Accounting of time factor during bottomhole zone treatment

V V Mukhametshin\textsuperscript{1} and L Se Kuleshova\textsuperscript{1}

\textsuperscript{1}Department of Oil and Gas Field Exploration and Development, Ufa State Petroleum Technological University, Ufa, Republic of Bashkortostan, Russia
\textsuperscript{2}Department of Oil and Gas Field Exploration and Development, Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, Oktyabrsky, Republic of Bashkortostan, Russia

E-mail: vv@of.ugntu.ru, markl212@mail.ru

Abstract. It was found that when treating the bottomhole zone with acid compositions preventing emulsification in terrigenous reservoirs, the time factor has a significant influence on the treatment efficiency, much more than the features of the geological structure of an objects. The algorithm, which allows reducing the negative influence of the time factor on the efficiency of oil production intensification by application of technological impact indices, is proposed. Geological-statistical models were obtained, which allow planning the treatment efficiency, selecting wells and technological treatment indicators taking into account the time factor in real time.

1. Introduction
The analysis of numerous studies on the bottomhole zone treatment (BHZ) using hydrochloric acid solutions shows that, for a particular method, its efficiency is determined by three large groups of parameters that reflect the following:

- geological-physical and physical-chemical properties of formations and saturating fluids;
- technological characteristics of wells and deposits performance;
- treatment technology [1–4]

The second group of parameters has a significant influence on the efficiency, including the values of time from the moment of well commissioning to the moment of treatment, water cut of well production, cumulative oil production and its ratio to extracted reserves, current formation pressure and its relative decrease to the initial one, well flow rate at the moment of treatment. This group characterizes the time factor.

Over time, the treatment efficiency is significantly reduced, which is caused by the increase of well water cut, reduction of formation pressure and production of oil reserves, although in some cases there is no clear dependence of operation efficiency on the duration of well operation. This seems to be bound to other factors [5–8].

In a certain way, the water cut of extracted products affects the efficiency of salt-acid treatment (SAT). The efficiency of both traditional and foam-acid formation treatments is significantly reduced at water cut of more than 50 %. Under the conditions of carbonate deposits of Tatarstan, traditional salt-acid treatment produce the greatest effect in wells, the water cut of which does not exceed 20 % until the bottomhole treatment, and when creating bottomhole caverns, the greatest effect is obtained in wells, where the water cut does not exceed 40 %. In the deposits of Belarus, high SAT efficiency is observed...
at the water cut of up to 18%, at its further growth the relative number of successful operations is significantly reduced, and at the water cut of more than 80% the success is only 28%.

The treatment efficiency decreases as the formation is developed. Thus, when creating caverns, it is desirable that the specific total production of oil in wells does not exceed 200 t/m, although in some cases, especially during the initial period of development, with the increase of cumulative production, there is a slight increase in the effect.

At the reduction of formation pressure during reservoir development under depletion mode the effective application of salt-acid treatment is significantly deteriorated. This is caused by the negative effect of reaction products on oil inflow, for the removal of which from the bottomhole zone pores the available formation energy is not sufficient. There is also a decrease in the effect on wells operating the formation zones, where the pressure decreased below the bubble point pressure.

As practice shows, there is no consensus on the effect of well flow rate at the time of treatment on SAT efficiency [9, 10]. However, although the time factor has a significant impact on the bubble point pressure of bottomhole treatment:

- the measures are often not planned in real time;
- the role and influence of the time factor on the efficiency of treatment methods, wells and technologies is not always sufficiently taken into account when carrying out measures to intensify oil flow rate and reduce the water cut;
- the extent and nature of the influence of the time factor on different performance indicators when using the analogy method is rarely taken into account;
- the different influence of the time factor on the efficiency forecast in different geological-physical conditions of deposits is poorly taken into account.

2. Methods and materials

To a large extent it concerns deposits of the Vasyugan suite in terrigenous reservoirs of the North Vartovsky monocline with hard-to-recover reserves of oil where the bottomhole treatment with the use of hydrochloric acid preventing emulsification (KSPEO) and the modifying additives were intensively used.

