A Single Phase Reservoir Simulator

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Introduction

Reservoir simulation plays a vital role as a diagnostics tool to better understand and predict reservoir performance under various operating conditions and strategies during planning, developing, and depleting of oil and gas reservoirs. This document presents a simple software to simulate one-dimensional, single-phase, slightly compressible fluid (oil) flow in a reservoir. A basic case example is presented with results.

Model Equation

The fundamental mathematical model that describes fluid flow in porous media is derived from Darcy's Law, material balance and an equation of state (EOS). For further information on the formulation of flow equations, the text **Basic Applied Reservoir Simulation** by Ertekin et al (2001) is recommended. In the case of one-dimensional (x-direction), slightly compressible fluid (oil) flow, the equation can be written as:

$$\frac{\partial}{\partial x}\left(\beta_c A_x K_x \frac{\partial p}{\partial x}\right)\Delta x + B^o \mu q_{sc} = \frac{V_b \phi \mu c_t}{a_c}\frac{\partial p}{\partial t} \tag{1}$$

Solution Method

Finite difference method (FDM) is used to discretize Eq.1 and pressure is solved implicitly (implicit backward difference). The linear system of equations to be solved for pressure is of the following form.

$$[\boldsymbol{A}][\boldsymbol{x}] = [\boldsymbol{B}] \tag{2}$$

Example Case

In this case example, we discretize a reservoir into 10 gridblocks as shown in Figure 1 with rock, fluid and well data as provided in Table 1. Dirichlet and Neumann boundary conditions are assumed at the western and the eastern ends of the reservoir respectively. We assume that the reservoir has only oil, it is at an initial pressure of 6000 psia and it will be producing oil from two wells, each at a constant rate of 75 STB/D from blocks 7 and 8. We evaluate pressure change over 1 and 3 years at timesteps 5 days and 15 days respectively.

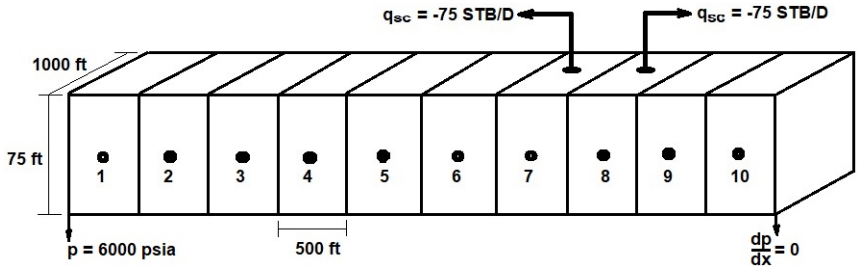

Figure 1: One-dimensional reservoir with 10 gridblocks (block-centered grid).

Table 1: Reservoir rock, fluid and well properties.

Property	Value	Property	Value	Property	Value
β_c	1.127	Well 1 Rate (q_{sc})	-75 STB/D	ϕ	0.18
K_x	15 mD	Well 2 Rate (q_{sc})	-75 STB/D	c_t	$3.5e^{-6}$
B^o	1 RB/STB	Left BC (Neumann)	6000 psia	a_c	5.614583
μ	10 cp	Right BC (Dirichlet)	$dp/dx = 0$	Well Radii	0.25 ft

Results

The results are visualised in the following figures.

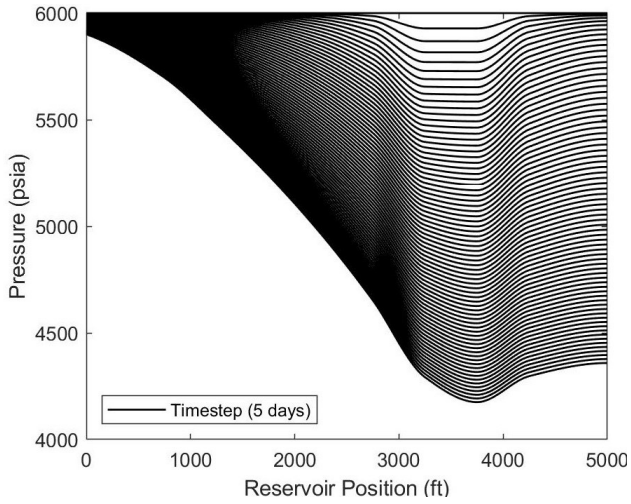

Figure 2: Results for timestep = 5 days over 360 days. Pressure decline wrt reservoir position and timestep

