Fluvial Channels and Boundary Conditions in relation to the Success of Shenhua CCS Demonstration Project, Ordos Basin*

Minh Nguyen[1], Ye Zhang[1], Xu Zhang[2], Ning Wei[3], Jun Li[3], Xiaochun Li[3], and Philip Stauffer[4]

Search and Discovery Article #80651 (2019)**
Posted January 14, 2019

*Adapted from oral presentation given at AAPG 2018 Annual Convention & Exhibition, Salt Lake City, Utah, United States, May 20-23, 2018
**Datapages © 2018. Serial rights given by author. For all other rights contact author directly. DOI:10.1306/80651Nguyen2019

[1]University of Wyoming, Laramie, WY, United States (minh.nguyen@uwyo.edu)
[2]Schlumberger Software Integrated Solutions, Houston, TX, United States
[3]Chinese Academy of Sciences, Wuhan, China
[4]Los Alamos National Laboratory, Los Alamos, NM, United States

Abstract

The Shenhua Carbon Capture and Storage (CCS) project at the Shenbei Slope injection site in North Yulin is the first 100,000 ton/year scale CCS pilot project in China with an injection operation lasting nearly three years. While the project turned into an operational success with 300,000 tons of CO_2 being sequestered, several aspects of reservoir dynamic behavior and the role of reservoir heterogeneity are not clearly understood. For example, although there was an initial period of wellhead pressure (WHP) increase at the injection well, WHP incrementally declined for most of the time. The majority of CO_2 was received by the topmost sandstone of the Liujiagou formation in the injection interval instead of the lowermost limestone of the Majiagou formation, suggesting strong reservoir heterogeneity. Knowledge of the key reservoir processes and properties that resulted in these observations would help for predicting long-term storage safety and aiding the design of a larger-scale CCS operation at the same site. In this study, we investigate various fluvial channel models and important boundary conditions to determine aspects of heterogeneity that have the most impact on pressure behavior at the injection well and the observed plume dynamics after injection. Simulation results suggest a system of interconnected fluvial channels providing large connected volumes may have allowed such high injectivity into the topmost sandstone Liujiagou formation, leading to relatively small pressure buildup throughout injection operations. In addition to connected volumes, we also find the possibility of leakage at the boundary of our model, which potentially contributed to the fact that 300,000 tons of CO_2 were successfully injected.

References Cited

Bai, B., X. Li, H. Wu, Y. Wang, and M. Liu, 2017, A methodology for designing maximum allowable wellhead pressure for CO_2 injection: application to the Shenhua CCS demonstration project, China: Greenhouse Gases: Science and Technology, v. 7/1, p. 158-181.

Bidgoli, T.S., W.L. Watney, P.M. Gerlach, and M.C. Nguyen, 2014, Episodic reactivation of critically-stressed basement faults in southern Kansas: implications for wastewater disposal and long-term storage of CO_2: in 2014 GSA Annual Meeting in Vancouver, British Columbia.

Jiang, P., x. Li, R. Xu, Y. Wang, M. Chen, H. Wang, and B. Ruan, 2014, Thermal modeling of CO_2 in the injection well and reservoir at the Ordos CCS demonstration project, China: International Journal of Greenhouse Gas Control, v. 23, p. 135-146.

Li, Q., R. Song, H. Shi, J. Ma, X. Liu, and X. Li, 2018, U-tube based near-surface environmental monitoring in the Shenhua carbon dioxide capture and storage (CCS) project: Environmental Science and Pollution Research, p. 1-19.

Li, C., K. Zhang, Y. Wang, C. Guo, F. Maggi, 2016, Experimental and numerical analysis of reservoir performance for geological CO_2 storage in the Ordos Basin in China: International Journal of Greenhouse Gas Control, v. 45, p. 216-232.

Nguyen, M.C., Y. Zhang, J. Li, X. Li, B. Bai, H. Wu, and P.H. Stauffer, 2017a, A geostatistical study in support of CO_2 storage in deep saline aquifers of the Shenhua CCS project, Ordos Basin, China: Energy Procedia, v. 114, p. 5826-5835.

Nguyen, M.C., X. Zhang, N. Wei, J. Li, X. Li, Y. Zhang, and P.H. Stauffer, 2017b, An object-based modeling and sensitivity analysis study in support of CO_2 storage in deep saline aquifers at the Shenhua site, Ordos Basin: Geomechanics and Geophysics for Geo-Energy and Geo-Resources, v. 3/3, p. 293-314.

Nguyen, M., T. Onishi, J.W. Carey, B. Will, W. Zaluski, D. Bowen, and P.H. Stauffer, 2017c, Risk Assessment of Carbon Sequestration into A Naturally Fractured Reservoir at Kevin Dome, Montana (No.LA-UR-17-31501): Los Alamos National Lab. (LANL), Los Alamos, NM (United States).

Onishi, T., P.H. Stauffer, M. Nguyen, and J.W. Carey, 2017, Big Sky Project Preliminary Results June 28, 2017 (No. LA-UR-17-25222): Los Alamos National Lab. (LANL), Los Alamos, NM (United States).

Xie, J., K. Zhang, L. Hu, P. Pavelic, Y. Wang, and M. Chen, 2015a, Field-based simulation of a demonstration site for carbon dioxide sequestration in low-permeability saline aquifers in the Ordos Basin: Hydrogeology Journal, v. 23/7, p. 1465-1480.

Xie, J., K. Zhang, L. Hu, Y. Wang, and M. Chen, 2015b, Understanding the carbon dioxide sequestration in low‐permeability saline aquifers in the Ordos Basin with numerical simulations: Greenhouse Gases: Science and Technology, v. 5/5, p. 558-576.

Xie, J., K. Zhang, C. Li, and Y. Wang, 2016, Preliminary study on the CO_2 injectivity and storage capacity of low-permeability saline aquifers at Chenjiacun site in the Ordos Basin: International Journal of Greenhouse Gas Control, v. 52, p. 215-230.

Zhang, K., J. Xie, C. Li, L. Hu, X. Wu, Y. Wang, 2016, A full chain CCS demonstration project in northeast Ordos Basin, China: Operational experience and challenges: International Journal of Greenhouse Gas Control, v. 50, p. 218-230.

