Technical University of Crete

School of Mineral Resources Engineering

MSc in Petroleum Engineering

Single-Well Tracer Test for S_{or} Estimation

Master Thesis

Student Name: Nikolaos Apeiranthitis

Supervisor: Prof. D. Christopoulos

Scientific Advisor: Dr. Ch. Chatzichristos

Abstract

The Single-well Tracer Test is a test used extensively to measure the residual oil saturation- S_{or} in watered-out reservoir. Also, it is implemented in order to evaluate enhanced oil recovery (EOR) using chemicals, such as Alkaline/Surfactant/Polymer flooding.

The tracer test, in particular, includes a water/oil partitioning tracer injection, along with water, to a radius of investigation of 30 feet around a test well. Then the well is shut in and the injected tracer, usually an ester, reacts with the formation water producing ethanol. The produced ethanol dissolves only in the water. When the well is again set on production, the produced water is measured regularly, in order to measure the concentration of the tracers; the remained unreacted ester, and the produced ethanol. Due to the fact that the ester is partitioning tracer and the ethanol is a passive tracer, a separation will be observed on the arrival of time that the peak concentration is measured. This separation gives the S_{or} estimation. A passive tracer is injected along with the ester, in order to monitor any losses of the injected volumes in the reservoir. During production the ester's and the passive tracer's peak concentration should arrive at the same time.

The test is affected by several parameters, such as the reservoir temperature, the brine salinity and the temperature gradient that is created after the injection. The temperature affects the partitioning coefficient of the tracer in positive way, as also the reaction rate, with the same way. Brine salinity affects the partitioning coefficient in positive way, while the reaction rate of the tracer is affected negatively. In order to take into consideration initial temperature and brine effect, the part. Coefficient and the reaction rate are measured in the lab at reservoir conditions, using the formation water at the reservoir temperature. Furthermore, the injection is done with formation water in order to keep the salinity effect constant.

The temperature effect, in terms of different reservoir and/or injection water temperature is examined, and also in terms of the different temperature gradient that is created using or not pre-flush water volume in order to cool down the reservoir. The reservoir temperature affects the results with the same way; more ethanol is produced, while the water temperature, affects the reaction only when pre-flush is used. Injection rate also affects the amount of the produced ethanol, with high injection rate to be optimal the test to be valid.

Regarding the history matching conducted under the described scope and the temperature effects, better result were obtained when a pre-flush volume is injected. Also, more satisfying results were obtained with increasing the separate layers of the investigation interval. The final S_{or} estimation was not uniformly distributed though out the reservoir, varying from 10% to 26% at same cases.

All simulations were done using the Chemical Simulator of the University of Texas (UTCHEM).

Acknowledgements

I want to express my thanks to the examination committee, Prof. Christopoulos Dionisios., Prof. Kalogerakis Nikolaos and Prof. Vafidis Antonios for being supportive for completing this thesis.

Also, I want to express my great gratitude to my main scientific advisor for this thesis, Dr. Christos Chatzichristos, who with his advice and great patience gave me the proper directions for understanding the main purpose of this work and all the knowledge that I received during this 3-month collaboration.

Last but not least, I want to thank my family for helping me with every way and encouraging me, completing this Master Course.

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1. Introduction

The need of more in quantity and more sufficient oil recovery from producing reservoir has led the oil industry to develop and apply methods that would serve this purpose. After the primary oil recovery, when the reservoir pressure is not enough, secondary recovery methods, such as waterflooding, are applied to maintain the pressure. At the end of these two phases a 30%- 40% of the total oil in place is produced. For the remained oil, EOR (Enhanced Oil Recovery) methods are used, such as ASP (Alkaline/Polymer/Surfactant) flooding, steam injection, microbial etc., to achieve a further recovery of 20%-30% of the oil. However, the application of an EOR methods needs evaluation before implementation, as every reservoir is different and has its own unique combination of physical characteristics. The most important parameter, which must be determined before EOR, in a waterflooded reservoir, is the residual oil saturation.

One way to measure the residual oil saturation is to perform well-logging, which may be difficult and expensive to apply due to well completions, (pumps). The use of tracer tests, either inter- or single- well tests has been proved more useful and more reliable, as the results are more representative of the whole reservoir.

Single-well tracer test are also applied after an EOR project, in order to measuring again the residual oil saturation and to evaluate the effectiveness of the EOR method.

This thesis will deal with single- well tracer tests. The procedure of the test and parameters that affect the reactions that take place during the test will be described. A short description of ASP flooding will also be presented. The effect of temperature and pH will be shown by sensitivity analysis and finally a history matching of real single-well tracer test data. The simulations are carried out using the UTCHEM simulator.

2. General Topics

2.1 ASP Flooding

After waterflooding is completed, the position of the residual oil is determined mainly by the capillary forces exerted in-between the pores. Another factor for the amount of the remaining oil in the pores is the interfacial forces between the oil and the water. A chemical EOR method may be used, such as alkaline flooding or polymer or surfactant flooding or even all three of them, simultaneously. The reason to use them together in injection water is that any of these components alone is not sufficient enough to achieve the desirable oil recovery.

Alkalis used, increase the pH of the injected water, react with the acidic members of the oil creating in situ soap. This decreases the interfacial tension between the water and the oil. The problem with alkaline flooding is that alkalis may be quickly consumed by the reaction with the water but also with the rock, clays usually, of the reservoir. So, can be assumed that there are changes in salinity and pH of the brine, where extensive scale precipitation takes place.

An Alkaline/Surfactant/Polymer flooding has a combinational role so that surfactant reduces the interfacial tension between oil and water, while alkali reduces the adsorption of the polymer during the procedure. Another benefit of the alkalis is the in-situ generation of soap in favor of IFT reduction. By adding polymer, the sweep efficiency of the water is improved by the increase in its viscosity (Sheng, 2011) (Abadli, 2012).

2.2 Tracers

Tracers are used in the oil industry more than 50 years. Over these years, tracers have been used to study a very broad range of topics. The tracers can be non-partitioning, partitioning, decaying (radioactive), adsorbing and each one of them is used for different purpose and measurement. A high percentage of the tracer application involves waterflooding tracer applications. The usefulness of waterflood tracers is based upon the assumption that the movement of the tracer reflects the movement of the injected water. Radioactive isotopes are used to tag chemical tracers to provide analytical tools of high selectivity and sensitivity.

In cases where the water entering the field comes from many different sources, managing the waterflood operation can become difficult. The addition of a tracer to the injected water is the only means of distinguishing between injection water and formation water, or between waters from different injection wells in the same field.

Tracers are added to waterfloods for many reasons and in a variety of circumstances. They can be a powerful tool for describing the reservoir, investigating unexpected anomalies in flow, or verifying suspected geological barriers or flow channels. They can also be used in a test section of the field before expanding the flood.

These applications are conducted under the scope of inter-well tracer test, covering a big portion of the reservoir, and making the results reliable.

Tracers are also used for Sor estimation, either with inter- or sinlge-well tests, which will be discussed later on.

Other application involves investigation and monitoring of the region near the borehole, regarding the fluids flow into the well, and tracers used in surface facilities (Zemel, 1995).

3. S_{or} Estimation: Well Logging- P IWTT

As mentioned at the introduction, the residual oil saturation S_{or} measurement can be done by well-logging or with tracer tests, inter- or single- well. Each method has its procedure with the respective restrictions. At this section, it will be presented, briefly, the well-logging Sor measurement, and the inter-well tracer test measurement.

3.1 Well Logging

Well logging measurements are used to quantify the reservoir thickness (net pay), pore space (porosity), and the type and amounts of fluids occupying that pore space (water, gas, and oil saturations). There are many tools, used for all these important data, for establishing finally the oil in place. Some of these tools are, porosity tools, resistivity tools, acoustic and neutron tools, among others. Most of them can measure near the well bore the porosity of the formation, a key-information for the water or oil saturation calculations. Yet there are saturation tools for this particular measurement.

Saturation tools are those logging tools, which are sensitive to (gas, oil, and water) saturation variations. Formation resistivity, Rt, estimated from these tools is used to estimate the uninvaded formation water saturation, Sw. The hydrocarbon saturation, So or Sg, is then 1_Sw. There are four types of open-hole saturation tools:

- Resistivity tools using electrodes
- Resistivity tools using coils, for air, mist, foam filled boreholes
- Resistivity tools using antennas, for heavy, viscous oils and very fresh waters.
- NMR logs, (Nuclear Magnetic Resonance).

By these tools, porosity can be acquired, and the presence and quantities of different fluids (water, oil, and gas), too.

Apart from these, has been created several relations that connect the porosity measurements by resistivity logs, with the formation resistivity that helps for the water or oil saturation in the reservoir (Ellis & Singer, 2007) (Aminzadeh & Dasgupta, 2013).

3.2 Partitioning Inter-Well Tracer Test

A way to measure the residual oil in a very big region of a reservoir is to implement an inter-well tracer test. These tests should be conducted in watered-out reservoirs, which are at residual oil state.

The injection of formation water, containing a partitioning and a non-partitioning tracer, allow measuring the residual oil saturation, by the difference in the arrival times. For the non-partitioning tracer, the travel velocity will be equal to that of the water injected. On the other hand, for the partitioning tracer, the velocity is smaller than that of water. The tracer will be distributed between the two fluids existing in the reservoir (oil and water), due to the value of the partitioning coefficient, for the particular fluids. This fact causes retardation to the partitioning tracer. The difference in arrival times (difference in peak concentrations), can give a residual oil measurement. The whole method will be described in detail later on.

The main problem for the inter-well test is the duration time. It may take months or even years for the production of the injected tracers by the production wells.

For this reason single well tracer test were developed, to anticipating this time dependence on the information acquisition (Zemel, 1995).

4. Single-Well Tracer Test Methodology

A suitable well for SWTT is this well that produces high enough water cut, so the region around, is at near residual-oil-saturation phase. The water used for the injection is formation water, in order to have the same salinity situation as in the reservoir. The selection of the tracers is based upon several factors, mainly at the reservoir temperature and formation water salinity. The reacting tracers used are formates, for low reservoir temperatures (70 to 135 F), and alkyl esters for higher values of temperatures (130 to 250 F).

The basic steps for the test apply, are four. At first, a bank of water is injected, containing the appropriate partitioning tracer (e.g. ester), at a given rate. Then, a second water bank is injected, so to push the first bank at a radius of ~20 ft. Usually another non-partitioning tracer (alcohol) is injected, in order to monitor at the end of the test, any water loss in the reservoir. A shut-in period follows and the reacting acetate reacts with the formation water to produce another alcohol which is detectable even at low concentration. The acetate must react at 10 to 50 % preferably.

$$CH_3COOC_2H_5 + H_2O \xrightarrow{[H+]} C_2H_5OH + CH_3COOH$$
Ethyl Acetate   Ethanol + Acid
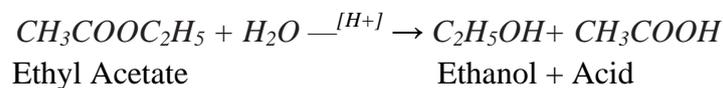
At the time that the production of the well starts, the injected acetate and the product of its reaction, alcohol, are at the same distance from the well (Fig.1). The fact that the remaining unreacted tracer participates more in the oil phase, while the product alcohol is insoluble in the oil, allow the residual oil to be measured, based on the chromatographic separation of these two in the reservoir. The different arrival times of the ester and the ethanol, allow us to compute the Sor.
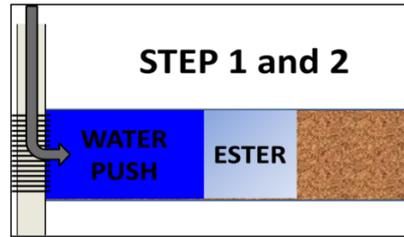
STEP 3: SHUT-IN PERIOD
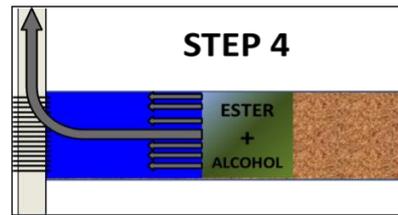
Figure 1 Single-Well Tracer Test steps

The partitioning coefficient of the esters between the water and the oil phase is the main characteristic that helps the measurement of the residual oil. It is defined as:

$$Kd = \frac{(Concentration\ of\ ester\ in\ oil)}{(Concentration\ of\ ester\ in\ water)}$$,at equilibrium. When the tracer injected, it will dilute more in the oil phase. During the injection, the primary tracer will participate between the water and the oil phase, resulting to its retardation. The material balance tracer in the first bank will reach further in the reservoir than the primary tracer, as it is soluble only in the water. After the shut-in and the reaction have taken place and production begins, the same effect will occur. The unreacted ester will be retarded again from the oil stationary phase, while, on the other hand, the product alcohol is insoluble in the oil and practically will travel with the same speed of water. This difference in velocities or the difference in arrival times, can give the residual oil in place.

In cases that no residual oil exists in the porous media, the unreacted ester and the product ethanol will arrive simultaneously at the surface.

The acid produced, as shown above at the reaction equation, is absorbed by the rock itself; so it is not appeared during production.

More specifically about the S_{or} calculation, let it be considered a specified volume of a porous media, the tracer equilibrium between the water and oil phase can be expressed as: $\beta i = \frac{(ni)oil}{(ni)water}$. Moles n_i of the tracer int the water are $(Ni)water = (Ci)water * Sw * dV$ and in the oil $(Ni)oil = (Ci)oil * Sor * dV$.

Combining these three equations, the definition of the partitioning coefficient from above and the expression of the saturation $Sw + Sor = 1$, the retardation factor can be extracted: $\beta i = Ki * \frac{Sor}{1-Sor}$.

Taking into consideration probability theory, the time that tracer molecule spends in water (f) and in oil (1-f), the retardation factor can also be written: $\frac{1-f}{f} = \beta i$.

Consequently, the velocity of a partitioning tracer is expressed as: $Vi = f * Vwater + (1 + f) * Voil$, and as long as the oil phase is residual the velocity of the tracer is dependent on by the water. The fact that the test is made in-situ and the product ethanol has the velocity of water and the ester has velocity depended on the partitioning coefficient the S_{or} can finally be calculated: $Sor = \dfrac{\beta i}{\beta i + Ki}$ (Deans & Carlisle).

4.1 Designing Parameters

The design parameters that are taken into consideration are: The oil-cut of the well to be tested, the reservoir temperature, the reservoir lithology, the production rate, the test interval size and average porosity and the brine salinity.

The oil cut and the reservoir temperature are mentioned at the beginning of this section. The well should have high water cut or very low oil-cut. In cases that the test is conducted at the early life of the reservoir, when no water is produced, then water is injected regionally, to cause a residual-oil-phase condition, nearby the well.

The reservoir temperature will define the partitioning tracer selection. As mentioned before, at low temperatures formates are chosen, while for higher temperatures esters are chosen.

The reservoir lithology involves the designing of the test whether it is in sandstone or in carbonate reservoir. Generally, tests conducted in sandstones are more flexible and give good production curves of the tracers injected, while carbonates need precision in designing, as till now many test give dispersed production profiles, which are more difficult to interpreting.

The volume that is to be injected in a well is depended on the regular production volume of water at one day or two, as upper limit. Generally, the volume is calculated so that the testing region to be at ~20 ft around the well. Also, the injection and the production rate should preferable be the same during the test.

The interval size of the test can vary and be 100 ft height. However, at this height the results may not be representative for interlayers with different oil saturation. Smaller intervals should be selected, preferably; 10 to 50 feet. The porosity and the interval height are used for the theoretical radius of investigation, but the results are not depended on them.

Water salinity has an effect on the partitioning coefficient, Kd and the reaction rate, Kh, (described below at Salt effect). For that reason these two are measured in the lab and used directly for the result interpretation. Regarding the Kd, it is increased when the salinity is increased for a specific temperature.

4.2 Tracer Test Procedures and Data Interpretation

After the necessary calculations have been made, the candidate well is prepared. The oil cut and the stabilized production are established. Also, the well is cleaned up, as well as

new surface facilities are set for the test's production measurements. The injection of the selected ester is done, based on the volume calculations and the well is shut-in. During production, water samples are taken regularly, for measuring the concentration of the tracer, and a rough estimation on the residual oil can be done.

The produced volumes of the tracers are linked as $Q_A=Q_B(1+\beta_A)$. This is valid when the primary tracer A and product B start to back flow from the same position, after the shut-in. By normalizing each concentration versus the respective volume, and trying fitting the two curves by trial and error, the β_A factor is estimated. Using this estimation in this formula $= \dfrac{\beta i}{\beta i + Ki}$, Sor is obtained.
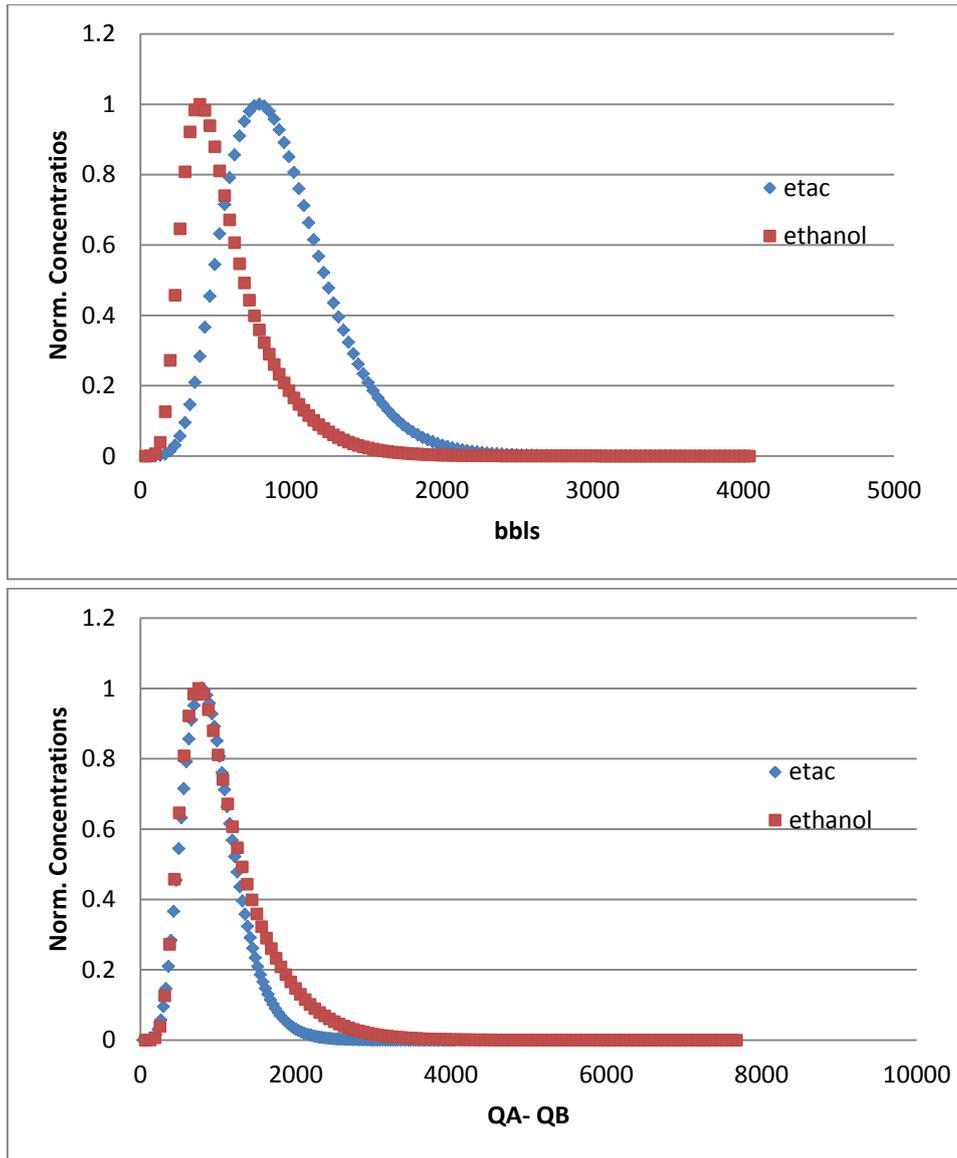
Figure 2. Qualitative Sor estimation

History matching is done, also, by simulating the test in software. By introducing the Kd of the tracer and the injection/production history and varying the value of the Sor, a final match between the real and simulated data is achieved.

One problem influencing the test is that the temperature effect during the reaction may cause different position to the product ethanol. In that case, caution is needed for the calculation.

Another problem that may be encountered is the estimation of the Sor is not representative of the test interval, due to different oil saturation in places. Different pressure status, at interlayers, causes non ideal flow of the injected and produced volumes, resulting to bad curves shapes, difficult to interpreting. In addition, when ester reacts during injection and not only at shut-in period, the Sor is not accurately computed (Deans & Carlisle).

4.3 Definition of Kh-Salt effect

The reaction rate is determined as the changes in concentration of the reactants/products per unit time. For the reactants the rate is negative, as the concentration is decreasing, while for the product(s) is positive. The reaction rate or changes of concentration may have linear relationship with time intervals, but exponential, too. This happens, because the changes in concentration may not be the same at the beginning, middle or at the end of the reaction. In that case, the reaction rate for a specific time is given by the slope of the curve, determined experimentally (Upadhyay, 2006).

Furthermore, the reaction rate can be expressed as: $Rate = k[A]^a[B]^b$, where k is the rate constant and $[A]$, $[B]$ the reactants of a reaction; and are proportionally related. The rate constant is equal to the reaction rate when A&B at unit concentration. Generally, the rate constant is expresses by the Arrhenius equation: $k = Ae^{-\frac{Ea}{RT}}$ and is temperature deepened. As long as the rate constant is temperature depended, the same is for the reaction rate. The rate constant, for every 10 °C increase, can be doubled or tripled.

In esters hydrolysis, two cases can be distinguished; first, auto-catalyzed hydrolysis by the acid product of the reaction and second, catalyzed hydrolysis in acidic $[H^+]$ or basic $[OH^-]$ environment (Jogunola, Salmi, Eranen, Warna, & Mikkola, 2011). In an acidic environment, the hydrolysis of esters is a first-order reaction: $CH_3COOC_2H_5 + H_2O \xrightarrow{[H+]} CH_3COOH + C_2H_5OH$, as the H_2O remains constant and only the ester's concentration decreases. However in presence of alkali, such as NaOH, the reaction is of second-order: $CH_2COOC_2H5 + NaOH \rightarrow CH_3COONa + C_2H_5OH$. The latter case of hydrolysis is considered more effective in favor of ester consumption (Jogunola, Salmi, Eranen, Warna, & Mikkola, 2011) (Upadhyay, 2006). Another effect that should be taken into account is the salt effect on the reaction rates. The salt effect includes the influence of ions in the solution and consequently to reaction rate, and is separated at primary and secondary. The primary salt effect is the influence of electrolyte concentration on the activity coefficient and the reaction rate in non-catalytic reaction, while the secondary salt effect is the actual changes in concentration of the reacting ions resulting from the addition of electrolytes. Esters hydrolysis is not influenced by primary salt effect, as they are neutral charged compounds in a solution. The secondary salt effect will cause different reaction rate due to the acidic or basic environment in a solution. The ions influence the concentration of $[H^+]$ or $[OH^-]$. In any case, as the ionic strength of the solution increases, the same effect will be on the concentration of the $[H^+]$ or $[OH^-]$.(Ionic strength is the intensity of the

electric field in a solution due to the concentration of the ions and their valence (Upadhyay, 2006).

From lab reports, the K_h of the ester hydrolysis is depended by the salinity of the brine. When the salinity is very low, the acid produced during the reaction, it is not buffered sufficiently, causing that way auto-catalyzation and a faster hydrolysis of the ester. On the other hand, when the salinity is higher, the acid is consumed and the above phenomenon does not take place. So, K_h will have lower values.

5. Modeling

Simulation and modeling of the test results is essential to understanding the reservoir behavior. Regarding the test in specific, the production profiles of the tracers are used against these of the simulation, for comparison. During the simulation, there is the flexibility of changing parameters and finding the best result. In this way, the test also is evaluated in terms of its reliability. UTChem gives this ability of simulating Single-Well Tracer Test, among other chemical applications.

5.1 UTCHEM description

UTCHEM is a 3-D chemical simulator, developed at The University of Texas. The application of UTCHEM includes multicomponent, multiphase, compositional model of chemical flooding processes which accounts for complex phase behavior, chemical and physical transformations and heterogeneous porous media properties, and uses advanced concepts in high-order numerical accuracy and dispersion control and vector and parallel processing. It can simulate several ground water applications, as oil reservoir application such as, chemical flooding (polymer, surfactant), water flooding and tracer tests, (single-, inter- well) etc. At this section, the formulas of the tracers will be described, as they are introduced in the software.

5.1.1 Modules Brief Description

Three main equations are introduced and solved by the software:

1) The mass balance equation for each species
2) Pressure for aqueous phase is calculated by an overall mass balance on volume-occupying components (water, oil, surfactant, co-solvent and air). The other phase pressures are computed by adding the capillary pressures between phases.
3) The energy balance equation.

Four phases are modeled; water, oil, microemulsion and air. Regarding the tracer, any number can be modeled and any type; partitioning, adsorbing, and decaying.

Mass Conservation Equation

The mass balance equation assumes local thermodynamic equilibrium. This is not the case for tracers, dissolution of organic component, immobile solid phase, Darcy's law etc.

The mass conservation for a component k in association with Darcy's law is expressed in terms of overall volume of component k per unit pore volume ($\widetilde{C_k}$) as:

$$\frac{\partial}{\partial t}\left(\varphi \widetilde{C_k} \kappa \rho_\kappa\right) + \vec{\nabla}\left[\sum_{l=1}^{n_p} \rho_\kappa \left(C_{kl}\vec{u_l} - \overrightarrow{\widetilde{D_{kl}}}\right)\right] = R_k$$

Equation 1

Where the overall volume of component k per unit volume is the sum over all phases including adsorbed phases: $\tilde{C}_\kappa = \left(1 - \sum_{\kappa=1}^{n_{CV}} \hat{C}_\kappa\right)\sum_{l=1}^{n_p} S_l C_{\kappa l} + \hat{C}_\kappa$, n_{CV} total number of volume-occupying component, n_p number of phases, $\hat{C}_\kappa$ adsorbed concentration of species k, ρ_κ density of pure component k at reference pressure P_R relative to its density at reference pressure P_{R0} equal to 1 atm. Ideal mixing, small and constant compressibilities C_κ^o is assumed. $\rho_\kappa = 1 + C_\kappa^o(P_R - P_{R0})$

Dispersive flux: $\overrightarrow{\widetilde{D}}_{\kappa l,x} = \varphi S_l \overrightarrow{\vec{K}}_{\kappa l} \cdot \vec{\nabla}C_{\kappa l}$

Dispersion tensor including molecular diffusion:

$\overrightarrow{\vec{K}}_{\kappa l} \equiv \frac{D_{\kappa l}}{\tau}\delta_{ij} + \frac{a_{Tl}}{\varphi S_l}|\vec{u}_l|\delta_{ij} + \frac{(a_{Ll}-a_{Tl})}{\varphi S_l}\frac{u_{li}u_{lj}}{|\vec{u}_l|}$, where a_{Ll} and a_{Tl} are phase l longitudinal and transverse dispersivities; τ is the tortuosity factor with the definition of being a value greater than one; u_{li}, u_{lj} are the components of Darcy flux of phase l.

Magnitude of vector flux for each phase, $|\vec{u}_l| = \sqrt{(u_{xl})^2 + \left(u_{yl}\right)^2 + (u_{zl})^2}$,

and the phase flux from Darcy's law is $\vec{u}_l = -\frac{k_{rl}\vec{k}}{\mu_l} \cdot \left(\vec{\nabla}P_l - \gamma_l\vec{\nabla}h\right)$,

The source terms R_k are a combination of all rate terms for a particular component and can be expressed as

$R_\kappa = \varphi \sum_{l=1}^{n_p} S_l r_{\kappa l} + (1 - \varphi)r_{\kappa S} + Q_\kappa$,where Q_k is the injection/production rate for component k per bulk volume. $r_{\kappa l}$, $r_{\kappa S}$ are the reaction rates for component k in phase l and solid phase s respectively

Energy Conservation Equation

Solving the energy conservation equation, it is assumed that it is a function of temperature. Advection and heat conduction are the ways of energy flux. It is modeled as:

$$\frac{\partial}{\partial t}\left[(1-\varphi)\rho_s C_{vs} + \varphi \sum_{l=1}^{n_p} \rho_l S_l C_{vl}\right]T + \vec{\nabla}\left(\sum_{l=1}^{n_p} \rho_l C_{pl} u_l T - \lambda_T \vec{\nabla}T\right) = q_H - Q_L$$

<div align="center">Equation 2</div>

where T is the reservoir temperature; Cvs and Cvl are the soil and phase l heat capacities at constant volume; Cpl is the phase l heat capacity at constant pressure; and lT is the thermal conductivity (all assumed constant). qH is the enthalpy source term per bulk volume. QL is the heat loss to overburden and underburden formations or soil.

Pressure Equation

The pressure is calculated by summing the mass material balance equations of all volume-occupying components, substituting Darcy's law for the phase flux terms, using capillary pressures and eliminating adsorbing phases from the equation.

$$\varphi C_t \frac{\partial P_1}{\partial t} + \vec{\nabla}(k^{\rightarrow\rightarrow})\lambda_{rTc}\vec{\nabla}P_1 = -\vec{\nabla}\sum_{l=1}^{n_p}(\vec{k})\,\lambda_{rlc}\vec{\nabla}h + \vec{\nabla}\sum_{l=1}^{n_p}\overrightarrow{(k)}\lambda_{rlc}\vec{\nabla}P_{cl1} + \sum_{k=1}^{n_{cv}} Q_k$$

<div align="center">Equation 3</div>

Where $\lambda_{rlc} = \frac{k_{\kappa l}}{\mu_l}\sum_{\kappa=1}^{n_{CV}}\rho_\kappa C_{\kappa l}$ and total relative mobility with the correction for fluid compressibility, $\lambda_{rTc} = \sum_{l=1}^{n_p}\lambda_{rlc}$. The total compressibility C$_t$ is the volume-weighted sum of the rock or soil matrix (C$_r$) and component compressibility (C_κ^o), $C_t = C_r + \sum_{\kappa=1}^{n_{CV}} C_\kappa^o \tilde{C}_\kappa$, where

$$\varphi = \varphi_R[1 + C_r(P_R - P_{R0})].$$

Tracer Modulation

Tracers can be partitioning or non-partitioning in a liquid phase, as mentioned before. So, they can be water tracer, oil tracer, partitioning water/oil tracer, gas tracer, partitioning gas/oil tracer. UTCHEM allows only two reacting tracer, for water/oil partitioning tracers. The main assumptions for the tracers are that tracers do not occupy volume and that they do not have any physical effect on the physical properties in the reservoir. The tracer concentration is calculated by the species conservation equations, which includes a reaction term for reacting tracers.

For partitioning water/oil tracers, the partitioning coefficient is expressed as the ratio of the concentration of the tracer in the oil phase and the water phase: $Kt = \frac{Ct,o}{Ct,w}$. The material balance equation for the partitioning tracer is: $Ct = C1Ct,w + C2Ct,o$, where C1, C2 the overall concentration of water and oil, respectively. The concentrations $C_{T,w}$ and $C_{T,o}$ are calculated by: $Ct,w = \frac{Ct}{C1+C2Kt}$ and $Ct,o = \frac{KtCt}{C1+C2Kt}$.

UTCHEM takes into consideration two factors affecting the partitioning coefficient, temperature and reservoir brine salinity. Both effects are formulated linearly. The temperature is described as:

$$Kti = Kti,Tref(1 + TKi(T - Tref)),$$

<div align="center">Equation 4</div>

for tracer I, where $K_{Ti,\ Tref}$ is the partitioning coefficient at reference temperature (Tref) measured in °F. TK_i is a constant input parameter in 1/°F.

The salinity effect is modeled as:

$$Kti = Kti,Sref(1 + TKSi(C51 - C51,ref))$$

<div align="center">Equation 5</div>

where C_{51} is the concentration of anions in aqueous phase and $C_{51,ref}$ is the electrolytes concentrations in chloride equivalent (eq/l) at reference conditions. $K_{Ti,Sref}$ is the partitioning coeff. at reference salinity of $C_{51,ref}$ and TKS_i is a constant in $(eq/l)^{-1}$.

Hydrolysis of the tracers and in particularly of the esters, is also formulated by an exponential temperature depended model. The equation is:

$$Khi = Khi,ref * \exp\left(HKi\left(\frac{1}{T} - \frac{1}{Tref}\right)\right),$$

<div align="center">Equation 6</div>

for tracer i. where $K_{hi,ref}$ is the rate of tracer hydrolysis at T reference in K, and HK_i is a constant parameter in 1/K. $K_{hi,ref}$ (day^{-1}) is measured in experimentally using reservoir brine at specific temperature. It should be pointed out that the changes of concentrations of reactant /product are assumed having linear relationship with time: $\frac{\partial C10}{\partial t} = -Kh * C10$ and $\frac{\partial C11}{\partial t} = Kh * C11$, where C10, C11 reactant and product, respectively. Also the reaction of the ester is considered irreversible and first-order reaction.

Here, should be mentioned that the injection of the tracers is done using reservoir brine, so the partitioning coefficient that is used for calculations, is measured at the specific brine salinity of each reservoir. In case that different water is used from this of the reservoir, the salinity equation is solved. Furthermore, the salt effect discussed at previous section is taken into account by calculating the rate of the reaction in reservoir brine.

As the temperature effect is to be examined during the tracer test, the heat transfer from the overburden and under-burden rock, its density and its thermal capacity, are also taken into account in the calculation (UTCHEM Technical Document, 2000).

6. Temperature Effect

At the previous section all the formulas describing the temperature effect were presented. In order to understand better why temperature is so important for the single-well tracer test, a sensitivity analysis is done, using UTCHEM.

It is important to consider, for the temperature effect, the temperature gradient, in the reservoir, during the test. (Park, Deans, & Tezduyar, 1991), report how the position of the temperature gradient (front) and the tracer bank effect the reaction of the tracer and consequently the measurement of the S_{or}. If the temperature front is farther than the bank of the primary tracer, then during the reaction the product ethanol will move to the higher temperatures, as temperature has a positive effect on the reaction. At this case, the temperature effect is significant (Fig. 3). On the other hand, when the tracer bank has reached at region, where the initial reservoir temperature dominates (farther than the temperature front), the effect of temperature is minimum, because the reaction is conducted under isothermal conditions. (Fig. 4)
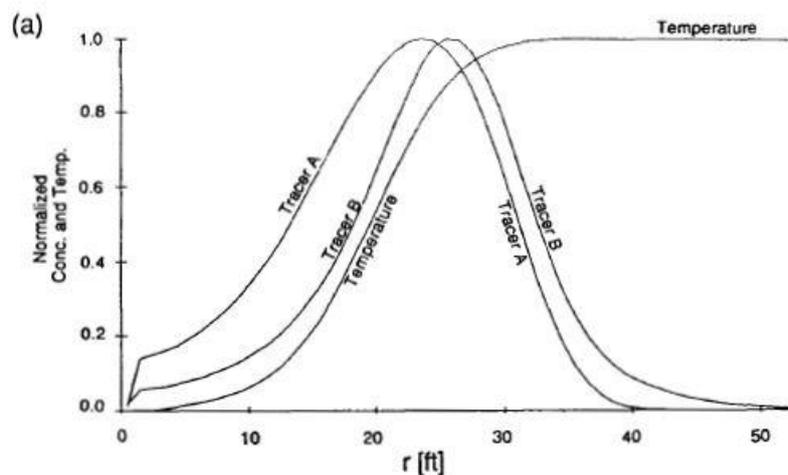

Figure 3 Temperature Effect. Tracer bank before temperature front.
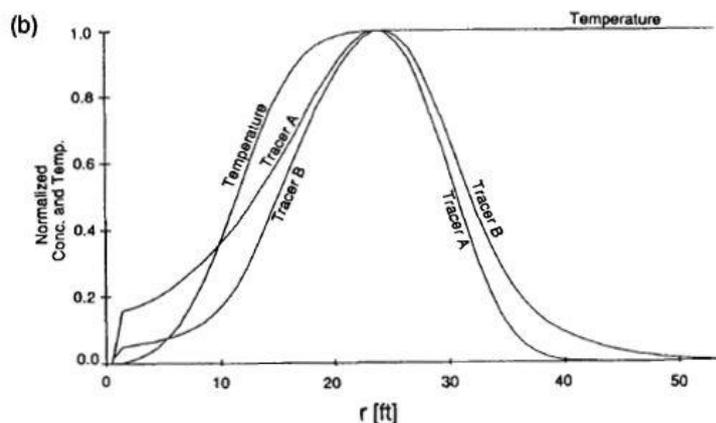
Figure 4 Temperature effect. Tracer bank after temperature front.

