
APPLICATION of a SWELLING/SHRINKAGE MODEL for ANALYSIS of RESERVOIR PERFORMANCE at a FIELD SITE

a presentation by

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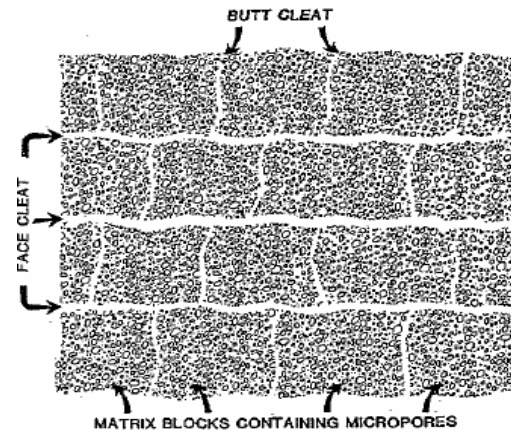


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CH₄ desorption causes coal to shrink during coalbed methane production.

Shrinkage

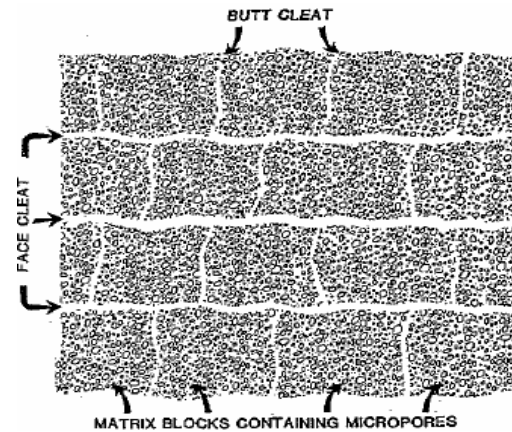
- increases apertures
- increases productivity
- may cause small subsidence
- under some conditions, decreased pore-pressure effects may exceed effects of swelling, decreasing aperture & productivity.



CO₂ sorption causes coal to swell during sequestration/ECBM production.

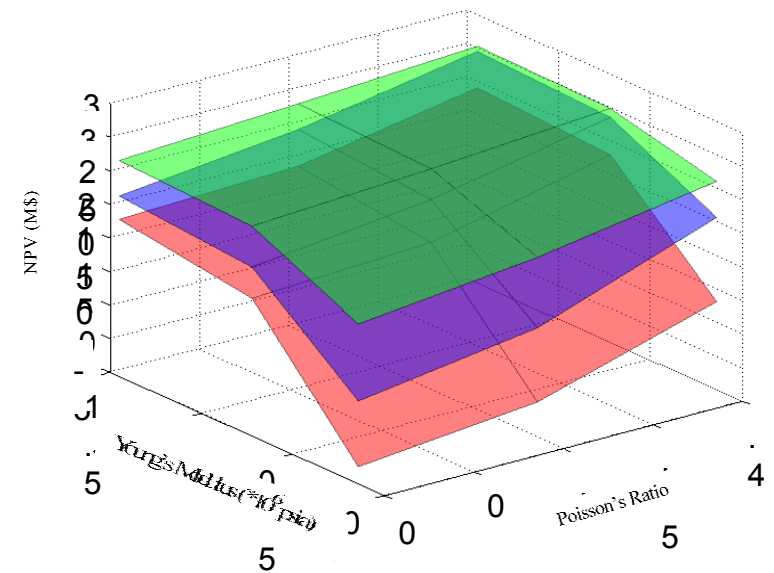
Swelling

- decreases apertures
- decreases injectivity
- may cause small uplift
- under some conditions, increased pore-pressure may overcome decreases of aperture & injectivity caused by swelling.



Reservoir engineering studies support practical importance of shrinkage & swelling.

- **Allison field project interpretations**
Reeves & Oudinot, ICBM 2005
- **Simulator comparison study**
Gunter, Law, Mavor, ICBM 2005
- **Economic sensitivity studies**
Gorucu, ..., Smith, SPE 97963



Changes in stresses, pore pressure, temperature, or fluid sorption cause matrix strains.

$$d\sigma_{ij} = 2Gd\varepsilon_{ij} + \left(K - \frac{2G}{3}\right)d\varepsilon_{kk}\delta_{ij} - 3K\alpha_T dT\delta_{ij} + \alpha dp\delta_{ij} \\ - C^{SW} f_1'(p) dp K \delta_{ij} + C^{SH} f_2'(p) dp K \delta_{ij}$$

σ_{ij} = stress tensor

ε_{ij} = strain tensor

p = pore pressure

G = shear modulus

K = bulk modulus

T = temperature

α_T = coefficient of thermal expansion

α = poroelastic constant



where

$$K = \frac{E}{3(1-2\nu)} \qquad G = \frac{E}{2(1+\nu)}$$

- **E = modulus of elasticity (Young's modulus)**
- **ν = Poisson's ratio**



Desorption-sorption shrinkage/swelling hysteresis is allowed by use of a different proportionality constant for each.

$$d\epsilon_v^{sw} = C^{sw} dV_a$$

$$d\epsilon_v^{sh} = C^{sh} dV_d$$

ϵ_v^{sw} = volumetric swelling strain

ϵ_v^{sh} = volumetric shrinkage strain

C^{sw} = swelling constant, **for each gas**

C^{sh} = shrinkage constant, **for each gas**

V_a = absorbed volume V_d = desorbed volume



In the S/S model, “any” absorption or desorption isotherm is allowed.

$$V_a = f_1(p) \qquad V_d = f_2(p)$$

- f_1 and f_2 = functions of the gas pressure
- f_1 need not equal f_2
- f_1 and f_2 need not have same mathematical form
- PSU-COALCOMP allows Langmuir, Toth, or UNILAN
- Langmuir used in this study



Linear strains are allowed to be anisotropic.

$$\mathcal{E}_V = \mathcal{E}_{xx} + \mathcal{E}_{yy} + \mathcal{E}_{zz}$$

- \mathcal{E}_V = volumetric strain
- \mathcal{E}_{xx} , \mathcal{E}_{yy} , \mathcal{E}_{zz} = linear strains in x-, y-, z-directions



Permeability is assumed to vary with porosity according to the cubic equation:

$$k = k_0 \left(\frac{\phi}{\phi_0} \right)^3$$

- **k = permeability**
- **ϕ = porosity**
- **K_0, ϕ_0 = reference permeability, porosity**
 - Original reservoir state (CBM)
 - No sorbed gas (ECBM)
- **Palmer & Mansoori, SPE 36737, 1996**



S/S model was added to an existing reservoir simulator.

