Numerical Simulation Evaluation of Compressed Gas Storage in Depleted Horizontal Wells of Low-Permeability Reservoirs

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Abstract

Power generation from renewable energy processes, such as photovoltaic cells and wind turbines, is intermittent in nature. The energy generated during these intermittent cycles can be stored in the form of compressed gas. When energy demand grows, the compressed gas could be expanded through a turbine to generate electricity. However, a limitation with this method is the large volume required for the gas storage. A possible alternative solution for the gas storage is to use depleted oil/gas horizontal wells with multiple hydraulic fractures, located in low-permeability (micro-Darcy to nano-Darcy) tight or shale formations. This work evaluated the potential use of horizontal wells with multiple hydraulic fractures for the storage of compressed gas using numerical reservoir simulation. A commercial numerical reservoir simulator, GEM from Computer Modeling Group (CMG), was used to model the injection of compressed gas into a depleted horizontal well with hydraulic fractures for temporary gas storage, and its subsequent production. The reservoir model was developed from published public information of the Niobrara formation in the DJ Basin[1].

Reservoir Model

- Properties of Niobrara formation in the DJ Basin are shown in Table 1[2],[3].
- Simulation was conducted using dry gas.
- WINPROP from CMG model was used.
- Fluid composition is shown in Table 2[4].

Table 1. Reservoir properties of DJ Basin

Table 1: Reservoir Properties	
Top Depth, D_{top} (ft)	7036
Height, h (ft)	250
Porosity, Φ (unitless)	0.06
Permeability, k (md)	0.001
Initial Reservoir Pressure, P_{res} (psi)	4000
Temperature, T (°F)	203

Table 2. Composition of Dry Gas

Component	Mole Fraction
CO_2	0.10
N_2	2.07
C1	86.12
C2	5.91
C3	3.58
IC4	1.72
IC5	0.50

- The actual trajectory of three wells (API #05-123-36252, API #05-123-36253, API #05-123-36254) located in the Wattenberg Field, Weld County are utilized in this simulation.
- The wells are fracture-stimulated with 18 stages, 200ft long fractures.

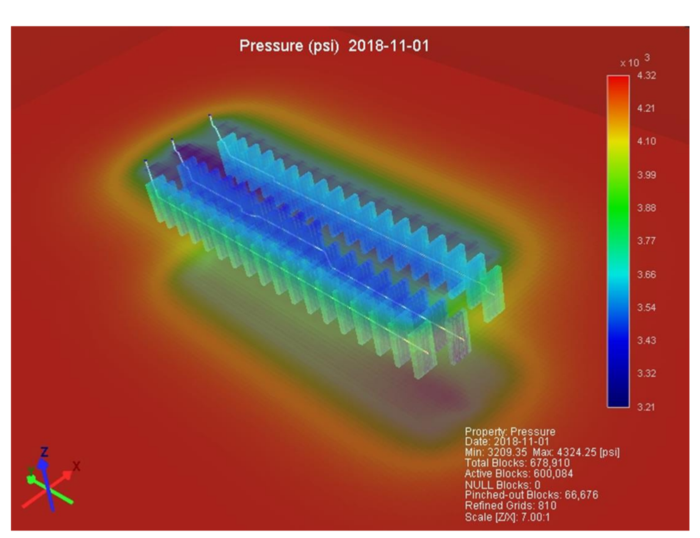

Figure 1: Model of reservoir with multiple wellbore trajectory and fractures

Initial Production Stage

- Simulated production rate matches typical historical production of an unconventional reservoir.
- Production rate peaks at early time and then declines over a short period of time
  - Fracture dominated flow and depletion of fracture pore pressure.
- Economic limit reached after 15 years
  - Production declines to 50 Mscf/day.

