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# Reservoir energy management based on the method of multi-tank material balance

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# Reservoir energy management based on the method of multi-tank material balance

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**Abstract**. To minimize risks according to the current state of reservoir pressure while planning well intervention operations, authors propose the multi-tank material balance method to determine the dynamics of reservoir pressure in the well drainage area. The method is based on using well test results and information on historical production and injection rates. The method is applicable under conditions where number and frequency of well tests are limited.

## 1. Introduction

One of the most important tasks of monitoring hydrocarbon field development is the control of reservoir energy state [1-2]. Misinterpretation of the current situation concerning distribution of the reservoir pressure values results in the risks of wrong strategy of oil remaining reserve recovery, inevitable losses in oil production, and often leads to economically unsuccessful workover operations.

In addition to estimation of the current reservoir pressure, it is also necessary to observe its dynamics. Analyzing the reservoir pressure dynamics, it is possible to clarify the ultimate values of recoverable oil reserves, as well as to judge the performance of reservoir pressure maintenance (RPM) system. To estimate the average reservoir pressure for the whole productive formation, isobar maps are designed taking into account well test (WT) results.

One of the most common pressure-mapping methods is the measurement interpolation method [3]. The adequacy of reservoir pressure maps obtained by interpolation strongly depends on WT frequency and its areal sweep efficiency. The shortcomings of isobar maps using interpolation method are:

- Presence of “blind zones” as a result of poor areal sweep efficiency;
- Disregard for the dynamics of production/injection rates, age of reservoir pressure ($P_R$) measurements;
- Neglect of aquifer activity (measurements of $P_R$ in oil-water contact).

As a result, there are often situations when the trends of decreasing average $P_R$ by isobar maps and the actual ones (by WT) differ (figure 1).

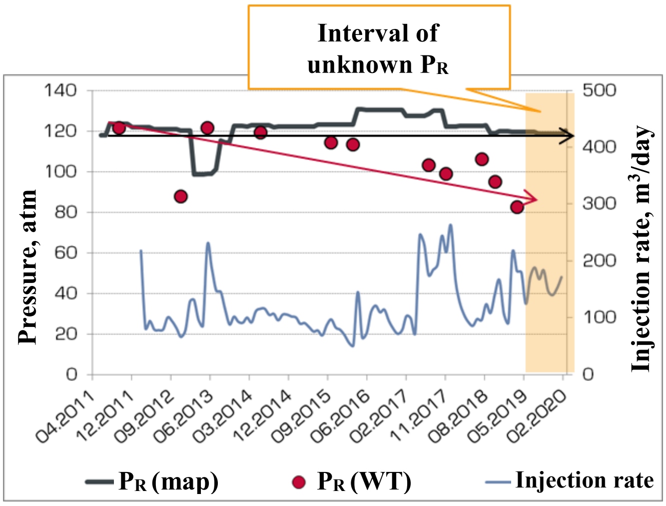


**Figure 1.** Reservoir pressure dynamics of one of the fields.

Application of computational methods for isobar mapping, partially or completely reproducing the development process physics, allows to obtain more accurate information about the distribution of the current reservoir pressure (table 1).

**Table 1.** Methods of isobar mapping.

| Method | Advantages | Disadvantages |
|---|---|---|
| Interpolation | low labor intensity when mapping | lack of consideration of the development process physics |
| Reduced order models (proxy-models, CRM, material balance) | low labor intensity of history matching, possibility of history matching automation | simplification of the development process physics |
| 3D-models | strict consideration of the development process physics | high labor intensity of the history matching |

Reservoir simulators (RS) allow obtaining the most accurate representation of the reservoir hydrodynamics, but require significant time and effort for history-matching of the models.

The application of reduced order models decreases the labor intensity by history-matching automation and eliminates the limitations of the interpolation method [4-6]. In this paper, we propose the application of multi-tank material balance (MMB) method [7-9].

## 2. Materials and methods

MMB method consists in two stages, the first of which is the solution of the direct problem to obtain the calculated profile of reservoir pressure (Fig. 2).

