U.S. Department of Energy (DOE)

MASTERING THE SUBSURFACE THROUGH TECHNOLOGY INNOVATION, PARTNERSHIPS AND COLLABORATION: CARBON STORAGE AND OIL AND NATURAL GAS TECHNOLOGIES REVIEW MEETING

Virginia Tech

A Black-oil Type Approach to Model Produced Gas Injection to Enhance Recovery of Oil-rich Shales and Reduce Flaring and Venting

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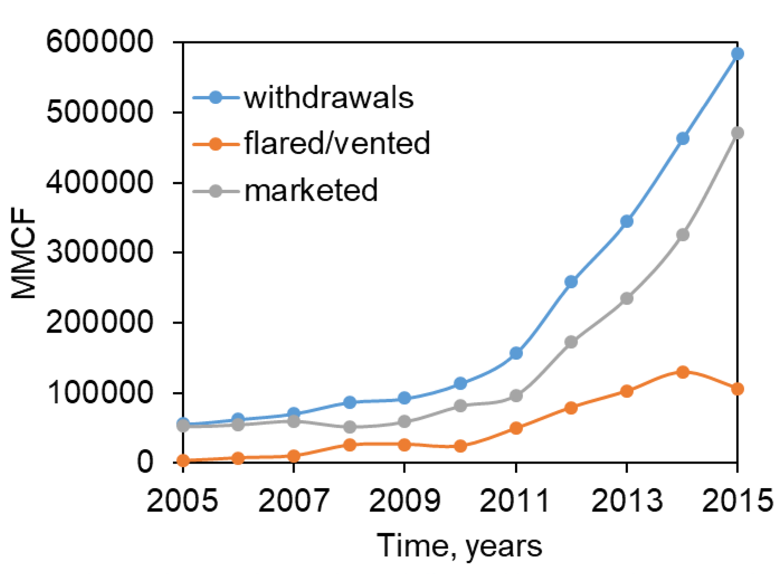
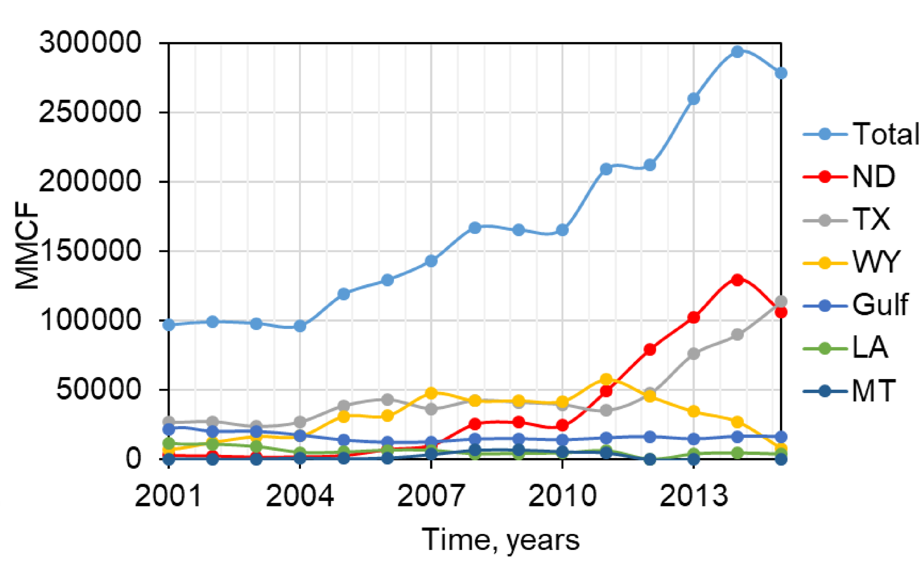
Motivation



Produced, marketed and flared/ vented natural gas in the state of North Dakota



Total flared/vented natural gas in United States

- ❑ Methane is a greenhouse gas, which is 80 times more potent than CO_2 according to Intergovernmental Panel on Climate Change (IPCC).
- ❑ Gas flaring from oil production operations causes different forms of pollution through toxic gases and rain acid in a local scale, and through extensive CO_2 and methane production in a global scale.
- ❑ Flaring and venting are common practices in many oil production operations.
- ❑ The amount of gas flared/vented in the US has substantially increased with the development of shale resources since 2001. North Dakota, where Bakken oil shale is located, contributed to more than one third of this total.
- ❑ The eia reports indicate that approximately 20% of the produced gas from Bakken shale (equivalent to 106 billion cubic feet) was flared or vented in 2015 and no gas has been reinjected since the start of Bakken development.
- ❑ Flaring reduction will be effectively possible only if it is cost effective and can create markets.
- ❑ Primary oil recovery of Bakken is less than 10% (Todd and Evans, 2016).

