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PERMEABILITY ESTIMATION OF HOMOGENEOUS RESERVOIR BASED ON TRANSIENT TEMPERATURE AND PRESSURE DATA

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Abstract. *A good estimation of permeability is important for enhanced reservoir management and accurate simulation of the reservoir. This paper presents a way of estimating the permeability of a homogeneous reservoir based on transient pressure and temperature data. To obtain the data we used numerical solutions of mass balance, energy equation, and Darcy's law. The study was divided into two stages, initially, synthetic data is obtained by using a solution of a coupled system of conservation equations where here this procedure is called as the direct problem and then the estimation of permeability is obtained by using an inverse problem considering a perturbation of permeability as a noise source. To solve the inverse problem we used the secant method combined with the relative error between the expected result and the estimated result. The results show how the inverse problem properly used can estimate accurately the permeability of the reservoir.*

Keywords: *Permeability, Inverse problem, Transient, Pressure, Temperature*

1. INTRODUCTION

Formation tests, or well test, are commonly used to estimate the characteristics of the reservoir and are based on the transient behavior usually of the bottom pressure of the well during the process of opening and closing the production valve. This test consists of capture information during the drawdown and buildup periods. As shown at Fig. 1.

The use of transient-temperature data for estimating reservoir parameters has been limited in the past. As mentioned by Onur and Cinar (2017) the main cause was partially associated to the variation of the temperature during the formation test from conventional reservoirs has been usually small so the reservoir-flow behavior maybe consider as isothermal and other cause was the poor resolution of the temperature sensor. However, recent studies (Galvao *et al.*, 2019) show that considering only pressure data can lead to misinterpretations due to the thermal effects neglected specifically in high transmissibility reservoirs such as in Brazilian Pre-Salt reservoir.

According to Duru *et al.* (2011) and Sidorova *et al.* (2015) with advances in technologies, the resolution of the temperature sensor has been increased better than 0.01K. Therefore, the use of transient temperature data has been increasing due to this improvement related to the quality and accuracy of the temperature sensors and also by the installation of permanent temperature and pressure sensors in intelligent wells. Li *et al.* (2011) presented a procedure to characterize the reservoir taking into account the temperature data and showed that including it improves the result of the analysis. The interpretation of the pressure and temperature transient data brought the need for complete models to take into account the non-isothermal flow in the reservoir.

When we are trying to infer some parameters that we cannot directly observe by using the information of system response we are in a typical inverse problem. Therefore, we are estimating specific reservoir parameters by using pressure and/or temperature results obtained during a formation test.

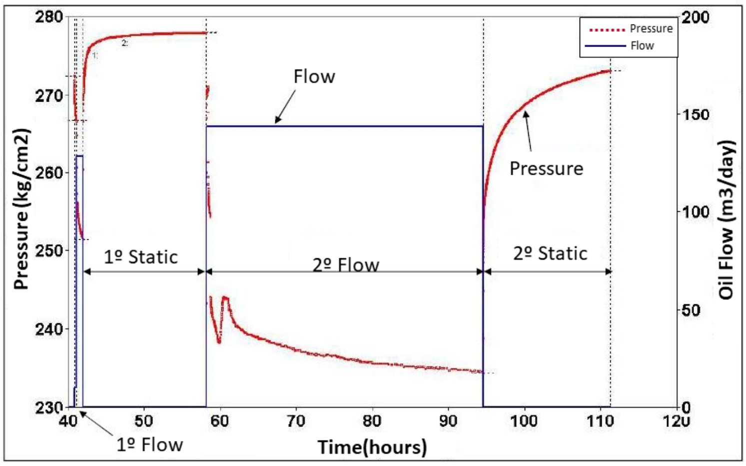

Figure 1. Example of well test with two periods of static and two of flow extracted from the class notes from ALVARO M. M. PERES (2012).

2. MATHEMATICAL FORMULATION

This work was developed in two stages. First we developed a routine for the solution of the direct problem and then we developed a model for the solution of the inverse problem. The equations used to solve the direct problem were made based on the equations of mass conservation, energy conservation and Darcy's law found in the literature (Onur and Cinar, 2017). To solve the equations system was used the International System of Units (SI) and the following basic assumptions:

1. One-dimensional flow (1-D), radial;
2. Single-phase (oil with immobile connate water saturation);
3. Homogeneous reservoir, isotropic, and infinite-acting;
4. Fluid flow is governed by Darcy's law;
5. Reservoir parameters and thermal properties of the fluid and matrix do not vary with pressure and temperature;
6. Solid matrix, oil and connate water are in the local thermal equilibrium so their temperatures are identical;
7. Gravitational and capillary effects are negligible;

2.1 DIRECT PROBLEM

Considering the rigid solid matrix and the immiscibility between oil and water in the porous medium the mass balance equation, as in Eq.(1) and Darcy's law, as Eq.(2) can be expressed as follows according to Onur and Cinar (2017). The following transient equation is an expansion of the continuity equation in the porous medium considering a single phase oil flow as a function of pressure and temperature.

$$\phi\left(c_t\frac{\partial p}{\partial t}-\beta_t\frac{\partial T}{\partial t}\right)=-c_o\mathbf{v}_o\bullet\nabla p+\beta_o\mathbf{v}_o\bullet\nabla T-\nabla\bullet\mathbf{v}_o \tag{1}$$

$$\mathbf{v}_o=\frac{-K}{\mu_o}\nabla p \tag{2}$$

Where c_o, β_o and μ_o are the compressibility, the thermal expansion of the oil and the viscosity of the oil phase, c_t, β_t represent the isothermal and thermal expansion coefficients of the total system (fluid + rock). K and ϕ is the permeability and the porosity of the reservoir.

