NUMERICAL RESERVOIR SIMULATION
COMPUTER PROJECT 2

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1 Introduction

A gas reservoir is used as a gas storage facility for City A. This gas reservoir has the same property spatial distributions given in CP1, except that the permeability distribution needs to be re-calibrated via multiplying 0.1. Gas purchased from nearby larger gas field will be injected to the reservoir. Gas from the storage field will be used by the communities in City A. The natural gas demand per month for each household over a typical year is given in table below.

Table 1: Gas demand of citizen in city A

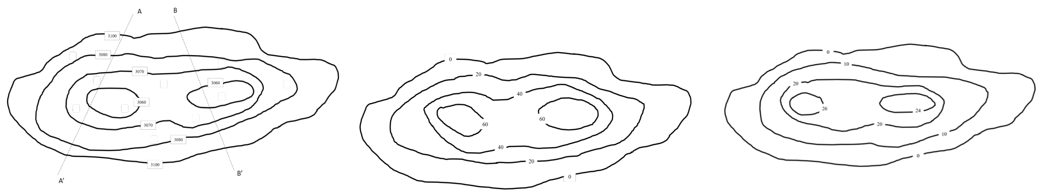
	Gas demand (MSCF/month/household)		**Gas demand (MSCF/month/household)**
Jan	140	July	28
Feb	130	Aug	25
Mar	115	Sep	45
Apr	90	Oct	65
May	60	Nov	85
Jun	40	Dec	120

The reservoir properties are shown as :

- Initial pressure and temperature are 4000 psia and 150 oF, respectively.
- Isothermal conditions exist inside the reservoir.
- The specific gravity of the natural gas in the reservoir is 0.6.
- The critical pressure and critical temperature for the gas are 680 psia and 385 R, respectively.
- The gas viscosity can be estimated using the correlation of Lee, Gonzalez and Eakin.
- The gas compressibility factor can be estimated from the attached subroutine of Dranchuk and Abou-Kassem (1975).

2 Reservoir and fluid properties

The reservoir is sealed and the permeability of boundaries is zero. Thickness distribution is from 0 to 60 ft. Reservoir is 3000 ft under the ground. Porosity distribution is from 0 to 26 percentage.



(a) Reservoir top (b) Reservoir thickness (c) Reservoir porosity

Figure 1: Reservoir properties distribution map

Reservoir permeability is shown in the figure below, and the permeability distirbution is re-calibrated with multiplying factor as shown in the table 2.

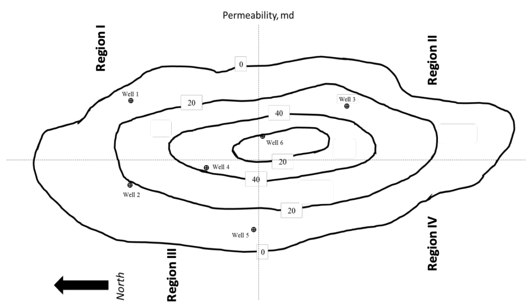
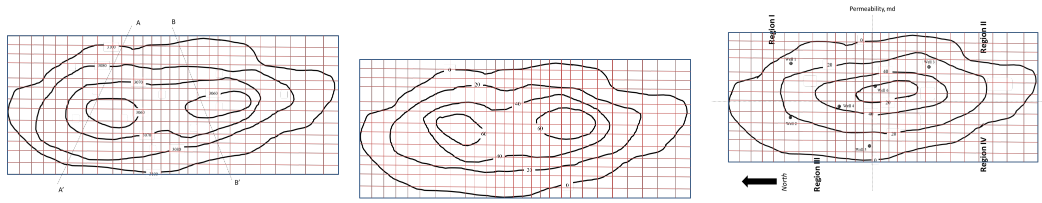


Figure 2: Reservoir permeability distribution

3 Methodology

3.1 Digitalize data

A web based tool (WebPlotDigitizer) have been used to extract data from images. The figure below is created to get the data at each gird point from WebPlotDigitizer.

