Flow-Tech Principles of Operation

Rob French, George Rihovsky, and Mark Meyer

Principles of operation

Water used in heating, cooling, and other processes may contain dissolved chemical species (minerals) that become less soluble due to environmental changes caused by the equipment used in such systems. This can lead to precipitation of solids from solution that deposit on the wetted surfaces of the equipment. It is the deposition of material and not the general act of precipitation that causes reduced heat transfer and flow efficiency.

Solid mineral scale forms from solution when physical conditions in the fluid change. When the change in condition is such that the dissolved ions within the solution become present at a concentration above that which the water phase can support, the fluid has become supersaturated. When supersaturation occurs, it is energetically favorable for the excess material present to precipitate out as a new, solid phase returning the fluid to a stable, saturated condition. This precipitate is the mineral scale.

The thermodynamics of solubility state that (i) when a new phase forms it begins from a supersaturated condition and (ii) when the new phase is forming, energy is released from the system. However, the creation of a new phase from solution (solid or gas) requires formation of a boundary surface – which requires energy. Creating fewer surfaces is energetically more efficient. Precipitation onto a pre-existing solid surface, or in a crevice, reduces the surface area the new phase must create and is thus more efficient. As a simple analogy, the bubbles in a carbonated drink are initially seen present at the glass wall until they grow large enough to float into bulk solution. A gas sphere forming at the glass wall requires 50% of the surface of a bubble forming spontaneously in solution. Thus, if that new phase begins to grow at an existing surface less energy is required for the new phase to form. The new phase then forms on the existing surface as fast as material can be transported to that site. In the case of the bubble in the drink, it grows until it detaches from the wall – the rate of growth is limited by the diffusion of gas to the bubble. In the case of solid precipitation, this also implies that the new phase will strongly adhere to the site from which it grows because intimate contact minimizes the quantity of new surface to be created thus creating a persistent, growing mineral deposit.

The deposits which form on equipment surfaces from the ions originally dissolved in water form because of deposition. Formation of the solid phase requires nucleation which requires energy. The formation of the new phase occurs most rapidly at existing surfaces, as this is energetically more efficient and is the predominant thermodynamic path of normal supersaturated chemical species. Control can be exerted by use of chemicals to kinetically interfere with the nucleation process. An alternate control strategy would be to induce homogenous crystallization at multiple nucleation sites suspended in bulk solution so that solid phase growth would occur in suspension and not at the tubular surface. Induction of a material phase change in bulk fluid generates a suspension as opposed to a precipitate. The problems associated with adherent deposits no longer occur but, as described above, is energetically disfavored.

The Flow-Tech signal overcomes the propensity to heterogeneous crystallization at surface by generating a pulsed electromagnetic field to provide the energy required to produce the surfaces needed for homogenous crystal formation in bulk solution. The electronic device makes energy available to the charged ions, that are crystallite precursors, through subjecting them to a fast moving and varying electromagnetic field. This induces homogeneous nucleation in the bulk liquid phase. As multiple nucleation sites are produced, the crystals do not grow to a large size as the ionic species that cause scaling are, in general, sparingly soluble. Diffusion limitation implies that there is insufficient dissolved material available to allow the crystals to grow to problematic dimensions whilst in the bulk phase as they rapidly pass through the system. The particles formed are in the 5-8µ diameter range and remain suspended in the fluids. Applications that allow concentration of these ionic species through evaporation of potable or well water will allow the crystals to grow in excess of 40µ with an average composite specific gravity around 2.5 – allowing removal through traditional filtration methods including centrifugal separation.

In the system described, the energy required for homogenous nucleation is provided by an alternating current electromagnetic pulse. The pulse is generated on the exterior of the hydronic system and transmitted both up and downstream. Impedance matching, of the signal generator and the system to be treated, maximizes signal propagation in the system with the water column acting as an antenna. As per figure 1, the signal induces a fluctuating field perpendicular to its plane of propagation. Any charged particle moving through this electromagnetic field generates energy. The charged, dissolved ions that are the crystallite precursors gain energy. The base frequency of the decaying signal transmitted is in the range of 80-380 kHz and is pulsed at a rate of 5-40 kHz.

The energy provided by the interaction of scaling ions and the pulsed field is sufficient to induce homogenous nucleation in the bulk phase of the fluid where the produced fluid is in a metastable state, i.e. the scaling ions are present above saturation concentration but there is insufficient energy to initiate the production of new surfaces to initiate nucleation without interaction with a surface. In this case the energy is provided by an electrical signal. A number of industrial processes use ultra-sound for the same purpose.