Assuming the local thermal equilibrium between the solid matrix and fluid phases can be reached instantly, the energy conservation equation presented by Barenblatt *et al.* (1989) and later rewritten taken into account the Joule-Thomson coefficient (ε_{JTo}) by Onur and Cinar (2017) it can be expresses as:

$$(\rho c_p)_t\frac{\partial T}{\partial t}-(\rho c_p\varphi)_t\frac{\partial p}{\partial t}+\rho_o c_{po}\mathbf{v}_o\bullet(\nabla T-\varepsilon_{JTo}\nabla p)-\nabla\bullet(\lambda_t\nabla T)=0 \tag{3}$$

The initial conditions used to solve the direct problem for pressure and temperature is expressed as:

$$p(r,t=0)=p^o \qquad ; \qquad T(r,t=0)=T^o \tag{4}$$

The boundary conditions for pressure can be expressed as:

$$\lim_{r \to r_w} \left(r \frac{\partial p}{\partial r} \right) = \frac{q_{sco} B_o \mu_o}{2\pi K_o h} \qquad and \qquad \lim_{r \to \infty} p(r, t > 0) = p^o \tag{5}$$

Where $r \to r_w$ means the beginning of the reservoir and $r \to \infty$ means the end of the reservoir.

The boundary conditions for temperature can be expressed as:

$$\lim_{r \to r_w} \left(r \frac{\partial T}{\partial r} \right) = 0 \qquad and \qquad \lim_{r \to \infty} T(r, t > 0) = T^o \tag{6}$$

We solve the partial differential equations using the finite difference method, which is largely used in reservoir simulations problems. A second order scheme is used for spatial discretization and an implicit time formulation of second order (Crank-Nicolson method) is also considered.

2.2 INVERSE PROBLEM

Since the goal of this work is to estimate specifically the permeability by using of transient pressure or/and temperature data is necessary to solve an inverse problem. The main idea of an inverse problem is to infer any parameter of a system by using some transient response observed. These inferences are statistics since the transient observed data is always subject to some kind of uncertainty. One of the difficulties related to the inverse problem is that the observed effects are mostly non-linear, so there may be several models that can fit the observed data. It makes extremely important to choose an appropriate objective function and also a method to minimize this objective function to ensure a good parameter estimation of the system.

In this work we use the relative quadratic error (known also as Euclidean norm) as the objective function. Initially was analyzed separately the transient data of pressure and temperature and then the combined pressure and temperature data. The equation below is the relative quadratic error equation (dimensionless), where f can be substituted by the pressure or temperature values. When the analysis is done considering both data together, it will be necessary to consider into the objective function the quadratic errors from the pressure and the temperature data.

$$E(K) = \sum_{i=1}^{N} \left(\frac{f\text{meas} - f_{\text{calc}}(K)}{f_{\text{calc}}(K)} \right)^2 \qquad \text{at where} \qquad f = p[\text{Pa}] \quad \text{or} \quad T[\text{K}] \tag{7}$$

Where f_{meas} represent the variable measured in the field and f_{calc} is a variable calculated numerically. In order to find the value of the permeability (K) that best fits, in other words, the value that will provide the smaller relative quadratic error is necessary to derive the objective function concerning the variable that we intend to estimate, obtaining the following function.

$$F(K) = \frac{\partial E(K)}{\partial K} = \sum_{i=1}^{N} 2 \left(\frac{f\text{meas} - f_{\text{calc}}(K)}{f_{\text{calc}}(K)} \right) \frac{f\text{meas}}{f_{\text{calc}}(K)^2} \left(\frac{f_{\text{calc}}(K + e0) - f_{\text{calc}}(K - e0)}{2 * e0} \right) \tag{8}$$

The best value will be the one that takes the derivative of the objective function to zero. In these work will be used the Secant method to minimize the derivative of the objective function. The Secant method is a root-finding algorithm that uses a succession of roots of secant lines to better approximate a root of a function F. In our case, these method consists of supply two initial guess values of permeability referring to a percentage of the correct value of the permeability of the data. With each initial guess, we calculated the secant line and the next guess will be the value that the line intersects the K axis. This procedure is done until we obtain the value of the permeability that best adjusts to the observed pressure and temperature data. The figure 2 illustrates how the secant method works.

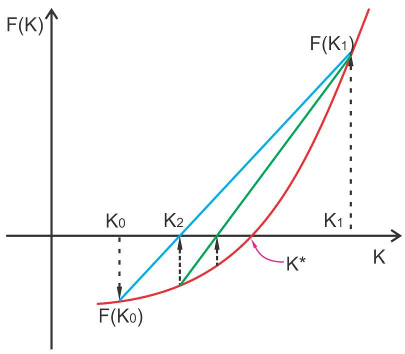

Figure 2. The sequence of the secant method used to find the root of the derivative of the objective function.