Fluvial Channels and Boundary Conditions in relation to the Success of Shenhua CCS Demonstration Project, Ordos Basin

Minh Nguyen, Ye Zhang – University of Wyoming
Xu Zhang – Schlumberger Software Integrated Solutions
Ning Wei, Jun Li, Xiaochun Li – Chinese Academy of Sciences
Philip Stauffer – Los Alamos National Laboratory

AAPG ACE 2018 Annual Convention & Exhibition
ACE 101: Bridging Fundamentals and Innovation
LA-UR-18-23568

Outline

- Introduction
- Geologic Model
- Simulation Model
- Results & Discussion
- Summary & Future Work

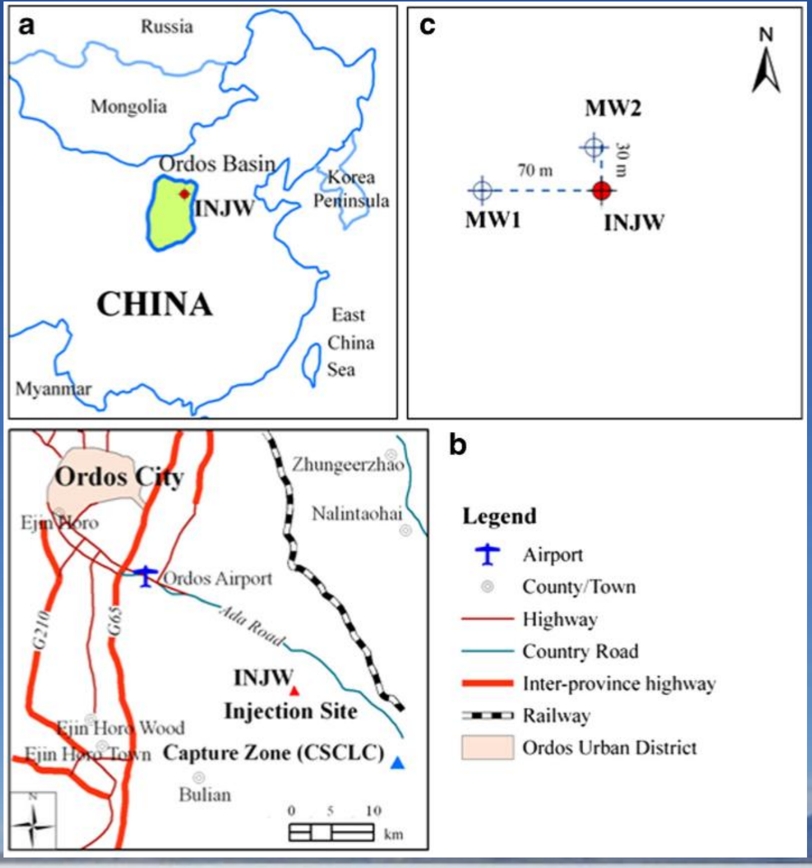
Ordos Basin China

- Second biggest sedimentary basin and largest coal and natural gas reserves
- Home to a coal-to-liquid center run by Shenhua
- Large CO_2 storage capacity

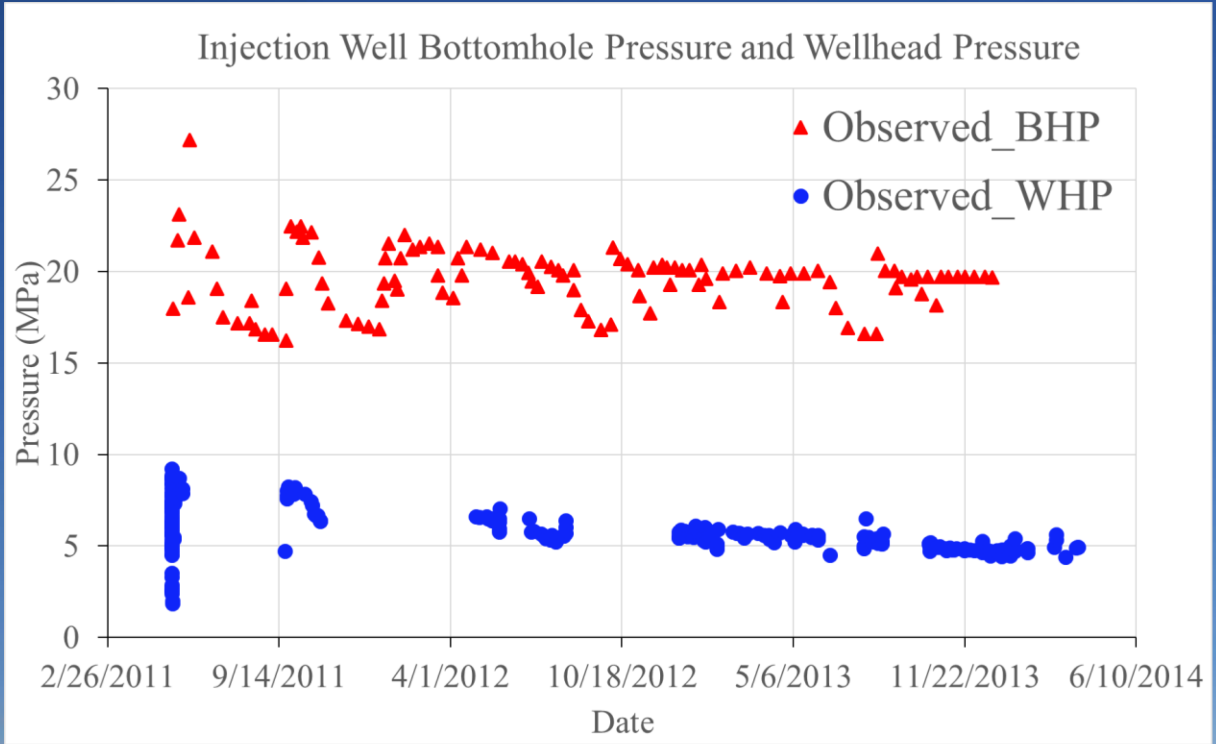
Shenhua Carbon Capture and Storage Demonstration

- CO_2 transported from Shenhua's direct coal liquefaction plant to a storage site located about 11 km to the west, cryogenic liquid CO_2 warmed by a heater (0 ºC) prior to injection – Nguyen et al. (2017a,b)

- Injection started May 2011. The well was finally shut-in in April 2014 with a total injection amount of **303,000 tons**.



Interesting Injection Data!

