Rock physics study of the Nisku aquifer according to reservoir simulations results

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ABSTRACT

This paper is part of the comprehensive reservoir study in the Wabamun Area CO_2 sequestration in the Nisku aquifer. Rock physics is the link between reservoir simulation and 4D seismic. The paper engages rock physics to calculate physical parameters for the solid part, fluid and jointly in the reservoir due to CO_2 injection to the Nisku aquifer in the project. The study area is the injection well number 3.The density and wave velocities in the fluids are a function of the pressure and temperature. For CO_2 physical properties Span-Wagner (1996) equation of state and for brine, Batzle-Wang (1992) paper were base of calculation. In the reservoir, the fluid is a mix of CO_2 and brine with various fractions of them, and Reuss average is used to calculate the mix fluid properties. Finally some equations are introduced for the fluids properties for the reservoir condition.

Gassmann's equations were used for estimating the saturated bulk modulus and the velocity in the each cell of the reservoir is available, so each cell has own physical model as a function of the pressure and the injection time as this process is isothermal.

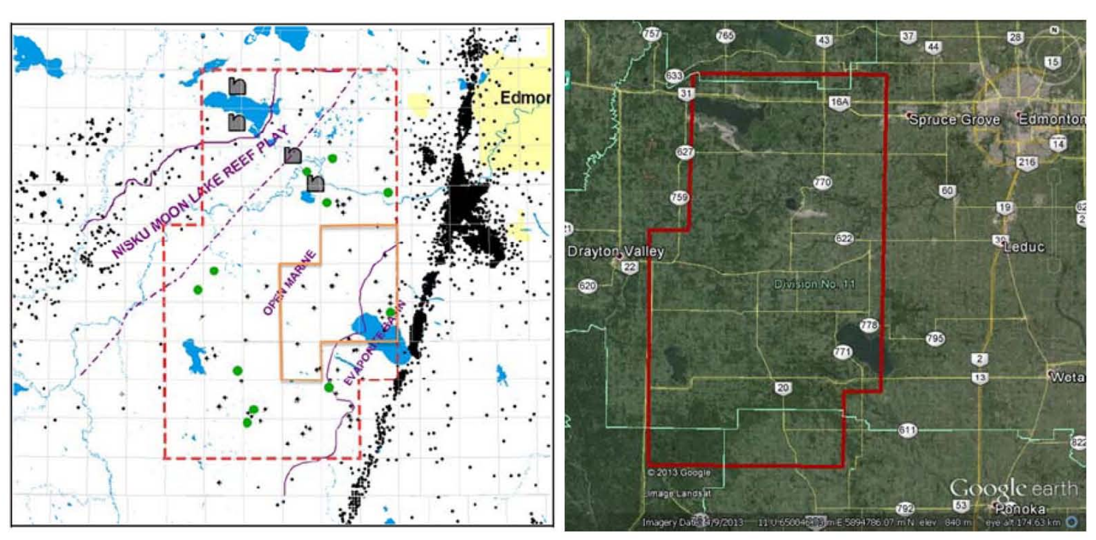

Fig.1.The project ara

WORKFLOW

Workflow for the seismic parameter estimation within the injection period, step by step are:

1.Reservoir fluid simulation for CO_2 injection with constant pressure rate in the target formation

2.Read in all property values (depth, porosity, saturation,) from log data, geomodel and fluid simulation result

3. Calculate the initial mineral bulk modulus with different mineral composition for the Nisku formation that is mainly carbonate

4. Using Batzle-Wang equations to calculate bulk modulus and density for brine water and CO_2 and mix fluid in each grid.

5. Compute the initial bulk modulus (Ksat) for saturated rock (before injection) by using log data 6. Estimate the saturated bulk modulus and so p wave velocity for each cell during injection.

