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Energy House, 103 Scarborough Beach Rd, Mount Hawthorn, WESTERN AUSTRALIA 6016
Tel: +61 8 9443 3400 Fax: +61 8 9242 1811 www.swanexhibitions.com.au

Long Term Solution to Scale Problems on a Malaysian Oil Platform.

Authors

(1) Zulkifli Abdul Rahim — Maintenance Engineer, PM Operations, Petronas/Carigali Sdn Bhd (PCSB), Malaysia.

(2) Anthony H Truman — Chemical Engineering Dept, Royal Melbourne Institute of Technology University, Australia.

(3) David Slater — Technical Manager, Apex Process Systems Pty Ltd, Brisbane, Australia.

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ABSTRACT

This paper describes the successful long-term solution to chronic scale problems on the Tinggi offshore oil platform in the South China Sea. The Tinggi platform had the worst scale problems amongst all of the Petronas Carigali Sdn Bhd (PCSB) offshore platforms. Scale deposition reduced production output by up to 18% and the platform had to be shutdown for de-scaling every 3 months. Scale deposition caused equipment/instruments failure, valves malfunction (within 2 - 4 weeks) and severe piping bottlenecks. PCSB had conducted extensive studies and trialed numerous chemical and non-chemical potential solutions over several years, that resulted in only short-term benefits. PCSB continued to pursue a long-term solution and in 2001 trialed a newly developed Scale-X™ Magnetic Fluid Conditioner (MFC) Unit. Installation of this MFC Unit resulted in elimination of the chronic scale problems caused by the scale-producing formation water of the Tinggi field.

PCSB had trialed other manufacturers MFC Units with only minimal or nil benefits observed prior to trialling the Scale-X™ MFC Units. These MFC Units are designed on a different basis using a different engineering approach and mode of application. Two Scale-X™ MFC Units were installed in August 2001 following successful laboratory trials that closely simulated Tinggi's scale problems.

Observable benefits 19 months after installation of these MFC's, proved that scale formation had been eliminated. The consequential benefits were seen as follows:

- New scale formation had been eliminated,
- Pre-existing scale had been removed,
- Quarterly de-scaling maintenance platform shutdowns have been eliminated,
- Significant production increase, production output has been maintained at 100% with no 18% drop off,
- Improved plant reliability and reduced operating costs,
- Platform operation (vessel pressure & liquid levels) have stabilised,
- Flow control valves remain 100% operational and life of the valves has been extended,
- Environmentally safe – no chemicals used,
- Return on investment within weeks,
- Produced significant HSE benefits.

The technology on which these MFC Units is based can be applied anywhere within the platform process, or down-hole.

This new method of application of MFC Units and the relationship to the cause and severity of the scale problem are addressed, including the need for MFC Units to incorporate functions to modify relevant governing parameters of the fluid dynamics during transit through the MFC Units.

Also included is a comparison of the performance of various scale control mechanisms trialed in the Malaysian oil fields in the search of an effective control mechanism to prevent scale build up.

INTRODUCTION

Scale problems in oil production can be costly, in terms of reduced production due to plant bottlenecks, equipment failure and de-scaling maintenance downtime. At some locations, scales deposits can contain NORM's (Naturally Occurring Radioactive Material), which can pose significant Health & Safety issues for personnel.

The PCSB Tinggi Field platform has had a chronic mixed scale problem for many years, requiring shutdown for de-scaling on a 3-monthly basis (two shutdowns of 3 days, and two of 18 hours each year). The scale is caused by the scaling properties of the Formation Water. The scale consists of calcite (95%), dolomite (3%) and barite (2%).

Chemical Scale Inhibitors have been used extensively, and these have only provided a decrease in the rate of Scale build-up, and have proved largely ineffective at preventing scale deposits.

Production decline on Tinggi-A over the 3 months between de-scaling shutdowns, (due to scale build up restricting production piping), was typically ~18%.

The scale formed in the following locations:

- Well-Head piping,
- The Separator Oil & Water Outlet standpipes,
- Water Line Level Control Valves & non-return valves,
- The piping before & after the Water Treatment System (Corrugated Plate Interceptors - converted to DGF Units).

Level Control Valves became non-functional (jammed) not long after mechanical and chemical de-scaling at the quarterly platform shutdowns.

The Tinggi scale problem was very costly in terms of lost production, equipment failure, operational costs, and platform maintenance de-scaling shutdowns. Also, personnel safety was a major concern because of the need for internal vessel maintenance work, exposure to NORMS, and cleaning chemicals. PCSB's objective was to minimize or eliminate, if possible, the need for manual de-scaling maintenance by finding a long-term solution.

Case History of Actions Taken to Solve the Scale Problem:

PCSB had, over several years, taken a well-documented methodical approach to solving the scale problem, which later proved important in development of a successful solution. (A case history of this scaling problem is detailed in the Society of Petroleum Engineers International technical paper SPE 60199[4], presented January 2000 at the 2000 Second International Symposium on Oilfield Scale held in Aberdeen, UK).