- **PSU-COALCOMP**
- **Dual-porosity flow**
- **“Validated” in comparison study**
- **Three isotherm models**
 - Langmuir
 - Toth
 - UNILAN
- **ideal adsorbate solution (IAS) theory**
- **Peng-Robinson equation of state**
- **Langmuir isotherm used in this study.**



Assumed Reservoir and Fluid Properties for Allison Field

Reservoir Thickness	44 ft
Coal-cleat Porosity	0.2 % - 0.4%
Depth	3440 ft
Initial Reservoir Pressure	1650 psia
Rock Density	1.46 g/cm³
CH₄ Sorption Volume constant	400 SCF/ton
CH₄ Sorption Pressure constant	514 psia
CO₂ Sorption Volume constant	584 SCF/ton
CO₂ Sorption Pressure constant	250 psia
Sorption time constant	10 days
Reservoir Temperature	120°F
Wellbore Radius	0.46 ft – 0.58 ft
Skin	1-10



Strategy for Figures 1-5:

- **Used measured production data for each well.**
- **Bottom-hole pressures calculated (flow rate specified).**



Figure 1: Model predictions (with no SS) matched simulations in the literature.

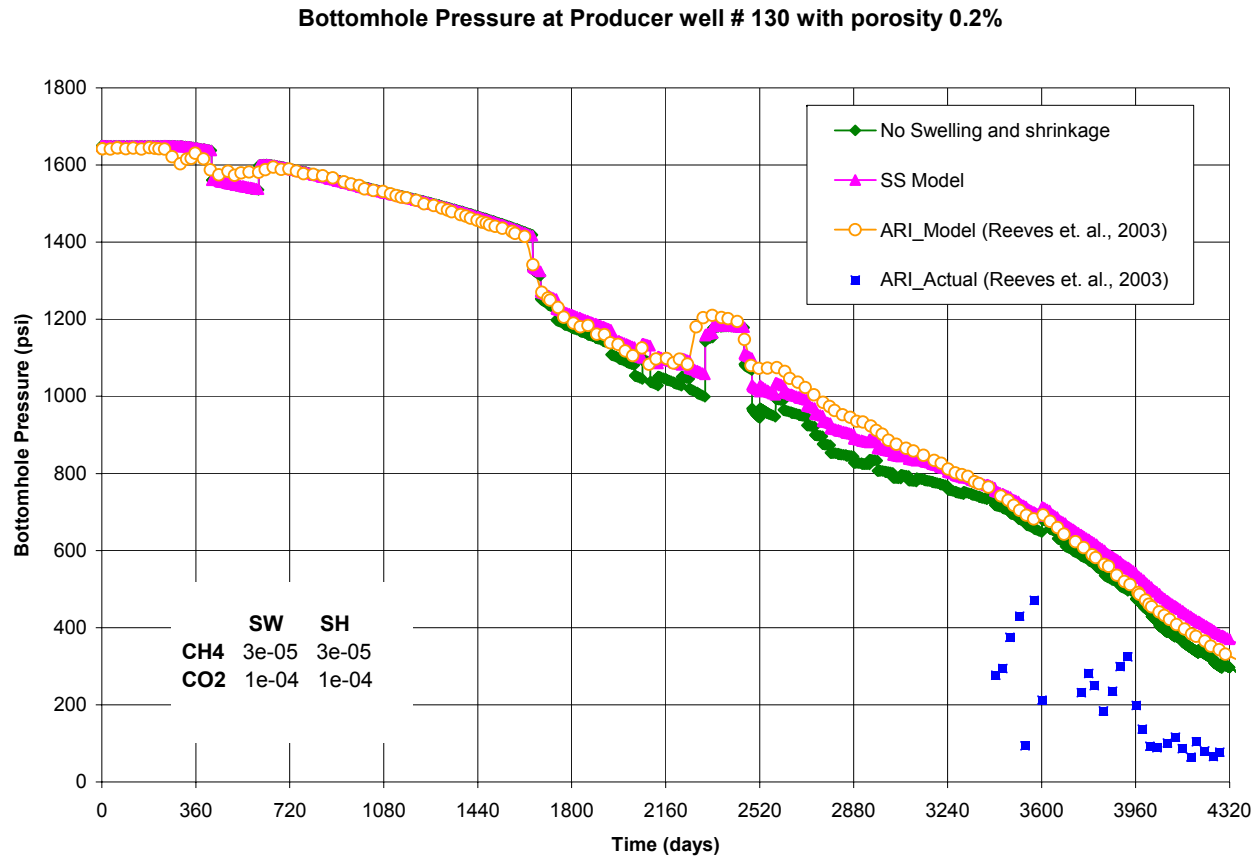


Figure 2: Model (without SS) gave good fit to the measured pressures (producer well # 130).