3. ROUTINE STRUCTURE

To explain how the direct and inverse problem works two flowcharts are used. The left one is the data-generating routine and the right one is the permeability estimating routine. For the data-generating routine, initially is entered the values of the system variables including the permeability value that we intend to estimate. Then we generate the space mesh that has a concentration of points near the initial region of the reservoir (Vinokur, 1983) and the permeability profile of the reservoir, which is along this work considered constant (homogeneous reservoir). After initializing the variables of interest (pressure, p; temperature, T and time, t), we solve the conservation equations of mass and energy including the boundary conditions until we simulate the entire period of the formation test.

In the permeability estimating routine we initially load the solution of the direct problem (pressure or/and temperature) then is set a randomic noise in order to simulate the data coming from the sensor. We provide two initial guess and calculate the errors between the values read and calculated from the guess. If one of these errors is smaller than the especified tolerance, the permeability value that achieve this condition is the estimated permeability. Otherwise, we apply the secant method between the guess and calculate the value of the next guess until we find the value of the permeability that causes an error smaller than the tolerance of 10^{-3}.

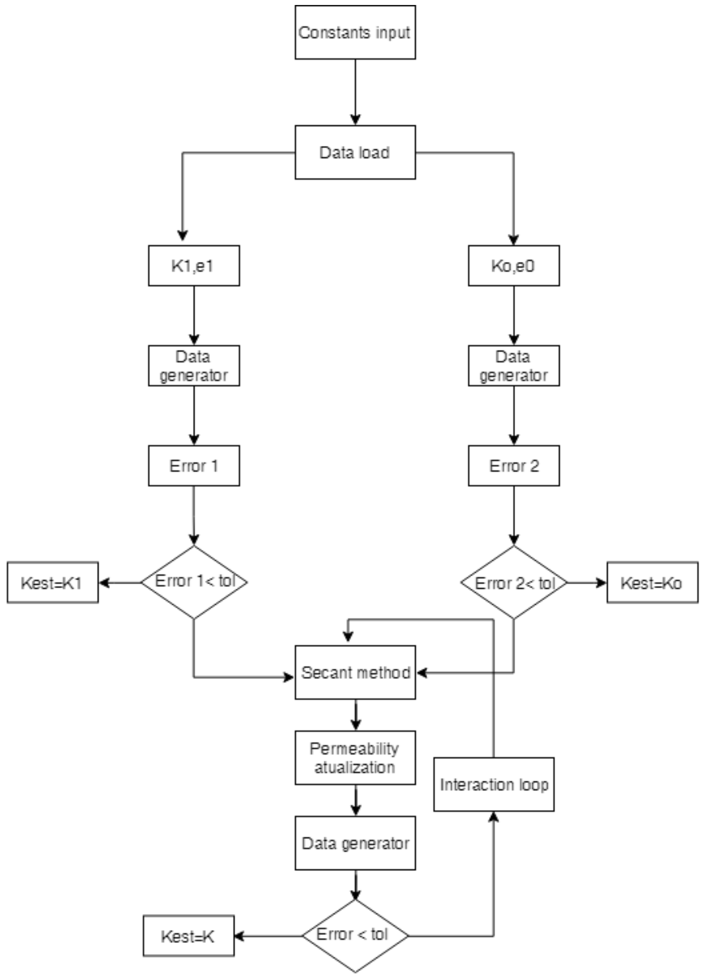

Figure 3. Flowchart of Generating data routine on the left side and the permeability estimator routine on the right side.

4. RESULTS

In this section, first we present the transient pressure and temperature results from the direct problem to validate the in-house simulator and then the results of the permeability estimation by using of an inverse problem for two different reservoirs, in low permeability and then at high permeability. It was also tested the robustness of the secant method to estimate the permeability.

As mentioned above the validation process was done comparing the solution of the direct problem between our in-house simulator with a commercial non-isothermal simulator solution (CMG software). The inputs data are listed in the table 1. Formation testing consist of a sequence of 120 hour of production at a constant oil production rate $q_{sco} = 3.128223 * 10^{-3}\ sm^3/s$ followed by a 360 hours of buildup. Here, the oil formation volume factor is 1.05427 m^3/sm^3.