As is seen from this paper, the scaling problem had remained unresolved for many years with an ongoing impact on production output. Various methods had been employed to locate points of scale build up and remove the scale, however, PCSB was unable to stop the build up of scale and it remained a chronic problem.

Both Scale Inhibitor Chemicals and Magnetic Fluid Conditioners (MFC's) had been trialed with only a short term solution being reached, which required shutdowns every 3-months for de-scaling. As noted in the SPE paper *"long term cheaper solutions must be pursued despite lack of such proven/cheap options..."*

One potential long-term measure, a commercially available Magnetic Fluid Conditioner (MFC) Unit, had been trialed in the Tinggi field with no benefit observed.

Comparison of Scale Control Mechanisms Trialed

A brief comparison of the effectiveness of both the chemical and non-chemical mechanisms trialed in the Tinggi field & other Malaysian platforms is included in Appendix A. All except one of the mechanisms trialed had minor or no effect and in some cases actually increased the rate of scale build up. Only the Scale-X™ MFC Units were totally successful.

PCSB Approach

One outcome of the experience gained from the trials of the various scale control mechanisms was that PCSB engineers recognized the need for a new approach to solve the scale problem. Based on those trials and from a review of technical literature [1][2][3] PCSB's engineers realized that magnetic fluid conditioning had the best potential to solve the severe scale problems, provided it was engineered properly to co-ordinate with both the plant design and fluid process conditions. The challenge was to find a company that applied a multi-disciplined total engineering approach to the design of the MFC's and who would work with PCSB engineers in "controlled" trials taking into consideration the entire platform fluid process conditions and plant design. In 1999, PCSB approached Magnetic Technology of Australia (MTA), a company that applies a total engineering approach.

The Tinggi oil-water separation system (like all platform systems) is a once through system and typically can't be treated with the commonly available "off the shelf" MFC's, which are suitable for re-circulating systems where the fluid has multiple passes through the MFC Unit.

Using a new approach to MFC Unit design, MTA carried out laboratory trials that closely simulated the Tinggi scaling conditions. In August 2001, two "application specific" MFC Units were installed in a separation vessel on the Oil & Water outlet stand-pipes, which were identified as having the most chronic scale problems.

PCSB engineers requested that ease of retrofit was incorporated into the design as a priority, so that no time consuming and costly modifications were required to the platform plant. No on-site "hot work" was also a requirement.

The PCSB specification required maintenance shutdowns to be reduced from 4 to 1 per year. To effectively measure performance, the outcomes monitored by PCSB were expanded to include the following categories:

1. Control Valve operational performance,
2. Oil Production levels,
3. Separator liquid levels,
4. Separator operating pressure,
5. Ability to stop new scale build up,
6. Ability to remove existing scale build up,
7. Ability to reduce de-scaling maintenance shutdowns from 4/ year, to the 1/ year specified by PCSB.

The Problem

When gas is released from the severe scaling Tinggi formation water at pressure reduction points, scale generation occurs.

Scale deposits occur throughout the platform wherever formation water is present, and where pressure drops occur. The pressure drop results in CO_2 being released, which affects the solubility of $CaCO_3$ causing it to precipitate out of solution, as scale.

The most chronic scaling occurred in the 2nd Stage Separator, which was operated in 3-Phase mode (gas/oil/water separation), and presented the worst environment for scale formation because of the large amount of gases liberated.

Also, the pressure drop across the Water Outlet Control Valve was 1300 kPa, (the pressure drop through the oil flow control valve was lower, at 600 kPa). The Separator stand-pipes scaled almost closed between platform de-scaling shutdowns, and the Control Valves became inoperative within 15 days when chemical scale inhibitors were not used, and within 28 days when the chemical scale inhibitors were used. Manual operation of the bypass line around the Control Valves was used for water level control of the Separator.

The platform had to be shutdown every 3 months for de-scaling and Appendix B shows the scale problem in the standpipes and valves at shutdown.

Note: The liquid in the Oil Outlet Stand pipe & Control Valve at this location in the separation process is 75% crude, & 25% formation water.

The scale bottlenecks reduced the production output level by ~18% over 3 months between de-scaling platform shutdowns.

Procedures to Treat the Scale Problem

Where applications of MFC Units are in re-circulating fluid systems, such as cooling water circuits, there is a cumulative magnetic energy effect due to multiple passes through the applied magnetic fields. The large majority of commercially available MFC Units are only suitable for re-circulating systems where small-bore and thin-walled piping is used. For many re-circulating system applications, even poorly designed MFC Units can produce observable benefits.

This is not the case with Oil Industry applications, which are mostly once-through processes, with only one 'chance' of effecting a treatment, and so require significantly different MFC Unit designs.