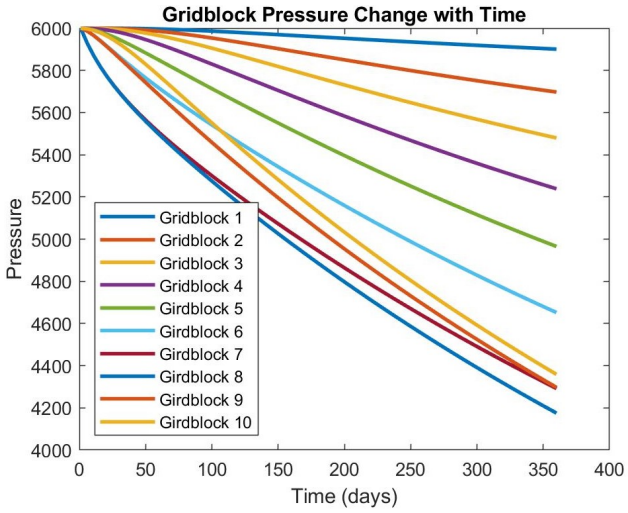

Figure 3: Results for timestep = 5 days over 360 days. Pressure decline wrt gridblock and timestep

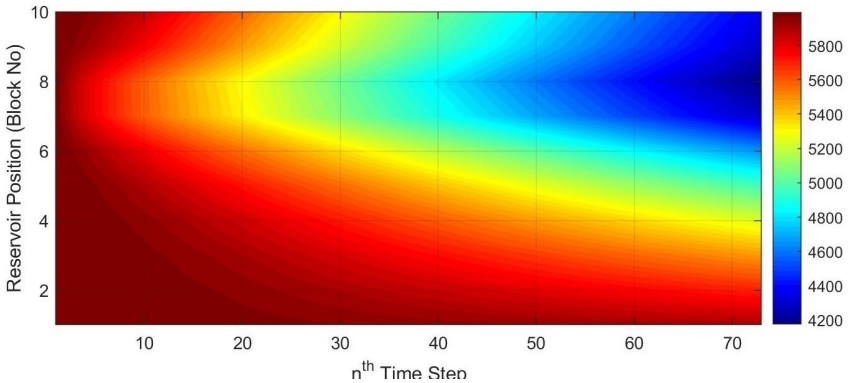

Figure 4: Results for timestep = 5 days over 360 days. Pressure decline wrt gridblock and timestep

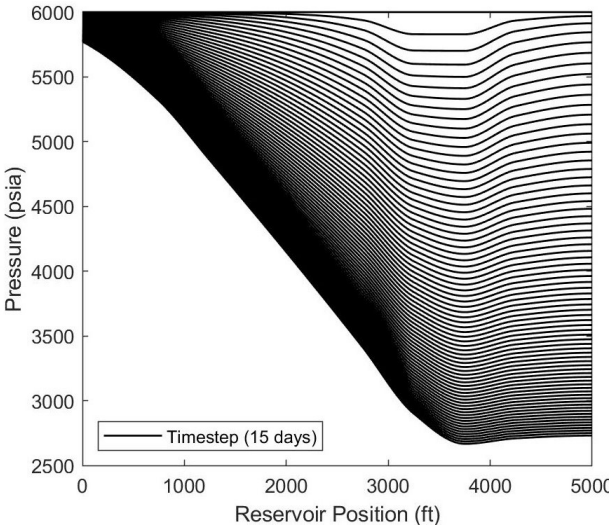

Figure 5: Results for timestep = 15 days over 3-years. Pressure decline wrt reservoir position and timestep

