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# Influence of flow rate and operating time on the temperature profiles of oil wells

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**Abstract.** During the production of oil and gas wells fluids at high temperatures flow through the tubing string. Consequently, the well structure experiences thermal gradients along its depth and in the radial direction. This affects different components such as casings, cement sheath and rock formation. Among the undesirable effects caused by the temperature variation there is the Annular Pressure Buildup (APB), associated to expansion of the fluids trapped between strings, and, the decrease of resistance of steel tubes and connections. The changes in temperature of fluids and components during the operation of a well depend on many factors, among which are: operating flow rate, inlet pressure and temperature, operation time, and the produced/injected fluid properties. In this context, this paper presents a parametric study aimed at understanding how the variation of the operating flow rate and production time impact the temperature profiles generated. The temperature profiles are evaluated at realistic operational values of flow rate and production time using an in-house developed thermal simulator, based on the simultaneous resolution of energy balance, momentum balance and mass balance equations. The main contribution of this work is to demonstrate the importance of isolated properties in the thermal response of well components. In addition, the methodology presented can be applied to other parameters and thus improve the understanding of how each property influences the well temperature.

**Keywords:** Temperature profiles, oil wells, parametric analysis

## 1 Introduction

In the last decades, even with the global drive to use renewable energy sources, the demand for oil in the world is growing. Consequently, efforts are directed to the optimization of the production process, mainly to overcome the great challenges posed by the hostile conditions normally associated with oil fields. In offshore basins, reservoir exploration is one of the great challenges of the oil industry, due, in part, to the high temperatures and pressures.

Oil wells, in general, are composed of a set of casings responsible for resisting the stresses to which the well is subjected. During the hydrocarbon extraction operation, fluids at high temperatures flow through the production pipe heating the adjacent region, as a consequence, a temperature gradient is generated. The thermal effects of this temperature variation can lead to failure in the casing, through, for example, the Annular Pressure Buildup (APB).

It is evident, therefore, that the knowledge about thermal phenomena in oil wells has great applicability in the management and operation of wells. In this sense, Sui et al. [1] studied the thermal effects in a well with the variation of some parameters, but without a specific criterion to choose the values assumed by the variables. Ferreira et al. [2] presented temperature profiles for different operating times, but for short times, up to 10 days.

In this context, this work presents a parametric study of thermal effects in an oil-producing well scenario caused by varying production flow rate and operating time, in order to enable a better understanding of how these properties influence the temperature distribution in the well components.

## 2 Temperature profiles simulator

The simulator used has been developed in-house, by the main author of this paper, based on the simultaneous resolution of energy balance, momentum balance and mass balance equations. To solve these equations, the well is discretized in the longitudinal direction and the problem is solved iteratively, using a method based on the procedure of Moradi et al. [3]. More details about the mathematical formulation can be seen in Sui et al. [1].

Detailing the simulator procedures is beyond the scope of this article. However, some aspects are addressed because they are fundamental for understanding the parametric study. One of these parameters is the radial heat flux $Q$ needed to solve the energy balance equation ([3]). This term is calculated by Eq. 1.

$$Q = 2 \cdot \pi \cdot r_0 \cdot U_{to} \cdot (T_f - T_{wb}) \tag{1}$$

where $T_f$ is the temperature of the fluid flowing in the pipe, $T_{wb}$ is the temperature at the well-formation interface, $U_{to}$ is the global heat transfer coefficient, and $r_0$ is the reference radius. Given the importance of heat flow in the thermal phenomena in the well, this variable is one of the parameters analyzed in this parametric study.

Furthermore, the global heat transfer coefficient $U_{to}$ is calculated through the inverse sum of the resistances between the fluid flowing in the pipe and the interface with the formation. To calculate the thermal resistances, models established in the literature are used (Colburn [4], Zhou [5]) these resistances depend on the temperature and heat flow and thus $U_{to}$ is also observed in these parametric study.