6.1 Domain description

The model uses radial coordinates, simulating that way the well and the area around it as specified by the user. The dimensions of this area is X=35 ft, Y=1 (default for radial coordinates), Y=20 ft. For X direction each cell has 1 ft length while for Z direction each cell has 5 ft height, resulting to a 4-layer reservoir. The well radius is at 0.25 ft.

About the tracers, three water tracers are used, IBA, a non-partitioning tracer, for material balance monitoring, Ethyl Acetate, as the main reacting tracer and as product of the reaction, the concentration of Ethanol is calculated. All concentration is measured in vol%. Simulation time and injection time are introduced in days, as also all output are written in days.

The initial reservoir properties are shown below:

Reservoir Prperties	
Depth (ft)	9135
Pressure (psia)	2000
Temperature (F)	194
Porosity	0.25
Permeability (X) (mD)	2000
Permeability (Z) (mD)	0

Table 1

Water Saturation	layer 1	layer 2	layer 3	layer 4
	0.75	0.715	0.805	0.82

Table 2

Tracers	Volume %
IBA	1435
ETAC	13160

Table 3

This model assumes four different injection/production wells, each for every layer. As long as, the permeability at Z direction is zero (0), then no hydraulic communication between the layers exists. So, **only one observation point is set at the first layer**, for the first modeled well.

The injection volume should be calculated, under specific constraints. The first injection water bank containing IBA and Ethyl Acetate, should reach at distance of 30ft and actually the center of this bank be positioned at this distance. This will be achieved injecting a second water bank to push the previous one. The mathematical formula for cylindrical volume calculation, adaptive to reservoir porous media is $V = \pi * r^2 * h * \Phi * Sw$. The relation of the two water banks is that the second is twice, in volume, the first bank (Table 5).

Total Injection Volume	
Sw	0.75
Φ	0.25
h (ft)	5
r (ft)	30
V	2649.375

Table 4 Values for Total Volume claculation

Tracer		**Volume (ft3)**
W	V1	2119.5
W+IBA+ETAC	V2	1059.75
Vtot	V1+V2	3179.25

Table 5 Final volumes injected

At the first table the injection volume for a radius of 30 ft is calculated. The summation of V1 and V2 is bigger and corresponds to a radius of 32ft. This happens because only half of V2 is in the 30ft radius.

6.2 Test procedure and Simulation Set-up

After the volume calculations, the injection and the production rate are chosen. These rates will define the simulation time. The V2 bank is firstly introduced and then the V1.

Generally, the injection and production rates are limited by the well design and resistance to pressure. Apart from that, the injection and production rate, what concerns the SWTT, may be the same. At this example, the injection rate is changed, while the production rate is kept constant.

A period of shut-in is then implemented. The ester reaction takes place and ethanol is produced. After this period is done the production commences and the concentration of the produced water in the tracers is regularly measured to establish the concentration profile. The final outcome is shown below (Fig 5).
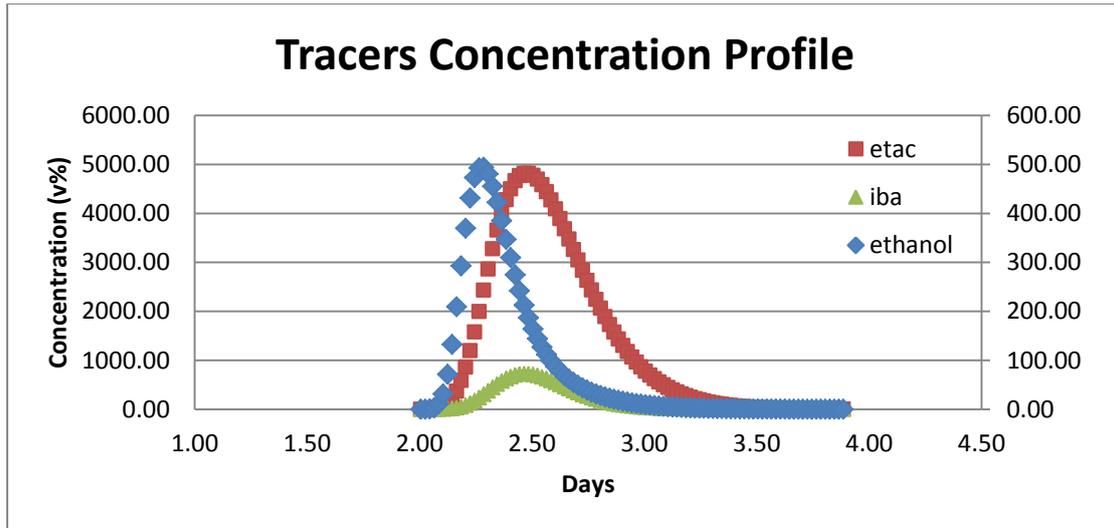
Figure 5 Typical tracer concentration profile after SWTT.

At the graph (fig 5), a standard tracer final profile is depicted. The time period starts when production commences and each tracer concentration is measured. The objective of the test is to find the peak concentration arrival time. So, it is clear that ethanol arrives first, while the other two tracers arrive together later.

The reference outcome of the test, which is used to controlling the analysis, is that product Ethanol should arrive first, as it moves with the speed of water during production, while Ethyl Acetate and IBA should arrive at the same time, after the Ethanol. EtAc arrives later due to its partitioning between the oil/water phases, so it delays. IBA is a non-partitioning tracer, so during injection will reach at bigger distance than the Et.Ac. In production stage, IBA travels with the same speed of water and EtAc with speed according to its partition coefficient.

However, EtAc is closer to the well and IBA is farther, they should arrive at the same time for the test to be valid. The relative difference in distance and velocity between the two tracers should not affect the final production profile. The velocities, due to the partitioning coefficient(s) and the relative distance are such, so the time that each tracer travels, in the reservoir, is the same.

UTCHEM has specific input options regarding the partitioning coefficient and the hydrolysis rate. Both partition coefficient, Kd and reaction rate, Kh are measured using reservoir brine and at reservoir temperature conditions. Under this scope, data form lab report is used. The Kd, Kh used are shown at the table below, and were measured at 86°C (186.6 °F). This temperature is introduced as T reference (TSTAND in UTCHEM). Beyond these, another two parameters are required for the proper solution of the tracer reaction. As shown below, TKT and TAKT are introduced. They are temperature depended, and were calculated by using literature data (Kh, Kd at different temperatures) in correlation with the equation of UTCHEM, described at previous section.

UTCHEM Input	Tracer options	
	Reservoir Brine Salinity (ppm)	2000
TK	Part. Coeff. Kd	3.3
TAK	Reac. Rate Kh (days^{-1})	0.0768
TKT	Part. Coeff. Kd (Temp. depended) (1/F)	0.0045
TAKT	Reac. Param. Coeff. (Temp. depended) (1/K)	-7988

Table 6 UTCHEM inputs for Tracers

6.3 Temperature Sensitivity Analysis

6.3.1 Temperature Effect without pre-flush

The sensitivity analysis is done at reservoir temperatures, 90°C, 100°C, 120°C,140°C and water temperatures 20°C, 60°C, 90°C, so as to examine the effect for different water temperature keeping the reservoir temperature as it is, and for examining the effect at high temperature reservoirs.

Temperature Comparisons			
Rate (ft^3/day)			
5000			
Tres (°C)			
90	100	120	140
Twater (°C) 20	20	20	20
60	60	60	60
90	90	90	90

Table 7

What concerns the rate changes, four different injection rate are implemented, 3000, 5000, 6000, 8000 ft^3/day, while the production rate is kept the same at 5000 ft^3/day. At all these cases, always the relative position of the temperature gradient and the tracer bank is depicted, in order to establish more accurately the total temperature effect.

Rate Comparison		
Rate (ft^3/day)		
3000		
Tres (°C)		
90	100	120
Twater (°C) 20	20	20
60	60	60
90	90	90
Rate (ft^3/day)		
6000		

	Tres (°C)		
	90	100	120
Twater (°C)	20	20	20
	60	60	-
	90	90	90

Rate (ft³/day)		
8000		

	Tres (°C)		
	90	100	120
Twater (°C)	20	20	20
	60	60	-
	90	90	90

Table 8

For the three reservoir temperature cases 90°C, 100°C, 120°C, the outcome of the simulator is correct, concerning the arrival of the tracers, at observation point; the product ethanol comes first, while the ethyl acetate and the IBA come together later. This does not happen for temperatures of 140°C and above (fig 8). Various water temperatures were simulated, but none of them had any other effect.

As it is shown at the comparative diagrams below, the effect of the different water temperature is negligible for all cases. However, it can be noticed that while the IBA tracer arrives at the same time and height position, the other two tracer pairs are shifted up, for the high temperature water values. This, perhaps, cannot be attributed to temperature effect.

In fig. 7 the comparison of different reservoir temperatures is done. The higher it is the more the produced ethanol, as expected.

The water temperature comparison for reservoir temperature 100°C (212 °F) and injection rate 5000 ft³/day is shown below (fig.6):
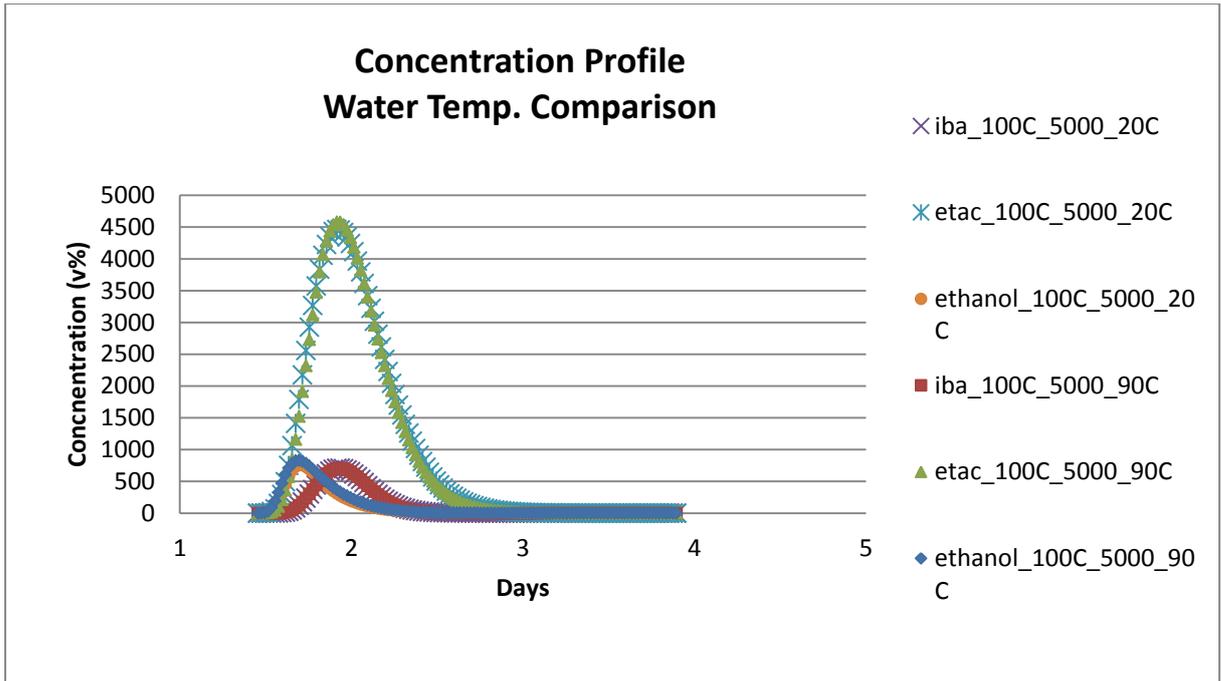
Figure 6 Water Temperature Comparison

	IBA			Et. Acetate			Ethanol		
T water (°C)	Days	Pore Volume	Conc.	Days	Pore Volume	Conc.	Days	Pore Volume	Conc.
20	1.94	0.595	708.1	1.91	0.585	4461.8	1.695	0.478	759.46
90	1.94	0.595	708.1	1.91	0.585	4581.2	1.695	0.478	830.62

Table 9 Arrival times and concentrations for tracers in Fig.6
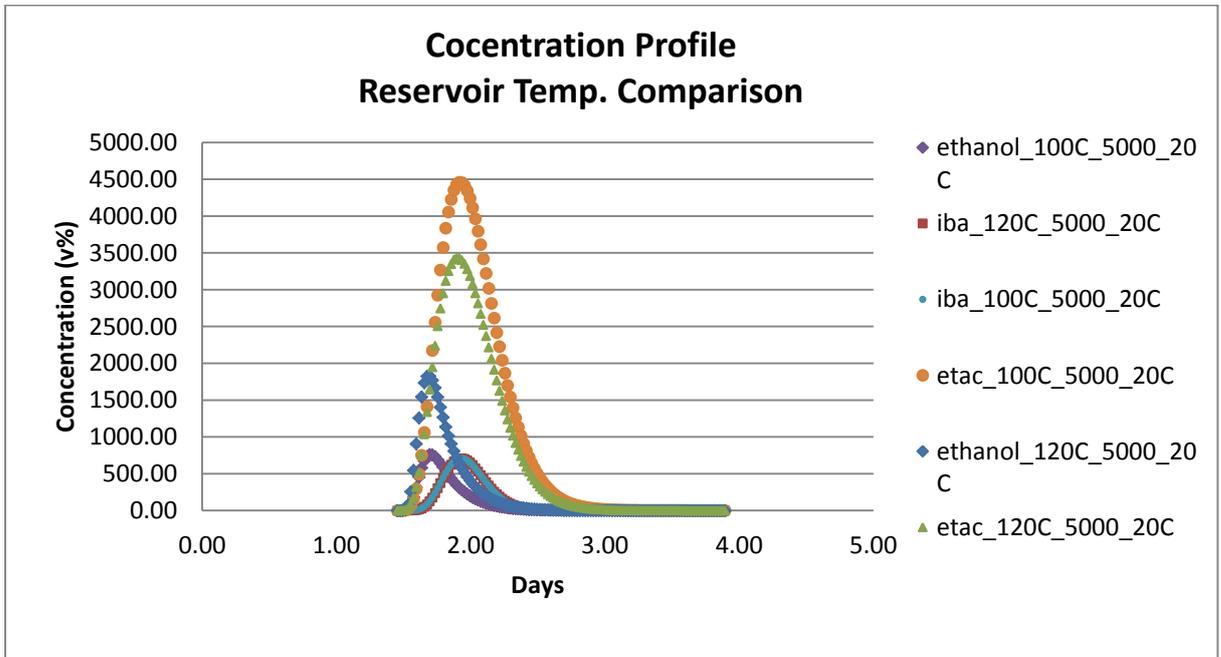
Figure 7 ReservoirTemperature Comparison
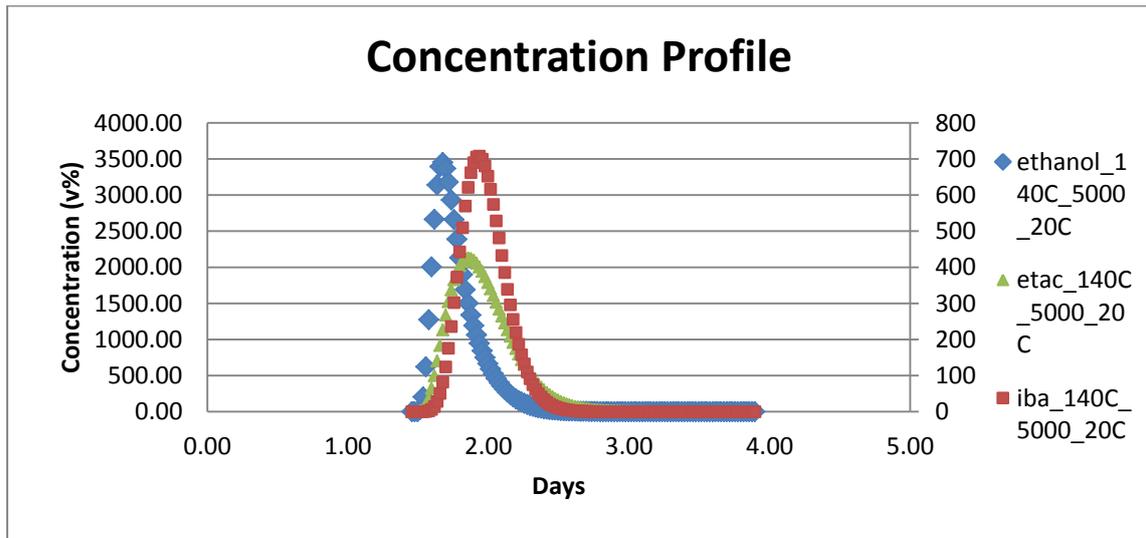
Figure 8 Concetration profile for 140°C reservoir temperature

Furthermore, as mentioned before, the temperature gradient is examined, too. When the injection period is finished, the temperature front takes its final position in the reservoir. Then, when the reaction progresses the analogous effect will occur, as described previously. At this example, for all cases, the tracer bank is inside the temperature front (Fig. 9 & 10), where the temperature effect is very little. This fact may be the reason for no or little variation of product ethanol, for the same reservoir temperature at different water temperatures.
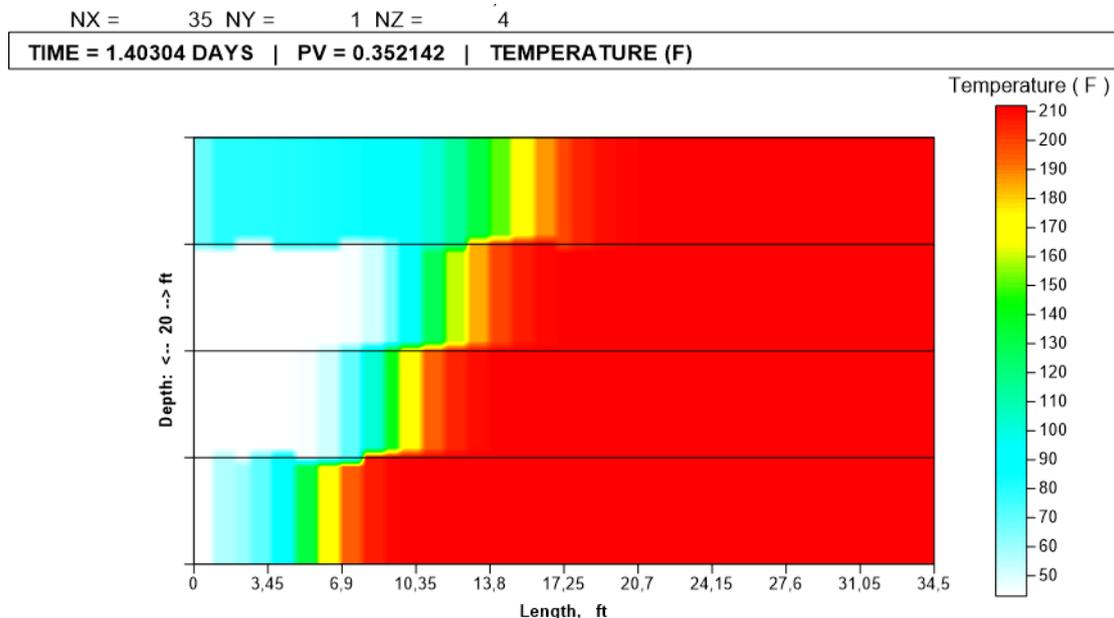
Figure 9 Temperature front for Tres=212°F and Twater=68°F
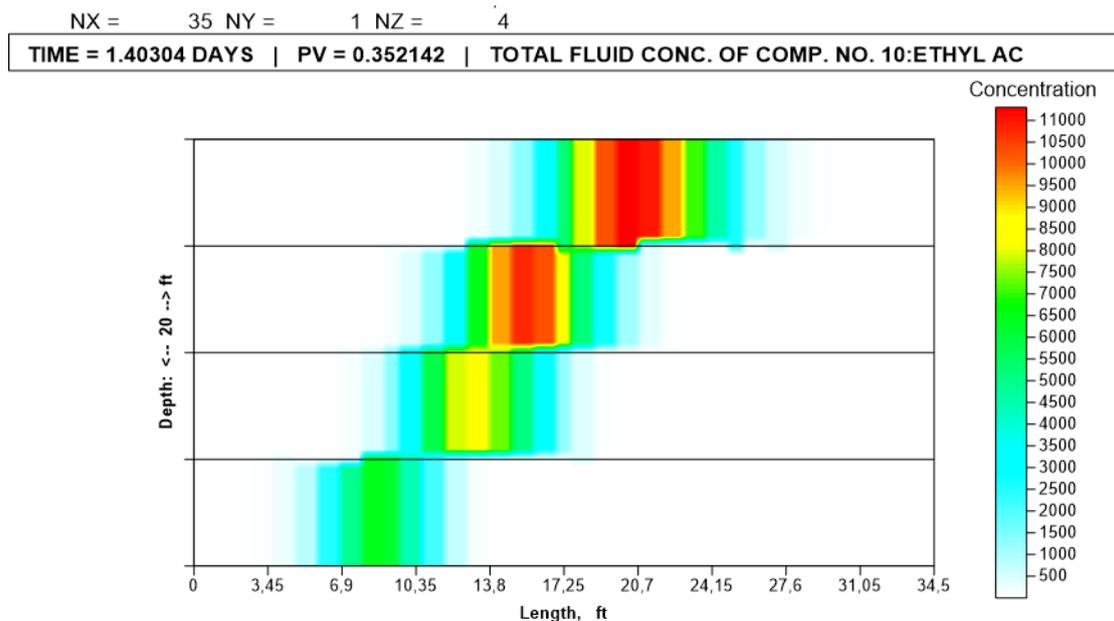
Figure 10 Ethyl Acetate position after the shut in period

Of course, the temperature gradient is different, for water temperatures of 60°C or 90°C. The temperature decreases less in the reservoir for higher water temperatures, so the temperature front is even closer to the well. However, the position of the ethyl acetate is always the same, for any temperature and any injection rate.

The different injection rates do not seem to have any effect on the temperature front.

A basic assumption for the tracer test is that the reaction of the tracer happens only during the shut-in period. In reality, there is reaction during injection phase, too. At low injection rates, this phenomenon is more intense, given that the injection period is longer in time, so more tracer will react during this period and more ethanol will be produced at the end. Actually, when this takes place, is not considered an accurate test, and the final oil saturation measurement is inaccurate, too. The minimum is the reaction during injection, the better estimation of the $S_{or.}$
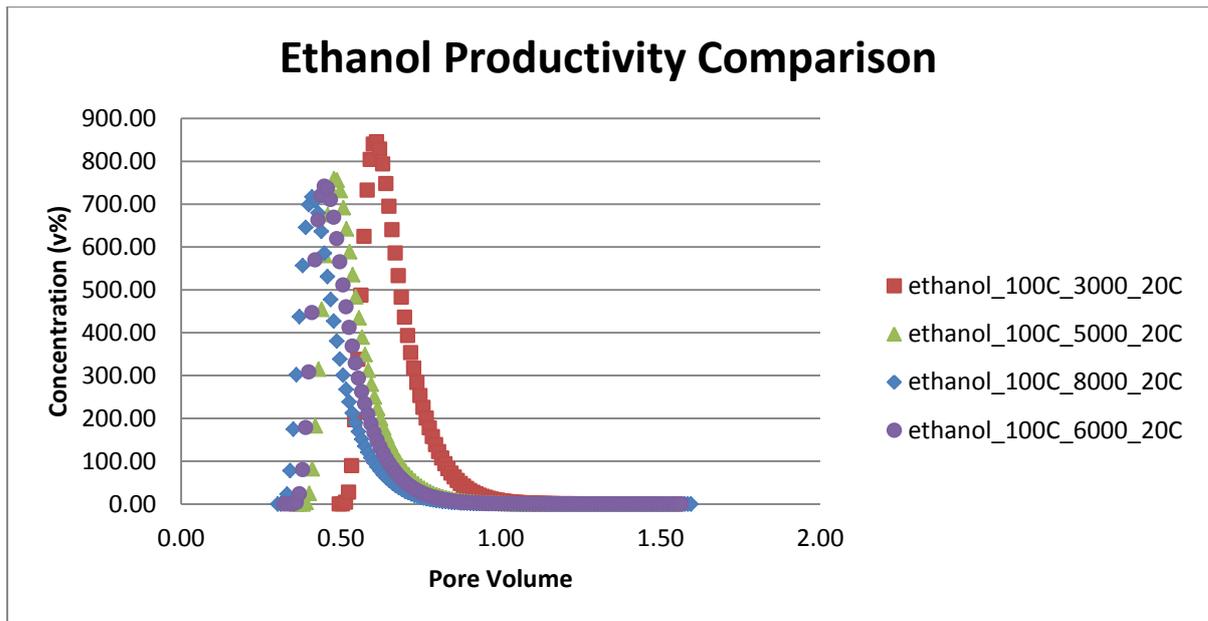
Figure 11. Injection Rate Comparison- Tres:100C_Injection Rate_Tw:20C

As it shown above (Fig. 11), the injection rate has an effect on the ethanol produced. The slower is the injection, the more is the ethanol. This phenomenon should be attributed to the extensive reaction of the ester prior to the shut-in period. At low injection rates, there is enough time for the main tracer to react something that is un-preferable for the correct Sor estimation.

6.3.2 Temperature Effect with pre-flush

The previous paragraphs describe a tracer test, when the tracer bank is in the region of little temperature effect, in respect with the temperature front.

For analyzing the other case, where the tracer bank is behind the temperature gradient, a pre-flush injection period can be implemented, so to cool the reservoir and then apply the main test.

The purpose of water injection before the main test is to move the temperature front beyond the region, where the main reaction of the ester takes place. The temperature of this water bank is chosen to be 20°C (68° F). The volume of the bank is calculated by trying different radius values to the volume equation of cylinder. Finally, a volume of 2649 ft^3 is injection at a ratio of 5000 ft^3/day.

Tracer		Volume (ft³)
W	V1	2119.5
W+IBA+EtAc	V2	1059.75
Water (pre-flush)	V3	2649

Table 10 Injected Volumes V3->V2->V1.

In order not to affect the previous geometry of the test and the final position of each bank, the pre-flush volume and accordingly, the injection time is just added and not included to the previous time calculations.

The final displacement of the temperature front is 6-7 feet, which is enough to pass the area of the reaction. The EtAc tracer is positioned again at ~22 ft away from the well, and the temperature front is almost at 24ft (fig. 12 & 13). These distances are not sharply distinguished because the concentrations are distributed in a narrow area and temperature gradient, too. What is definite is that the reaction takes places in temperatures below the reservoir temperature. The effect is that the product alcohol is shifted during the reaction a higher temperatures (fig. 14), as it is described previously.
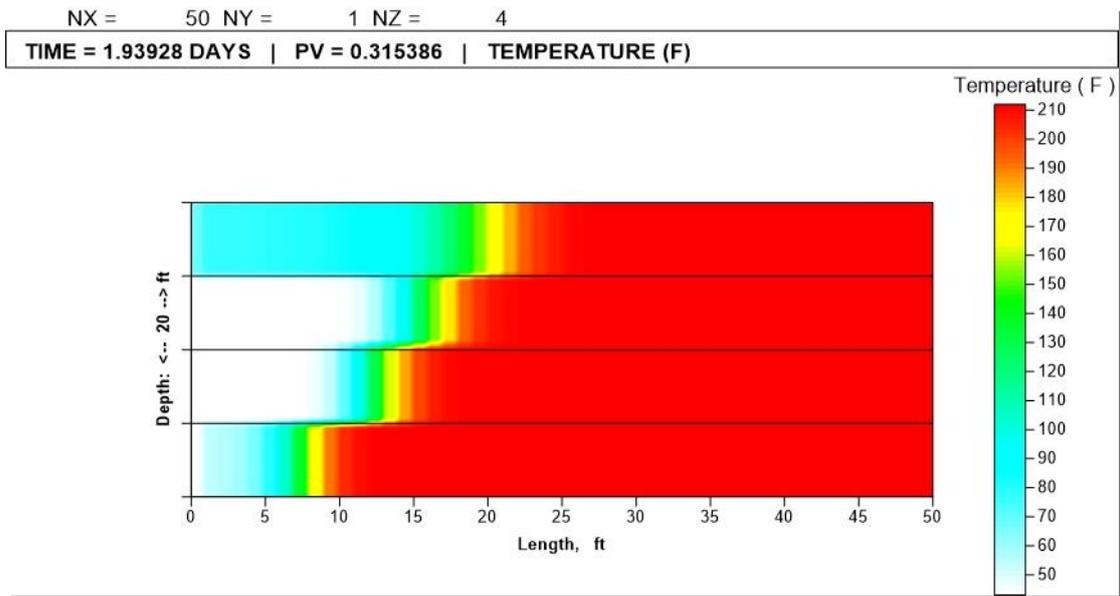
Figure 12 Temperature front after pre-flush, tracer and push bank are injected
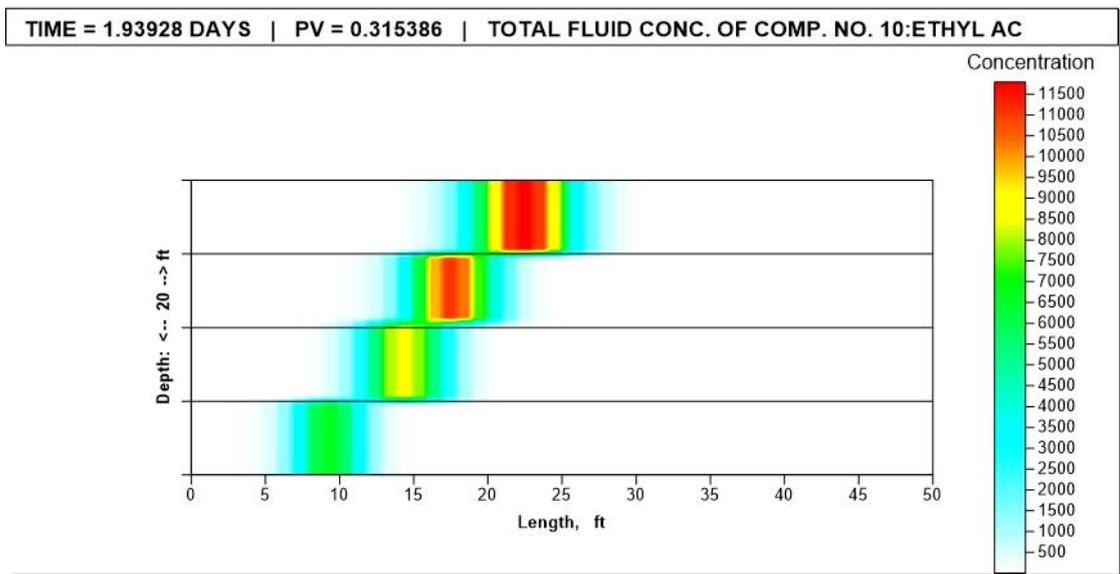
Figure 13 Ethyl Acetate position during shut in period

TIME = 1.93928 DAYS | PV = 0.315386 | TOTAL FLUID CONC. OF COMP. NO. 11:ETHANOL
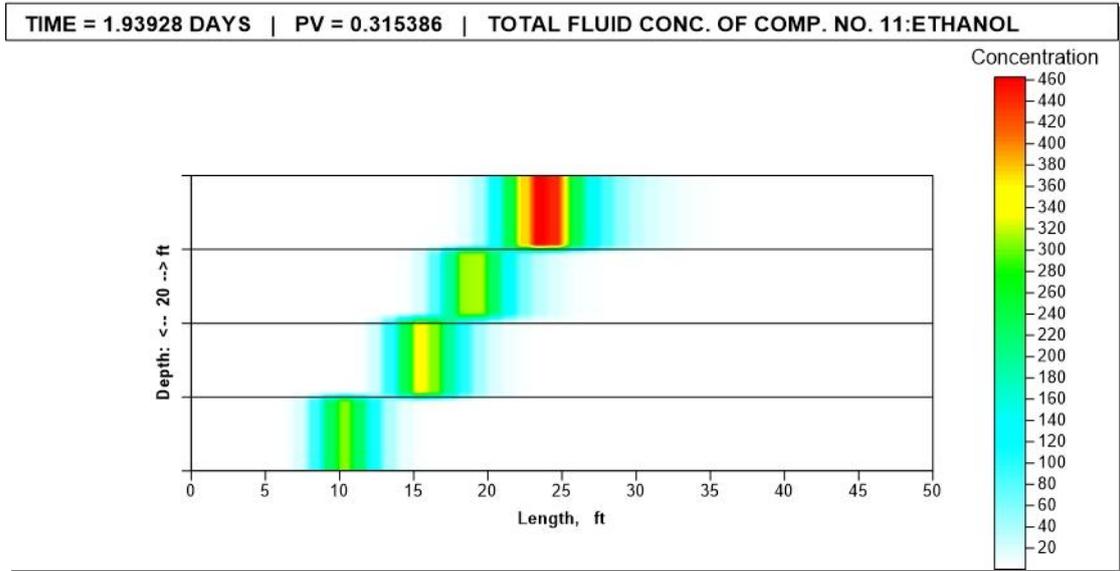
Figure 14 Ethanol position at the end of shut in period

A similar sensitivity analysis is done to examine this type of temperature effect. For reservoir temperature of 90°, 100°, 120° and 140° C, a standard pre-flush bank is implemented at water temperature 20° C, and then water containing the tracers, had 20°, 60° C. For the reservoir temperature of 100°C, 90° C of injection water is also applied for better results comparison. Two different injection rates are applied, only for the tracer banks; 5000ft^3/day and 8000 ft^3/day (Table 11).