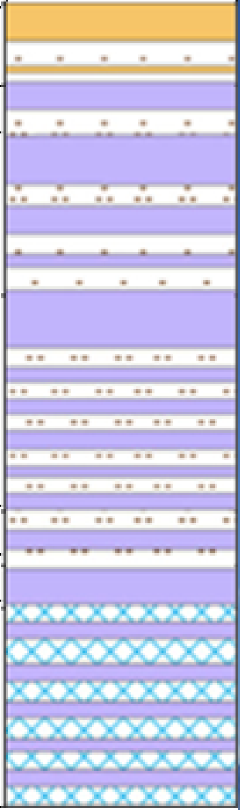


After Li et al. (2018)

Geologic Model

Limestone	Sandstone
Mudstone	Sandy mud

Era	Period	Formation	Top (m)	Bottom (m)	Lithology
Mesozoic	Triassic	*Liujiagou*	1578	1724	
Paleozoic	Permian	*Shiqianfeng*	1724	1992	
		Shihezi	1992	2233	
	Carboniferous	*Shanxi*	2233	2321	
		Taiyuan	2321	2371	
	Ordovician	*Majiagou*	2371	2578	

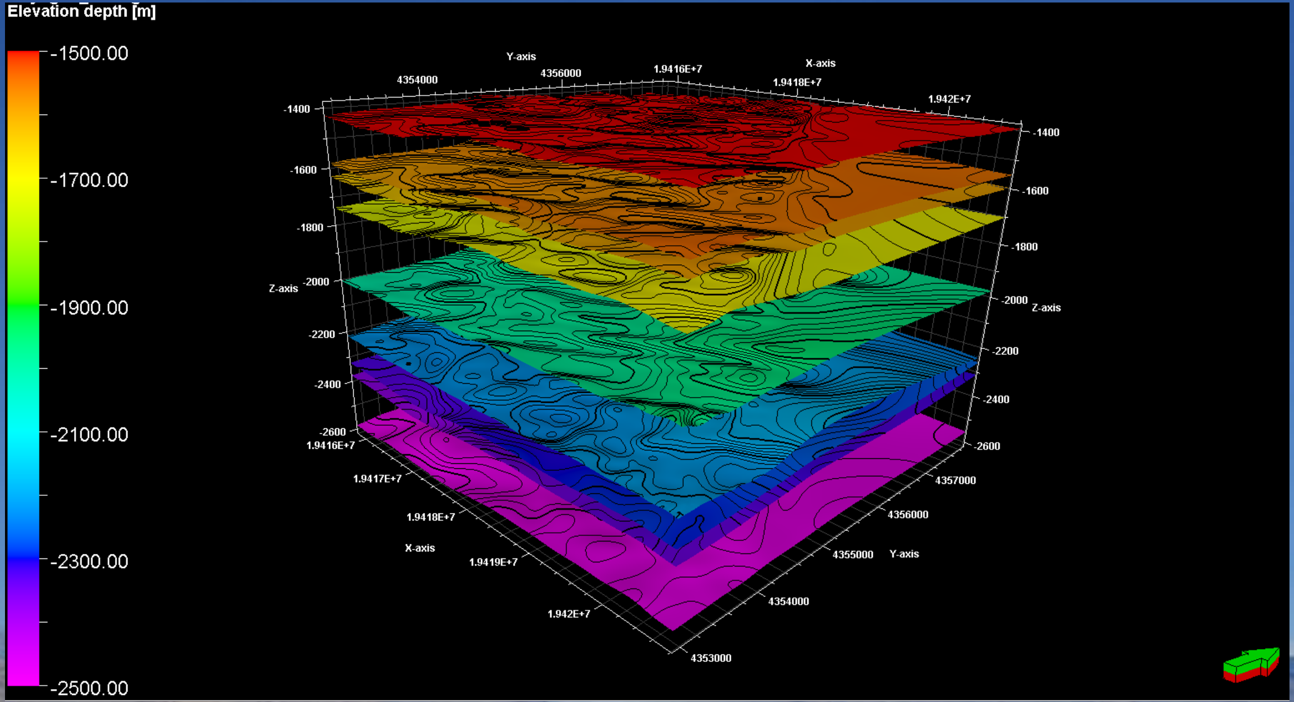


Stratigraphic column of the Shenhua injection site (after Xie et al., 2015b)

Each formation is perforated at the injection well (Zhang et al., 2016)

Geologic Model – Seismic Data

Horizons for each formation from Liujiagou to Majiagou



Geologic Model – Well Data

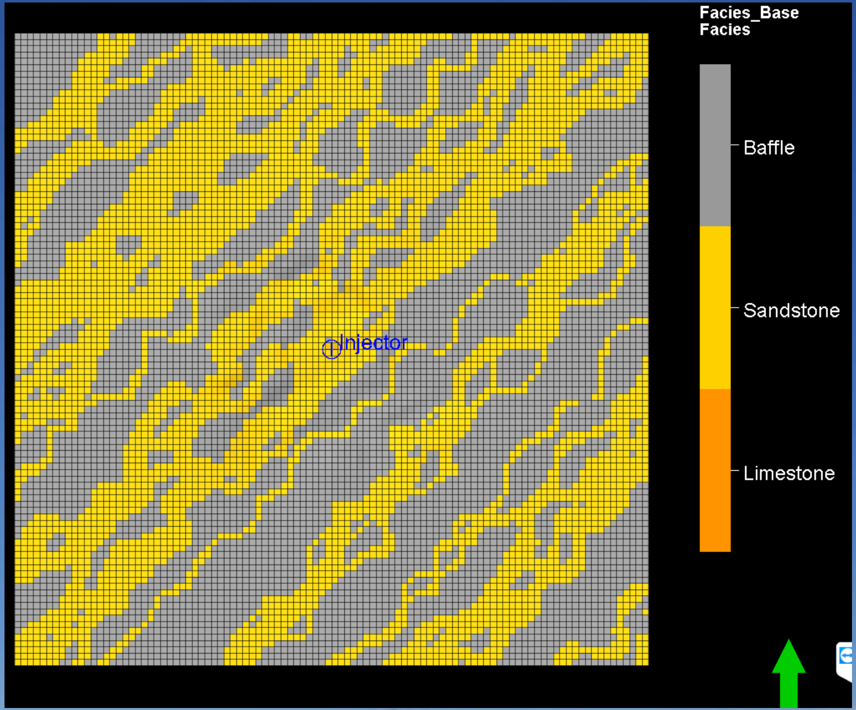
	Measured	Calculated	Note
Injection well* (INJW)	GR, SP, Sonic, Caliper, LLD, LLS	N/A	Helpful logs to interpret facies
Monitoring well 1 (MW1)**	GR, Shale%, LLS, LLD	Porosity and Permeability	Helpful logs to interpret facies
Monitoring well 2 (MW2)	GR, Density, LLD, LLS, SP, Neutron, Sonic, Sw, Shale%, Sandstone%, Temperature	Porosity and Permeability	MW2 has the most suite of logs. Helpful to interpret facies.

