Exhausted Brine Extraction and Completed CO_2 Storage in Jianghan Basin, China

枯竭式卤水开采与完整式CO_2地质储存

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China Australia Geological Storage of CO_2

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PRESENTATION OUTLINE 概要

1. Background
   研究背景
2. Methodology
   研究方法
3. Results
   结果分析
4. Conclusion
   主要结论

Background

For the conventional industrial-scale CO_2 injection in saline formations, pressure buildup can limit storage capacity and security.

对于传统的咸水层中CO_2规模化灌注，压力积累是制约储存容量和储存安全的主要因素。

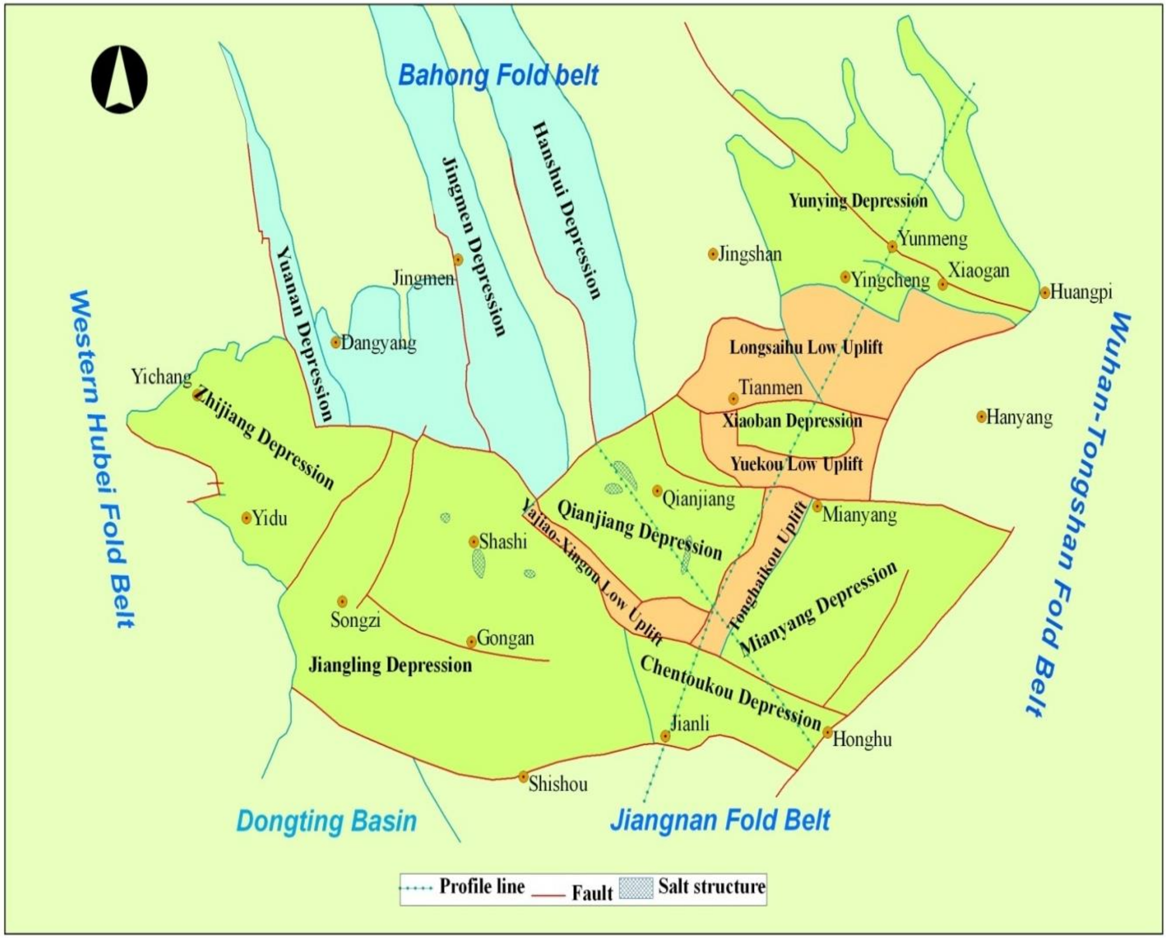
For the conventional industrial-scale production of fluid resource underground, severe pressure reduction may bring in unwanted effects such as potential collapse,land subsidence risk.

对于传统的地下液体资源规模化开采，严重的压力下降有可能带来负面作用如地面塌陷沉降风险。

A distinct advantage of CCS-EOR is that it involves fluid extraction, which increases CO_2 storage capacity and offsets pressure buildups, which conventional saline-formation GCS does not..

CCS-EOR的显著优势在于涉及流体开采，不仅可以增加储存量而且可以实现压力补偿，这是传统咸水层中GCS所不具备的。

Background



Location map of the Jianghan Basin

The Jianghan Basin is a representative salt-lake rift basin covering an area of 36350 km^2 with the salinity up to 325g/L. Qianjiang Depression and Jiangling Drepression are the two brine-richest areas.

江汉盆地属于我国典型的盐湖裂谷型盆地，面积36350km^2。盆地咸水层盐度高达325g/L。其中，属潜江凹陷和江陵凹陷卤水资源最为丰富。

Background

The hot potassium-rich brine is very rich in the depths of Jiangling Depression in Jianghan Basin. The brine formation rich in potassium lies in Shashi formation of Paleocene.

江汉盆地江陵凹陷深处赋存高温富钾卤水，含卤地层主要是古新统沙市组。

The salinity of brine is up to 325g/L, with the potassium content varying from 9.1 to 9.6g/L and KCl content from 17.5 to 18.5g/L.