The major factors considered in development of the new MFC Units, which were specifically designed for the Tinggi A platform scale problem, were:

1. Fluid dynamics at each scaling point,
2. The need to modify fluid conditions to bring them into the operational range of the governing parameters of magnetic fluid treatment,
3. The incidence and severity of the scaling problem,
4. The chemical composition of the mixed scale formation,
5. The mechanisms of scale generation/formation,
6. Availability of locations & space for installation of MFC Units,
7. The relationship between the cause of scaling, the location of the scale generating point and available MFC installation points,
8. The fluid dynamics at each available location to install an MFC,
9. The fluid process is once through only,
10. Velocity ramping of liquids through the MFC Units to produce the required conditions for rate & duration of magnetic field interaction,
11. The zones of treatment relative to available installation locations,
12. The structure of the vessels, valves & piping,
13. Flow patterns in the vessels and the impact of introducing MFC's on these patterns,
14. The overall water cut of the producing wells,
15. Materials of the system construction,
16. Ease and cost of retrofit,
17. The retrofit not to require on site Hot Work,
18. The need to incorporate Vortex Breaker functions,
19. The capital cost of the alternative options available,
20. The highly corrosive conditions of the fluid process,
21. The severe sand problem existing in the system,
22. Need to improve HSE.

It was obvious that a new approach to the problem was required, particularly as to how the magnetic treatment of fluids technology might be applied, from a technical point of view, and with respect to ease of installation and cost.

MTA engaged a Fluid Process Engineering company and an experienced O&G Engineering & Manufacturing company to advise on the fluid dynamics issues and on how to integrate MFC Units into the platform fluid process system without affecting the process, and without introducing new scale producing problems. It should be noted that changes in fluid flow conditions can also produce new scale formation problems.

The new mode of application of this technology involved locating the MFC Units internally to the vessels and pipes and the incorporation of velocity amplification and flow profiling to modify the fluid dynamics to bring the relevant fluid parameters within the operating range in which magnetic fluid treatment will function. The method of integrating the velocity amplifiers and flow profilers into the MFC Units was critical otherwise new scaling points could be generated, and the fluid process could be altered.

In this particular application, Vortex Breaker duties were also incorporated into these designs. Careful consideration was given to magnetic field structures, field penetration, field strength and the intersection of the field gradient and the fluid velocity vectors. Another major issue was the sourcing of raw materials that would withstand the environmental conditions for the specified period of >10 years.

Laboratory trials closely simulating the Tinggi scaling conditions were conducted on various MFC Unit designs, and on the effects of changes in the governing parameters involved in MFC performance. These are considered later.

Two prototype Scale-X ™ MFC Units were developed and manufactured for installation on the 2nd Stage Separator Oil & Water outlet stand-pipes, to treat the most chronic scaling problem on the platform. These units were installed during the August 2001 scheduled platform de-scaling shutdown. The Vortex Breakers were removed and replaced by the MFC Units.

When the MFC Units were installed, the Control Valves and non-return valves were mechanically and chemically cleaned. However, associated pipe work was not cleaned with the exception of the Separator water-outlet standpipe, which was only partially de-scaled.

Laboratory Simulated Trials

Because of PCSB's methodical engineering approach in seeking a resolution to their scale problems over several years, they were able to supply a detailed chemical analysis of the scale formations on the Tinggi field platform and the fluid process conditions causing the scale build-ups.

Based on this information, MTA had laboratory trials conducted and the platform scale problems and process conditions were accurately simulated in the NATA accredited laboratory of Thames Water Australia Pty Ltd. Rates of scale build up and crystal structure and size were checked against the reported observations made during de-scaling maintenance shutdowns of the Tinggi platform. A detailed knowledge of the scale problem and the cause of the problem is essential to developing a solution to the problem.

A number of MFC designs were tested incorporating various velocity amplifier ratings, magnetic field structures, magnetic field densities, penetration and depth of field and flow profiles of velocity vectors relative to magnetic field gradients. Other governing parameters effecting MFC performance were also evaluated.

Basic Principles of Magnetic Fluid Treatment (MFT) Theory:

The basic principles of Magnetic Fluid Treatment (MFT) theory involve the changing of scale crystal growth patterns by altering the electric charge on the growing crystals.

The American Petroleum Institute in a paper released at the 45th Annual Meeting of the International Water Conference in 1984 stated, *"A fundamental law of physics states that the motion of a conductor through a magnetic field will cause a voltage to be produced. This principle of electromagnetic induction was first demonstrated by Faraday, and applies not only to conducting solids such as wires, but also to conducting fluids such as aqueous solutions containing dissolved electrolytes*".

Professor John Donaldson and Dr. Sue Grimes of the Chemistry Department of the City University, London have conducted extensive research into the effects of magnetic fields on flowing fluids. They have stated that a magnetic field will interact with any substance that carries a charge, however small, in any fluid. The nuclei on which the crystals start growing and the growing crystallites are very small and will have charged surfaces. As they pass through the magnetic field, these charged particles encounter considerable forces as the magnetic field interacts with them. The magnetic field acts at the surface of the crystallites modifying the nature of the charges at the surface. This alters the growth pattern of the crystal in general and on specific planes. [3] [6]

Magnetic Fluid Treatment functions only for scale substances that are diamagnetic and have a magnetic susceptibility less than a particular value.