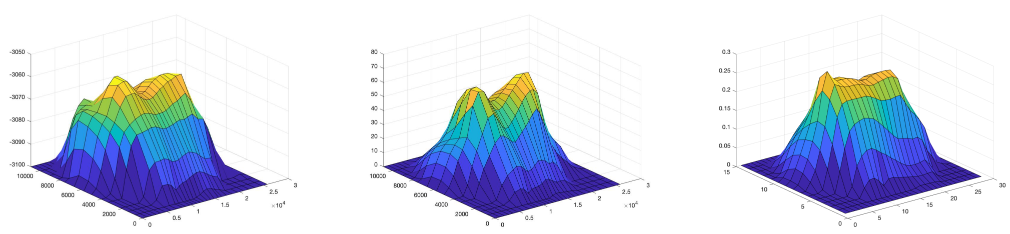


(a) Reservoir top (b) Reservoir thickness (c) Reservoir permeability

Figure 3: Reservoir properties distribution map before digitalizing

3.2 Mesh grid system building

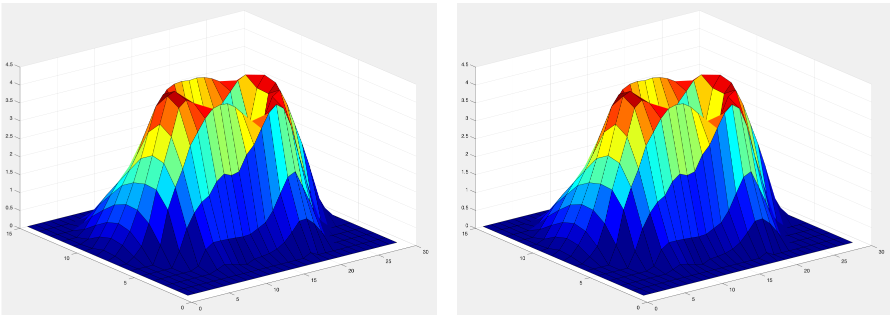
After digitalizing and getting data from images, a mesh grid system is built to cover the reservoir. The reservoir is divided in 351 blocks and each grid point is assigned with specific value of permeability, thickness, porosity and top by using harmonic spline interpolation function. Because the permeability and thickness outside boundaries of the reservoir are zeros, the data got from interpolation method need to be filtered in order to represent the reservoir more accurate. Specifically, permeability and thickness values outside the boundaries of reservoir are assigned to zeros. Top values outside are assigned to 3100 because the boundary circle of reservoir is 3100 ft.



(a) Reservoir top (b) Reservoir thickness (c) Reservoir porosity

Figure 4: Reservoir properties distribution map after digitalizing

The permeability distribution after calibration with multiplying of 0.1 is shown as :



(a) Permeability along W-E direction (b) Permeability along N-S direction

Figure 5: Reservoir permeability distribution map in N-S and W-E directions.

3.3 Define active block by numbering

The number of active blocks which have non-negative value of transmissibility is count by a for loop in python. There are 247 active blocks in the reservoir with properties values is greater then zero. Next, a boundary with all zeros values is established to calculate the transmissibility of each block.

3.4 Partial differential equation governing reservoir flow

Single-phase 2D with compressible fluid reservoir flow equation is shown:

$$\begin{aligned}\frac{\partial}{\partial x}\left(\frac{A_x\beta_c k_x}{\mu B}\frac{\partial\Phi}{\partial x}\right)\Delta x+\frac{\partial}{\partial y}\left(\frac{A_y\beta_c k_y}{\mu B}\frac{\partial\Phi}{\partial y}\right)\Delta y+q_{gsc}&=\frac{V_b}{\alpha_c}\frac{\partial}{\partial t}(\frac{\phi}{B_g})\\&=\frac{V_bT_{sc}}{p_{sc}T}\frac{\partial}{\partial t}(\frac{\phi p}{Z})\end{aligned}$$