卤水矿化度达325g/L以上，其中K^+含量达9.1~9.6g/L，KCl为17.5~18.5g/l。

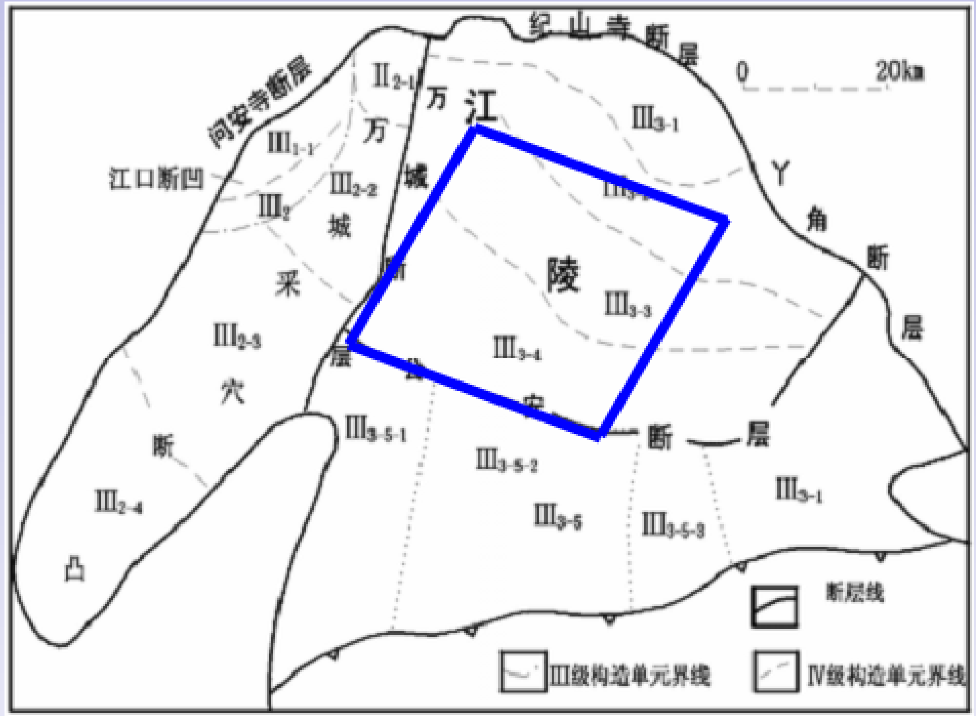
China attaches great importance to the extraction of potassium rich brine resource . The activity of brine extraction is being carried out in Jiangding Depression, Jianghan Basin.

我国非常重视钾盐矿卤水资源开采，江汉盆地江陵凹陷的富钾卤水资源已在开采实施阶段。

Background

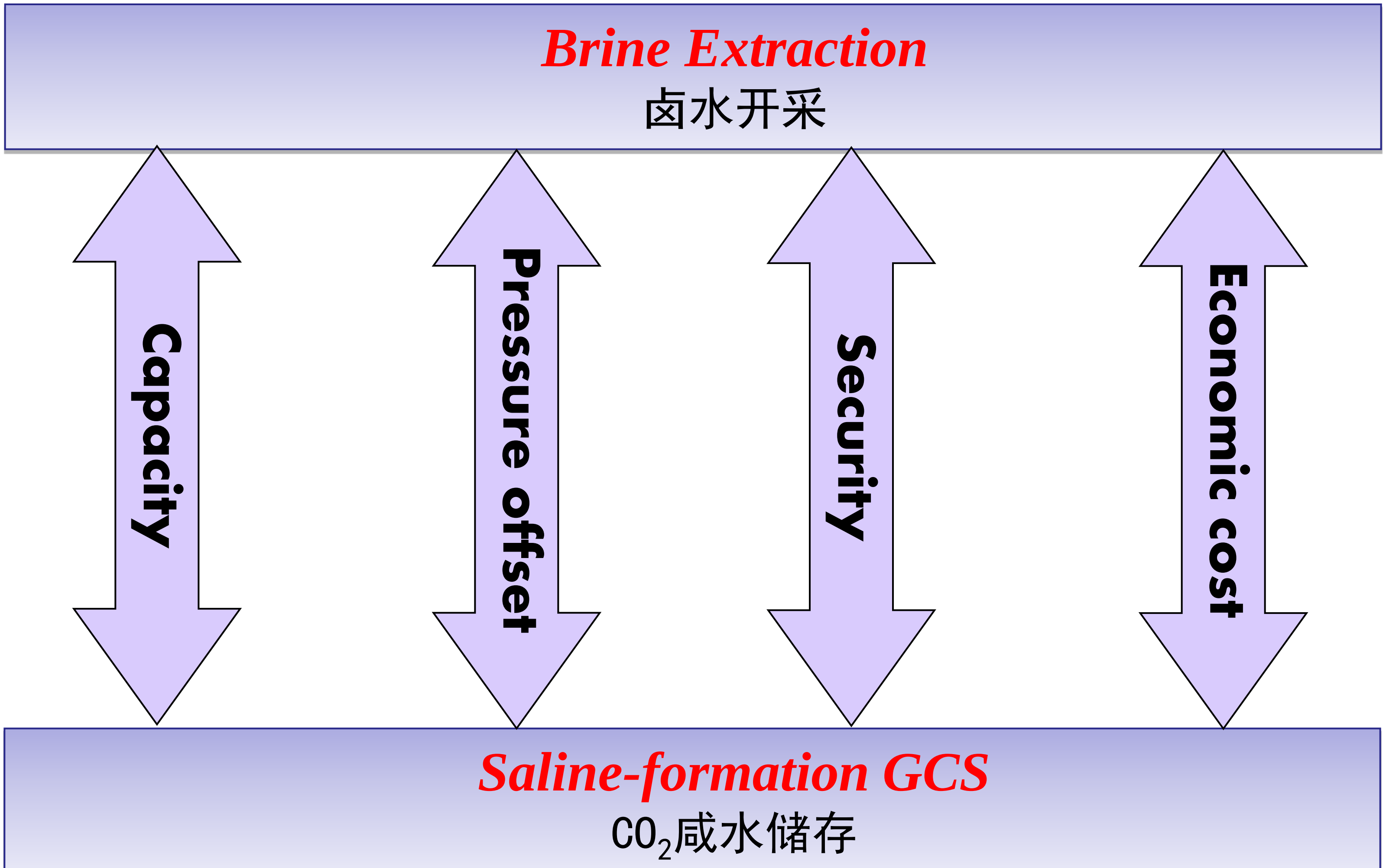
The evaporites in Shashi Formation mainly distirbutes in the sag of Jiangling Depression, acting as a separated geological unit. The Jiangling Sag has an area of 1600km², with the distribution area of the potassium-bearing brine 960km².

沙市组蒸发岩主要分布于江陵断凹的洼陷内，成为一个相对独立盐盆。江陵洼陷面积1600km²，富钾卤水控制面积960km²。



The distribution area of the potassium-bearing brine in Jiangling Depression

Background



Brine Extraction
卤水开采
Capacity
Pressure offset
Security
Economic cost
Saline-formation GCS
CO_2咸水储存