Bottomhole Pressure at Producer well # 130 for No Swelling and Shrinkage case

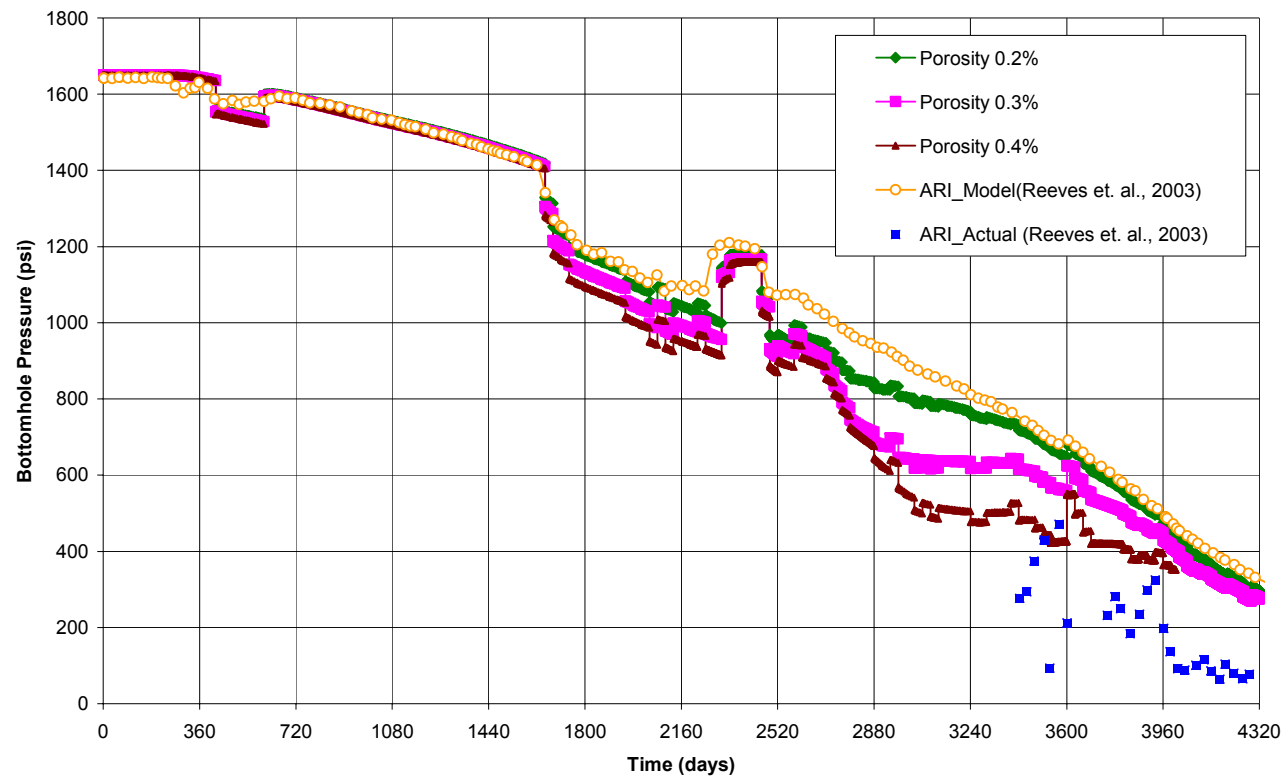


Figure 3: 0.2% porosity (no SS) gave good fit to the measured pressures (producer #113).

Bottomhole Pressure at Producer well # 113 with no swelling and shrinkage

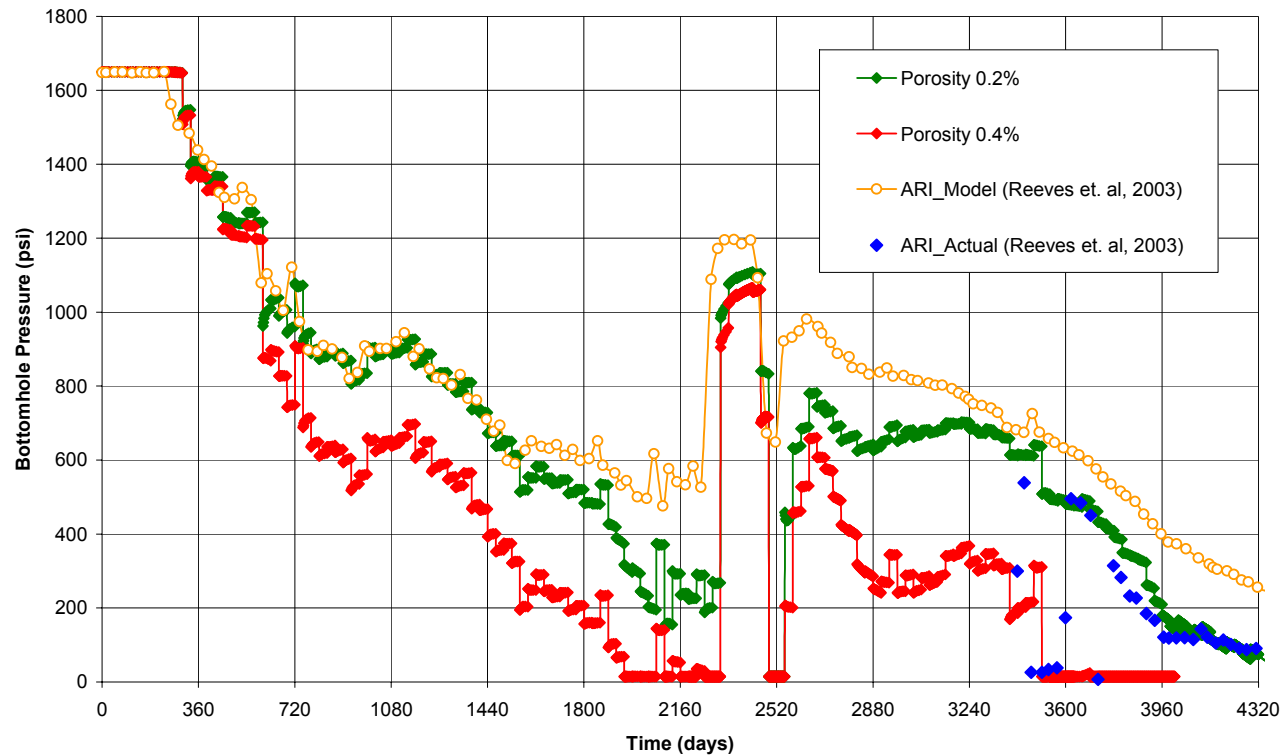


Figure 4. Fit appeared better without Swelling/Shrinkage (0.2% porosity, Well #113).
Bottomhole Pressure at Producer well # 113 with porosity of 0.2%