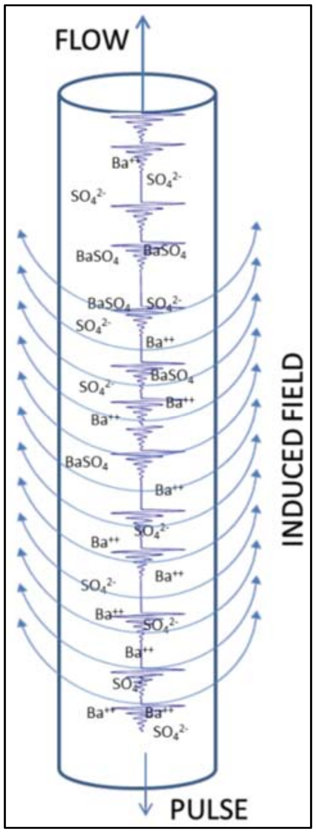


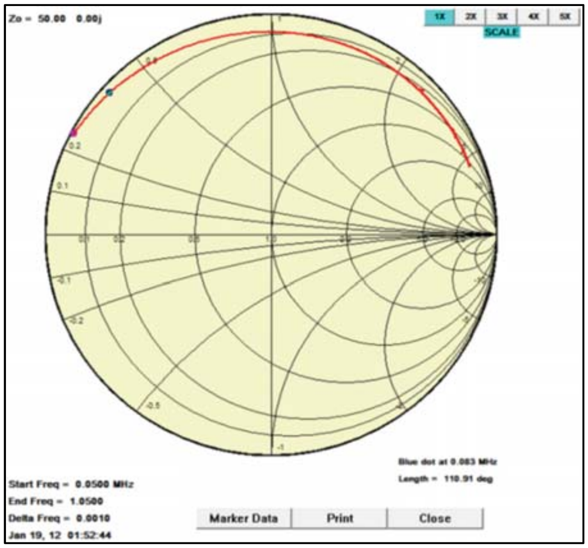
Figure 1
Induced Field
In Pipe

With the signal generator unit correctly connected, the hydronic system acts as an antenna and signal propagation distance is equivalent to the transition from "Near Field to Far Field" Transmission. The use of an electromagnetic signal allows propagation of the signal throughout the hydronic system. Efficient signal propagation is verified by use of simple Smith impedance as in Figure 2.

Equipment protection

The formation of these crystals protects equipment sensitive to scale accumulation. Chillers use approximately 1% more energy for every thousandth of an inch of calcium scale, flow restrictions cause performance issues, increased energy consumption, and premature failure in pumps and other equipment, and additional labor is required to remove scale even in primarily cosmetic conditions such as pools and water features.

Softening or removal of existing scale
As calcium carbonate precipitates out of solution due to the Flow-Tech signal, small amounts of carbon dioxide are disassociated. This process will soften and dissolve scale over time and will reduce labor required to clean the system.



Zo = 50.00 0.00j
Blue dot at 0.083 MHz
Length = 110.91 deg
Start Freq = 0.0500 MHz
End Freq = 1.0500
Delta Freq = 0.0010
Jan 19, 12 01:52:44

Figure 2
Smith Impedance Chart From Pipe With Optimized Flow-Tech Signal

Bacteria Control
Bacteria populations are controlled by two different processes. In evaporative cooling applications, the precipitate encapsulates bacteria rendering them unable to reproduce or even sustain life. Automated filtration systems can remove the encapsulated bacteria. In addition to this process, the propagating Flow-Tech signal comes in nearly constant direct contact with bacteria throughout the hydronic system and causes sufficient physical damage to limit bacteria counts in a wide range of applications – even in non-evaporative applications where there is no precipitation. Either process is sufficient to maintain very low bacteria counts even if the system is not operated for a few days.

Biofilm control
Due to the randomness of the Flow-Tech signal, all equipment and piping surfaces are contacted by a signal that causes any existing biofilm to detach and prevents bacteria from forming new biofilm – even where chemicals are unable to penetrate and disperse the biofilm. Systems without biofilm are at a much lower risk of high bacteria counts and legionella outbreaks.

Corrosion control
By setting evaporative cooling applications to operate above the saturation point for calcium carbonate, the precipitate acts as a very effective natural corrosion inhibitor. Single-pass, closed-loop, and other applications that do not allow for supersaturation of calcium carbonate will not benefit from increased corrosion protection.

