# Uncertainty Analysis of 1-D Modeling Tracer Elution Curve Analysis (TECA) for Reservoir Heterogeneity Overview

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# Uncertainty Analysis of 1-D Modeling Tracer Elution Curve Analysis (TECA) for Reservoir Heterogeneity Overview

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***Abstract*—In December 2018, a tracer test was conducted at pattern area "X" in C-Zone as the reservoir target of the injection. The injection pattern is inverted-7 spots, where the injection well is located in the middle of monitoring wells. By referring to the mathematical model proposed by Abbaszadeh and Brigham (1983), a one-dimension modeling of Tracer Elution Curve Analysis (TECA) was done to describe reservoir layering characterization in C-Zone (net pay, porosity, and permeability of each layer). Since the assumption of TECA's mathematical model is that the saturation and the porosity of each layer have the same value, uncertainty analysis is required to obtain an overview about reservoir heterogeneity in the pattern area.The research begins with data preparation and quality control; data input to the TECA program; the number of peak determination as to the function of layer number or tracer flow unit number from the injection well to the monitoring wells; streamline and properties calculation by TECA for each tracer flow unit; and the uncertainty analysis using of porosity and water saturation value sensitivity. The uncertainty analysis shows the effect of porosity and water saturation change on the output of TECA. The tracer test analysis by using one-dimension modeling of Tracer Elution Curve Analysis has given us an overview of reservoir connectivity and heterogeneity in the pattern area. Hence, the output parameters can be used in waterflooding and polymer injection optimization.**

***Keywords—tracer test; tracer elution curve analysis; uncertainty analysis; reservoir heterogeneity***

## I. INTRODUCTION

A comprehensive and integrated understanding of reservoir heterogeneity is a key element in designing and successful implementation of Enhanced Oil Recovery (EOR). In an injection process, reservoir heterogeneity has a great impact on determining swept efficiency and preventing an early breakthrough. Therefore, a tool to define reservoir heterogeneity by observing fluid movement in the reservoir is required, and the tracer test can help us to do so.

"F" oil field has been producing for 60 years since 1961. In 1995, the secondary oil recovery through waterflooding was conducted. Moreover, a polymer injection was planned to be conducted in 2020. To support the EOR program, a tracer test was conducted at pattern area "X " in December 2018. The reservoir target of the tracer test is C-Zone. The injection pattern is inverted-7 spots as shown in Fig. 1 where injection well (F-01) is located in the middle of 6 monitoring wells (F-02, F-03, F-04, F-05, F-06, and F-07).

This paper discusses the 1-Dimension modeling of TECA along with uncertainty analysis. This paper can give us a better overview of reservoir connectivity and heterogeneity (in the concept of reservoir layering). The overview can be very useful in updating the dynamic model for waterflooding evaluation and optimization, also for a successful polymer injection implementation. Therefore, an optimal, efficient, and economical result of the EOR program could be obtained.

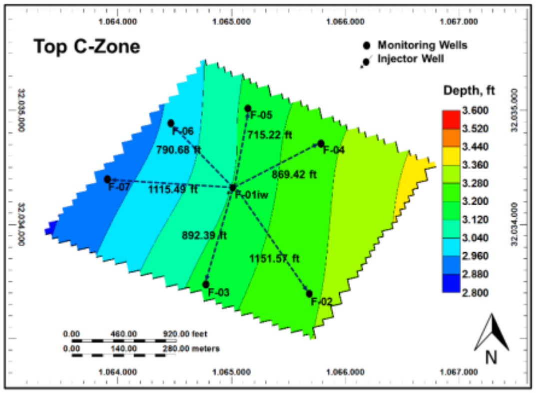


Fig. 1. *Pattern Area "X"*

## II. LITERATURE REVIEW

### A. *Tracer Test*

Several literature reviews summarized in Schlumberger [1], state that tracer is a chemical or any other material that is being put inside or around a wellbore to measure the fluid movement on injection wells through the breakthrough time and the breakthrough concentration observation. Al-Qasim, A. et.al. [2] state that the tracer test is a key element of reservoir surveillance tool to analyze well/reservoir connectivity, sweep efficiency, fluid saturation distribution, reservoir heterogeneity, also on waterflooding/EOR optimization. Fig. 2 shows the illustration of tracer injection and monitoring.