## 3 Oil well configuration

The hypothetical scenario applied to this study allows the thermal phenomena to be observed in different well zones. The case studied is an offshore well that has 3 annuli and 4 casings in a production operation, with bentonite mud with 90% water confined in the annuli. The produced fluid is water, chosen for the ease of finding the PVT data (pressure-volume-temperature), these data are obtained from the NIST [6] (National Institute of Standards and Technology). The arrangement and dimensions of the columns and annuli, the geothermal profile and the representation of the oil well used in the analysis are shown in Figure 1.

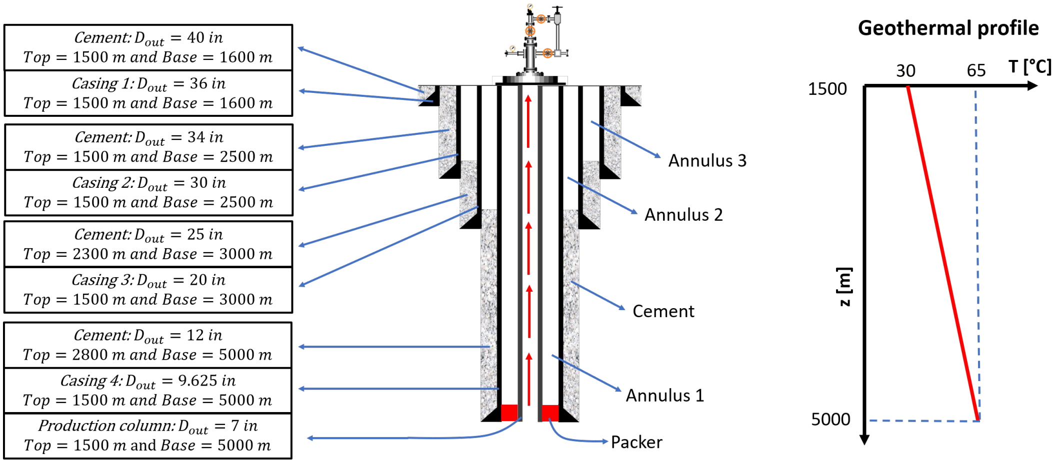


Figure 1. Schematic representation of the adopted well

As observed in Figure 1, the well length is 3500 m. Starting at 1,500 m, due to the water depth, and ending at a depth of 5,000 m. The fluid is extracted at a depth of 5000m, at a pressure of 103.42 MPa (15000 psi) and at a temperature of 65°C. The thickness of metal tubes is approximately 0.625". In addition, the well is drilled in a rock formation modeled with thermal properties homogeneous, these properties are: thermal conductivity $k = 1.59\ Wm^{-1} \cdot K^{-1}$, density $\rho = 2242.58\ kg/m^3$ and specific heat $C = 1256.9\ Jkg^{-1} \cdot K^{-1}$.

## 4 Range of the parametric study

To determine the values assumed by the production flow rate, first an interval is determined with maximum and minimum limit values of the allowable flow rate for the well and then this range is divided in a defined number of sub-intervals. The flow rate can be written as the product of the cross-section average velocity $V$ and the tube area $A$. Thus, since $A$ is constant, using the maximum and minimum allowable velocity, it is possible to establish a range for the flow rate. Standard [7] establishes that the limitations imposed on velocity are intended to prevent problems with erosion, waterhammer pressure surges, noise, vibration and reaction forces. So, considering a carbon steel production tubing, the maximum velocity for liquids is 6 m/s and the minimum velocity is 0.8 m/s.

On the other hand, as the wells operating time $t$ varies a lot from well to well, then values. ranging from 1 month to 16 months are used, following a geometric progression with ratio 2. The values adopted for the two variables are presented in Table 1.

