

Evaluation of Scale Deposition and Inhibition Using a Pilot-Scale Test System

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ABSTRACT

The deposition of inorganic scale from waters supersaturated with minerals is a significant flow assurance issue in oil and gas production. Several laboratory techniques are routinely used to assess scale deposition and qualify chemical inhibitors but these all have limitations with regard to matching field conditions such as the hydrodynamic regime and residence time that the fluids are likely to experience. In some cases, these tests do not give sufficient confidence to develop scale management strategies and a more field-representative method is required to bridge the gap between laboratory tests and full field trials.

The design and use of a large pilot-scale test system to evaluate scale deposition and inhibition is described in this paper. The system involves flowing large quantities of brine through a test piece at high flow rates for several hours. Different test piece configurations can be used and these are constructed from shorter lengths of pipe allowing scale deposit location and quantity to be readily analysed. An example is given in which sections of pipe made from different materials are used to investigate the effect that this has on scale adhesion. Chemical inhibition has been investigated by the injection of scale inhibitor into the flow stream and evaluating the reduction in surface deposits. Design considerations for these tests are also discussed with results from smaller scale preliminary tests used to ensure that sufficient deposits will be formed in the full-scale tests.

The successful implementation of the pilot-scale test system described provides an important industry tool enabling the evaluation of inorganic scale deposits under field-realistic flow conditions and methods to mitigate the flow assurance issues resulting from them. The results obtained from the tests also advance the understanding of the effect that the use of different materials in oilfield flow systems have on scale deposition.

Key words: Scale Deposition, Inhibition, Pilot-Scale Testing, Coatings, Strontium Sulphate

INTRODUCTION

The formation of common inorganic scales (such as BaSO_4 , SrSO_4 , CaSO_4 and CaCO_3) in production tubing presents a significant problem in the oil and gas industry. The mixing of incompatible waters or changes in temperature, pressure, pH or hydrodynamics of a fluid may result in scale deposition, with the potential to cause constrictions in production tubing when allowed to build up. This can lead to costly interventions that result in delayed production and loss of revenue. Therefore, an effective scale mitigation strategy is a crucial part of field development and management.

The most common method of scale mitigation is chemical inhibition. Prior to use in the field, laboratory tests are usually carried out to determine a suitable inhibitor chemistry and the minimum effective dose (MED) required. Typically, static bottle tests and dynamic tube blocking tests are used to assess a chemical and while these methods provide a quick method of assessing a large number of chemicals, they have limitations.¹ For example, static bottle tests are a useful method to quickly screen a large number of chemicals but do not take fluid flow dynamics into account. Dynamic tube blocking tests meanwhile provide a single-pass test, similar to a field system but the flow tends to be laminar, not the turbulent flow typically seen in oilfield pipelines, and the residence time is short. Consequently, the most effective inhibitor chosen by these methods may not be the most suitable one for the field or the determined MED may be too high or low. A jet impingement technique to simulate high shear and highly turbulent conditions has been developed to allow evaluation of scale inhibitor performance under more field representative conditions.²⁻⁴ However, this method is a small-scale recirculating system that, while relating inhibitor concentration to scale deposition as well as precipitation, also does not fully replicate a field flow system.

In some cases, these tests do not give sufficient confidence to develop scale management strategies and a more field-representative method is required to bridge the gap between laboratory tests and full field trials. Pilot-scale testing, with larger test pieces and volumes of fluid, offers an intermediate stage between small-scale bench-top tests and full-scale field trials.

One advantage of pilot-scale tests is that it is possible to incorporate field devices into the test piece. For example, previously published work from our laboratories has described the examination of calcium carbonate scaling in an inflow control valve (ICV).^{5,6} The test piece was a simplified version of a typical field valve, having the same general geometric features as one used in the field, and 2,000 L of brine was heated to 75 °C and pumped through the ICV at 8.5 L/min and at a pressure of 208 bar. A series of tests investigated the effects of shear stress and anti-scale coatings on the mass of scale deposited on the valve.

Further pilot-scale work investigated the effect of hydrodynamics on SrSO_4 scale deposition in an inflow control device (ICD) simulating fluid passing through a sand screen and small diameter nozzle.⁷ For these tests, 70 °C brine was passed through a test piece at 10 L/min and at a pressure of 30 bar. The test piece itself was composed of two perpendicular sections of 1-inch stainless steel tubing. A piece of sand screen was installed upstream of the 90° bend and to induce a high shear stress in the system, the brine was forced through a 2 mm hole when passing between the two perpendicular sections. A wide range of shear stresses were calculated to arise within the test piece ranging from <1 Pa in the long straight sections of tubing to 20,000 Pa at the 2 mm orifice.

Martins *et al.* used pilot-scale tests to investigate calcium carbonate scaling in a prototype sliding sleeve valve.⁸ This pilot-scale testing was reported to allow scaling in the valve to be investigated under physicochemical, kinetic and fluid dynamic conditions similar to those of the field.