For the purpose of increasing the efficiency of treatment planning with the use of this technology in real time taking into account the time factor, the field experience of this type of oil production intensification with creation of models and their analysis was summarized.

The absolute ($\mathcal{E}_1$) and relative ($\mathcal{E}_2$) gains of an output of oil, absolute ($\mathcal{E}_3$) and relative ($\mathcal{E}_4$) of decrease in water content of products, the general gain of production during effect ($\mathcal{E}_5$), the complex parameter of efficiency ($\mathcal{E}_6$) were used as response functions.

The parameters characterizing the formation were used as independent variables:

- geological-physical properties of formations in a well: general ($H_{\text{formation}, m}$), effective ($H_v, m$), effective oil-saturated ($H_m, m$) formation thickness, sandiness ($K_u$), compartmentalization ($K_p$), open porosity ($m$), oil saturation ($K_o$); permeability coefficients ($K_{\text{permeability}, 10^{-12} \mu m^2}$), induced potential logging ($\alpha_{\text{ind}}$); readings in the formation according to lateral logging ($M_{\text{L}, \Omega m}$), SP amplitudes ($A_{\text{SP}, \Omega m}$), on GP1 ($A_{0.4M0.1N}$), GP2 ($A_{1.0M0.1N}$), GP3 ($A_{2.0M0.5N}$), GP4 ($A_{4.0M0.5N}$), PZ ($A_{0.5M6.0N}$), gamma logging ($\gamma$, $\mu R/hr$), big probe TNPH ($\beta'_{\text{HKT}}$), small probe TNPH ($\beta''_{\text{HKT}}$), induction probe ($\beta_{\text{IE}, \text{sym}}$); specific electrical resistance of the probe by IL ($\rho_{\text{IL}, \Omega m}$), LL ($\rho_{\text{IL}, \Omega m}$), electric logging probe complex ($A_{\text{el}, \Omega m}$), penetration zones by electric logging probe complex ($A_{\text{el}, \Omega m}$), relation of diameter of a zone of penetration of a washing fluid filtrate to well diameter ($d_3/d_2$); the values of parameters were used both on a section ($X_i$) in general, and on its perforated part ($X_j$);
- time factor including process parameters of wells and deposits: time ($t, \text{month}$), maximum oil flowrate ($Q_{\text{Hmax}, \text{t/month}}$) since the beginning of well operation until treatment; flowrate ($Q_{\text{H1}, \text{t/month}}$), water cut ($f_1, \%$), cumulative oil production ($Q_{\text{max}, t}$) at the time of treatment; initial oil flowrate ($Q_{\text{Hmax}, \text{t/month}}$);
• treatment technology: consumption of 22% hydrochloric acid (HCl, t); consumption of modifiers and hydrofluoboric acid [MK-V(K), t], volume of pumped solution (V, m³), treatment frequency (N).

Using multivariate regression analysis, the models of response function dependencies on considered parameters are obtained in three options:

1. when using the whole set of parameters;
2. without using parameters characterizing the time factor;
3. when using parameters characterizing the time factor and treatment technology.

3. Results

The analysis of models presented in Tables 1–3, the values of multiple correlation coefficients (R) and data on the percentage of contribution of parameters included in the models to general variability of efficiency parameters (Table 4) shows that the influence of parameters characterizing the time factor is more significant in comparison with parameters characterizing the features of geological structure of formations. If using the whole set of parameters (option 1), and the average percentage of their contribution is 52, then in the absence of parameters characterizing geology, this percentage decreases to 41, and in the absence of parameters characterizing the time factor – to 31. It should be added that earlier similar studies using acid compositions injection in the same geological and field conditions with the addition of Aldinol-20 [21] showed a different scenario. The influence of parameters characterizing geological-physical properties of formations is more significant than the influence of parameters characterizing the time factor. However, the impact of the time factor remains very significant, as well as the use of KSPEO (Table 4).