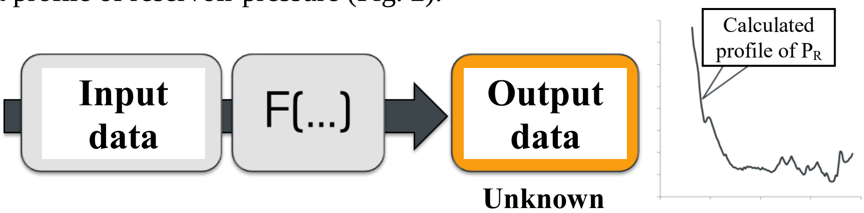


**Figure 2.** Schematic representation of a direct problem.

The problem is solved numerically, according to equation (1) for all tanks containing the well, taking into account the cross-flows of fluids between the tanks. The aquifer is also represented by one or more tanks with zero production/injection rate (Fig. 3).

$$\begin{aligned}
&\text{accumulative term} && \sum_{l=w,o}\left(\left(S_l\frac{V_p}{B_l}\right)_i^{n+1}-\left(S_l\frac{V_p}{B_l}\right)_i^{n}\right)+ \\
&\text{flow term} && +\sum_{j\in\omega_i}T_{i,j}\left(P_i^{n+1}-P_j^{n+1}\right)+ \qquad (1)\\
&\text{source/sink term} && +\sum_{l=w,o}Q_{l,i}^{n+1}-\lambda Q_{inj,i}^{n+1}=0
\end{aligned}$$

Where $S_l$, $B_l$ - saturation and formation volume factor of $l$ phase; $V_{p,\ i}$ - porous volume of $i$ tank; $P_i$ - reservoir pressure in $i$ tank; $T_{i,\ j}$ - inter-tank transmissibility; $Q_{l,\ i}$ - production rate of $l$ phase in $i$ tank; $Q_{inj,\ i}$ - water injection rate in $i$ tank; $\lambda_i$ - coefficient of injection rate efficiency in $i$ tank; $\omega_i$ - list of neighbouring tanks for $i$ tank; $n$ –number of time step.

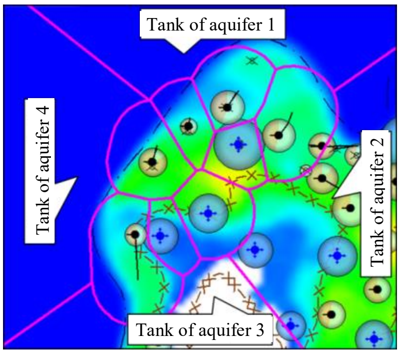


**Figure 3.** Well tanks (Voronoy cells) on the map of initial oil reserves.

The second stage is the solution of the inverse problem – selection of certain parameters of the tanks (multidimensional space of parameters) to fit the calculated reservoir pressure to the available actual pressure measurements (figure 4).

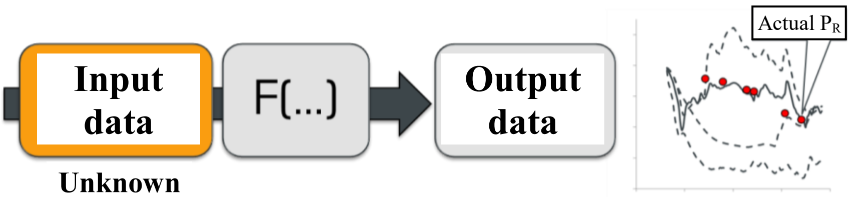


**Figure 4.** Schematic representation of an inverse problem.

Main history-matching parameters of the tanks:

- Inter-tank transmissibilities $T_{i,\ j}$, characterizing the cross-flow rates between the tanks; for the tank with the injection well, these parameters allow to estimate degree of the waterflood influence on the neighboring production wells;

- Coefficient of the injection efficiency $\boldsymbol{\lambda_i}$ for the tank with injection wells; this parameter shows the fraction of the injection agent volume, which did not get into the productive intervals due to different geological and technological aspects;
- Well productivity index $\boldsymbol{J_i}$ for the tanks with fluid withdrawal; this parameter is used for additional history matching of computational bottom-hole pressure;
- Aquifer volume $\boldsymbol{V_p}$.