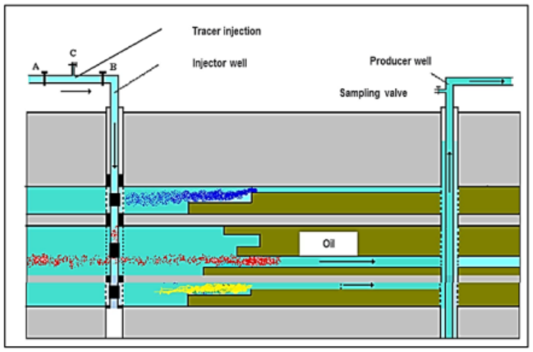


Fig. 2. The Illustration of the Tracer Injection and Monitoring [3]

### B. *Tracer Elution Curve Analysis*

Tracer Elution Curve Analysis (TECA) is one of the quantitative-interpretation methods of a tracer test by using a mathematical model that describes the pattern of tracer breakthrough curve as the response of reservoir layering with different properties in a reservoir. To analyze the tracer breakthrough profile of each layer, Brigham, W.E. and Smith D.H. [4]; Baldwin, D.E. Jr. [5]; and Yuen, D.L. et al. [6] have researched mathematical modeling to describe the tracer breakthrough profile. Yet, those research lead to an inaccurate interpretation of the tracer breakthrough curve. In 1983, Abbaszadeh, M. and Brigham, W.E. [7] formulated a mathematic-analytical solution to accurately describe the reservoir layering from tracer breakthrough profile using nonlinear optimization/multiple regression techniques. The solution then being elaborated for several injection patterns, and it gives us the characteristic of reservoir layering for net pay, porosity, and the permeability of each layer.

To quantify the response of tracer breakthrough as the function of several layers responses, the assumptions used in Abbaszadeh and Brigham's [8] 1-dimension model are:

- Each layer is homogenous (having the same porosity and permeability for each layer);
- There is no crossflow between layer;
- The dispersion/mixing's constant (α) is the same for each layer;
- Water saturation is constant and the same for each layer; and
- Mobility ratio displacement is one.

### C. *Uncertainty Analysis*

Schlumberger [1] defines uncertainty as the degree to which the analysis of a dataset could be in error or stray from predicted values. In other words, uncertainty is the amount of inaccurate possibility. It can cause many problems. Therefore, Thakur, G. [9] describes that uncertainty analysis is very important in successful reservoir management. Ismail, A. et al. [10] state that uncertainty parameters can be considered as spatial and quantitative variations of the reservoir characteristic that can affect reservoir volumes and fluid movement. Moreover, the uncertainty analysis is the change of the impact of the uncertainty in input data to the output to assess risks before we set or take decisions about reservoir management planning.

## III. RESEARCH METHODOLOGY

The research begins with preparation and quality control data as input to the TECA program. The program is built using MatLab software. After data input is done, the first step is to determine the number of tracer peak concentrations as the number of layers from the tracer breakthrough curve for each monitoring well. After that, by using the mathematical model for the inverted-7 spots injection pattern, the peclet number (a/α), pattern pore volume (PV), and the injected tracer pore volume is calculated along with the streamline. The iteration of error is done to calculate the error of the number of layers and streamline's error function. When the error is bigger than $1 \times 10^{-8}$, then the new number of layers will be determined again until the maximum error requirement is met.

The next is the nonlinear optimization or the multiple regression techniques done by MatLab software using the mathematical equations formulated by Abbaszadeh and Brigham [7]. The program will use the porosity value input to the program, then indirectly guess the first value of permeability (k, mD) and net thickness (h, ft) for each layer without changing the total transmissibility (Σkh) value of each monitoring wells; to calculate the Xj and Zj. With both parameters, the program will calculate the value of tracer concentration of each layer (j) in streamline at a certain time (i). When the sum of the tracer concentration from each layer j at the time i (Ci) is the same as the total tracer concentration at the time i of tracer breakthrough data (Ci*), then the objective function (F) will be 0, and the iteration will be stopped. If no, then the program will guess again the value of permeability and net thickness until the objective function is relative equals to 0. When the nonlinear optimization succed, we could obtain the permeability and net thickness of each layer with the same value of porosity. Since we only use one value of porosity and water saturation in the program, the uncertainty analysis for several values of porosity and water saturation is done. Fig. 3 shows the flow chart of 1-dimension modeling Tracer Elution Curve Analysis.