Table 1. Values assumed by the variables in the parametric study

| Variable | Unit | Values | | | | |
|---|---|---|---|---|---|---|
| Flow rate | $m^3/s$ | 0.0150 | 0.0395 | 0.0640 | 0.0885 | 0.1129 |
| Operation time | month | 1 | 2 | 4 | 8 | 16 |

Thus, the well described in section 3 is simulated by varying the parameters presented in Table 1. It is noteworthy that this variation is made independently between the variables, that is, when the flow rate is varied, the operating time is kept in 4 months. Similarly, when the operating time is varied, the flow is kept at 0.064 $m^3/s$.

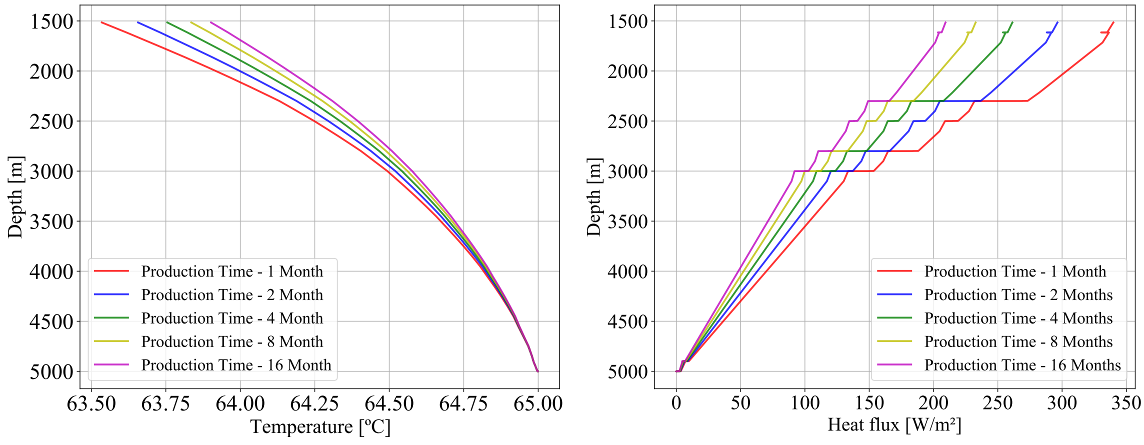
## 5 Results

The results obtained in the parametric study are presented in this section. It is noteworthy that many thermal phenomena can be observed with the variation of the proposed parameters. This work focused on observing the behavior of the temperature profiles of the fluid produced and from the first annular which is considered more critical because it is the annular that faces the greatest thermal variation, since it is closer to the flow.

### 5.1 Temperature distributions for the produced fluid

Figure 2 presents the longitudinal produced fluid temperature distributions (Figure 2.a) and the radial heat flux as a function of depth (Figure 2.b) for the proposed production times presented in the Table 1.