Project Objectives

- ❑ Assess effectiveness of produced gas reinjection as an alternative for flaring and venting
- ❑ Develop a fast and robust simulation tool to model produced gas injection enhanced recovery in shale reservoirs
- ❑ Investigate the effect of large-gas oil capillary pressure on gas injection EOR effectiveness in oil-rich shales

Approach

- Compositionally extended black-oil formulation is used.

$$\nabla\cdot\left(\sum_{j=1}^{N_p}\left(\omega_{ij}\rho_j\frac{kk_{rj}}{\mu_j}\nabla\cdot P_j-g\rho_j\nabla z\right)\right)+\sum_{j=1}^{N_p}M_{ij}=\frac{\partial}{\partial t}\left(\sum_{j=1}^{N_p}\phi S_j\rho_j\omega_{ij}\right)\quad,\quad \nabla\cdot\left[\frac{kk_{rw}}{B_w\mu_w}\left(\nabla P_w-g\rho_w\nabla z\right)\right]-q_w=\frac{\partial}{\partial t}\left(\frac{\phi S_w}{B_w}\right)$$

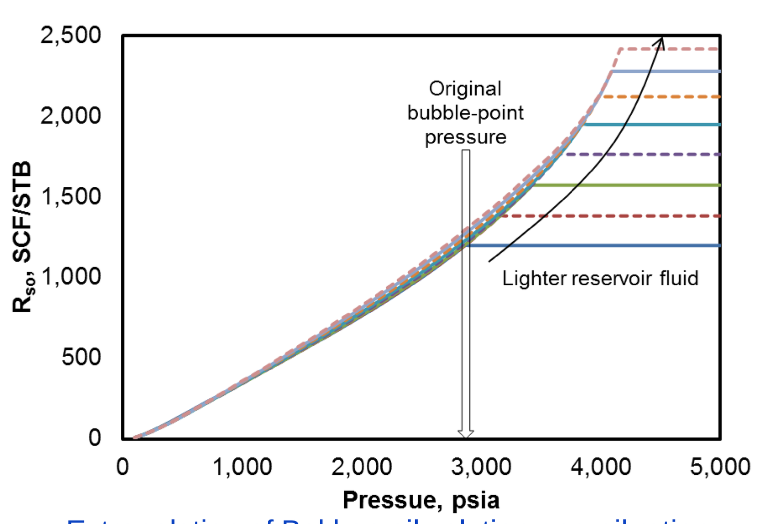
- Compositionally-extended black-oil fluid properties (oil and gas densities and viscosities, solution gas-oil ratio, volatilized oil-gas ratio) are calculated by using flash calculation.
- The effect of large gas-oil capillary pressure is included in the phase behavior model.

$$f_i^o\left(T,P_o,x_1,x_2,\ldots,x_{N_C}\right)=f_i^g\left(T,P_g,y_1,y_2,\ldots,y_{N_C}\right)$$

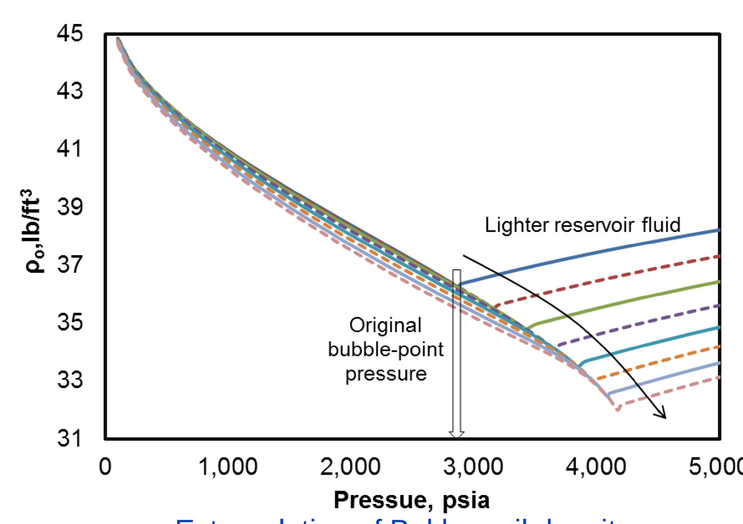
$$P_g=P_o+P_c \qquad P_c=\frac{2\sigma}{r}$$

