Carbonate Acidizing: A Physical Simulation of Well Treatments.

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Acid injection is the recommended treatment for productivity enhancement in carbonate reservoirs. Acid stimulation is a difficult challenge due to the instability of the dissolution figure, named wormhole, which depends strongly from the nature of the carbonate (heterogeneity). The objective of the study described hereafter is to compare various stimulation strategy to improve current treatment procedures.

In matrix acidizing of horizontal wells, the propagation of wormholes as deeply as possible into the formation with the maximum coverage along the wellbore is a major concern. Diverting agents based on polymer crosslinking at high pH are currently used for matrix acidizing (Figure 1). The crosslinking occurs as the acid is consumed. Wormholes formed in the high permeability zone are temporarily sealed and the subsequent acid slug enters the low permeability zone. The treatment is efficient, provided that the diversion procedure is adequately designed.

For acid fracturing treatments, the productivity benefit is directly related to the fracture length and conductivity (Figure 2). Maximising the fracture length cannot be achieved without controlling the acid filtration rate from the fracture walls (fluid loss). Since most of the filtration occurs from the wormholes rather than uniformly, it is important to limit the wormhole formation. Finally, the last criteria for the selection of a fracturing fluid is related to the etching of the fracture walls: an irregular etching pattern favours a good fracture conductivity.

The experimental methodology described in this paper helps to choose the best strategy in terms of fluid composition, either for matrix acidizing of horizontal wells or for acid fracturing. In the first part, we present the laboratory equipment used to mimic the dynamic process occurring during acid placement and acid fracturing. The discussion of the results gives elements for the implementation of the best strategy for acid treatments in carbonate reservoirs.

Experimental design for the simulation of well stimulation.

The main originality of the equipment is that it simulates flow from an open-hole or a fracture wall.

One or two tangential cells are used for acid fracturing or acid diversion respectively (Figure 3). The fluid is injected continuously in the tangential loop at a high flow rate and enters the core through a ΔP. The volume of fluid recovered at the outlet of the core is measured and the filtration rate is calculated. The acid breakthrough time is recorded and the wormhole propagation rate is calculated. The main parameters are the pressure gradient, the nature of the fluid and the mineralogy of the core, and the temperature.

Acid fracturing: behaviour of gelled acids, acids in emulsion and straight acids.

Three fluids at an acid concentration of 15%, are compared at 50°C in a 5 md limestone. The filtration rate ranges in the order plain acid > acid in emulsion > gelled acid (Figure 4). The last one has a very low filtration rate and is very powerful to limit fluid loss from the fracture. Acids range in the same order for the wormhole propagation rate. These data are readily explained when considering that the development of wormholes increases the surface area for fluid filtration.

In order to appreciate the effect of viscosity, the filtration rate measured with the gelled acid is compared to the filtration rate of water in the same conditions. Indeed, this represents the apparent relative viscosity (η_r^a) of the gelled acid in porous media (Figure 5). When compared to the relative viscosity of the gelled acid, the value of η_r^a is very low and ranges from 4 to 10. This shows that there is a considerable loss of viscosity in the porous medium and that the filtration rate for viscous acids, cannot be estimated from a simple Darcy evaluation, i.e. with the bulk value of the viscosity, but must be affected by a coefficient which can be deduced from experiments. Although such practice is well known in the modelling of acid fracturing, values of the fluid loss coefficient are rather seldom.

Finally, etching on the core face must be appreciated for a complete evaluation of the efficiency of the acid fluid. The fracture faces must be etched in a non-uniform manner to create conductive flow channels that remain after closure of the fracture. Unfortunately, viscous acids are not suitable for an appropriate etching of the fracture wall (Figure 6). Core faces are very flat. In contrast, etching is maximum with plain acids with compact dissolution. Actually, various factors will affect the etching. Among them, the rock heterogeneity provides various dissolution rates and favours non-uniform dissolution. The temperature is another factor. Consequently, the use of the reservoir core material is highly recommended to make these evaluations.

In conclusion:

- the equipment and the methodology described here are useful for the comparison of various acid fracturing fluid,
- wormhole formation, fluid loss and etching are evaluated,
- moreover, an estimation of the fluid loss coefficient is readily available by comparing the filtration rate of the viscous acid fluid to the filtration rate of non viscous water in the same conditions,
- the use of the reservoir core material is highly recommended to make these evaluations.