Without depth gradient, the equation become:

$$\begin{aligned}\beta_c\frac{A_xk_x}{\mu B\Delta x}\bigg|_{i+\frac{1}{2},j}(p_{i+1,j}-p_{i,j})+\beta_c\frac{A_xk_x}{\mu B\Delta x}\bigg|_{i-\frac{1}{2},j}(p_{i-1,j}-p_{i,j})+\\\beta_c\frac{A_yk_y}{\mu B\Delta y}\bigg|_{i,j+\frac{1}{2}}(p_{i,j+1}-p_{i,j})+\beta_c\frac{A_yk_y}{\mu B\Delta y}\bigg|_{i,j-\frac{1}{2}}(p_{i,j-1}-p_{i,j})+q_{gsc}\\=\left(\frac{V_b\phi_tT_{sc}}{p_{sc}T}\right)_{i,j,k}\frac{1}{\Delta t}\left(\frac{p^{n+1}_{i,j,k}}{Z^{n+1}_{i,j,k}}-\frac{p^{n}_{i,j,k}}{Z^{n}_{i,j,k}}\right)\end{aligned}$$

3.5 Transmissibility calculation in North, South, West and East directions

Because using interpolation for generating reservoir property values, each point in the grid map have unique value lead to the fact that a block have four values of permeability, thickness and top. Block center grid method is used to implement in this project.
Transmissibility between two block is calculated by harmonic averaging:

$$\frac{2\beta_c}{\mu B\left[\frac{1}{(\frac{A_x k_x}{\Delta x})_{i,j}} + \frac{1}{(\frac{A_x k_x}{\Delta x})_{i+1,j}}\right]}$$

The viscosity, formation volume factor and density is calculated using pressure values from 2 neighbor blocks.

$$\mu^n_{i+\frac{1}{2},j,k} = \mu^n\left(p^n_{i+\frac{1}{2},j,k}\right)$$

$$B^n_{i+\frac{1}{2},j,k} = B^n\left(p^n_{i+\frac{1}{2},j,k}\right)$$

$$\rho^n_{i+\frac{1}{2},j,k} = \rho^n\left(p^n_{i+\frac{1}{2},j,k}\right)$$

3.6 Well properties definition and calculation

Productivity index of each well is calculated by the equation:

$$\Omega_{i,j,k} = \left[\frac{2\pi\overline{k}\Delta L}{\mu B(ln(\frac{r_e}{r_w}) + s)}\right]$$

3.7 Coefficient matrix construction

The reservoir has 247 active blocks, so a system of equations of size 247×247 need to be built by assigning the transmissibility values to the system of equations. A typical for loop is used to create the cofficient matrix.

4 Drilling schedule

4.1 Schedule 1

At the begining of drilling plans, eleven wells will be drilled in the location show in the figure below:

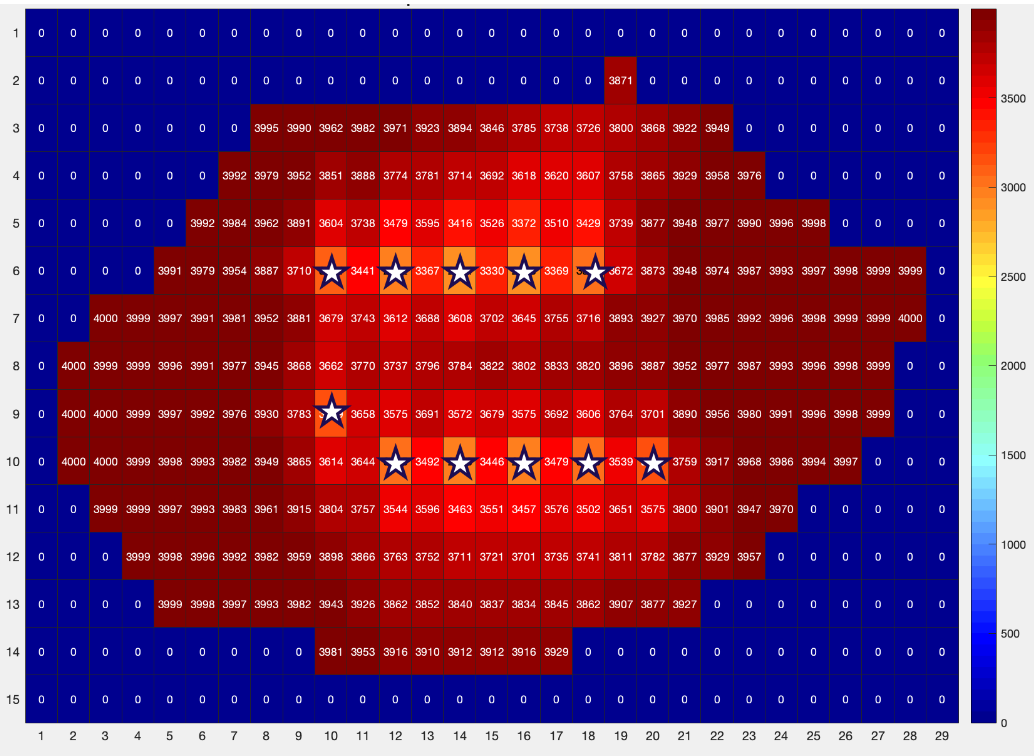


Figure 6: Production and injection schedule 1

4.2 Schedule 2

Due to the drop of gas demand from January to August, the injection plan should start in September. In this plan, eight injection wells (the arrow symbol) will be implemented as shown below.

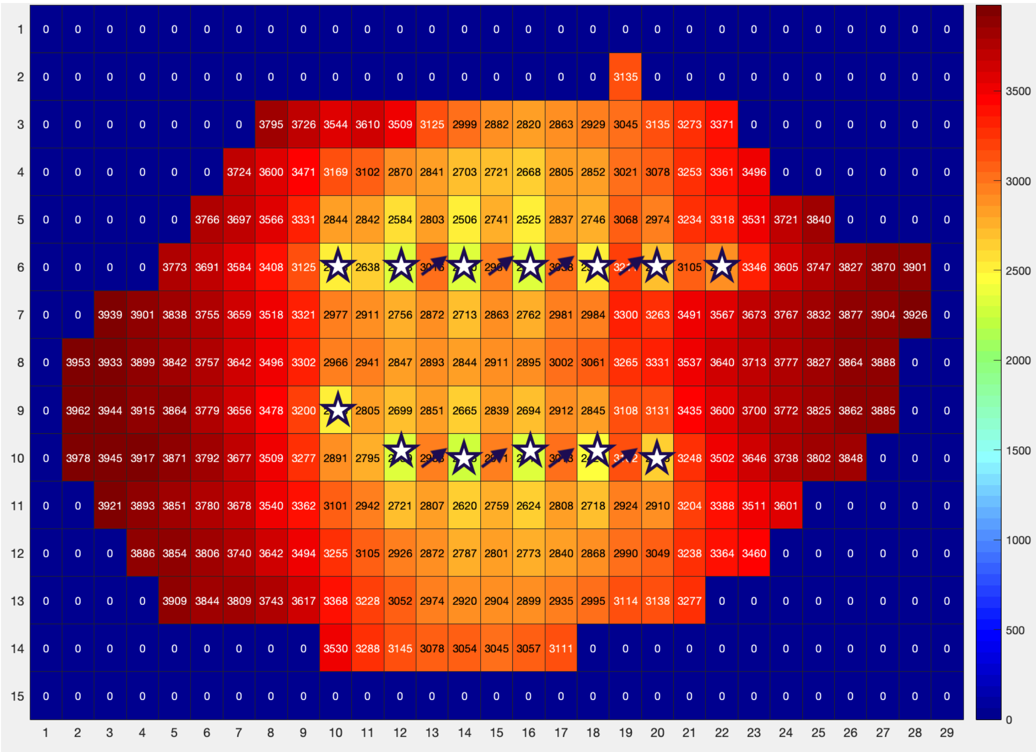


Figure 7: Production and injection schedule 2

The constraints for injection and production well:

Table 2: Well constraints

Constraints	Production wells	Injection wells
Bottom hole pressure (psi)	500	NA
Injection rate (MMSCF/D)	NA	10

The transmission line from the gas field to storage reservoir is limited at a working capacity of 100 MMSCF/day (maximum total injection rate into the storage reservoir). So, the injection rate should be chosen at 10 MMSCF/day/well.

