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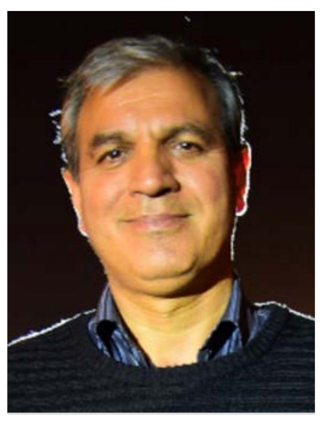
Impact of hydrogren solubility on depleted gas field's caprock for underground hydrogen storage purpose



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Impact of hydrogen solubility on depleted gas field's caprock; an application for underground hydrogen storage

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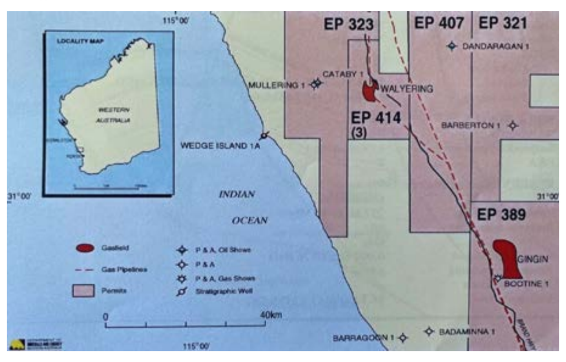
The depleted gas fields are considered one of the low-risk locations for underground hydrogen storage purposes to balance seasonal fluctuations in hydrogen supply and demand. The objective of this study is to identify any significant risk of hydrogen leakages stored in depleted gas fields. The capability of the storage area in terms of sealing efficiency varies with parameters such as rate of diffusion, solubility, thickness, and capillary threshold pressure of the caprock. The most common caprock are shales, which contain organic material. The solubility of hydrogen into organic material and possibly many other interactions between diffusive hydrogen and the caprock could change rocks' petrophysical properties such as porosity and permeability. Any changes in rock's petrophysical characteristics can reduce the capillary threshold pressure thus reducing the cap rock efficiency for the safe storage of hydrogen.

There is about more than 20% of the remaining gas volume in the depleted gas field, which helps to prevent brine from entering the production streamlines and maintain reservoir pressure. The characteristic data of hydrogen at different high pressure and temperature have been evaluated and imported into the simple finite element model. The modelling code has written in the Python programming language using all related python packages for visualisation and solving partial differential equations of fluid flow in porous media. Most of the parameters that influence reducing the strength of the caprock are identified. Crucial parameters are the rate of diffusion, the solubility of hydrogen in Kerogen, geomechanical deformation, threshold capillary pressure, long period of injection, and withdrawing of hydrogen. The model shows that the native gas production with hydrogen is low due to significant density variation and mobility ratio between methane and hydrogen. Finally, a wide range of parameters and reservoir conditions has been considered for minimizing the potential risks of possible leakages.

Introduction:

Hydrogen's higher heating value exceeds natural gas by about three times. In Western Australia, the Perth area is considered as a high-demand location where all required infrastructures including depleted gas fields in North Perth Basin are present .In this study, most of the depleted oil and gas fields in the North Perth Basin which can be suitable for hydrogen storage from a technical and logistic point of view have been evaluated. The physical property of hydrogen and selection criteria of depleted gas field in North Perth Basin are listed in the following tables.