FLUID SIMULATION RESULT

For the rock physic model, well number 3 with the simulation result (by Black Oil method) for the one year CO2 injection in the aquifer was selected, so the saturation and the pressure pattern around the well's shaft after one year injection are shown in the Figure 2. The numerical matrix of the saturation and the pressure previously has been used for estimating the fluid's physical properties.

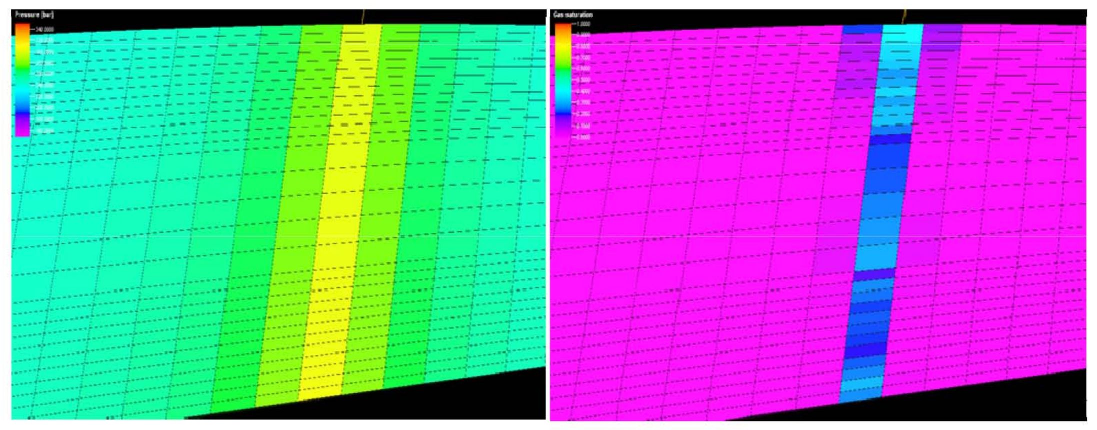

Fig.2.Saturation and pressure pattern around well 3 after a year injection.

FLUID PROPERTIES

During the injection, all fluid properties are changed. Batzle and Wang (1992) studied seismic properties of pore fluid that it is base of calculation in the current paper. Another research by Span and Wagner (1996) on thermodynamic behavior of Carbon Dioxide was used.

Water and brine

The density of pure water is a function of temperature and pressure. By a polynomial it is possible to calculate the density of pure water in the various temperatures (T) and pressures (P) as:

ρ_w = 1 + 10-6 (-80T - 3.3T2 + 0.00175T3 + 489P - 2TP + 0.016T2P - 1.3x10^{-5}T3P - 0.333P2 - .0.002TP2) (Eq. 2)

For the brine, salinity is another parameter that should be considered in the density calculation. There is a direct relation between salinity (S) and density.

$\rho_b = \rho_w$ + S {0.668 + 0.44S + 10^{-6} [300P - 2400PS + T(80 + 3T - 3300S - 13P + 47PS)]} (Eq. 3)

In the two previous equations pw and pb are water and brine density in g/cm3, P is pressure in MPa, T is temperature in Celsius and S is the weight fraction of salt (NaCl) in ppm/1000000.

For water and brine , the density and bulk module can be explained as a linear function of the pressure by (for the Nisku aquifer 15<Pressure<40 MPa and T=60C):

ρ_w = 0.000398424 P + 0.98403 (Eq. 4)

K_w = 0.00683 P + 2.363936927 (Eq. 5)

and for brine with 190000 mg/l NaCl :

ρ_b = 0.00032239 P + 1.12265 (Eq. 6)

K_b = 0.00763456 P + 3.21838 (Eq. 7)