*Mud loss observed at the injector during drilling through Liujiagou formation

**Well with formation top picks and core measurements

Geologic Model – Fluvial Channels

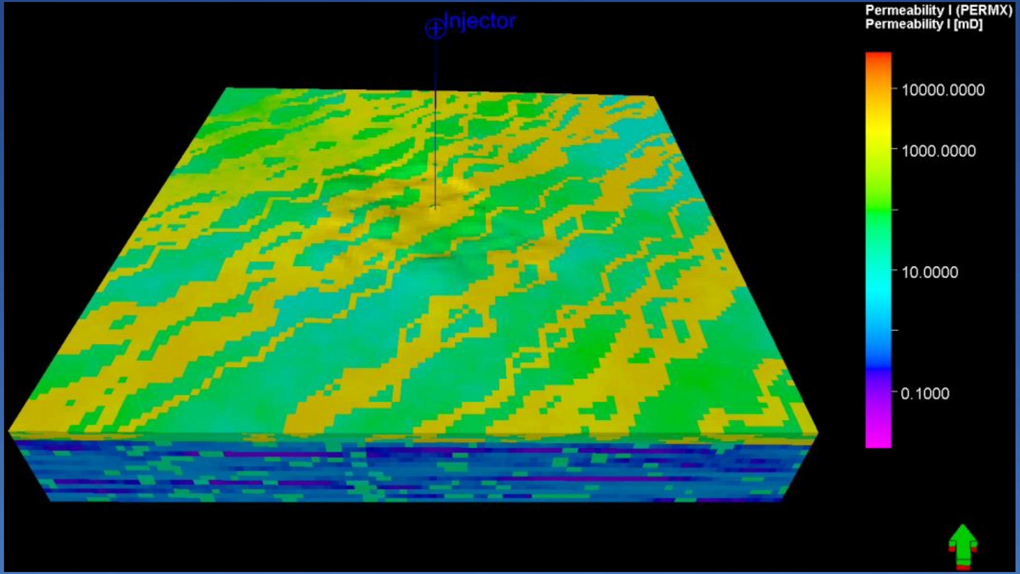
- Previous study built homogeneous and/or heterogeneous models that inadequately explain the flow behavior during injection
- From outcrop study (Liujiagou) we incorporate Northeast-Southwest fluvial meandering sandbody channels
- Channels are built so that they are interconnected to one another to allow higher storage capacity – add scale bar



Research Hypotheses

- Interconnected fluvial channels provide the pore volume for successful CO_2 injection.
- Open boundary conditions allow pressure to stay relatively low (potential for leakage)
- An extensive system of fractures allows high injectivity and BHP to remain below 30 MPa

Simulation Model

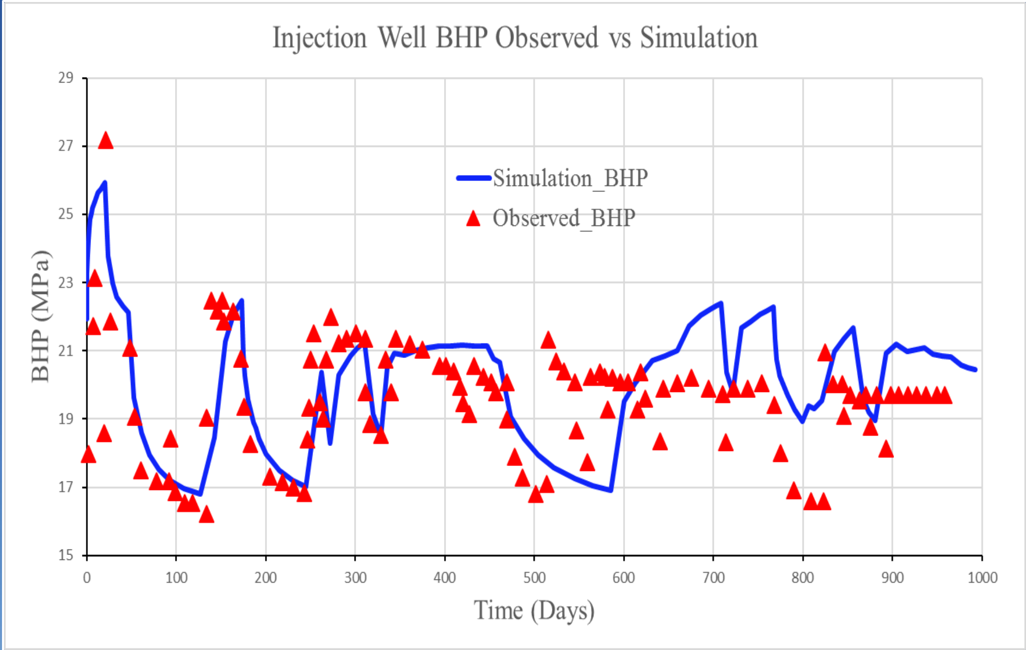


Model setup

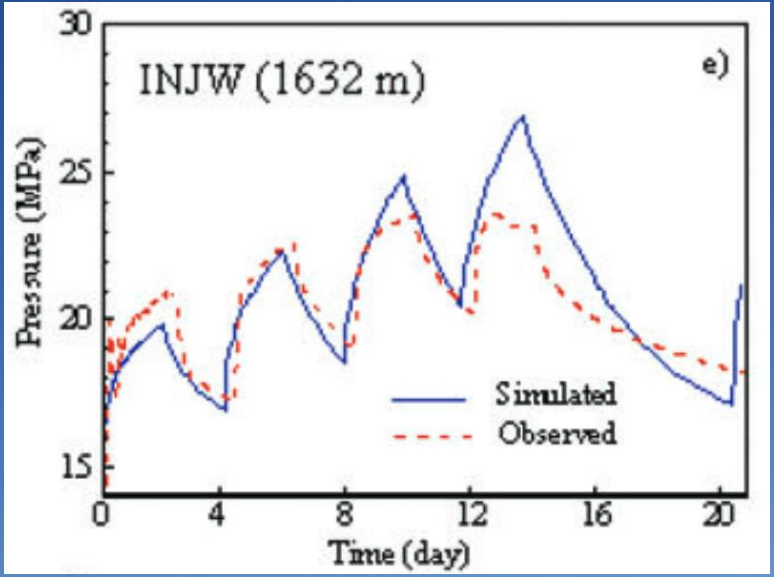
- Areal extent: 15 x 15 (km)
- Grid resolution: 250,000 cells
- Pore volume multiplier at lateral boundaries
- Permeability multiplier to resemble fractures
- 3-phase system (Water, Gas, Solid)
- 3-component system (H_2O, CO_2, NaCl)
- 3 years of CO_2 injection
- Hydrostatic initialization

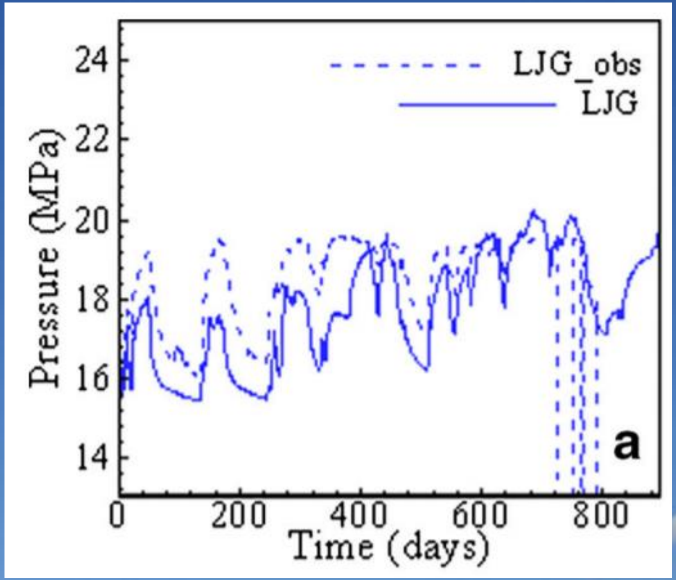
Simulation Results

- Successfully injected 300,000 tons of CO_2
- Obtained an improved BHP match compared to previous study. (At 1632m)