PREFLUSH				
Pre-flush Rate (ft^3/day)	5000	T water (°C)		20
Rate (ft^3/day)				
5000				
		Tres		
	90	100	120	140
Twater	20	20	20	20
	60	60	60	
		90		
Rate (ft^3/day)				
8000				
		Tres		
	90	100	120	140
Twater	60	60	60	60

Table 11

For the same reservoir temperature and different water temperature, more ethanol, in terms of concentration, is produced for 20°C and is decreased for higher temperatures of water (fig. 15)
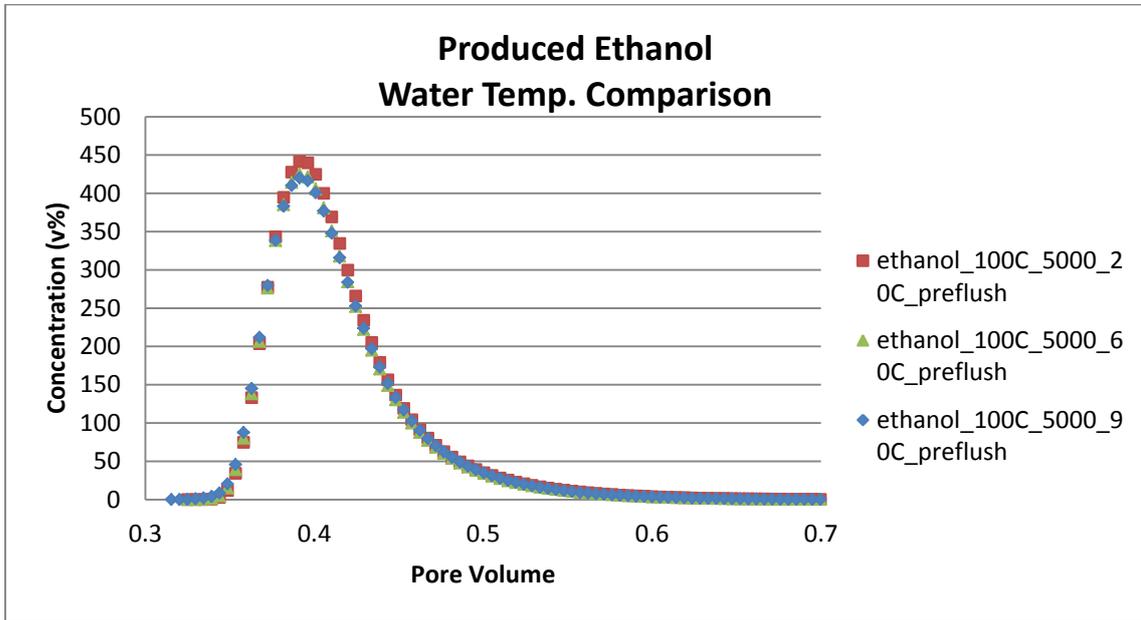
Figure 15 Water Temperature Comparison for Ethanol Production

.
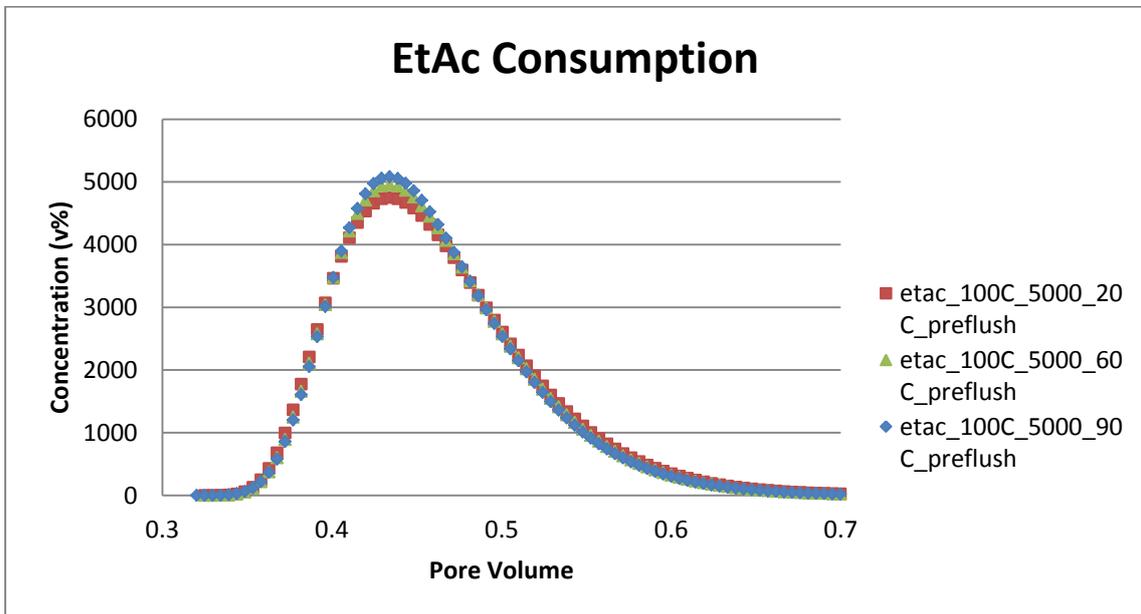
Figure 16 Water Temperature Comparison for EtAc consumption

The opposite effect happens to EtAc's concentration as less is reacted (fig.16)

For different reservoir temperatures, more ethanol is produced at higher reservoir temperatures (fig. 17)
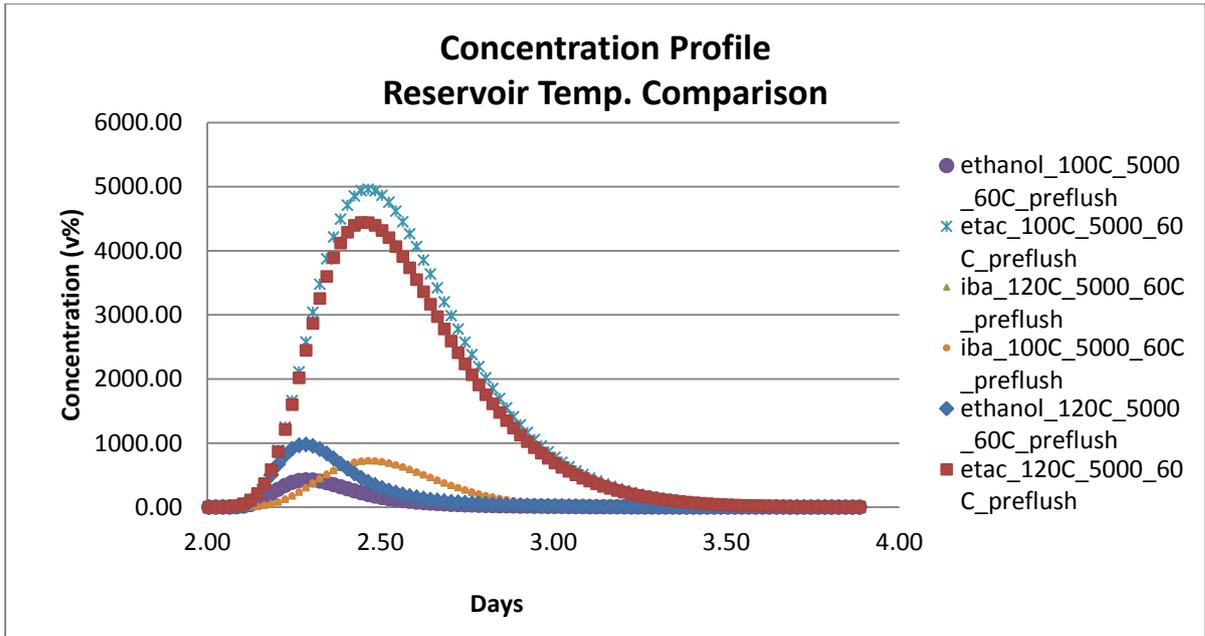
Figure 17 Reservoir Temperature Comparison for consumed/produced ethyl acetate/ethanol, respectively
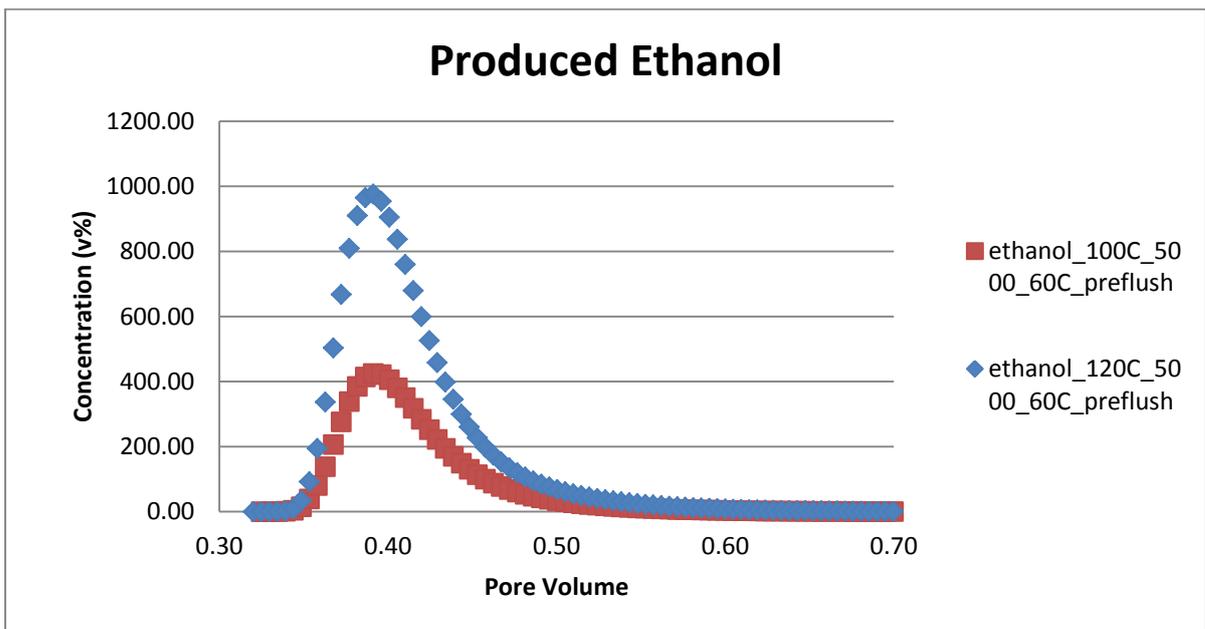
Figure 18 Ethanol Production for different reservoir temperatures

For different injection rates more ethanol is produced at low injection rate, both in terms of pore volume and concentration, (Fig. 19)
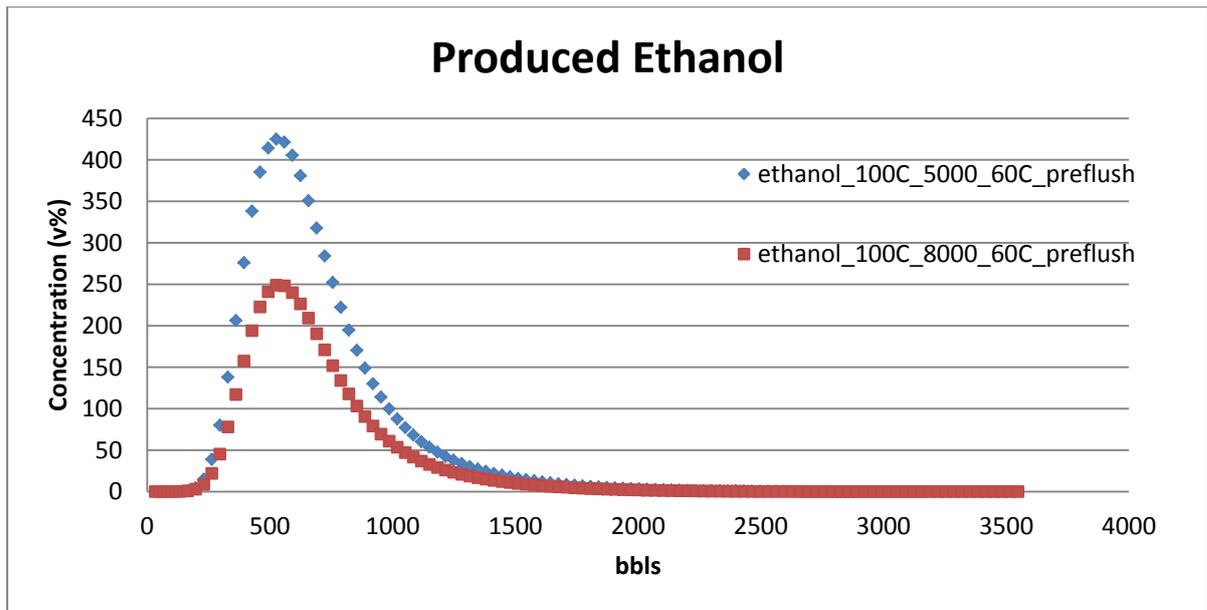
Figure 19 Ethanol production for different injection rates

Again this can be attributed to ester reaction during injection period.

Regarding the reservoir temperature of 140°C, at the previous case, the results were not considered valid, so it is rejected as unsuccessful test. It is thought that by injecting water and precooling the reservoir, the outcome would change. For this purpose two pre-flush water temperatures are tried; at first, one at 20°C (fig.20), the same with the other reservoir temperatures and one at 6°C (fig. 21). The concentration profiles are better for 20°C but they are more improved for 6°C.

PREFLUSH			
Pre-fush Rate (ft3/day)	5000	T water (°C)	6
Rate (ft3/day)			
5000			
Tres			
140			
T water	20	60	

Table 12
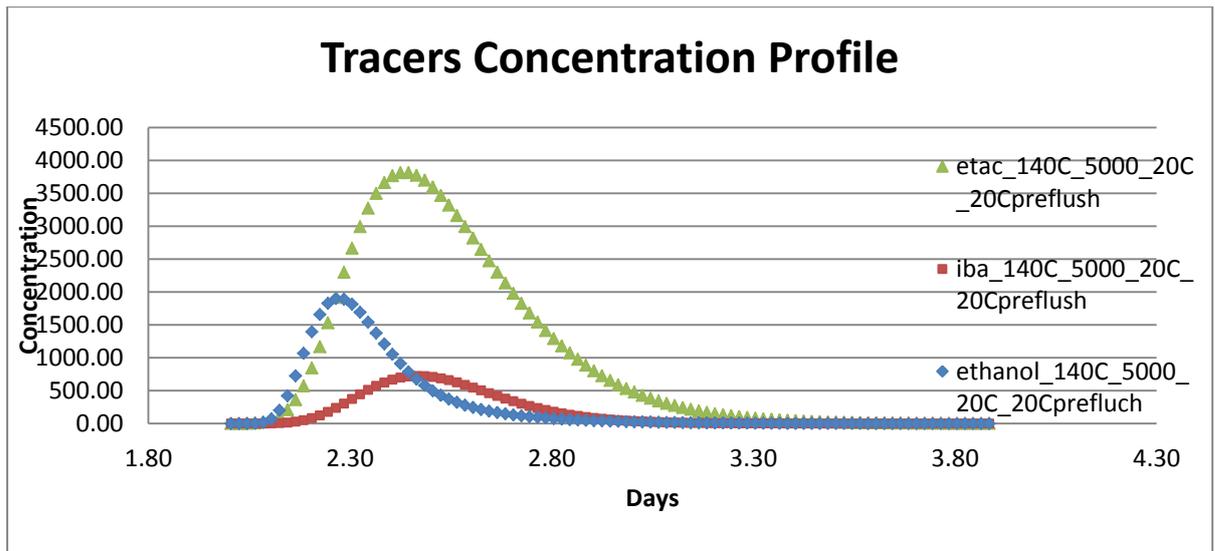
Figure 20 Concentration Profile for Tres=140°C and Twater=20°C
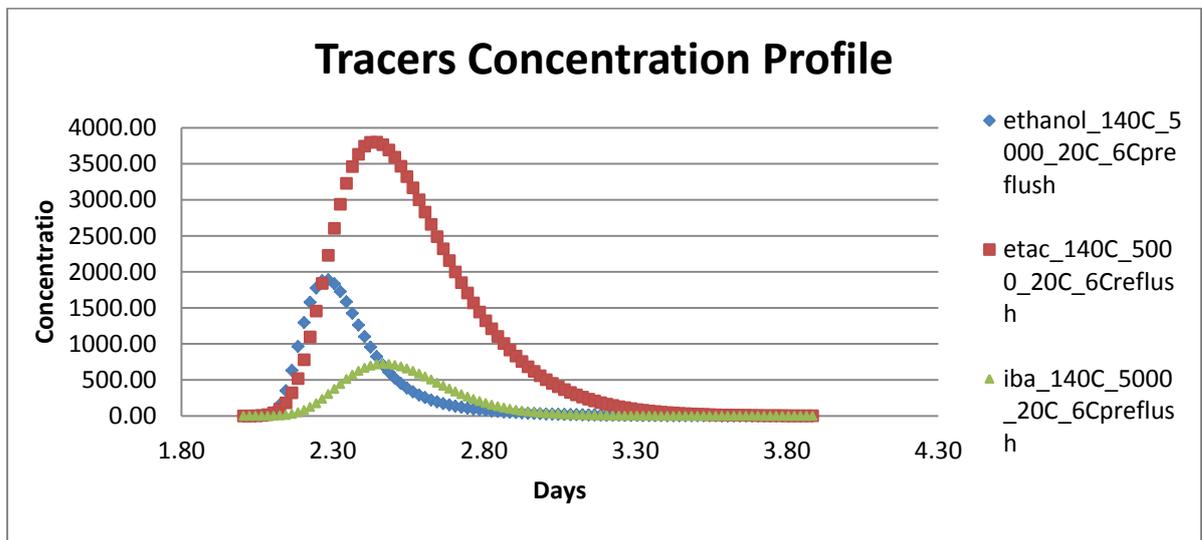
Figure 21 Concentration profile for Tres=140°C and Twater=6°C

Tres (°C)	140								
	IBA			EtAc			Ethanol		
Tw (°C)	Days	Pore Volume	Concen.	Days	Pore Volume	Concen.	Days	Pore Volume	Concen.
6	2.465	0.434	723.26	2.445	0.429	3801.5	2.285	0.391	1890.3
20	2.465	0.434	723.26	2.425	0.424	3812.9	2.265	0.386	1900.3

Table 13 Comaprison on the arrival times of the tracers, for different Twater, at Tres=140 °C

From the table 13 can be seen that IBA arrives at the same time, while for the EtAc tracer there is a difference. For 6°C water temperature the difference between the arrival time of IBA ant EtAc is smallest than that of the second case. So, for this high reservoir temperature, a water bank could be used, prior the main test.

6.4 Temperature Effect Comparison

Comparing the results of the two cases; one, the reaction takes plays in front of the temperature front , affected more by the high reservoir temperature and two, the reaction takes plays behind the temperature front, in cooler region due to the pre-flush water bank, more ethanol in term of concentration is produced at the first case. However, as it is shown below (fig.22), the highest concentration of the second case corresponds to higher amount of produced water, as an effect of its farther place just after the end of the reaction. In the first case, when no pre-flush exists, the S_{or} estimation will be higher in percentage than that of the second case, as the difference in the arrival time is higher.
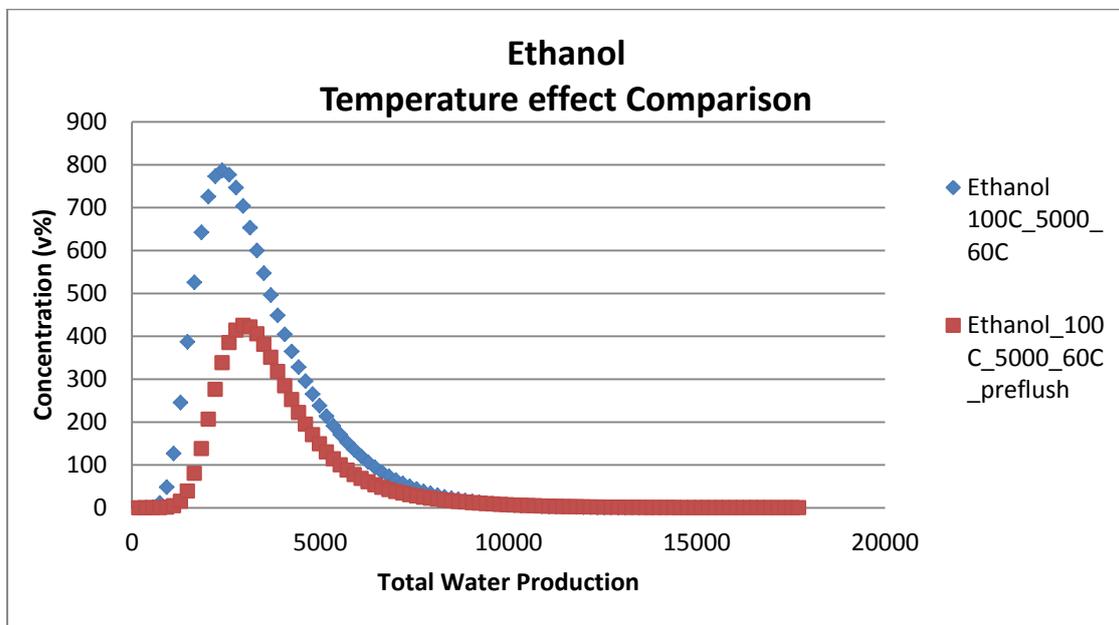

Figure 22 Temperature effect Comparison using produced Ethanol

7. History Matching

7.1 Reservoir description and History data

At this section a real SWTT case will be presented. Data from a reservoir in Southern America, are acquired in order to simulate the SWTT conducted and obtain the value of the S_{or}.

The main reservoir properties are collected below:

Reservoir Properties	
Lithology	Sandstone
Pressure, Psia	1813
Gross Thickness, ft	4.24
Average Porosity	0.29
Reservoir Temperature, °C	86
Initial Sw for simulation	0.78
Water Salinity, ppm	2000

Table 14

The volumes, injection and production rates are shown below:

	bbls	ft^3/d
TRACERS VOLUME	96.56	542.0878
PUSH VOLUME	409	2296.126
Vtot	505.56	2838.214

	bbls/d	ft^3/d
Injection rate	496	2784.544
Production rate	1610	9000

Table 15

The concentrations of the tracers are, for IPA equal to 7060 ppm and for Et.Ac equal to 14020 ppm, which is the reacting tracer. In addition, the investigation depth is 30 feet around the wellbore.

The tracers' concentration profiles from this test describe the S_{or} after an ASP flooding.
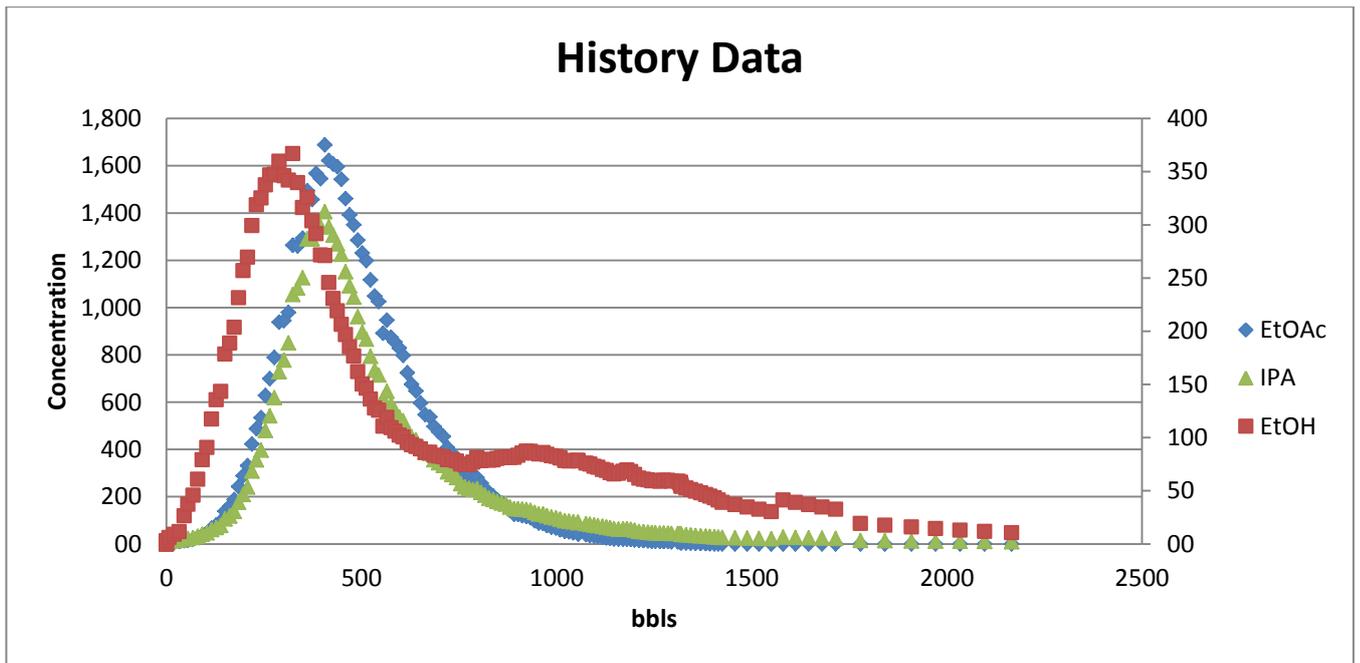
Figure 23 Tracers Concentration Profile – History data

As can be seen (fig.23), the IPA and EtOAc have a good peak overlap in arrival time, while the ethanol arrives much earlier, indicating a fair value for residual oil saturation.

Ethanol profile seems to have a second concentration peak at a later production time, which cannot be attribute to a peak at EtOAc profile, as it should have been. This will be tried to be explained at the end.

7.2 Simulation

From lab reports, the K_d of the reacting tracer and the K_h of the reaction are taken and introduced to the simulation model. As mentioned before, the UTCHEM requires two more inputs, for solving the equation of K_d and K_h, associated to the temperature. These values are obtained, correlating measured data for K_d and K_h in different temperatures, with the expressions the UTCHEM uses for each parameter. So the values are:

UTCHEM Input	Tracer options	
	Reservoir Brine Salinity (ppm)	2000
TK	Part. Coeff. Kd	3.3
TAK	Reac. Rate Kh (days^{-1})	0.6192
TKT	Part. Coeff. Kd (Temp. depended) (1/F)	0.0045
TAKT	Reac. Param. Coeff. (Temp. depeneded) (1/K)	-124

Table 16 UTCHEM Inputs for history matching

Taking into account the production history data and the above input values, the simulation is set.

At first, it is decided to separate the investigation interval of 4.24 ft in three equal layers in terms of thickness, and also separate equally the injection volume. The initial S_w is set to 0.78 (S_{or}=0.22). The main parameters that are regulated are the product of porosity and thickness, $\varphi*h$, the initial S_w, and the volume injected in every layer. In this case the porosity φ is kept constant and only the layer thickness is changed, and also the initial S_w. In some cases the average production rate is changed than that reported above.

Each parameter, affect the final position of each tracer, taken that the volumes are not changed. The increase of thickness would affect the closer to the well final position of the tracers and vice versa, while the Sw will affect only the EtAc tracer, as it is partitioning. For high values of Sw, less oil exists and the retardation is less for the EtAc; so, it travels in longer distance in the reservoir. On the other hand, low Sw, means more residual oil in the pores, so the EtAc travels to shorter distance in the reservoir. The ethanol position is mainly linked by the position of the EtAc, without being affected by the Sw. Regarding the production rate regulation, it affects the tail of the profile, and in some case it is adjusted for a better match.

Another parameter that affects the profiles and mostly the ethanol profile is the temperature front. The affecting way is described in detail in previous section. Nevertheless, two ways of simulation the production history are applied; one with direct injection of the tracers and the push volume and a second with a pre-flush volume of water in order to move the temperature at higher horizontal depth.

7.2.1 Three-layer simulation without pre-flush

At this simulation, the tracers are injected directly to the reservoir. The volume is separated into three equal parts, each for every layer. The injection and production rate are the same with the history rates. Each layer is simulated, with a different well. So, three wells exist in the model, and each has one observation point for concentration measurements.

Layers	Thickness	Sw
1	1.413	0.78
2	1.413	0.78
3	1.413	0.78

Table 17 Initial thickness and Sw values

Tracer	Volume (ft^3)	Layers	FT^3
IPA/EtAc	542.0878	1	180.6959
		2	180.6959
		3	180.6959
Water	2296.126	1	765.3753
		2	765.3753
		3	765.3753
Production	12159.45	1	4053.151
		2	4053.151

	3	4053.151

Table 18 Initial injection/production volumes per layer

	Ft³/d
Injection rate	2784.544
Production rate	9000

Table 19

For the comparison of the results between the history and the simulation, the concentrations from every observation point are added for every production time interval. The final tracer concentration is plotted against cumulative water production, and then is compared to the history tracer profile. For less calculation time, the concentrations of the tracers are introduced as unity, not the real ones. This does not cause any problem for the matching as the relative position of the profiles is compared.

Many changes were performed till the final match. Only the first and the last will be presented.

No. Trials	Changed Parameter		Layer 1	Layer 2	Layer 3	Produc. Rate (ft3/day)
1	-	-				9000
2	Thickness		2	1.12	1.12	9000
3	Sw		0.78	0.75	0.75	9000
4	Sw		0.78	0.74	0.7	9000
5	Sw		0.78	0.74	0.82	9000
6	Sw		0.78	0.74	0.84	9000
7	Sw		0.78	0.74	0.86	9000
8/FINAL	Sw	Produc. Rate	0.78	0.74	0.87	8000
9	-	2 stages Prod. Rate				7000/6500

Table 20 Changes applied through history matching

7.2.1.1 Initial Conditions
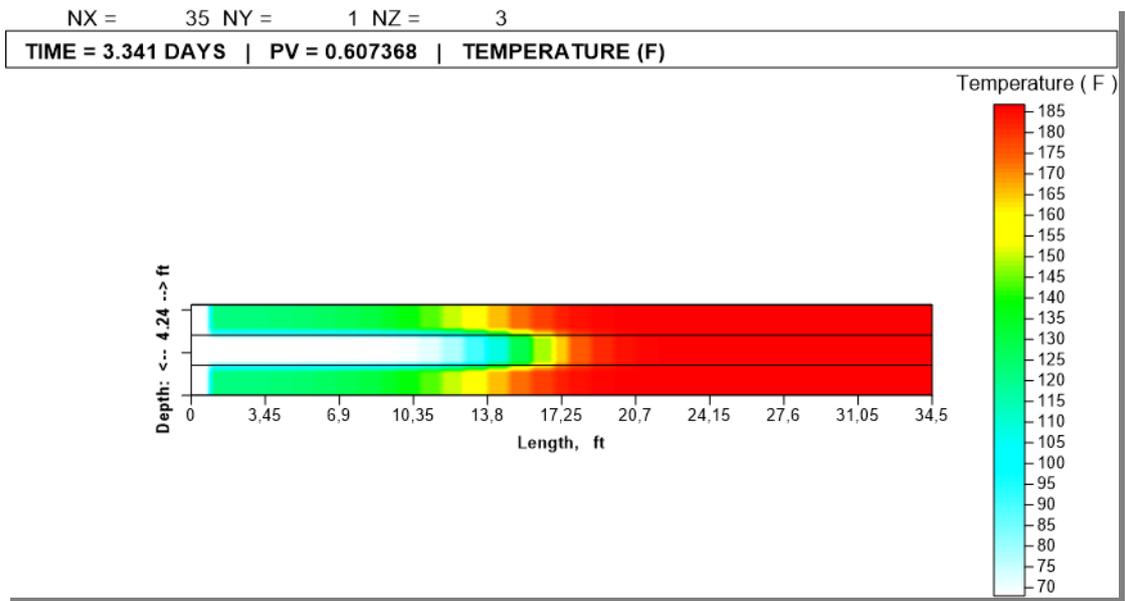
**Figure 24 Temperature front at the end of shut-in period**
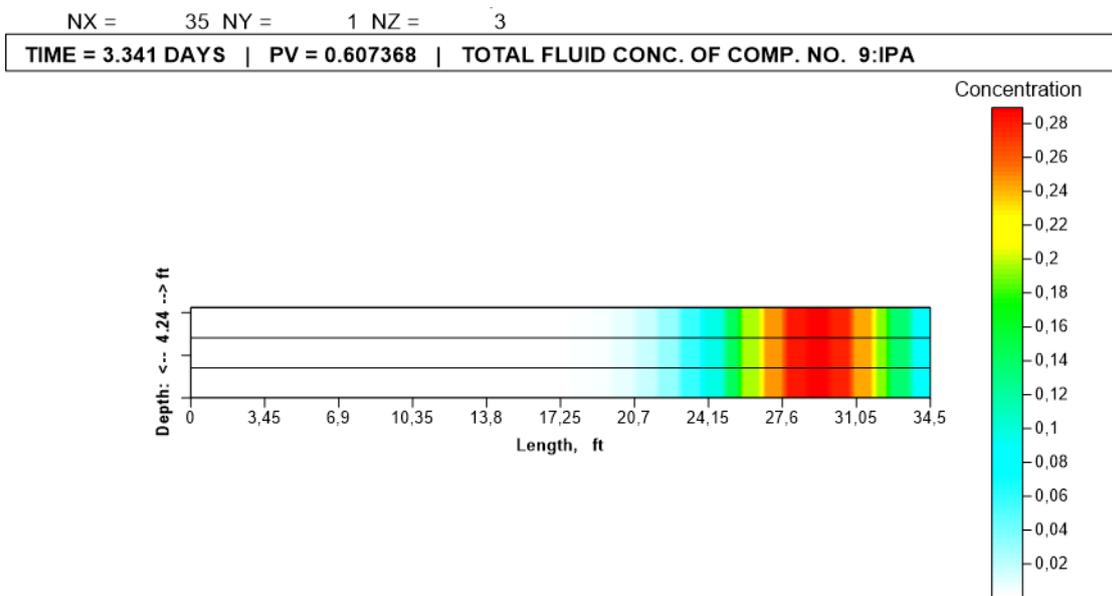
Figure 25 IPA's position just before production

TIME = 3.341 DAYS | PV = 0.607368 | TOTAL FLUID CONC. OF COMP. NO. 10:ETHYL AC
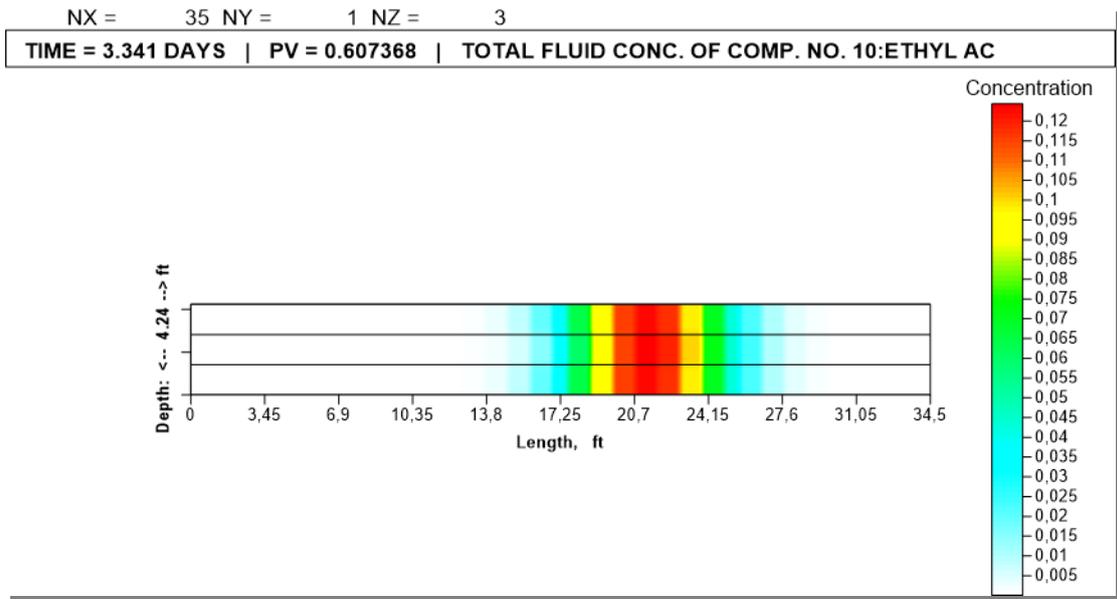
Figure 26 Ethyl Acetate' s position just before production