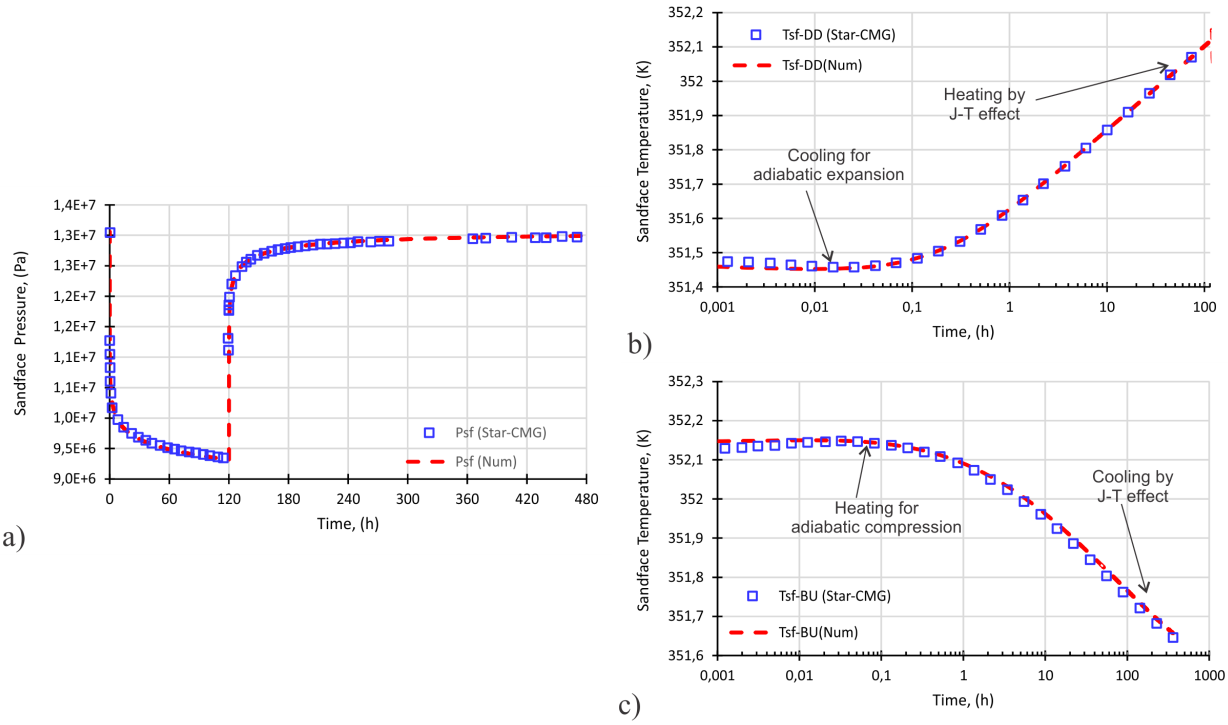

Figure 4. Comparison of sandface pressure and temperature solutions from a comercial software (CMG) and our in-house simulator.

Figure 4a shows a comparison of the sandface pressure generated from the commercial CMG-STARS that is a non-isothermal simulator and our in-house simulator. Fig. 4b shows the sandface temperature during a drawdown period and Fig. 4c during a buildup period. There are good agreement between results obtained from non-isothermal simulator and the in-house simulator that it will be used in the data-generating routine.

4.1 IN A LOW PERMEABILITY RESERVOIR

Here we consider 20 days (480 hours) of test, where the first 5 days (120 hours) are in the drawdown period with a constant flow rate of $q_{sco} = 3.128223 * 10^{-3}\ sm^3/s$ and the remaining days are in buildup period. In these case, we consider for the drawdown period an amplitude of 4.0% of the p^o and for the buildup we consider 1.0% of p^o to simulate the pressure sensor response and for the temperature sensor response we consider $0.004\%\ T^o$ and $0.002\%\ T^o$ for the drawdown and buildup period respectively. The criteria to use less amplitude during the buildup period is because there is less noise during this period. The table below is the properties of the fluid and reservoir with lower permeability extracted from Onur and Cinar (2017) (Tab.2, example 1).

Table 1. Properties of fluid and reservoir extracted from Onur and Cinar (2017) (Tab.2, example 1).

K$[m^2]$	1.056×10^{-13}	$c_o[Pa^{-1}]$	1.077×10^{-9}	$\rho_o[kg/m^3]$	834.56
ϕ [fraction]	0.29	$c_w[Pa^{-1}]$	4.398×10^{-10}	$\rho_w[kg/m^3]$	1000.03
$T^o[K]$	351.48	$\mu_o[Pa.s]$	2.949×10^{-3}	$\rho_r[kg/m^3]$	2643.05
$H[m]$	30.48	$c_{po}[J/kgK]$	2177.1	$c_{pr}[J/kgK]$	962.96
$p^o[MPa]$	13.06	$c_{pw}[J/kgK]$	4186.8	$\beta_r[K^{-1}]$	9.0×10^{-5}
$r_w[m]$	0.125	$\beta_o[K^{-1}]$	7.2×10^{-4}	$\lambda_t[J/msK]$	3.4615
$r_e[m]$	15000	$\beta_w[K^{-1}]$	9.0×10^{-4}	$\alpha_t[m^2/s]$	1.42×10^{-6}
s_w [fraction]	0.15	$\varepsilon_{JTo}[K/Pa]$	-4.432×10^{-7}	$(\rho c_p)_t[J/m^3K]$	2.437×10^{6}
$c_r[Pa^{-1}]$	4.351×10^{-10}	$\varphi_o[K/Pa]$	1.72×10^{-7}	$(\rho c_p \varphi)_t[J/m^3Pa]$	5.63×10^{-2}
$c_t[Pa^{-1}]$	1.417×10^{-9}	$\varphi_w[K/Pa]$	4.554×10^{-8}	$\varphi^*[K/Pa]$	2.31×10^{-8}

On the following subsections will be presented the results of three different objective function to estimating the permeability.