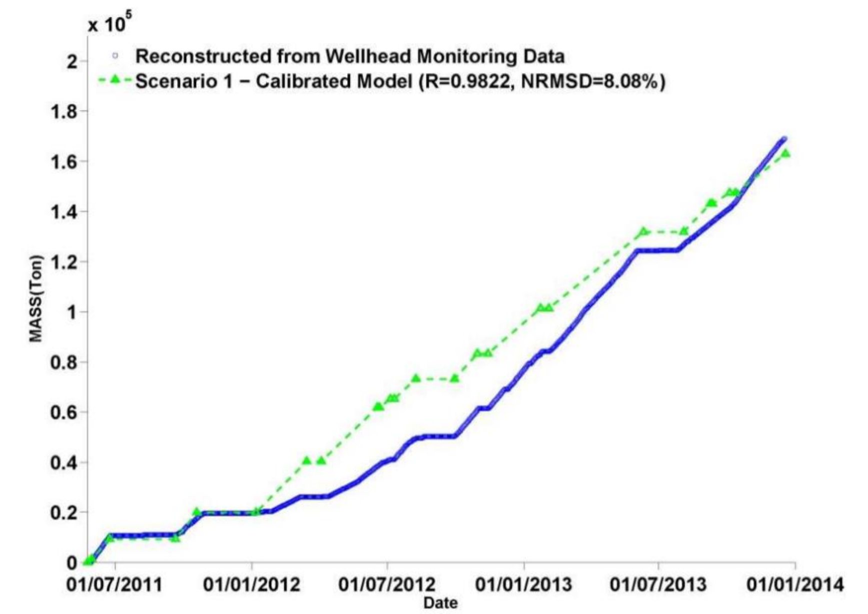
Previous Analysis

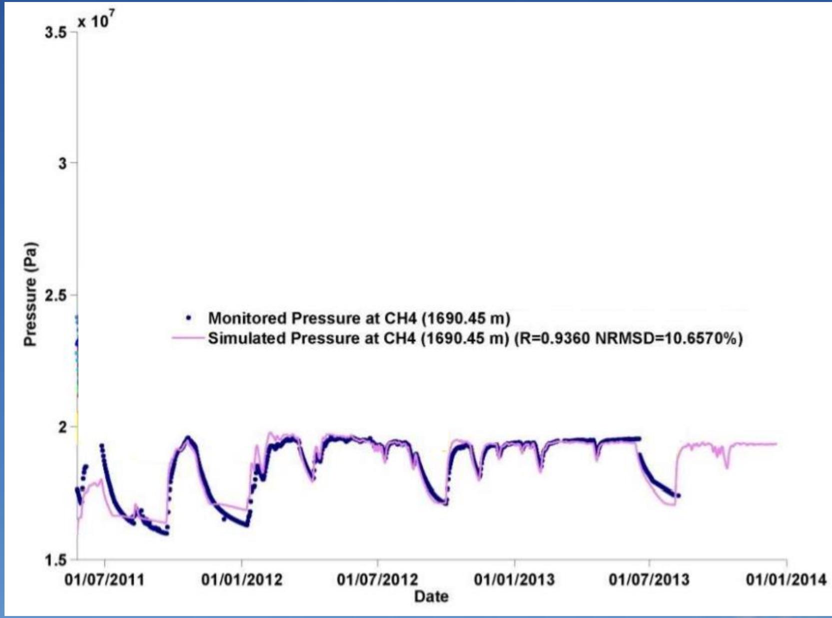




BHP match by Xie et al. (2015a,b)