- Black-oil fluid properties are extrapolated up to the critical point by adding fractions of bubble-point gas.

$$Z_{new}=(1-\alpha)\times Z_{old}+\alpha\times y_{old} \qquad \alpha=0.1$$



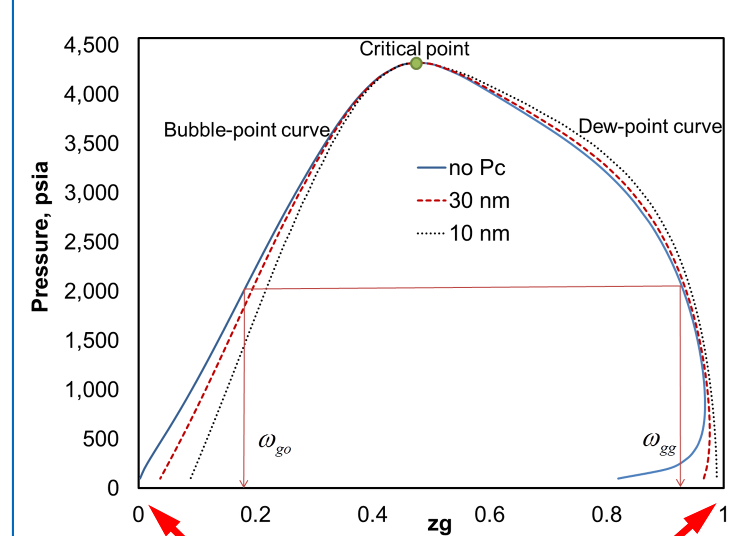
Extrapolation of Bakken oil solution gas-oil ration



Extrapolation of Bakken oil density

Nojabaei and Johns, 2016

Results



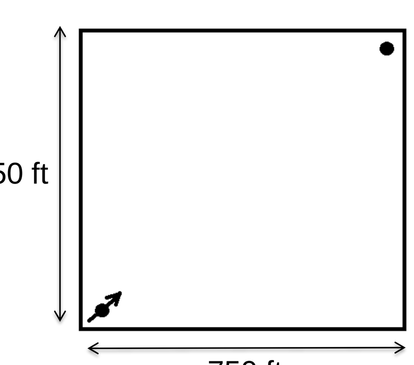
Dead oil composition

Surface gas composition

Pressure composition plot of Bakken oil

Nojabaei and Johns, 2016

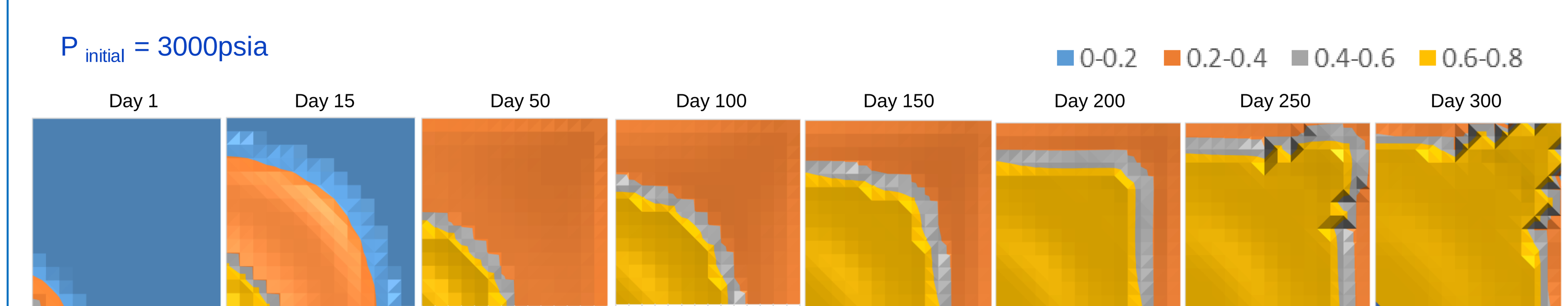
- ❑ Produced gas (surface gas) is injected continuously.
- ❑ A five-spot pattern is used.
- ❑ Stimulated reservoir volume is considered for tight reservoirs.
- ❑ q_{inj}= 1000 MSCF
- ❑ $P_{production}$=$P_{initial}$-100 psi
- ❑ Original bubble-point pressure= 2860 psia
- ❑ Critical point pressure or MMP=4325 psia