Diamagnetic substance react differently under the influence of magnetic fields to how paramagnetic and ferromagnetic substances react. When a diamagnetic substance is passed through a magnetic field under certain conditions, the velocity of the electrons is increased, and subsequent to passing through the magnetic field, the electrons continues to revolve at their new higher velocity, ie: the electrons remain in the higher energy or excited state. [5]

It is this higher energy state of the electrons that results in the diamagnetic substance displaying modified properties. In the case of scales that are diamagnetic, this alters the crystal growth patterns resulting in a change in crystal size and change of shape. The crystals have "softer" or rounded edges. The strength of crystal bonding to form scale is in the sharp edges of the untreated crystals (the electric charge concentrates at the sharp edges). The softer or rounded edges of the MFT treated crystals reduce crystal bonding strength (rounded edges reduces the concentration of electric charge), with the result that the crystals then don't grow as large and do not aggregate to form scale build ups. These changes are viewable under a microscope. This also explains why MFC is scale-type dependent and not industry-type dependent.

Governing Parameters of Magnetic Fluid Treatment Theory - Scale Control Factor (SCF)

The correct application of MFC's is based on scientific principles and, for MFC Technology to function properly, all the MFC governing parameters must be taken into consideration.

The MFC will only operate if it is designed to function within the operating range of those parameters. Otherwise, like all other technologies, if the governing parameters are not met the MFC will not produce the required result.

The following limited information on some of the governing parameters of MFT is presented:

The Scale Control Factor (SCF) of an MFC is a function of a combination of the following governing parameters within the particular fluid process system:

Em = MFT energy generation factor

$= [\, J \,.\, \mathcal{V}_m^{kp} \,.\, \mathbf{B}_{sg}^{pg} \,.\, \sin \upsilon \,] \,.\, [\, \phi \,.\, \ell \,]$ - where

J is a constant,

$\mathcal{V}$ is the fluid velocity in the effective operating range of "m" to "kp",

B is the magnetic flux density in the effective operating range of "sg" to "pg",

υ is the angle of intersection of the fluid velocity vector and magnetic field gradient

ϕ is a variable and

ℓ is the length of MFC treatment

(Note: 1. The effect of the magnetic field on the diamagnetic scale crystal in the fluid as it passes through the magnetic field is proportional to the rate at which the magnetic flux is intersected. [7]

2. The MFT energy is the increase in the electric charge on the growing scale crystals

produced by the interaction of the magnetic field on the crystals).

Ed = MFT energy dissipation factor

= Function of fluid turbulence, heat transfer, elapsed time and distance travelled after treatment by the MFC.

Cs = Scaling Category

= Function of $[\Phi . Tp_{pp}^{sp}]$, Ms and $[\lambda . \mathcal{X}m_s^{-:}]$ - where

Φ is a variable

Tp is the fluid process operating temperature within the range "pp" to "sp",

Ms is the mixed scale factor,

λ is a variable and

$\mathcal{X}$m is the magnetic susceptibility of each type of scale within the effective operating range of "s" to "-:".

("Tp" can be a major factor with some organic scale treatment with definite operating ranges, however, it usually has little influence in inorganic scale treatment within most fluid process operating temperatures ranges)

Rg = Rate of scale generation factor

= Rate at which scale builds up per unit thickness

Gs = Type of scale generator factor

= Function of one or more of the following – heat transfer, evaporation, gas release, fluid shear and/or chemical reaction

Qs = Severity of scale generator factor

= Function of the severity of the type of scale generator and $[\beta . t_d]$

= Function of $[\Gamma . \Delta T]$, $[X . \Delta P]$ and $[\beta . t_d]$ - where

Γ is a variable

ΔT is the temperature differential between the fluid and the vessel or pipe wall

X is a variable

ΔP is the pressure drop of the fluid

β is a variable and

t_d is the duration of the time the fluid is subject to the scale generator

SCF = Function { Em, Ed, Cs, Rg, Gs, Qs }

There is no simple empirical formula, as can be seen from above, as there are many variables involved in the correct design and application of a MFC Unit to treat a particular fluid process scale problem. The values of the various constants and variables have been derived by MTA through laboratory experiments and simulated trials and through extensive industrial applications.

In many applications it is necessary to modify the fluid dynamics at the point of application of the MFC Unit to bring the variables within the operating range of magnetic fluid treatment technology.

Where there are a number of scale forming points in a fluid process it is often necessary to apply multiple MFC Units in various strategic locations in the fluid system to totally eliminate/control all scale generating points. These should be organized into a number of overlapping zones of treatment.

The Scale-X™ MFC Units were designed using these principles and the simulated laboratory tests showed that the new Scale-X™ MFC designs would completely eliminate the worst scale problem being experienced on the Tinggi field platform.

The Solution

The solution involved a new mode of application for MFC Units by locating the MFC internal to the vessel and mounting them on the standpipes of the liquids to be treated. These MFC Units were "application specific" and replaced the vortex breakers. The zone of treatment of these MFC Unit's was designed to eliminate the scale build-ups in the standpipes and the Control Valves. The MFC Units incorporated velocity amplification, flow profiling and vortex breaker duties. A photograph of the MFC on the water outlet standpipe is shown in Appendix D.

This new approach MFC Units is a world first and took 2-1/2 years to develop specially for this application.

Visual Inspection 8 Months After Installation

There was a general field shutdown in May 2002, 8 months after installation of the MFC's, which allowed an internal visual inspection of the separation vessel, valves and pipes to be carried out. Photographs from that inspection are contained in Appendix C and visually shows that new scale formation had been eliminated.

