# SIMULATION OF PRESSURE DROP FOR OIL FLOW THROUGH CHOKES

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## ABSTRACT

The knowledge of the behavior of pressure, flow rates and flow patterns during displacement of the fluid from the wells to the production lines is critical for the oil industry. The choke appears in this context as a device that imposes a restriction on the flow line and it is generally located between tubing and the discharge line. It not only protects surface equipment and provides controlled back pressure in the production line, but it is also used to control and optimize production. This work aimed to elaborate an Excel® spreadsheet to analyze the performance of chokes with single - phase oil flow. The equations found in the literature were implemented in the program and the data from a well were used to show their application. The spreadsheet enabled the calculations to be performed quickly and straightforwardly. It could be observed from the results an agreement with those found by analytical solution.
**KEYWORDS**: chokes, single phase flow, oil production.

## SIMULAÇÃO DA QUEDA DE PRESSÃO EM CHOKES DE PRODUÇÃO DE ÓLEO

## RESUMO

Na indústria do petróleo, é fundamental conhecer o comportamento da pressão, vazão e padrões de fluxo durante o escoamento dos fluidos nas tubulações. O choke é um dispositivo que impõe uma restrição ao fluxo, e geralmente, está localizado entre a coluna e a linha de produção. O uso desse dispositivo protege os equipamentos de superfície por meio do controle da vazão e da pressão. Este trabalho teve como objetivo a elaboraração de uma planilha em Excel® para análise da queda de pressão em chokes de produção de óleo. As equações encontradas na literatura foram implementadas no programa e os dados de um poço foram usados para mostrar a aplicação do simulador. A planilha permitiu que os cálculos fossem realizados de forma rápida e prática. Os resultados encontrados na simulação estão de acordo com os obtidos na solução analítica do caso estudado.
**PALAVRAS-CHAVE:** chokes, fluxo monofásico, produção de óleo.

## INTRODUCTION

Fluid flow often occurs in the oil industry and these fluids are transported in the porous medium of the reservoir and in the vertical and horizontal stretches of the oil well, passing through the wellhead, flowing through the production line and reaching the separators, where from there they are finally transported to the storage tanks (OMANA et al., 1969).

During the displacement process, petroleum engineers are faced with the most varied possible flows, and to be aware of the pressure behavior, the phase flow and the flow patterns during the displacement of the fluids must be known to design the systems (BEGGS; BRILL, 1982).

There are cases where the available reservoir pressure is much higher than required to produce a desired flow rate, and a restriction to the flow on the surface must be added to control the well production flow (ROSSI, 2009). This restriction is known as choke. It is usually located between the tubing and the discharge line. It is used not only to control and optimize production flow, but also to protect surface equipment, to control and prevent undesirable flow of fluids and to provide controlled back pressure in the production formation.

To optimize the production of oil wells, it is very important to know the behavior of the choke in respect of the parameters of the flow and the nature of the produced fluids (GUITERAS, 2003). A correct understanding of how the oil and/or gas behave during each flow step is of fundamental importance in order to design a production systems capable of producing with high efficiency.

When determining how much oil and/or gas a given well will produce, one should evaluate the effects of various components such as choke openings, wellhead pressure (upstream of the choke) and pressure in the separator (downstream of the choke) (BROWN; BEGGS, 1984). These components are combined in order to obtain the permissible flow rate at the wellhead, to control the production flow, to protect the surface teams, to control and prevent aeration problems by providing sufficient pressure in the production formation, to gather information to calculate the productivity index at each stage of the productive life of a well and also to prevent the coning of gas and water (GUO et al., 2007).

Computational simulation has been used in several researches in the area of petroleum. As examples it can be cited the works of Michael et al. (2013); Kohshour et al. (2014); Wang e Gong (2015); Hakimi e Abdullah (2015); Nandanwar et al. (2016); Gharagheizi et al. (2017) and Kurkalova e Carter (2017).

The present work aimed to elaborate a spreadsheet in Excel® to analyze chokes with single phase flow of oil in a subcritical regime. In addition to the importance of fluid analysis and the type of flow that occurs in choke, this work was motivated by the possibility offered by Excel® to perform calculations quickly and easily, from a data entry. Excel® is an affordable computer program with a wealth of features that can be explored.

## MATERIAL AND METHODS

For the elaboration of the spreadsheet, the equations necessary to analyze the performance of the choke were implemented in Excel® 2010 cells. Since critical velocities are high for single-phase liquids, flow behavior is always subcritical (CALIXTO, 2009).

The subsequent steps must be followed for the calculation.

Step 1 - Calculating Oil Properties

When working with oil the following equations can be used to find its density, specific gravity and viscosity. These calculations will be required to obtain the Reynolds Number in the next step.

