CO_2 Storage and enhanced Oil Recovery

Introduction

- Increase of anthropogenic source of CO_2 has disturbed the natural Carbon cycle
- CO_2 sequestration has therefore become a necessity
- Additionally high pressure injected CO_2 can increase overall recovery in Oil fields.
- Besides old Oil fields depleted gas fields, coal seams (not covered in this ppt) and saline aquifer provides the locales for storage of CO_2 in the subsurface.

- Like oil and gas fields saline aquifers also are found within sedimentary basins which in turn are formed due to tectonic forces and sediments are transported from highlands by water and redeposited.
- Subsidence takes place due to loading and /or continued tectonic forces.
- Regional cap rock like marine shales,salt,basalt cover,evaporites is essential for an effective top seal.

- CO_2 enhanced Oil recovery has been commercially deployed in Texas for three decades.
- 300000 bopd is being produced in Permian basin in Texas and new mexico through CO_2 injection.
- Weyburn field in SE Saskatchewan Canada discovered in 1954,under water injection in 1960 is under CO_2 sequestration since 2000.

- Carbon capture and sequestration technology moved to the international stage with CCS technology deployed by Statoil in 1996 at the Sleipner gas field in North sea.
- Definition of storage permanence :99% of injected CO2 remain securely confined after 100 years.
- Entails reliable accurate leakage monitoring, plume detection and monitoring, volume accounting technology

- Recent global study indicates that 50 large basins ,middle east and Africa, can additionally produce 470bbl through injection of 140bmt of miscible CO_2.
- EU,Canada,Australia,Algeria and now Brics are also following suit.
- It is time for India and already ONGC has initiated pilot projects in Gujarat.

- CO_2 can also be stored in saline aquifers in subsurface and this has huge potential and are amenable to monitoring, through time lapse surveys.
- In a depleted oil field CO_2 reacts with Oil ,which has widely varying physical properties.
- However financial incentive is limited .

- Also the Geology of the habitats of saline aquifer is less known.
- Trapping Mechanism needs to be ascertained through seismic to ensure that CO2 does not leak back into the atmosphere

- EOR or enhanced oil recovery is a tertiary method of oil production after natural depletion and water flooding of the reservoir.
- CO2 is injected into oil bearing stratum under high pressure ….WAG.
- Miscible CO2,under super critical conditions, interacts with reservoir oil ,reduces viscocity,interfacial tension and increase mobility.

- Supercritical Carbon dioxide in liquid form has a lower density and lower compressibility as compared to saline aquifer.
- Seismic velocities are therefore different and CO2 plume shows up in the seismic data .
- Incase where CO2 is injected in Oil field ,both for Miscible and Immiscible case the attributes are altered.
- This change is captured through time lapse seismic/VSP and/or pressure and saturation studies.

- Even for immiscible CO_2 ,due to OIL quality (heavy/too light) or too low reservoir pressure there could be some gain in mobility and thus lower residual oil saturation.
- Industrialization of the process would warrant a steady supply of CO_2 through pipelines, selection of a large number of oil pools as sink candidates and rigorous monitoring of the reservoir.

- Recent advances incorporate very large volume of injected CO2(1---1.5HCPV),better mobility control through alternate injection of water and gas, advanced and optimized infill well drilling and target reservoirs above OWC or in bypassed zones.
- Rigorous monitoring is done through pressure studies and time lapse seismic/ down hole seismic and calibration with saturation tools.

- Seismic prospecting even for Longitudinal P wave, across different offsets and azimuth , is based on acoustic and elastic impedance contrast between the overlying and underlying rock strata.
- It is an interface property and through inversion of data layered property of a horizon,ie geology is obtained.
- Seismic data acquired aerially at different times in the life cycle of project can detect changes in the reservoir ,provided the changes are above repeatability noise.
- Interpreting and analyzing changes is a major challenge.

Case Studies

- Permian Basin in South west Texas and South East New Mexico accounts for 17% of US Oil production.
- OXY is a main operator in this basin and 2/3 rd of fields are under CO2 flooding.
- OXY injects 550 bcf of high pressure CO2 into Carbonate shelf/platform reservoirs of Paleozoic age, at 2/3 km depth ,with heterogeneous petro physical properties.

- Recovery has gone up from 20% with natural depletion to around 40/50%
- 2.6 bbl can be further produced through WAG as per USGS.
- Weyburn oil field in Canada was discovered in 1954 with OOIP of 1.4bbl.
- In 1963 oil production went upto 31500bopd

- In 1966 production peaked to 47200 bopd.
- In 1986 production declined to 9400bopd.
- Infill wells could increase production to 22000bopd.
- By 1998 23% of OOIP was produced ie 330mmbbl
- Production started declining since then .

- A synfuel plant to produce methane from coal with 96% CO2 as waste gas was set up .
- Waste gas through a 330 km pipeline is reinjected into the Weybarn at a pressure of 152 bar, through 37 injection wells, helping oil to flow toward 145 active producers.
- It is estimated that 130mmbbl of oil would be produced through injection of over 20mmt of CO2 buried permenantly at a depth of 1.4km.

- Sleipner field in North sea is another example where CO2 has been injected into Utira sand.
- A saline acquifier of late Cenozoic age ,200mts below reservoir top at a depth of 1km below sea bed.
- Time lapse 3D surveys were carried out in 1994,1999,2001,2002,2004,2006,2008etc.