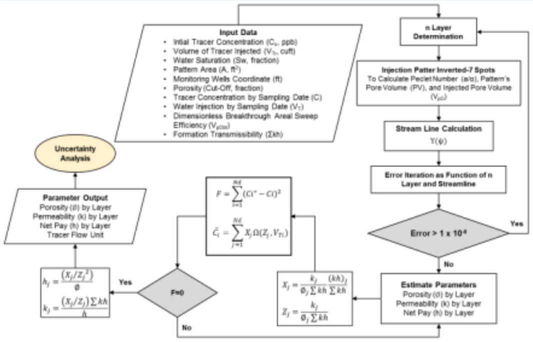


Fig. 3. Research Methodology of 1-D Modelling Tracer Elution Curve Analysis

## IV. RESULT AND DISCUSSION

### A. The Input Data

The data needed as input to the TECA program are the initial tracer concentration; the injected tracer volume; the water saturation; the pattern area; the monitoring wells coordinate; the porosity; the tracer concentration and the water injection by sampling date; the dimensionless breakthrough areal sweep efficiency; and the formation transmissibility for each monitoring wells.

TABLE I. THE INPUT DATA SUMMARY FOR TRACER ELUTION CURVE ANALYSIS

<table>
<tr><th>Input Data Parameters</th><th colspan="3">Value</th><th>Remarks</th></tr>
<tr><td>Tracer Initial Concentration ($C_0$, ppb)</td><td colspan="3">112 x 10<sup>6</sup></td><td>Tracer concentration data</td></tr>
<tr><td>Injected Tracer Volume ($V_{Tr}$, cuft)</td><td colspan="3">1.41</td><td>Injection tracer data</td></tr>
<tr><td>Water Saturation ($S_w$, fraction)</td><td colspan="3">0.44</td><td>Average Sw value at dynamic model at tracer injection date</td></tr>
<tr><td>Pattern Area (A, ft$^2$)</td><td colspan="3">2.13 x 10<sup>6</sup></td><td></td></tr>
<tr><td rowspan="7">Monitoring Wells' coordinates to Injection Well F-01 (ft)</td><td>Well</td><td>X</td><td>Y</td><td rowspan="7">Based on well location</td></tr>
<tr><td>F-02</td><td>666.51</td><td>938.22</td></tr>
<tr><td>F-03</td><td>239</td><td>857.18</td></tr>
<tr><td>F-04</td><td>773.14</td><td>390.85</td></tr>
<tr><td>F-05</td><td>699.9</td><td>134.03</td></tr>
<tr><td>F-06</td><td>555.27</td><td>558.96</td></tr>
<tr><td>F-07</td><td>1112.69</td><td>66.7</td></tr>
<tr><td rowspan="7">Porosity, fraction</td><td>Well</td><td colspan="2">Input</td><td rowspan="7">Average porosity based on cut-off porosity analysis (minimum value of porosity which oil can flow)</td></tr>
<tr><td>F-02</td><td colspan="2">0.12</td></tr>
<tr><td>F-03</td><td colspan="2">0.17</td></tr>
<tr><td>F-04</td><td colspan="2">0.14</td></tr>
<tr><td>F-05</td><td colspan="2">0.16</td></tr>
<tr><td>F-06</td><td colspan="2">0.13</td></tr>
<tr><td>F-07</td><td colspan="2">0.12</td></tr>
<tr><td>Tracer Concentration by Sampling Date</td><td colspan="3">For Each Well</td><td>Tracer concentration data</td></tr>
<tr><td>Water Injection Rate by Sampling Date ($V_T$)</td><td colspan="3">For Each Well</td><td>Injection data</td></tr>
<tr><td>Dimensionless Breakthrough Areal Sweep Efficiency ($V_{pDbt}$)</td><td colspan="3">0.743682</td><td>For 7-spot pattern (Abbaszadeh and Brigham, 1983)</td></tr>
<tr><td rowspan="7">Transmissibilty (Σkh)</td><td>Well</td><td colspan="2">Σkh</td><td rowspan="7">From permeabilty and net pay of each well</td></tr>
<tr><td>F-02</td><td colspan="2">235.00</td></tr>
<tr><td>F-03</td><td colspan="2">866.00</td></tr>
<tr><td>F-04</td><td colspan="2">3291.00</td></tr>
<tr><td>F-05</td><td colspan="2">1101.00</td></tr>
<tr><td>F-06</td><td colspan="2">1429.00</td></tr>
<tr><td>F-07</td><td colspan="2">551.00</td></tr>
</table>