Calculation of specific gravity of stock tank oil:

$$\gamma_o = \frac{141.5}{^\circ API + 131.5} \qquad (1)$$

Where:
$\gamma_o$: specific gravity of stock tank oil, 1 for freshwater
*ºAPI*: API gravity of stock tank oil

Calculation of the density of stock tank oil:

$$\rho = 62.4\gamma_o \qquad (2)$$

Where:
$\rho$*:* density of stock tank oil, lbm / ft³
$\gamma_o$: specific gravity of stock tank oil, 1 for freshwater

Calculation of the viscosity of the dead oil in atmospheric conditions:
Dead oil can be defined as the oil under standard conditions. Its viscosity can be calculated by Equation (3):

$$\mu_{od} = \left(0.32 + \frac{1.8 \times 10^7}{API^{4.53}}\right)\left(\frac{360}{t + 200}\right)^A \qquad (3)$$

Where:
$\mu_{od}$*:* viscosity of dead oil, cp
*t*: temperature, °F
*A*: calculated by Equation 4

Calculation of variable "A" used in Equation (3):

$$A = 10^{\left(0.43 + \frac{8.33}{API}\right)} \qquad (4)$$

Calculation of oil viscosity at bubble pressure:

$$\mu_{ob} = 10^a \mu_{od}^b \qquad (5)$$

Where:
$\mu_{ob}$: viscosity of saturated crude oil, cp

Calculation of the variables "a" and "b" that will be used in Equation (5):

$$a = R_s(2.2 \times 10^{-7} R_s - 7.4 \times 10^{-4}) \qquad (6)$$

$$b = \frac{0.68}{10^c} + \frac{0.25}{10^d} + \frac{0.062}{10^e} \qquad (7)$$

Where:
$R_s$: solution gas–oil ratio, scf/stb

Calculation of the variables "c", "d" and "e" that will be used in Equation (7):

$$c = 8.62 \times 10^{-5} R_s \tag{8}$$

$$d = 1.10 \times 10^{-3} R_s \tag{9}$$

$$e = 3.74 \times 10^{-3} R_s \tag{10}$$

Calculation of oil viscosity for a given pressure p.

$$\mu_o = \mu_{ob} + 0.001(p - p_b)(0.024\mu_{ob}^{1.6} + 0.38\mu_{ob}^{0.56}) \tag{11}$$

Where:
$\mu_o$: oil viscosity, cp
$p$: pressure, psia
$p_b$: bubble point pressure, psia

Step 2 - Calculating Reynolds Number - NRe

The Reynolds number for the fluid can be calculated from Equation (12):

$$N_{\mathrm{Re}} = \frac{1.48q\rho}{d\mu} \tag{12}$$

Where:
$N_{\mathrm{Re}}$: Reynolds number
$q_o$: oil flow rate, bbl/d
$\rho_o$: density of stock tank oil, lbm / ft$^3$
$d$: choke diameter, in.
$\mu_o$: viscosity of Oil, cp

Step 3 - Calculation of Choke Discharge Coefficient ($C_D$)

Guo et al. (2007) use Equation (13) to calculate the Choke Discharge Coefficient ($C_D$) for nozzle-type choke and for Reynolds numbers between $10^4$ and $10^6$.

$$C_D = \frac{d_2}{d_1} + \frac{0.3167}{\left(\frac{d_2}{d_1}\right)^{0.6}} + 0.025[\log(N_{\mathrm{Re}}) - 4] \tag{13}$$

Where:
$C_D$: choke discharge coefficient
$d_1$: upstream pipe diameter, in.
$d_2$: choke diameter, in.
$N_{Re}$: Reynolds number based on $d_2$

Step 4 - Calculating the Pressure drop

The pressure drop for the flow of a single phase liquid through a choke is due to the variation of the kinetic energy. Since there is a flow restriction, it is expected a decrease in the velocity of displacement of the fluid causing the energy variation (GUO et al., 2007). Thus, Equation (14) can be used for the calculation:

$$\Delta p = \left( \frac{q_o \sqrt{\rho_o}}{8074\, C_D\, d_2^2} \right)^2 \tag{14}$$

Where:
*Δp:* pressure drop, psi
$q_o$: oil flow rate, bbl/d
$C_D$: choke discharge coefficient
$d_2$: choke diameter, in
$\rho_o$: density of stock tank oil, lbm/ft³

**Worksheet Validation - Case Study**

To verify its consistency, the spreadsheet elaborated in Excel® was used to analyze the performance of a choke. The production data from a well were taken from the literature.

Guo et al. (2007) present the case of a well that only produces oil and use a nozzle-type choke. The production data are given in Table 1.