Outcomes: 19 Months After Installation

The platform has not been shutdown for de-scaling since installation of the MFC Units 19 months prior. The platform still continues to operate the same as it did at the 8-month internal inspection and all operational parameters indicate that it will be able to run continuously without a shutdown.

The outcomes (after 19 months) in operational, production and maintenance benefits in the treated zone resulting from the installation of the Scale-X™ MFC Units has exceeded the PCSB specification in all categories, and:

1. Completely stopped the scale build up in the Stand-pipes & Control Valves.
2. Removed existing scale build up.

3. De-scaling maintenance shutdowns can be reduced from 4 per year, to less than 1 per year and can most likely be totally eliminated.
4. Production output has been significantly increased due to no drop off in production and elimination of de-scaling maintenance shutdowns.
5. Control valves remain fully functional and valve life has been lengthened.
6. Operational performance of the platform has remained stable with no ramping of vessel pressure or liquid level required.
7. An economic evaluation of the Scale-X™ MFC Units has a return on investment within a matter of weeks.
8. Significant benefits have been achieved in HSE issues (No vessel entry or chemical handling).

Appendix C photographs show the scale build-ups after 3 months without the MFC Units and no scale build-up at 8 months with the MFC Units installed. (The photographs at 8 months were taken during the general field shutdown.)

Appendices E & F show the improved operational performance of the platform system in maintaining full production output with the control valves remaining fully operational.

Conclusions

Scale-X™ MFC Units can produce long-term solutions to chronic scale problems in the Oil industry.

Total elimination of scale in the stand-pipes, valves and piping was a major achievement. PCSB had, from previous experience with scale control trials, not expected that the scale problem could be totally eliminated and existing scale softened and removed. These new MFC' Units have created a new perspective, and raised expectations with respect to what this technology can achieve, to a new level.

The application of Scale-X™ Magnetic Fluid Conditioners on the Tinggi platform has shown that:-

1. Scale-X™ MFC's can eliminate chronic scaling problems in large industrial applications including oil production systems.
2. Magnetic fluid treatment technology must be applied in a scientific way taking into consideration fluid process conditions, fluid dynamics and plant design and plant construction materials.
3. This technology must be designed to suit the individual application
4. MFC's can be designed to successfully treat systems involving a single pass through the MFC
5. A typical "off the shelf" approach to the application of this technology will fail in many applications because such MFC's are engineered to operate only within a limited range of fluid process conditions. "Off the shelf" MFC's are only suitable for some re-circulating fluid systems. For industrial process systems an "application specific" approach is required to achieve success.
6. Where fluid dynamics and the fluid process parameters are not within the operating range of this technology, velocity amplifiers and flow profiling must be incorporated into the MFC's
7. It is possible to design MFC's which are simple to retrofit in large industrial applications and are low in capital cost
8. Scale can be totally eliminated in major industrial plants resulting in the plants running continuously without the need for shutdowns to de-scale
9. Many MFC's commonly available in the market place are generally not suitable for application in major industrial applications.

References

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Acknowledgements

These new magnetic fluid conditioners (MFC's) were developed by Magnetic Technology of Australia and are marketed under the name Scale-X™ Magnetic Fluid Conditioners. Further information can be obtained from

www.scale-x.com.