Figure 2. Temperature distributions and radial heat flux for the proposed times

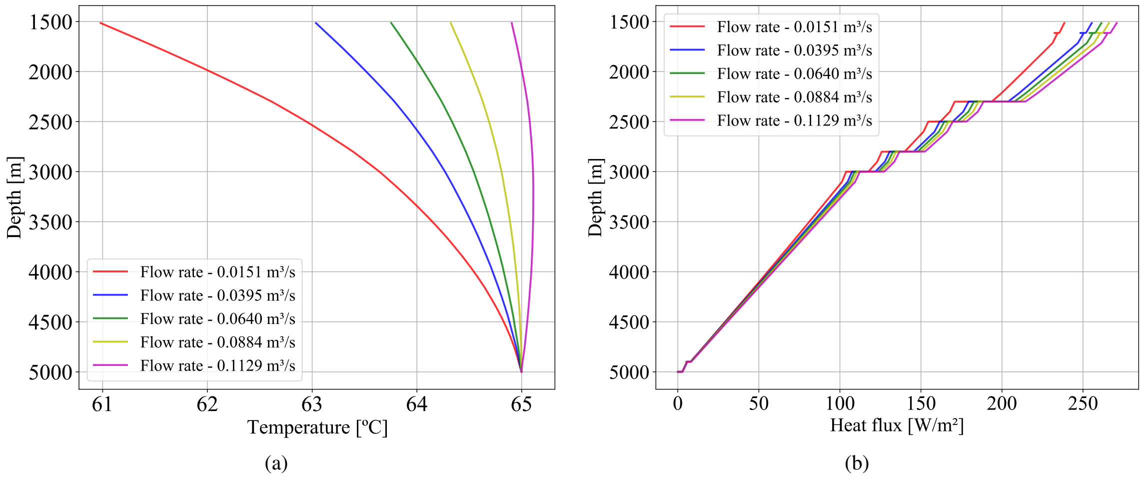


(a) (b)

It is possible to observe that as the months pass, the amplitude in the temperature distribution decreases, as shown in Figure 2.a. This can be explained by observing that over time the radial heat flux decreases, as seen in Figure 2.b. This behavior is natural, since thermal energy (like any other form of energy) travels the path in the direction of potential drop, that is, the heat flow goes from the point of highest to the lowest temperature, over time, and with the increase in fluid temperature decreases the thermal potential and, thus, the heat flow. In a situation of a infinite time the thermal balance between the fluid and the surrounding rock formation is reached, leading to the flow of heat to cancel itself.

The results obtained for the production flow rates values presented in Table 1 are presented in Figure 3, including the temperature distributions of the fluid produced (Figure 3.a) and the radial heat flux (Figure 3.b).

Figure 3. Temperature distributions and radial heat flux for the proposed flow rates



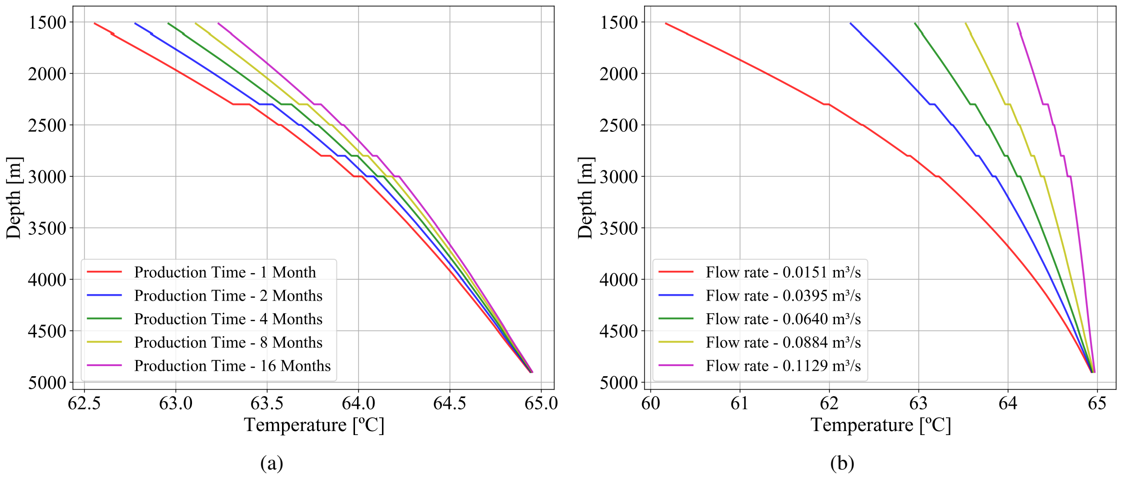
(a) (b)

For the flow rate, the observed behavior is slightly different from what happened for the production time, since, as can be seen in Figure 3.b, with the increase in flow, the heat flow also increases. The main reason for this behavior is that, with higher flow rates, more fluid flows through the tube in the same time interval, providing more energy in the system, this is reflected in the temperature distributions which, as shown in Figure 3.a, have their temperatures increased considerably with increasing flow rate.