The optimality criterion for parameter estimation is minimum of target function (2) taking into account the deviation of the calculated values of pressures (reservoir and bottom-hole) from the actual ones.

criterion of "Min ΔP$_R$"
$$f(x)=\sum_{i=1}^{n_r} w_i^r\left(P_r^{act}-P_r^{calc}\right)^2+$$

criterion of "Min ΔP$_{BHP}$"
$$+\alpha_{bhp}\sum_{i=1}^{n_{заб}} w_i^{bhp}\left(P_{bhp}^{act}-P_{bhp}^{calc}\right)^2+ \tag{2}$$

L2-regularization term
$$+a_{reg}\sum_{i=1}^{n_{par}} x_i^2 \to \min$$

Where $w_i^r$, $w_i^{bhp}$ - weight coefficients that play role of relative "importance" of measurements; $\alpha_{bhp}$ - coefficient of "preference" between the criteria "Min ΔP$_R$" and "Min ΔP$_{BHP}$"; $a_{reg}$ - regularization parameter to prevent "overfitting".

The aquifer parameters are adjusted during depletion mode of field development (without waterflooding), if available.

## 3. Results

To find the error in calculated and actual reservoir pressure values, MMB method was tested on the wells of Urals-Volga region fields presented by the subsoil user, on which WT was carried out in 2019 before scheduled acidizing (figure 5).

Computational scheme:

- During history-matching the check measurements of P$_R$ of test wells were completely excluded from the calculation;
- For the rest of the wells the data on P$_R$ were used to adjust the inter-tank transmissibilities according to MMB method.

According to test calculations, there is a high accuracy in the assessment of P$_R$. The average deviation between the calculated and actual (obtained by WT) values of P$_R$ is 4.1%. The deviations can be explained by simplification of hydrodynamics of reservoir simulation.

The computational results are given in table 2.