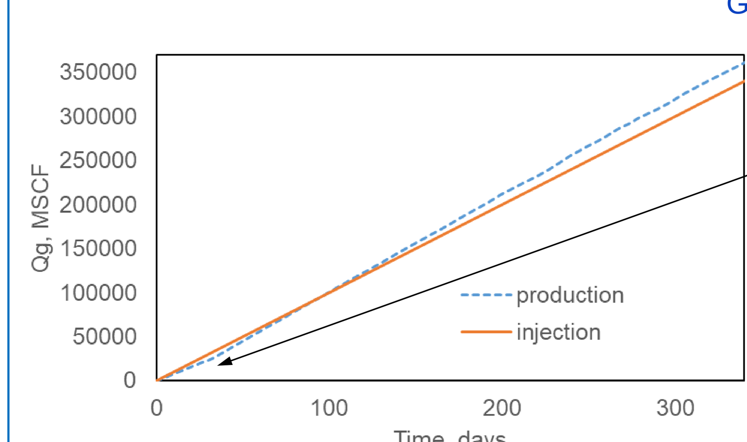
Matrix permeability	1000 md
Matrix porosity	10%
Reservoir thickness	10 ft
Fluid type	Bakken fluid
Temperature	240^{o}F

Model application for conventional reservoirs

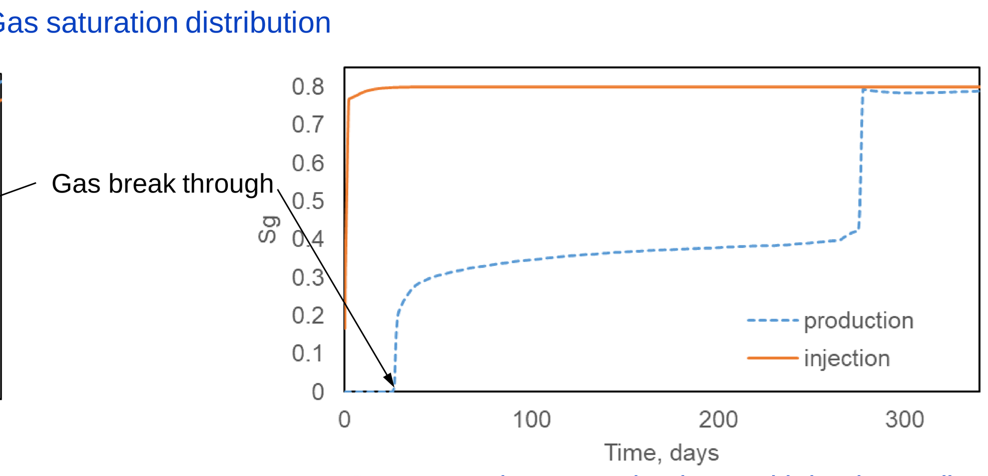
$P_{initial}$ = 3000psia



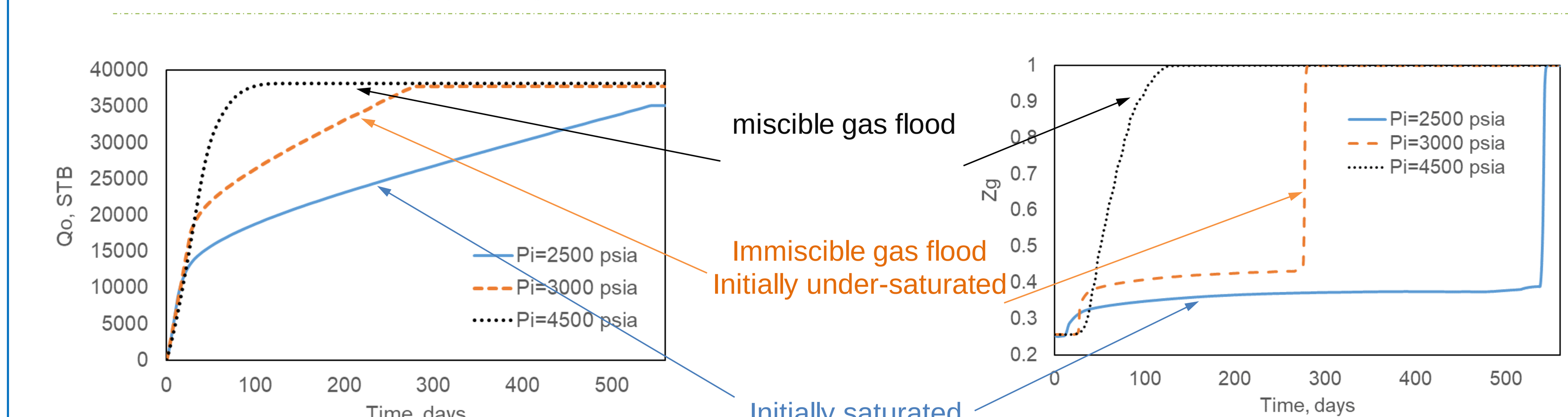
Gas saturation distribution



Produced and injected gas



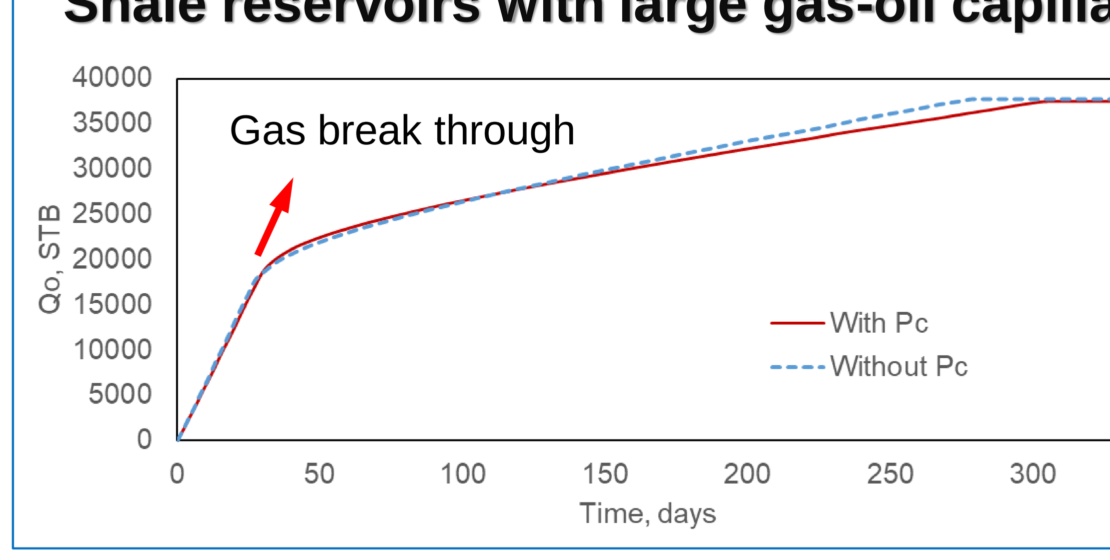
Gas saturation at production and injection wells



Cumulative oil production

Gas composition at production well block

Shale reservoirs with large gas-oil capillary pressure



- ❑ Early time: larger Q_o w Pc due to faster gas break through for the case w/o Pc
- ❑ Later time: larger Q_o w/o Pc
- ❑ Longer production with Pc

Summary and Conclusions

- ❑ A compositionally extended black-oil approach was used to model miscible and immiscible gas floods.
- ❑ Reinjection of produced gas is an alternative for flaring and venting and it substantially enhances oil recovery.
- ❑ The amount of produced gas is comparable to the injected gas.
- ❑ Composition front gets smaller as reservoir pressure is higher.
- ❑ Large gas-oil pressure causes a delayed gas break through and increased production during early time.
- ❑ Ultimate recovery is higher without capillary pressure effect.

Future Research

- ❑ Huff-and-Puff gas injection for a fractured well in Bakken