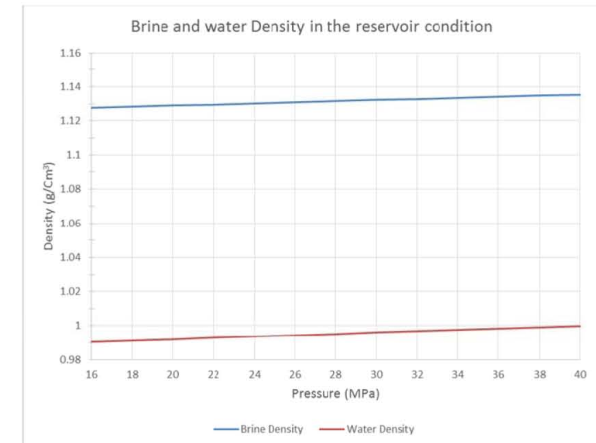

FIG.3. Water and brine density for 16<Pressure<40 MPa and T=60°C

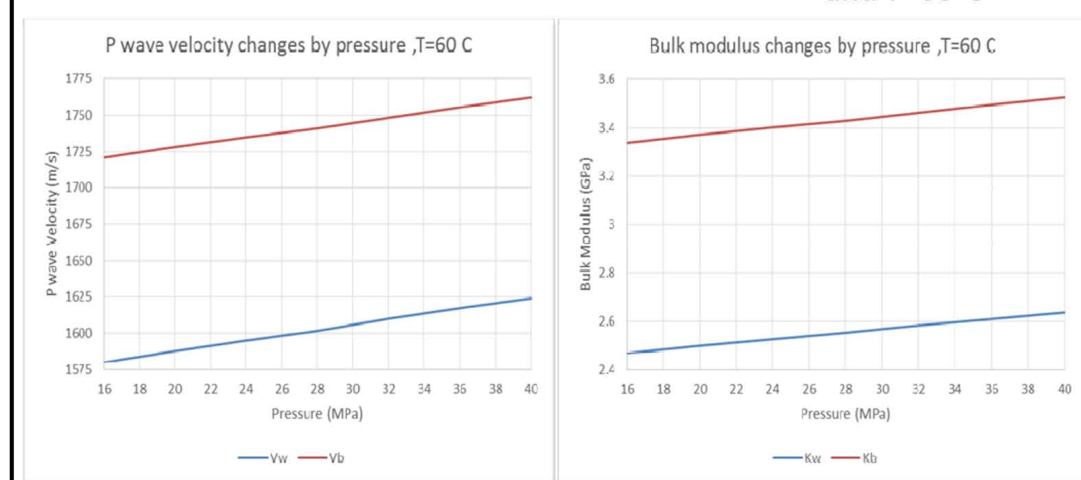

FIG.4. P wave velocity and bulk modulus of water and brine in the reservoir within the injection

Carbon Dioxide

With solving equations (Span and Wang thermodynamic model and equations), for the WASP condition it was possible to define a friendly function for the density and bulk modulus changes in the reservoir condition as following relations:

K_{CO2}=12.8P-131 (Eq. 8)

(equation is suitable for 15<P<32 MPa)

ρ_{CO2}= 138.2 ln(P-11.15) + 429 (Eq. 9)

(For 15<P<40 MPa) (Density in Kg/m^3)