TIME = 3.341 DAYS | PV = 0.607368 | TOTAL FLUID CONC. OF COMP. NO. 11:ETHANOL
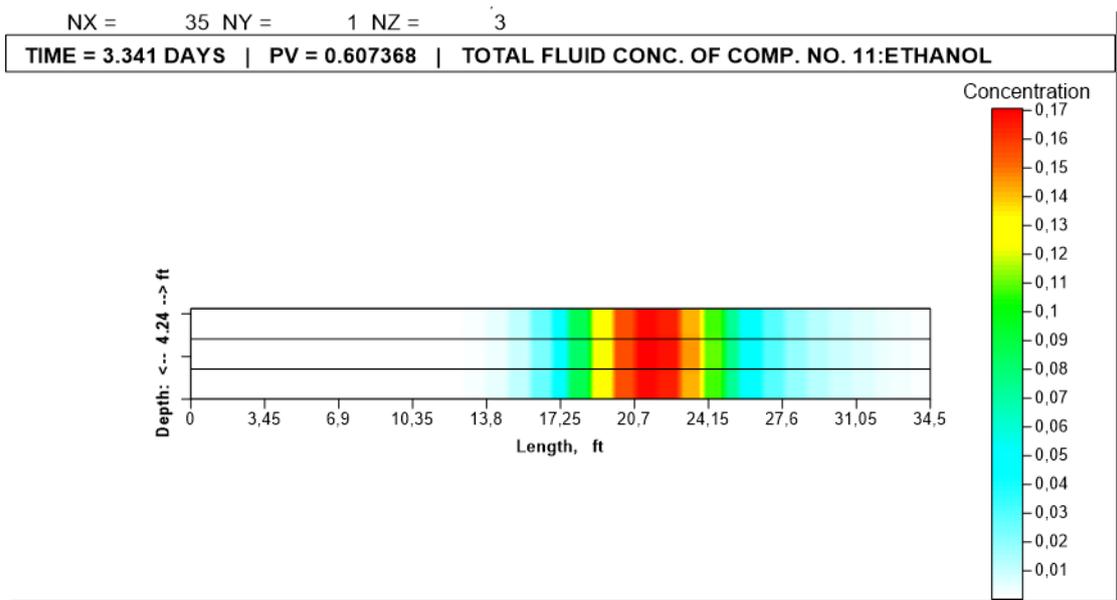
**Figure 27 Ethanol produced during shut-in.**
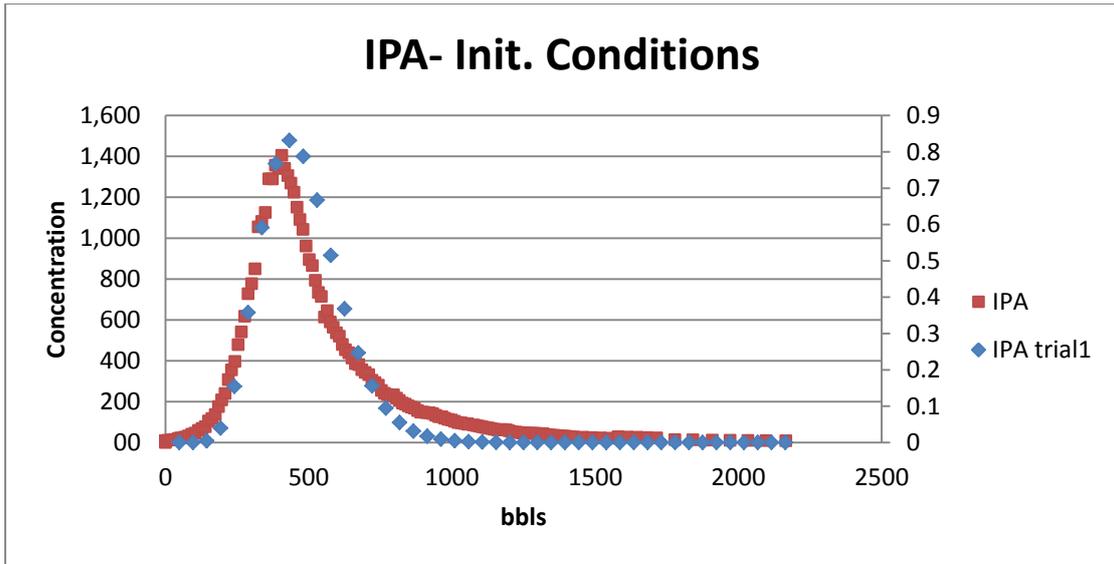
Figure 28 IPA comparison Trial 1 (blue) -History data (red)
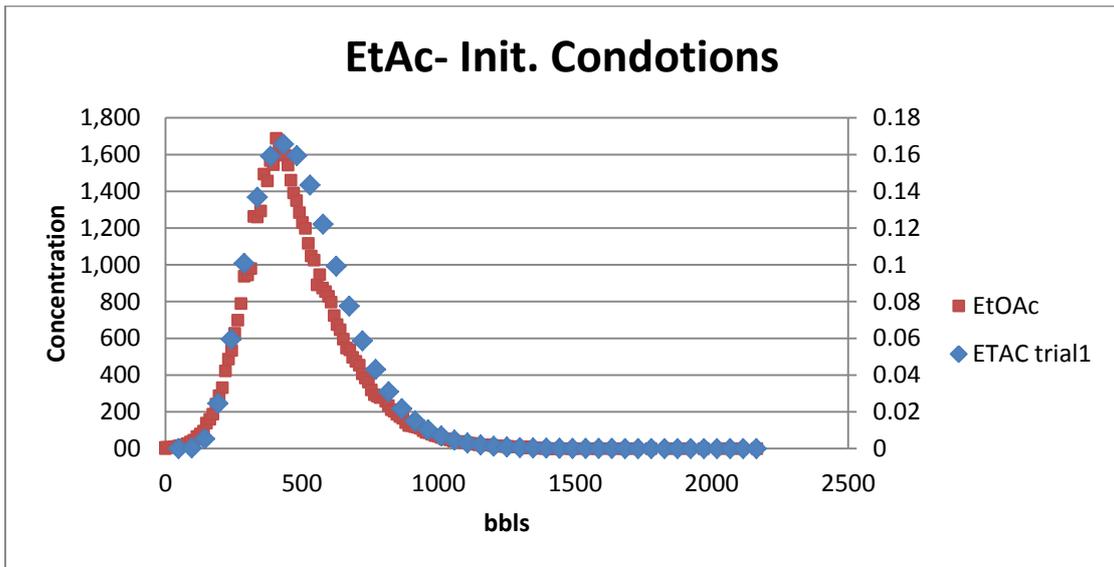
Figure 29 EtAc profile- Trial1 (blue) -History data (red)
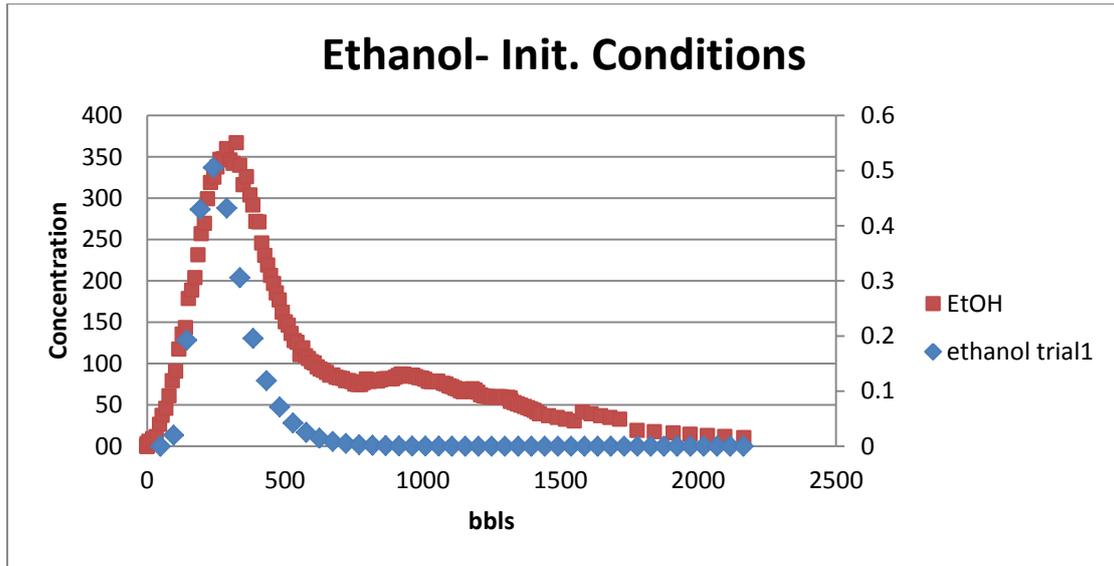
Figure 30 Ethanol profile- Trial (blue) –History data (red)

On the three figures above (28, 29, 30), each concentration profile is compared to the respect history profile. For tracer IPA, the simulation gives a delayed arrival on the peak concentration as also for tracer EtAc. So, both profiles should arrive earlier. On the other hand, the ethanol peak concentration is appeared earlier than that of the history data. In other words, the final position in X- direction for IPA and EtAc should be that far away from the wellbore, and the opposite for ethanol.

7.2.1.2 Final Results
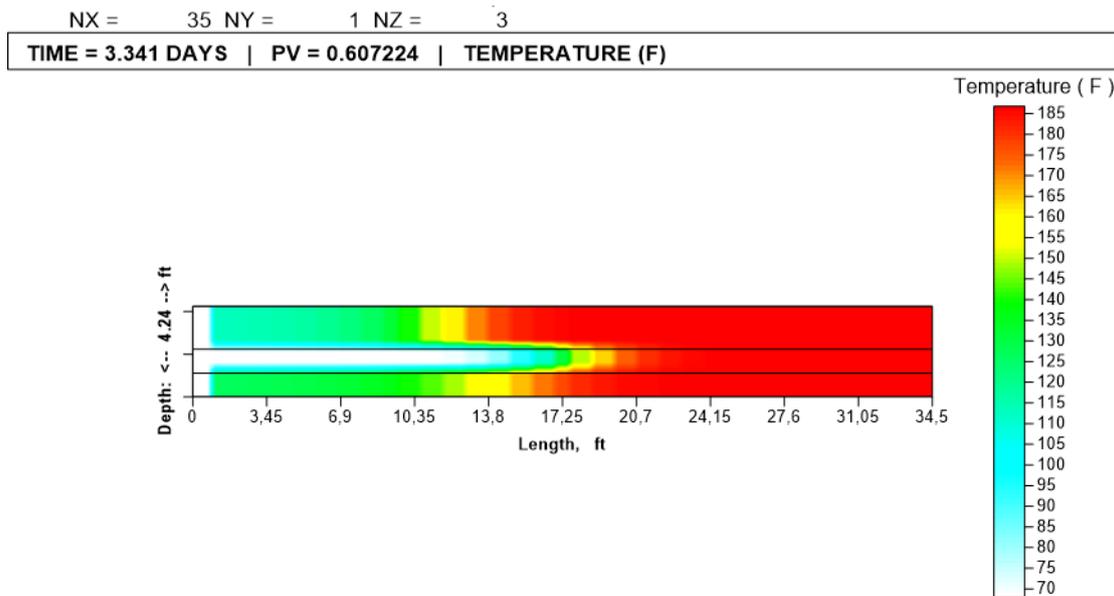
Figure 31 Temperature front after history matching

First parameter that was changed is the thickness. At the first layer the thickness is increased to 2 ft, while the other two layers shares equally the rest thickness, 1.12 ft each.

By this way IPA has a better match with the history data. The thickness and the volume injected in a layer are the only parameters that can affect the IPA profile, as it is not a partitioning tracer and distributes only in the water phase. As long as, the volume is not changed, only the thickness is regulated.
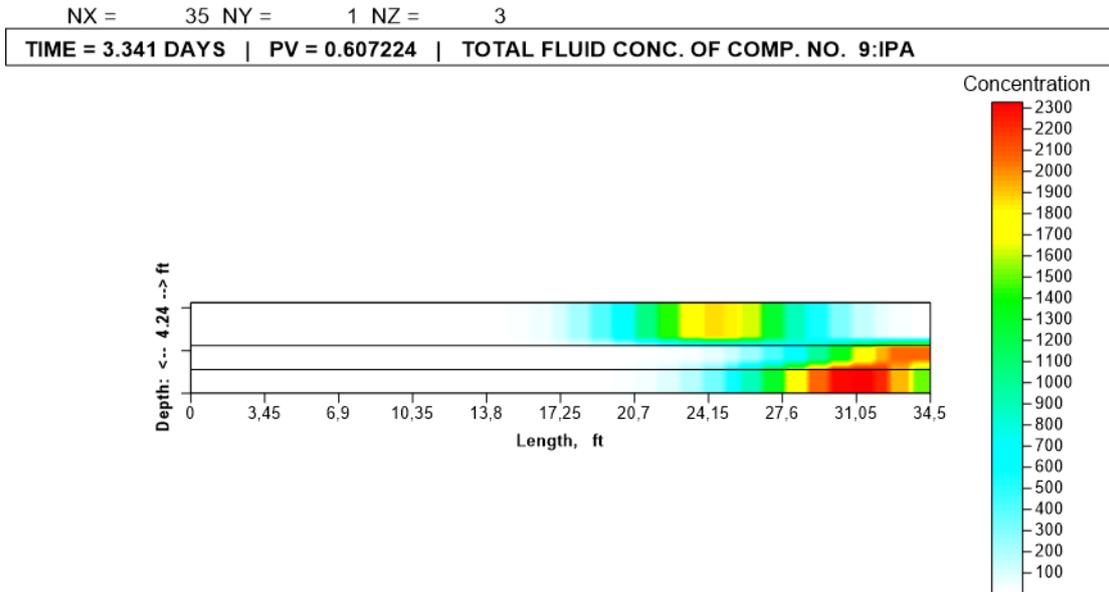
Figure 32 IPA's position after history matching
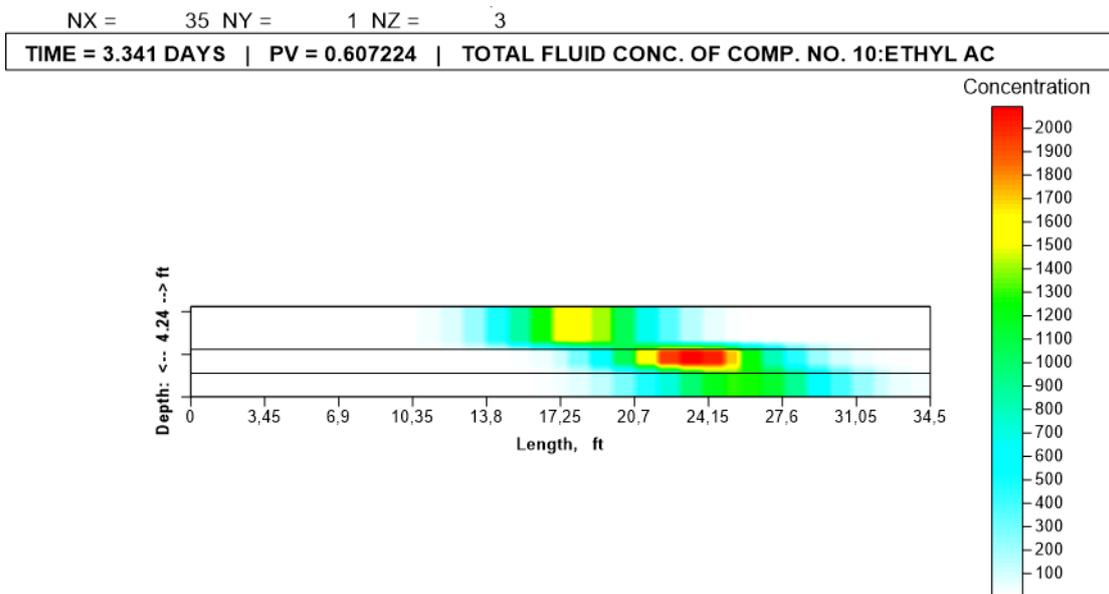
Figure 33 Ethyl Acetate's position after history matching

Figure 34 Ethanol produced position after history matching

Figure 35 Final IPA matching
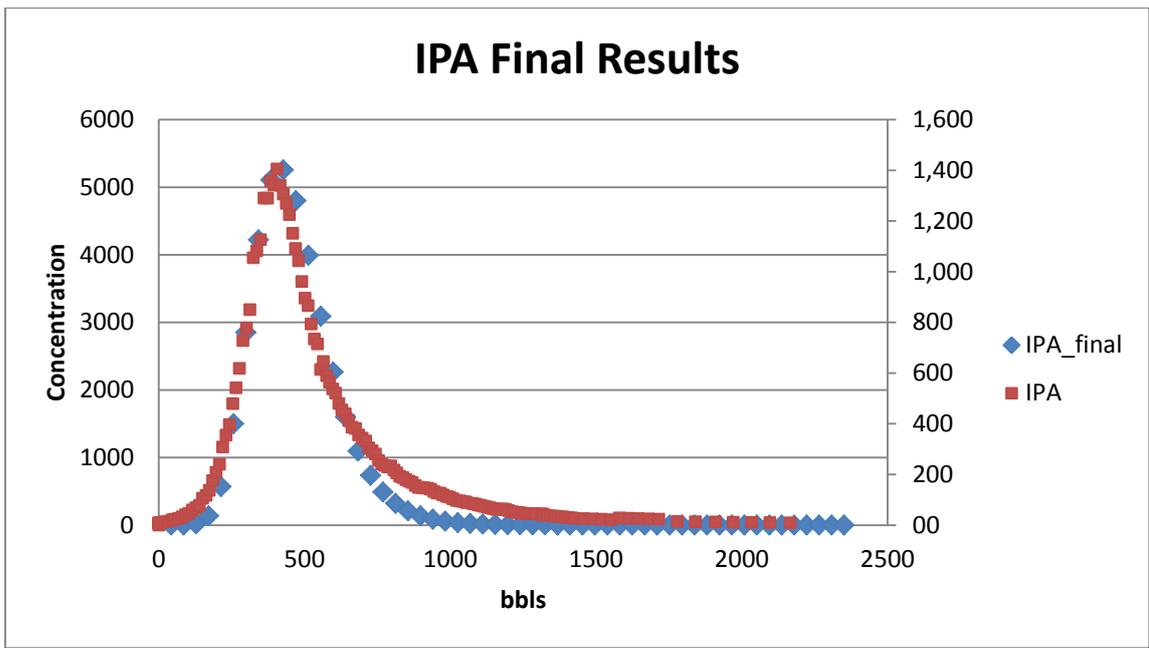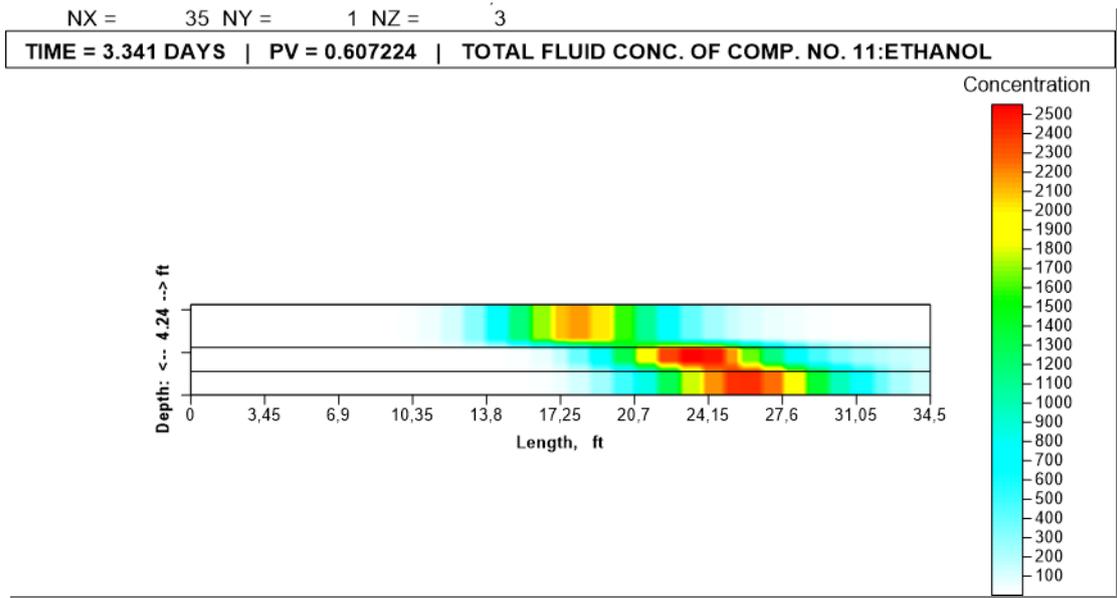
EtAc profile, on the other hand, is not affected enough by this change in thickness. The S_w should also be regulated, in order to be changed the residual oil in place and consequently the retardation of the tracer. This will also change the ethanol profile, as it is the product of the reaction and its position will be the same as the EtAc's, just before production.
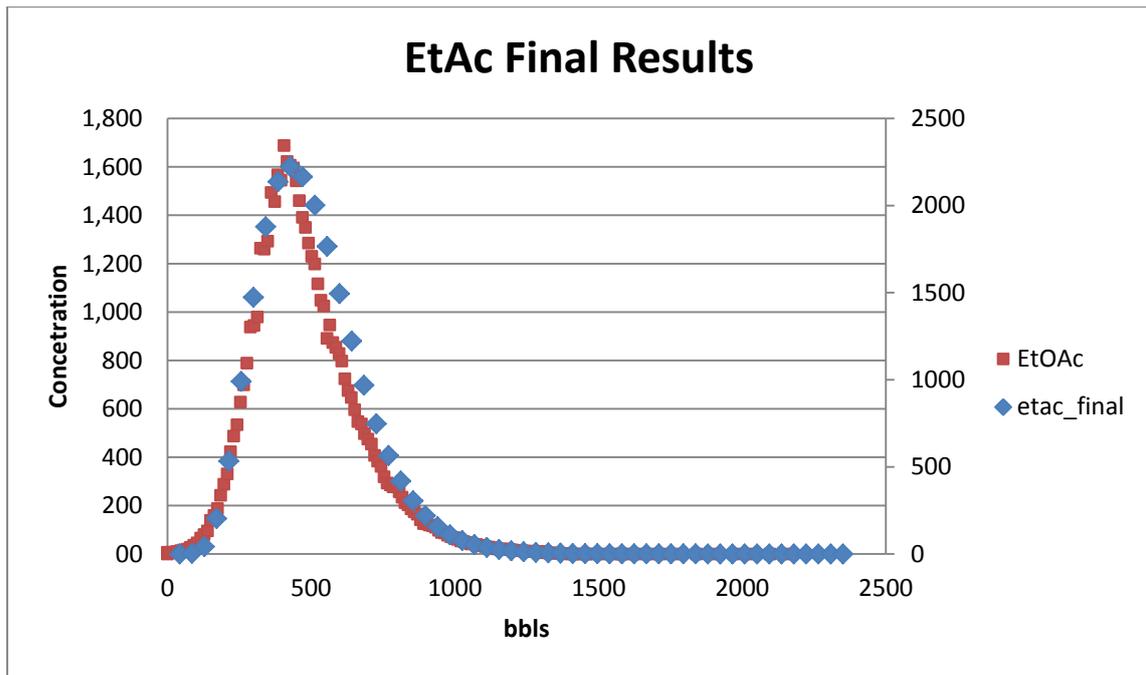
Figure 36 Final EtAc matching
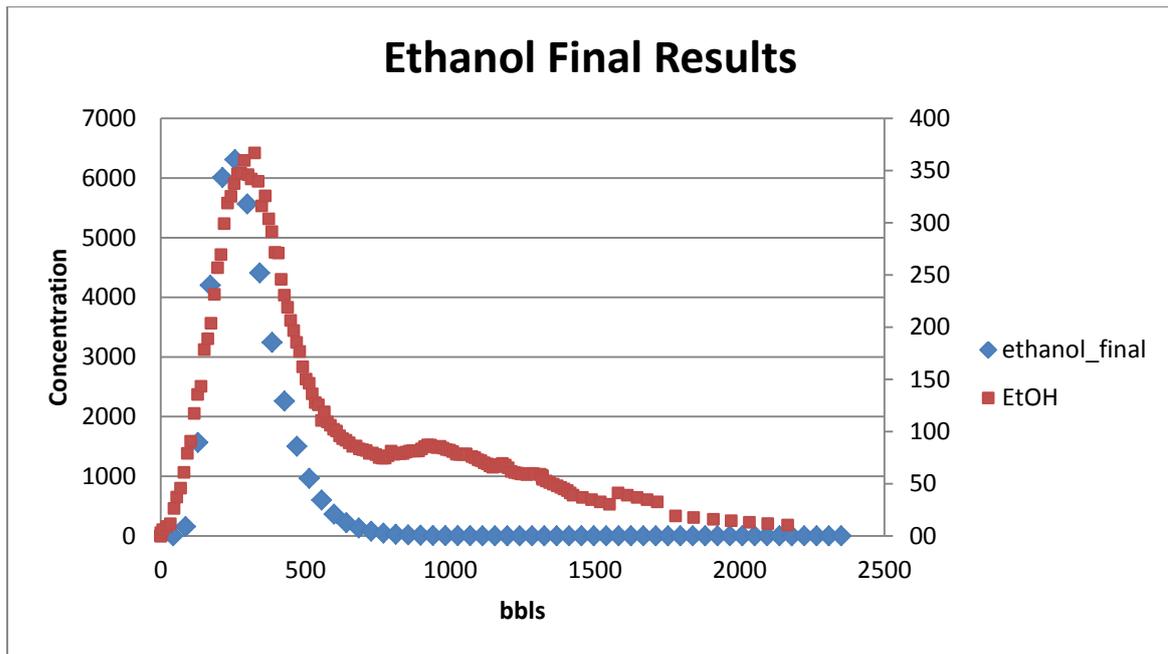
Figure 37 Ethanol final matching

Under this scope, the S_w in each layer is regulated, but not equally. At the first layer it is kept the same, 0.78, at the second is reduced to 0.74 and the last one is increased to 0.87. The purpose was to delay the ethanol profile as much as possible. IPA profile was almost totally fixed by the thickness changes. However, the EtAc profile, as it was observed at the end, did not have almost any change, especially at the tail of the profile (fig. 39). By changing the production rate from 9000 ft^3/day to 8000 ft^3/ day, little difference occurred, but not a better much. This consistency on the delayed tail may is attributed to the reaction

itself and the parameters that affect it (temperatures effects). At the whole procedure, the second peak of the ethanol is not appeared and could not be matched.

Layers	Thickness	Sw
1	1.413	0.78
2	1.413	0.74
3	1.413	0.87

Table 21 Final matching Sw values

	Ft^3/d
Injection rate	2748.544
Production rate	8000

Table 22 Final matching rates
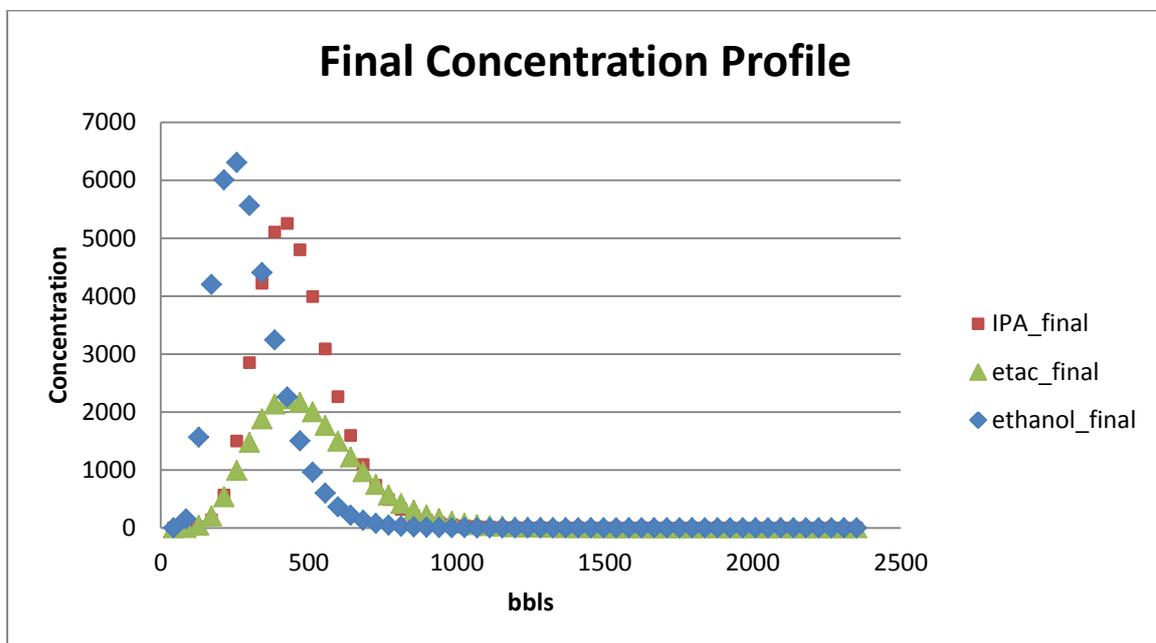
Figure 38 Tracers Final Profiles
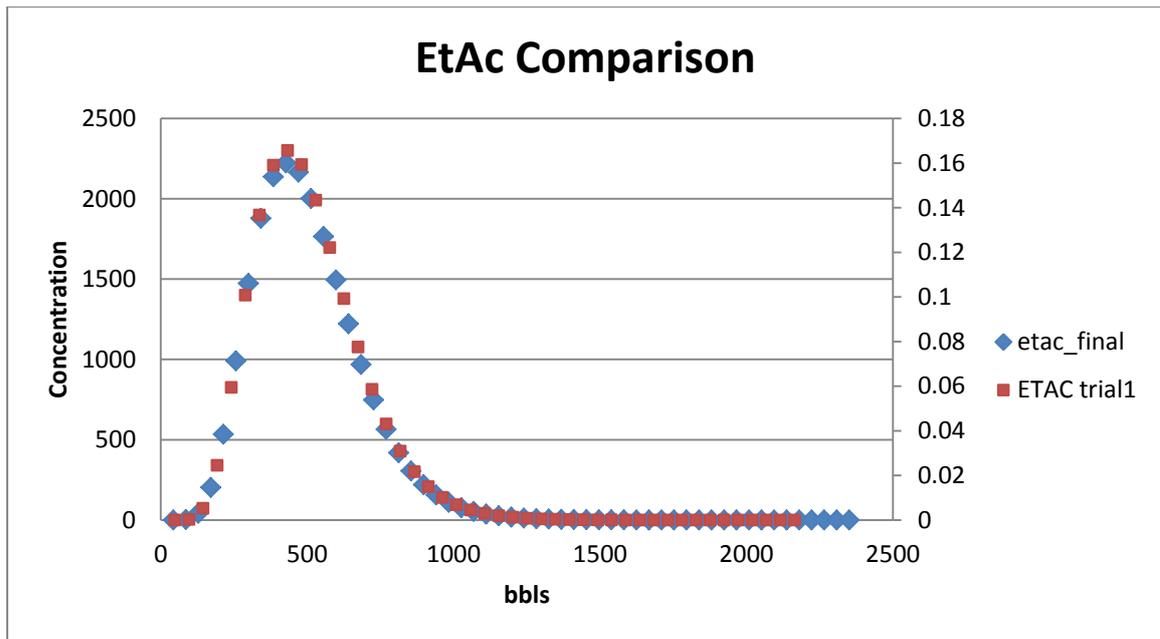
Figure 39 EtAc Comparison for Simulation 1

7.2.2 Three-layer simulation with pre-flush

At this simulation a pre-flush volume of water is used in order to move the temperature front towards the reservoir, so the reaction to take place in cooled area and examine the respective temperature effect. Again only the first and last trial will be presented.

The pre-flush volume is defined by the final position of temperature front. At all simulations that pre-flush is used, a rate of 5000 ft^3/day is implemented, injecting 4818 ft^3 of water.

No. Trials	Changed Parameter		Layer 1	Layer 2	Layer 3	Produc. Rate (ft3/day)
1	-	-				9000
2/FINAL	Thickness		2	1.12	1.12	9000
3	Sw		0.78	0.78	0.74	9000
4	Sw		0.78	0.78	0.7	9000
5	Sw		0.74	0.78	0.7	9000

Table 23 Changes applied through history matching

7.2.2.1 Initial Conditions
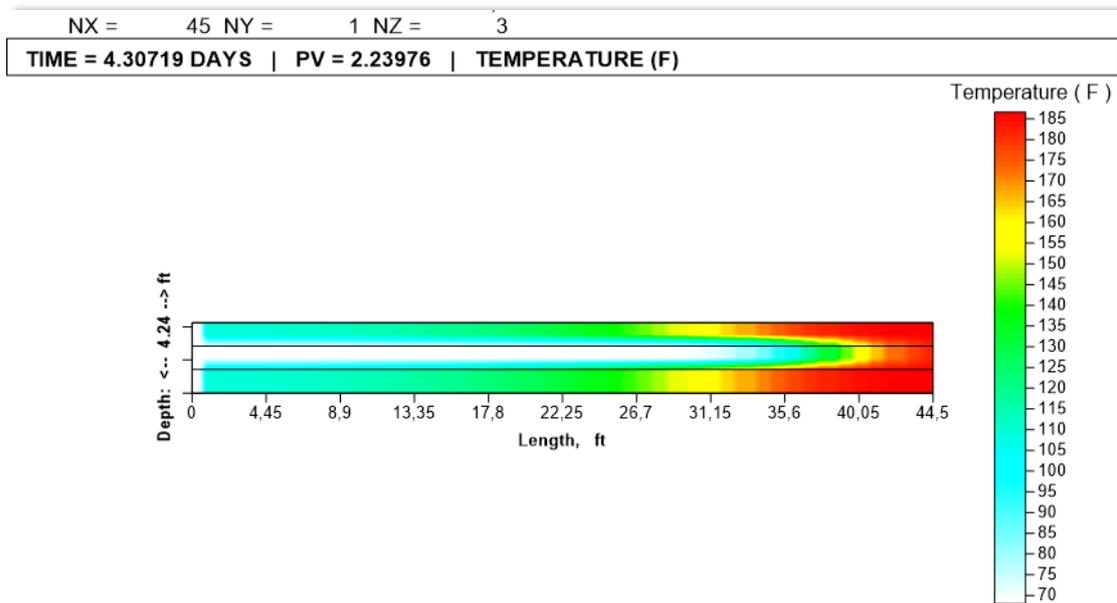
Figure 40 Temperature front at the end of shut-in period. Pre-flush volume is injected

Cross-sectional depiction of the reservoir is shown, along with the position of the temperature front, and that of the tracers. It is obvious that the temperature front is moved away from the wellbore. The middle layer is cooled down much more than the first and last layer. The cooling that takes place at the first and last layer affect also the middle one, so the temperature drawn-down is more intense. This fact has an effect also at the ethanol position just after the end of shut in period. As it can be seen at fig.40, the ethanol at the second layer is moved more to the right, at higher temperatures.
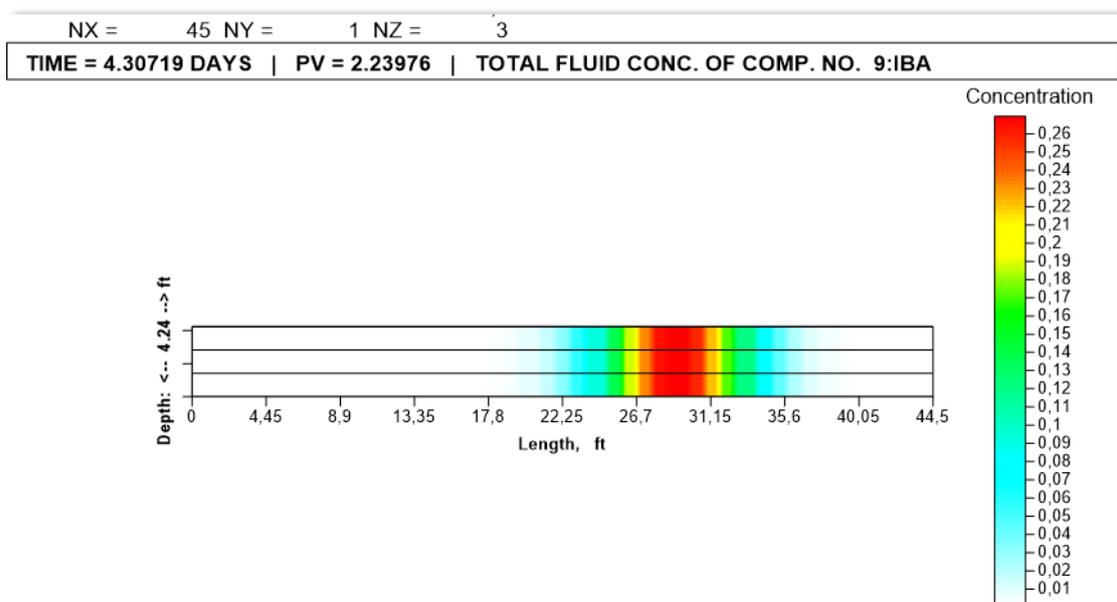
Figure 41 IPA position at the end of shu-in period

NX =   45 NY =   1 NZ =   3

TIME = 4.30719 DAYS | PV = 2.23976 | TOTAL FLUID CONC. OF COMP. NO. 10:ETHYL AC
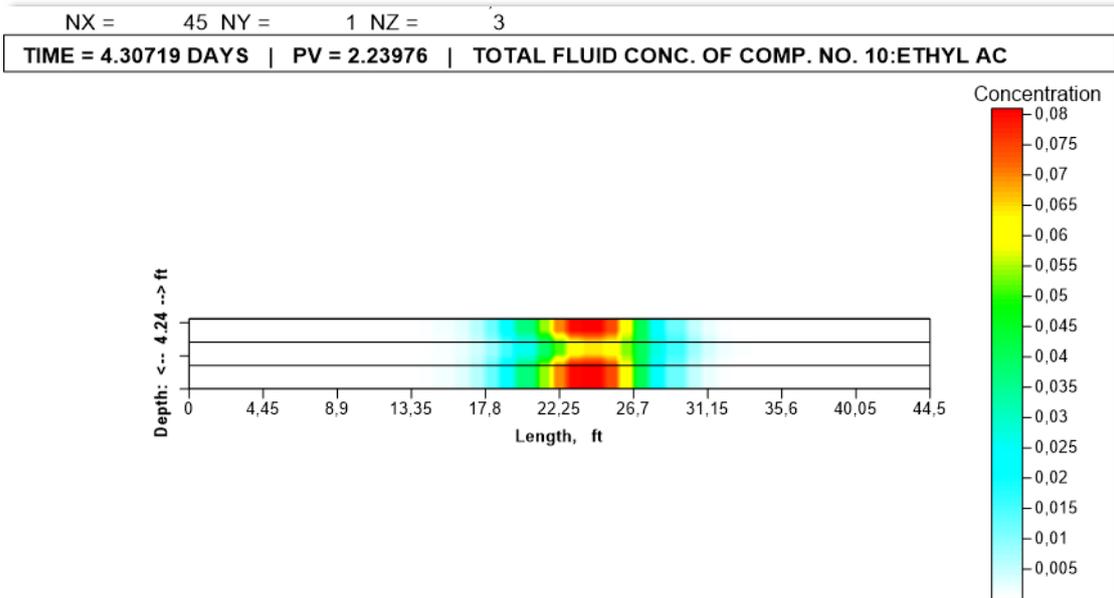
Figure 42 Ethyl Acetate position just before production

