Thermal acid impulse method for enhanced oil recovery

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Abstract. The injection rate created by the equipment does not provide uniform heating of the acid solution with thermo-acid samples. The first portion of the solution overheats, and the subsequent ones turn out to be underheated. Therefore, the effectiveness of acid and thermo-acid treatment of highly drained wells with low reservoir pressure is rather low [1]. To increase the efficiency, a method of acid and thermo-acid impulses was proposed, a methodology for its application was developed, and simple designs of the necessary underground and ground equipment for wells were developed (tip reactors and a universal wellhead). If in a well intended for thermoacid treatment by pulsation the filter or some part of it turned out to be blocked by a sand plug, then they were preliminarily cleaned with a bailer without opening the sump. Thermo-acidic (as well as acidic) well treatment by pulsation is carried out without the use of a pumping unit, which can significantly reduce costs. Thus, the most suitable acidic solution for thermoacid pulsation is 15\% HCl inhibited by unicol.

1. Introduction
The injection rate created by the units does not provide uniform heating of the acid in thermo-acid samples. The first portion of the solution overheats, and the subsequent ones turn out to be insufficiently heated. Therefore, the efficiency of acidic and thermo-acidic treatments of highly drained wells with low reservoir pressure is rather low [1]. To increase the efficiency, a method of acidic and thermo-acidic pulsation was proposed, a methodology for its application was developed, and simple designs of the necessary underground and ground equipment for wells were developed (tip reactors and a universal wellhead).

2. Results and discussion
The method of thermoacidic pulsation is based on the use of a special tip reactor (Figure 1). A reactor, the main nodes of which are a valve and the reactor itself, filled with magnesium chips, are lowered into the well on tubing until it stops in the bottom with its perforated nozzle tip. At the moment of stop, the valve body rod lifts the ball from the valve seat, and the acid solution, which has been pre-filled into the tubing, penetrates the prefilter zone of the reservoir. The rate of passage of the solution from the pump tubing string through the magnesium-chip reactor is initially much higher than that created by the injection of the acid solution by the aggregate.
Figure 1. Tip reactors for acid and thermo-acid treatment of wells by pulsation: a – tip reactor for thermo–acid pulsation; b – tip for acid pulsation; c – universal tip reactor for acid and thermo–acid pulsation; g – cone with a magnesium rod (discharged into the well for repeated processing); 1 – pumping compressor pipe; 2 – valve ball; 3 – valve seat; 4 – coupling; 5 – connecting pipe; 6 – persistent branch pipe; 7 – valve body; 8 – coupling; 9 – reactor; 10 – magnesium shavings; 11 – filter (grill); 12 – sub; 13 – coupling; 14 – perforated pipe tip; 15 – saddle for cone with magnesium core; 16 – connecting pipe (adapter sub); 17 – insert fitting; 18 – magnesium rod; 19 – fitting body

Then, after the level of the acid solution in the pipes decreases, its flow rate decreases. Thus, uniform heating of the acid solution to the required approximately constant temperature is achieved [2].

It should be noted that in wells prior to thermo-acid treatment by pulsation, conventional acid and thermo-acid treatments were unsuccessfully carried out. The flow rate of the acid solution from the tubing after opening the valve of the reactor tip when conducting thermo-acid pulsation is shown in Figure 2.

The volume of solution poured into the tubing during thermo-acid treatment by pulsation depends on their length and internal diameter. Usually it is taken equal to 1.2–2 m³.

If in a well planned for thermo-acidic treatment by pulsation, the filter or some part of it turned out to be blocked by a sand plug, then they were preliminarily cleaned with a bailer without opening the sump [3–7].

Thermo-acidic (as well as acidic) well treatment by pulsation was carried out without the use of a pumping unit, which can significantly reduce costs.

Accelerating the movement of the acid solution, heating the entire volume to the desired temperature and creating pressure (due to the weight of the column of solution) increase the depth of penetration and the effectiveness of the effect of acid on the formation.
3. Experimental

Figure 2. Estimated time $I$ of the fluid flow from 73-mm pipes with a variable head $H$ depending on the diameter of the nozzle $d$: row 1: $d = 10$ mm; row 2: $d = 15$ mm; row 3: $d = 20$ mm; row 4: $d = 25$ mm

3. Experimental

Figure 3 shows thermograms taken during pulsed pumping of acid (with a variable pressure) through magnesium chips.

Hydrochloric acid of 15% concentration was prepared with formalin and unicol. It is known that the reaction time for acid salts with magnesium depends on the presence of these inhibitors in the acid solution. The use of unicol to inhibit the acid, which goes to the thermochemical part of the process, inhibits the reaction, especially at elevated pressure, by almost 20 times [8–10]. After each experimental pumping of hydrochloric acid, the residual acidity of the solution was recorded (Table 1).

Figure 3. Thermograms taken on the test bench in the process of thermoacid pulsation during the reaction: row 1 – 10% HCl with magnesium shavings; row 2 – 15% HCl with magnesium chips; row 3 – 15% HCl inhibited by formalin; row 4 – 15% HCl, inhibited by unicol
Table 1. Residual acidity of the solution after thermoacid pulsation

| Acidic solution | Residual content of HCl after reaction with magnesium [%] |
|-----------------|----------------------------------------------------------|
| 10% HCl         | 9.5                                                      |
| 15% HCl         | 13.7                                                     |
| 15% HCl inhibited by formalin | 12.9                                                   |
| 15% HCl inhibited by unicol    | 12.4                                                     |

4. Conclusion

Based on the experiments, the following conclusions can be drawn.

1. The process of thermoacid pulsation to achieve uniform heating of the acid solution is regulated by:
   - increase in pumping pressure (pressure is regulated by a column of liquid poured into pipes);
   - decrease in pumping speed; the speed of passage of the solution from the column of pumping pipes through the reactor with magnesium chips is initially much higher than the speed created by the injection of the acid solution by the setup; then, as the level of acid in the pipes drops, its outflow rate decreases; as a result, uniform heating of the acid solution to the required temperature is achieved.

2. Inhibition of HCl by formalin and unicol inhibits the reaction. However, only unicol is able to prolong the reaction of HCl with magnesium for the required time, during which the entire process of pumping acid through nozzles proceeds.

Thus, the most suitable acidic solution for thermoacid pulsation is 15%-HCl inhibited by unicol.

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