4.1.1 PERMEABILITY ESTIMATION USING PRESSURE DATA

The objetive function defined in Eq. (7) is only a function of transient pressure data, p. Here, initially we estimate f_{meas} using the solution of the direct problem in order to obtain the correct pressure evolution setting the real permeability. In this results was used a random function to represent a noise and simulate the data coming from the sensor, as shown in Fig. 5a in a continuous line. Then the inverse problem start using two initial guess of permeability. For example if is considered and error of 10% of the real permeability both initial guess will be $0.9\overline{K}$ and $1.1\overline{K}$. Both initial guess K_0 and K_1 keeping the same values for the others parameters generates two pressure evolution results as shown in Fig. 5a represented by discrete symbols along the entire formation test. Applying the estimating routine is possible to achieve approximately to the real permeability after some iterations. Figure 5b shows the final iteration that represent an permeability error of 1.07%. Values of another initial guess are shown in Tab. 2 and its corresponding error and number of iterations.

About the tables is valid to point out that as we increase the range of percentual error of permeability in the value of the initial guess the number of iterations increases. When we consider an initial guess with 50% around the real value the routine generates a big error, this means that for this initial guess we find another root of the objective function. The secant method can make good estimations until up to 40% of the real permeability value.

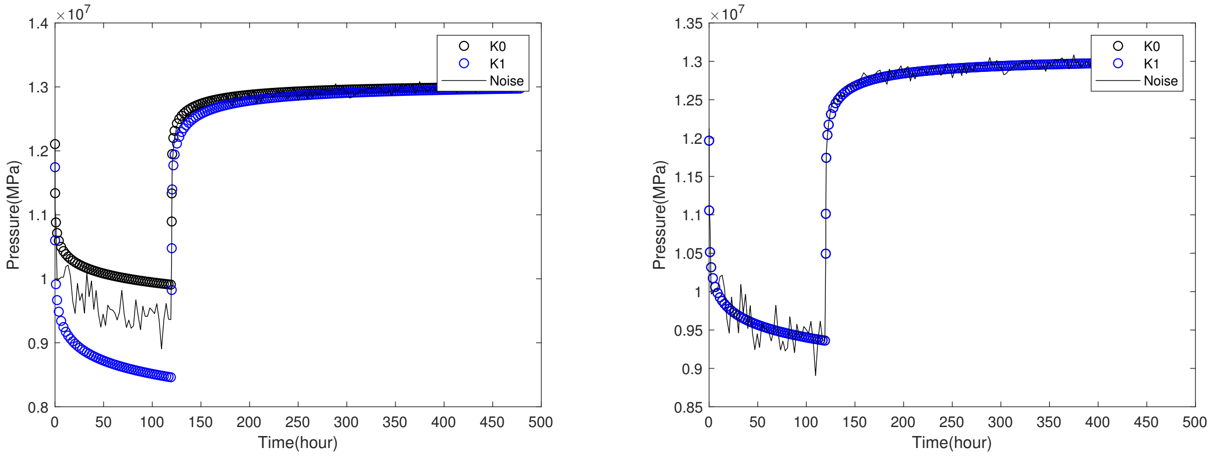

Figure 5. The beginning and the end of the process to estimate the permeability considering only the pressure data respectively.

Table 2. Values of K_{est}, percentage error and number of iterations for the different initial guess, using pressure as the basis for the accounts of the lower permeability reservoir.

Pertubation	Initial guess	$K_{estimate}$	Error %	Iteration
Perturbation 1	$0.9\overline{K}$ and $1.1\overline{K}$	1,0673E-13	1,07	6
	$0.8\overline{K}$ and $1.2\overline{K}$	1,0673E-13	1,07	7
	$0.7\overline{K}$ and $1.3\overline{K}$	1,0673E-13	1,07	9
	$0.6\overline{K}$ and $1.4\overline{K}$	1,0673E-13	1,07	15
	$0.5\overline{K}$ and $1.5\overline{K}$	1,5041E-13	42,43	5

4.1.2 PERMEABILITY ESTIMATION USING TEMPERATURE DATA

In this case the objetive function defined in the Eq. (7) is a function only of transient temperature data, T. The procedure is similar as mentioned in the previous subsection. The range of the initial guess are show in the Tab. 3 and the estimated permeability, the error and the number of iteration needed for each initial guess. As similar as considering the pressure data mentioned in previous subsection the secant method is not able to make a good estimation of permeability using an initial guess above 40% of real permeability.