Background

Exhausted Brine Extraction and Completed CO_2 Storage
枯竭式卤水开采与完整式CO_2地质储存

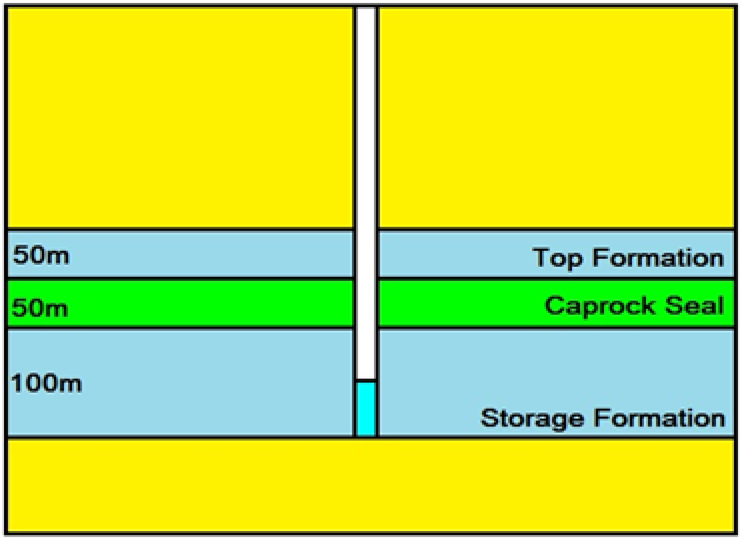
Studyarea: potassium-bearing area in Jiangling Depression
选取江汉盆地江陵凹陷富钾卤水区域作为研究区域

Near Injection well and regional pressure regulation;
近井区及区域含水层压力调控；
Brine extraction capacity and total prodcution;
卤水开采效率与总开采量；
CO_2 injectivity and storage capacity;
CO_2可注入性与储存容量；
Manipulation of CO_2 plume migration and storage security;
CO_2羽迁移的操纵与储存安全；

2. Methodology

研究方法

Methodology - hydrogeological properties



Properties	Formation	Seal
Thickness(m)	100	50
Permeability (m^2)	10^{-14}	10^{-20}
Pore compressibility (Pa^{-1})	4.5×10^{-10}	4.5×10^{-10}
Porosity	0.10	0.05
van Genuchten m	0.46	0.46
Van Gemuchten α (Pa^{-1})	5.1e-5	1.6e-7
Residual CO_2 saturation	0.05	0.05
Residual water saturation	0.30	0.30

Figure 2: Scheme of vertical spatial subdivision and hydrogeological properties used in this study. The formation for brine extraction and CO_2 storage is 100m thick below 3000m underground covered by a sealing unit with thickness of 50m. The wells are permeable in the low half of the storage formation.

图 2：本模型中垂向空间剖分与水文地质参数。供卤水开采与 CO_2 储存的主咸水层厚 100m，埋深地下 3000m，上覆厚 50m 的盖层。井射孔穿透下半个储层。

Methodology - well placement

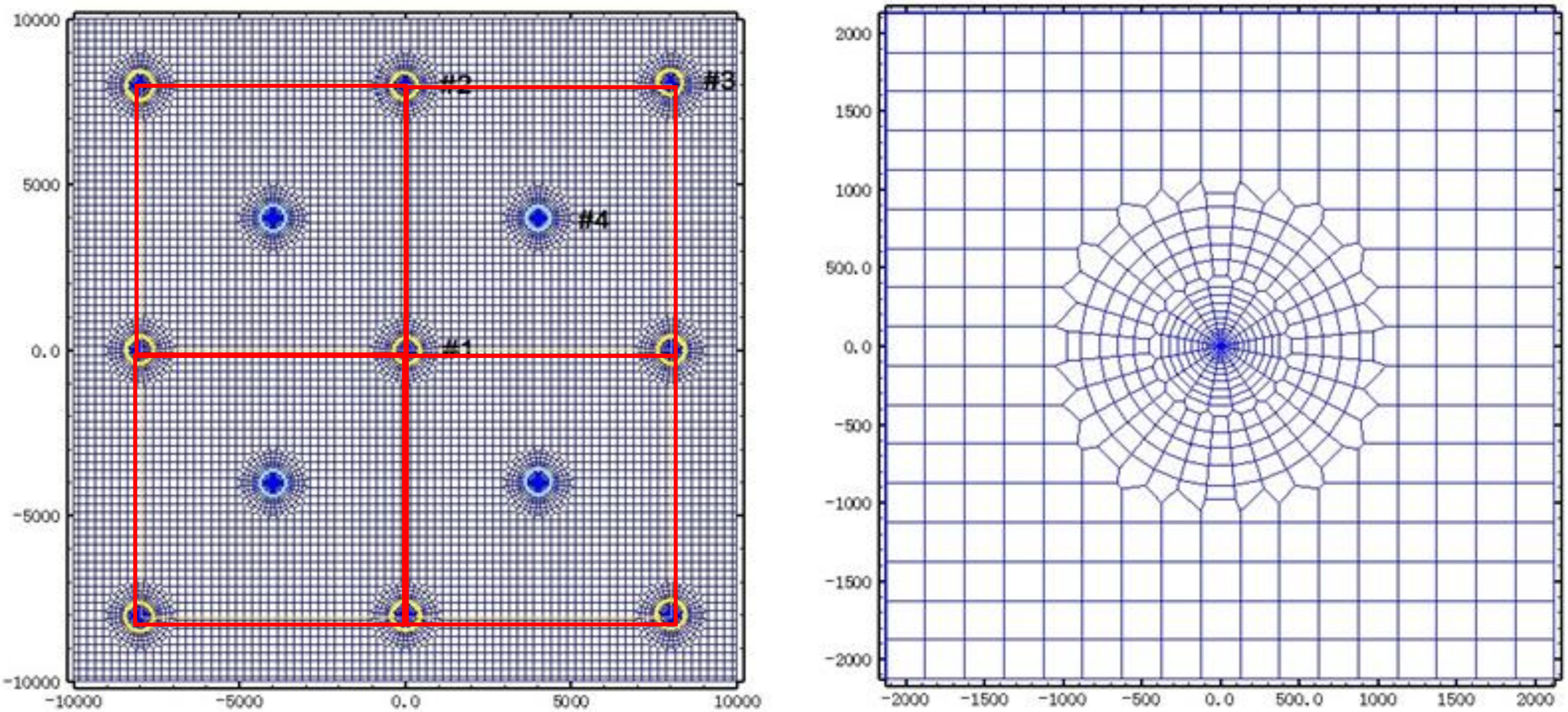


Figure 1: Scheme of multiwell placement and grid generation in the horizontal direction of the model. Note that the well spacing is 8 km and the linked wells are in the same group while the others are in another. All the wells are assumed to be vertical wells.