Matrix acidizing: optimising acid placement in horizontal wells.

The SGAD is currently used in open-hole horizontal wells. The questions encountered for the design of a treatment with this product are twice:

- First, what is the diversion efficiency in terms of flow distribution between the various zones.
- Second, what is the extent of the acid stimulation in the low permeability zone.

The methodology presented below provides guidelines for the choice of the composition of the treatment.

Figure 7 gives results of dual core experiments where the diverter composition is varied. The best formulation is with a diverter fluid with 1% HCl. For example in the case where the permeability ratio is 11, the flow rate ratio during the diverter injection is strongly reduced to a value of 2. Although the flow rate ratio increases during the stimulation (acid 15%), the treatment is very efficient with the same acid penetration in each core. Note that if no diverter was injected, the stimulation length should be at least 11 times deeper for the high permeability core compared to the low permeability one. In such case, no stimulation of the low permeability would occur, most of the treatment by-passing the damage.

The effect of a drilling mud damage is also investigated. The drilling fluid is a carbonate based fluid. It is injected following a current IFP procedure. There is no drastic difference in the diversion efficiency. Analysis by photo-observations of the cores after the treatments gives complementary information (Figure 8). First, the face of the damaged core after acidizing shows pitting, which means that some damaged material remains, even after the acid treatment. The treatment penetrates only by some preferential points, even if on the whole wormholing has occurred as shown on the Xray photograph.

In conclusion, the methodology described in this paper provides a laboratory evaluation of an acid placement technique with a Self Gelling Acid Diverter.

- The experiments consist in the injection at constant ΔP of alternate slugs of diverter and acid in two cores mounted in parallel.
- The fractional flow are recorded and the acid penetration is measured from Xray photographs. It is shown that the injection of a low acid concentration in the diverter slug followed by an acid treatment with 15% HCl provides the stimulation of a low permeability core previously damaged with a drilling fluid.

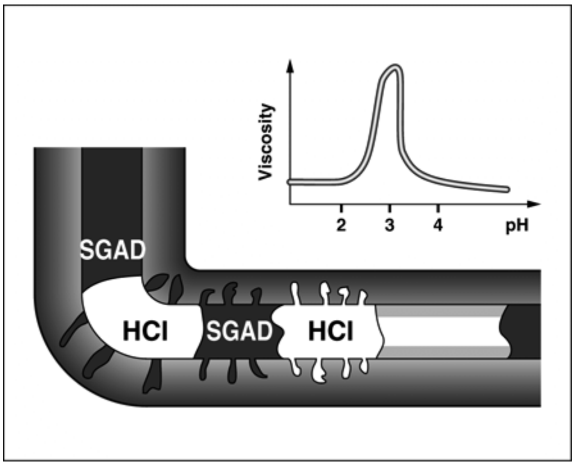

Figure 1: schematic representation of the diversion with the Self Gelling Acid Diverter

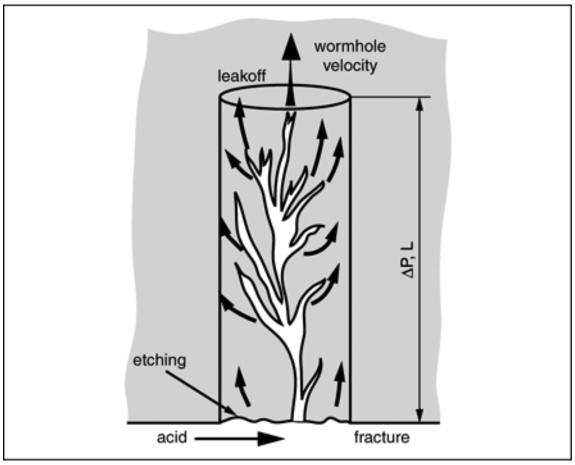

Figure 2: Acid Fracturing Application.