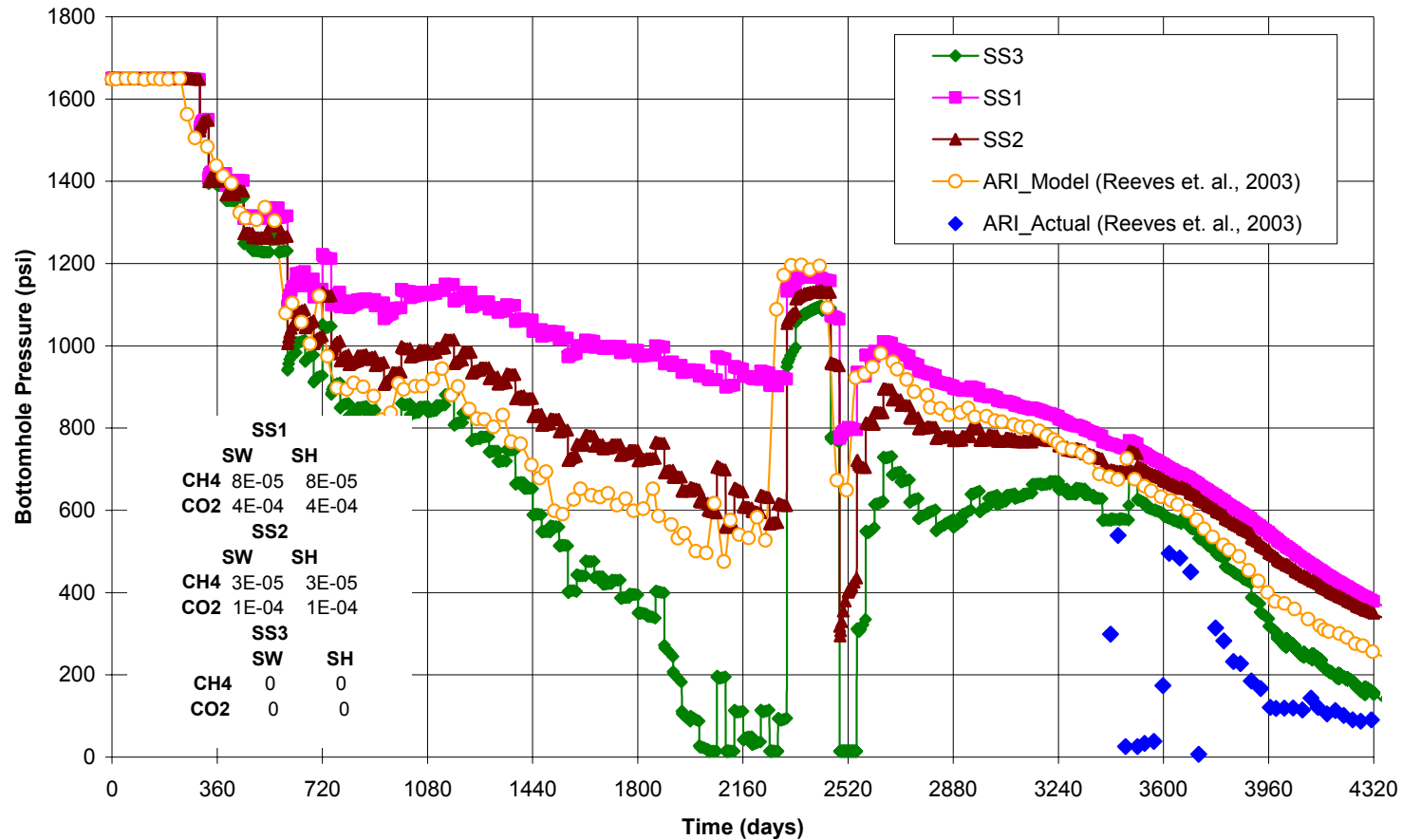
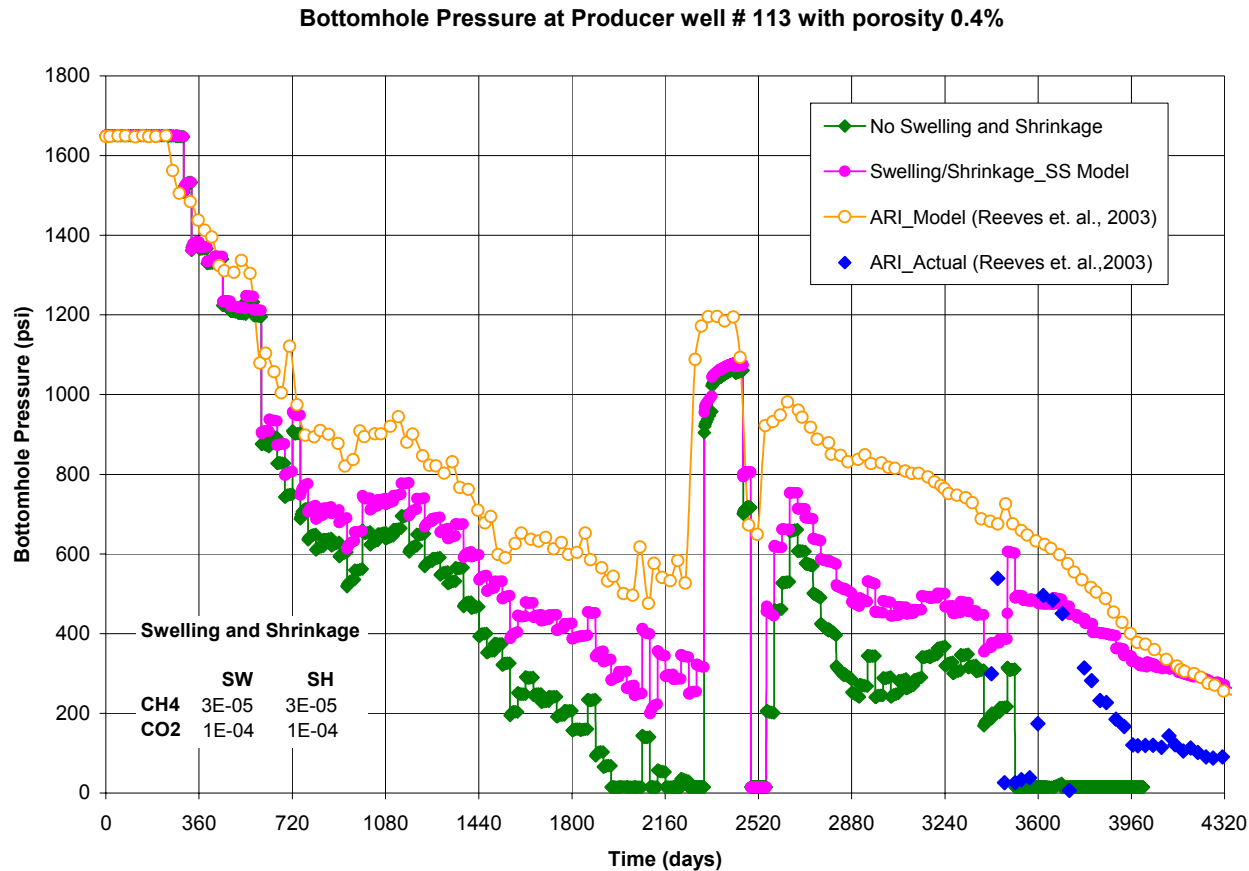


Figure 5. However, for 0.4% porosity fit was better with Swelling and Shrinkage (Well #113).