NX =   45 NY =   1 NZ =   3

TIME = 4.30719 DAYS | PV = 2.23976 | TOTAL FLUID CONC. OF COMP. NO. 11:ETHANOL
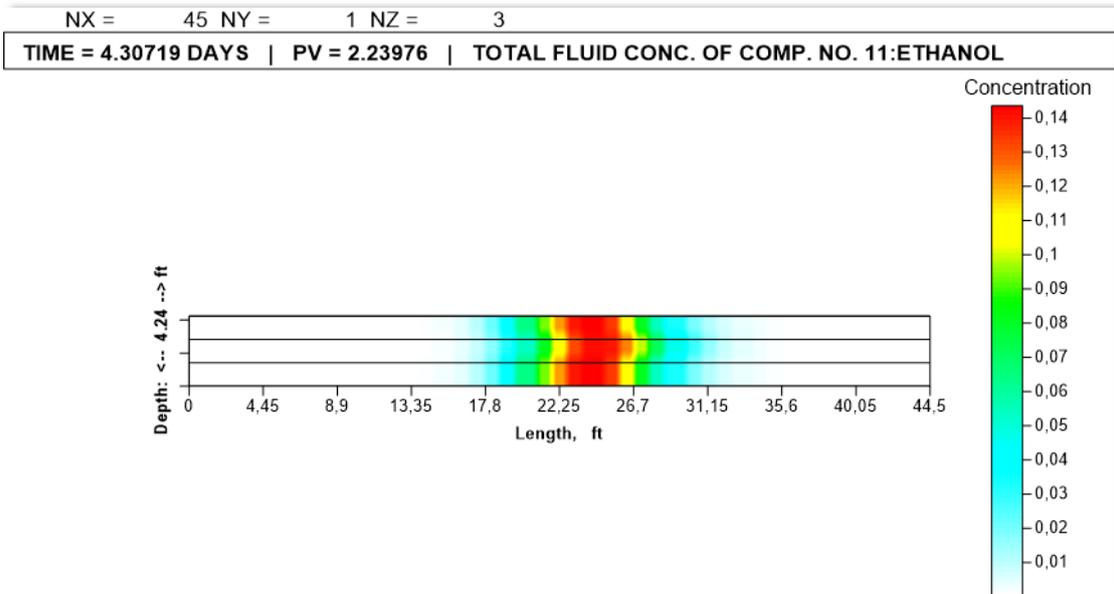
Figure 43 Ethanol shifted position just before shut-in
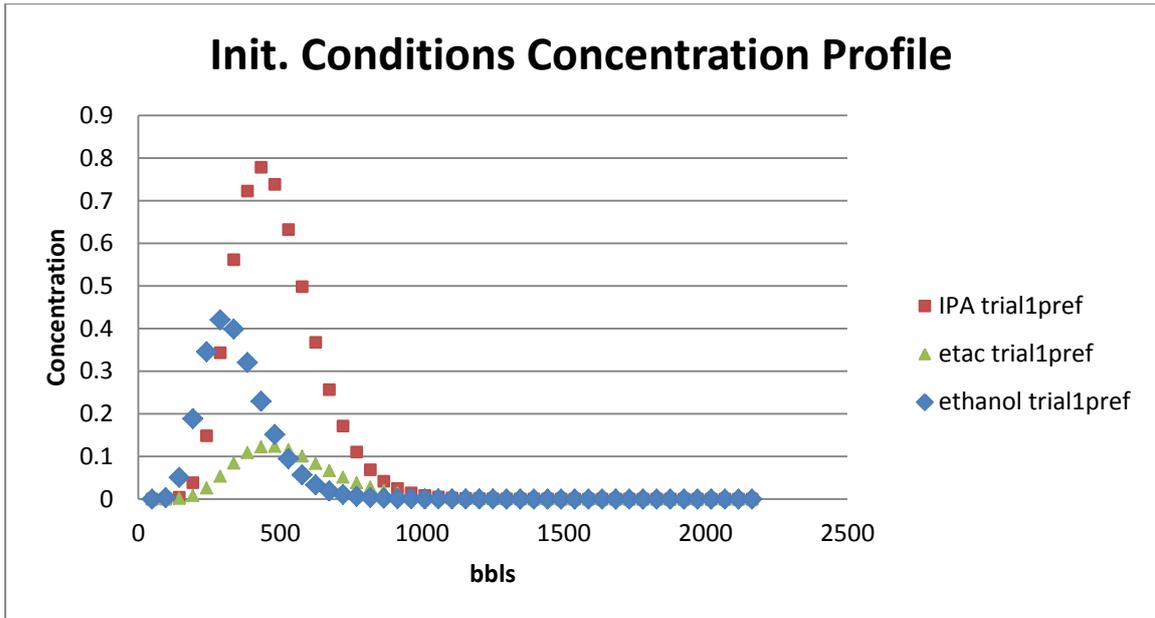
Figure 44
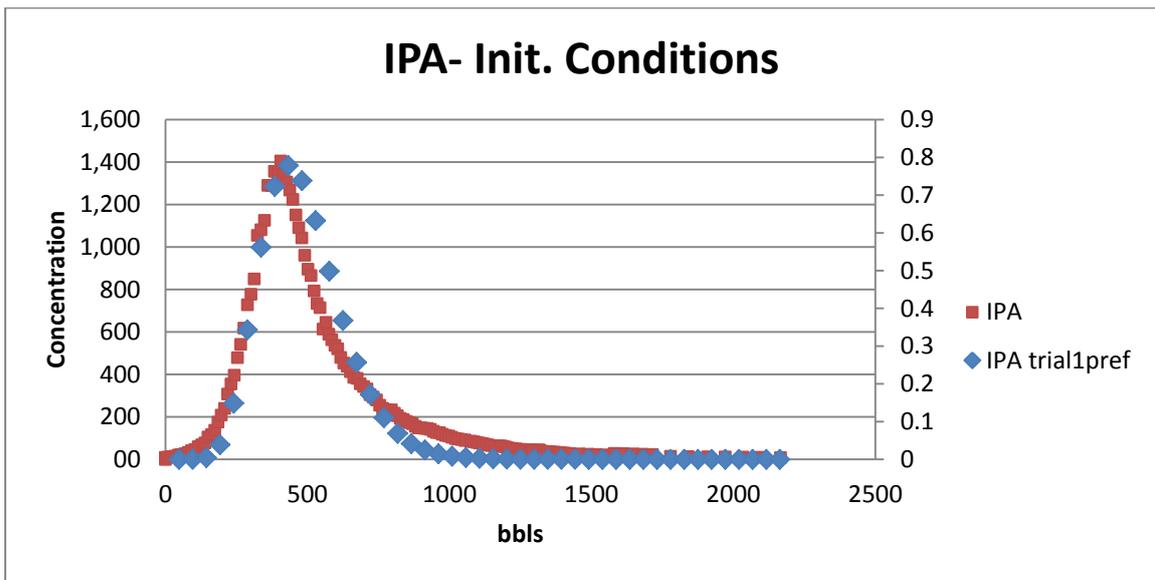
Figure 45 IPA profile- Trial 1 (blue)- History data (red)
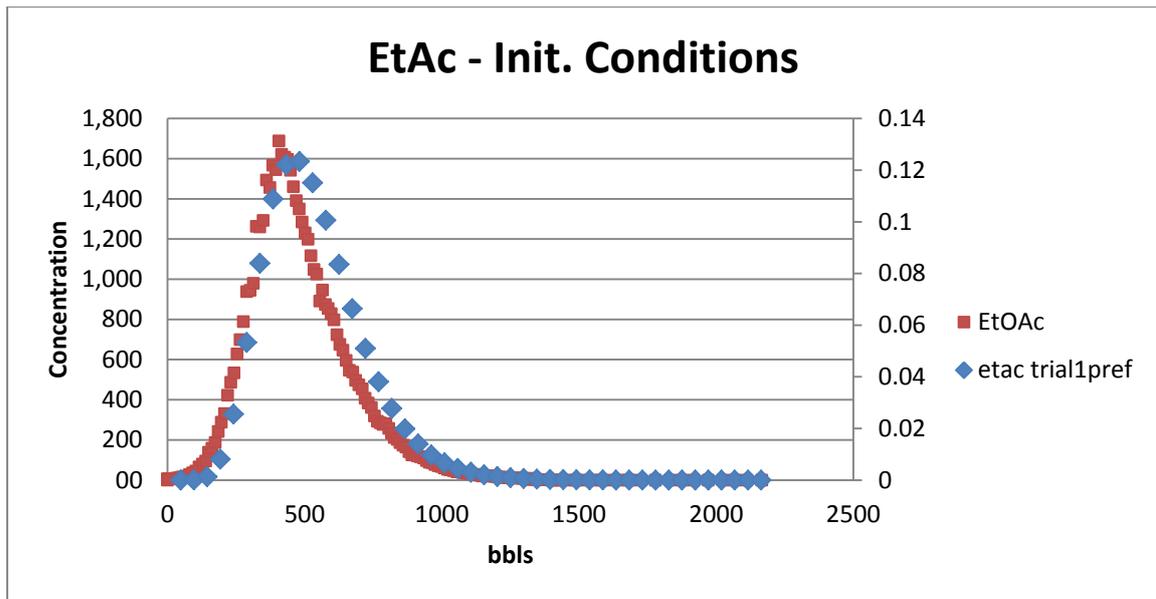
Figure 46 EtAc profile- Trial 1 (blue)- History data (red)
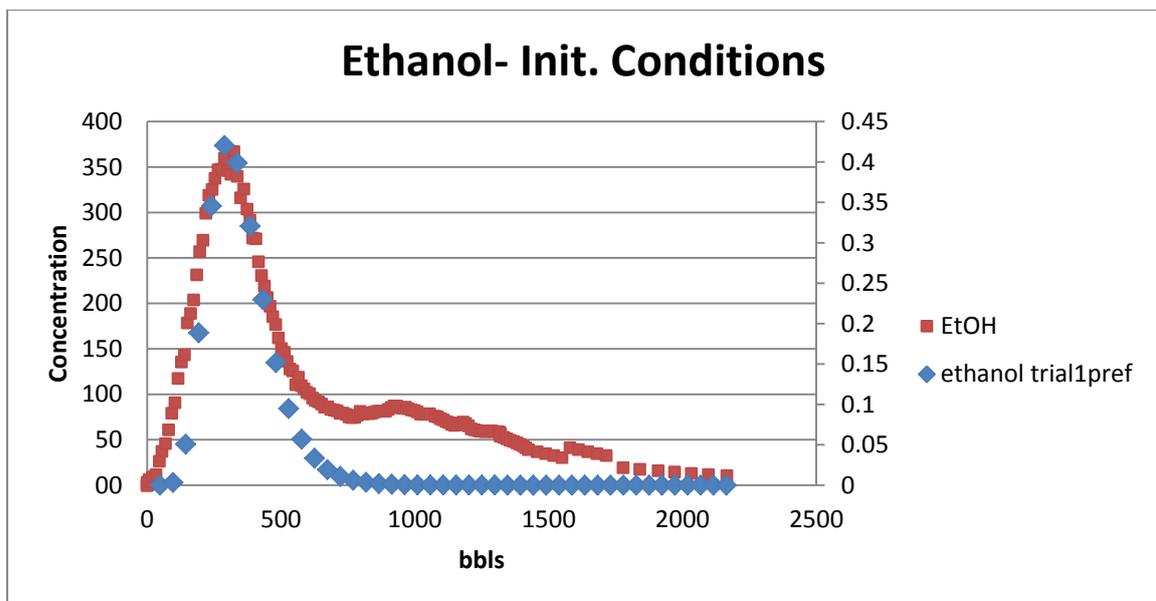
Figure 47 Ethanol Profile- Trial 1 (blue)- History data (red)

Regarding the initial conditions with a pre-flush volume, the concentration profiles are shown above (fig. 45, 46, 47). For tracer IPA and EtAc, is almost the same situation as the previous case. Both need to be produced in less time than they do. However, the ethanol profile is totally different. It has a very good match from the very beginning.

7.2.2.2 Final Results

NX =   55 NY =   1 NZ =   3
TIME = 4.30719 DAYS | PV = 1.49593 | TEMPERATURE (F)
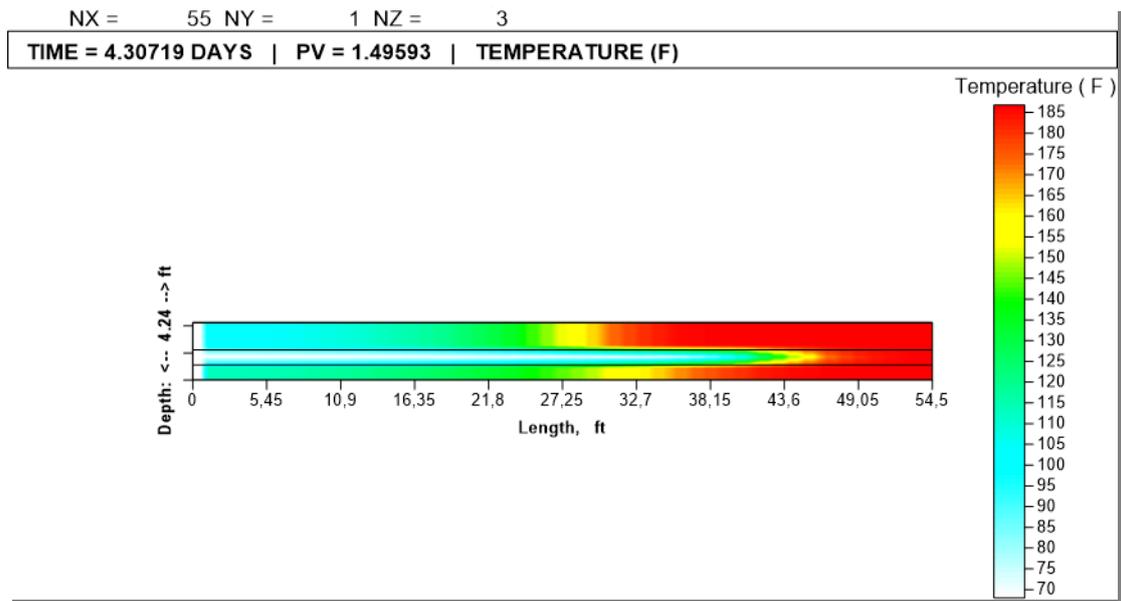
Figure 48 Temperature front after pre-flush, at the end of shut-in period

NX =   55 NY =   1 NZ =   3
TIME = 4.30719 DAYS | PV = 1.49593 | TOTAL FLUID CONC. OF COMP. NO. 9:IPA
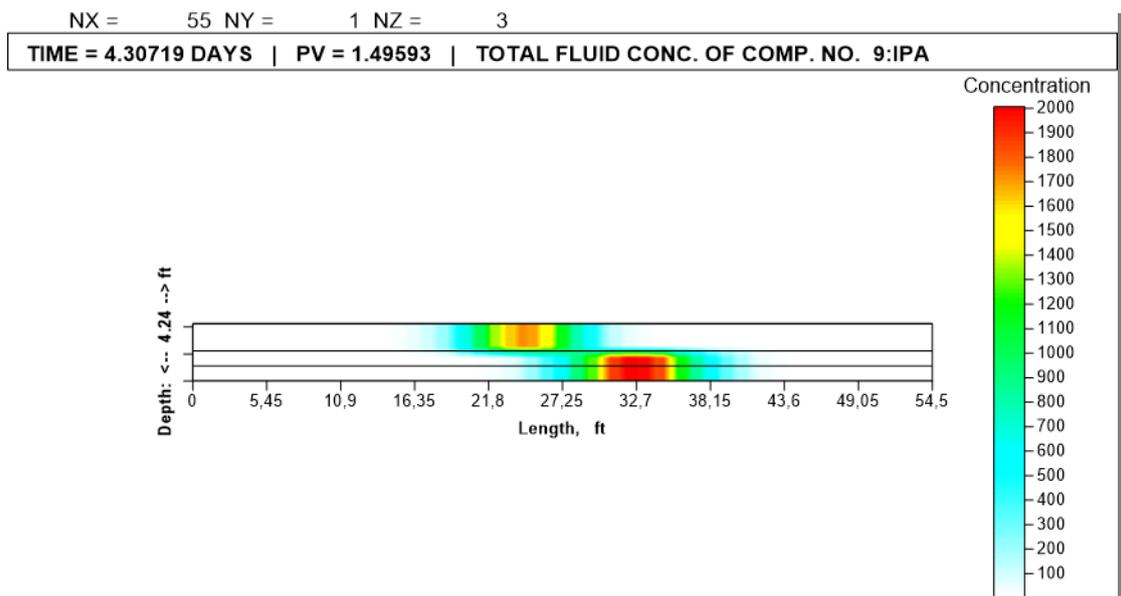
Figure 49 IPA position just before production

By changing the thicknesses the volume distribution in every layer diverges, compared to the Initial Conditions. As long as the volume supply is not changes for the layers the consequent cool down will be different for every layer. As it can be seen the reaction takes place in different temperatures. For the first layer the EtAc in placed at areas with 125-130°F (~52°C). For the second layer the reaction takes at 70-80°F (~24°C), while for the third layer at temperatures around 155°F (68°C).
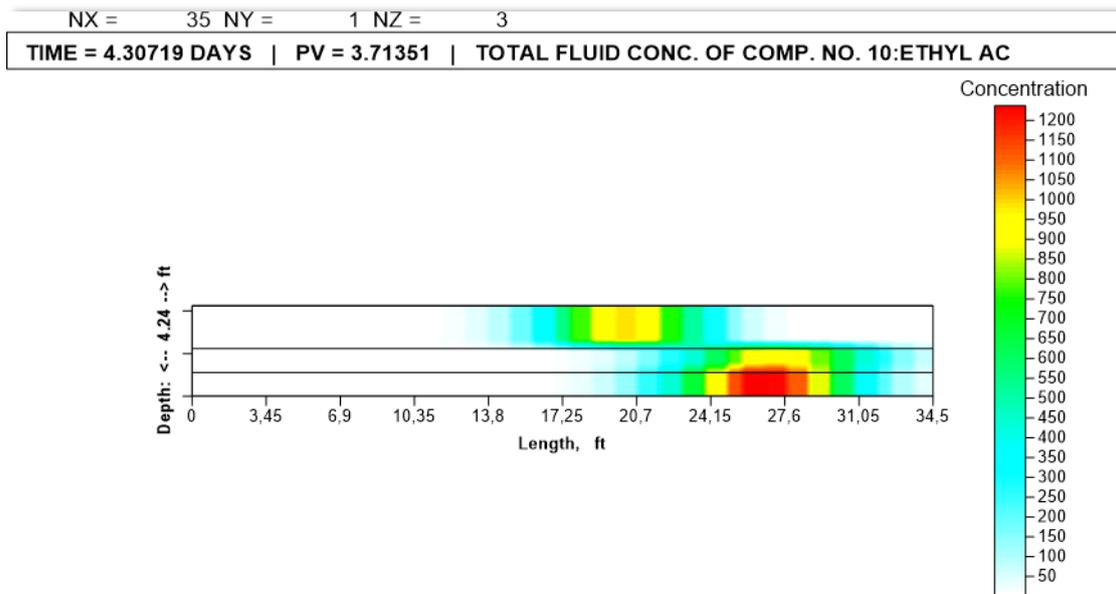
Figure 50 Ethyl Acetate's position at the end of shut-in period
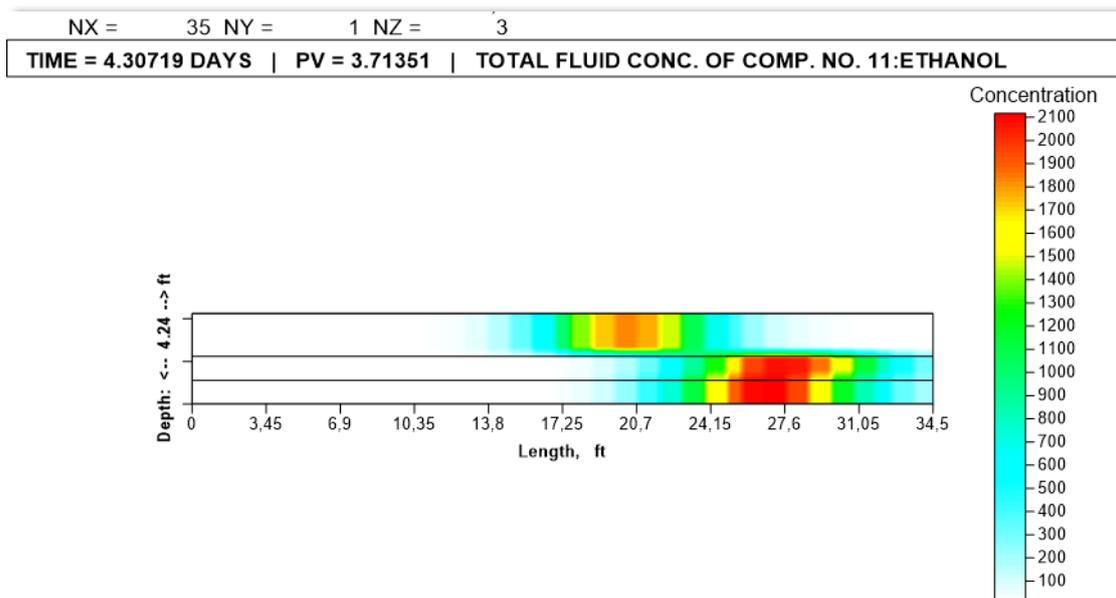
Figure 51 Ethanol shifted position at the end of shut-in period

For matching the two tracers, IPA and EtAc the thickness of each layer is changed, in the same way. Only by this regulating, the matching is considered satisfying for IPA and Ethanol (fig 52, 54). More trials regarding changes in initial S_w were performed, for fixing the EtAc profile but none of them had any effect. On the contrary, the overlap of the IPA and EtAc was negatively affected, making the EtAc to delay. So, the S_w in this case is the same with the initial value, 0.78 for every layer.
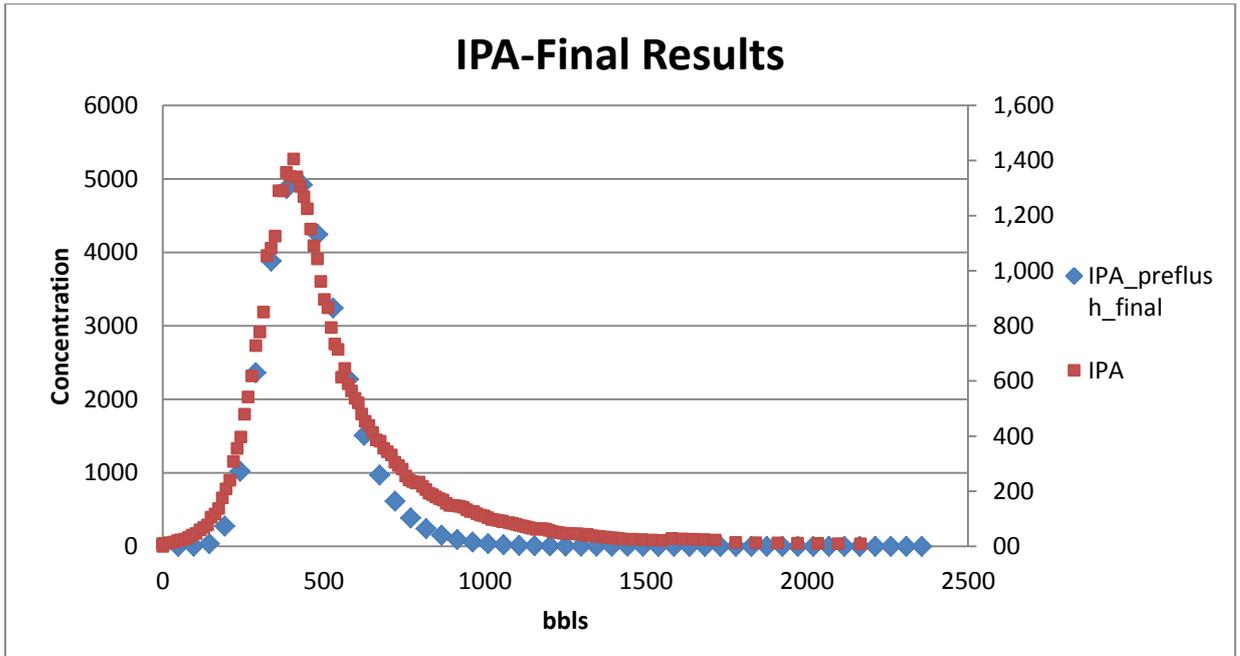
Figure 52 IPA final matching
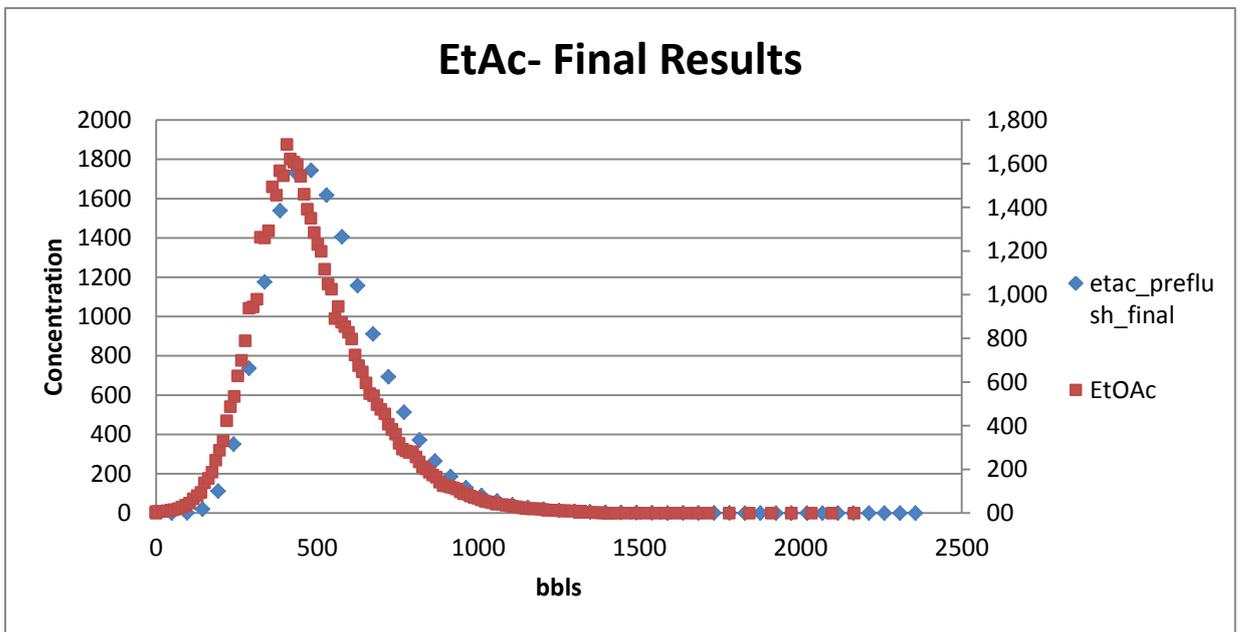
Figure 53 EtAc final matching
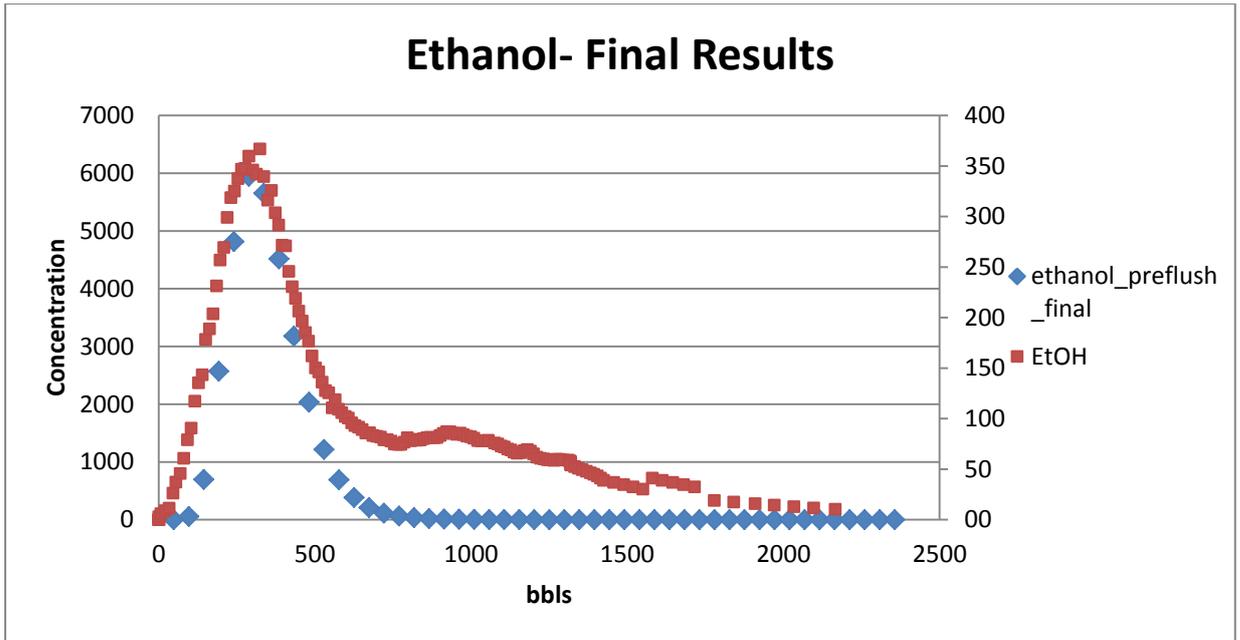
Figure 54 Ethanol final matching
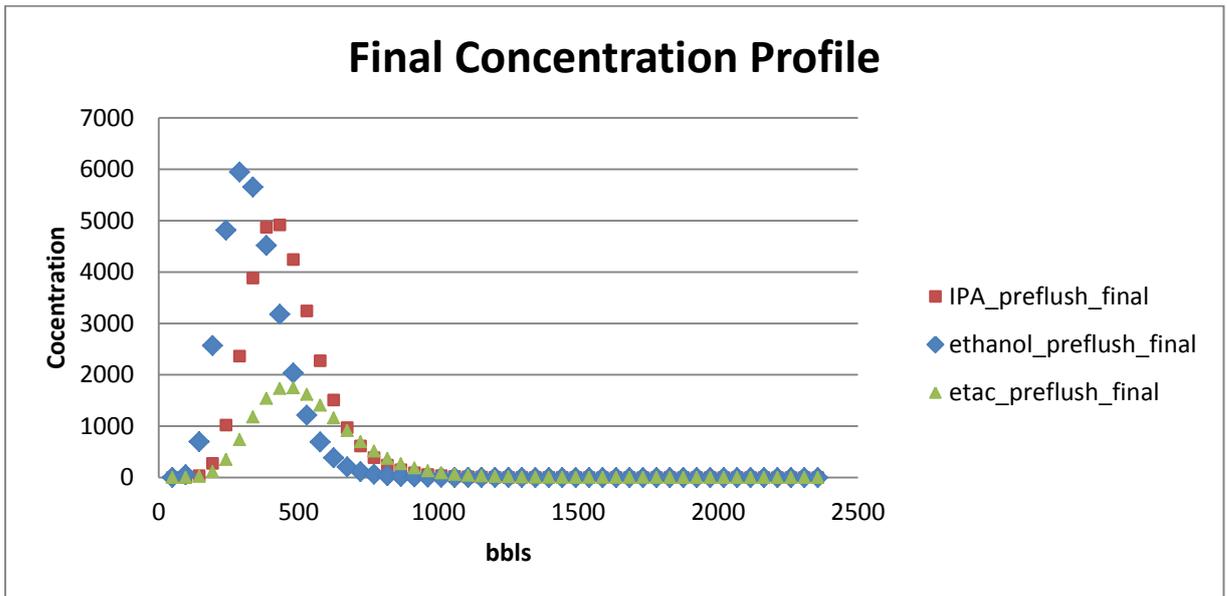
Figure 55 Final Concentration Profile, after pre-flush

From the previous simulation, the ethanol needed to be delayed and EtAc should had a position further from the wellbore, so the S_w was regulated. On this case, this lag on the arrival is done by the fact that the produced ethanol is moved towards the warmer areas in the reservoir during the reaction.

Again, it should be pointed out that the EtAc profile is the same after every change, either on thickness or on S_w value

7.2.3 Four-layer simulation

The purpose of this simulation set was for matching the second peak of ethanol that appears on the real data, during production. As long as, there satisfying match with 3 layers, a fourth layer should be added to simulate this second peak. It is tried both, direct injection of the tracer and a pre-flush water injection prior the tracers. Parameters regulated are the thickness of the layers and the S_w of each layer.

7.2.3.1 Four-layer simulation without pre-flush

Firstly, the injection volume is separated in four equal parts, each for every simulated layer. Again the injection and production rate is the same as previous, as also the initial S_w.