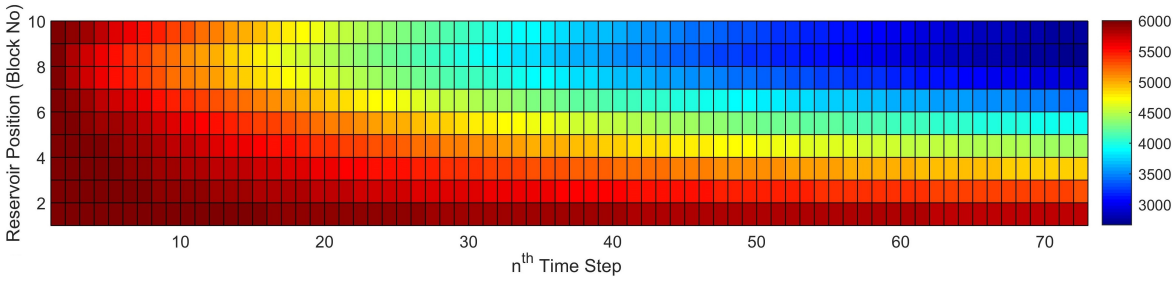

Figure 6: Results for timestep = 15 days over 3-years. Pressure decline wrt gridblock and timestep

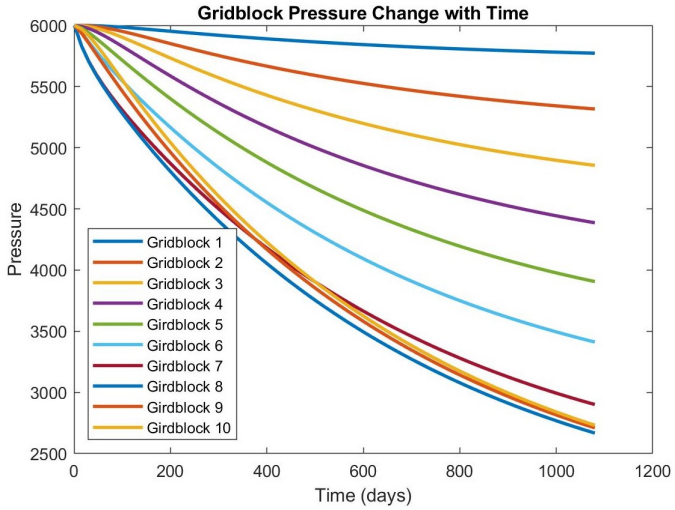

Figure 7: Results for timestep = 15 days over 3-years. Pressure decline wrt gridblock and timestep

Table 2. Printed pressure values per timestep for year 2 and 3.

BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5	BLOCK 6	BLOCK 7	BLOCK 8	BLOCK 9	BLOCK 10
5.8849e+03	5.6502e+03	5.4024e+03	5.1330e+03	4.8340e+03	4.4983e+03	4.1196e+03	3.9882e+03	4.1001e+03	4.1568e+03
5.8810e+03	5.6386e+03	5.3833e+03	5.1069e+03	4.8015e+03	4.4602e+03	4.0768e+03	3.9418e+03	4.0513e+03	4.1067e+03
5.8771e+03	5.6272e+03	5.3646e+03	5.0813e+03	4.7697e+03	4.4230e+03	4.0349e+03	3.8964e+03	4.0035e+03	4.0577e+03
5.8734e+03	5.6160e+03	5.3463e+03	5.0563e+03	4.7386e+03	4.3865e+03	3.9940e+03	3.8520e+03	3.9568e+03	4.0098e+03
5.8697e+03	5.6051e+03	5.3283e+03	5.0318e+03	4.7081e+03	4.3508e+03	3.9540e+03	3.8086e+03	3.9110e+03	3.9629e+03
5.8661e+03	5.5944e+03	5.3108e+03	5.0078e+03	4.6783e+03	4.3159e+03	3.9148e+03	3.7662e+03	3.8663e+03	3.9171e+03
5.8626e+03	5.5839e+03	5.2936e+03	4.9844e+03	4.6492e+03	4.2817e+03	3.8765e+03	3.7246e+03	3.8226e+03	3.8722e+03
5.8592e+03	5.5737e+03	5.2768e+03	4.9614e+03	4.6207e+03	4.2483e+03	3.8390e+03	3.6840e+03	3.7798e+03	3.8284e+03
5.8558e+03	5.5636e+03	5.2604e+03	4.9390e+03	4.5927e+03	4.2156e+03	3.8023e+03	3.6443e+03	3.7380e+03	3.7855e+03
5.8525e+03	5.5538e+03	5.2443e+03	4.9170e+03	4.5654e+03	4.1837e+03	3.7665e+03	3.6054e+03	3.6971e+03	3.7435e+03
5.8493e+03	5.5442e+03	5.2286e+03	4.8955e+03	4.5387e+03	4.1524e+03	3.7314e+03	3.5674e+03	3.6571e+03	3.7025e+03
5.8461e+03	5.5349e+03	5.2132e+03	4.8745e+03	4.5126e+03	4.1218e+03	3.6971e+03	3.5302e+03	3.6179e+03	3.6623e+03
5.8430e+03	5.5257e+03	5.1981e+03	4.8540e+03	4.4870e+03	4.0918e+03	3.6635e+03	3.4938e+03	3.5796e+03	3.6230e+03
5.8400e+03	5.5167e+03	5.1834e+03	4.8338e+03	4.4620e+03	4.0625e+03	3.6307e+03	3.4582e+03	3.5421e+03	3.5846e+03
5.8371e+03	5.5079e+03	5.1690e+03	4.8142e+03	4.4376e+03	4.0339e+03	3.5985e+03	3.4234e+03	3.5055e+03	3.5471e+03
5.8342e+03	5.4993e+03	5.1549e+03	4.7949e+03	4.4136e+03	4.0059e+03	3.5671e+03	3.3893e+03	3.4696e+03	3.5103e+03
5.8313e+03	5.4909e+03	5.1411e+03	4.7761e+03	4.3902e+03	3.9784e+03	3.5363e+03	3.3560e+03	3.4346e+03	3.4743e+03
5.8286e+03	5.4826e+03	5.1276e+03	4.7577e+03	4.3673e+03	3.9516e+03	3.5063e+03	3.3234e+03	3.4003e+03	3.4392e+03
5.8259e+03	5.4746e+03	5.1144e+03	4.7396e+03	4.3449e+03	3.9254e+03	3.4768e+03	3.2915e+03	3.3667e+03	3.4048e+03
5.8232e+03	5.4667e+03	5.1015e+03	4.7220e+03	4.3230e+03	3.8997e+03	3.4481e+03	3.2603e+03	3.3339e+03	3.3711e+03
5.8206e+03	5.4590e+03	5.0889e+03	4.7047e+03	4.3015e+03	3.8746e+03	3.4199e+03	3.2298e+03	3.3018e+03	3.3382e+03
5.8181e+03	5.4515e+03	5.0765e+03	4.6879e+03	4.2806e+03	3.8500e+03	3.3924e+03	3.2000e+03	3.2704e+03	3.3060e+03
