Automatic Optimisation of Oilfield Scale Inhibitor Squeeze Treatments

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Summary
Oilfield scale deposition is a serious challenge facing the oil and gas industry. Among the available techniques to prevent formation of scale deposition, squeeze treatment is one of the most efficient and common techniques. Squeeze treatments consists of the injection of chemical scale inhibitor followed by an overflush stage. The chemical will prevent scale deposition if the concentration of inhibitor in the produced brine is above a certain concentration level, known as the Minimum Inhibitor Concentration (MIC).
The main purpose of this paper is to present squeeze treatments designs for a field case with a specified target lifetime. The methodology presented in this paper includes an optimisation algorithm suitable for this complex real life problem. The algorithm, which is described, presents a number of optimum designs, from amongst which the Pareto optimal front is calculated to identify the most efficient design for the particular conditions of the well under risk of scale deposition.

Introduction
The deposition of organic and inorganic material in surface facilities, wellbore and near wellbore areas may lead to a number of serious problems. Scale deposition in the near wellbore area may cause blockage in the perforations or the near-well formation that leads to a reduction in well inflow performance. Deposition in the tubing or the surface facilities leads to significant flow restriction problems, see Figure 1. In addition, other important problems caused by scale deposition are subsurface safety valve failure, choke failure, and pump wear (Zavala *et al.*, 2008; Vazquez *et al.*, 2016).

Figure 1 Pipe with scale deposits on the left and after scale removal on the right and [5]

The main types of oilfield scales commonly found worldwide are carbonate and sulphate scales. Carbonate scales may precipitate due to pressure decrease that leads to evolution of dissolved carbon dioxide. On the other hand, sulphate scales, such as calcium, strontium or barium sulphates, may precipitate due to mixing of incompatible brines - such as cation rich reservoir brine mixing with sulphate rich injected brine (Vazquez *et al.*, 2016; Zavala *et al.*, 2008).
Once scale has formed in the reservoir it will be difficult to remove. Carbonate scales are highly soluble, hence they can be removed from the wellbore by using acid washes or by mechanical methods. Sulphate scales, such as strontium and barium sulphate, have low solubility, and they are not acid soluble, therefore they are usually removed by well interventions (Powell *et al.*, 1996; Zavala *et al.*, 2008; Vazquez *et al.*, 2016). However, one of the most efficient and common techniques used to avoid the formation of scale deposition is scale inhibitor squeeze treatment, where a scale inhibitor chemical solution is pumped down a producer into near well formation. Squeeze treatments commonly comprises four stages: preflush, main slug, overflush, and shut-in stages. The preflush stage is used to act as a buffer and to clean the area around the wellbore. The main slug is where the pill of scale inhibitor (SI) will be injected at the operational concentration, usually between 5 and 15%. The overflush is injected to push the chemical slug deep in the reservoir, exposing the chemical to more fresh formation rock, and thus maximizing retention; the overflush is normally at least two times larger than the main slug volume. When the well is put back in production, the SI is slowly released from the rock into the production brine. SI will prevent scale deposition as long as the produced concentration is above a certain threshold concentration, commonly known as MIC (Minimum Inhibitor Concentration), which usually varies between 1-20 ppm (Vazquez *et al.*, 2009, 2016, 2017) The squeeze treatment lifetime is determined by the time taken for the return concentration to fall below the MIC, given either in production days or in volume of water protected.

Impact of scale on production and economics
Scale formation causes different kind of problems that may influence the production. For instance, scale formation within perforations or production tubing may significantly reduce production rates. Here, scale deposition in the tubulars decreases the diameter available for fluid flow, as shown in Figure 1. Between the period of 1999-2003, BP has estimated that about 18% of their well losses were attributed to scale. One of the famous examples is the Miller field in the North Sea, where the production fell from 30,000 bpd to 0 within 24 hours. Moreover, scale formation may cause safety valve and choke failure or pump wear that can influence production as well (Wayne and Fenier, 2009; Zavala *et al.*, 2008).
According to Figure 2, which illustrates the worldwide loss of production from different processes, it is clear that 28% of production is lost due to scale. Scale is one of the most

10.1190/RDP2018-41993986.1

expensive water related operational costs in the oil and gas industry. Based on Figure 3, it is clear that it has a significant economic impact, with annually \$100 million losses caused in the Middle East alone.

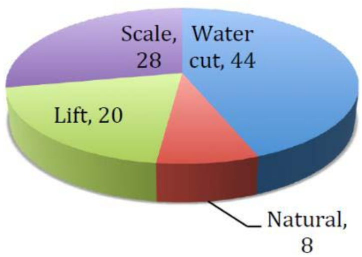

Figure 2 Percent of production loss from different processes, (Wayne and Frenier, 2009).

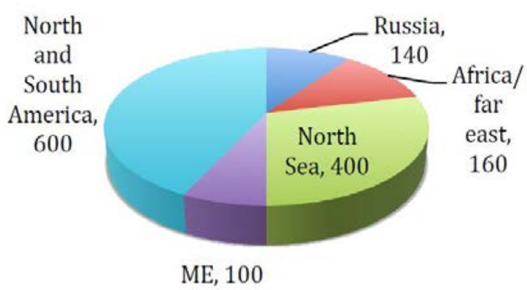

Figure 3 Economic impact of scale in different regions (\$MM), (Wayne and Frenier, 2009).