**TABLE 1:** Production data

| Properties | Value |
|---|---|
| °API | 40 |
| Oil flow rate ($q_o$) | 200 bbl/d |
| Temperature (t) | 100°F |
| Upstream pipe diameter ($d_1$) | 2 in |
| Choke diameter ($d_2$) | 1 in |
| Solution gas–oil ratio ($R_s$) | 0 |

**SOURCE:** Adapted from Guo et al., (2007).

Considering the information presented in Table 1, the data of the case under study were implemented in the elaborated spreadsheet and the simulation results where compared to those obtained by analytical solution.

## RESULTS AND DISCUSSION

By implementing Equations (1) to (14) in Excel® spreadsheets, it was possible to develop a simulator to make chokes analysis faster and straightforward. In the spreadsheet, some data are essential for the simulator to work properly. If one or more variables are not provided, the calculation steps cannot be completed and, therefore, the simulator will not function correctly. It is important to state that each variable must be supplied in the required unit in the worksheet.

The simulator has the following input data: °API, oil flow rate, choke diameter, upstream pipe diameter, temperature and oil viscosity. As output information: cross-sectional area of choke, choke discharge coefficient, specific gravity of stock tank, density of stock tank, Reynolds number and pressure drop through nozzle-type choke.

In order to validate the spreadsheet elaborated for the analysis of chokes, the values obtained by analytical solution were compared with those found in this work. The data from well that produces only oil and uses a nozzle-type choke were implemented in the spreadsheet to single-phase oil flow, as shown in Figure 1. The simulation results were obtained and compared with analytical solution (Table 2).

**SINGLE-PHASE LIQUID FLOW**

**INPUT DATA:**

| | | |
|---|---|---|
| **° API** | 40,00 | ° API |
| **Flow rate ($q_o$)** | 200,00 | bbl/d |
| **Choke diameter ($d_2$)** | 1,00 | in |
| **Upstream pipe diameter ($d_1$)** | 2,00 | in |
| **Temperature (t)** | 100,00 | °F |
| **Viscosity of oil ($\mu_o$)** | 2,8811 | cp |

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**SOLUTION:**

| | | | | |
|---|---|---|---|---|
| **Cross-sectional area of choke (Ac)** | 0,7854 | in² | d2/d1 | 2 |
| **Choke discharge coefficient ($C_D$)** | 2,19 | | | |
| **Specific gravity of stock tank oil ($\gamma_o$)** | 0,8251 | | | |
| **Density of stock tank oil ($\rho_o$)** | 51,48 | lbm/ft³ | | |
| **Reynolds number ($N_{Re}$)** | 2.644,73 | Turbulent flow | | |
| **Pressure drop ($\Delta p$)** | 0,007 | psi | | |

**FIGURE 1:** Simulator for Single-Phase Fluid, Oil - Subcritical

**TABLE 2:** Results of Choke analysis - Single Phase Flow - Oil – Subcritical

| Variables | Units | Authors* | Simulation |
|---|---|---|---|
| Cross-sectional area of choke ($A_C$) | in$^2$ | 0.7854 | 0.7854 |
| Choke discharge coefficient ($C_D$) | - | 2.19 | 2.19 |
| Viscosity of Oil ($\mu_O$) | cP | 2.8616 | 2.8811 |
| Specific gravity of stock tank oil ($\square_O$) | - | 0.8251 | 0.8251 |
| Density of stock tank oil ($\rho_O$) | lb$_m$/ft$^3$ | 51.48 | 51.48 |
| Reynolds number ($N_{Re}$) | - | 2662.51 | 2644.73 |
| Pressure drop ($\Delta p$) | psi | 0.007 | 0.007 |

*Analytical solution

Figure 1 shows that the simulator (Excel worksheet) has input and output data. After completing the simulator with the data in Table 1 the results of the simulation were observed in “solution”. Table 2 compares the results of the analytical solution with those obtained in the simulator.

The values obtained in the simulation for cross-sectional area of choke, choke discharge coefficient, specific gravity of stock tank oil, density of stock tank oil and pressure drop were the same as those determined in the analytical solution. The results of the viscosity of oil and Reynolds number (simulations) presented deviations of 0.68% and -0.67%, respectively, when compared to the analytical solution. As observed in Table 2, there are small differences between the results found with the simulator and the results found by analytical solution. It is important to note that the values that showed deviations did not affect the prediction of the choke pressure drop, which was 0.007 psi in both solutions.

The computational solution of engineering problems is important because it saves time as it provides the results quickly, and avoids exhaustive calculations by hand. Thus, computer simulation has been prominent in engineering, including oil production. Computational simulation has been used in several researches in the area of petroleum. Examples include the work of Michael et al. (2013); Kohshour et al. (2014); Wang and Gong (2015); Hakimi and Abdullah (2015); Nandanwar et al. (2016); Gharagheizi et al. (2017) and Kurkalova and Carter (2017)

## CONCLUSIONS

A simulator was developed for analysis of single-phase oil flow in a subcritical regime. The calculations necessary to analyze the performance of the choke are executed quickly and easily using the equations contained in the literature.

