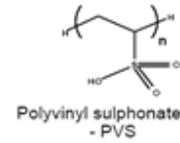
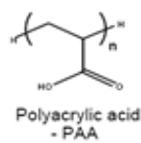
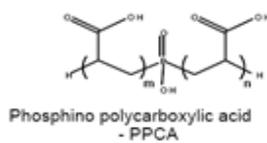
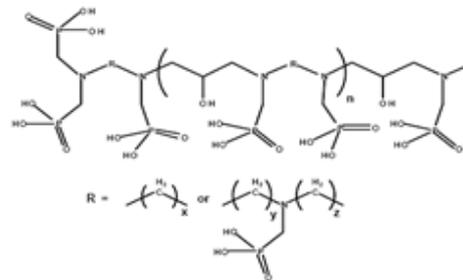
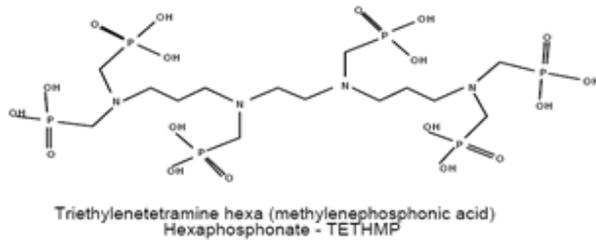
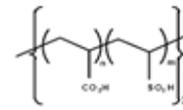
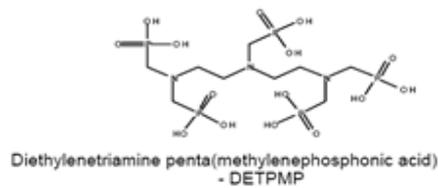
Threshold inhibitors

Threshold inhibitors reacts chemically with the scale crystal nucleation side thereby reducing the crystal growth. Threshold inhibitors are very effective, inhibiting scale mineral formation at concentrations of 100 time less than balance stoichiometric ratio²⁴ which significantly reduces cost of treatment. Most of these compounds are of phosphate components. Examples:

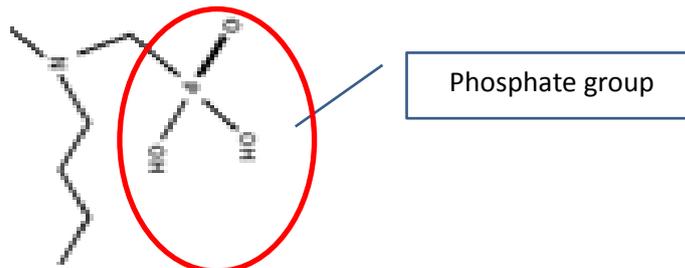
- Inorganic polyphosphate compounds
- Organic phosphate esters
- Organic phosponate
- Organic polymers

²³ Wigg, H. and Fletcher, M.: Establishing the True Cost of down Hole Scale Control, Paper presented at the International Conference on solving oilfield scaling. Aberdeen Scotland (1995)

²⁴ Rosenstein, L.: Process of Treating Water, US Patent No 2,038,316 1936



Chemical Structure of common inhibitors



This is achievable by locking up the unwanted metal ions by the phosphate group.

These compound minimize scale deposition. They do so by combination of crystal dispersion and stabilization of scale²⁵ (fig 9)

²⁵ Nancollas, G.H. Kazmierczak, T.F. and Schuttringer. E.: A Controlled Composition Study of Calcium Carbonate Growth, the influence of scale inhibition corrosion NACE 37, (2) 1981 pp76-81

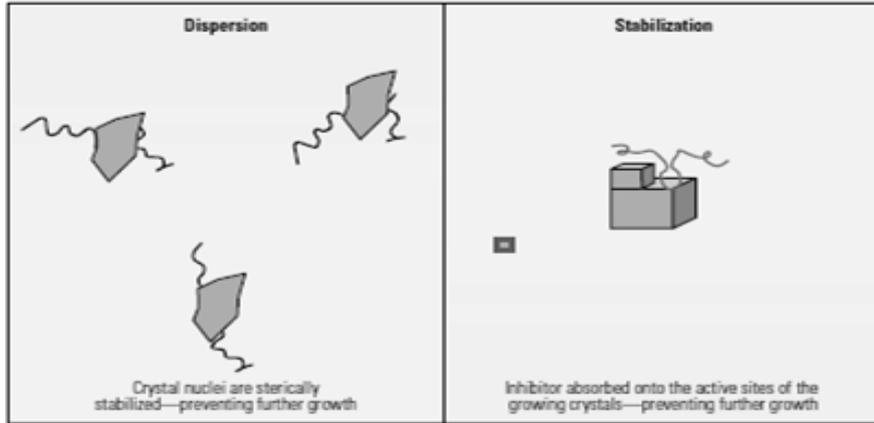


Figure 9: Dispersion and stabilization²⁶ (dispersion prevents small seed crystal from adhering to the wall and other crystal while stabilization chemicals modify the deposited scale structure preventing additional crystal attachment)

In scale inhibition strategies, one important measure is the life time of the compound in the formation to either be adsorbed in the pore walls or to precipitate in the pore space, which yield the best treatment lifetime when retained in the formation. (Fig 10)