This paper describes the design of a large pilot-scale test system and its use to evaluate both the effect of different materials and surfaces on scale deposition, and mitigation by chemical inhibition. The importance of selecting appropriate test design and conditions, and the role of smaller scale preliminary tests are also discussed.

EXPERIMENTAL PROCEDURE

Laboratory Set-up

The scaling tests described in this paper were carried out in a custom-built pilot-scale laboratory. The laboratory was designed to allow the preparation of up to 12,000 L of brine. Heat exchangers linked to boilers allow the brines to be heated up to 80 °C. Two triplex pumps enable flow rates of up to 10 L/min per brine (20 L/min combined) and pressure up to 345 bar (5000 psi) to be achieved. The laboratory has the capability to install large test pieces consisting of long sections of tubing (up to several metres in length) with the option to incorporate field devices, such as ICDs, within the test piece design.

For these tests, 1,000 L each of formation water (FW) and seawater (SW) brines were prepared in separate IBCs and preheated to the test temperature of 70 °C by recirculating through the heat exchangers. Two high-pressure pumps were then used to pump the brines into the mixing T-piece at the inlet of the test piece. The flow rate from the high-pressure pumps was controlled by two frequency inverters. The flow rate for the tests described here was 5 L/min combined (2.5 L/min of each brine). The test piece itself was not heated but the temperature of the effluent brine was monitored and did not drop significantly below 70 °C. A control system of valves and pressure transducers connected to logging software was used to monitor the apparatus. Figures 1 and 2 show images of the laboratory apparatus.