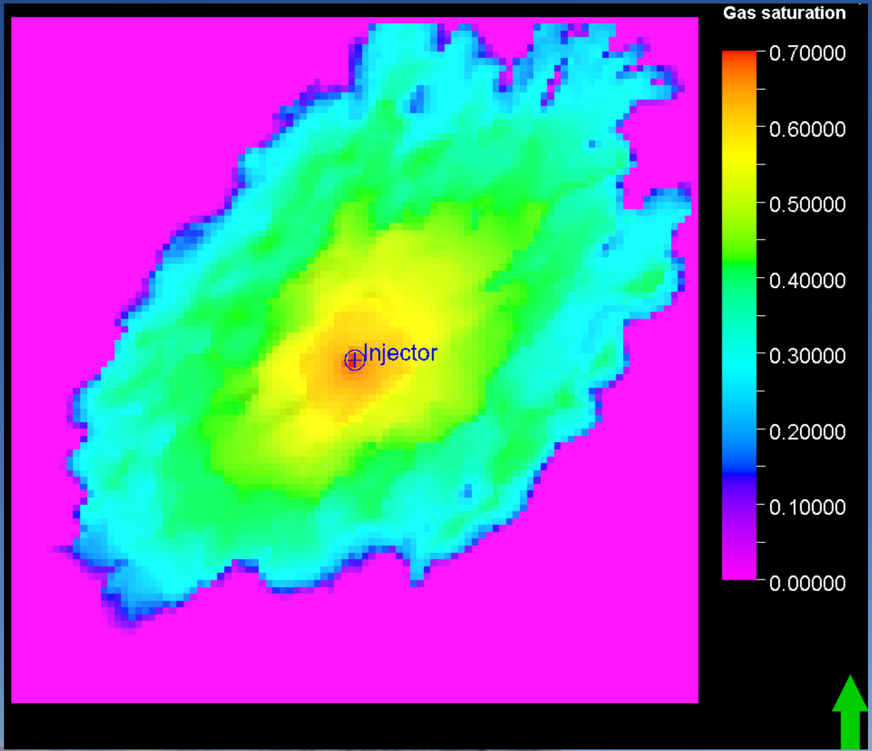
Previous Analysis

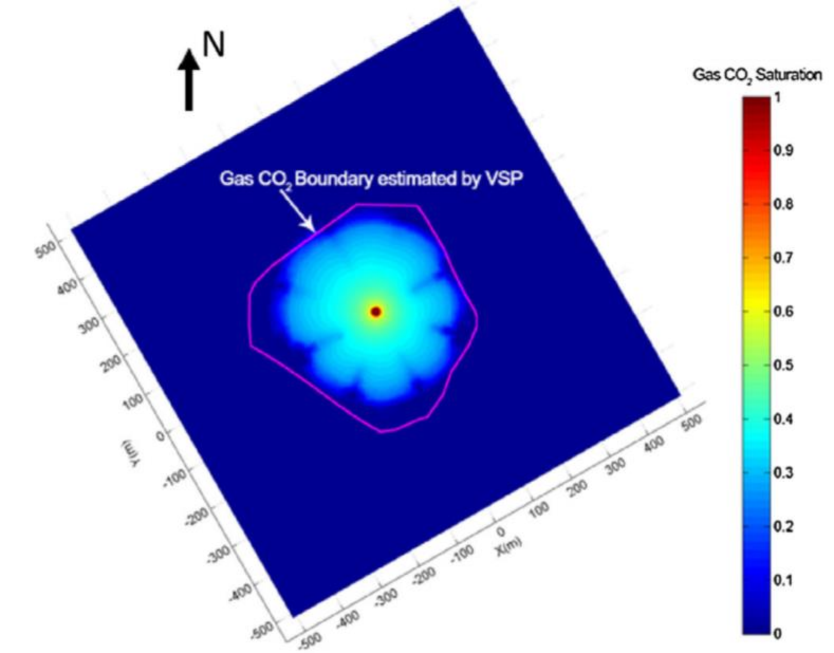




BHP pressure match by Li et al. (2016)

Discussion



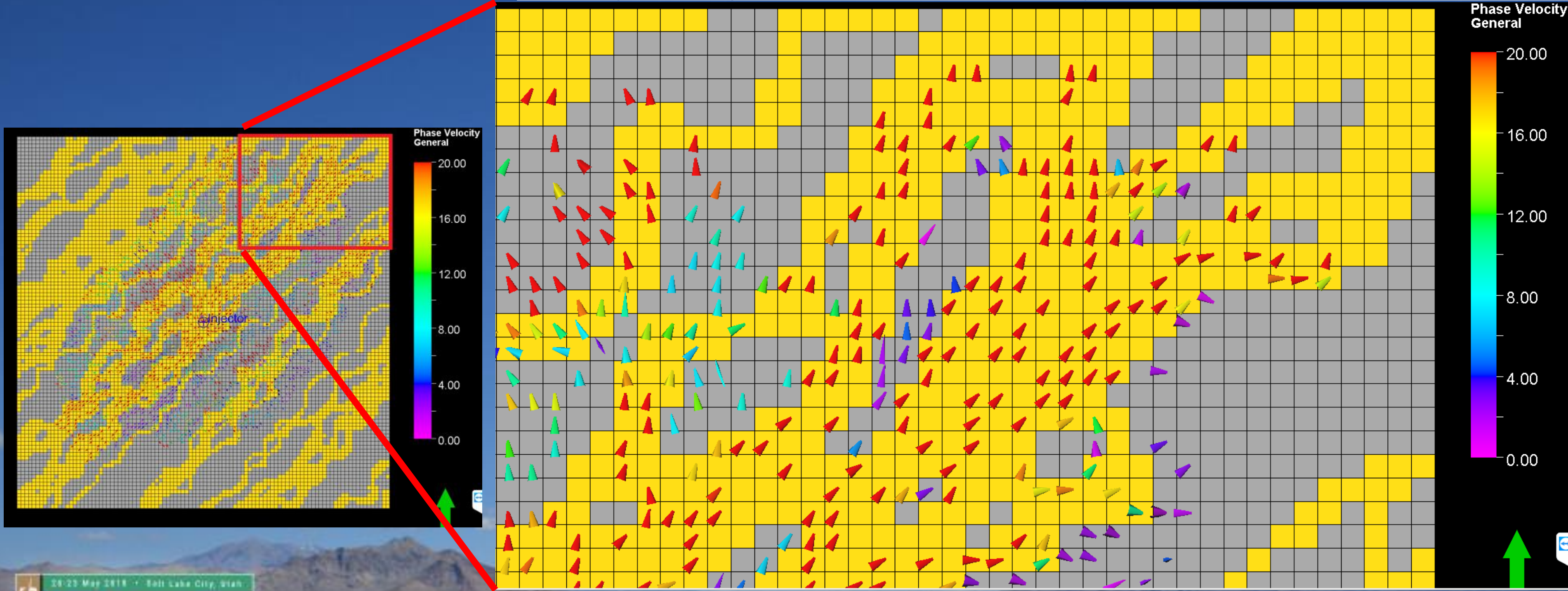


CO_2 Boundary (Liujiagou) estimated by VSP seismic data (after Li et al., 2016)

Discussion

SI Units (m) varying channel parameters

		Min	Med/ mean	Max/ std	
Width	Triangul	500	550	600	
Thickness	Triangul	50	55	60	
Orientation	Triangul	40	45	50	[Compass degrees]
Amplitude	Triangul	600	800	1000	[Horizontal distance units]
Wavelength	Triangul	1000	1500	2000	[Horizontal distance units]
Rel. sinuosity	Triangul	0.2	0.3	0.4	[Positive number]



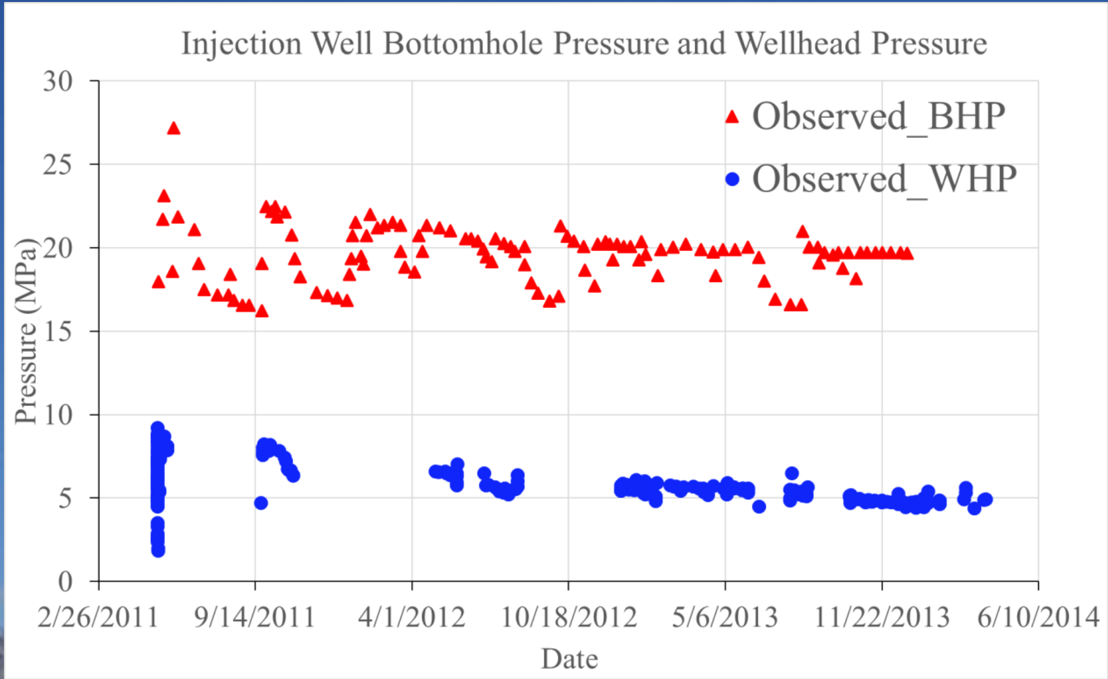
Summary

- Simulation results and drilling observation suggest the likely existence of fracture networks
- Reservoir connectivity plays a key role in the success of CO_2 injection operation
- Boundary conditions may have a significant control on pressure behavior at the injection well