5.8156e+03	5.4441e+03	5.0644e+03	4.6714e+03	4.2600e+03	3.8260e+03	3.3654e+03	3.1708e+03	3.2396e+03	3.2745e+03
5.8132e+03	5.4369e+03	5.0526e+03	4.6552e+03	4.2400e+03	3.8025e+03	3.3391e+03	3.1422e+03	3.2096e+03	3.2437e+03
5.8108e+03	5.4298e+03	5.0410e+03	4.6394e+03	4.2203e+03	3.7795e+03	3.3133e+03	3.1143e+03	3.1802e+03	3.2135e+03
5.8085e+03	5.4229e+03	5.0297e+03	4.6240e+03	4.2011e+03	3.7570e+03	3.2881e+03	3.0870e+03	3.1514e+03	3.1840e+03
5.8062e+03	5.4162e+03	5.0186e+03	4.6088e+03	4.1823e+03	3.7350e+03	3.2634e+03	3.0602e+03	3.1233e+03	3.1552e+03
5.8040e+03	5.4096e+03	5.0078e+03	4.5940e+03	4.1639e+03	3.7135e+03	3.2393e+03	3.0341e+03	3.0958e+03	3.1270e+03
5.8018e+03	5.4031e+03	4.9972e+03	4.5796e+03	4.1460e+03	3.6925e+03	3.2157e+03	3.0085e+03	3.0688e+03	3.0994e+03
5.7997e+03	5.3968e+03	4.9868e+03	4.5654e+03	4.1284e+03	3.6719e+03	3.1926e+03	2.9835e+03	3.0425e+03	3.0724e+03
5.7976e+03	5.3906e+03	4.9767e+03	4.5516e+03	4.1112e+03	3.6517e+03	3.1700e+03	2.9590e+03	3.0167e+03	3.0459e+03
5.7956e+03	5.3845e+03	4.9668e+03	4.5380e+03	4.0943e+03	3.6320e+03	3.1479e+03	2.9351e+03	2.9915e+03	3.0201e+03
5.7936e+03	5.3786e+03	4.9571e+03	4.5248e+03	4.0779e+03	3.6127e+03	3.1262e+03	2.9116e+03	2.9669e+03	2.9948e+03
5.7917e+03	5.3728e+03	4.9476e+03	4.5118e+03	4.0618e+03	3.5939e+03	3.1051e+03	2.8887e+03	2.9427e+03	2.9701e+03
5.7898e+03	5.3672e+03	4.9383e+03	4.4992e+03	4.0460e+03	3.5754e+03	3.0844e+03	2.8663e+03	2.9192e+03	2.9459e+03
5.7879e+03	5.3616e+03	4.9292e+03	4.4868e+03	4.0306e+03	3.5574e+03	3.0642e+03	2.8444e+03	2.8961e+03	2.9223e+03
5.7861e+03	5.3562e+03	4.9203e+03	4.4746e+03	4.0155e+03	3.5397e+03	3.0444e+03	2.8229e+03	2.8735e+03	2.8991e+03
5.7843e+03	5.3509e+03	4.9116e+03	4.4628e+03	4.0008e+03	3.5224e+03	3.0250e+03	2.8019e+03	2.8514e+03	2.8765e+03
5.7825e+03	5.3457e+03	4.9031e+03	4.4512e+03	3.9863e+03	3.5055e+03	3.0061e+03	2.7814e+03	2.8298e+03	2.8543e+03
5.7808e+03	5.3406e+03	4.8948e+03	4.4398e+03	3.9722e+03	3.4890e+03	2.9875e+03	2.7613e+03	2.8087e+03	2.8326e+03
5.7792e+03	5.3357e+03	4.8867e+03	4.4287e+03	3.9584e+03	3.4729e+03	2.9694e+03	2.7417e+03	2.7880e+03	2.8115e+03
5.7775e+03	5.3308e+03	4.8787e+03	4.4178e+03	3.9449e+03	3.4570e+03	2.9517e+03	2.7225e+03	2.7678e+03	2.7907e+03
5.7759e+03	5.3261e+03	4.8709e+03	4.4072e+03	3.9317e+03	3.4416e+03	2.9343e+03	2.7037e+03	2.7480e+03	2.7704e+03
5.7744e+03	5.3214e+03	4.8633e+03	4.3968e+03	3.9188e+03	3.4264e+03	2.9174e+03	2.6853e+03	2.7286e+03	2.7506e+03
5.7729e+03	5.3169e+03	4.8559e+03	4.3866e+03	3.9061e+03	3.4116e+03	2.9008e+03	2.6673e+03	2.7097e+03	2.7312e+03