### B. Number of Layer Determination

The number of peak tracer concentrations will very affect the output of the TECA program. The number of peak tracer concentrations is set to determine the number of layers from the injection well F-01 to the monitoring wells as the tracer flow path. Fig. 4 shows the result of the n layer determination based on peak tracer concentration. It can be seen that monitoring well F-02 has 4 tracer concentration peaks, which indicates that the well has 4 layers or 4 tracer flow units. The monitoring well F-03 has 3 tracer concentration peaks, which indicates that the well has 3 layers or 3 tracer flow units. The monitoring well F-04 has 4 tracer concentration peaks, which indicates that the well has 4 layers or 4 tracer flow units. The monitoring well F-05 has 2 tracer concentration peaks, which indicates that the well has 2 layers or 2 tracer flow units. The monitoring well F-06 has 3 tracer concentration peaks, which indicates that the well has 3 layers or 3 tracer flow units. Meanwhile, the monitoring well F-07 has 2 tracer concentration peaks, which indicates that the well has 2 layers or 2 tracer flow units.

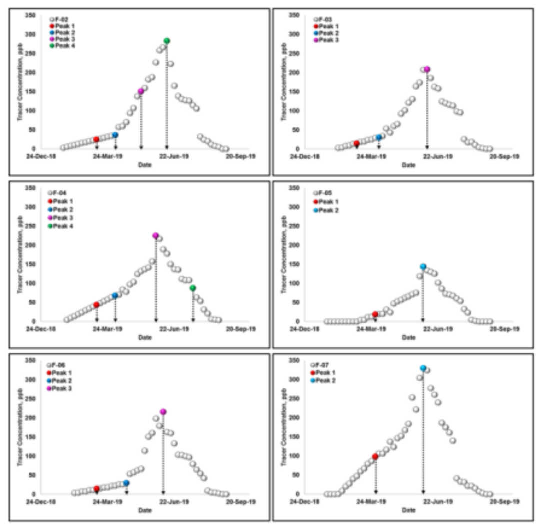

Fig. 4. The n Layer Determination based on Peak Tracer Concentration

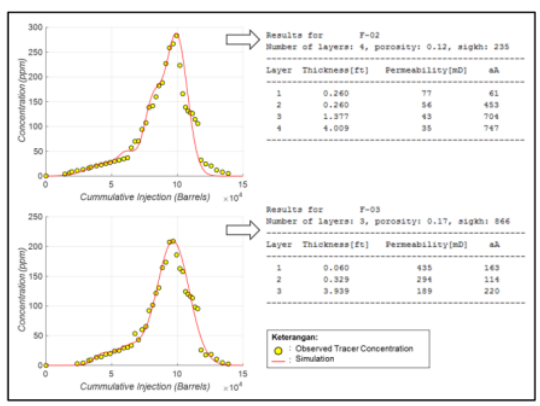


Fig. 5. Matching and Ouput TECA for Well F-02 and F-03

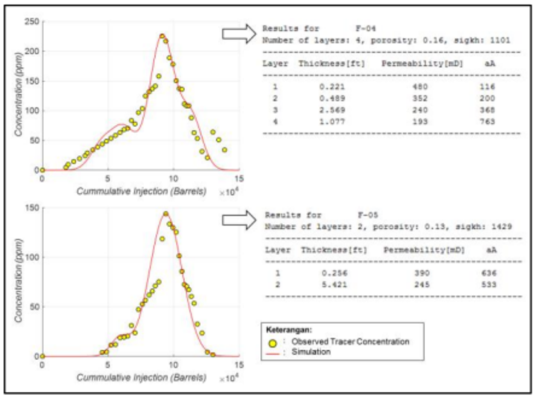


Fig. 6. Matching and Ouput TECA for Well F-04 and F-05

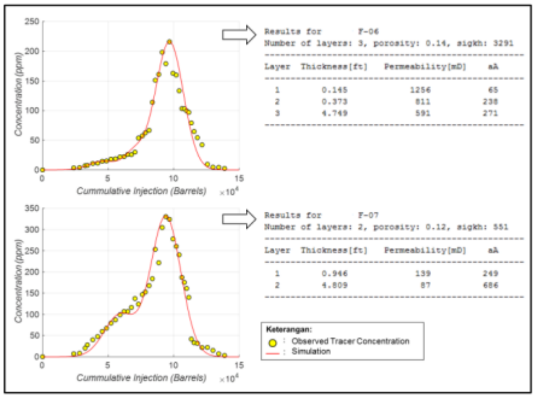


Fig. 7. Matching and Ouput TECA for Well F-04 and F-05

### C. *Matching and Output of 1-D Modelling*

After input data is done and the number of layers is determined, the nonlinear optimization/multiple regression is done by the TECA program and the iteration is done to obtain the porosity, permeability, and net thickness of each layer from each monitoring wells. Fig. 5 to Fig. 7 show the matching of the tracer concentration curve along with the reservoir layering property from each monitoring wells.