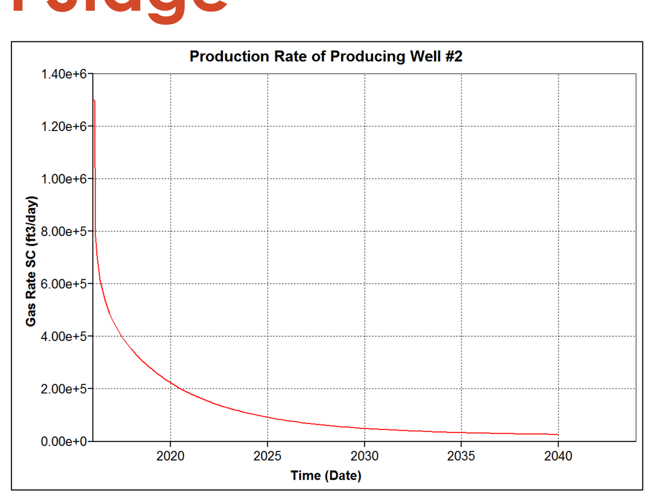

Figure 2: Simulated production rate

Injection and Production Cycle

- Simulation properties:
  - Nine injection and production cycles.
  - Injected gas: Nitrogen gas (N_2).
  - Injection and production rates of 1 MMscf/day.
- Two simulation cases: 7 days and 3 months duration of inj./prod. cycles.
- Two conditions:
  - Limited production by constraining bottom hole pressure to 3000 psia.
  - Non-constrained well bottom hole pressure