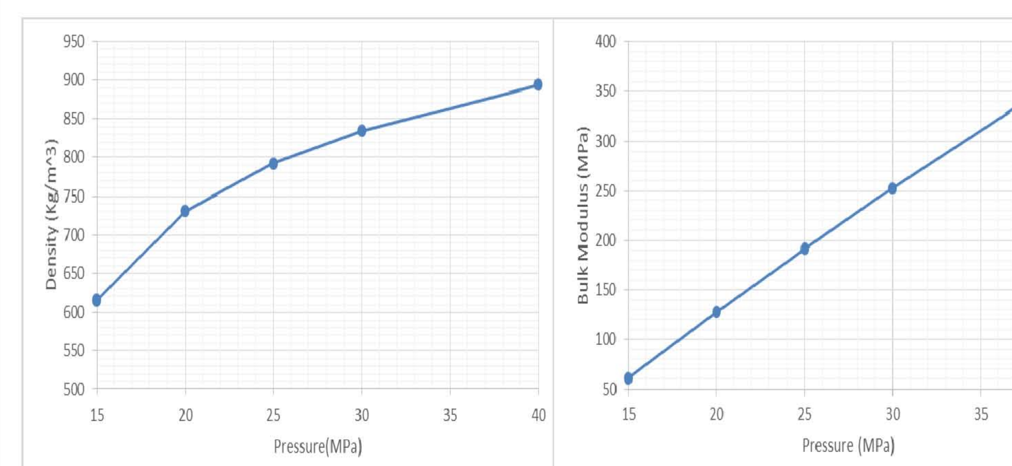

FIG.5. The density and bulk modulus of CO_2

Mix fluid (H_2O and CO_2)

In the reservoir, mix of CO_2 and brine is expected. For a fine mix fluid, Reuss average is useful , for other kind of mix as a patchy mix, Brie's equation and Voigt average are useful. For the WASP, Reuss average was used in the calculations.

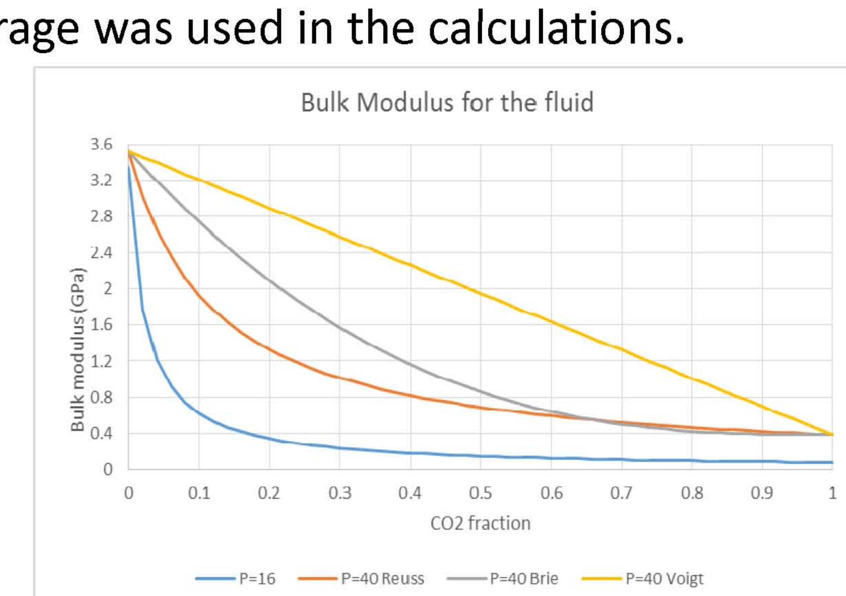

FIG.6.Reuss and Voigt average as lower and upper boundary for the fine scale mix and patchy mix fluid. The gray curve was calculated by Brie's fluid mixing model.

