Identifying the efficiency factors on the basis of evaluation of acidizing of carbonate reservoirs

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Abstract. This study was carried out to determine the optimal flow and rate of injection of acid compounds during acidizing treatments of formations and to determine the factors that influence the technological and economic efficiency of implementing such technology. The research included evaluating the results of the industrial experimental work performed to implement the technology of large-volume acid treatment, analyzing formation treatments with relatively high specific volume of acid compositions, as well as studying the results of the performed acid fracturing. Altogether, the undertaken statistical and factor analyses covered the results for 180 borehole operations. The results of the study confirmed the hypotheses about the influence of the injection rate and specific flow of the acid composition on the efficiency of the treatments, i.e. the increase of acid composition flow, and identified the factors that increase the risk of performing inefficient operations: exceeding the hydraulic fracturing pressure in the process of implementing the technology significantly increases the risk of water encroachment in the well after the treatment; energy level of the formation: the level of reservoir pressure in the desired production target is 40% below the initial one; the presence of active water-saturated feed zones that maintain the formation pressure in the process of production but increase the risk of water breakthrough.

1. Introduction

The main factors of acidizing treatment efficiency are the average daily flow gain and the term of effect (ensuring the economic efficiency) as well as the increase in the productivity index, decrease in the skin factor, and increase in the sweep efficiency (increasing the technological efficiency).

However, acidizing treatment efficiency is influenced by a number of factors, the basic ones being: the length of the treated perforated interval or penetrated thickness of the formation; water cut in the well before the treatment; the state of the formation pressure at the moment of treatment planning and execution as an indicator of a formation's energy potential; the flow of the acid composition during the

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implementation of the technology (can be analyzed). A correct analysis of the influence of the acid composition flow on the efficiency of acidizing requires accounting for all the factors above [1].

2. Methods and materials
The identified factors and the obtained results that allowed to suggest implementing changes in the technologies were obtained by means of statistical analysis, factor analysis, and numerical modeling.

3. Results and discussion
Assessment of the length of the treated perforated interval or penetrated thickness of formation.
In order to neutralize the effect of the length of the treated interval on the efficiency of acidizing, the analysis used the specific values of acid composition volume and flow.

In the case of horizontal wells with prolonged treatment intervals, there is a high degree of uncertainty of the values of the specific flow of acid per meter of the treated formation due to the absence of information about the effective length of the horizontal wellbore intervals [2].

Table 1 presents the distribution of the ratio of the sums of the working intervals' lengths (effective length) to the total length of the horizontal wellbore (according to the data of geophysical studies of the horizontal wells developing carbonate reservoirs), which indicates a significant variance of this parameter's values.

Table 1. Distribution of the sums of the working intervals' lengths effective length) to the total length of the horizontal wellbore

	Ratio of the effective length of the horizontal shaft to the total				
	0-20	20-40	40-60	60-80	80-100
Share of wells	20%	33%	30%	10%	7%

Besides, in the case of horizontal wells, the specific volumes of the acid compositions used during the treatments under study are significantly lower than in the conditionally vertical wells [3].

This way, the evaluation of treatment efficiency depending on the specific volume and flow of acid in horizontal wells requires a separate study. In this regard, horizontal wells were excluded from further analysis.

Assessment of the influence of water cut in wellbore fluids.
All treatments were carried out in wells with at least 30% water cut. Hence, a conclusion can be made that the effect of this factor on the efficiency of the treatments performed during the period of interest is approximately equal.