### D. *Uncertainty Analysis*

The uncertainty analysis is done to porosity and water saturation value. In porosity uncertainty analysis, the analysis is conducted at the same value of water saturation 0.44. Meanwhile, in water saturation uncertainty, the analysis is conducted at the same value of porosity 0.12. Table 2 shows the uncertainty analysis result for well F-02 as the sample. It can be seen that the greater porosity or water saturation value, the greater permeability value, and the smaller net thickness value for each layer. With both porosity and water saturation uncertainty analysis, we can get several reservoir layering models that can be applied to the dynamic model. By so, we could minimize the error that can cause by updating dynamic model properties by only using one output TECA program model.

TABLE II. UNCERTAINTY ANALYSIS OF 1-D MODELLING TRACER ELUTION CURVE ANALYSIS

| Well | Layer/Tracer Flow Unit | Porosity Uncertainty Analysis (Sw = 0.44) | | | | | |
|---|---|---|---|---|---|---|---|
| | | ϕ = 0.12 | | ϕ = 0.14 | | ϕ = 0.16 | |
| | | Thickness, ft | Permeability, mD | Thickness, ft | Permeability, mD | Thickness, ft | Permeability, mD |
| F-02 | TFU-1 | 0.260 | 77 | 0.223 | 90 | 0.195 | 102 |
| | TFU-2 | 0.260 | 56 | 0.223 | 66 | 0.195 | 75 |
| | TFU-3 | 1.377 | 43 | 1.18 | 50 | 1.033 | 54 |
| | TFU-4 | 4.009 | 35 | 3.437 | 41 | 3.007 | 47 |

| Well | Layer/Tracer Flow Unit | Water Saturation Uncertainty Analysis (ϕ = 0.12) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sw = 0.4 | | Sw = 0.44 | | Sw = 0.48 | |
| | | Thickness, ft | Permeability, mD | Thickness, ft | Permeability, mD | Thickness, ft | Permeability, mD |
| F-02 | TFU-1 | 0.286 | 70 | 0.260 | 77 | 0.238 | 84 |
| | TFU-2 | 0.286 | 51 | 0.260 | 56 | 0.239 | 61 |
| | TFU-3 | 0.515 | 39 | 1.377 | 43 | 1.262 | 47 |
| | TFU-4 | 4.41 | 32 | 4.009 | 35 | 3.675 | 38 |

## V. CONCLUDING REMARKS

Uncertainty analysis shows the overview of how the porosity and water saturation change affect the output of the Tracer Elution Curve Analysis (TECA) program. Both parameters do not affect the number of layers of the tracer flow path but affect the permeability and net thickness of each layer. Tracer test analysis with 1-dimension modeling of TECA has successfully given us an overview of reservoir connectivity and heterogeneity on the pattern area of tracer injection. The understanding of reservoir heterogeneity from the analysis can be very useful and can be used for waterflooding and polymer injection plan optimization.

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