Methodology

As already discussed, the main objective of this paper is to show the automatic optimisation of squeeze treatment designs. An optimisation algorithm is described that identifies optimum designs. This is a complex real-life optimisation problem, and so a population stochastic search algorithm is used, since they are known to be very effective for this type of problem (Onwubolu and Babu, 2004). There are different types of population based algorithms, such as genetic algorithm, differential evolution or particle swarm optimisation (PSO) (Vazquez *et al.,* 2016). In this study, particle swarm optimisation is applied (Kennedy and Eberhart, 1995). The optimum designs are then identified using the Pareto approach.

PSO algorithm

Particle swarm optimisation is a stochastic algorithm that is inspired by bird flocking behaviour to find food (Kennedy and Eberhart, 1995). According to Vazquez *et al.* (2017) "The particle represents a single part of the population (swarm) which corresponds to a prospective solution. The position of the particle showing the highest level of success is described as personal best (p-best). While, the position of the best particle across the whole population is denoted as global best (g-best)''. In addition, Vazquez *et al.* (2016) have described the main computational steps, which are:

1. Set the algorithm with particle population of N designs which are randomly created from the parameter space, where every particle is allocated with a random velocity
2. Assess the fitness for each particle
3. Estimate p-best and g-best
4. Update the velocity of every particle ''i'' by using equation 1:

$$v_i^{k+1} = w \cdot v_i^k + c_i^1 \cdot r_1 \cdot \left(pbest_i - x_i^k\right) + c_i^2 \cdot r_2 \cdot \left(gbest^k - x_i^k\right)$$

where:

v_i^k is the velocity of particle *i* at iteration *k*
x_i^k is the position of particle *i* at iteration *k*
w is the inertia parameter
r_1, r_2 random number in the range [0,1]
c_i^1, c_i^2 are the acceleration terms

5. Update the motion of every particle ''i'' motion by using equation

$$x_i^{k+1} = v_i^{k+1} + x_i^k$$

6. Repeat steps 2-5 until the maximum number of iterations is reached or another stopping criterion is met.

The fitness of every particle is measure by conventional L1 norm, where the lower the objective value the greater the fitness:

$$\boldsymbol{Objective} = |\boldsymbol{T} - \boldsymbol{S}|/\boldsymbol{T}$$

Where, T is target squeeze lifetime, and S is suggested design squeeze lifetime. According to the equation above, it is clear that the closer the suggested squeeze lifetime is to the target, the lower the objective value and the greater the fitness.

Parameter space

As mentioned previously, a squeeze treatment consists of the following stages: preflush, main treatment, overflush, shut-in and back production. Normally, the preflush and shut-in are set by operational constraints, so the main treatment and the overflush volume will be considered in the optimisation search. The parameter search space will consist of three dimensions, the main treatment and overflush volumes, and the injected concentration, where the limits of the search space are determined by high and low multipliers.

Multi-objective optimisation
The main objective of this paper is to demonstrate how to achieve the target squeeze lifetime. However, achieving the target or even longer squeeze lifetime does not imply that the identified design is the most efficient. This is due to the fact that other aspects, such as the cost of the treatment and engineering considerations need to be considered. Due to the nature of scale inhibitors, by injecting very great volumes of water and by adding greater proportions of scale inhibitor, it is possible to achieve longer squeeze lifetimes. However, it is important to consider the impact of lifting the injected water back and the obvious increased expenses. Hence, the optimisation becomes multi-objective, where three independent objectives should be included in the optimisation exercise; specifically, target squeeze lifetime, cost of the treatment and total volume of injected water need to be taken into account. These three objectives are conflicting with each other, since the higher the volume the longer squeeze lifetime, but the more expensive it will be, as a higher volume of chemical will be deployed and the more water will be injected. Therefore, there exist a number of Pareto Front optimal treatment designs, each of which is not dominated by any other design.
Designs that are not dominated form the Pareto front; a design is said to be dominant, if there is no other design with better objectives, i.e. longer treatment life, cheaper and injecting less water.

Field Example Optimisation Results
A field case consisting in 8 layers was considered to find the most efficient design, with a target squeeze lifetime of 18 months (546 days). The base design is shown in Table 1, and the parameter space limits are depicted in Table 2.

Table 1 Original Squeeze treatment design.

[SI], ppm	142,500
Main treatment Volume, bbl	600
Overflush Volume, bbl	3,000
Squeeze Lifetime, days	272
MIC, ppm	5.5

Table 2 Squeeze Treatment parameter space limits .

	Original Design	**High**	**Low**
SI, ppm	142,500	142,500	7,125
MT Volume, bbl	600	30	1,800
OF Volume, bbl	3,000	9,000	150

The graph below shows the squeeze lifetimes for suggested designs, and the Pareto front assuming the total injected volume is to be minimised, this being a major concern for this particular well.