References

Ertekin, T., Abou-Kassem, J.H., and King, J.R., 2001. Basic Applied Reservoir Simulation. Society of Petroleum Engineers.

Appendix

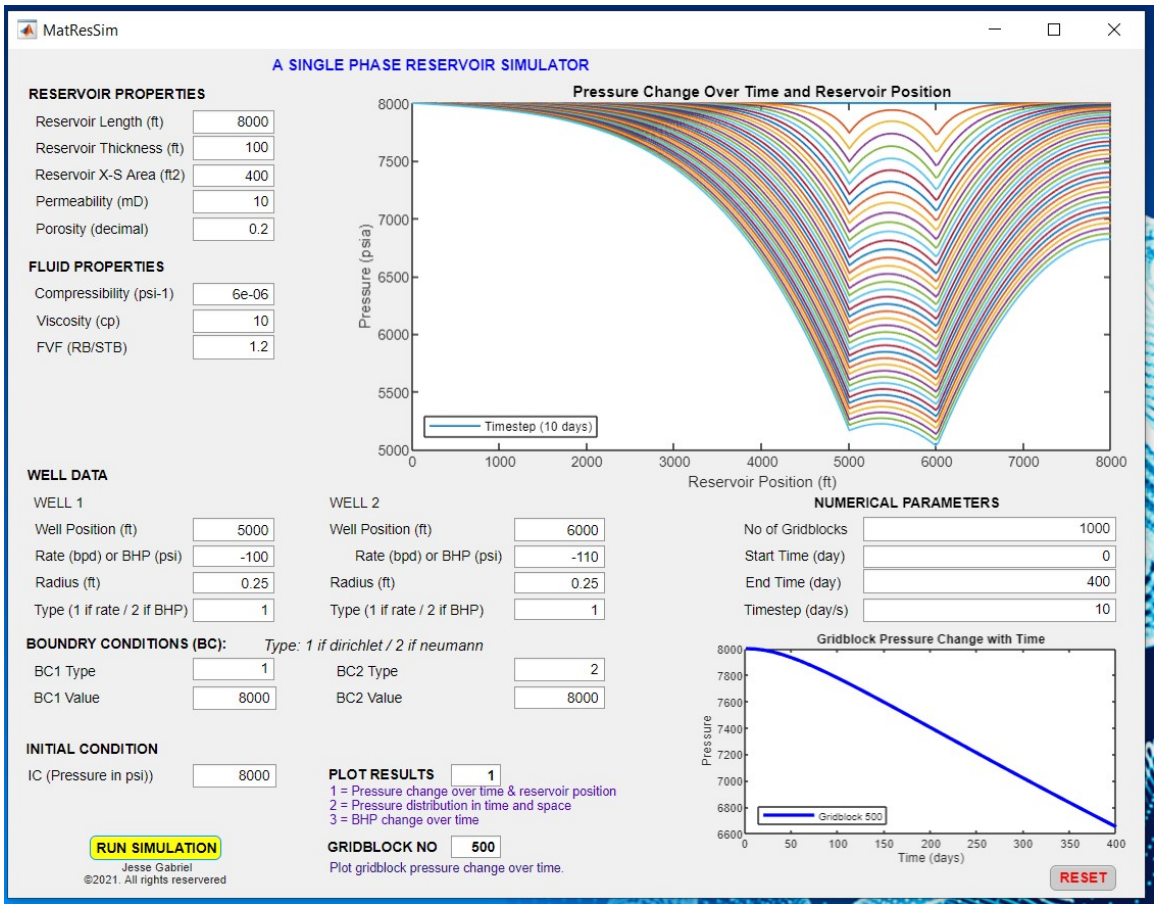

Figure 8: GUI for a single phase (oil) reservoir simulator (NB: accounts any number of gridblocks)