图 1：本模型中井群布置与平面网格剖分示意图，平面共布置 13 口井，井间距为 8km，被划分为两组（CO_2注入井与卤水开采井），且均为垂直井。

Methodology - simulation scheme

Scheme 注采方案	9B4C_Q	4B9C_Q	9B4C_P	4B9C_P
Number of CO_2 wells CO_2注入井个数	4	9	4	9
Number of brine wells 卤水开采井个数	9	4	9	4
CO_2 Injection scheme CO_2注入方案	Constant injection rate 0.25Mt/yr per well		Constant inejction pressure of 40Mpa	
Brine Extraction scheme 卤水开采方案	constant extraction pressure of 1Bar 固定抽水压力为一个大气压			
Simulation Run Time 模拟时间(yr)	Simultaneous CO_2 injection and brine extraction for 100 years and monitoring for 100years			
Simulation Tool 模拟软件	TOUGH2_ECO2N_MP			

3. Results -- constant rate part

研究结果—定速注入部分

Results - pressure response

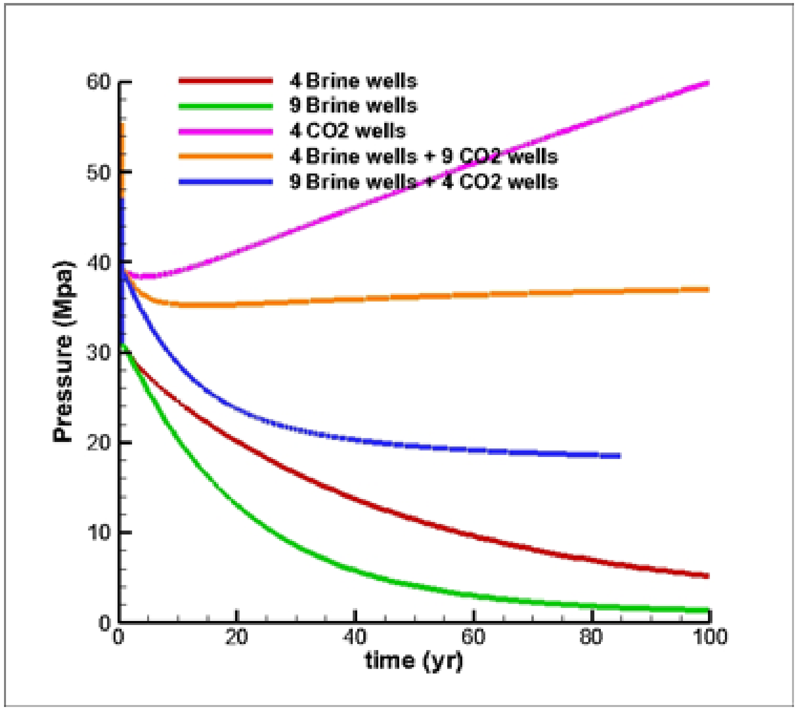


Figure 3: Pressure response of different CO_2 injection and brine extraction cases varying with time for the constant injection rate mode.

图 3：CO_2定速注入不同抽注模式对应的注入井压力随时间的变化。

The combination of CO_2 injection and brine extraction can effectively regulate the pressure buildup of storage formation and maintain it at a stable value.

CO2 与卤水耦合注采可有效地控制主作业层的压力，使其保持在稳定范围内。

Results - pressure response

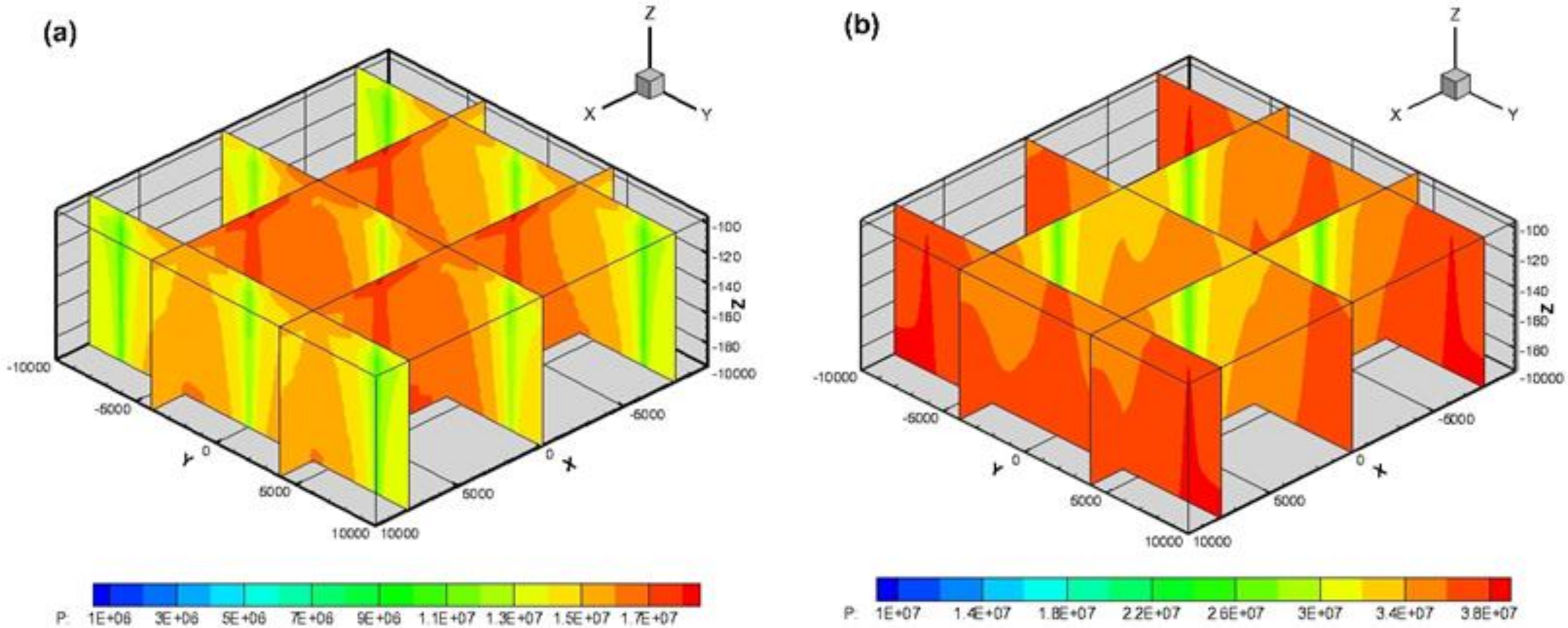


Figure 4: (a)Spatial distribution of pressure for 9 brine extraction wells and 4 CO_2 injection wells case after 85 years' simultaneous brine production and CO_2 injection. (b) Spatial distribution of pressure for 4 brine extraction wells and 9 CO_2 injection wells case after 100 years' simultaneous brine production and CO_2 injection.