Current state of the formation pressure. Analysis revealed (Figure 1) the dependence of the efficiency of large-volume treatments on the state of formation pressure (the ratio between the level of formation pressure at the moment of the treatment and the value of the initial formation pressure).
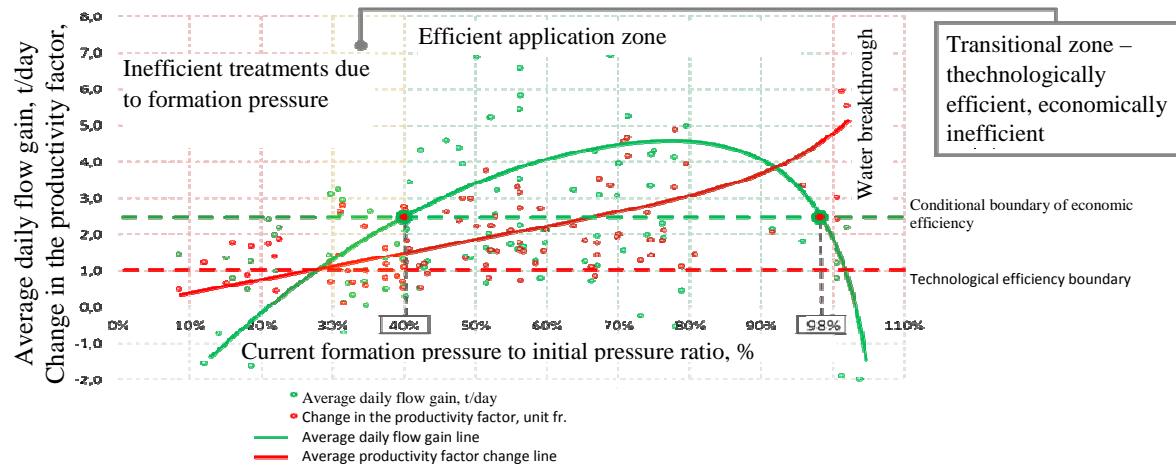
Figure 1. Dependence of the efficiency of acidizing on the current level of formation pressure.

The largest gains in the average daily flow are only observed when the values of formation pressure at the moment of treatment are more than 0.4 of the initial value [4-6]. When the values of formation pressure are less than 0.4 of the initial one, the probability of gain in the oil flow that would satisfy the investment conditions decreases.

The area where formation pressures remain close to the initial level also displays a decrease in the share of wells with flow rate gains that satisfy the investment conditions [7, 8]. This phenomenon is conditioned by the presence of an active water-saturated zone in the immediate vicinity, which, on the one hand, allows to retain the formation pressure, and, on the other hand, increases the risk of water breakthrough during the process of treatment [9-11].

In the course of further analysis, the wells that failed due to low values of formation pressure were excluded.

Acid composition flow during treatments.

Figure 2 shows the comparative distribution of treatments by specific volume and flow of the acid composition and by the magnitude of specific gains in average daily oil flow per technology: conventional hydrochloric acid treatment (HAT), large-volume hydrochloric acid treatment (LHAT), and acid fracturing (AF) [12]. For the correct representation of the specific values, the diagram shows treatments with comparable values of the treated formation thicknesses that are equal to 10 m on average.

The specific volumes of the acid composition during the LHAT executed within the scope of the industrial experimental work in 2013 comprised from 2.0 to 3.9 m^3 per meter of treated thickness at the specific flow from 0.5 to 4.2 m^3 per hour.

With the specific flow of acid composition less than 1.8 m^3 per meter of treated thickness, an area of decreased specific gain of average daily flow of oil is distinguished. The absolute values of flow gains after treatments for this group do not exceed 2.5 tons per day.