Layers	Thickness	Sw
1	1.06	0.78
2	1.06	0.78
3	1.06	0.78
4	1.06	0.78

Table 24 Initial values of thickness and Sw

Tracer	Volume (ft^3)	Layers	FT^3
IPA/EtAc	542.0878	1	135.522
		2	135.522
		3	135.522
		4	135.522
Water	2296.126	1	574.03
		2	574.03
		3	574.03
		4	574.03
Production	12159.45	1	3039.863
		2	3039.863
		3	3039.863
		4	3039.863

Table 25 Volumes injected/produced per layer

	Ft^3/d
Injection rate	2784.544
Production rate	9000

Table 26 Injection/Production Rate

No. Trials	Changed Parameter		Layer 1	Layer 2	Layer 3	Layer 4	Produc. Rate (ft3/day)
1	-						7000
2	Sw	Produc. Rate	0.78	0.74	0.74	0.78	9000
3	-	Produc. Rate	0.78	0.74	0.74	0.78	7000

4	Thickness		1.5	1	1	0.74	7000
5	Sw	Thickness	0.78/ 1.5	0.76/1.2	0.76/1.2	0.82/0.5	7000
6/FINAL	Sw		0.78	0.76	0.76	0.9	7000

Table 27 Changes applied through history matching

Initial Conditions
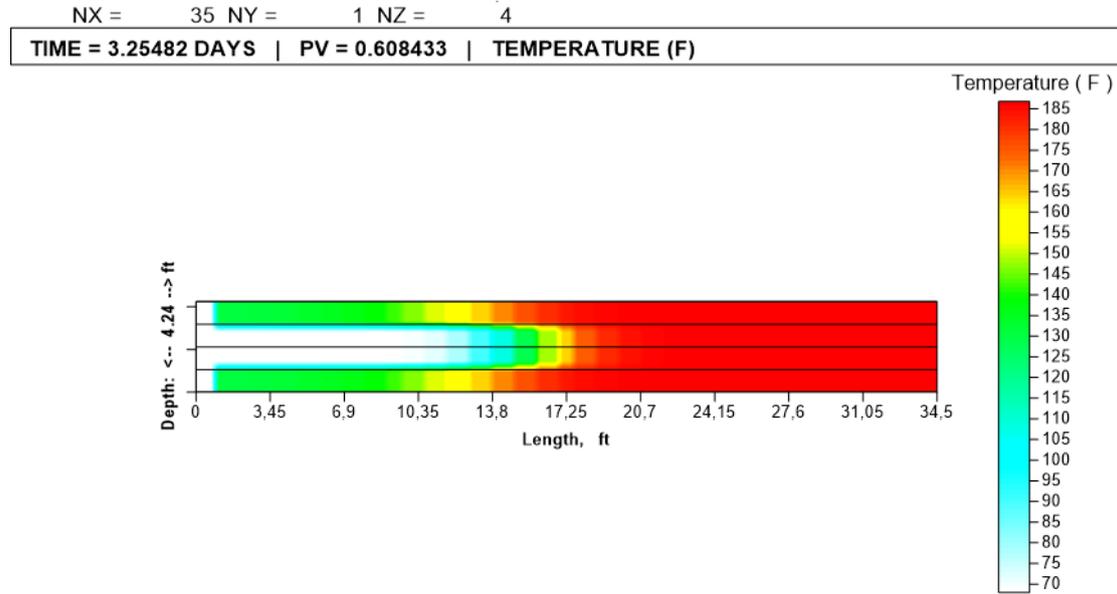
Figure 56 Temperature front just before production
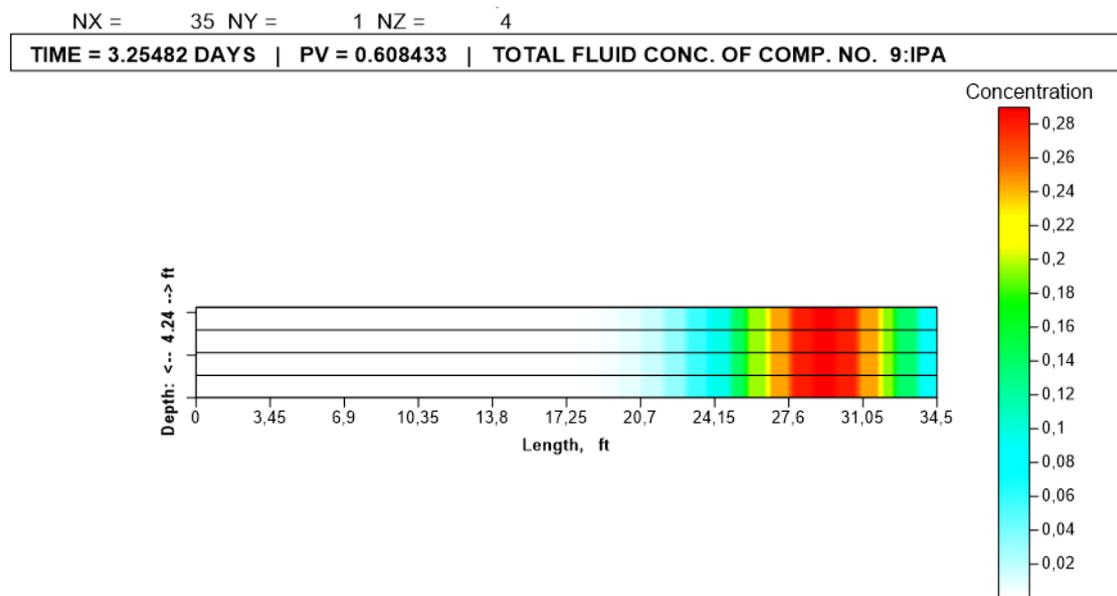
Figure 57 IPA position hust before production
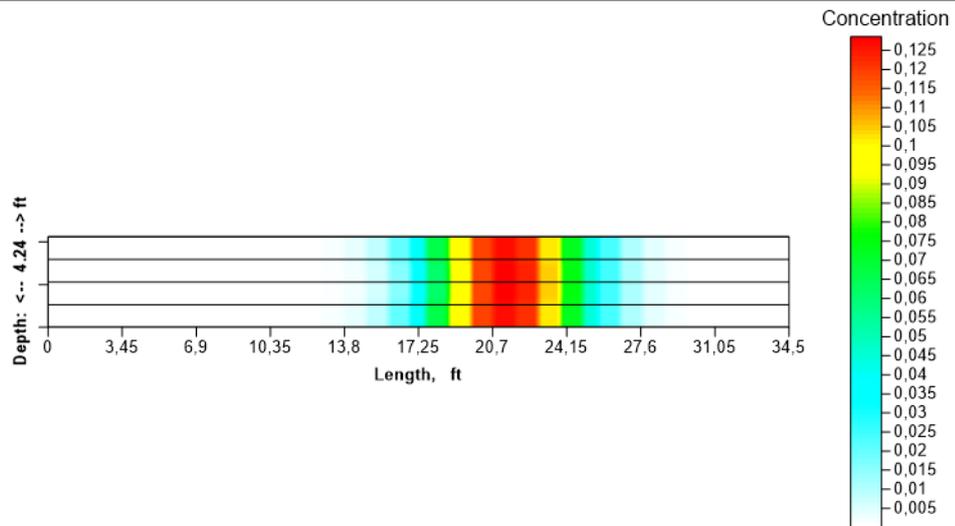
Figure 58 Ethyl Acetate position just before proction
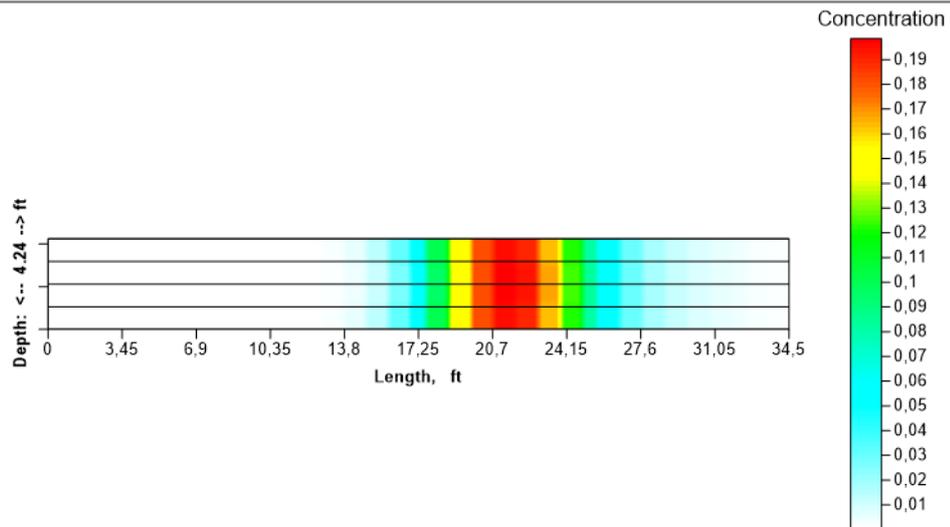
Figure 59 Produced Ethanol position just before production

The simulation with 4 layers is analogous with that of 3 layers. The temperature gradient is the same for the first and last layers while for the second and third is different as they are enveloped between the other two. The tracers' distribution is uniform and the same for all layers. The reaction takes place in areas with temperatures equal to that of the reservoir 186°F.
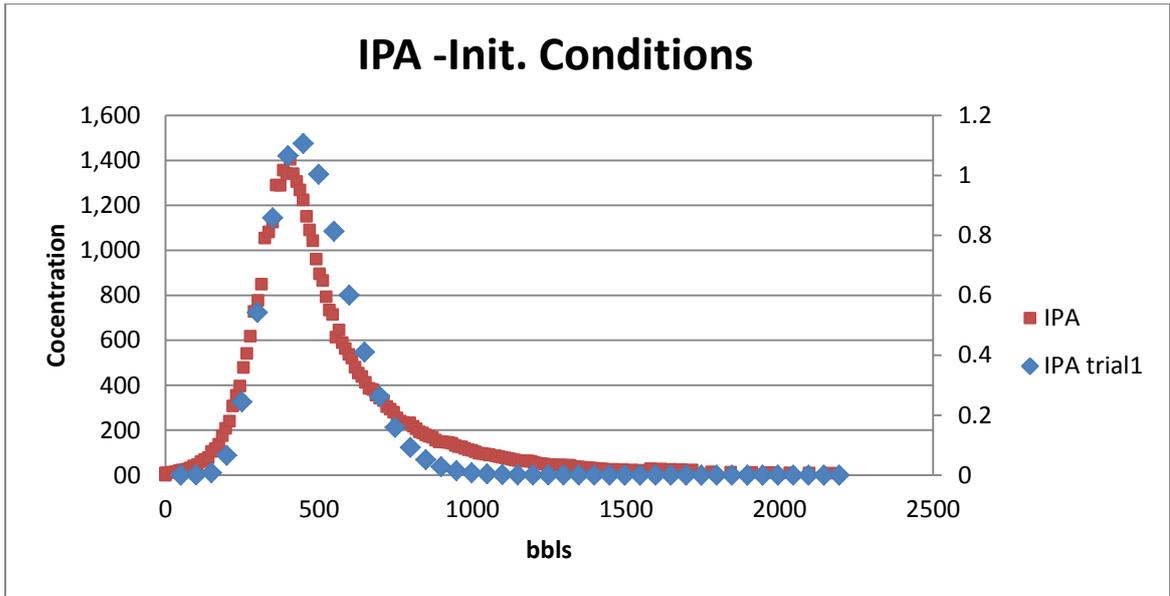
Figure 60 IPA profile- Trial 1 (blue)- History data (red)
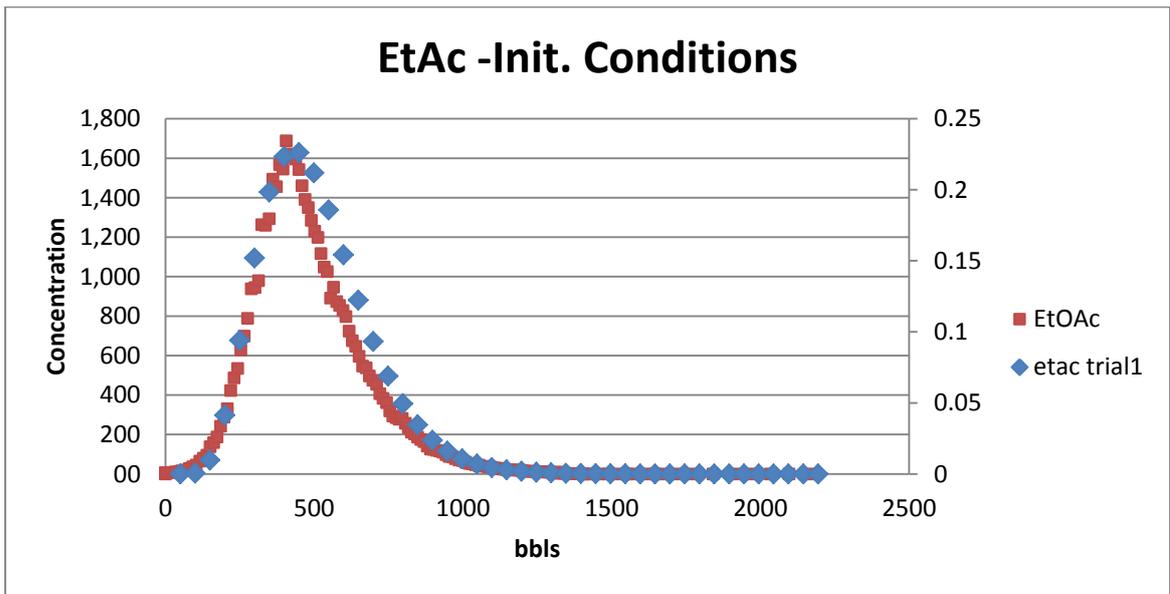
Figure 61 EtAc profile- Trial 1 (blue)- Histroy data (red)

These initial tracers' profiles are the same as those at previous simulations. IPA and EtAc need to be produced earlier in time, while ethanol later.
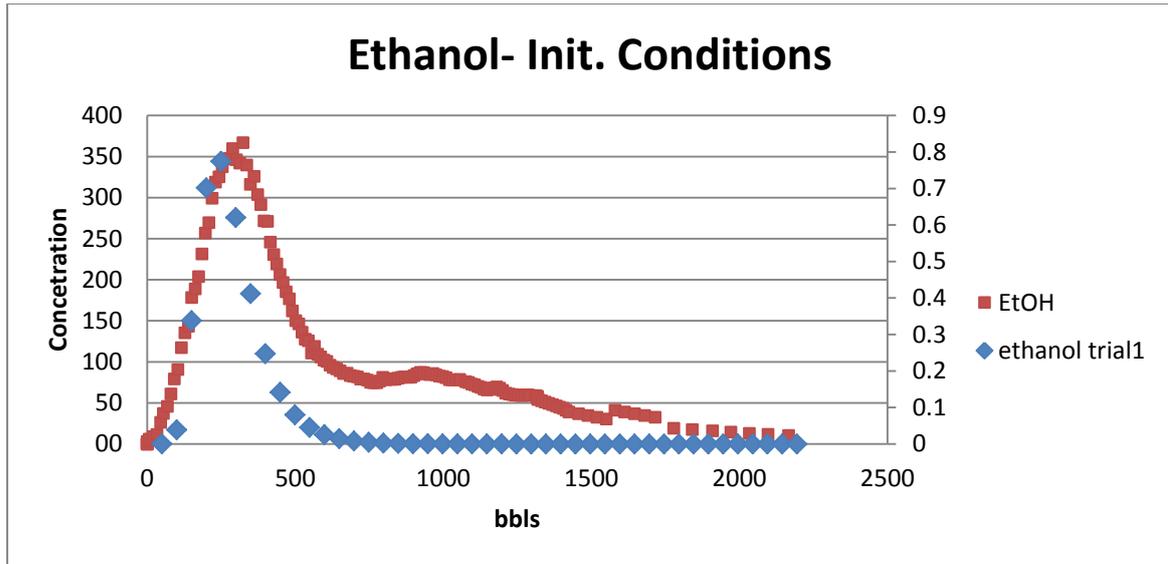
Figure 62 Ethanol profile- Trial 1 (blue) –History data (red)

Final Results

After the changes in thickness and Sw at each layer, the temperature front is slightly differentiated with no any significance for the reaction.

Layers	Thickness	Sw
1	1.5	0.78
2	1.12	0.76
3	1.12	0.76
4	0.5	0.9

Table 28 Final matching values for thickness and Sw per layer

On the other hand, the final position of the tracers is changed. The concept was to match all the peaks of the tracers, using the experience of the previous simulations, as the changes are almost the same. The results are shown below.

NX =   45 NY =   1 NZ =   4
TIME = 3.25482 DAYS | PV = 0.366883 | TEMPERATURE (F)
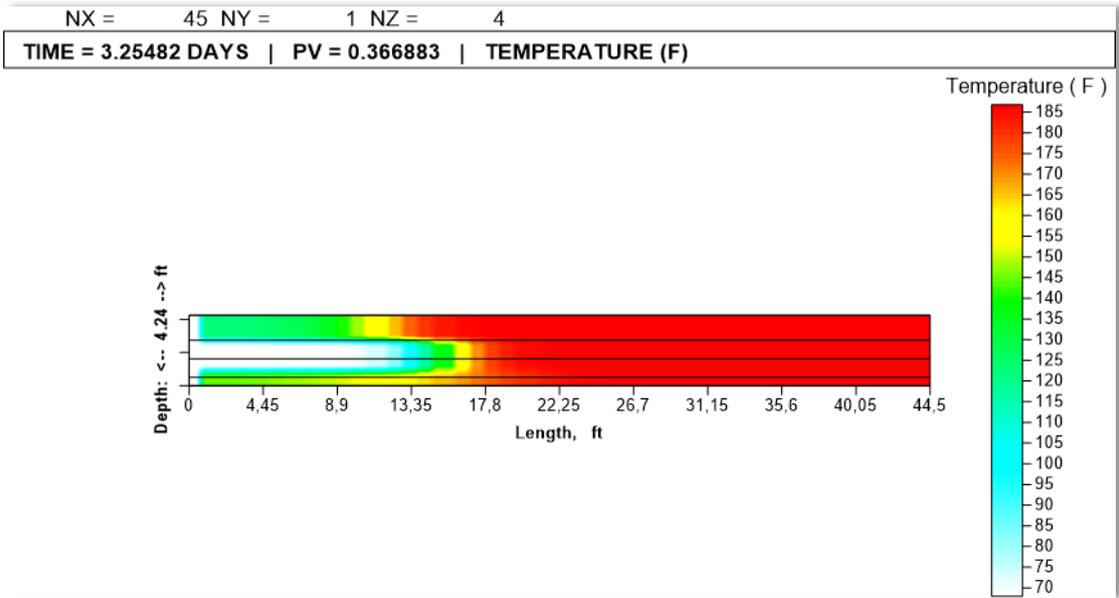
Figure 63 Temperature front after history matching, at the end of shut-in period

NX =   45 NY =   1 NZ =   4
TIME = 3.25482 DAYS | PV = 0.366883 | TOTAL FLUID CONC. OF COMP. NO. 9:IPA
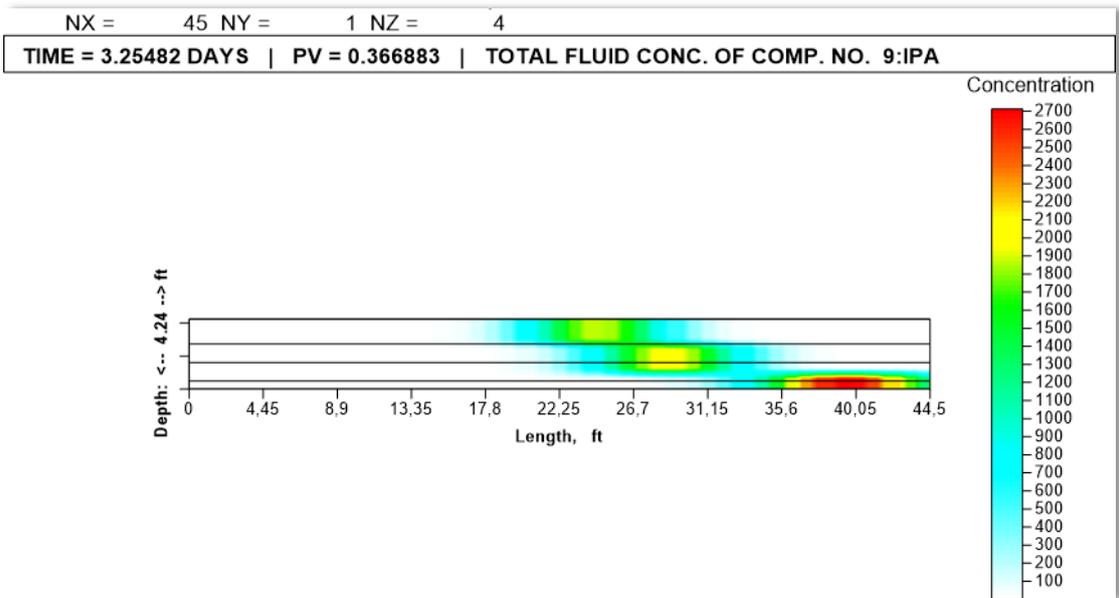
Figure 64 IPA position after final matcing
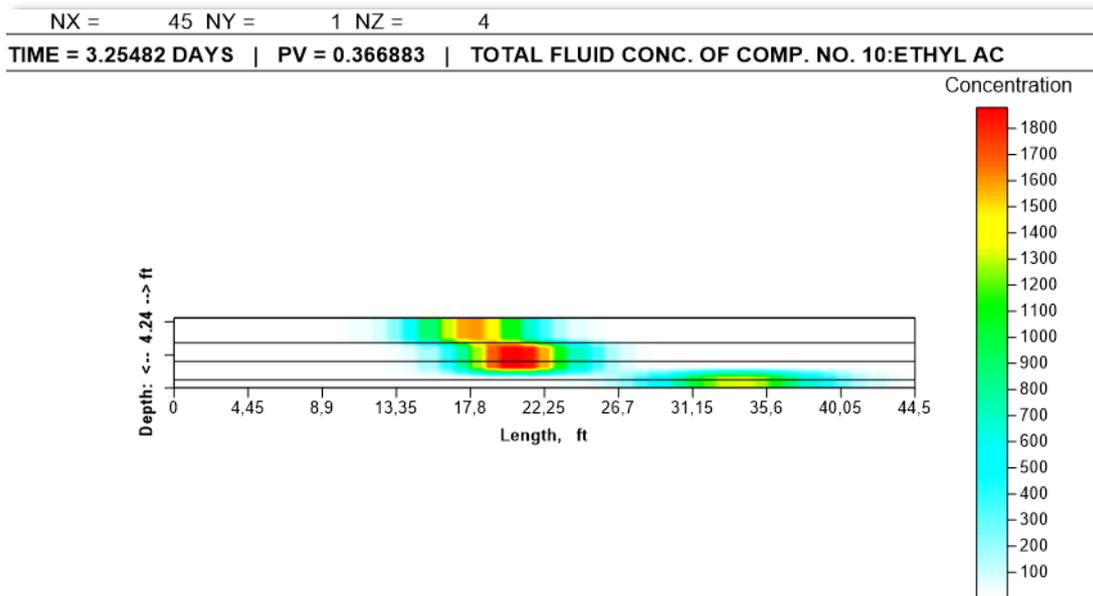
Figure 65 Ethyl Acetate position after final matching, at the end of shut-in period
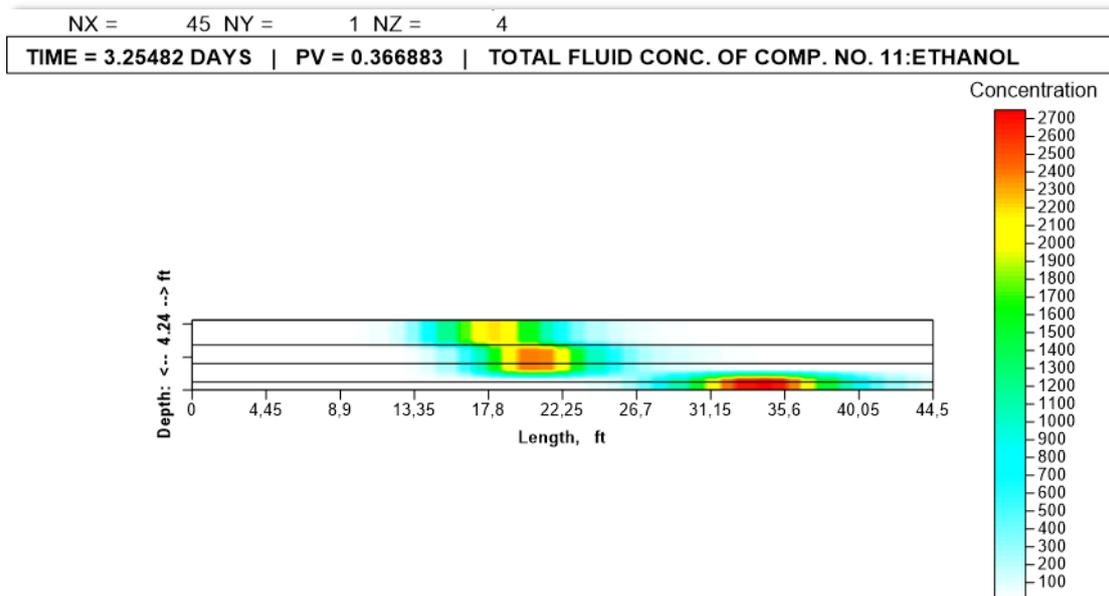
Figure 66 Produced ethanol's position just before production period
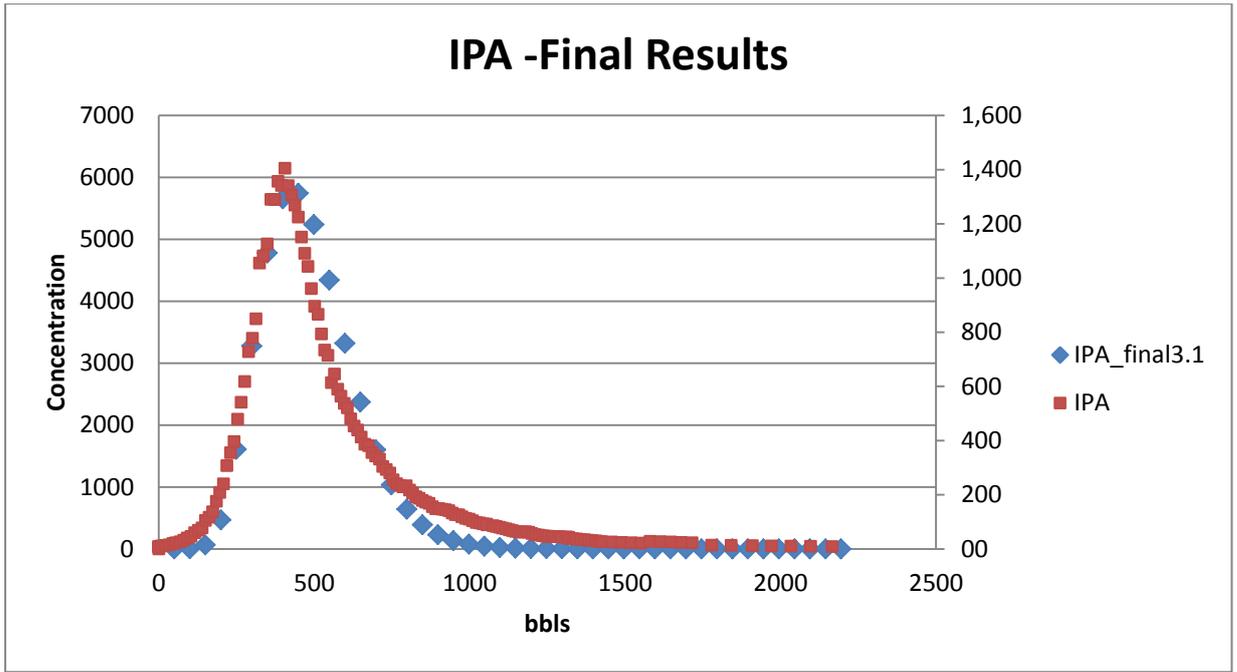
Figure 67 IPA final matching- Final (blue)-History data (red)
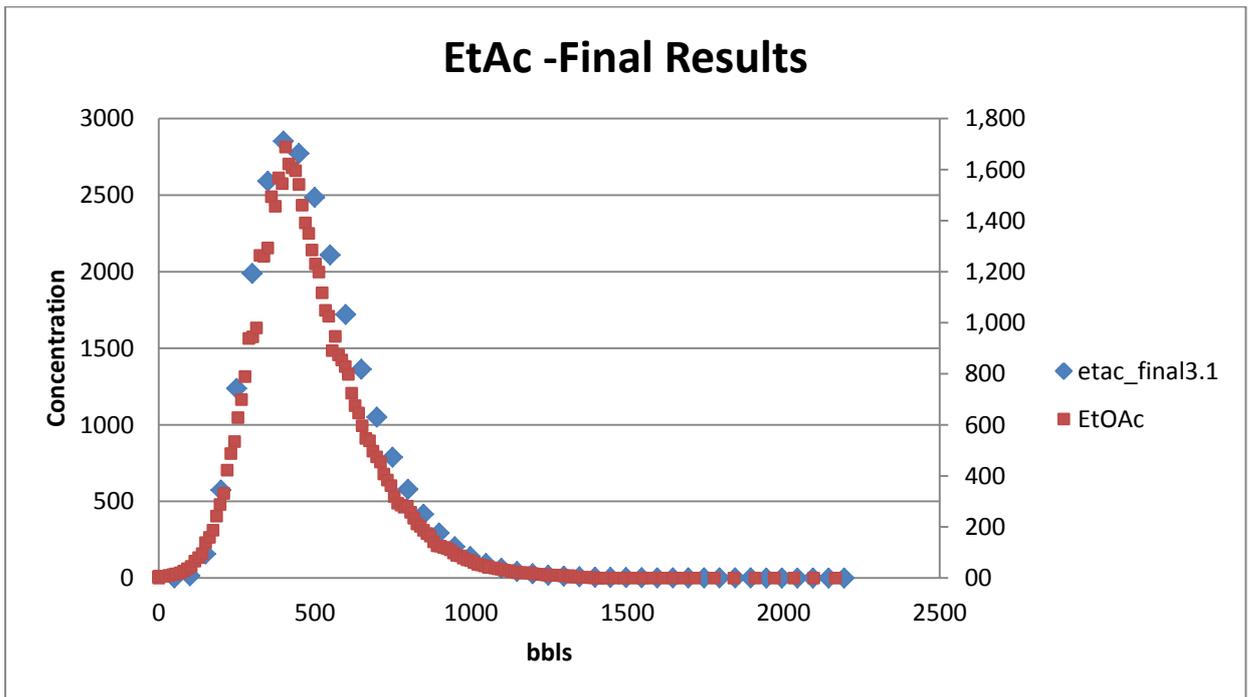
Figure 68 EtAc final matching- Final (blue)- History data (red)
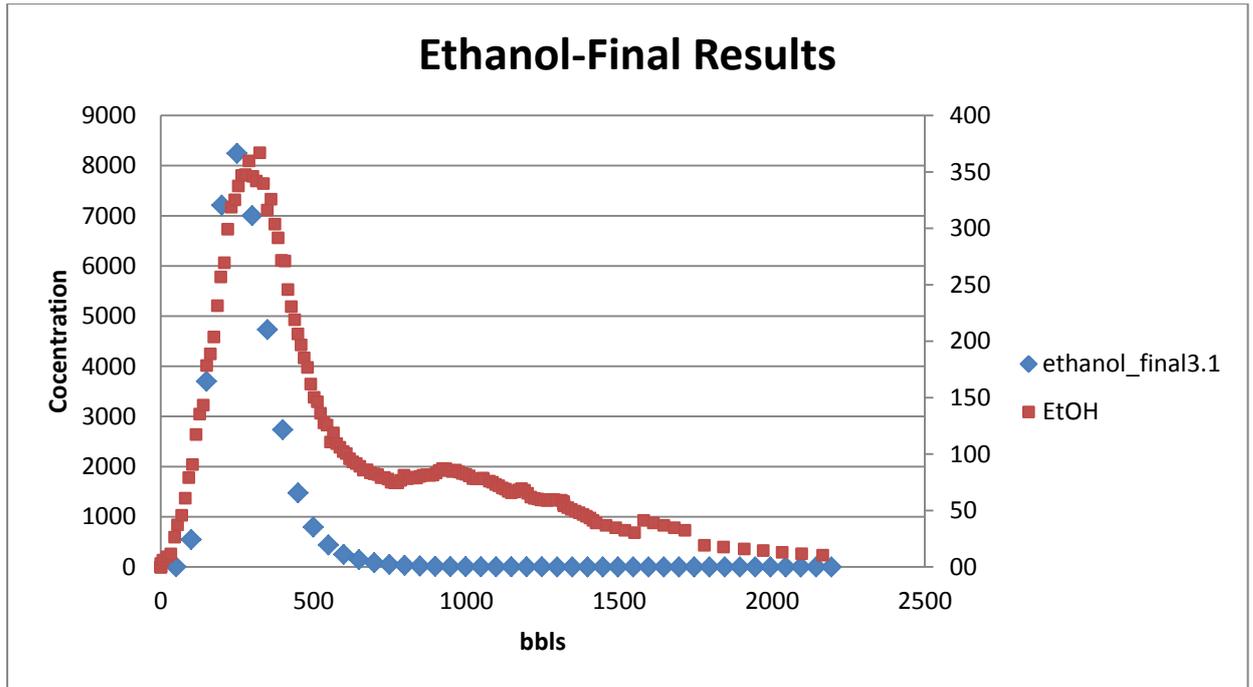
Figure 69 Produced ethanol final matching –Final (blue)-History data (red)

It is tried through this simulation to create two peaks of ethanol. It was not successful. The changes done in thickness and S_w were on the direction that one very thin layer give this particular second peak, as the position of the EtAc would be far enough from the wellbore. One thing that is good about this simulation is the good match of EtAc (fig. 68), in comparison to the previous simulations; meaning that more of the tracer is reacted during the shut-in period. On the other hand, IPA and ethanol profiles are similar to the previous simulations.

7.2.3.2 Four-layer simulation with pre-flush

At this simulation with pre-flush water injection, will be tried again to match the second peak of ethanol. The domain of the reservoir is separated the same as previous, as also the volumes and the rates.

No. Trials	Changed Parameter		Layer 1 (ft)	Layer 2 (ft)	Layer 3 (ft)	Layer 4 (ft)	Produc. Rate (ft3/day)
1	-	-					9000
2	Thickness		1.5	1.12	1.12	0.5	9000
3	Sw		0.78	0.74	0.78	0.9	9000
4	Sw	Thickness	0.76/1.6	0.74/1.12	0.74/1.12	0.9/0.4	9000