Future Work

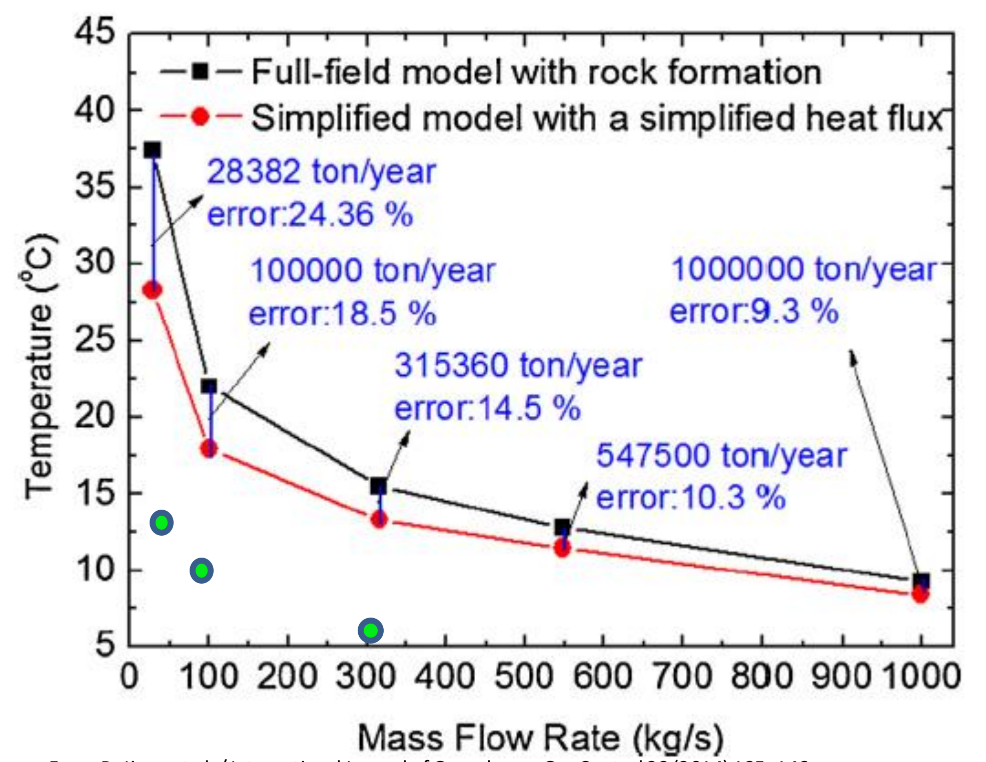
- Investigate potential of CO_2/brine leakage through abandoned wells and sealing layers using the National Risk Assessment Partnership (Nguyen et al., 2017c; Onishi et al., 2018)
- Wellbore flow simulation to investigate pressure disconnection between WHP and BHP (Jiang et al., 2014)
- Attempt to find more log/seismic on Pressure/Temperature downhole in the injector and fracture data through contact with Shenhua Company

Thank You!



Injection Well Bottomhole Pressure and Wellhead Pressure
Observed_BHP
Observed_WHP
Pressure (MPa)
30
25
20
15
10
5
0
2/26/2011
9/14/2011
4/1/2012
10/18/2012
5/6/2013
11/22/2013
6/10/2014
Date

Next steps to add thermal impacts



From P. Jiang et al. / International Journal of Greenhouse Gas Control 23 (2014) 135–146

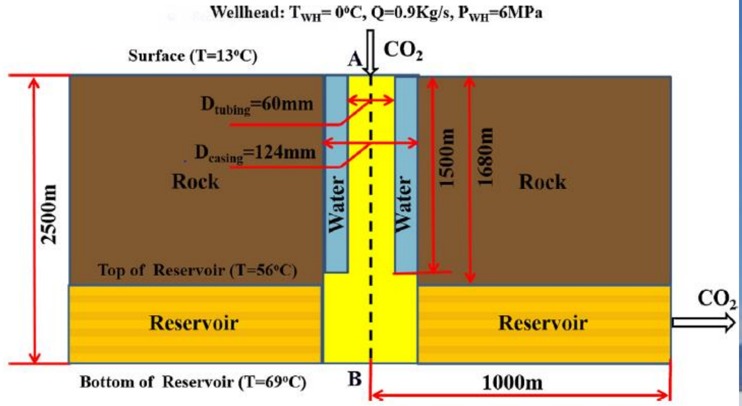
Fig. 7. The bottomhole temperature of CO_2 at different mass flow rate in both the full-field model with rock formation and the simplified model with a simplified heat flux (injection time = 10 days).

- Transient FEHM full water-CO_2-heat with 20 km reservoir

JT compression heating
Gravitational potential energy
Liquid/Supercritical transition

Temperature at top of reservoir 1575 m vs 1700m

FEHM results at longer times.