图 4: (a) 9 口抽卤井与 4 口注气井同时抽注 85 年后的压力空间分布；(b) 4 口抽卤井与 9 口注气井同时抽注 100 年后的压力空间分布。

Results - gas saturation migration

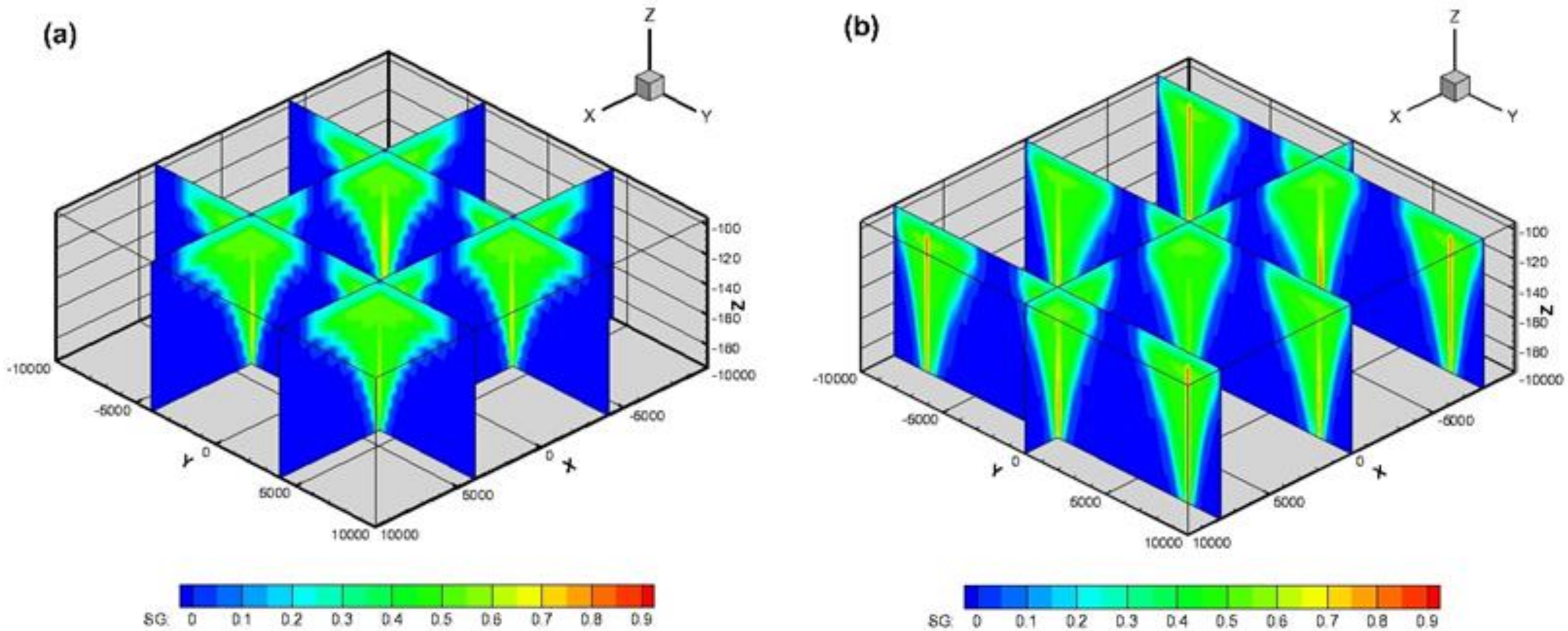
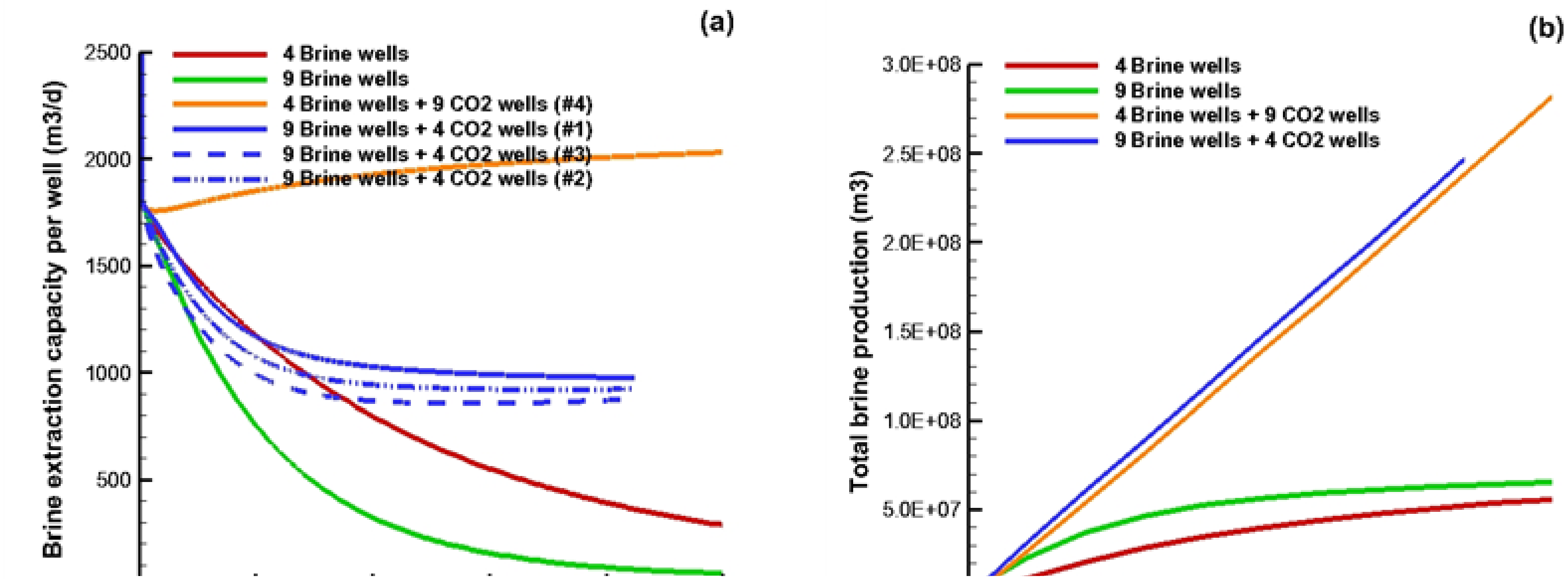


Figure 5: (a)Spatial distribution of gas saturation for 9 brine extraction wells and 4 CO_2 injection wells case after 85 years' simultaneous brine production and CO_2 injection. (b) Spatial distribution of gas saturation for 4 brine extraction wells and 9 CO_2 injection wells case after 100 years' simultaneous brine production and CO_2 injection.