## 5.2 Temperature distributions for the annulus 1

Figure 4 presents the longitudinal distributions of the temperature of the annulus 1 for the different values of production time (Figure 4.a) and produced flow rate (Figure 4.b) following the values presented in Table 1.

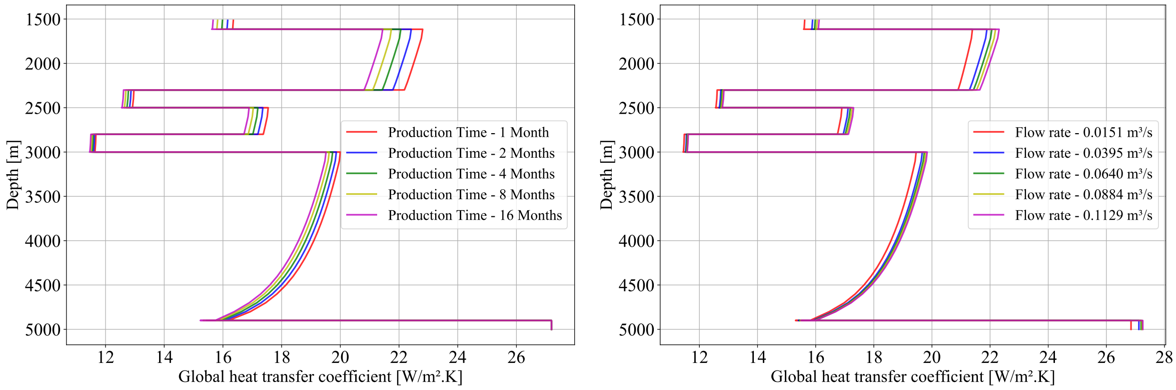
Figure 4. Temperature distributions for the annulus 1



(a) (b)

The temperature profiles in the annular 1 contains a lot of similarities with the temperature profile of the fluid produced, both for the variation in production time and for the production flow. On the other hand, it is important to emphasize that the software used to calculate the temperature profiles considers a heat flow in the longitudinal direction of the well as negligible, that is, it only considers the heat flow in the radial direction. Thus, it is possible to clearly observe that in areas where the geometry changes (depths of 1600m, 2300m, 2500m, 2800m and 3000m, see Figure 1) and, therefore, the radial thermal resistance also changes, the thermal distribution in the annulus is modified, causing a sharp change in temperature with a small variation in depth. In order to observe this behavior, the global heat transfer coefficient as a function of the studied variables is presented in the Figure 5.

Figure 5. Temperature distributions and radial heat flux for the proposed times



(a) (b)

In Figure 5 it is possible to see clearly the depths where there is a change in the geometry of the radial resistances. Thus, it is possible to observe that the global heat transfer coefficient decreases over time, since this coefficient is directly proportional to the heat flow, which also reduced over time. On the other hand, as the flow rate increases, the global heat transfer coefficient also increases, again similar to the behavior of the heat flow.

## 6 Conclusions

This work presented a parametric study of how production flow and operating time influence the temperature profiles of the produced and annular 1 fluids, radial heat flow and global heat transfer coefficient in an oil well scenario. For the parameters considered, the temperature profile of the fluid produced showed higher temperature distributions for higher flows, as over time the fluid tends to seek geothermal equilibrium with the formation. The temperature distributions in the annular 1 are directly related to the temperature distributions of the fluid produced, showing many similarities in the curves. On the other hand, the heat flux had a diametrically opposite behavior for the variation of time and flow, while with the passage of time the heat flux presented a reduction, with the increase in flow this flow also increased. While the global heat transfer coefficient increased with flow and decreased with time. In future works, it is possible to study the optimization of the operation for the same volume produced, in order to understand if it is more viable, from the point of view of the thermal integrity, to produce for a longer time, but at a lower flow rate or produce for a shorter time at a higher flow rate.

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