Previously, analysis of the international experiences of carrying out LHAT and numerical modeling of the process of reaction between hydrochloric acid and carbonate reservoir was used to provide recommendations for maximizing the volume and flow of acid compositions. For the deposits represented by carbonate reservoirs, increasing the volume and flow of acid is limited by the injection pressure that should not exceed the breakdown pressure and the maximum possible pressure to the formations (the critical gradient of pressure to the cement stone and the bridge between the oil-saturated and water-saturated formations) [13, 14].
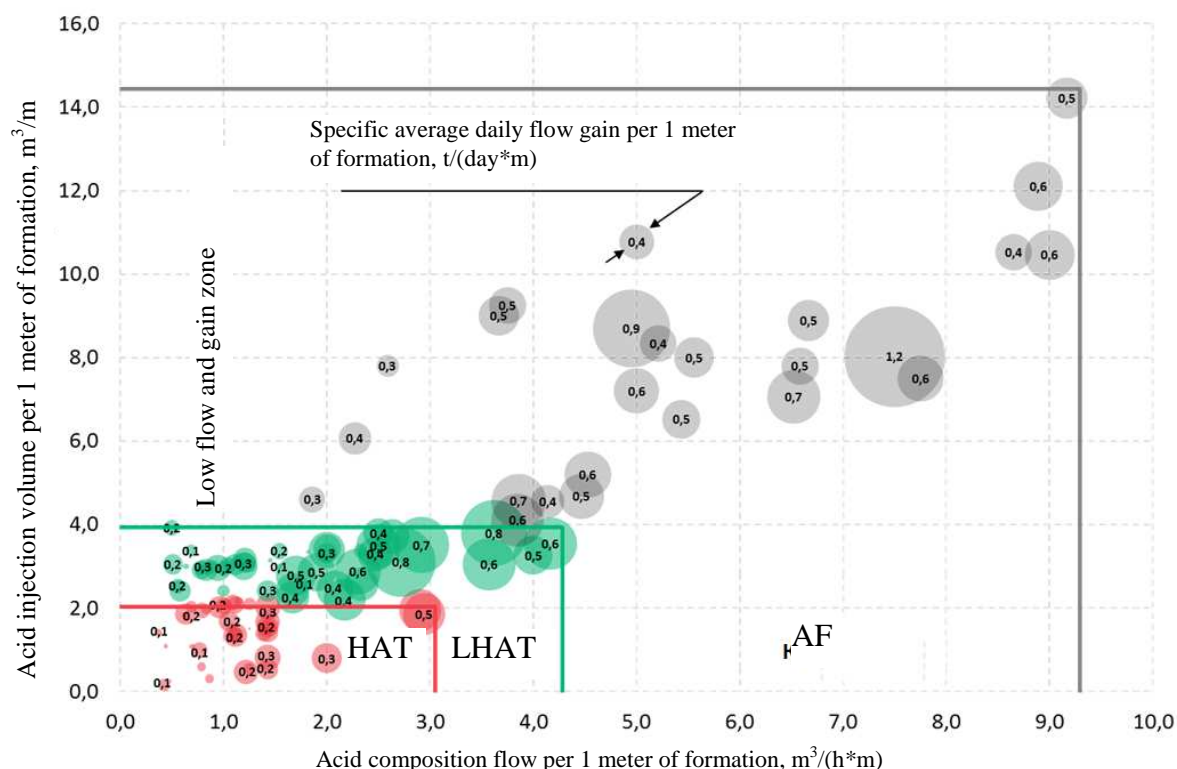
Figure 2. Acidizing efficiency depending on the specific volume and flow of acid composition

Assessment of the acidizing effect duration

Treatment efficiency was addressed from the point of view of gain in the average daily flow of oil as well as from the perspective of the duration of effect from such treatment. The analysis included the assessment of the expected duration of the effect for wells that worked four or more months after the treatment. The results are presented in Figure 7. The average expected duration of the effect from the LHAT performed within the scope of the industrial experimental work in 2013 is 14 months.

The analysis indicated that gains in the average daily oil flow during LHAT have similar values regardless of the acid composition flow but the duration of effect in the case of LHAT with increased acid composition flow is significantly longer: 30-40 months as compared to 14 months for LHAT with the specific flow of acid composition less than 5 m^3 per hour per meter of formation [15]. It is possible that this is related, as mentioned above, with the commingling of the previously undrained reserves of oil and the increase in formation pressure.

AF is comparable with LHAT with the increased acid flow in effect duration, however, it is characterized by lesser gains in average daily oil flow and a significant share (17%) of treatments with negative gains due to water influx.

Using the LHAT technology as a method of intensifying oil production in the conditions of high depletion of reserves is unreasonable because of the short duration of the effect. Similar efficiency can be gained with less costly methods of carbonate reservoir stimulation [16].

Using the LHAT technology in the increased acid flow mode as a technology of increasing the formation sweep by stimulation is most prospective due to the significantly longer duration of the effect conditioned by the commingling of the previously undrained reserves.

4. Findings and conclusion

The results of the study confirmed the hypotheses about the influence of the injection rate and specific flow of the acid composition on the efficiency of the treatments, i.e. the increase of acid composition flow, and identified the factors that increase the risk of performing inefficient operations: exceeding

the hydraulic fracturing pressure in the process of implementing the technology significantly increases the risk of water encroachment in the well after the treatment; energy level of the formation: the level of reservoir pressure in the desired production target is 40% below the initial one; the presence of active water-saturated feed zones that maintain the formation pressure in the process of production but increase the risk of water breakthrough.

In order to increase the efficiency of carbonate reservoir treatment, the following changes to the technology have been adopted: use specific values of parameters depending on the depth of the treated interval and penetrated thickness when planning the volumes of acid composition, inject the acid composition with the maximum possible specific flow (not less than 1.8 m^3 per hour per meter), decrease the minimum allowed pressure level for performing large-volume acid treatments from 60% to 40% of the initial level without exceeding the breakdown pressure. Furthermore, limits were introduced in candidate well selection: do not perform treatments in the vicinity of a feed zone characterized by retention of formation pressure after significant accumulated amounts of well extraction.

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