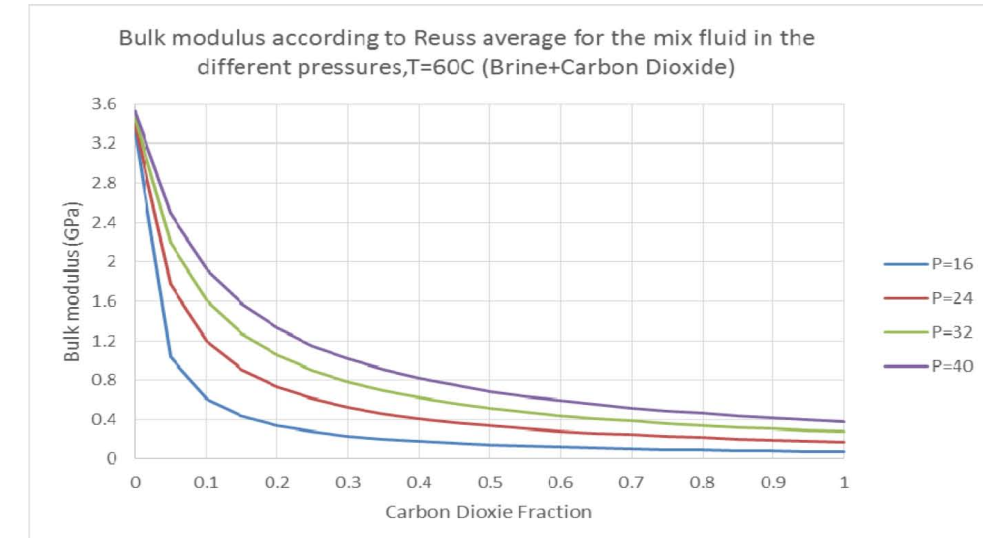

FIG.7. Bulk modulus estimation for different fraction of fluid mix by Reuss average in T=60 C and different pressures

BULK MODULUS AND VELOCITY AFTER INJECTION

For this model, it has been considered one year injection by the constant well bottom pressure (40 MPa), increasing CO_2 saturation can decrease bulk modulus and P wave velocity in the model.Fig.8 shows velocity decreasing by CO_2 injection.

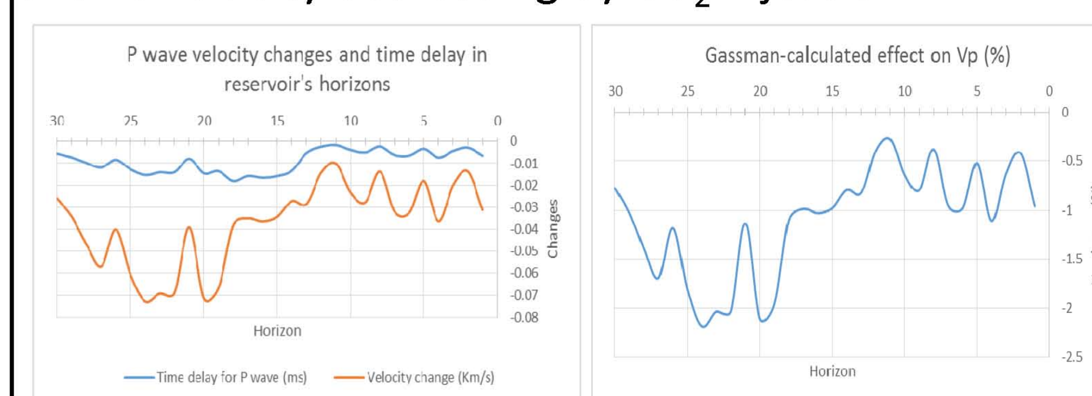

FIG.8. Left: it shows P wave velocity change because of CO_2 injection in the each horizon and wave time delay (one way). Right: Gassman-Calculated velocity for the Nisku aquifer after one year injection that shows a velocity change maximum to -2%.,

In a 4D seismic study, time delay in the reservoir, is a significant parameter. By using velocity results and time delay (one way) for the Nisku aquifer after injection will be 0.27 ms.

CONCLUSIONS

According to estimations, the density of CO_2 increases 38% and the bulk modulus of CO_2 has a sharp growth even more than 500% within injection, for the brine ,increasing are 0.6% and 5% respectively. With the calculated data, Gassmann's equation is used for estimating the bulk modulus and so velocity in the each cell of the reservoir, so each cell has own physical model as a function of the injection time. According to Gassmann's equation, after and before injection, the bulk modulus in the reservoir's horizons drops between 2 to 7% and for velocity its maximum to 2% .With considering low CO_2 saturation range and with comparing results with lab and theoretical (base on Gassmann's equation) experiences of CO_2 displacement (Wang,2001) all results are acceptable.

ACKNOWLEDGMENTS

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