Table 1. KSPEO efficiency forecast models (option 1)

| Option | Equation |
|--------|----------|
| $E_1$ | $282.032 - 112.468K_a + 8.373K_p + 4.633A_{AnC} - 6.746H_{H_a} + 14.533K_a - 349.155V - 68.856\bar{\alpha}_{en} + 12.293\bar{p}_{HK}$ |
| $E_2$ | $42.565 - 9.616K_a - 1.997K_p - 0.349A_{AnC} - 0.443\bar{H}_{H_a} - 3.803\bar{K}_a + 79.773\bar{\alpha}_{en} + 1.191\bar{\alpha}_{en} + 0.759\bar{p}_{HK}$ |
| $E_3$ | $390.774 - 40.495K_a + 1.473K_p + 1.701A_{AnC} - 1.188\bar{H}_{H_a} + 0.758\bar{K}_a - 606.928\bar{\alpha}_{en} - 74.817\bar{\alpha}_{en} + 1.265\bar{p}_{HK} - 2.413\bar{A}_{AnC} + 10.463\bar{d}_{\bar{u}} + 1.938\bar{p}_{HK} + 0.002Q_{max} - 0.257t + 0.02Q_{max} + 0.296f - 0.136Q_{H} - 12.94HCl - 56.913V + 32.37t - 2.697V/\bar{H}_{H_a} + 624.804MK-B(K) - 64.984HCl/V - 144.686HCl/\bar{H}_{H_a} - 703.162MK-B(K)/\bar{H}_{H_a} (R = 0.732) |
| $E_4$ | $1692.192 - 674.811K_a + 50.238K_p + 27.796\bar{A}_{AnC} - 40.475H_{H_a} + 87.199\bar{\alpha}_{en} - 2094.93\bar{m} - 413.138\bar{m}_{en} + 73.759\bar{p}_{HK} - 24.823\bar{A}_{AnC} + 895.981\bar{d}_{\bar{u}} + 77.222\bar{p}_{HK} + 0.039Q_{max} - 2.908t + 0.254Q_{max} - 9.614t - 3.487Q_{H} - 77.638HCl - 661.106V + 316.859N - 239.546V/\bar{H}_{H_a} + 694.321MK-B(K) - 1405.772HCl/V + 1697.856HCl/\bar{H}_{H_a} - 33644.026MK-B(K)/V - 6664.682MK-B(K)/\bar{H}_{H_a} (R = 0.714) |
| $E_5$ | $336.536 - 156.553K_a - 9.289K_p - 0.364A_{AnC} - 4.792\bar{H}_{H_a} - 28.292\bar{K}_a + 1322.526\bar{m} - 122.532\bar{m}_{en} + 12.068\bar{p}_{HK} - 6.794\bar{A}_{AnC} + 9.822\bar{d}_{\bar{u}} - 14.039\bar{p}_{HK} - 0.002Q_{max} + 0.003t + 0.056Q_{max} - 3.659f - 0.13Q_{H} + 91.917HCl - 50.348V + 47.276N + 110.134V/\bar{H}_{H_a} + 83.745MK-B(K) - 319.119HCl/V - 159.007HCl/\bar{H}_{H_a} + 628.325MK-B(K)/V - 563.851MK-B(K)/\bar{H}_{H_a} (R = 0.750) |
| $E_6$ | $48.697 + 6.787K_a + 0.49K_p + 0.034A_{AnC} + 0.718\bar{H}_{H_a} - 1.436\bar{K}_a - 61.706\bar{m} - 6.067\bar{m}_{en} - 0.442\bar{p}_{HK} + 0.096\bar{A}_{AnC} + 0.096\bar{d}_{\bar{u}} + 0.897\bar{p}_{HK} - 0.004t - 0.004Q_{max} + 0.166f - 0.002Q_{H} - 1.24HCl - 5.9V - 0.407N + 0.807V/\bar{H}_{H_a} + 61.902MK-B(K) - 19.433HCl/V + 13.491HCl/\bar{H}_{H_a} - 326.073MK-B(K)/V - 62.943MK-B(K)/\bar{H}_{H_a} (R = 0.760) |
Relatively high values of multiple correlation coefficients allow proposing the obtained models to forecast the impact efficiency, wells and technologies in conditions of identification series deposits both at the stage of deposits introduction into development (option 3) and in case of the absence of representative geological-geophysical material (option 2). It should also be noted that the role of the time factor in evaluating different performance indicators is also different.