Preliminary Results

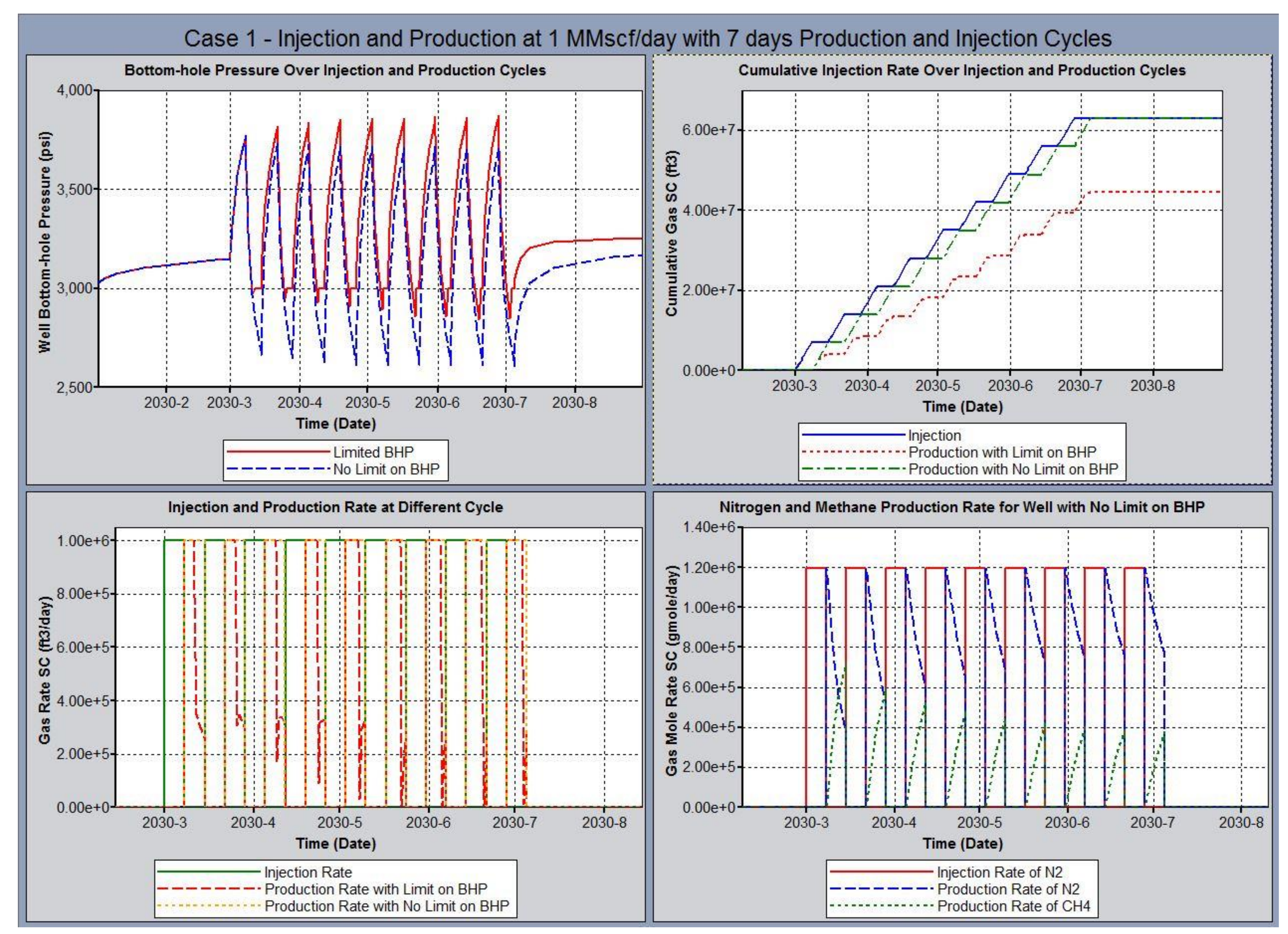

Figure 3: Overview of simulation results for case 1 showing increasing cycle over time.