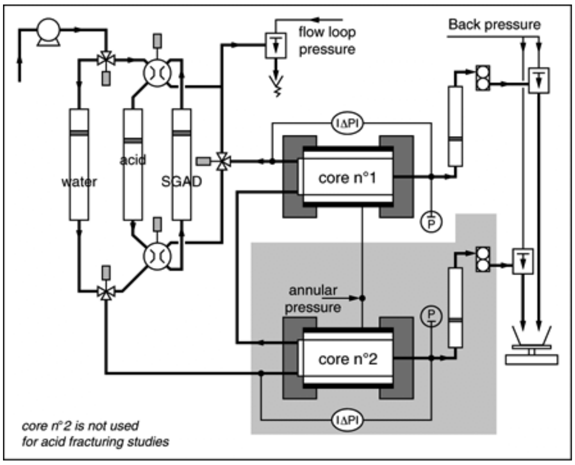

Figure 3: Experimental Set up.

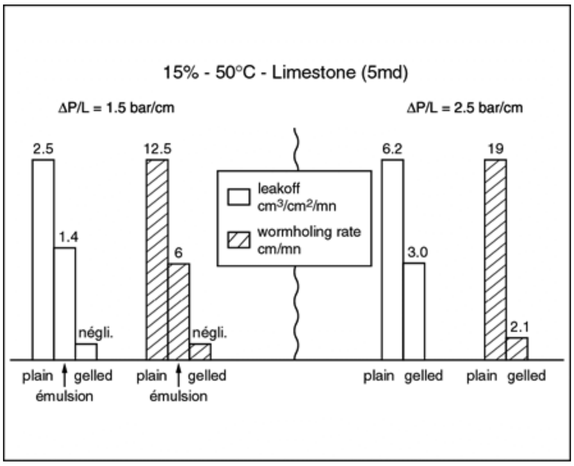

Figure 4: Properties of common acid fracturing fluids

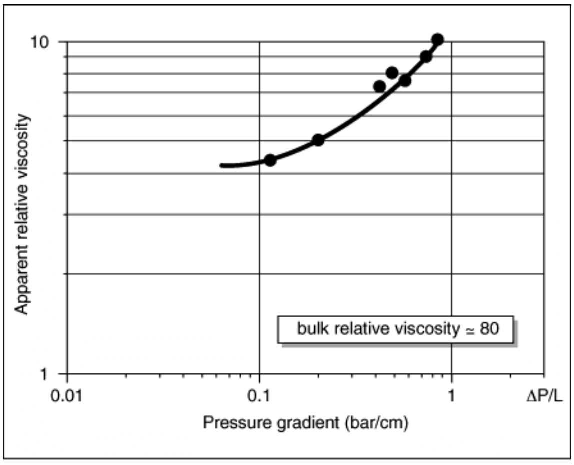

Figure 5: Apparent relative viscosity of the gelled acid in a carbonate porous media.

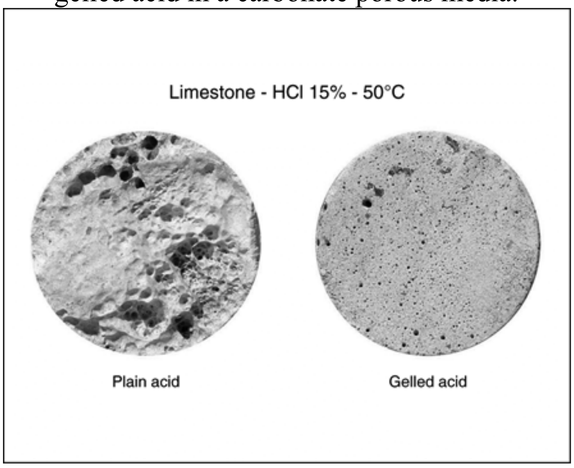

Figure 6: Comparison of the etching behaviour.