### Table 2. KSPEO efficiency forecast models (option 2)

| $\mathcal{E}_1$ | $135.258 \pm 50.362K_1 + 0.66K_p + 2.464d_{\text{HC}} + 19.236\bar{H}_m - 100.214K_3 + 335.695m - 215.091\bar{a}_{\text{en}} + 15.047\rho_{\text{ini}} - 4.811\lambda_{0.4} + 192.54d_{\text{en}} + 14.398\bar{H}_{\text{ini}} - 1.807\text{HCl} - 106.205V + 44.039N - 36.046V/\bar{H}_m + 1003.897\text{MK-B}(K) - 322.976\text{HC}/V + 253.506\text{HC}/\bar{H}_m - 5687.843\text{MK-B}(K)/V - 582.092\text{MK-B}(K)/\bar{H}_m$ (R = 0.514) |
| $\mathcal{E}_2$ | $48.323 - 16.565K_1 - 2.018K_p - 0.329A_{\text{in}} - 1.076\bar{H}_m + 5.459\bar{K}_{\text{en}} + 60.612\bar{m} - 7.414\bar{a}_{\text{en}} - 0.658\rho_{\text{ini}} - 1.218\lambda_{0.4} - 40.66d_{\text{en}} - 3.334\bar{H}_{\text{ini}} + 0.362\text{HCl} + 10.887V + 3.388N + 14.978\bar{V}/\bar{H}_m + 105.189\text{MK-B}(K) + 83.722\text{HC}/V - 40.325\text{HCl}/\bar{H}_m + 712.229\text{MK-B}(K)/V - 26.012\text{MK-B}(K)/\bar{H}_m$ (R = 0.561) |
| $\mathcal{E}_3$ | $302.52 - 5.592K_1 + 1.017K_p + 1.058A_{\text{in}} + 6.836\bar{H}_m - 34.452K_3 - 338.942m - 86.505\bar{a}_{\text{en}} + 3.743\rho_{\text{ini}} - 2.906\lambda_{0.4} + 55.792d_{\text{en}} + 3.138\bar{H}_{\text{ini}} - 2.506\text{HCl} - 62.854V + 31.821N - 12.409\bar{V}/\bar{H}_m + 605.718\text{MK-B}(K) - 184.298\text{HC}/V + 166.358\text{HC}/\bar{H}_m - 3039.927\text{MK-B}(K)/V - 547.966\text{MK-B}(K)/\bar{H}_m$ (R = 0.575) |