Strategy for Figures 6-11:

- For each well, bottom-hole pressures before ~3500 days were calculated to fit production data.
- After 3500 days, measured bottom-hole pressures were used (with slight adjustments to fit measured production data).
- Same Shrinkage (C_{SH}) and Swelling (C_{SW}) Constants (ton/scf) used in all fits:

	SW	SH
CH4	3×10^{-5}	3×10^{-5}
CO2	1.2×10^{-4}	1.2×10^{-4}



Figure 6: Fit to Total Gas Production Rate was good with No Shrinkage or Swelling.

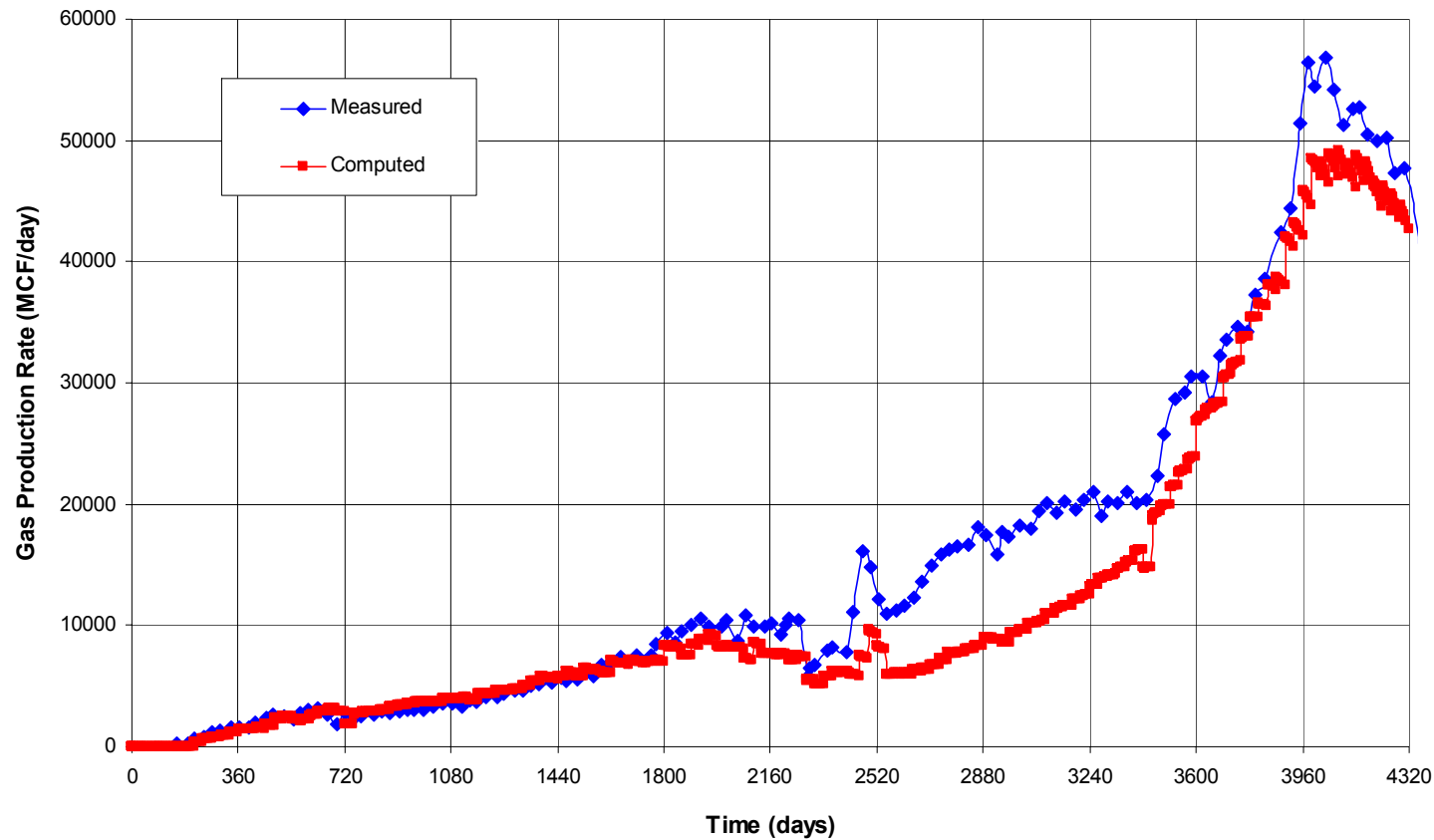


Figure 7: Fit to Total Gas Production Rate was somewhat better with Shrinkage and Swelling.