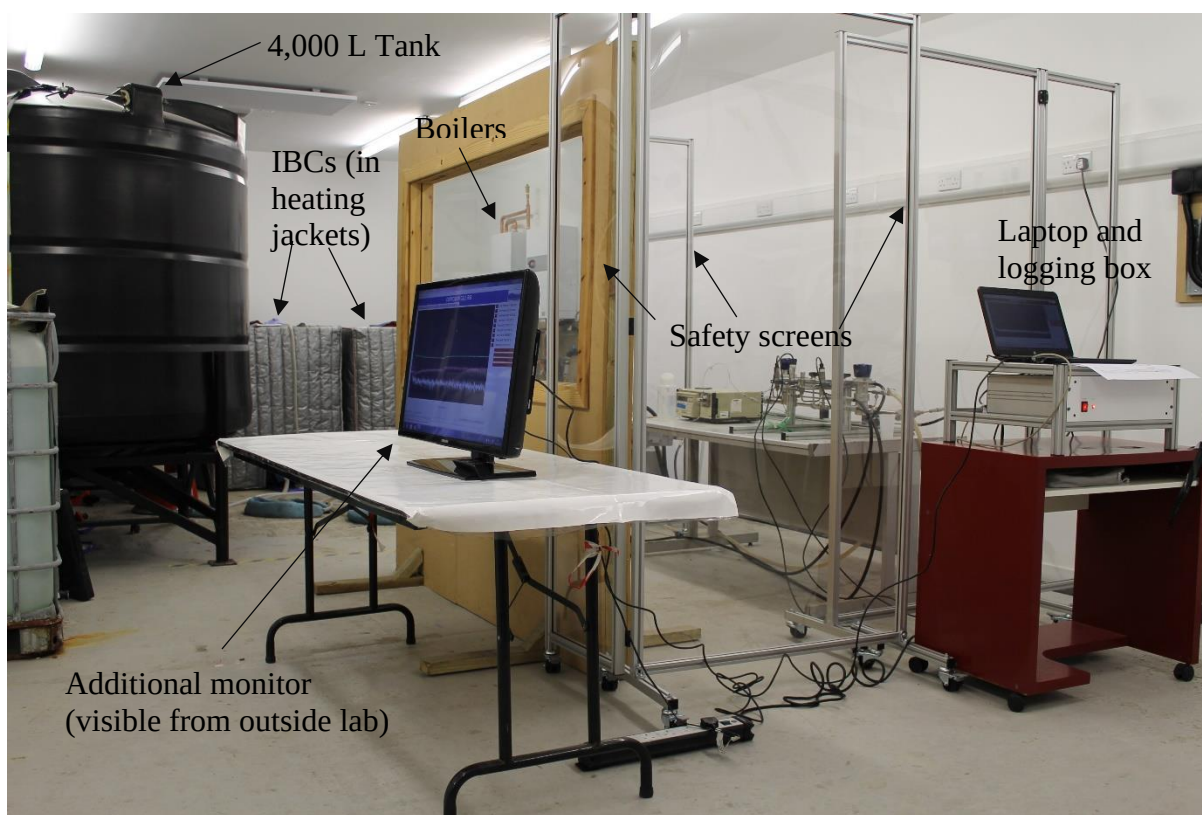


Figure 1: Pilot Laboratory Set-up

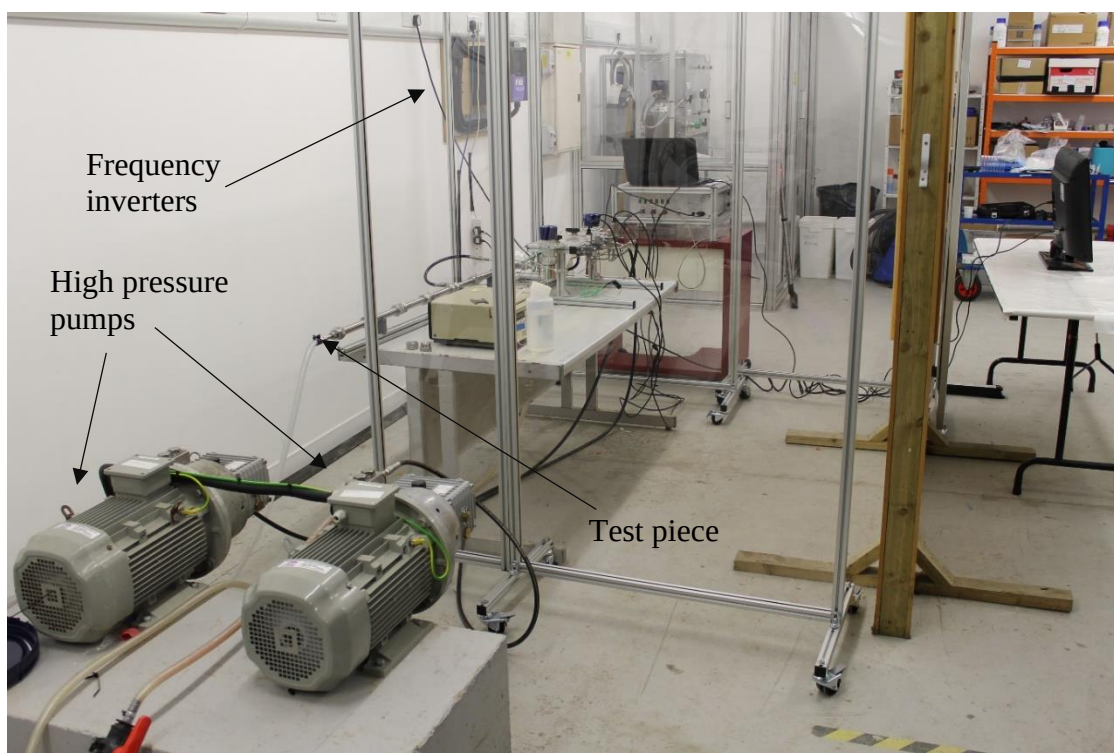


Figure 2: Pilot Laboratory Set-up

Test Piece Design

The design of the pilot rig allows different test piece configurations to be used. For most experiments these are constructed from shorter lengths of pipe allowing the test piece to be dismantled after testing to assess the distribution and quantity of scale. For the experiments presented in this paper, the test piece was composed of 23 sections of 20 cm long tubing with an outer diameter of 1 inch (2.54 cm) which had an inner diameter of 2.2 cm. The brines were pumped separately into the mixing T-piece and an injection quill was installed on the FW inlet to the T-piece to ensure mixing of the brines. Preparing the brines and running each test on this scale can be time-consuming and so in this case, the design effectively allowed two experiments to be conducted within the same run. The first 18 sections were designed to investigate the scale adherence to tubing of different materials or surface treatments. The latter part of the test piece was designed to demonstrate chemical inhibition of scale deposition. A T-piece located between sections 18 and 19 allowed an inhibitor solution to be injected into the flow of brine. This passed through 5 sections of tubing (sections 19 to 23) before passing through the $\frac{1}{2}$ inch outlet to waste. A schematic is shown in Figure 3 and images in Figure 4.

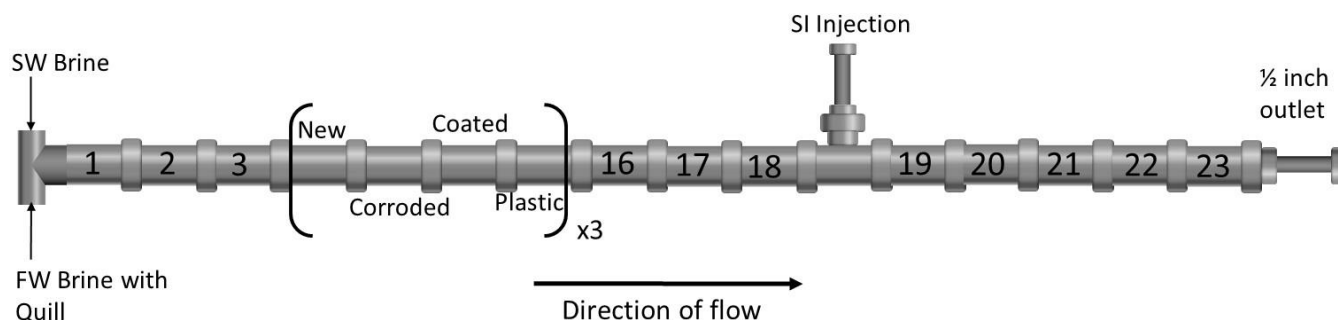


Figure 3: Test Piece Schematic