Appendix A

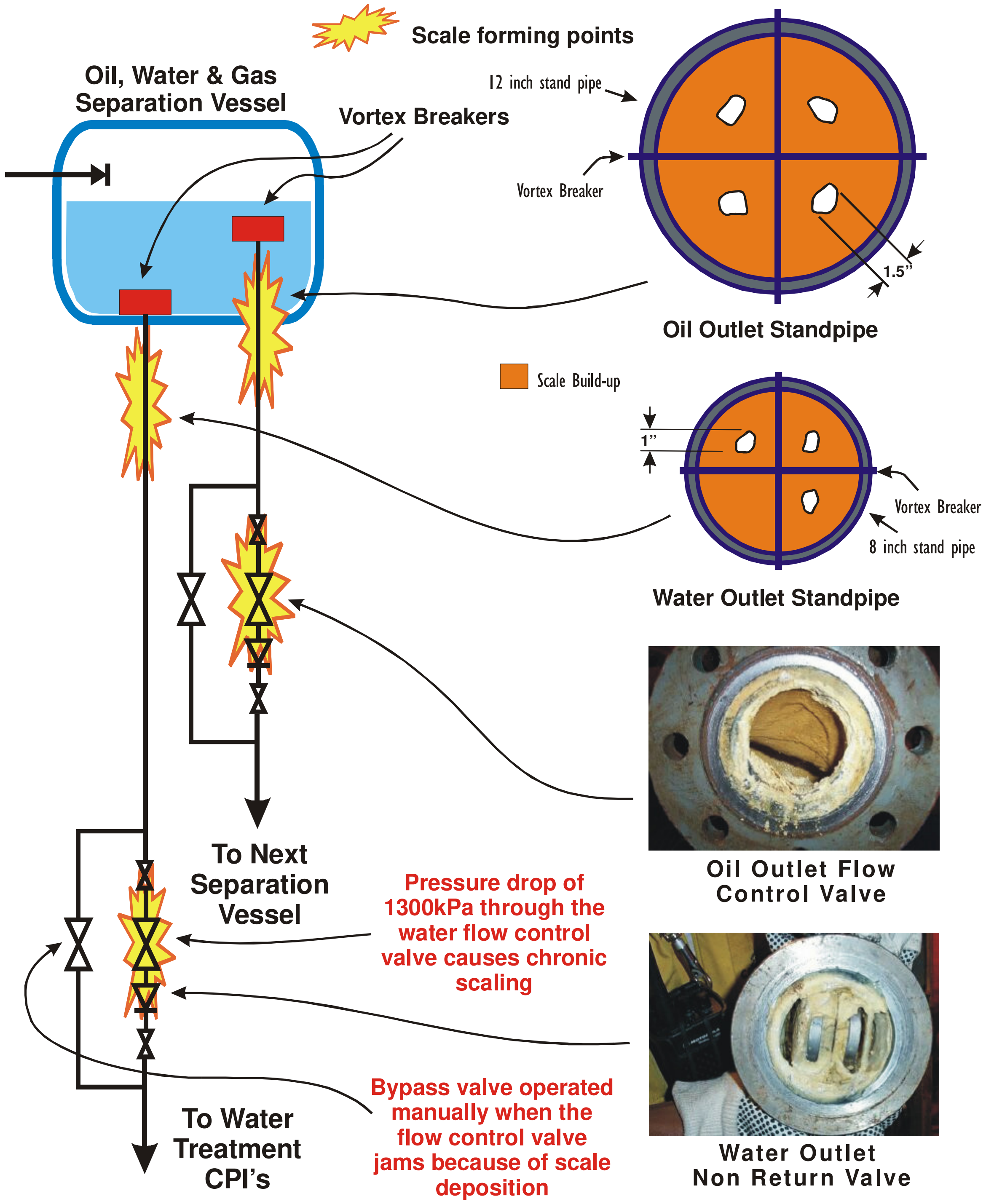
Evaluation of scale control mechanisms trialed and/or applied on Tinggi & Other Offshore Oil Fields in Malaysia			
Control Mechanism	**Product Name**	**Effectiveness (scale 1 to 10)**	**Comments**
Magnetic Fluid Conditioner	**MFC "A"** (see Note A)	6	Cleans reduced from 2 per year to 1 per year
Magnetic Fluid Conditioner	**MFC "B"** (see Note B)	5	Cleans reduced from 3 monthly to 5 monthly. MFC units suffered from front end fouling.
Magnetic Fluid Conditioner	**Scale-X™**	**10**	Eliminated scale build up. (Reduced calcite by 100%, barite by 100% and dolomite by 100%). Removed existing scale build ups. Exceeded PCSB specification.
Chemical scale inhibitor	**Surflo SI 2750**	0	Increased scale problem - barite by 480%, calcite by 100% and dolomite by 8%
Chemical scale inhibitor	**Surflo SI 3007**	1	Reduced calcite by 33%. Increased barite by 500% and dolomite by 8%
Chemical scale inhibitor	**Scaletrol-5**	1	Reduced calcite by 19% and dolomite by 0.4%. Increased barite by 109%
Chemical scale inhibitor	**Techni-Hib 764**	6	Reduced calcite by 63% and dolomite by 14%, increased barite by 100%
Chemical scale inhibitor	**Techni-Hib 767W**	3	Reduced calcite by 47% and dolomite by 3% and increased barite by 103%
Chemical scale inhibitor	**Techni-Hib 7576**	2	Reduced calcite by 27% and dolomite by 7%, increased barite by 100%

Note A: Supplied by Magniflo

Note B: Supplied by MagWell

Appendix B

Oil/Water/Gas Separation Vessel
Oil and Water Standpipes and Control Valves
Scale Build Up Before Descaling At 3 Monthly Platform Shutdown Before Installation of MFC's



Appendix C

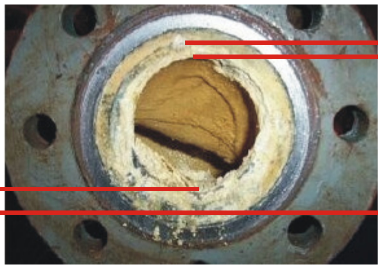
Scale Build Up Before and 8 Months After Installation of Scale-X™ MFC's

Photographs taken before descaling at 3 monthly platform shutdown before installation of Scale-X MFC's

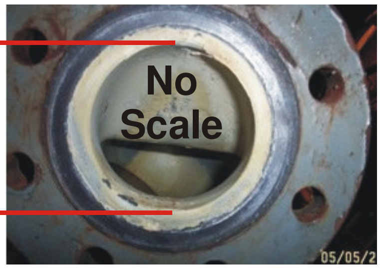
Photographs taken during the general field shutdown 8 months after installation of the Scale-X MFC's