Table 29 Changes applied through history matching

Initial Conditions

The temperature gradient has the same scheme as previous, but displaced at higher horizontal depth. The tracers' distribution is also the same, with the difference that the ethanol, for layer 2 and 3 id shifted to areas with higher temperatures.
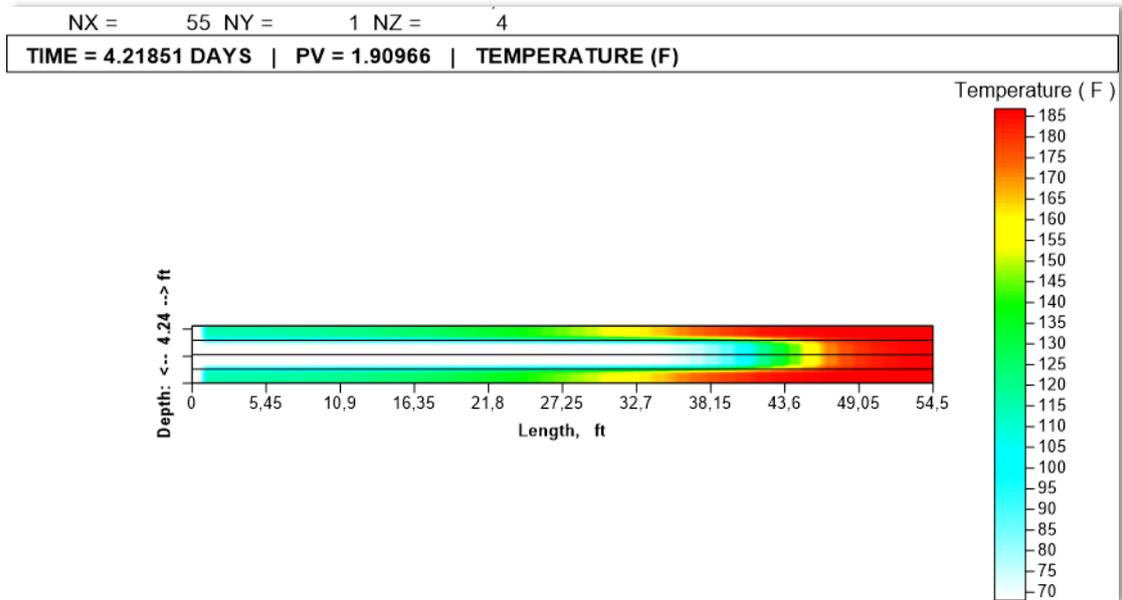
Figure 70 Temperature front after preflush, at the end of shut-in period
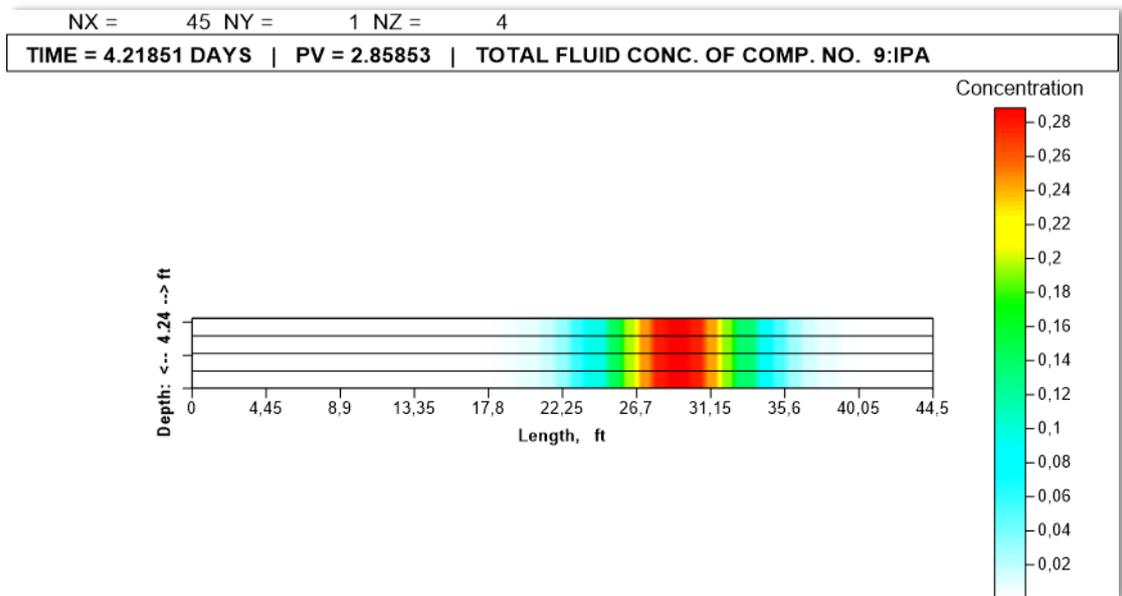
Figure 71 IPA position at the end of shut-in period
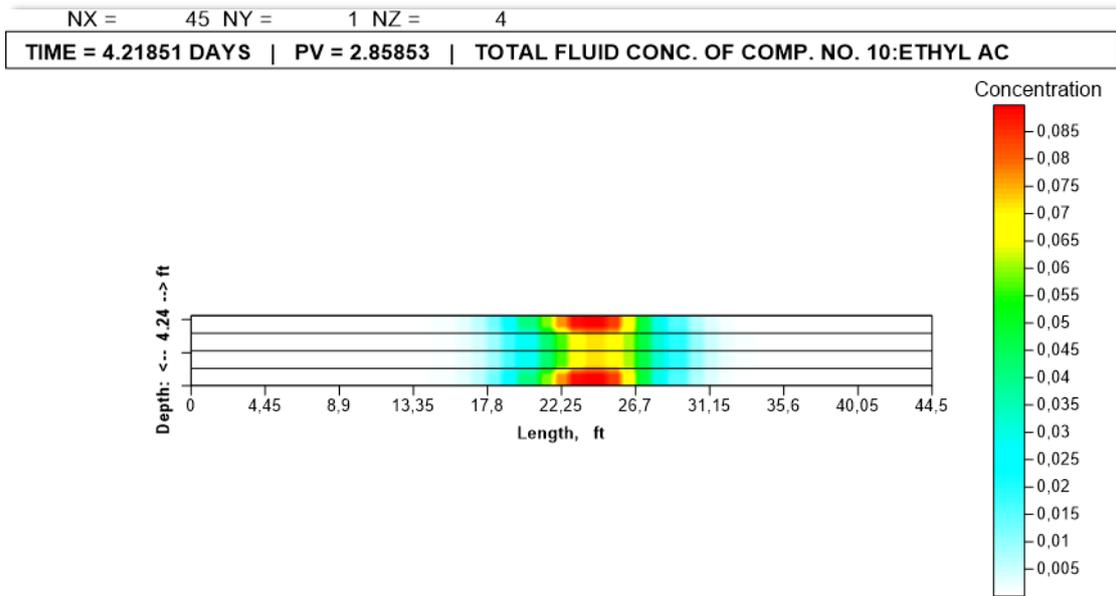
Figure 72 Ethyl Acetate's position at the end of shut-in period
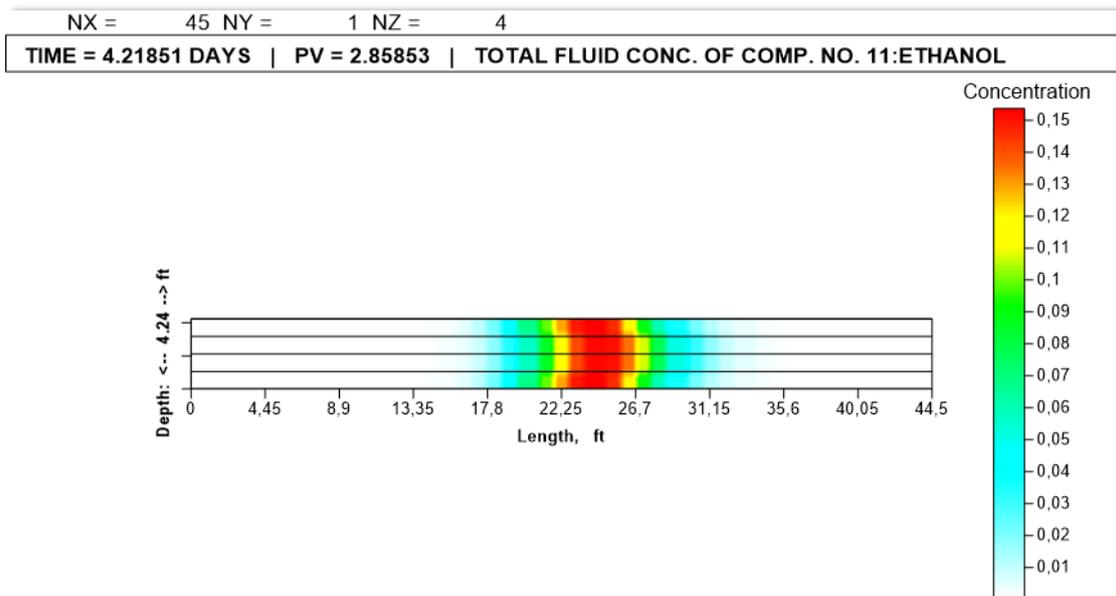
Figure 73 Produced ethanol's shifted position at the end of shut-in period
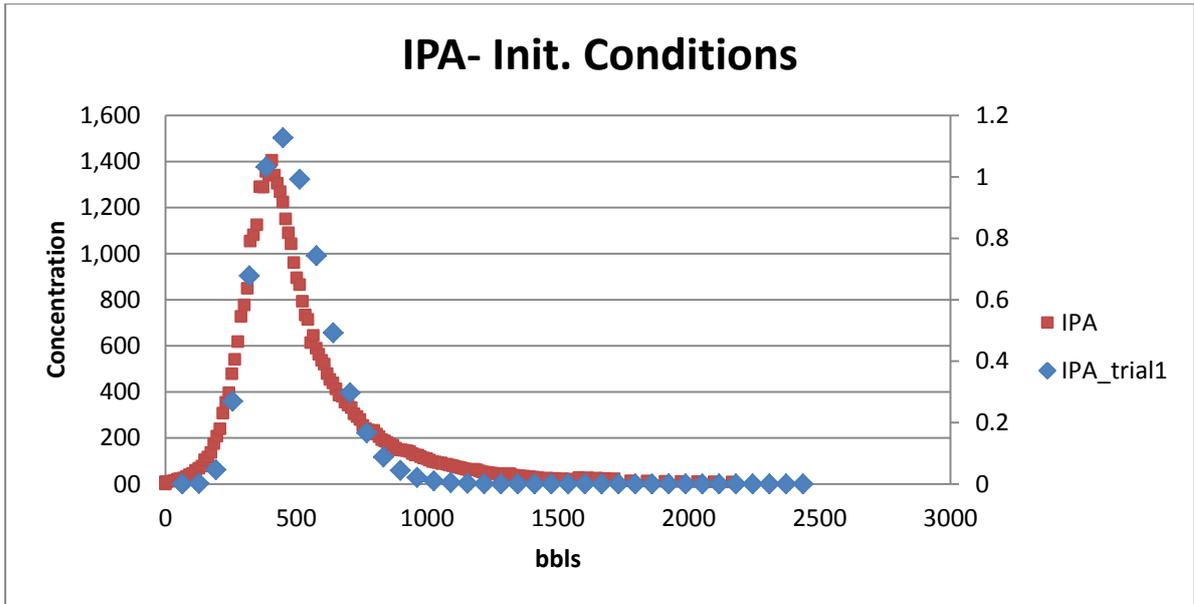
Figure 74 IPA profile- Trial (blue)-History data (red)
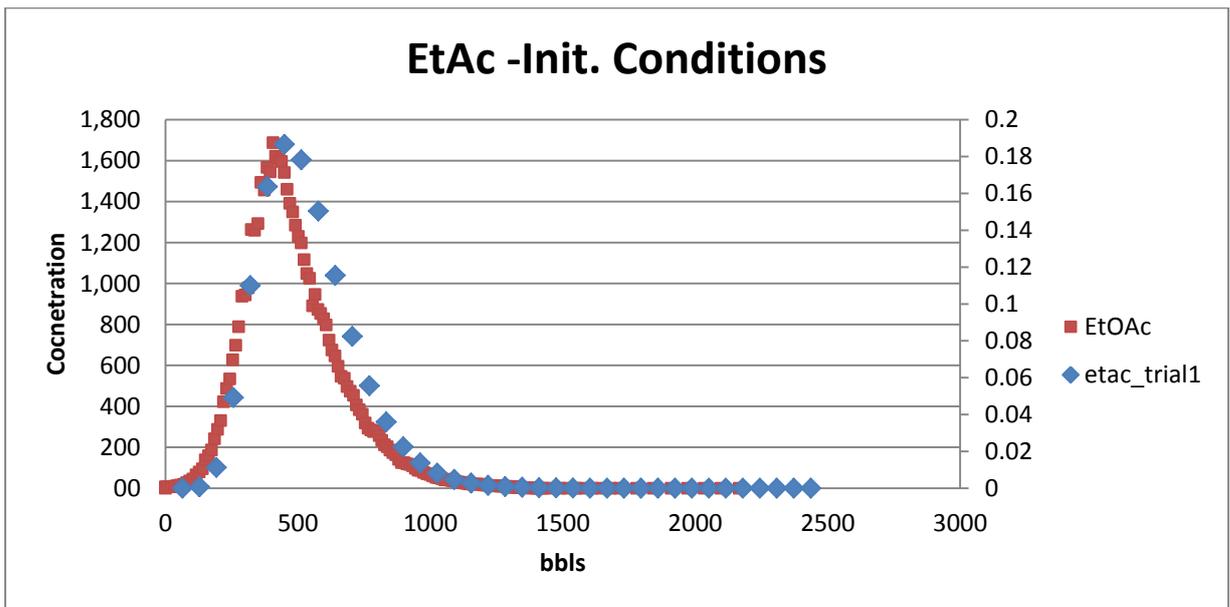
Figure 75 EtAc profile- Trial1 (blue)-History data (red)

Regarding the profiles, the IPA and Etac has to be produced earlier in time, while the Ethanol has a good match.
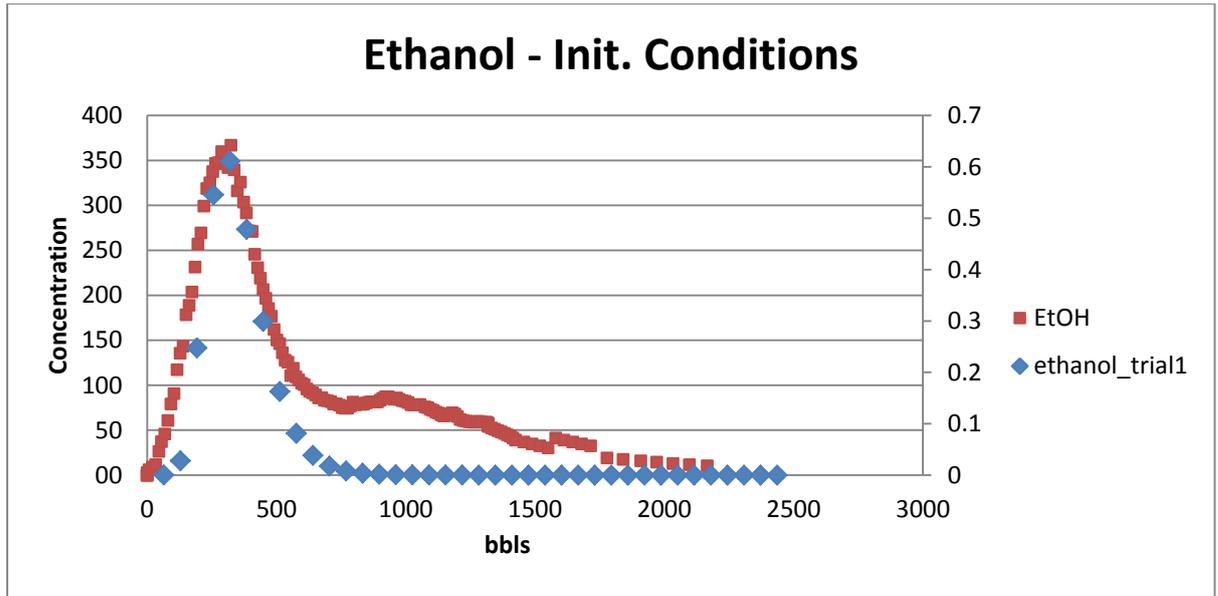
Figure 76 Produced ethanol profile - Trial 1 (blue)-History data (red)

Final Results

For matching the profiles of the tracers the changes shown below were performed.

Layers	Thickness	Sw
1	1.6	0.76
2	1.12	0.74
3	1.12	0.74
4	0.4	0.9

Table 30 Final matching values for thickness and Sw per layer
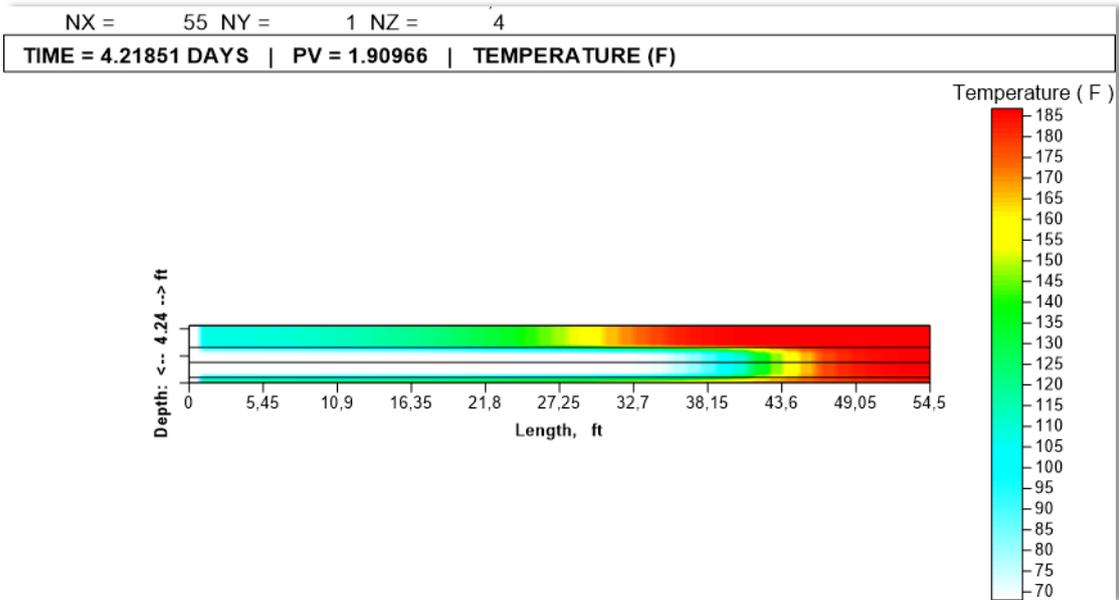
Figure 77 Temperature front after pre-flush, at the end of shut-in period
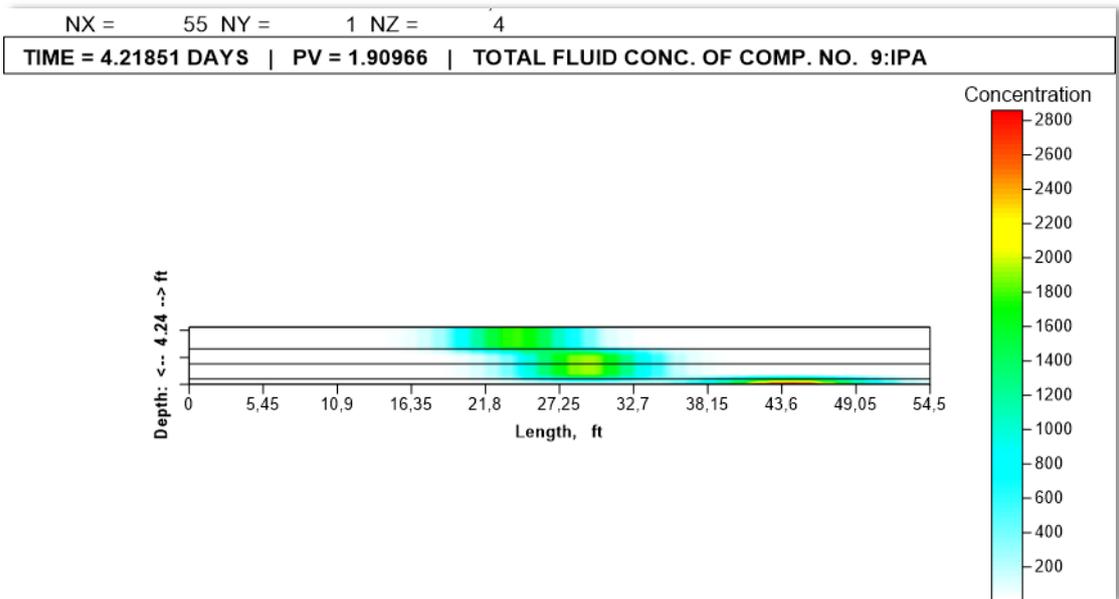
Figure 78 IPA position at the end of shut-in period

NX =   55 NY =   1 NZ =   4
TIME = 4.21851 DAYS | PV = 1.90966 | TOTAL FLUID CONC. OF COMP. NO. 10:ETHYL AC
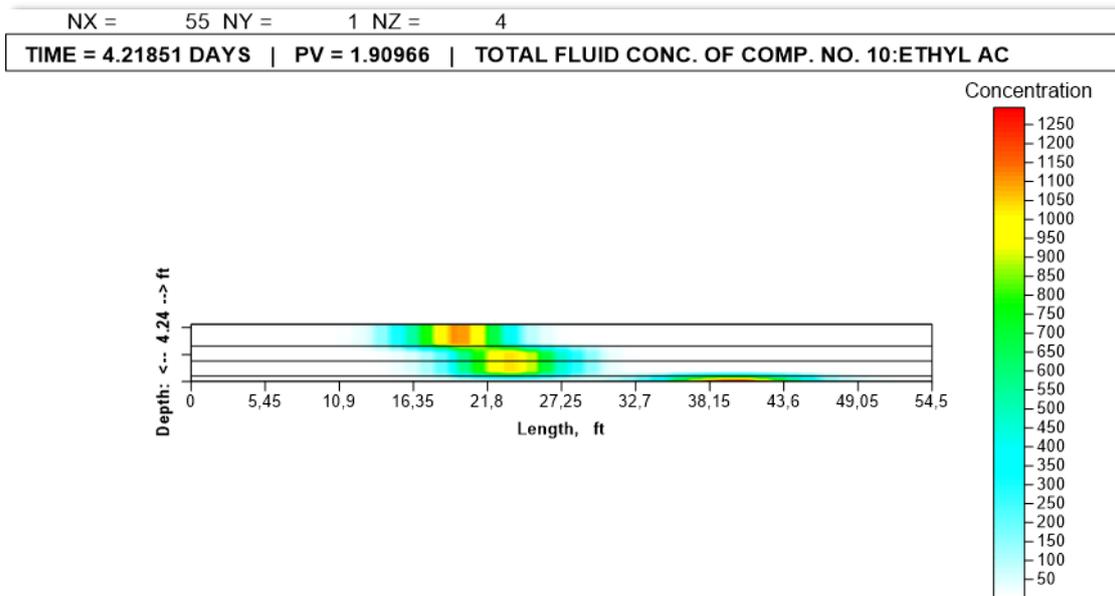
Figure 79 Ethyl Acetate position at the end of shut-in period

The temperature gradient is almost the same, only slightly changed for the last layer. The reaction takes place in different temperature for each layer. For the first one, the temperature is around to 130°F (54°C), for the second and third it is at 70°F (20 °C), while for the last it is around to 155°F (68°C). The ethanol distribution is shifted towards higher temperatures except from the last layer where the temperature is almost equal to that of the reservoir.

NX =   55 NY =   1 NZ =   4
TIME = 4.21851 DAYS | PV = 1.90966 | TOTAL FLUID CONC. OF COMP. NO. 11:ETHANOL
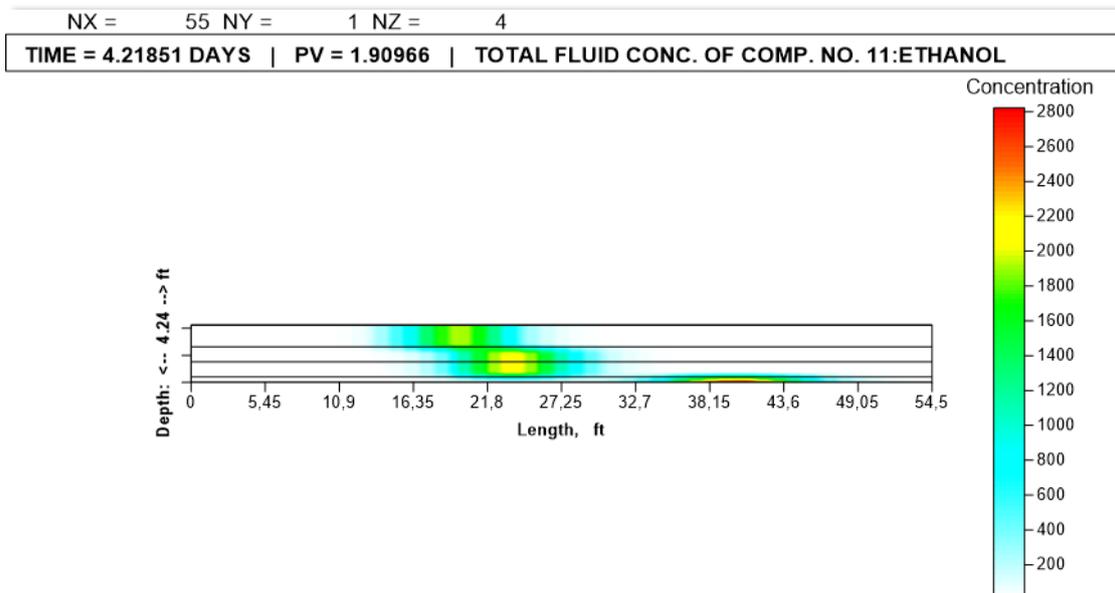
Figure 80 Produced ethanol shifted position at the end of shut-in period
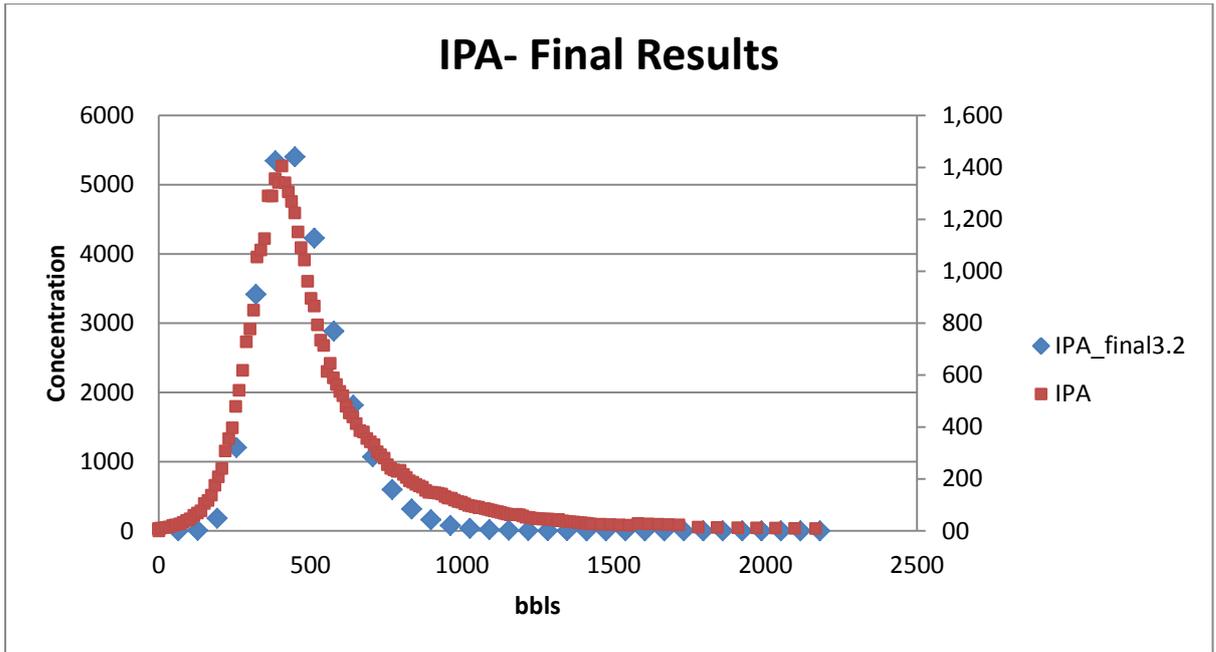
**Figure 81 IPA final matching- Final (blue)- History data (red)**
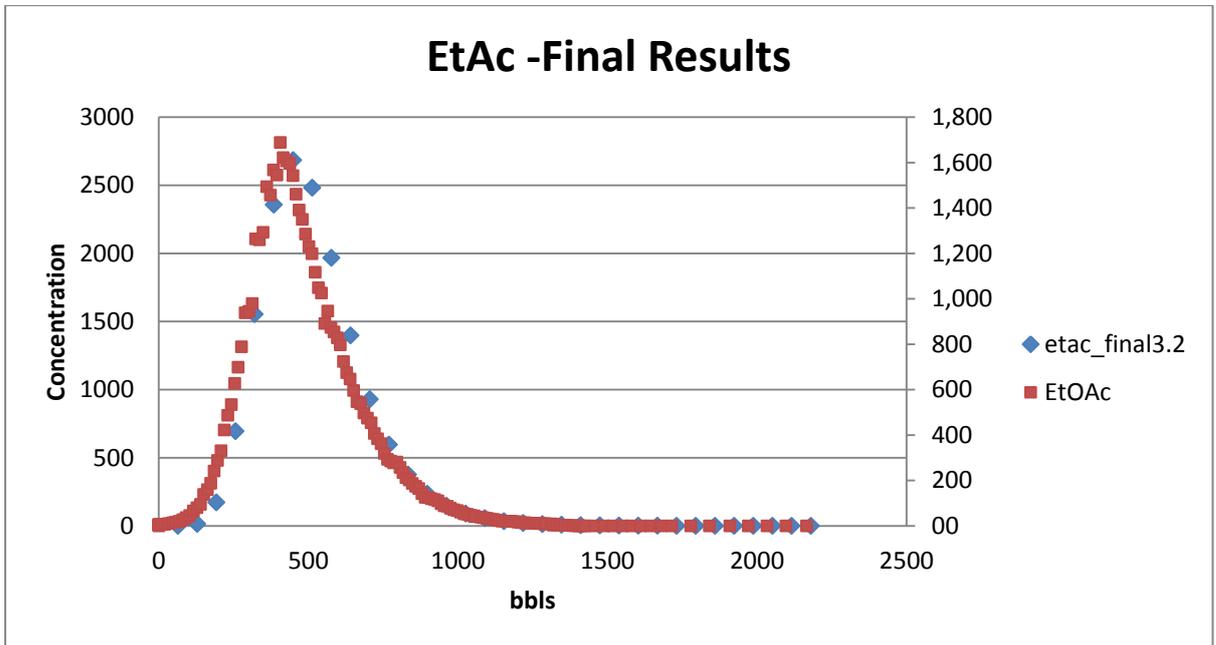
**Figure 82 EtAc final matching- Final (blue)- History data (red)**
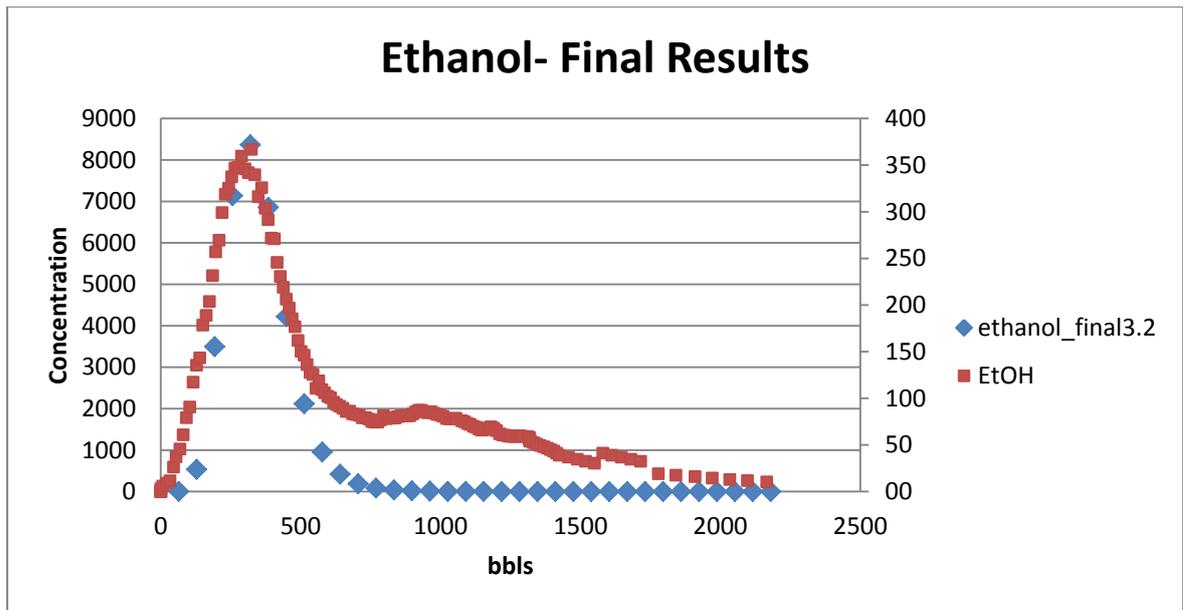
Again, the second peak of the ethanol could not be matched. The other two tracers have good final overlap with the history profiles.

7.3 Simulation Comparison

The history matching simulations presented previously can be categorized in two groups; first, the history matching simulating three layers (Simulations 1 &2) and second, the history matching using 4 layers (Simulation 3). In both groups the temperature effect is also taken into account, which is described in previous section.

About the 3-layerd case withour pre-flush the matching for IPA is very good, while for EtAc the tail is retarted more than that of the history data. It mentioned before that actually, the profile of EtAc is not changed at all during the implantation of the different changes. This fact is associated to the reaction of the tracer, as the production rate that could affect the tail of the profile did not have any impact. The final ethanol profile is much better from that of the beginning but still needed shifting at later time production.

About the 3-layerd case with pre-flush, IPA has a final good match. EtAc's profile it is not changed after the changes in thickness. It was tried to be improved but the overlap of IPA and EtAc was not good. Ethanol on the other hand, has a very good overlap with the history data profile. At this case, due to the natural shifting of the ethanol towards higher temperatures (after using the pre-flush volume), the delay of the ethanol was provided by the condition of the reaction itself.

Between these two simulations, better results gave the second one. IPA profiles are the same, as this tracer is not affected by the temperature or the Sw (fig 84). EtAc profiles (fig. 85) are the same in terms of the shape and the time that the peak concentration arrives,

but in terms of reaction, more ethyl acetate is consumed at the second case. Ethanol profile is obviously better matched at the second case (fig 86).
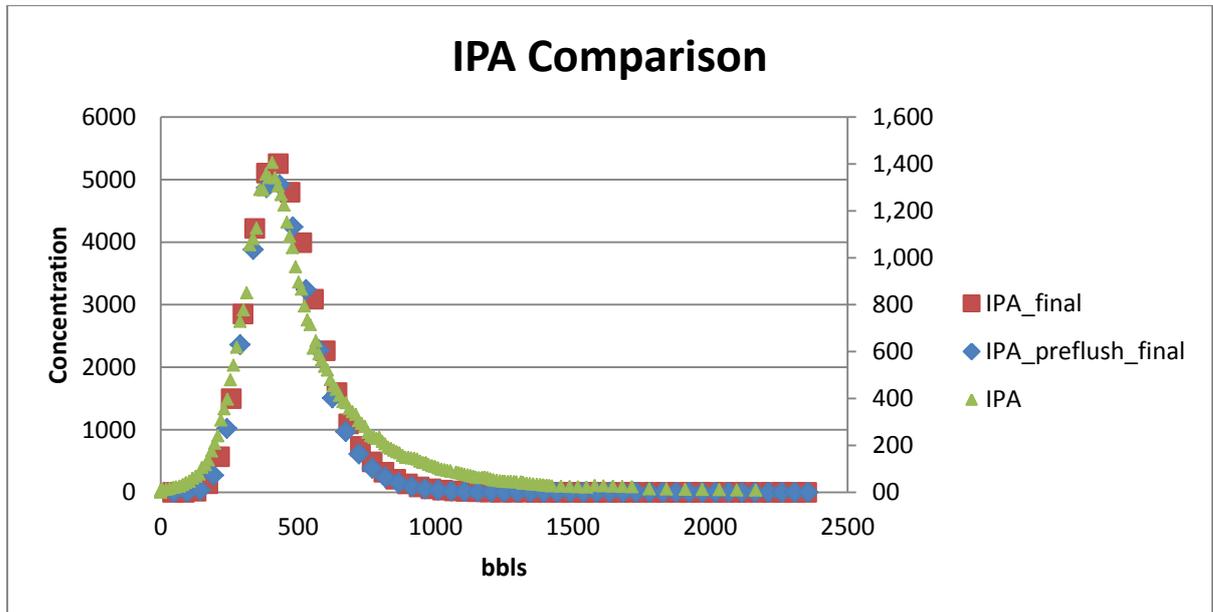
Figure 84 IPA profiles comparison. final: 3layer without pre-flus, pre-flush_final: 3 layer with pre-flush- Histroy data
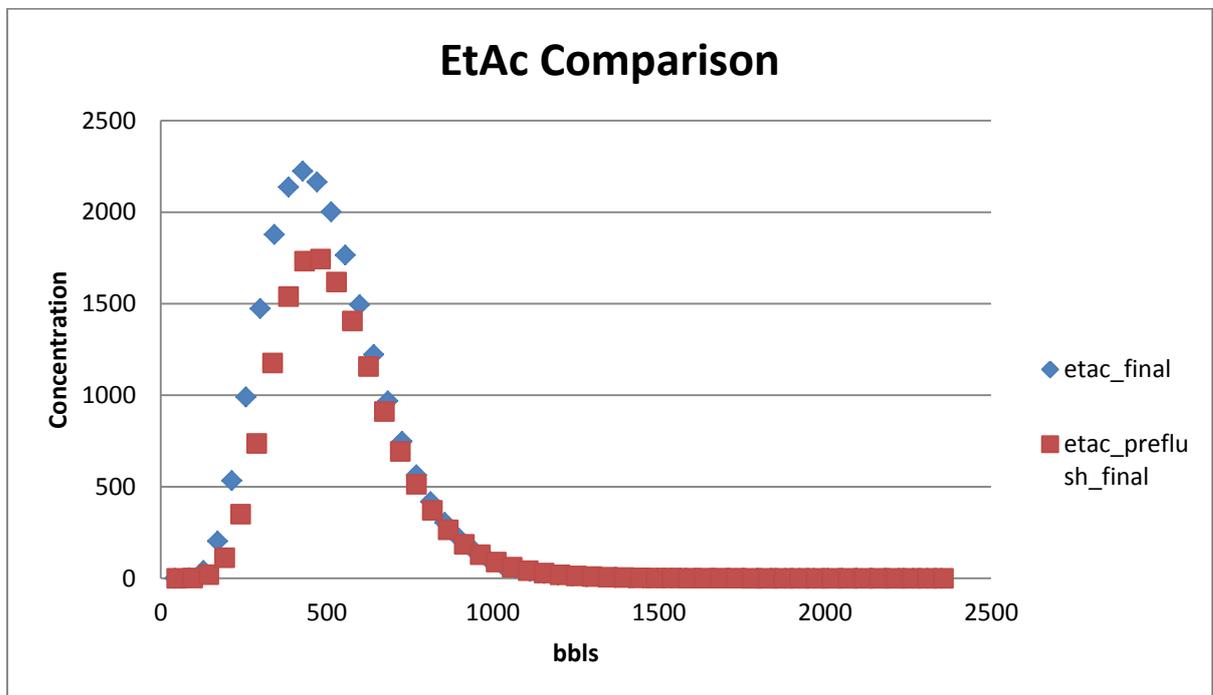
Figure 85 EtAc profiles comparison. final: 3layer without pre-flus, pre-flush_final: 3 layer with pre-flush
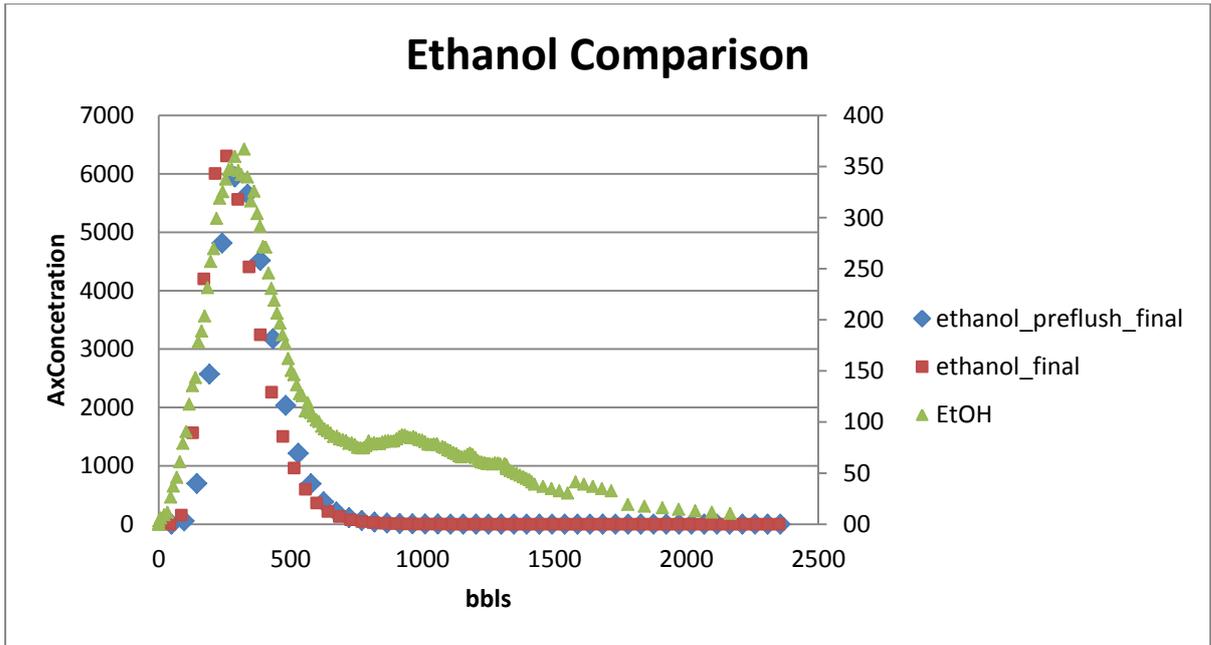
Figure 86 Produced ethanol profiles comparison. final: 3layer without pre-flus, pre-flush_final: 3 layer with pre-flush-History data (green)