- CO_2 plume is seen in seismic as a number of sub horizontal reflectors of tuned wavelets .
- Arising from thin layers of CO_2 trapped beneath thin intrareservoirs mudstone and reservoir cap rock growing in time.
- Post stack stratigraphic inversion of the 1994 and 1996 Sleipner field 3 D data provided baseline P wave impedance and subsequent data provided the change

- Prestack inversion of the same data with 50 iteration in the window 750- 1400 ms provided changes in S wave impedance and refined P wave impedance and thus the areal extent could be computed at different stages.
- Spectral decomposition, of seismic data in this window provided thickness of CO2 layer making estimates feasible.

Monitoring ,Verification and accounting of CO2

- Identify and quantify injected CO2 within the horizon
- Leakage of sequestered CO2
- Seismic prospecting in Time lapse mode
- Detecting changes in elastic rock property.

- Assessing repeatability of time lapse surveys in the non reservoir
- Quantative Interpretation and analysis of detected changes (volume of permanent storage and monitoring leakage)
- Saline aquifers are better candidates for time lapse monitoring for compressibility of high pressure CO2 is lower then surrounding aquifer

- Injected CO2 in low GOR residual oil field can also be monitored for compressibility changes are significant.
- High GOR Oil field or residual high gas saturation in pore spaces are poor candidates for monitoring
- Flat spot movement due to Oil production may help.

- Rocks with large porosity and low dry frame bulk modulus i.e. high compressibility And
- Unconsolidated sands,turbidites and large fractures produces large 4D signal.
- Carbonates, Tight sands ,well cemented sandstones, deeper targets produces poor 4 D signal.

- Gassman s fluid substitution equation relates the bulk modulus of fluid saturated rock to that of bulk modulus of dry rock and fluid at reservoir conditions.
- Assumptions are single phase fluid saturation in relatively inert systems,ie rock porosity is homogenous and rigidity modulus is constant.

- In reality supercritical state of CO_2 phase can get altered incase CO_2 escapes to shallower stratigraphy and can give rise to patchy porosity
- Also CO_2 can interact with host rock and alter its porosity .It can even dissolve rock material and create secondary porosity.
- Changes in P wave velocity is very different in the three cases ie homogenous porosity, patchy porosity ,overall change in rock porosity.
- Lab SEM studies of core data when integrated can provide inputs for a realistic rock physics modeling

- Compressiblity of a rock as a function of CO2 saturation depends on the size of the CO2 fluid patches
- Patches less then quarter wavelength of seismic wave form the non linear lower bound of Gassman equation,while larger patches have a different behaviour.
- Log data and ultrasonic lab data is also very different from low frequency seismic data.

- Calibration of compressiblity – CO_2 saturation is the key and each case is unique and this is the goal of rock physics modeling.
- Also Seismic measures total porosity while it is the effective porosity which decides the volume of stored CO_2
- Unlike P waves Shear wave data do not get altered by presence of fluid.
- Its behavior is same for patchy or homogenous porosity.

- There is a minor increase in velocity due to decrease in density due to change in porosity.
- However when the host rock is altered rigidity modulus is lowered and shear wave velocity drops.
- Thus increase/decrease of shear wave velocity can throw light on the interaction of CO2 with the host rock.

- Amplitude variation with Offset in the case of brine filled aquifer vis a vie CO_2 filled reservoir in super critical condition is different.
- Zopperitz equation models the reflection coefficient as a function of offset angle at a interface and it depends on contrast in acoustic impedance and VP/Vs ratio.
- An experiment conducted in SACROC oil field in Permian basin showed that injected CO_2 had altered the intercept as well as the critical angle as compared to brine solution.

- Thus it is important to combine P wave,S wave and Amplitude variation with offset which is also a function of VP/Vs and SEM studies from core data to carry out rock physics modeling.
- Integrated studies which can explain the deviation from classical Gassman ‘s equation.
- Thus inversion of P wave,S wave ,spectral decomposition, to obtain CO2 layer thickness, time lapse saturation logs are inputs for volumetric.
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- Passive and Micro seismic data besides VSP is also being increasingly used to support analysis from conventional time lapse
- The analysis is based on the assumptions of repeatablity
- However three factors mainly affect seismic data during acquisition and through cross equalisation ,static shifts and wavelet phase correction these are attenuated during processing

- Earth effects like spherical divergence, absorption and transmission losses ,interbed multiples, converted waves, tuning, anisotropy and structure affect seismic amplitudes.
- Acquisition effects like source and receiver arrays, tides, Directivity, changes in near surface, shooting media and receiver sensitivity, positional inaccuracies alter seismic data.
- Noise can be coherent or random and this also affects amplitudes.

- Processing of data attempts to correct most of the above ,but in the process can generate its own artifacts.
- Algorithms used in today s industry are also approximate solution and therefore may not be time invariant.
- Permanent sensors and OBS in Marine are also deployed to minimize non repeatability.
- 4D noise is defined as the changes between two campaigns at the non reservoir level and changes above this level at the reservoir is considered signal and used for analysis.

Conclusion

- Capturing and storing CO2 from atmosphere is necessary in view of increase in anthropogenic source.
- Saline aquifier,Coal seams ,old Oil field and depleted gas fields in subsurface within sedimentary basin provides ideal storage
- 140bmmt of CO2 can be stored in large oil fields in 50 large basins producing additional 470bbl of oil.

- Saline aquifier can possibly store upto 20 times this volume based on US experience.
- Rock physics modeling based on SEM of core data, lab studies ,with both P and S wave can in principal analyze the changes in VP and VS with saturation of CO2.
- Movement of flat spot and other seismic attribute can provide inputs incase of miscible CO2.

- Monitoring movement of injected CO2 with time is essential to ensure permanence in storage.
- Time lapse seismic with all its constrain is still the best way to monitor the movement