Oil Control Valve

Thick Scale

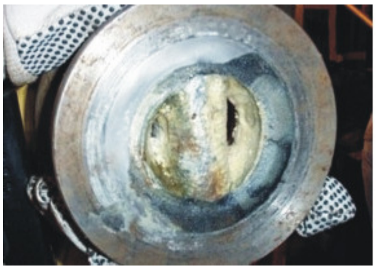


Thick Scale Build Up
After 3 Months
Without MFC's Installed



No Scale Build Up
After 8 Months
With MFC's Installed

Non-Return Valve

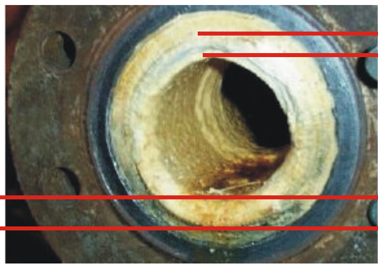


Heavy Scale Build Up
After 3 Months
Without MFC's Installed

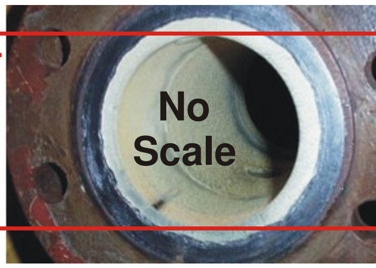
No Scale Build Up
After 8 Months
With MFC's Installed

Block Valve Reducer Downstream of Oil Control Valve

30mm Scale



Thick Scale Build Up
After 3 Months
Without MFC's Installed
Thickness of Scale is 30mm



Inside Diameter Clean Bore

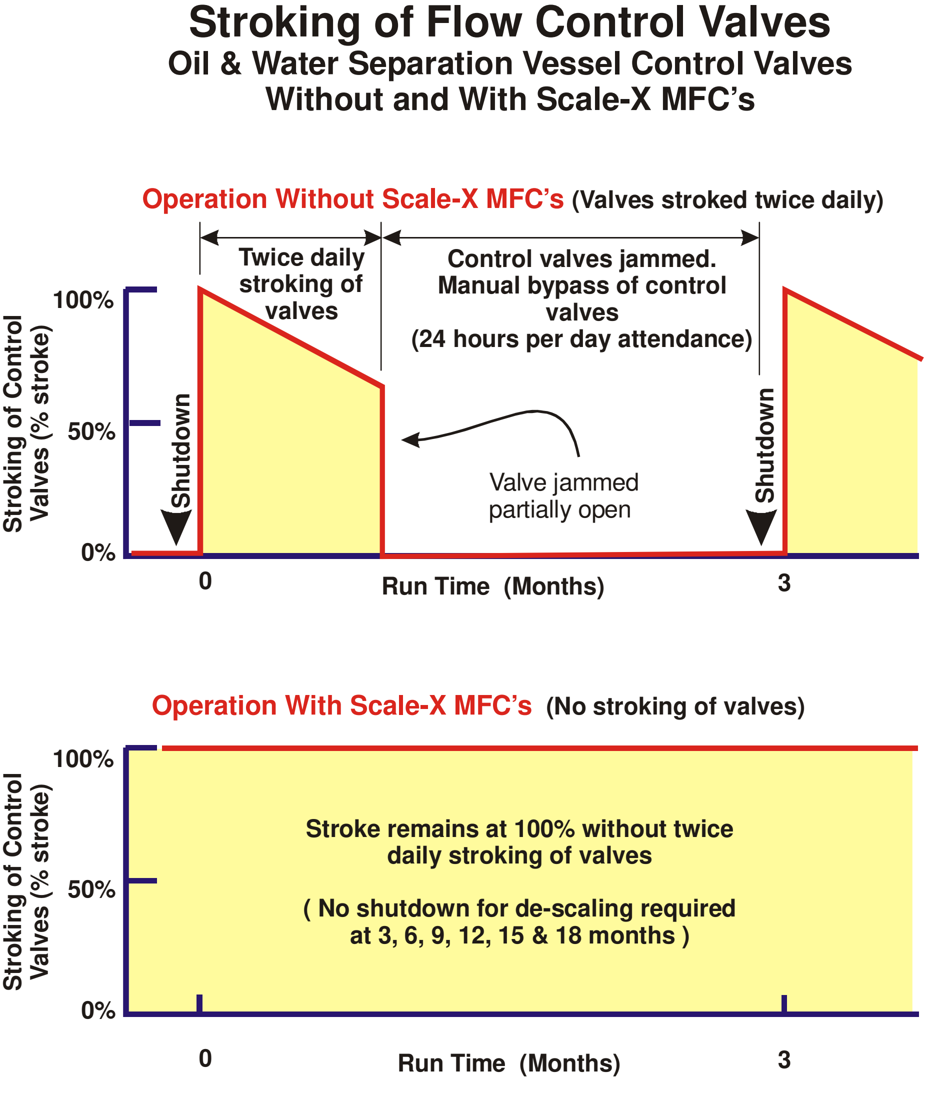
No Scale Build Up
After 8 Months
With MFC's Installed
Scale is eliminated

NOTE: The liquid through these valves and reducer is 3 parts crude oil and 1 part formation water.