图 5: (a) 9 口抽卤井与 4 口注气井同时抽注 85 年后的 CO_2 气体饱和度空间分布；(b) 4 口抽卤井与 9 口注气井同时抽注 100 年后的 CO_2 气体饱和度空间分布。

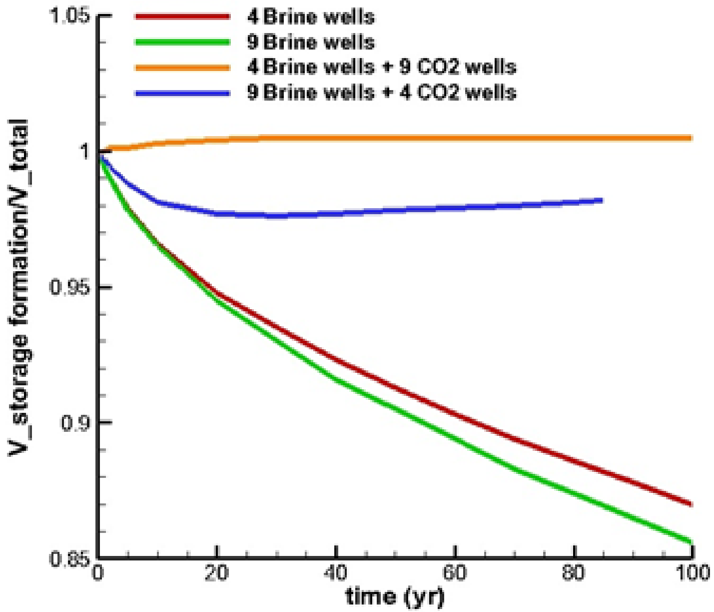
Results - brine production



Till 100 years, the total brine production of 4 brine wells case, 9 brine wells case and the combination case of 4 brine wells with 9 CO_2 wells is up to 55.7M m^3, 65.2M m^3, and 282M m^3, respectively accounting for 1.17%, 1.33% and 6.74% of the total brine volume in the storage formation. Due to the convergence problem, we only get the data of 85 years for the 9 brine wells and 4 CO_2 wells case. Till 85 years, the brine production is 247M m^3, accounting for 6.11% of the total brine volume.

4 口抽卤井、9 口抽卤井与 4 口抽卤井与 9 口注气井联合注采方式同时注采 100 年后的卤水总开采量分别为 55. 7M m^3，65. 2M m^3，282M m^3，占卤水总储量的 1. 17%，1. 33%，6. 74%。而 9 口抽卤井与 4 口注气井联合注采方式同时注采 85 年后卤水总产量为 247M m^3，占卤水总储量的 6. 11%。

Results - leakage flow



The leakage recharge occurs between the storage formation and the overlying geological units due to the excessive pressure gradient.

The combination of brine extraction and CO_2 injection can effectively mitigate the vertical cross flow from top to down.

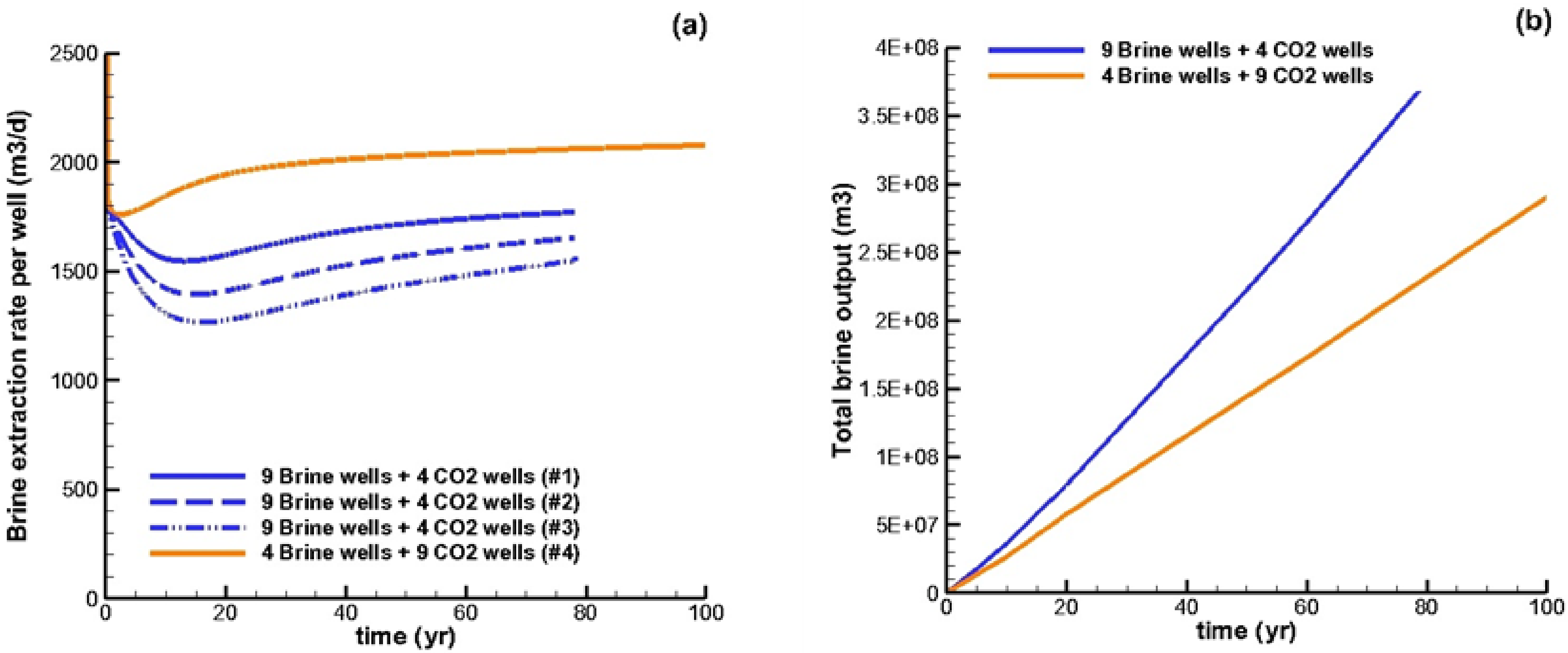
过高的压力梯度导致主作业层与上覆地质体发生越流补给。CO_2与卤水耦合注采模式可有效缓解垂向越流的发生。

Figure 7: Comparison of volume ratios between water change of storage formation and total brine production for different brine extraction and CO_2 injection cases.
图 7：不同抽注模式下主作业层总水量变化与卤水抽取总量体积比对比。

3.Results -- constant pressure part

研究结果—定压注入部分

Results - brine production



Under the constant injection pressure case, the brine production capacity of single well is greatly enhanced for 9 brine wells and 4 CO_2 wells case, with the average daily production capacity up to 1500 m^3/d. The total brine production amount after 79 years reaches up to 368Mm^3 accounting for 8.75% of the total brine volume. There is no significant improvement for 4 brine wells and 9 CO_2 wells case, however, as the pressure is elevated 2MPa compared to the constant injection rate mode.