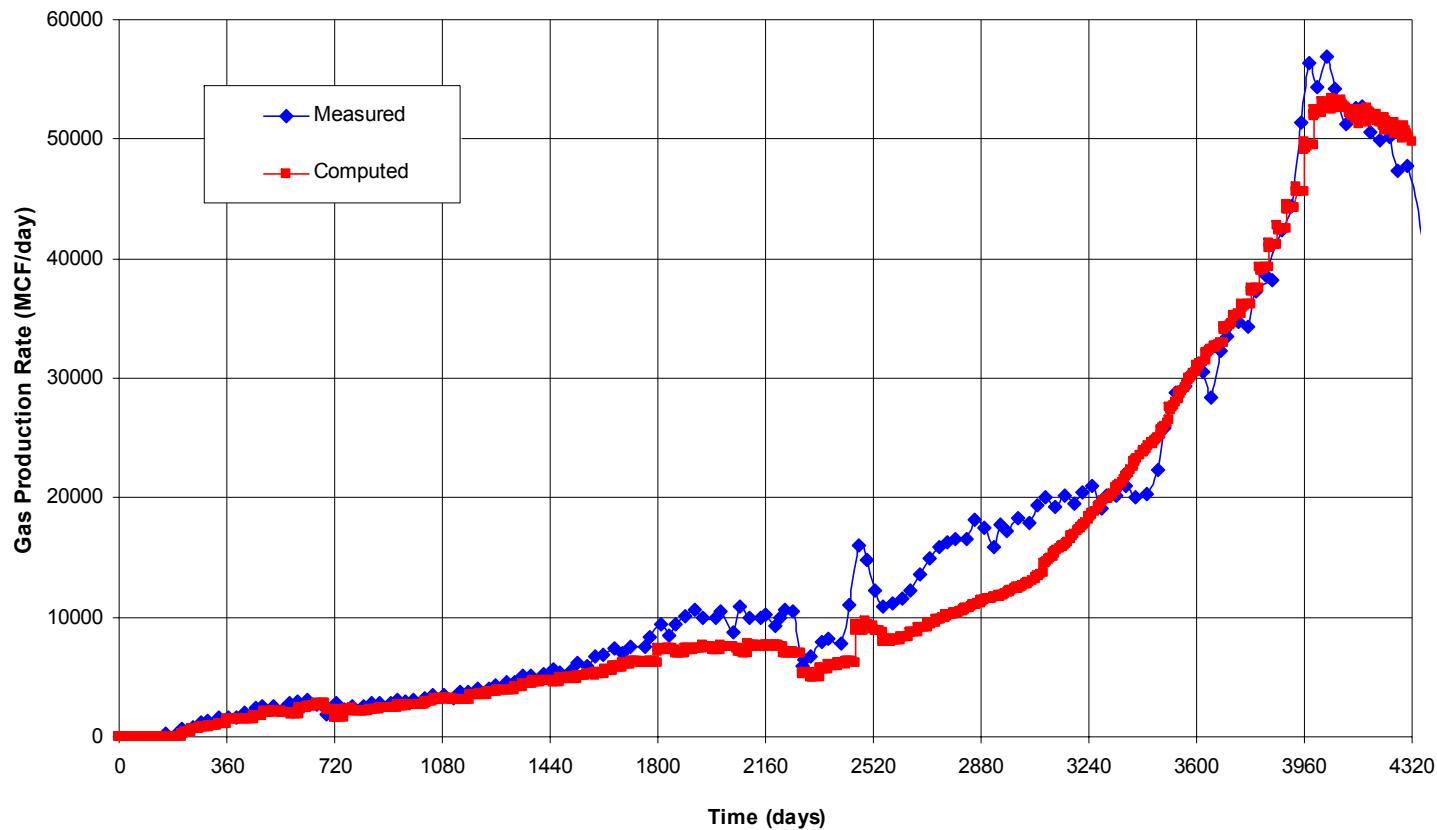


Figure 8: SS model with reported Elastic Modulus gave excellent fit to Total Production.

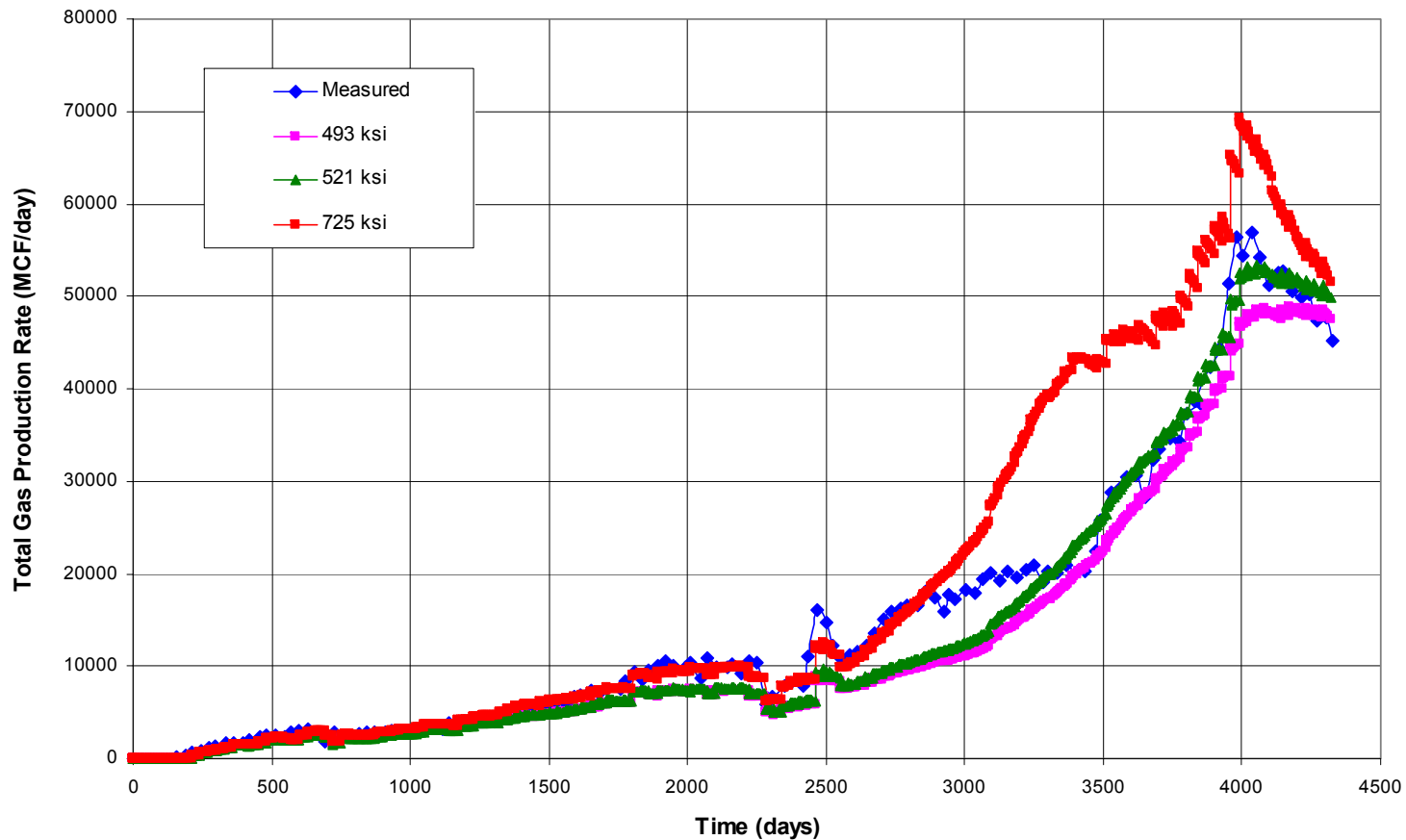


Figure 9: Did CO₂ injection reduce the elastic modulus? (Well # 113)