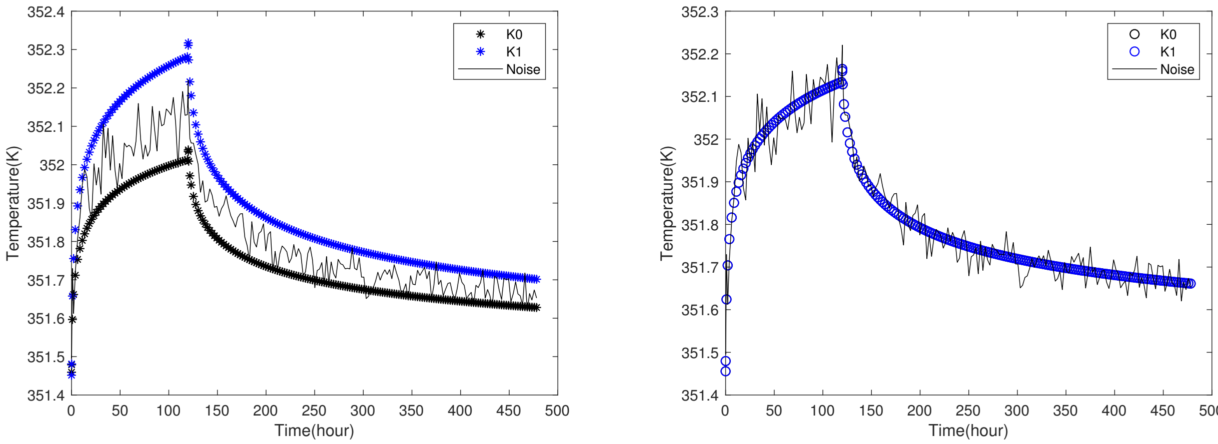

Figure 6. The beginning and the end of the process to estimate the permeability considering only the temperature data respectively.

Table 3. Values of K_{est}, percentage error and number of iterations for the different initial guess, using temperature as the basis for the accounts of the lower permeability reservoir.

Pertubation	Initial guess	$K_{estimate}$	Error %	Iteration
	$0.9\overline{K}$ and $1.1\overline{K}$	1.0337E-13	2.11	6
	$0.8\overline{K}$ and $1.2\overline{K}$	1.0337E-13	2.11	7
Perturbation 2	$0.7\overline{K}$ and $1.3\overline{K}$	1.0337E-13	2.11	10
	$0.6\overline{K}$ and $1.4\overline{K}$	1.3499E-13	27.83	5
	$0.5\overline{K}$ and $1.5\overline{K}$	1.5041E-13	42.43	5

4.1.3 PERMEABILITY ESTIMATION USING PRESSURE AND TEMPERATURE DATA

Finally, in this subsection, the pressure and temperature data were combined. Here, it was necessary to extend the objective function to consider the relative quadratic errors from the pressure and temperature data. As in previous cases, when we consider a initial guess with high error, the method cannot find the desired root of the objective function, leading to another permeabilities values. It is possible to observe that with the result of the combined data is the same as the pressure data separated. These means that for these objective function formulation the pressure data is more dominant.

Table 4. Table with the values of K_{est}, percentage error and number of iterations for the different initial guess, using pressure and temperatura as the basis for the accounts of the lower permeability reservoir.

Analysis	Initial guess	$K_{estimate}$	Error %	Iteration
	$0.9\overline{K}$ and $1.1\overline{K}$	1,0673E-13	1,07	6
	$0.8\overline{K}$ and $1.2\overline{K}$	1,0673E-13	1,07	7
Analysis 1	$0.7\overline{K}$ and $1.3\overline{K}$	1,0673E-13	1,07	9
	$0.6\overline{K}$ and $1.4\overline{K}$	1,0673E-13	1,07	15
	$0.5\overline{K}$ and $1.5\overline{K}$	1,5041E-13	42,41	5

4.2 IN A HIGH PERMEABILITY RESERVOIR

On these case we consider 3 days (72 hours) of test, where the first day (24 hours) is the drawdown period with a constant flow rate (q = 1.6203e-2 m^3/s) and the remaining days are in buildup period. In these case, differently from the low permeability we consider the Dp as reference to make the amplitude of pressure data. Dp is the difference between the inicial pressure (p^o) and the pressure into the end of drawdown period. For the drawdown we consider 10.0% of Dp and for the buildup we consider 5.0% of Dp. For the temperature sensor response we consider 0.0004% T^o and 0.0002% T^o for the drawdown and buildup period respectively. The table below describe the properties of the fluid and reservoir with higher permeability are extracted from Galvao *et al.* (2018).

Table 5. Fluid and reservoir properties extracted from Galvao *et al.* (2018)

K$[m^2]$	8.882×10^{-12}	$c_o[Pa^{-1}]$	1.122×10^{-9}	$\rho_o[kg/m^3]$	770.0
ϕ [fraction]	0.12	$c_w[Pa^{-1}]$	4.0381×10^{-10}	$\rho_w[kg/m^3]$	998.2
$T^o[K]$	334	$\mu_o[Pa.s]$	0.9×10^{-3}	$\rho_r[kg/m^3]$	2643.05
$H[m]$	50.0	$c_{po}[J/kgK]$	2252.90	$c_{pr}[J/kgK]$	887.99
$p^o[MPa]$	49.033	$c_{pw}[J/kgK]$	4209.35	$\beta_r[K^{-1}]$	9.0×10^{-5}
$r_w[m]$	0.624	$\beta_o[K^{-1}]$	1.11×10^{-3}	$\lambda_t[J/msK]$	3.4401
$r_e[m]$	25000	$\beta_w[K^{-1}]$	5.27×10^{-4}	$\alpha_t[m^2/s]$	1.4841×10^{-6}
s_w [fraction]	0.15	$\varepsilon_{JTo}[K/Pa]$	-3.4405×10^{-7}	$(\rho c_p)_t[J/m^3K]$	2.3179×10^6
$c_r[Pa^{-1}]$	3.059×10^{-10}	$\varphi_o[K/Pa]$	2.324×10^{-7}	$(\rho c_p\varphi)_t[J/m^3Pa]$	4.43×10^{-2}
$c_t[Pa^{-1}]$	1.3202×10^{-9}	$\varphi_w[K/Pa]$	4.214×10^{-8}	$\varphi^*[K/Pa]$	1.9116×10^{-8}