4.3 Schedule 3

Starting from November, the natural gas demand increase steadily, so one more well (blue symbol) will be drilled in a new location as shown in figure 8.

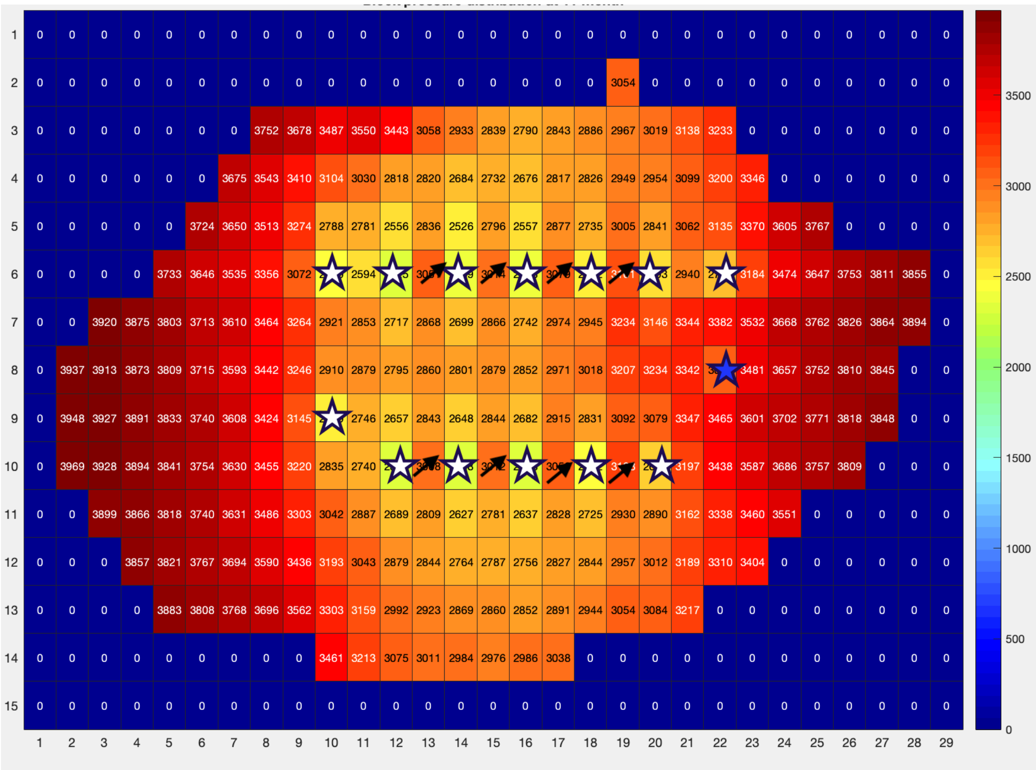


Figure 8: Production and injection schedule 3

4.4 Schedule 4

In december, the natural gas rise significantly to nearly the same with the January and February gas demand. One more well need to be drilled to meet that rise.