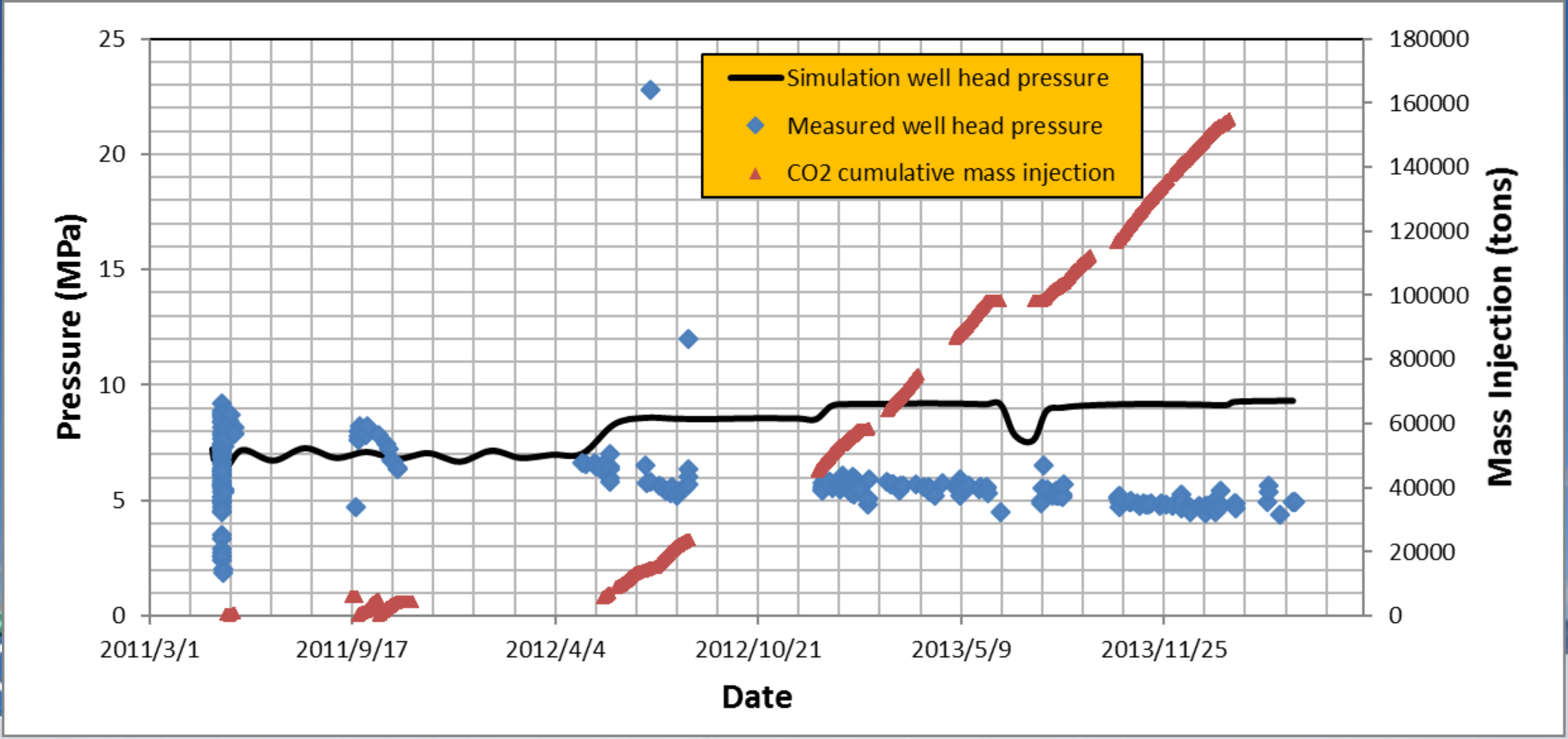


Bai et al. (2017) derived the upper BHP injection limit

- Using a thermal-hydraulic coupling model of wellbore and reservoir flows with explicit solutions, Bai et al. (2017) determined that the upper limit of injection wellhead pressure should be 13.0 MPa

- During the Shenhua injection operation, wellhead pressure rarely exceeded this upper limit.

Wellhead pressures and cumulative mass injection



Possible answers to pressure drop

- Stress from increased CO_2 injection could open flow paths, therefore enhancing permeability over time.
- Thermal contraction of the rocks due to cold CO_2 injection.
- Existence of a fracture network that allowed high injectivity.
- Chemical reactions between the CO_2 and rocks (which will take longer time).

References

- Jiang, P., Li, X., Xu, R., Wang, Y., Chen, M., Wang, H., & Ruan, B. (2014). Thermal modeling of CO_2 in the injection well and reservoir at the Ordos CCS demonstration project, China. International journal of greenhouse gas control, 23, 135-146.
- Xie, J., Zhang, K., Hu, L., Pavelic, P., Wang, Y., & Chen, M. (2015a). Field-based simulation of a demonstration site for carbon dioxide sequestration in low-permeability saline aquifers in the Ordos Basin, Hydrogeology Journal, 23(7), 1465-1480.
- Xie, J., Zhang, K., Hu, L., Wang, Y., & Chen, M. (2015b). Understanding the carbon dioxide sequestration in low-permeability saline aquifers in the Ordos Basin with numerical simulations. Greenhouse Gases: Science and Technology, 5(5), 558-576.
- Li, C., Zhang, K., Wang, Y., Guo, C., & Maggi, F. (2016). Experimental and numerical analysis of reservoir performance for geological CO2 storage in the Ordos Basin in China. International Journal of Greenhouse Gas Control, 45, 216-232.
- Xie, J., Zhang, K., Li, C., & Wang, Y. (2016). Preliminary study on the CO 2 injectivity and storage capacity of low-permeability saline aquifers at Chenjiacun site in the Ordos Basin. International Journal of Greenhouse Gas Control, 52, 215-230.
- Zhang, K., Xie, J., Li, C., Hu, L., Wu, X., & Wang, Y. (2016). A full chain CCS demonstration project in northeast Ordos Basin, China: Operational experience and challenges. International Journal of Greenhouse Gas Control, 50, 218-230.
- Bai, B., Li, X., Wu, H., Wang, Y., & Liu, M. (2017). A methodology for designing maximum allowable wellhead pressure for CO2 injection: application to the Shenhua CCS demonstration project, China. Greenhouse Gases: Science and Technology, 7(1), 158-181.
- Nguyen, M. C., Zhang, Y., Li, J., Li, X., Bai, B., Wu, H., ... & Stauffer, P. H. (2017a). A geostatistical study in support of CO2 storage in deep saline aquifers of the Shenhua CCS project, Ordos Basin, China. Energy Procedia, 114, 5826-5835.
- Nguyen, M. C., Zhang, X., Wei, N., Li, J., Li, X., Zhang, Y., & Stauffer, P. H. (2017b). An object-based modeling and sensitivity analysis study in support of CO2 storage in deep saline aquifers at the Shenhua site, Ordos Basin. Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 3(3), 293-314.
- Nguyen, M., Onishi, T., Carey, J. W., Will, B., Zaluski, W., Bowen, D., ... & Stauffer, P. H. (2017c). Risk Assessment of Carbon Sequestration into A Naturally Fractured Reservoir at Kevin Dome, Montana (No. LA-UR-17-31501). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).
- Onishi, T., Nguyen, M.C., Carey, J.W., Will, B., Zaluski, W., Bowen, D., Devault, B., Duguid, A., Zhou, Q., Fairweather, S., Spangler, L., and Stauffer, P.H. (2018) Potential CO2 and Brine Leakage through Wellbore Pathways for Geologic CO2 Sequestration Using the National Risk Assessment Partnership Tools: Application to the Big Sky Regional Partnership, International Journal of Greenhouse Gas Control
- Li, Q., Song, R., Shi, H., Ma, J., Liu, X., & Li, X. (2018). U-tube based near-surface environmental monitoring in the Shenhua carbon dioxide capture and storage (CCS) project. Environmental Science and Pollution Research, 1-19.