Location Map, Walyering depleted gas field



Comparison of physicochemical properties of hydrogen and methane

Physical properties	Hydrogen	Methane
Molar mass	2.02	16.043
Lower heating value (MJ/Kg)	120.0	52
higher heating values (MJ/Kg)	142.0	47
Density at 273 K (Kg/m³)	0.09	0.65
Liquid density (Kg/m3)	70.80	450
Diffusion Coefficient in air (cm²/s)	0.61	0.16
Minimum ignition energy [mJ]	0.02	0.29
Auto ignition temperature [°C]	585.0	540
Flammability limits [vol% in air]	4-75	5.3 -15

North Perth Basin hydrogen storage potential sites

Properties	Walyering	Beharra Spring	Dongara	Gingin
Reservoir	Cattamarra Coal Measure	Beekeeper Formation	Dongara Sandstone	Cattamarra Coal Measure
Seal	Intraformational siltstones, clays and shales	Kockatea shale	Kockatea shale	Intraformational siltstones, clays and shales
Total depth (mSS)	3544.3	3651	2112.4	4341.3
gross pay (m)	125	20	11	300
Net pay (m)	39	12.5	11	nd
Porosity %	11.3	15.2	18.6	8
Permeability (mD)	0.1 - 93	514	128	70
Temperature (ºC)	102	141	72.2	nd
Initial reservoir pressure (Psia)	4916	4975	2457	5290
Driving Mechanisms	Pressure Depletion	Pressure Depletion	Water Drive	Water Drive

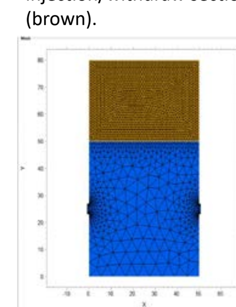
Modelling of hydrogen solubility and diffusion in CapRock

The model simulates the interaction between kerogen invaded porous media and hydrogen during injecting and withdrawing of hydrogen from the reservoir. We used FlexPDE (the software used to perform numerical calculations) and FreeFEM (mesh generation) to generalized flux boundary condition between the hydrogen storage area and caprock with considering the solubility and diffusion phenomenon (flexpde).

According to the general nature of diffusion and solubility between two systems, the model can be easily specialized to describe different domains, e.g storage in an area which fluid is flowing from injection toward production wells and seals which always is contacted with hydrogen . In this case study, Walyering depleted gas field was selected as a suitable field for hydrogen storage for the following reasons:

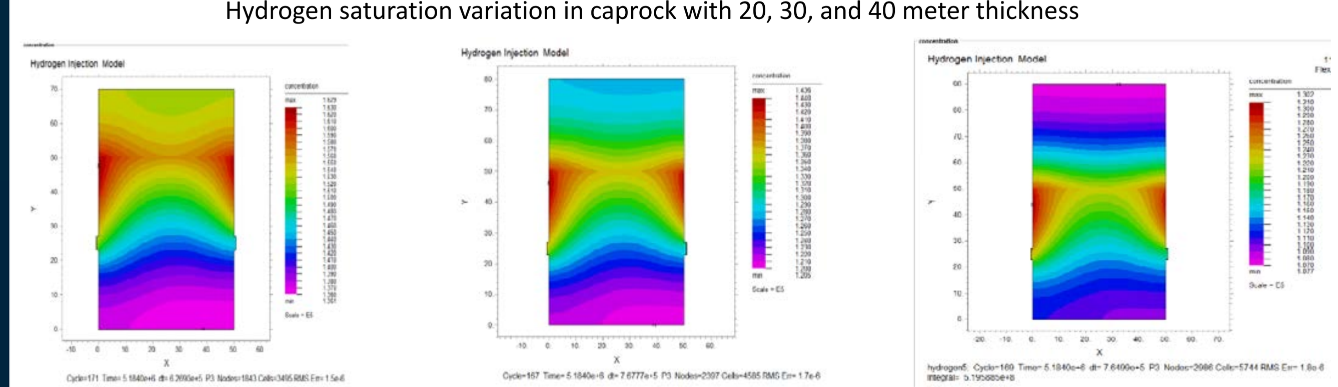
- Small scale project
- Low permeability formation which causes slow injection to get more stability
- Preventing premature gas spillage
- Having enough remaining gas which can act as a cushion gas
- Available infrastructure (pipeline) close to the gas field

hydrogen storage area (blue) with injection/withdraw sections and caprock (brown).