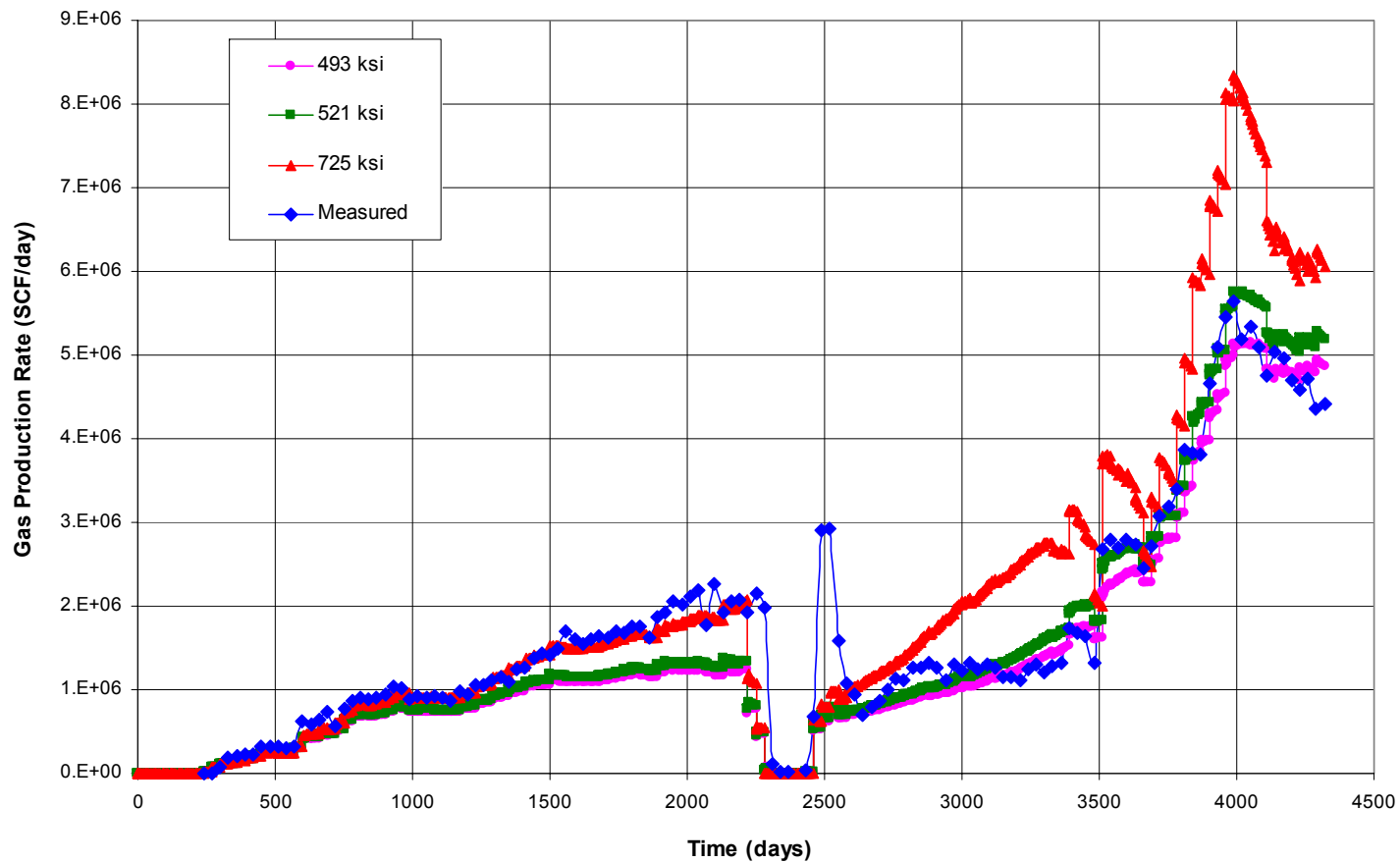


Figure 10: Porosity 0.2% gave best fit to production data (Well # 113).