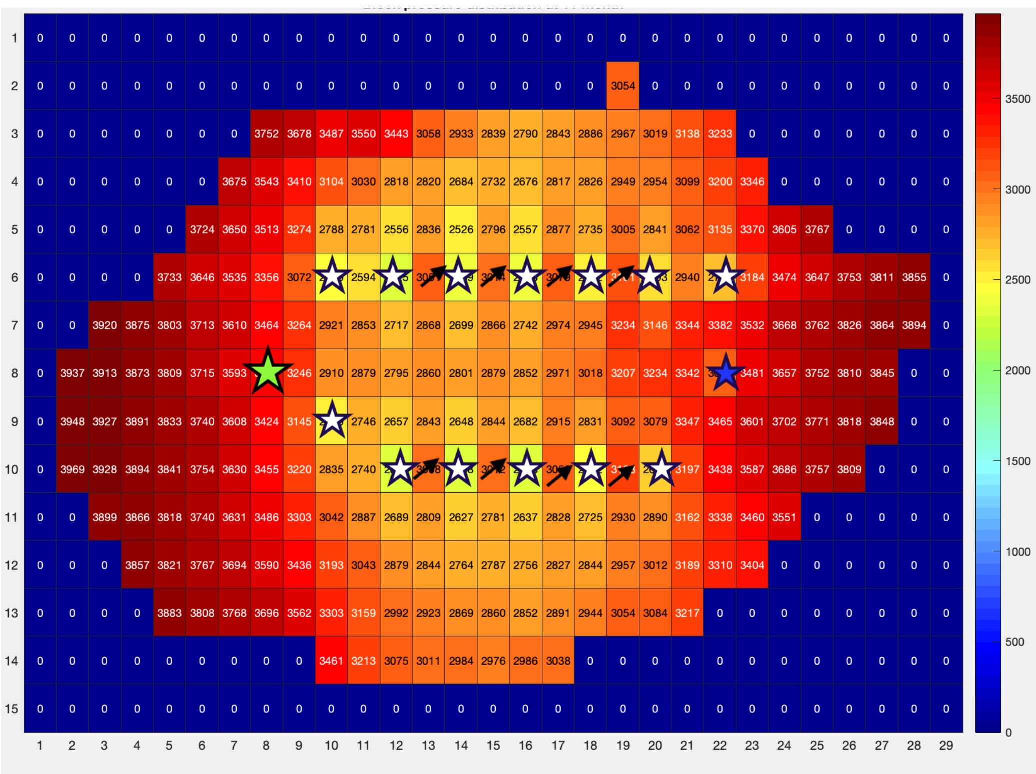
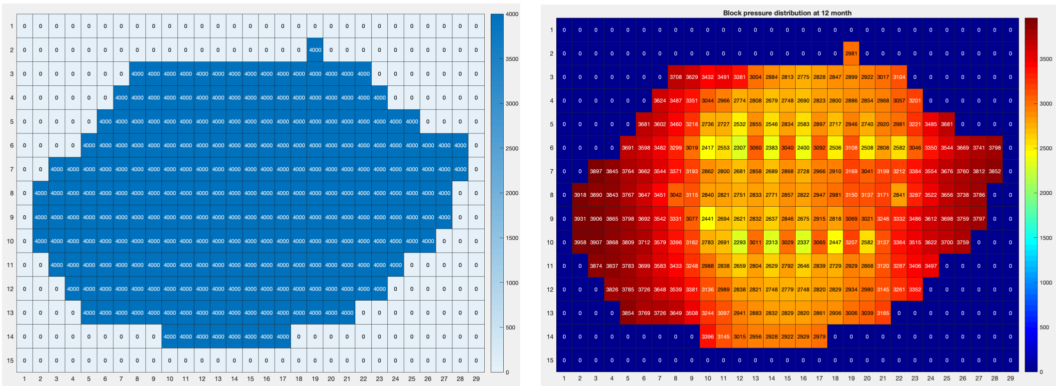


Figure 9: Production and injection schedule 4

5 Result

5.1 Reservoir pressure

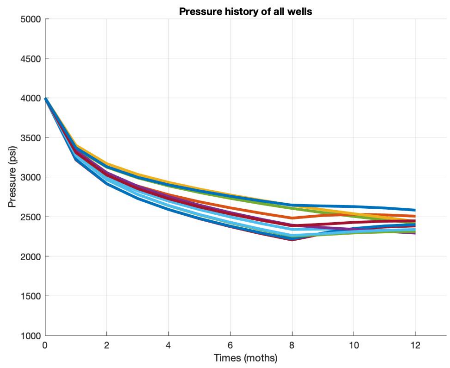


(a) Initial pressure distribution (b) Reservoir pressure at 1 year

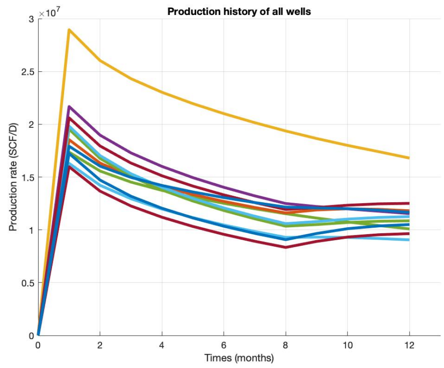
Figure 10: Reservoir pressure distribution