定压注入方式下，9口抽卤井与4口注气井联合注采方案中单井卤水开采量得到很大的提升，平均日产量达1500m^3，79年后卤水总产量达到368Mm^3，占总储量的8.75%。4口抽卤井与9口注气井联合注采方案没有显著提高，原因在于定压注入相对于定速注入，压力只提升了2Mpa。

Results - CO_2 injection and capacity

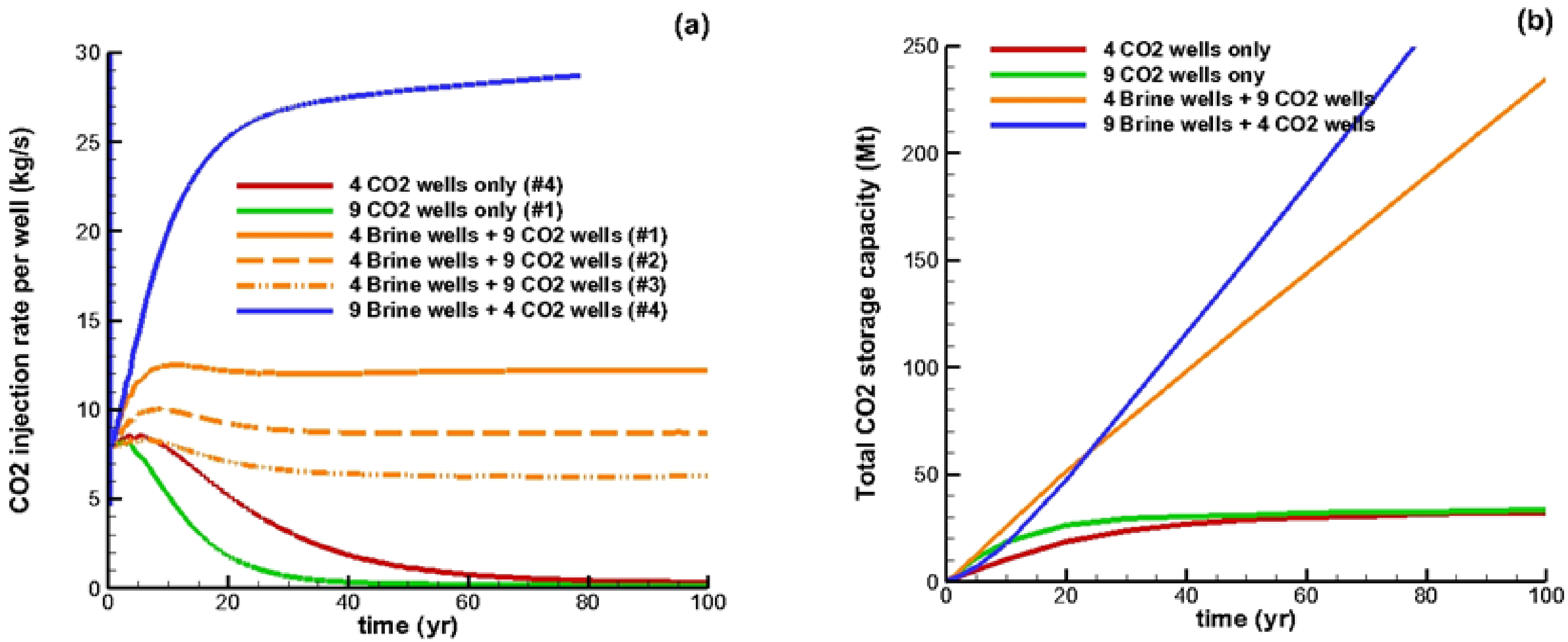


Figure 9: CO_2 injection rate per well (a) and total CO_2 injection capacity of all injection wells (b) varying with time for the constant injection pressure mode.

CO_2 injectivity is significantly improved, with the injection rate up to 28kg/s for 9 brine wells and 4 CO_2 wells case and the total storage capacity up to 252Mt after 79yrs' simultaneous brine extraction and CO_2 injection, which is 7.8 times compared to the only CO_2 injection case.

定压注入方式下CO_2可注入性得到显著提高，尤其是对于9口抽卤井与4口注气井联合注采方案，单井注入速率达到28kg/s，同时注采79年后，CO_2总储量达到252Mt，是只注入CO_2方案对应储量的7.8倍。