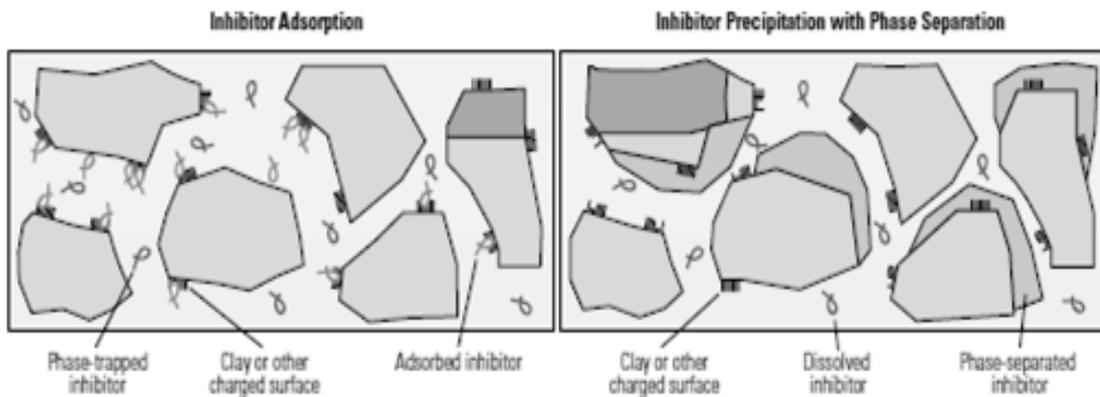


Figure 10: Adsorption and Precipitation; (scale inhibitors yield the best treatment lifetime when they are retained in the formation either by adsorption to the pore walls or by precipitating in the pore space²⁷).

The life time strongly depends on the surface chemistry, pH, and temperature of the compound, which usually have short time of 3-6 month due to adsorption capacity of reservoir rock under reservoir condition and is basically limited^{28,29}. But under low water production rate, life time of up to 2 years can occur.

²⁶ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; Oil Field Review, Autumn (1999)

²⁷ Nancollas, G.H. Kazmierczak, T.F. and Schuttringer. E.: A Controlled Composition Study of Calcium Carbonate Growth, the influence of scale inhibition corrosion NACE 37, (2) 1981 pp76-81

²⁸ Browning, F.H. and Fogler, H.S.: Precipitation and Dissolution of Calcium Phosphates for the Enhancement of Squeeze Life time. SPE Production Facilities, 10 (3) 1995, pp 144-150

²⁹ Meyers, K.O. Skillman, H.L. and Herring, G.D.: Control of Formation Damage at Prudhoe Bay, Alaska, by inhibitor squeeze treatment Paper 12472 SPE California, USA (1984) pp 13-14

For good treatment, life time should reach up to 1-year even under high-water production rate³⁰. For example, carboxylic acid inhibitors of phosphate is known for inhibition of $CaCO_3$ scale. When these inhibitors are placed, calcium ions are often liberated and precipitation is the dominant long time retention mechanism in carbonate formation. As such calcium chloride brine over flush to reduce the scale inhibition precipitation and thus extend the life time of the reservoir³¹.

Also, to achieve longer life time inhibition, large volumes of the inhibitors are pumped into the formations such that they are absorbed to a large surface area. But this is not always successful because, sometimes squeezing water based inhibitors in oil zone temporarily change the formation wettability and can cause lower production.

In that case oil soluble inhibitors are used, these will not cause formation rock wet and as such retained longer and then longer protection life time.

Another important measure is the inhibitor placement. A good treatment performance is strongly based on scale prevention and not on the life time of the inhibitor. A good inhibitor placement is one of the key points for good performance of an inhibitor squeeze treatment.

It is considered as good practice to place scale inhibitor in heterogeneous formation adopting the method used to control acid placement. This is because bullheading the inhibitor into the formation can cause overtreatment of low pressure and high permeability zone.

It is even of advantage to combine treatment of acid and scale inhibitor to ensure that scale inhibitor is controlled along with acid. It should be noted that the acid pH do not exceed that required for precipitations³².

Protection propped fracture is also greatly considered against scale fouling. This is dependent on good inhibitor placement. When these fracture portion are left untreated by the inhibitor they may cause irreversible damage due to ineffective contact of the scale in proppant packs with the scale solvents. It was reported that, for proppant pack coverage, scale inhibitor is pumped in fracturing fluid³³.