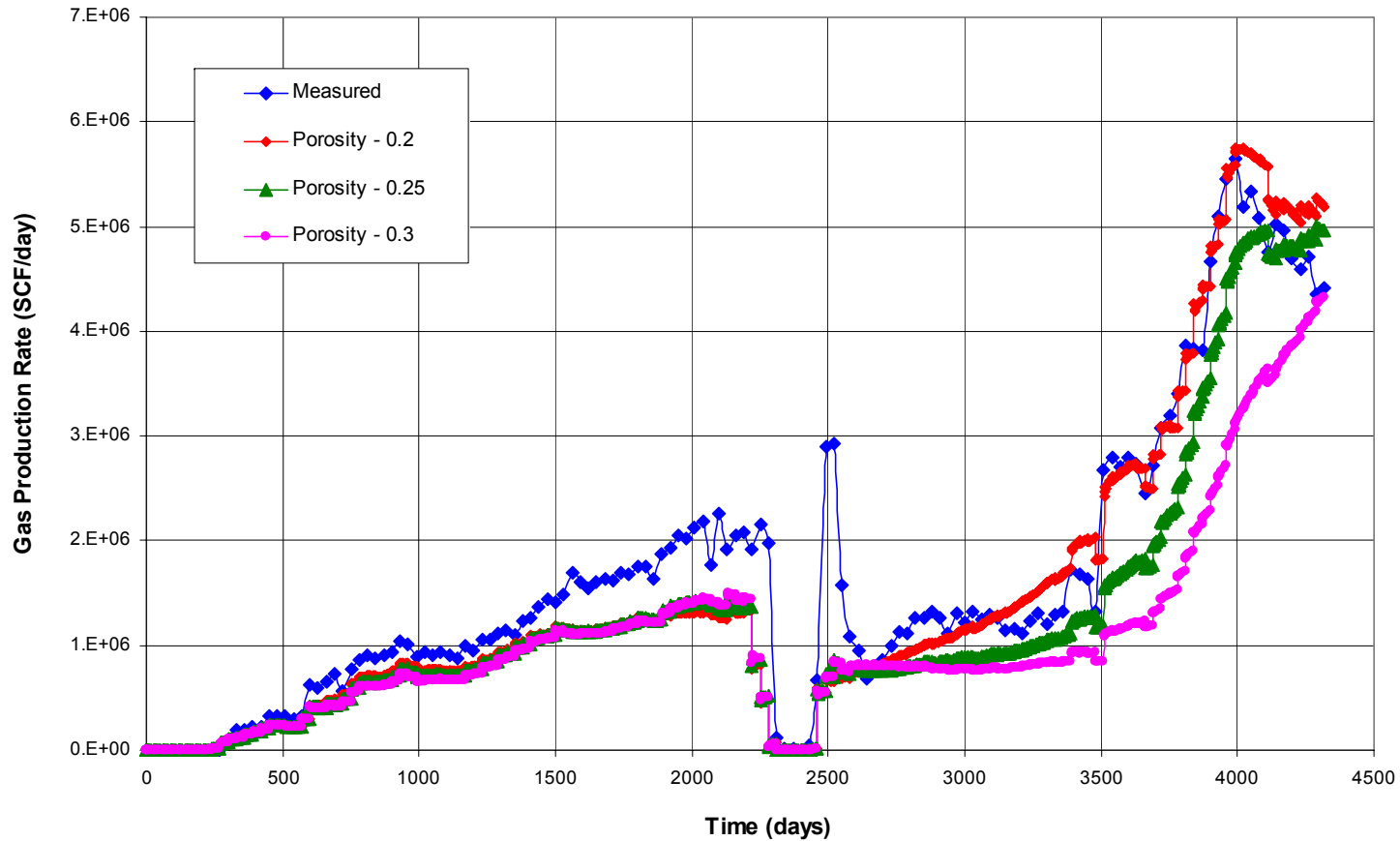
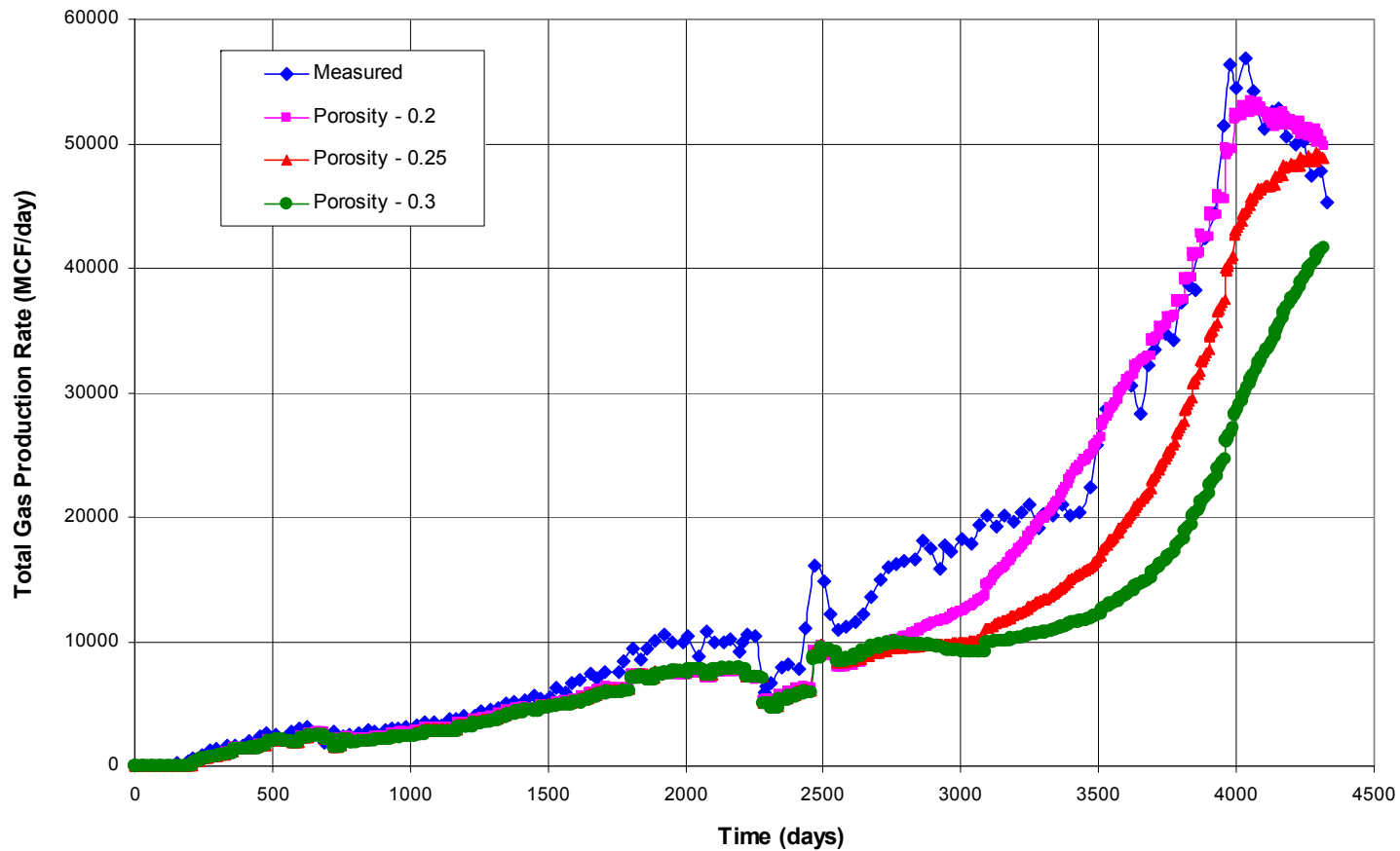


Figure 11: Porosity 0.2% also gave best fit to Total production data.



S/S model introduces additional generality into swelling/shrinkage chemistry & geomechanics.

- **CH₄ desorption shrinks coal, increases apertures & productivity, may cause ground movements.**
- **CO₂ sorption swells coal, decreases apertures & injectivity, may cause ground movements.**
- **SS model allows different isotherms for sorption & desorption, strain hysteresis, strain anisotropy, different amounts of sorption-induced strain for different fluids.**



The SS model was used to investigate the influence of coal swelling/shrinkage on sequestration.

- **Porosity, Swelling and Shrinkage Constants all had a significant influence on the computed bottom hole pressures at Allison field.**
- **An increase in porosity lowered the bottom hole pressure.**
- **An increase in shrinkage constant increased the bottom hole pressure.**
- **An increase in swelling constant decreased the bottom hole pressure.**



Which of phenomena in the S/S model are not needed? What effects should be added?

Delete?

Sorption/desorption isotherm hysteresis.

Different strain proportionality constants for shrinkage and swelling.

Strain anisotropy (x, y, z).

Add?

Sorption-dependent elastic constants.

Explicit effective cleat-apertures.

etc.