Comparing the results of the cases with 4 layers without and with pre-flush, IPA profile (fig 87) is the same in both cases, as also the EtAc profile (fig. 88). For the ethanol, the second case gives better result in terms of history matching (fig. 89).
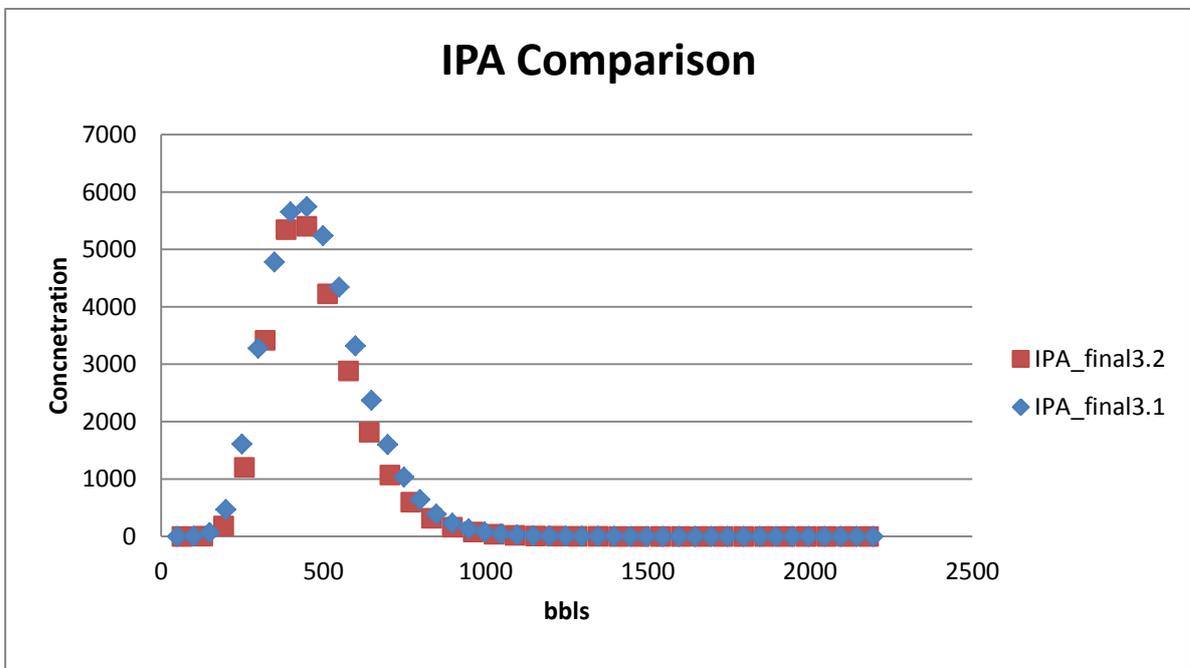
Figure 87 IPA Cmparison -final3.1: 4layer withour pre-flush, final3.2: 4layer with preflsuh

Figure 88 EtAc profiles comparison-final3.1: 4layer withour pre-flush, final3.2: 4layer with preflsuh

Figure 89 Produced ethanol profiles comparison- final3.1: 4 layer without pre-flush, final3.2: 4layer with pre-flush

The greater similarity in EtAc profile in this group simulation can be attributed to the number of the simulated layers and the consequent more accurate simulation of the different Sw values per layers that dominate the reservoir. In terms of chemical reaction, EtAc comparison can be depicted as below:
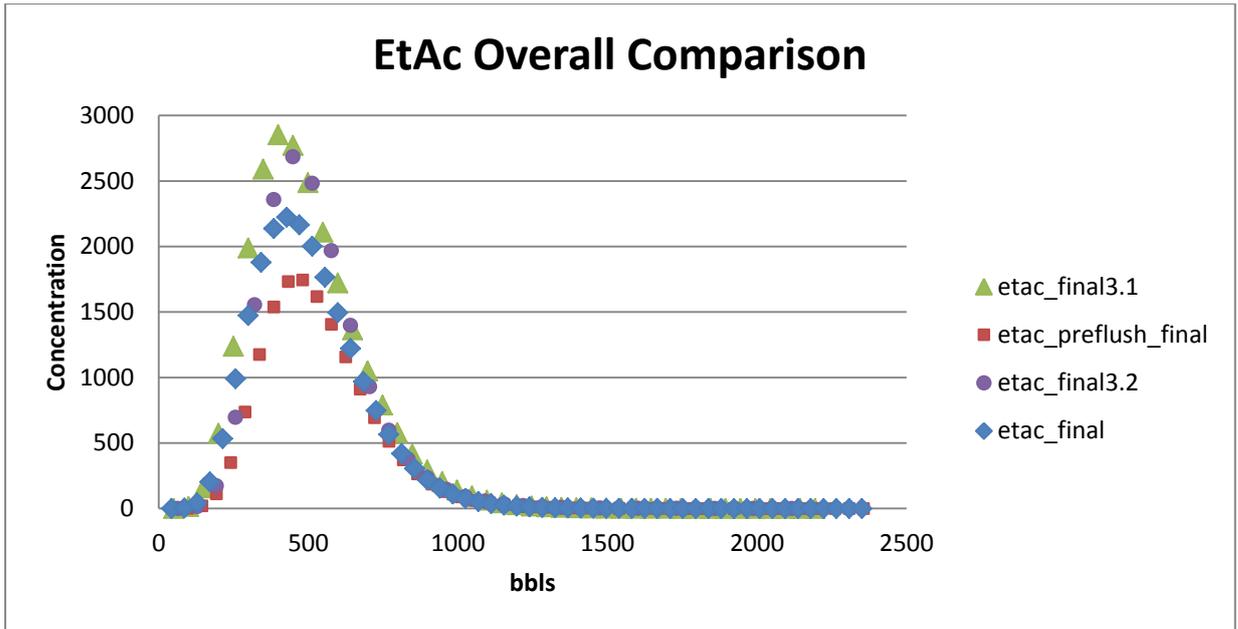
Figure 90 EtAc overall comparison
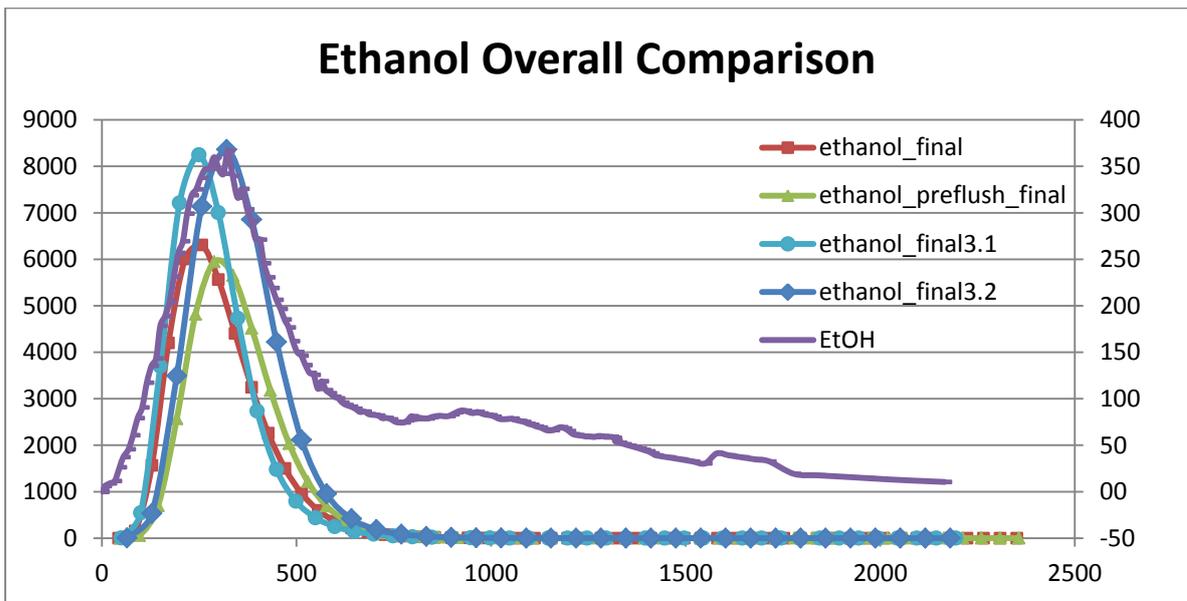
Figure 91 Overall Ethanol Comparison

It can be seen (Fig. 90) that more EtAc is reacted at 3layer with pre-flush simulation (red dots). At 3layer without pre-flush simulation less is consumed, and at the last two cases almost the same is reacted.

At fig. 91, the produced ethanol is compared. It is obvious that it is better matched the dark blue dots, (final 3.2), corresponding to the 4layer-with-pre-flush simulation.

8. Conclusions

The purpose of this work was to examine the Single-Well Tracer Test, used for S_{or} estimation, and the parameters affecting the test (reaction of tracer); temperature and injection rate. After this examination, the experience gained, was implemented in order to perform history matching on a real case scenario, and finally estimate Sor. The final S_{or} estimations, by the different simulations, are compared in order to point out the most satisfactory matching.

The chemical reaction that takes place during the SWTT, describes the hydrolysis of the main partitioning tracer (ester) that is injected, and the product of this hydrolysis, ethanol. The difference in the arrival time, after production, between the remained ester and the ethanol gives the final S_{or} estimation.

The temperature has a positive effect on this type of 1st-order reaction, resulting to more produced ethanol. However, as it is described, the reservoir temperature and the water temperature injected play significant role on the reaction. This significance is more intense when pre-flush volume of water is injected prior the implementation of the main test.

To sum up the results, these are the most important conclusions:

SWTT without pre-flush (tracers in front of the temperature front):
- Injection water temperature does not affect the reaction, in terms of the produced amount. The product ethanol has the same position after the shut in period with the EtAc.
- Higher reservoir temperature produces more ethanol. No effect on the position of the ethanol.

SWTT with pre-flush (tracers behind the temperature front):
- Injection water temperature affects the produced ethanol. For low temperatures, more ethanol is produced. The ethanol is shifted towards the higher temperatures, so the local chemical equilibrium is disturbed.
- Again, higher reservoir temperatures have a positive effect on the reaction.
- In cases of high reservoir temperatures (140°C), SWTT can be implemented after a suitable pre-flush volume with low enough temperature.

Comparing the above, the ethanol arrives later than that of the first. So, the **S_{or}** estimation value is **lower** in the **SWTT with pre-flush.**

For both cases, the injection rate has also a significant effect. The lower it is the more the produced ethanol. In cases with low injection rate, there is time, for the EtAc to react, during injection. This phenomenon is not desirable, as the reaction is supposed to take place only during shut-in period. Otherwise, the difference in arrival times is not representative and consequently the S_{or} estimation is wrong.

Regarding the history matching, two main simulations were conducted; one with 3 layers and another with 4 layers. In both simulations, the influence of the pre-flush was examined.

The S_{or} finally estimated, is not uniformly distributed for the whole investigated interval, as for every layer is attributed a different value. Also, the thickness of every layer is different, in the end.

Better results were obtained when pre-flush is used, as the necessary delay on the arrival time of ethanol was physically provided by the respective temperature effect described in detail. Of course, the detail of 4 layer simulation with pre-flush has an even better approximation on the reservoir condition.

The initial S_{or} value was 22% for the whole reservoir and after the history matching for **3-layer without pre-flush varies from 13%- 22%,** while **with pre-flush** remained at **22%.**

On the other hand for the **4-layer case without pre-flush, S_{or} varies from 10% to 22%**, while with **pre-flush from 10% to 24%.**

9. Bibliography

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10. Appendix

UTCHEM script example

```
CC******************************************************************
CC                              *
CC   BRIEF DESCRIPTION OF DATA SET : UTCHEM (VERSION 9.95)        *
CC                              *
CC******************************************************************
CC                              *
CC  SINGLE WELL TRACER INJECTION                    *
CC                              *
CC  OUTER RADIUS (FT) :        PROCESS : TRACER INJECTION    *
CC  THICKNESS (FT) :        INJ. RATE (FT3/DAY) :        *
CC                    COORDINATES : RADIAL        *
CC  POROSITY : 0.25        VERTICAL   WELL            *
CC  GRID BLOCKS : 35X1X4                    *
CC  DATE : June 2011                      *
CC                              *
CC******************************************************************
CC
CC******************************************************************
CC                              *
CC   RESERVOIR DESCRIPTION                    *
CC                              *
CC******************************************************************
CC
CC
*----RUN NUMBER
UTEX05
CC
CC
*----TITLE
RUN: EX05, SINGLE-WELL TRACER TEST
RADIAL OPTION, REACTING TRACER IS ETAC WITH TEMP. VARIATION
CONSTANT INJECTION IN EACH LAYER, INCLUDES SHUT IN PERIOD
CC
CC SIMULATION FLAGS
*---- IMODE IMES IDISPC ICWM ICAP IREACT IBIO ICOORD ITREAC  ITC  IGAS IENG
    1   4   3   0   0   0   0   2   1   0   0   1
```

CC
CC NUMBER OF GRID BLOCKS AND FLAG SPECIFIES CONSTANT OR VARIABLE GRID SIZE
*----NX   NY NZ IDXYZ   IUNIT
   35 1 4 0   0
CC
CC CONSTANT GRID BLOCK SIZE IN R, AND Z
*----R(1) dx   dz
   0.25 1 5.0
CC
CC TOTAL NO. OF COMPONENTS, NO. OF TRACERS, NO. OF GEL COMPONENTS
*----N   NO NTW NTA NGC NG NOTH
   11 0   3   0 0 0 0
CC
CC IF THERE IS TRACER, NAME OF THE TRACERS
*---- SPNAME(IT) FOR IT=1,NT
WATER
OIL
NONE
NONE
NONE
NONE
NONE
NONE
IBA
ETHYL ACETATE
ETHANOL
CC
CC FLAG INDICATING THE UNITS OF INJECTED TRACERS (1 = VOL% , 2 = WT%)
*----ITRU(IT) FOR IT=1,NT
   1 1 1
CC
CC FLAG INDICATING IF THE COMPONENT IS INCLUDED IN CALCULATIONS OR NOT
*----ICF(KC) FOR KC=1,N
   1 1 0 0 0 0 0 0 1 1 1
CC
CC**
CC   *
CC   OUTPUT OPTIONS   *
CC   *
CC**
CC
CC
CC PV OR DAYS(1:P.V,0:DAYS)TO PRINT OR STOP
*----ICUMTM   ISTOP   IOUTGMS IS3G
     0   0   0   0

CC
CC FLAG INDICATING IF THE PROFILE OF KCTH COMPONENT SHOULD BE WRITTEN
*----IPRFLG(KC),KC=1,N
   0 0 0 0 0 0 0 0 1 1 1
CC
CC FLAG FOR PRES,SAT.,TOTAL CONC.,TRACER CONC.,CAP.,GEL, ALKALINE PROFILES
*----IPPRES IPSAT IPCTOT IPBIO IPCAP IPGEL IPALK IPTEMP IPOBS
    1   1   1   1   0   0   0   1   1
CC
CC FLAG FOR WRITING SEVERAL PROPERTIES
*----ICKL IVIS IPER ICNM ICSE IFOAM IHYST INONEQ
    0   0   0   0   0   0   0   0
CC
CC FLAG FOR WRITING SEVERAL PROPERTIES TO PROF
*----IADS IVEL IRKF IPHSE
    0   0   0   0
CC
CC
*----NOBS
        1
CC
CC
*----IOBS JOBS ZOBS
     1   1   1
CC
CC**
CC   *
CC   RESERVOIR PROPERTIES   *
CC   *
CC**
CC
CC
CC MAX. SIMULATION TIME (DAYS)
*---- TMAX
    3.90
CC
CC ROCK COMPRESSIBILITY (1/PSI), STAND. PRESSURE(PSIA)
*----COMPR PSTAND
    0.   2000.
CC
CC FLAGS INDICATING CONSTANT OR VARIABLE POROSITY, X,Y,AND Z PERMEABILITY
*----IPOR1 IPERMX IPERMY IPERMZ IMOD ITRNZ   INTG
     0   0   0   0 0 0   0
CC
CC CONSTANT POROSITY

```
*----PORC1
  .25
CC
CC CONSTANT X-PERMEABILITY (MILIDARCY) FOR LAYER K = 1,NZ
*----PERMX(1)
  2000.0
CC
CC CONSTANT Z-PERMEABILITY (MILIDARCY) FOR LAYER K = 1,NZ
*----PERMZ(1)
  0.0
CC
CC FLAG FOR CONSTANT OR VARIABLE DEPTH, PRESSURE, WATER SATURATION
*----IDEPTH  IPRESS  ISWI  ICWI
   0     1     1   -1
CC
CC CONSTANT DEPTH (FT)
*----D111
  9135.
CC
CC CONSTANT PRESSURE (PSIA) AT DEPTH (FT)
*----PINIT    HINIT
  2000.   9135.
CC
CC CONSTANT INITIAL WATER SATURATION
*----S(K,I)
  0.75  0.715  0.805  0.820
CC
CC CONSTANT CHLORIDE AND CALCIUM CONCENTRATIONS (MEQ/ML)
*----C50    C60
  0.00    0.00
CC
CC****************************************************************
CC                                                    *
CC   PHYSICAL PROPERTY DATA                      *
CC                                                *
CC****************************************************************
CC
CC
CC OIL CONC. AT PLAIT POINT FOR TYPE II(+)AND TYPE II(-), CMC
*---- C2PLC   C2PRC  EPSME  IHAND
  0.    1.    .0001   0
CC
CC FLAG INDICATING TYPE OF PHASE BEHAVIOR PARAMETERS
*---- IFGHBN
     0
```

CC SLOPE AND INTERCEPT OF BINODAL CURVE AT ZERO, OPT., AND 2XOPT SALINITY
CC FOR ALCOHOL 1
*----HBNS70 HBNC70 HBNS71 HBNC71 HBNS72 HBNC72
   0.001 .030 .191 .026 .363 .028
CC
CC SLOPE OF BINODAL WITH TEMP., SLOPE OF SALINITY WITH TEMP. (1/F)
*---- HBNT0   HBNT1   HBNT2   CSET
    0.00017 0.00017 0.00017 0.00415
CC SLOPE AND INTERCEPT OF BINODAL CURVE AT ZERO, OPT., AND 2XOPT SALINITY
CC FOR ALCOHOL 1
*----HBNS70 HBNC70 HBNS71 HBNC71 HBNS72 HBNC72
   0.00 .0 .0 .0 .0 .0
CC
CC LOWER AND UPPER EFFECTIVE SALINITY FOR ALCOHOL 1 AND ALCOHOL 2
*----CSEL7 CSEU7 CSEL8 CSEU8
   .177 .344 0. 0.
CC
CC THE CSE SLOPE PARAMETER FOR CALCIUM AND ALCOHOL 1 AND ALCOHOL 2
*----BETA6 BETA7 BETA8
   0. -2. 0.
CC
CC FLAG FOR ALCOHOL PART. MODEL AND PARTITION COEFFICIENTS
*----IALC OPSK7O OPSK7S OPSK8O OPSK8S
   1 0. 0. 0. 0.
CC
CC NO. OF ITERATIONS, AND TOLERANCE
*----NALMAX EPSALC
   0 0.
CC
CC ALCOHOL 1 PARTITIONING PARAMETERS IF IALC=1
*----AKWC7 AKWS7 AKM7 AK7 PT7
   4.671 1.79 48. 35.31 .222
CC
CC ALCOHOL 2 PARTITIONING PARAMETERS IF IALC=1
*----AKWC8 AKWS8 AKM8 AK8 PT8
   0. 0. 0. 0. 0.
CC
CC IFT MODEL FLAG
*--- IFT
   0
CC
CC INTERFACIAL TENSION PARAMETERS
*----G11 G12 G13 G21 G22 G23
   13. -14.8 .007 13. -14.5 .010
CC

CC LOG10 OF OIL/WATER INTERFACIAL TENSION
*----XIFTW
   1.3
CC
CC MASS TRANSFER FLAG
*---- IMASS ICOR
    0   0
cc
cc
*---- iwalt iwalf
    0   0
CC
CC CAPILLARY DESATURATION PARAMETERS FOR PHASE 1, 2, AND 3
*----ITRAP T11   T22   T33
   0   0.   0.   0.
CC
CC RELATIVE PERM. FLAG (0:IMBIBITION COREY,1:FIRST DRAINAGE COREY)
*---- IPERM   IRTYPE
    0   0
CC
CC FLAG FOR CONSTANT OR VARIABLE REL. PERM. PARAMETERS
*----ISRW IPRW IEW
   0   0   0
CC
CC CONSTANT RES. SATURATION OF PHASES 1,2,AND 3 AT LOW CAPILLARY NO.
*----S1RWC S2RWC S3RWC
   .25   .5   .0
CC
CC ENDPOINT REL. PERM. OF PHASES 1,2,AND 3 AT LOW CAPILLARY NO.
*----P1RW P2RW P3RW
   1.0 1.0   1.0
CC
CC REL. PERM. EXPONENT OF PHASES 1,2,AND 3 AT LOW CAPILLARY NO.
*----E1W E2W E3W
   1.4 1.4 2.
CC
CC WATER AND OIL VISCOSITY , RESERVOIR TEMPERATURE
*----VIS1 VIS2 TSTAND
   1.0   1.0   186.8
CC
CC VISCOSITY-TEMP. PARAMETER
*-----BVI(1) BVI(2)
    0.0   0.0
CC
CC VISCOSITY PARAMETERS

*----ALPHA1 ALPHA2 ALPHA3 ALPHA4 ALPHA5
   0.   0.   0.   0.   0.
CC
CC PARAMETERS TO CALCULATE POLYMER VISCOSITY AT ZERO SHEAR RATE
*----AP1   AP2   AP3
   52.   2430. 40000.
CC
CC PARAMETER TO COMPUTE CSEP,MIN. CSEP, AND SLOPE OF LOG VIS. VS. LOG CSEP
*----BETAP CSE1 SSLOPE
   1.   .01 .175
CC
CC PARAMETER FOR SHEAR RATE DEPENDENCE OF POLYMER VISCOSITY
*----GAMMAC GAMHF POWN   IPMOD   ishear rweff GAMHF2
   4.   20.   1.1   0   0   0.25   0
CC
CC FLAG FOR POLYMER PARTITIONING, PERM. REDUCTION PARAMETERS
*----IPOLYM EPHI3 EPHI4 BRK   CRK   RKCUT
   1   1.   1.   1000. 0.0186   10
CC
CC SPECIFIC WEIGHT FOR COMPONENTS 1,2,3,7,AND 8 , AND GRAVITY FLAG
*----DEN1 DEN2 DEN23   DEN3 DEN7 DEN8 IDEN
   .433   .433 0.433 .42 .346 0.   1
CC
CC FLAG FOR CHOICE OF UNITS (0: FT3 AT BOTTOMHOLE CONDITION, 1: STB)
*-----ISTB
    0
CC
CC COMPRESSIBILITY FOR VOL. OCCUPYING COMPONENTS 1,2,3,7,AND 8
*----COMPC(1) COMPC(2) COMPC(3) COMPC(7) COMPC(8)
   0.   0.   0.   0.   0.
CC
CC CONSTANT OR VARIABLE PC PARAM., WATER-WET OR OIL-WET PC CURVE FLAG
*----ICPC   IEPC IOW
   0   0 0
CC
CC CAPILLARY PRESSURE PARAMETER, CPC
*----CPC
   0.
CC
CC CAPILLARY PRESSURE PARAMETER, EPC
*---- EPC
    6.
CC
CC MOLECULAR DIFFUSIVITY OF KCTH COMPONENT IN PHASE 1 (D(KC),KC=1,N)
*D(1) D(2) D(3) D(4) D(5) D(6) D(7) D(8) D(9) D(10) D(11)

```
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
CC
CC MOLECULAR DIFFUSIVITY OF KCTH COMPONENT IN PHASE 2 (D(KC),KC=1,N)
*D(1) D(2) D(3) D(4) D(5) D(6) D(7) D(8) D(9) D(10) D(11)
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
CC
CC MOLECULAR DIFFUSIVITY OF KCTH COMPONENT IN PHASE 3 (D(KC),KC=1,N)
*D(1) D(2) D(3) D(4) D(5) D(6) D(7) D(8) D(9) D(10) D(11)
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
CC
CC LONGITUDINAL AND TRANSVERSE DISPERSIVITY OF PHASE 1
*----ALPHAL(1)    ALPHAT(1)
   0.5       0.0
CC
CC LONGITUDINAL AND TRANSVERSE DISPERSIVITY OF PHASE 2
*----ALPHAL(2)    ALPHAT(2)
   0.5       0.0
CC
CC LONGITUDINAL AND TRANSVERSE DISPERSIVITY OF PHASE 3
*----ALPHAL(3)    ALPHAT(3)
   0.5       0.0
CC
CC FLAG TO SPECIFY ORGANIC ADSORPTION CALCULATION
*----IADSO
    0
CC
CC SURFACTANT AND POLYMER ADSORPTION PARAMETERS
*----AD31 AD32  B3D   AD41  AD42  B4D IADK, IADS1, FADS refk
   1.  .5   1000. .7    0.  100. 0    0    0   0
CC
CC PARAMETERS FOR CATION EXCHANGE OF CLAY AND SURFACTANT
*----QV   XKC  XKS  EQW
   0.0   0.0  0.0  1.
CC
CC TRACER PARTITIONING COEFFICIENT (TK(IT),IT=1,NT)
*---- TK(1)  TK(2)  TK(3)
   .0    3.3   0.
CC
CC TRACER PARTITION COEFFICIENT SALINITY PARAMETER (1/MEQ/ML)
*----TKS(IT), IT=1,NT    C5INI
    0.0  0.0    0.0  0.0
CC
CC TRACER PARTITIONING COEF. TEMP. DEPENDENT (1/F)
*-----TKT(IT),IT=1, NT
    0.0   0.0045  0.0
```

CC
CC RADIACTIVE DECAY COEFFICIENT (RDC(IT),IT=1,NT)
*---- RDC(1) RDC(2) RDC(3)
    .0   .0   .0
CC
CC TRACER RETARDATION COEFFICIENT (RET(IT),IT=1,NT)
*---- RET(1)   RET(2) RET(3)
    .0   0.   0.
CC
CC TRACER REACTION RATE (DAYS-1)
*---- NRT TAK1
    1 0.0768
CC
CC TRACER MOLECULAR WEIGHT (TMW(IT),IT=1,NT)
*---- TMW(1) TMW(2)   TMW(3)
   74.123   88.107   46.069
CC
CC TRACER DENSITY IN G/CC (TDEN(IT),IT=1,NT)
*---- TDEN(1) TDEN(2)   TDEN(3)
   0.802   0.901   0.789
CC
CC TEMP. DEPENDENT TRACER REACTION COEF. PARAMETER
*----TAKT
   -7988.0
CC
CC INITIAL RESERVOIR TEMPERATURE
*----TEMPI(F)
   248.0
CC
CC ROCK DENSITY, RES.THERMAL CONDUCTIVITY, ROCK AND FLUID HEAT CAPACITY
*----DENS(LB/FT3) CRTC   CVSPR   CVSPL(1) CVSPL(2) CVSPL(3)
   115.5   0.0   0.275   0.6   0.6   0.0
CC
CC HEATLOSS FLAG, ANALYTICAL FLAG
*-----IHLOS   IANAL
     1   0
CC
CC OVERBURDEN AND UNDERBURDEN THERMAL PROPERTIES
*-----TCONO,DENO, CVSPO,TCONU,DENU,CVSPU
   35. 115.5   0.275 35. 115.5 0.275
CC**
CC   *
CC   *
CC   WELL DATA   *
CC   *

CC**
CC
CC
CC FLAG FOR PRESSURE CONST. BOUNDARIES
*---- IBOUND IZONE
    0   0
CC
CC TOTAL NO. OF WELLS, WELL RADIUS FLAG, TIME OR COURANT NO
*----NWELL IRO ITIME NWREL
     4   2   0   4
CC
CC WELL LOCATIONS, FLAG FOR SPECIFYING WELL TYPE, WELL RADIUS, SKIN, PERF.
*----IDW IW JW IFLAG RW   SWELL IDIR KFIRST KLAST IPRF
   1 1 1 1   .25   0. 3   1   1   0
CC
CC NAME OF THE WELL
*---- WELNAM
SSXL1
CC
CC ICHEK MAX. AND MIN. ALLOWABLE BOTTOMHOLE PRESSURE AND RATE
*----ICHEK PWFMIN PWFMAX QTMIN QTMAX
    2   0.0   9000. 0.0   9000.
CC
CC WELL LOCATIONS, FLAG FOR SPECIFYING WELL TYPE, WELL RADIUS, SKIN, PERF.
*----IDW IW JW IFLAG RW   SWELL IDIR KFIRST KLAST IPRF
   2 1 1 1   .25   0. 3   2   2   0
CC
CC NAME OF THE WELL
*---- WELNAM
SSXL2
CC
CC ICHEK , MAX. AND MIN. ALLOWABLE BOTTOMHOLE PRESSURE AND RATE
*----ICHEK PWFMIN PWFMAX QTMIN QTMAX
    2   0.0   9000. 0.0   9000.
CC
CC WELL LOCATIONS, FLAG FOR SPECIFYING WELL TYPE, WELL RADIUS, SKIN, PERF.
*----IDW IW JW IFLAG RW   SWELL IDIR KFIRST KLAST IPRF
   3 1 1 1   .25   0. 3   3   3   0
CC
CC NAME OF THE WELL
*---- WELNAM
SSXL3
CC
CC MAX. AND MIN. ALLOWABLE BOTTOMHOLE PRESSURE AND RATE
*---- ICHEK PWFMIN PWFMAX QTMIN QTMAX

```
     2   0.0   9000. 0.0   9000.
CC
CC WELL LOCATIONS, FLAG FOR SPECIFYING WELL TYPE, WELL RADIUS, SKIN, PERF.
*----IDW IW JW IFLAG   RW    SWELL IDIR KFIRST KLAST IPRF
    4  1  1  1    .25    0. 3   4    4    0
CC
CC NAME OF THE WELL
*---- WELNAM
SSXL4
CC
CC MAX. AND MIN. ALLOWABLE BOTTOMHOLE PRESSURE AND RATE
*----ICHEK  PWFMIN  PWFMAX QTMIN  QTMAX
    2   0.0   9000. 0.0   9000.
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID  QI(M,L)  C(M,KC,L)
    1   5000  1.0  0. 0. 0. 0. 0. 0. 0. 1435. 13160. 0.
    1   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    1   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID  TEMPINJ
    1  68.0
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID  QI(M,L)  C(M,KC,L)
    2   2900.709  1.0  0. 0. 0. 0. 0. 0. 0. 1435. 13160. 0.
    2   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    2   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID  TEMPINJ
    2  43.0
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID  QI(M,L)  C(M,KC,L)
    3   1839.474  1.0  0. 0. 0. 0. 0. 0. 0. 1435. 13160. 0.
    3   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    3   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID  TEMPINJ
    3  43.0
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
```

```
*----ID   QI(M,L)  C(M,KC,L)
   4   778.239   1.0  0. 0. 0. 0. 0. 0. 0. 1435. 13160. 0.
   4   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   4   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
    4   43.0
CC
CC CUM. INJ. TIME , AND INTERVALS (PV OR DAY) FOR WRITING TO OUTPUT FILES
*----TINJ   CUMPR1  CUMHI1   WRHPV   WRPRF  RSTC
 0.211  0.249  0.249     10.   0.07141   1.25
CC
CC FOR IMES=3 ,THE INI. TIME STEP,CONC. TOLERANCE,MIN. AND MAX. TIME STEP
*----DT      DCLIM   DTMAXF(C.N=0.5)   DTMINF(C.N=0.05)
   0.0001 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.0008     0.00005
CC
CC
*--- IBMOD
   0
CC
CC IRO, ITIME AND NEW FLAG FOR ALL THE WELLS
*---- IRO ITIME IFLAG
    2   1   1 1 11
CC
CC  NO. OF WELL CHANGS IN LOCATION OR SKIN
*----NWEL1
   0
CC
CC  NO. OF WELLS WITH RATE CHANGES,, ID
*---- NWEL2   ID
    4     1 2 3 4
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L)  C(M,KC,L)
   1   5000   1.0  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   1   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   1   0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
   1   68.0
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L)  C(M,KC,L)
```

```
    2  2900.709  1.0  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    2  0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    2  0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
```
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
```
    2  43.0
```
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L) C(M,KC,L)
```
    3  1839.474  1.0  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    3  0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    3  0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
```
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
```
    3  43.0
```
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L) C(M,KC,L)
```
    4  778.239  1.0  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    4  0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
    4  0.      0.   0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
```
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
```
    4  43.0
```
CC
CC CUM. INJ. TIME , AND INTERVALS (PV OR DAY) FOR WRITING TO OUTPUT FILES
*----TINJ   CUMPR1 CUMHI1   WRHPV   WRPRF   RSTC
```
 0.635    10.    10.    10.    0.394    10.
```
CC
CC FOR IMES=3 ,THE INI. TIME STEP,CONCS,TOLERANCE,MIN. AND MAX. COURANT NO.
*----CN   DCLIM   CNMAX   CNMIN
```
   0.0001 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1  0.5     0.01
```
cc
cc
*--- ibmod
```
   0
```
CC
CC IRO, ITIME, FLAG
*---- IRO ITIME IFLAG
```
    2   0   1 1 1 1
```
CC
CC NO. OF WELLS WITH CHANGES IN LOCATION OR SKIN

```
*----NWEL1
   0
CC
CC NO. OF WELLS WITH RATE CHANGES, ID
*----NWEL2  ID
   4    1 2 3 4
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L)  C(M,KC,L)
   1   0.    0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   1   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   1   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
   1  68.0
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L)  C(M,KC,L)
   2   0.    0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   2   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   2   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
   2  43.0
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L)  C(M,KC,L)
   3   0.    0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   3   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   3   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
   3  43.0
CC
CC ID,INJ. RATE AND INJ. COMP. FOR RATE CONS. WELLS FOR EACH PHASE (L=1,3)
*----ID   QI(M,L)  C(M,KC,L)
   4   0.    0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   4   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
   4   0.     0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
CC
CC ID, INJECTION TEMPERATURE IN DEGREE F
*----ID   TEMPINJ
```

```
    4   43.0
CC
CC CUM. INJ. TIME , AND INTERVALS (PV OR DAY) FOR WRITING TO OUTPUT FILES
*----TINJ   CUMPR1  CUMHI1    WRHPV    WRPRF   RSTC
 1.435   10.     10.     10.     0.899   10.
CC
CC FOR IMES=3 ,THE INI. TIME STEP,CONC. TOLERANCE,MIN. AND MAX. TIME STEP
*----DT      DCLIM   DTMAXS    DTMINS
   0.005 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1   0.03     0.005
cc
cc
*--- ibmod
   0
CC
CC IRO, ITIME, NEW FLAGS
*---- IRO  ITIME IFLAG
   2    1    4 4 4 4
CC
CC  NO. OF WELLS WITH CHANGES IN LOCATION OR SKIN
*----NWEL1
   0
CC
CC NO. OF WELL WITH CHANGES IN RATE, ID
*----NWEL1  IDW
   4     1 2 3 4
CC
CC ID,PRDUCTION RATE (FT3/DAY)
*----IDW   QI(M,L)
   1  -5000
CC
CC ID,PRDUCTION RATE (FT3/DAY)
*----IDW   QI(M,L)
   2  -1886.64
CC
CC ID,PRDUCTION RATE (FT3/DAY)
*----IDW   QI(M,L)
   3  -2156.16
CC
CC ID,PRDUCTION RATE (FT3/DAY)
*----IDW   QI(M,L)
   4  -179.68
CC
CC CUM. INJ. TIME , AND INTERVALS (PV OR DAY) FOR WRITING TO OUTPUT FILES
*----TINJ    CUMPR1   CUMHI1   WRHPV    WRPRF   RSTC
   3.90    0.999   0.999   0.02     2.533   3.99
```

CC
CC FOR IMES=3 ,THE INI. TIME STEP,CONC. TOLERANCE,MIN. AND MAX. COURANT NO.
*----DT   DCLIM   CNMAX   CNMIN
   0.0000001 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1   0.5 0.01