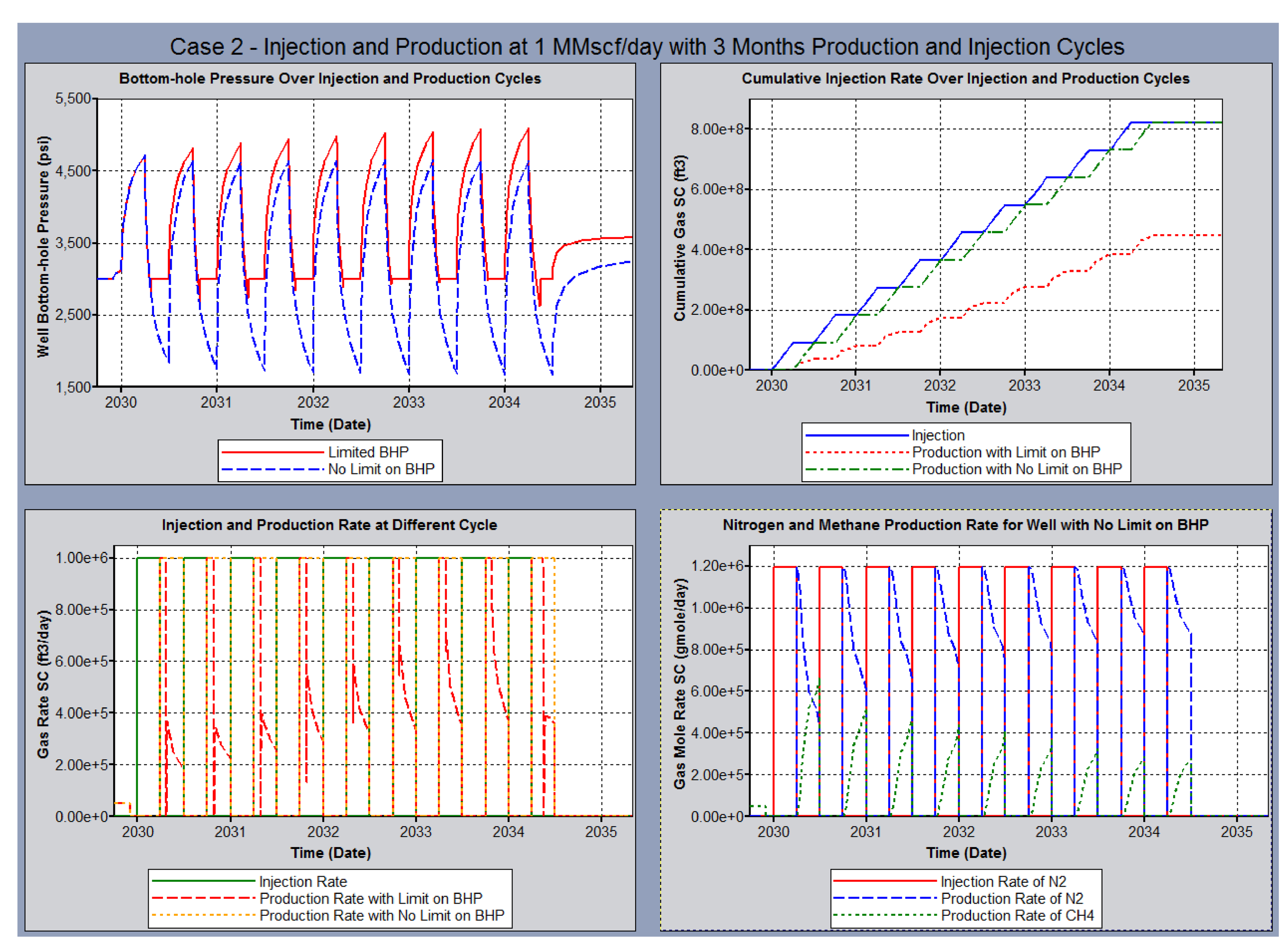

Figure 4: Overview of simulation results for case 2 showing increasing cycle over time.

Analysis

1. Reservoir pressure increases over time as injection cycle increases
   - Albeit marginal increase in unlimited bottom hole pressure (BHP).
   - Tight reservoir can hold energy in the form of pressurized and compressed gas.
   - Reservoir pressure settled at the end of cycle.
2. For case with BHP limited to 3000 psi
   - Represents the minimum required downhole pressure of the turbine generator for sufficient electric production.
   - Amount of gas injected is more than the produced gas.
   - Gas lost into the formation.
3. For limited BHP,
   - Greater increase in reservoir pressure after injection.
   - Injected gas is used to energize the reservoir.
   - Production rate tends to decrease at early time.
   - Production rate sustained longer with each cycle.
4. Once the BHP restriction is removed (control case),
   - Reservoir is able to produce at the same rate as the injection rate.
   - Higher pressure drawdown from reservoir to maintain constant rate.
   - Production BHP is significantly lower.
   - Production of reservoir hydrocarbon decreases more rapidly
5. When the injection cycle is longer (3 months),
   - Still can produce at same rate as injection.
   - The effect of limited BHP is more dominant.
   - The reservoir becomes more energized.
6. In terms of reservoir fluids,
   - Possible to produce remaining hydrocarbons (mainly Methane) along with the compressed gas injected.
   - The amount of hydrocarbon produced decreases as cycle increases.
   - Produced hydrocarbons can be used to heat up the generator as well as provide additional energy for production.

Conclusions

- Numerical reservoir simulation is a valid method to study the possibility of using unconventional reservoir for compressed gas storage.
- This preliminary works shows that this method of energy storage is promising for the solution to a complex problem related to renewable energy.
- The fracture network provide an excellent conduit for gas storage since it has large surface area for gas dissipation into the reservoir.
- Some potential problems and scenarios in real systems that require further analysis include:
  - Friction in the production and injection tubing.
  - Fluids blockage in fracture.
  - Adsorption of injected gas on the reservoir rock.
  - Long term effect of multiple injection and production on reservoir rock.

References

[1] COGCC. 2013. Colorado Oil and Gas Conservation Commission, http://cogcc.state.co.us (accessed 2 June 2013)
[2] Sonnenberg, S. (2015). New Reserves in an Old Field, the Niobrara/Codell Resource Plays in the Wattenberg Field, Denver Basin, Colorado. *First Break*, *33*(12), 55-6.
[3] Wang, D., Zhang, J., (2014, August). Flow Rate Behavior and Imbibition Comparison Between Bakken and Niobrara Formations. In *UTCE, Denver, Colorado, 25-27 August 2014* (pp. 1606-1618). Society of Exploration Geophysicists, AAPG, SPE.
[4] McCain, W. D. (1990). *The Properties of Petroleum Fluids*. PennWell Books.