On the following subsections will show the results of three different objective function to estimating the permeability. In the Figure 7 the left image shows the two results of the initial guess as well as the data with noise and on the right one the last interaction of the permeability estimation routine. Moreover, the tab. 6 shows the percentual from the initial guess, the error between the estimated result and the real result as in Tab. 5 and the number of iterations that the routine made to estimate the permeability. About the tables, as shown for the previous case, is valid to mention that as we increase the deviation in percentage of permeability in value of the initial guess the number of iterations increases. When we insert a guess with a deviation of 50% in the permeability value the routine generates a big error, this means that for this initial guess we find another root of the derivative of the objective function under analysis and that the method in question can make good estimates with up to 40% of the permeability value. Figure 7 shows the sequence of procedure of estimating of permeability using only pressure data and for a first initial guess shown in the Tab. 6. In Figure 8 show the sequence of procedure of estimating of permeability using only temperature data. Table 7 shows a results of permeability estimate, the error and the number of iterations needed for each initial guess.

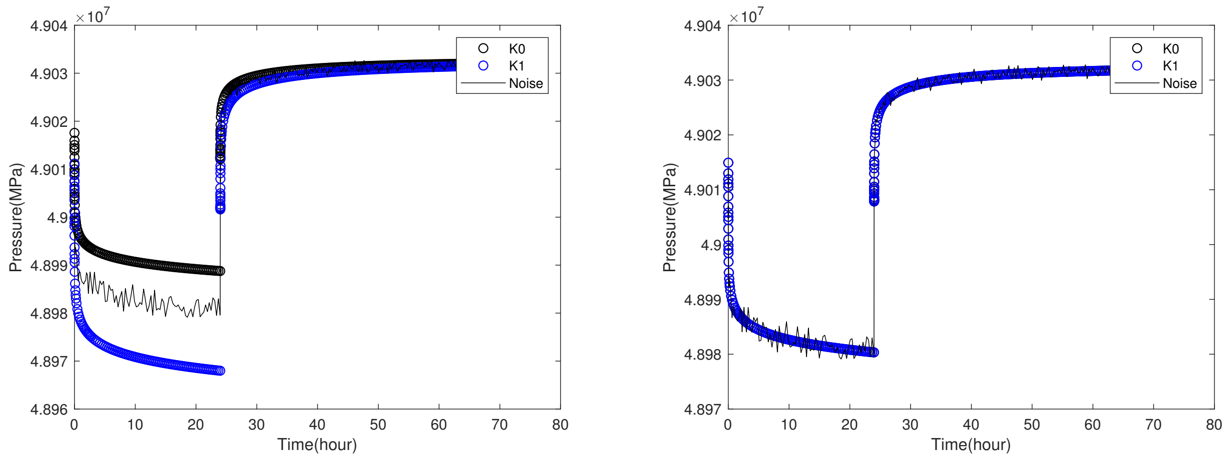

Figure 7. The beginning and the end of the process to estimate the permeability considering only the pressure data respectively.

Table 6. Values of K_{est}, percentage error and number of iterations for different initial guess, using pressure as a reference for a higher permeability reservoir.

Pertubation	Initial guess	$K_{estimate}$	Error %	Iteration
Perturbation 3	0.9 $\overline{K}$ and 1.1$\overline{K}$	8.8703E-12	0.14	6
	0.8$\overline{K}$ and 1.2$\overline{K}$	8.8703E-12	0.14	7
	0.7$\overline{K}$ and 1.3$\overline{K}$	8.8703E-12	0.14	10
	0.6$\overline{K}$ and 1.4$\overline{K}$	8.8703E-12	0.14	17
	0.5$\overline{K}$ and 1.5$\overline{K}$	1.2641E-11	42.32	5