A delivery system is proposed by Schlumberger called scaleFRAC that combines a scale inhibitor and fracture treatment into a single step process using fluid. The inhibitor is placed effectively every where in the propped fracture. This is done by pumping the inhibitor during pad and sand-laden stages of the fracture treatment. (Fig 11)

³⁰ Martins, J.P. Kelly, R. Lane, R.H. Olson, J.B. and Brannon, H.D.: Scale Inhibition of Hydraulic Fractures in Prudhoe Bay. Paper SPE 23809, USA (1992) pp2-27

³¹ Meyers, K.O. Skillman, H.L. and Herring, G.D.: Control of Formation Damage at Prudhoe Bay, Alaska, by inhibitor squeeze treatment Paper 12472 SPE California, USA (1984) pp 13-14

³² Crowe, C. McConnell, S.B. Hinkel, J.J. and Chapman, K.: Scale Inhibition in Wellbores. Paper SPE 27996, Tulsa, Oklahoma, USA 1994 pp 29-31

³³ Powell, R.J. Fischer, A.R., Gdanski, R.D. McCabe, M.A. and Pelly, S.D.: Encapsulated Scale Inhibition for use in Fracturing Treatments. Paper SPE 30700. Dallas, Texas, USA 1995 pp21-25

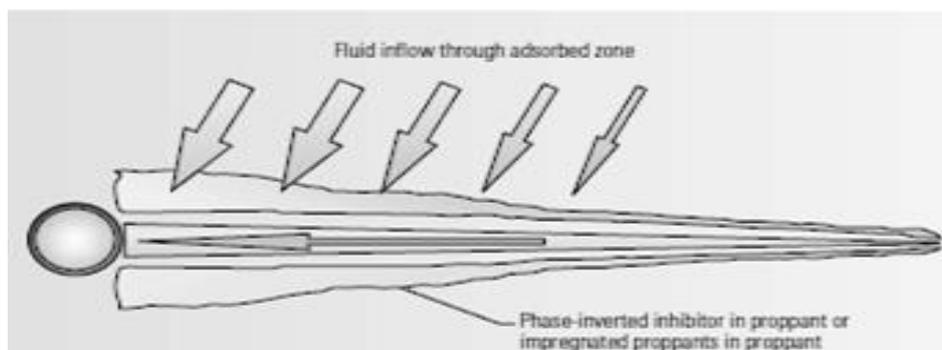


Figure 11: Fracture stimulation with inhibitor placement.

A high efficient inhibitor placement is achieved by pumping the chemical into the fracturing fluid during fracture stimulation. The inhibitor is retained by adsorption on the leakoff zone, or by precipitation on the proppant³⁴. As formation water passes through the inhibitor absorbed zone, it dissolves enough inhibitor to prevent the water from precipitating in the fractures and wellbore. This system is found applicable in the north sea and the permian basin³⁵.

Scale Management

Scale-inhibition Innovative technologies in a most demanding condition

Developed comprehensive scale-control technologies and processes have to be geared for most complex projects. The Scale management strategy has to address issues surrounding complicated well completions, high temperature and pressure, deep water and other harsh environment production as well as stricter environmental regulations. A methodology comprising of a comprehensive knowledge in line with scale inhibitor chemistries should be employed, focusing on this keys areas

- Continuous injection of scale inhibitor through gas lift system
- Non aqueous base scale used for pre-emptive reservoir squeezing
- End capped polymeric, such as encapsulated scale inhibitors

Pre-screening process to identifying where problems are likely to be expected

Technologies using computer simulation software are used based on the data made available from the well and or from the process systems are now used to predict and determine potentials of scales and risks that may occur. Highly trained and knowledgeable personnel should be employed to assess the results, which are then used to determine potentials of scale and its environment. This is then used as the basis for chemical screening and laboratory testing.

Environmental compliance for every chemical application

Approved product should only be used on a field having been approved by a well reliable Eco-toxicological laboratory. This laboratory should ensure that all proposed products comply with each country's environmental requirements. These eco-toxicological tests, should include biodegradation, bioaccumulation and toxicity testing

³⁴ Powell, R.J. Fischer, A.R., Gdanski, R.D. McCabe, M.A. and Pelly, S.D.: Encapsulated Scale Inhibition for use in Fracturing Treatments, paper SPE 30700. Dallas, Texas, USA 1995 pp21-25

³⁵ Mike Crabtree, David Eslinger, Phil Fletcher, Matt Miller, Ashley Johnson, and George King; Fighting scale, removal and preventions; oil field review, autumn (1999)

Conclusion

Destructions caused by scale formations in production facilities could be very severe. When scale is held to the production equipment surface, it reduces its diameter and subsequently continues to grow until it blocks the tubing as well as the surface equipment. This leads to production stoppage, and results in losses to the production company. Therefore, scale formation is given a priority treatment because it is taken as a threat to smooth production flow. Thus, treatment strategies dosage are used such that it inhibit the growth nucleation and or disperse it in the crude thereby preventing it from building up or having further occurrence. Just as the medics said; “prevention is better than cure”

Many significant advances in scale control and removal have been reported in recent years. Nowadays, operations have access to both chemical and mechanical products designed to remove scale and prevent it growth. Development in scale removal from improvements in chemistry and fluid finish for effective scale inhibitions provide fast and reliable ways by which scale can be removed from inside the tubular without risk to the steel tubing.

Each new technology improves one aspect of scale the problem. Combining these technologies becomes part of scale management processes in which one can apply surveillance method to identify the onset of scaling conditions and also develop the optimum strategy for reducing scale related production losses and remediation expenses. The strategy may include element of scale preventions and removal. Every improvement in the technology providing a means for combating scale problems will gratefully be considered.