### Table 3. KSPEO efficiency forecast models (option 3)

| $\mathcal{E}_1$ | $288.664 + 0.007Q_{\text{max}} - 0.638t - 0.009Q_{\text{max}} + 0.138t_1 - 0.479Q_{\text{H}} - 61.907\text{HCl} - 36.46V + 31.968N - 24.935V/\bar{H}_m + 633.324\text{MK-B}(K) + 296.039H_{\text{C}/V} + 118.364\bar{H}_m + 3357.343\text{MK-B}(K)/V - 478.708\text{MK-B}(K)/\bar{H}_m$ (R = 0.617) |
| $\mathcal{E}_2$ | $21.575 + 0.032t + 0.002Q_{\text{max}} - 0.585t_1 - 0.029Q_{\text{H}} + 10.427\text{HCl} + 4.844V + 4.859N - 0.969V/\bar{H}_m - 104.856\text{MK-B}(K) + 23.273\text{HC}/V - 11.342\text{HC}/\bar{H}_m + 612.429\text{MK-B}(K)/V - 61.553\text{MK-B}(K)/\bar{H}_m$ (R = 0.564) |
| $\mathcal{E}_3$ | $214.275 + 0.003Q_{\text{max}} - 0.26t - 0.002Q_{\text{max}} + 0.583t_1 - 0.128Q_{\text{H}} + 26.445\text{HCl} - 38.389V + 27.467N - 14.081V/\bar{H}_m + 492.946\text{MK-B}(K) + 46.767\text{HCl}/V + 123.829\text{HCl}/\bar{H}_m + 2460.441\text{MK-B}(K)/V - 453.086\text{MK-B}(K)/\bar{H}_m$ (R = 0.565) |
| $\mathcal{E}_4$ | $1731.983 + 0.043Q_{\text{max}} - 3.826t - 0.056Q_{\text{max}} + 0.826t_1 - 2.875Q_{\text{H}} + 371.442\text{HCl} - 218.761V + 191.806N - 149.611V/\bar{H}_m + 3799.946\text{MK-B}(K) + 1776.233\text{HC}/V + 710.182\text{HCl}/\bar{H}_m - 2014.057\text{MK-B}(K)/V - 2872.25\text{MK-B}(K)/\bar{H}_m$ (R = 0.617) |
| $\mathcal{E}_5$ | $96.889 - 0.001Q_{\text{max}} + 0.103t + 0.038Q_{\text{max}} - 3.857t_1 - 0.123Q_{\text{H}} + 97.016\text{HCl} - 38.202V + 47.066N + 168.269V/\bar{H}_m - 121.119\text{MK-B}(K) - 259.326\text{HCl}/V - 264.205\text{HCl}/\bar{H}_m + 1630.056\text{MK-B}(K)/V - 373.33\text{MK-B}(K)/\bar{H}_m$ (R = 0.675) |
| $\mathcal{E}_6$ | $48.514 - 0.034t - 0.004Q_{\text{max}} + 0.167t_1 - 0.005Q_{\text{H}} - 0.466\text{HCl} - 5.559V - 0.291N - 2.938\bar{V}/\bar{H}_m + 66.472\text{MK-B}(K) - 18.688\text{HC}/V + 17.944\text{HC}/\bar{H}_m - 351.622\text{MK-B}(K)/V - 64.134\text{MK-B}(K)/\bar{H}_m$ (R = 0.708) |


Table 4. Percentage of contribution of parameters included in models to overall variability of efficiency parameters

| Option | \( \mathcal{E}_1 \) | \( \mathcal{E}_2 \) | \( \mathcal{E}_3 \) | \( \mathcal{E}_4 \) | \( \mathcal{E}_5 \) | \( \mathcal{E}_6 \) |
|--------|------------------|------------------|------------------|------------------|------------------|------------------|
| 1      | 51               | 44               | 54               | 51               | 56               | 57               |
| 2      | 26               | 31               | 33               | 26               | 36               | 33               |
| 3      | 38               | 32               | 43               | 38               | 46               | 50               |

4. Conclusion

Thus, the following conclusions can be made from the study of the bottomhole treatment using KSPEO in terrigenous reservoirs of the Vasyugan suite:

- the time factor has a significant influence on the treatment efficiency, much more than the features of the geological structure of an object;
- in the conditions of different objects and treatment technologies the time factor has different influence, which should be taken into account when using the cumulative experience in other geological conditions;
- when assessing the treatment performance using different performance indicators, the degree and nature of the impact of the time factor is not constant and this should be taken into account in planning;
- the algorithm, which allows reducing the negative influence of the time factor on the efficiency of oil production intensification by application of technological impact indices, is proposed;
- geological-statistical models were obtained, which allow planning the treatment efficiency, selecting wells and technological treatment indicators taking into account the time factor in real time.

5. References

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