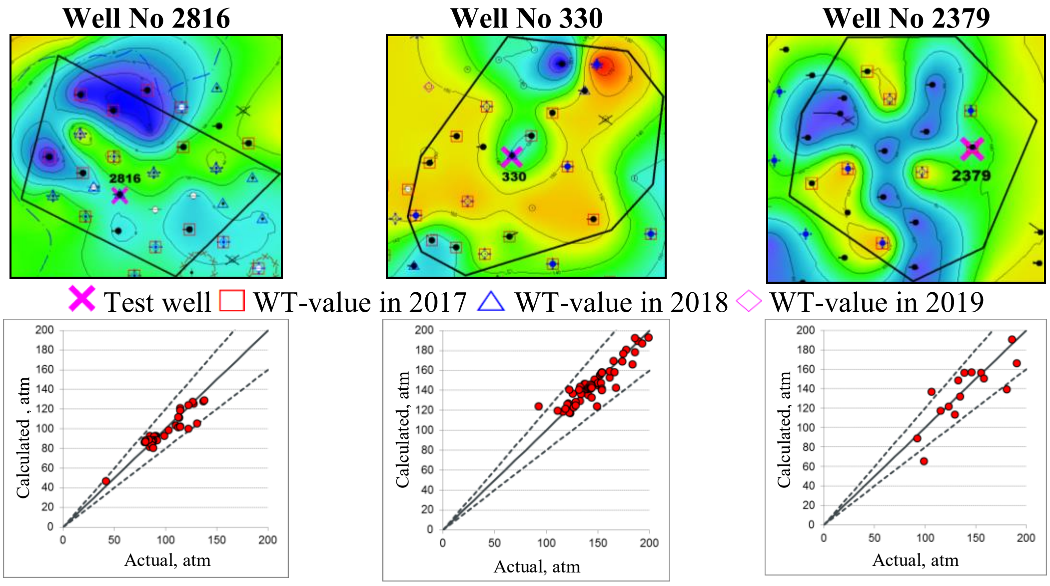


**Figure 5.** Areas of isobar maps and results of history matching by MMB.

**Table 2.** Comparison of calculated and actual reservoir pressure values for the fields of Urals-Volga region.

| Well | Productive formation stage | $P_R$, atm Well test | MMB | Deviation, % |
|---|---|---|---|---|
| 2816 | Bashkirian | 90.8 | 92.9 | 2.3 |
| 330 | Bashkirian | 141.1 | 131.6 | -6.7 |
| 2379 | Vereiskian | 95.1 | 93.5 | -1.7 |
| 4270 | Tournaisian | 148.2 | 128.2 | -13.5 |
| 501 | Vereiskian-Bashkirian | 121.6 | 117.4 | -3.5 |
| 537 | Podolskian- Kashirskian-Vereiskian | 89.6 | 85.6 | -4.5 |
| 758 | Vizeisky | 114.7 | 116.5 | 1.6 |
| 876 | Bashkirian | 67.5 | 107.6 | 59.4 |
| 2077 | Vereiskian | 94.8 | 97.7 | 3.1 |

The significant deviation is observed only for well No 876. Below are the possible reasons of high level of deviations:

- The majority of measurements of $P_R$ are carried on injection well (lack of information about pressure in oil withdrawal zones);
- A lot of workover operations (WO) on well No 876 leading to the productivity index change;
- No well tests were carried out in the well.

MMB method demonstrates better convergence than the interpolation method. The correlation coefficient of $P_R$ for actual and the calculated values is 0.803. In figure 6 you can see the convergence cross-plots of the reservoir pressure values obtained by both methods.

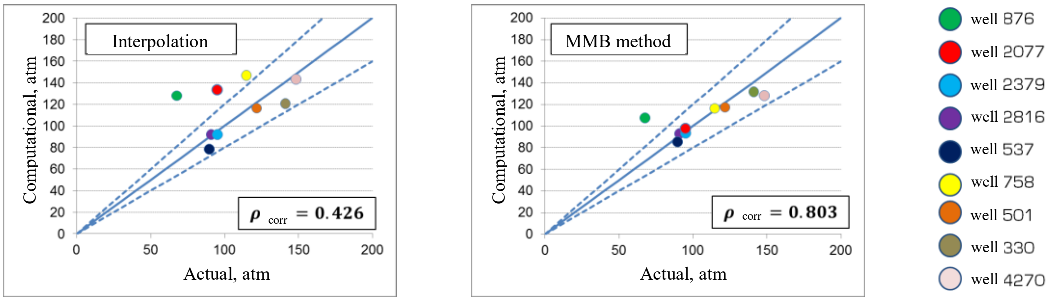


**Figure 6.** Schematic representation of the module operation.

The specifics of proposed MMB method allows reduction in the number of well tests especially for those reservoir areas, where the measurements can be relatively accurate reproduced from the dynamics simulation of the reservoir pressure [10].

## 4. Discussion

As a result of the review of different methods, it is proposed to use the method of multi-tank material balance to recover the computational dynamics of reservoir pressure taking into account the actual measurements and history of production/injection rate.

The method is applicable under the limitations of number and relevance of measurements; the testing demonstrates high accuracy of $P_R$ assessment.

## 5. Conclusion

The method application gives the possibility to:

- Eliminate the risks with $P_R$ when planning acidizing;
- Decrease the costs associated with “unsuccessful” acidizing operations;
- Decrease the costs through optimization of well test program;
- Make the recommendations on development adjustment and optimization.

In general, the issue of computation convergence based on 3D-model of 3-phase filtration and MMB model of 1-phase filtration arises an additional interest, the detailed study of which was not envisaged as a part of this work. Further, it is proposed to elaborate this issue as a separate extended investigation.

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