By means of a case study it was possible to validate the simulator. The results showed that the equations were implemented correctly in the spreadsheet, and that the computational solution of choke performance reduces the differences and calculation errors that can occur for manual solution.

## REFERENCES


BEGGS, H.D., BRILL, J.P.. **Two-Phase Flow in Pipes**, 4. ed., University of Tulsa Printer, USA, 1982.

BROWN, K. E. BEGGS, H. D. **The Technology of Artificial Lift Methods**, v.1. 491 p. Tulsa, Oklahoma: PennWell Publishing Company, 1984.

CALIXTO, F.J. **Modelagem do Escoamento Multifásico através de Chokes.** 2009. 151 f. Dissertação (Mestrado em Engenharia de Reservatório e de Exploração), Centro de Ciência e Tecnologia da Universidade Estadual do Norte Fluminense. Macaé, 2009.

GHARAGHEIZI, F., MOHAMMADI, A. H., ARABLOO, M., SHOKROLLAHI, A. Prediction of sand production onset in petroleum reservoirs using a reliable classification approach. **Petroleum**, v. 3, n. 2, p. 280-285, 2017. Disponível em: <http://www.sciencedirect.com/science/article/pii/S2405656116000109>. doi: 10.1016/j.petlm.2016.02.001

GUITERAS, O.H.J. **Metodologia de Análise Global para o Desenvolvimento de um Campo de Gás Natural**. 2003. 285f. Dissertação (Mestrado em Engenharia Mecânica), Departamento de Engenharia Mecânica – PUC. Rio de Janeiro, 2003.

GUO, B.; LYONS, W. C.; GHALAMBOR, A. **Petroleum Production Engineering**: A Computer-Assisted Approach. Elsevier Science & Technology Books, 2007.

HAKIMI, M. H.; ABDULLAH, W. H. Modelling petroleum generation of Late Cretaceous Dabut Formation in the Jiza-Qamar Basin, Eastern Yemen. **Marine and Petroleum Geology**, v. 61, p. 1-13, 2015. Disponível em: <https://doi.org/10.1016/j.marpetgeo.2014.11.004>. doi: 10.1016/j.marpetgeo.2014.11.004.

KOHSHOUR, I. O.; AHMADI, M.; HANKS, C. Integrated geologic modeling and reservoir simulation of Umiat: A frozen shallow oil accumulation in national petroleum reserve of Alaska. **Journal of Unconventional Oil and Gas Resources**, v. 6, p. 4-27, 2014. Disponível em: <https://doi.org/10.1016/j.juogr.2013.11.001>. doi: 10.1016/j.juogr.2013.11.001.

KURKALOVA, L. A.; CARTER, L. Sustainable production: Using simulation modeling to identify the benefits of green information systems. **Decision Support Systems**, v. 96, p. 83-91, 2017. Disponível em: <https://doi.org/10.1016/j.dss.2017.02.006>. doi: 10.1016/j.dss.2017.02.006.

MICHAEL, K.; BUNCH, M.; VARMA, S. Simulation of the cumulative impacts of $CO_2$ geological storage and petroleum production on aquifer pressures in the offshore Gippsland Basin. **International Journal of Greenhouse Gas Control**, v. 19, p. 310-321, 2013. Disponível em: <https://doi.org/10.1016/j.ijggc.2013.09.009>. doi: 10.1016/j.ijggc.2013.09.009.

NANDANWAR, M. S., ANDERSON, B. J., AJAYI, T., COLLETT, T. S., & ZYRIANOVA, M. V. Evaluation of gas production potential from gas hydrate deposits in National Petroleum Reserve Alaska using numerical simulations. **Journal of Natural Gas Science and Engineering,** v. 36, p. 760-772, 2016**.** Disponível em: <https://doi.org/10.1016/j.jngse.2016.11.021>. doi: 10.1016/j.jngse.2016.11.021.

OMANA, R.; HOUSSIRERE, C. Jr.; BROWN, K. E.; BRILL, J. P.; JAMES P.B.; THOMPSON, R. E. **Multhipase Flow Through Chokes**. Society of Petroleum Engineers – SPE. Reunião de Outono da Society of Petroleum Engineers da AIME, Denver, Colorado, 1969.

ROSSI, N.C.M. **Elevação natural e Artificial de Petróleo** – Curso de Formação de Engenheiros de Equipamentos Júnior. Rio de Janeiro: Petrobrás, 2009.

WANG, H.; GONG, B. Hierarchical stochastic modeling and optimization for petroleum field development under geological uncertainty. **Computers & Industrial Engineering**, v. 80, p. 23-32, 2015. Disponível em: <https://doi.org/10.1016/j.cie.2014.11.007>. doi: 10.1016/j.cie.2014.11.007.