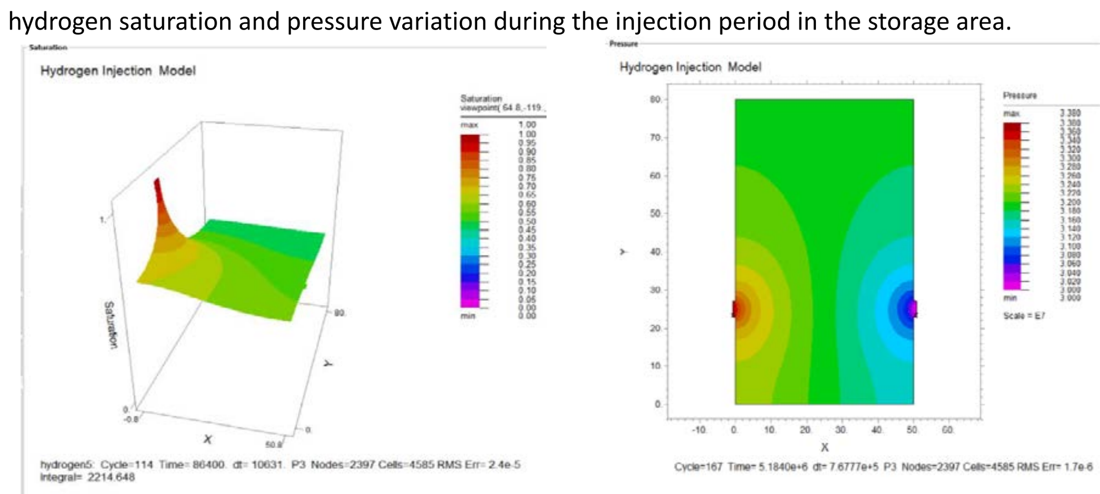
The role of caprock in the preventing upward flow of hydrogen from the underground storage is considerable. In this study, we focused on the solubility of hydrogen into kerogen that may exist in the shaly caprocks. The modelling shows the thickness of the caprock is most important to prevent hydrogen to move up within the seal. We tested three different thicknesses 20, 30, and 40 meters to see the variation of hydrogen concentration within the seal zone. Results shows that thickness above 30 meters will tend to keep most of the hydrogen in the stored area. Diffusion and solubility of hydrogen into kerogen results in the extrusion of kerogen or organic materials from caprock making it permeable to gas. This process can ultimately lead to the leakage of hydrogen quickly due to its high mobility of hydrogen. Diffusion of hydrogen into the caprock is creased due to the high solubility of hydrogen into residual kerogen in the caprock.

Hydrogen saturation variation in caprock with 20, 30, and 40 meter thickness



Pressure and temperature have a direct impact on the solubility of hydrogen into hydrocarbon phases including kerogen within the shale. In this study, the reservoir pressure of 5000 Psia and temperature of 102 ºC have been considered. Results (left) shows the variation of hydrogen injection saturation with native methane in the storage area. Modelling results show the caprock pressure has not been significantly impacted by injection pressure (right). The caprock pressure takes a long time to be impacted by hydrogen diffusion at 30 meter thickness above (green section).

hydrogen saturation and pressure variation during the injection period in the storage area.



Conclusion:

The results of this modelling show that the Walyering depleted gas field can be one of the suitable candidates for the hydrogen storage project. Available Infrastructure near the field and reservoir characteristics of storage area and high thickness of the caprock are supporting this depleted gas field at a small scale of hydrogen project.

Modelling results show that the optimum caprock thickness required for safe storage of hydrogen in the North Perth basin should be more than 30 meters. The required caprock thickness depends on initial reservoir pressure and also the storage pressure and temperature. The kerogen content within the shale formation also has a significant impact on possible leakage from caprock due to solubility and diffusion phenomenon.

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