The reservoir pressures are always maintained above 1000 psia, and less than 5000 psia at any time, to avoid the closure of pores/fractures in the reservoir and bursting pressure. I also test the BHP pressure of 0 psia, after one year, the reservoir pressures are always bigger than 1000 psia. So, we do not need to care about the pores or fractures pressure.

5.2 Pressure and production profile



(a) Well block pressures

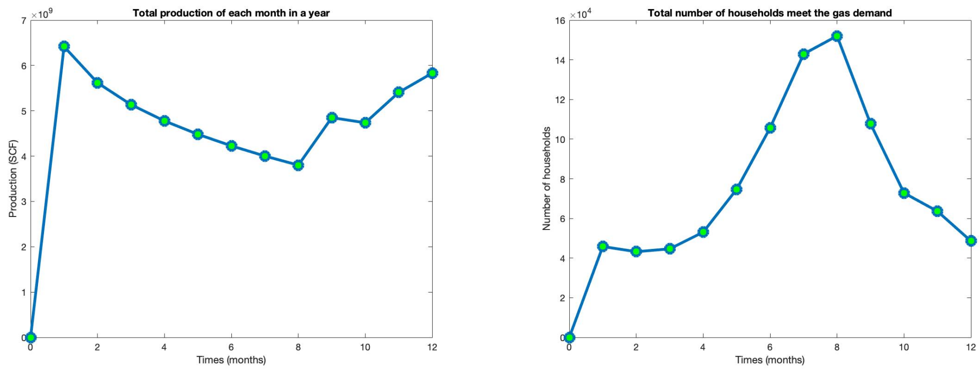


(b) Well production profile

Figure 11: Pressure and production of all wells

The smallest values of reservoir pressure are at well block pressure. Figure 11a shows that reservoir pressures are always bigger than 2000 psia. And, figure 11b is the production profile of all production wells per month after one year production. It is clear that the production rates are typically from 7 to 30 MMSCF per day.

5.3 The gas supply for city A



(a) Total natural gas to supply citizen (b) Number of households meet the demand

Figure 12: The total gas to supply city A and total number of households meet their demand

Since the natural gas demand decreases when the weather change from winter to summer. Although the production rate decreases from January to August, the number of households that can get their demand grows sharply. The objective is to maximize the number of households, so the schedule as mentioned is a possible choice to supply this city.

6 Summary and conclusion

This project is constructed for single phase with compressible fluid in 2-D. The heterogeneity of reservoir is shown through different distribution in permeability in both X and Y directions, diverse distribution in porostiby, thickness and grid dimensions.
In this project, using different programming languages and Webplot digitizing tools, the reservoir model is generated. A simulation is run for 1 years with injection plans and new drilling plans to meet demand of the city and maximize the number of households.

Additional conclusion

Since gas purchased from nearby larger gas field can be supplied the communities in this city, we do not need to reinject this amount of gas to reservoir again. This is a good option to save money and buy more gas to supply the demand from citizen.

My implementation

I have used mainly matlab to solve the computer project 2.
The main file is "**cp2_matlab.m**"
The file "**cp2_python.m**" is my implementation on Python
The file "**cp2_julia.jl**" is my implementation on Julia. My implementation on Julia using chain rule to construct Jacobian matrix, not the finite-different approximation.

References

[1] Numerical reservoir simulation slides. Dr-Miao Zhang

[2] Turgay Ertekin, Jamal H. Abou-Kassem, Gregory R.King. *Basic applied reservoir simulation.* Chaper 8.4, Single phase compressible flow problem, 205–210.