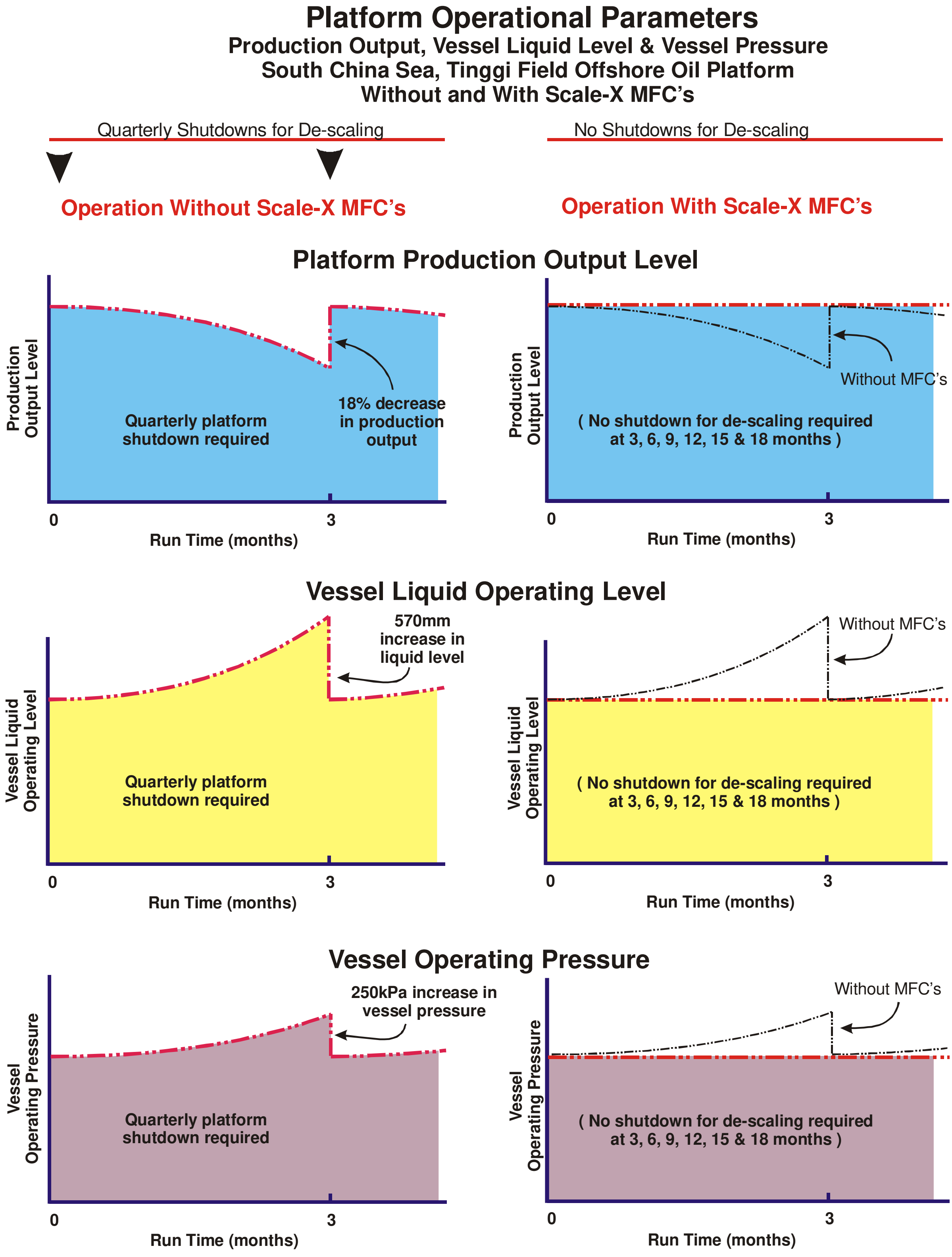
Appendix D

Scale-X™ MFC Installed on the Separation Vessel Water Outlet Standpipe

Appendix E



Appendix F


Platform Operational Parameters
Production Output, Vessel Liquid Level & Vessel Pressure
South China Sea, Tinggi Field Offshore Oil Platform
Without and With Scale-X MFC's
Quarterly Shutdowns for De-scaling
No Shutdowns for De-scaling
Operation Without Scale-X MFC's
Operation With Scale-X MFC's
Platform Production Output Level
Production Output Level
Quarterly platform shutdown required
18% decrease in production output
Without MFC's
(No shutdown for de-scaling required at 3, 6, 9, 12, 15 & 18 months)
0
3
Run Time (months)
Vessel Liquid Operating Level
Vessel Liquid Operating Level
570mm increase in liquid level
Quarterly platform shutdown required
Without MFC's
(No shutdown for de-scaling required at 3, 6, 9, 12, 15 & 18 months)
0
3
Run Time (months)
Vessel Operating Pressure
Vessel Operating Pressure
250kPa increase in vessel pressure
Quarterly platform shutdown required
Without MFC's
(No shutdown for de-scaling required at 3, 6, 9, 12, 15 & 18 months)
0
3
Run Time (months)