Results - gas saturation migration

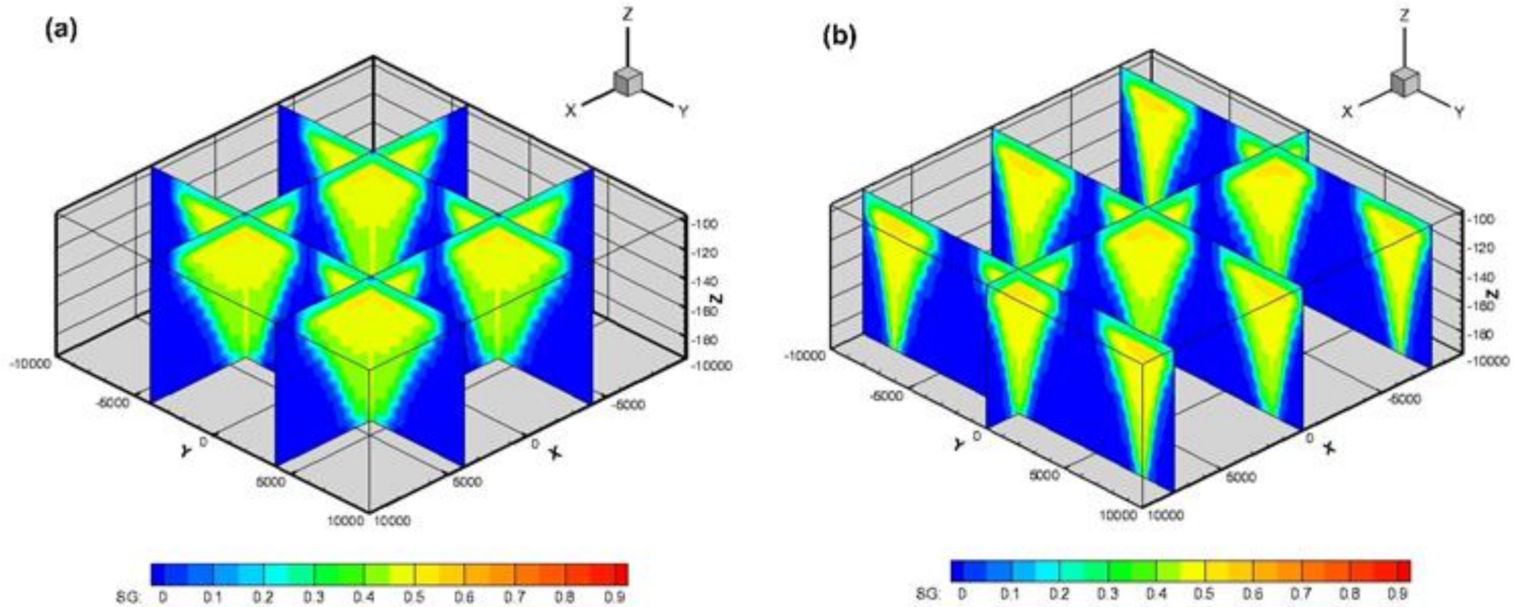


Figure 10: (a)Spatial distribution of gas saturation for 9 brine extraction wells and 4 CO_2 injection wells case after 79 years' injection. (b) Spatial distribution of pressure for 4 brine extraction wells and 9 CO_2 injection wells case after 100 years' injection.
图 10: (a) 定压方案 9 口抽卤井与 4 口注气井同时抽注 79 年后的 CO_2 气体饱和度空间分布；(b) 定压方案 4 口抽卤井与 9 口注气井同时抽注 100 年后的 CO_2 气体饱和度空间分布。

Results - gas saturation migration

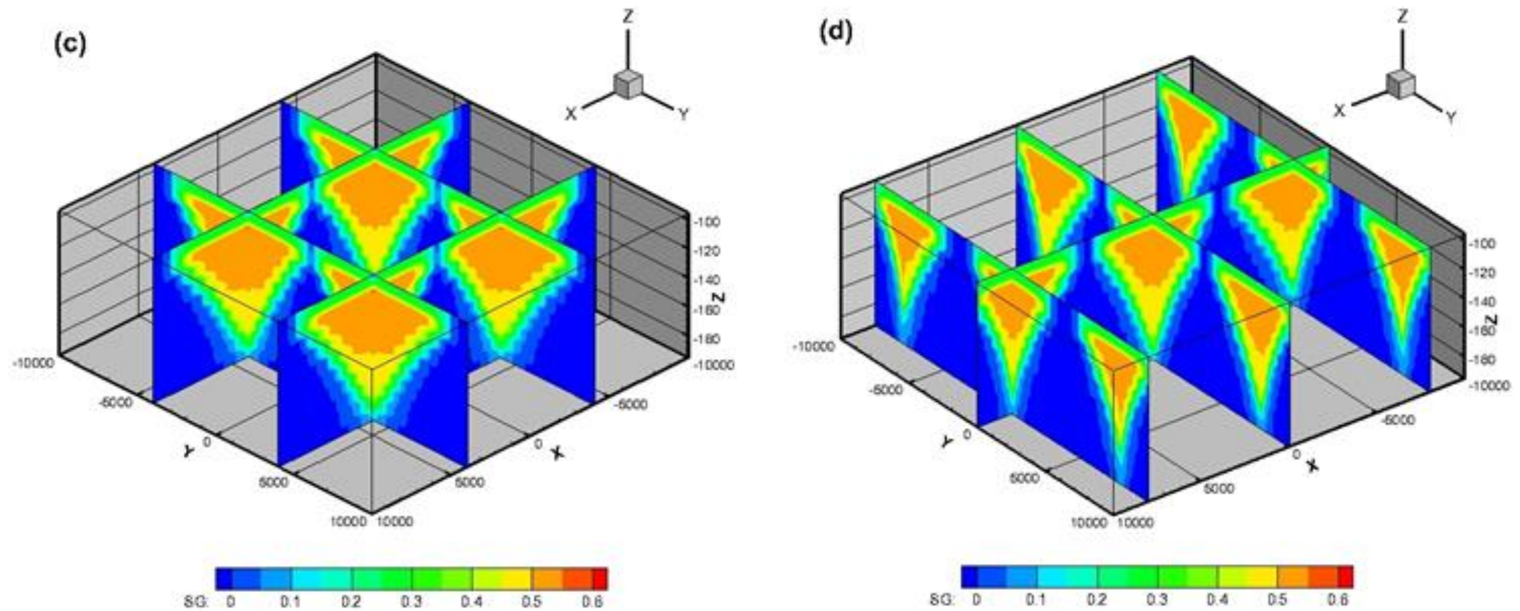


Figure 10: (c)Spatial distribution of gas saturation for 9 brine extraction wells and 4 CO_2 injection wells case at 200 year after injection. (d) Spatial distribution of pressure for 4 brine extraction wells and 9 CO_2 injection wells case at 200 year after injection.

图 10: (c) 定压方案 9 口抽卤井与 4 口注气井 200 年后的 CO_2 气体饱和度空间分布；
(d) 定压方案 4 口抽卤井与 9 口注气井 200 年后的 CO_2 气体饱和度空间分布。

3. Results -- comparison

研究结果—两种模式对比

Results - comparison

Scheme 注采方案	9B4C_Q	9B4C_P	4B9C_Q	4B9C_P
Simulation Run Time 模拟时间(yr)	85	79	100	100
CO_2 Injection Capacity CO_2注入总量(Mt)	85 (2.6)	252 (7.8)	225 (7.0)	235 (7.3)
Brine Total Production 卤水总开采量(Mm^3)	247 (4.4)	368 (6.6)	282 (5.0)	290 (5.2)
Well Pressure Buildup 注入井压力积累(Mpa)	19	40	38	40
Pressure Recovery 停注后压力恢复(Mpa)	NA	30	35.6	36.3

4. Conclusion

结论

Conclusion

- The combination of CO_2 injection with brine extraction can effectively regulate the region pressure balance of the formation.

- 传统规模化注入CO_2会造成地层压力的严重积累，从而制约着CO_2储存量；传统规模化开采卤水则会造成地层压力的严重降低，带来塌陷风险。CO_2注入与卤水开采耦合模式可有效地调控地层的区域压力平衡。

Conclusion

- The combination of CO_2 injection with brine extraction can significantly enhanced the production of brine extraction wells and keep it at a stable value.

- CO_2注入与卤水开采耦合模式可显著地提高卤水开采井的单井产量，使其保持于一个稳定值。

- The combination of CO_2 injection with brine extraction can effectively prevent the leakage recharge between the geological units.

- CO_2注入与卤水开采耦合模式可有效地防控地质单元间越流补给的发生。

Conclusion

- The scheme of constant pressure injection is much superior to the one of constant rate injection.

- The combination of 9 brine extraction wells and 4 CO_2 injection wells with the constant pressure injection is the best scheme in brine production, pressure regulation, CO_2 injectivity and storage capacity.

- 定压注入方案明显优越于定速注入方案。定压注入方案下9口抽卤井与4口注气井的耦合方案在卤水开采量、压力调控以及CO_2注入性与储存量方面表现最佳。

Thank You !