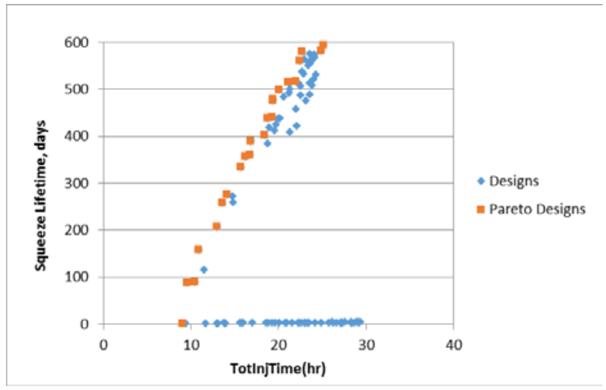

Figure 4 Pareto front considering squeeze lifetime against total injected volume (injection time).

Table 3 shows a selection of designs that are part of the Pareto front. These designs are non-dominated, i.e. they are the most efficient considering the injected total volume and the squeeze lifetime. As you can see, some of the designs are below the target squeeze lifetime and others above. Considering the squeeze lifetime, total injected time, total injected volume, Design 4 was recommended, as it meets the squeeze lifetime target, the injection time is within operational constraints and volume injected is 1,000 bbls less than Design 1, the longest design. The recommended design, Design 4, is described in Table 4.

Table 3 Selected designs from the Pareto front.

Num	**SI (ppm)**	**Tot Inj Time (hrs)**	**Tot Inj Vol (bbls)**	**Sqz Time (days)**
1	119,167	25	8,027	593
2	127,510	25	7,938	582
3	141,047	23	6,992	580
4	**136,500**	**22**	**6,890**	**560**
5	135,759	22	6,720	517
6	134,826	21	6,386	516
7	132,615	21	6,358	516
8	137,611	20	5,906	499
9	140,739	19	5,610	480
10	134,765	19	5,596	475

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Table 4 Recommended Squeeze treatment design.

[SI], ppm	136,500
Main treatment volume, bbl	1,384
Overflush volume, bbl	5,506
Squeeze lifetime, days	560
MIC, ppm	5.5

Conclusions

A methodology to automatically find the most efficient squeeze design has been presented. A stochastic search algorithm was described, which identified a number of optimum designs. Then Pareto optimal front was calculated, i.e. the designs that are not dominated or bettered by any other design. Finally, the most efficient design was identified as it is part of the Pareto front.

The methodology was applied to a field case, where the most efficient design was identified and recommend based on the constraints present. The advantage of this automated optimisation procedure is that the resulting design can be demonstrated to be optimum – i.e. it cannot be improved upon, because it lies on the Pareto front. Engineering judgment is still required in the application of the treatment, but this, for the first time, can now be done with confidence that the design is as good as it can be given the various constraints.

References

Kennedy, J. and Eberhart, R., 1995. Particle Swarm Optimisation. Proceedings of IEEE International Conference on Neural Networks.

Onwubolu, G. C. and B. V. Babu, 2004. New Optimisation Techniques in Engineering, Springer.

Powell, D., Frazer, L. and Dibrell, B., 1996. Optimisation of scale inhibitor squeeze procedures in a North Slope oil field. NACE-96185, Issue 185, p. 14.

Vazquez, O., Fursov, I. and Mackay, E., 2016. Automatic optimisation of oilfield scale inhibitor squeeze treatment designs. Journal of Petroleum Science and Engineering, p. 6.

Vazquez, O., Fursov, I. and Mackay, E., 2016. Automatic optimisation of oilfield scale inhibitor squeeze treatment designs, *Journal of Petroleum Science and Engineering*, 147, pp. 302–307. doi: 10.1016/j.petrol.2016.06.025.

Vazquez, O., Mackay, E. & Sorbie, K., 2009. Impact of mutual solvent preflush on scale squeeze treatments: Extended squeeze lifetime and improved well clean-up time. SPE 121857, p. 14.

Vazquez, O., Mackay, E., Ross, G. & Baskoro, A., 2017. Automatic optimisation of oilfield scale inhibitor squeeze treatment delivered by DSV. SPE-184535-MS, p. 12.

Wayne, W. & Frenier, M., 2009. Formation, removal and inhibition of inorganic scale in the oilfield environment. Society of Petroleum Engineers.

Zavala, J. A. P., Mackay, E. J., Vazquez, O., Boak, L. S., Singleton, M. and Ross, G., 2008. The Cost and Value of Field, Laboratory, and Simulation Data for Validating Scale Inhibitor Treatment Models, in SPE International Oilfield Scale Conference.

Acknowledgments

The authors would like to thank Heriot-Watt University for allowing to present this work. The FAST JIP sponsors are thanked: ADNOC, Baker Hughes, MI-Swaco, Multi-Chem, Nalco-Champion, OGIC, Petrobras, Petronas, Repsol Sinopec, Staoil, Total and Wintershall. Energi Simulation are thanked for funding the chair in Reactive Flow Simulation held by Eric Mackay.