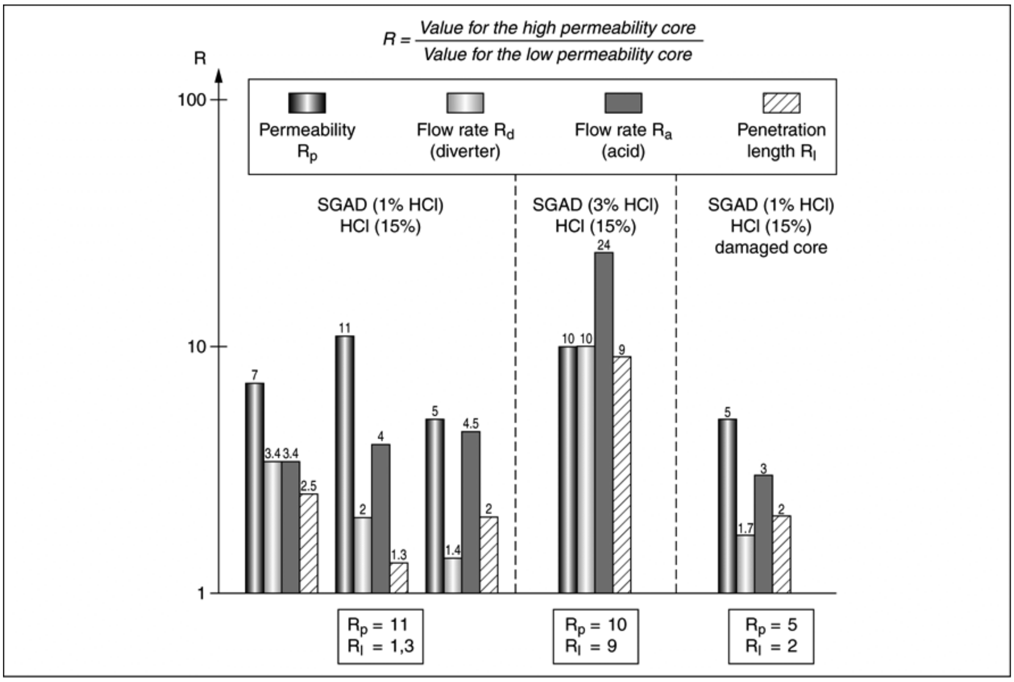

Figure 7: Diversion efficiency of the SGAD for matrix treatment in open-holes.

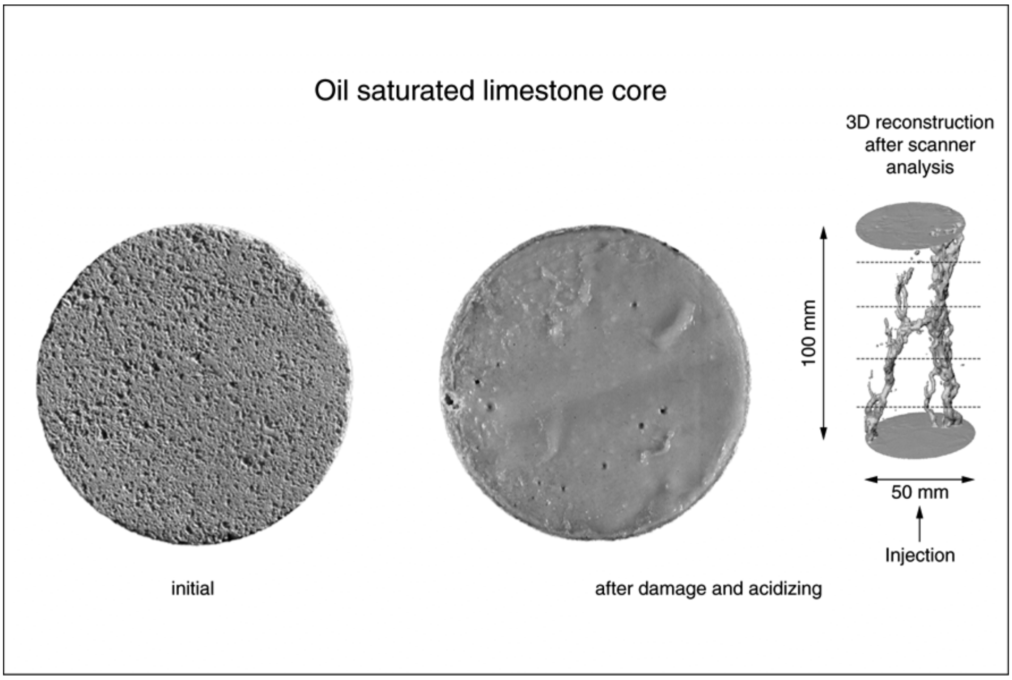

Figure 8: Treatment of an oil saturated carbonated core previously damaged with a drilling fluid.