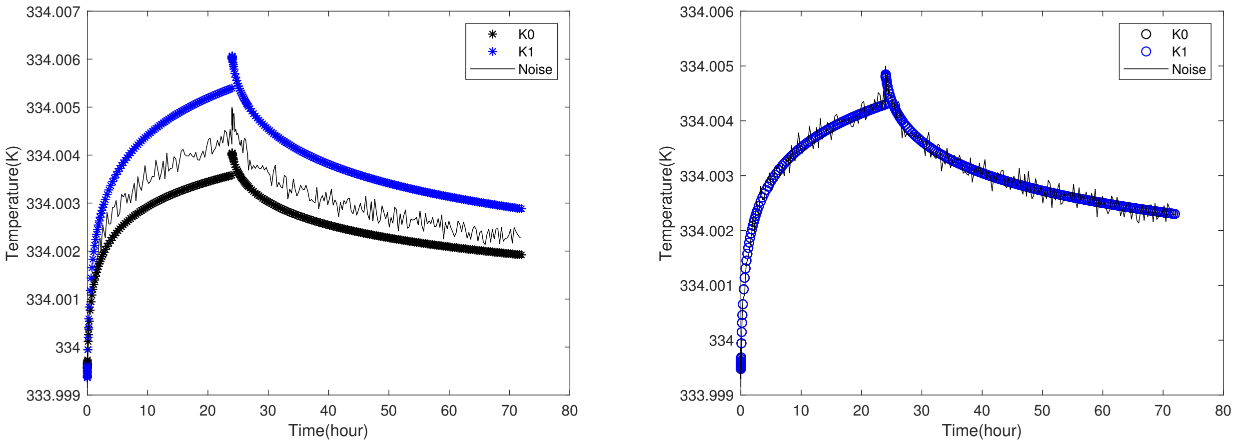

Figure 8. The beginning and the end of the process to estimate the permeability considering only the temperaute data respectively.

Table 7. Values of K_{est}, percentage error and number of iterations for different initial guess, using temperature as a reference for a higher permeability reservoir.

Pertubation	Initial guess	$K_{estimate}$	Error %	Iteration
	0.9 $\overline{K}$ and 1.1$\overline{K}$	8.9062E-12	0.27	6
	0.8$\overline{K}$ and 1.2$\overline{K}$	8.9062E-12	0.27	7
Perturbation 4	0.7$\overline{K}$ and 1.3$\overline{K}$	8.9062E-12	0.27	10
	0.6$\overline{K}$ and 1.4$\overline{K}$	8.9062E-12	0.27	19
	0.5$\overline{K}$ and 1.5$\overline{K}$	1.2712E-11	43.12	5

Finally, the pressure and temperature data were combined. Here, it was necessary to extend the objective function to consider the relative quadratic errors coming from pressure and temperature data. As in the analysis with the separated data, when we insert a high initial guess, the method cannot find the desired root of the objective function, leading to a higher error. Another conclusion that we can see, is that with the result of the combined data is the same as the pressure data separated. These means that for these objective function formulation the pressure data is more relevant.

Table 8. Values of K_{est}, percentage error and number of iterations for different initial guess, using pressure and temperatura as a reference for a higher permeability reservoir.

Analysis	Initial guess	$K_{estimate}$	Error %	Iteration
	0.9$\overline{K}$ and 1.1$\overline{K}$	8.8703E-13	0.14	6
	0.8$\overline{K}$ and 1.2$\overline{K}$	8.8703E-13	0.14	7
Analysis 2	0.7$\overline{K}$ and 1.3$\overline{K}$	8.8703E-13	0.14	9
	0.6$\overline{K}$ and 1.4$\overline{K}$	8.8703E-13	0.14	17
	0.5$\overline{K}$ and 1.5$\overline{K}$	1.2641E-11	42.32	5

5. FINAL REMARKS

- The direct problem modeling was successfully implemented and validated of a non-isothermal homogeneous reservoir.
- The inverse problem was implemented and tested by using the secant method and was used the relative quadratic error as an objective function. Results show how the inverse problem properly used can estimate accurately the permeability of the reservoir.
- The secant method is also robust when a high deviation of initial guess of the permeability is considered, i.e. until 40% of deviation of the real permeability when pressure data is used and 30% when temperature data is used at low permeability reservoir. At high permeability reservoir deviation of initial guess until 40% was successful for both pressure and temperature data.

- Using the combined pressure and temperature data the secant method shows that the pressure data is more dominant into the objective function used in this work.

Nomenclature

c_t	total system compressibility fluid + structure, Pa^{-1}
β_t	coefficient of total thermal expansion of the fluid + structure system, K^{-1}
ϕ	porosity
p	pressure, Pa
T	temperature, K
v	velocity vector, m/s
t	time, s
ρ	density, kg/m^3
μ	viscosity, $Pa.s$
cp	specific heat, $J/kg-K$
φ	coefficient of adiabatic expansion of the liquid, K/Pa
ε_{JTo}	coefficient of expansion Joule-Thomson, K/Pa
λ_t	effective thermal conductivity of the porous medium, $J/m-s-K$
β	Thermal expansion coefficient, K^{-1}
$u_{co}(r,t)$	convection heat transfer rate, m/s
α_t	thermal diffusivity, m^2/s
φ_t^*	coefficient of effective adiabatic expansion, K/Pa
Q	volumetric flow rate, m^3/s
K	effective permeability, m^2
H	Thickness of the reservoir, m
r_e	reservoir radius, m
r_w	well radius, m
U	Internal energy, J
A	Mesh concentration factor
s	Saturation Fraction
θ	temporal discretization parameter

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8. RESPONSIBILITY NOTICE

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