Water savings
Due to the increased acceptable cycles of concentration in evaporative cooling applications and the ability to reduce bacteria counts, prevent scale, and precipitate impurities, water can often be used for much longer before needing to be bled or replaced with fresh water.

Enhanced flocculation and filtration
In addition to calcium carbonate, many other minerals and impurities will also precipitate in the bulk water. In evaporative applications the precipitate will increase in size after supersaturation. The resulting increase in size and weight aid in the filtration processes. In other processes where flocculants and coagulants are added to the water, this process can improve their performance while reducing the quantity required.

References

Krag, Anders, Fergusson, Alasdair Macneil, and Grainger, Martin. (2014) Preventing Scale Deposition Downhole Using High Frequency Electromagnetic AC Signals from Surface to Enhance Production Offshore Denmark. Society of Petroleum Engineers. doi:10.2118/170898-MS

Tomson, M. B., Fu, G., Watson, M. A., & Kan, A. T. (2002, January 1). Mechanisms of Mineral Scale Inhibition. Society of Petroleum Engineers. doi:10.2118/74656-MS

Hinrichsen, C. J. (1998, January 1). Preventing Scale Deposition in Oil Production Facilities: An Industry Review. NACE International.

Patton, Charles C. Oilfield water systems.[Norman, Okla.] : Campbell Petroleum Series, 1977

Nancollas, G. H., Gerard, D., & Zachowicz, W. (2004, January 1). Calcium Carbonate Scaling. A Kinetics And Surface Energy Approach. NACE International

A.W. Adamson, Physical Chemistry of Surfaces Third Edition, pp372-383, John Wiley and Sons New York 1976

Nancollas, G. H., & Reddy, M. M. (1974, April 1). The Kinetics of Crystallization of Scale-Forming Minerals. Society of Petroleum Engineers. doi:10.2118/4360-PA

Kapustin, A. P. 'The Effects of Ultrasound on the Kinetics of Crystallisation'. USS Academy of Sciences Press. Engl. Trans. Consultants Bureau, New York, 1963; Martynovskaya, N. V. Akust. Ul'trazvuk. Tekh. 1970 (6), 14; Reshetnyak, I. I. Akust. Zh. 21 99 (1975).

Maglione, R., Burban, B., & Soulier, L. (1994, January 1). electromagnetic Transmission Improvements Applied To On/Offshore Drilling In The Mediterranean Area. Society of Petroleum Engineers.

Hassan, S. S., Ahmad, T., Farooqui, S., Ali, H. M., & Qamar, A. (2011, January 1). Remedy of Severe Scale Build Up Issue in OMV (Pakistan) at Well; Society of Petroleum Engineers. doi:10.2118/156210-MS

Muswar, H., Parker, W. L., Falsini, F., & Thaib, D. (2010, January 1). Field Effectiveness of a Physical Water Treating Device to Control Carbonate Scale in Indonesia. Society of Petroleum Engineers. doi:10.2118/133526-MS

Garzon, F. O., Solares, J. R., Al-Marri, H. M., Mukhles, A., Ramadan, N. H., & Al-Saihati, A. H. (2009, January 1). Analysis of Deposition Mechanism of Mineral Scales Precipitating in the Sandface and Production Strings of Gas-Condensate Wells. Society of Petroleum Engineers. doi:10.2118/120410-MS

Fergusson, A. , Al-Matrushi, Q. N. A., Ferjani, H. O., (March 2014) Preventing Scale Deposition Downhole Using High Frequency AC Signals from Surface to Extend ESP Run-Life at TEKNA Oilfield Chemistry Symposium

Sear, R. P. (2007). Nucleation: theory and applications to protein solutions and colloidal suspensions. J. Physics Cond. Matt. 19 (3): 033101. Bibcode:2007JPCM...19c3101S. doi:10.1088/0953-8984/19/3/033101

Tavare, N.S. (1995). Industrial Crystallization Plenum Press, New York

McCabe & Smith (2000). Unit Operations of Chemical Engineering' McGraw-Hill, New York

Hefter, G.T.; Tomkins, R.P.T (Editors) (2003). The Experimental Determination of Solubilities. Wiley-Blackwell. ISBN 0-471-49708-8.

Mendham, J.; Denney, R. C.; Barnes, J. D.; Thomas, M. J. K. (2000), Vogel's Quantitative Chemical Analysis (6th ed.), New York: Prentice Hall, ISBN 0-582-22628-7 Section 2.14

Pauling, Linus: General Chemistry, Dover Publishing, 1970, p 450