Introduction

X is a carbonate field located in Bintulu, Sarawak. The field is a Miocene age isolated rimmed platform type carbonate build up with a water depth of 452 ft and shares common aquifer with nearby field (Y), while its isolated tight zone 2 acts as a baffle to fluid flow. The reservoir characteristics are good, particularly in the upper reservoir zones, with porosity ranging from 5 to 40% and permeability range of 3 to 400 mD. The overview of X field is listed in the Table 1 below.

<table>
<thead>
<tr>
<th>GIIP</th>
<th>12 Tcf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity (gas zone)</td>
<td>30%</td>
</tr>
<tr>
<td>Initial Pressure</td>
<td>2490 psi</td>
</tr>
<tr>
<td>Temperature</td>
<td>230 °F</td>
</tr>
<tr>
<td>Contaminants</td>
<td>2.8 % CO₂, 12 ppm H₂S, 0.4 % N₂</td>
</tr>
</tbody>
</table>

X field has been identified as one of potential storage sites. However, there are unknown impacts of short and long-term CO₂ rock-fluid reaction during CO₂ storage the field. This is due to unavailability of data/information on the geochemical, geomechanical, rock and fluid properties. It is critical to perform analysis focusing on investigating and generating relevant experimental data to minimize uncertainties on modelling the storage capacity and injectivity. The objectives of the study are to identify key changes in physical, chemical, mechanical rock and fluid properties during CO₂ injection and storage and to define the range and limits of injectivity of CO₂ into reservoir.

Method and/or Theory

Advanced Mineralogy Study

This section discusses about a study of the effect of CO₂ to the carbonate rock’s porosity and mineralogy. To study the changes in porosity, the study was analysed using microCT scan and PerGeos software. QEMSCAN equipment was used to study the changes in mineralogy. Both equipments are used to scan the sample before and after the samples are aged with supercritical CO₂. However, for X field, the aging samples are from core chip and powder, thus, no micro-CT scan and DCA were conducted. The determination of porosity is obtained from the changes of mineralogy composition from pre-aging and post-aging experiments.

Reaction Kinetic Study

Reaction kinetic study, also known as static batch experiment/static ageing experiment, is an analysis to study the geochemical reaction of CO₂, formation water and carbonate rock. To mimic the field condition, the study was done using actual X samples from core chip and powder in accumulator at reservoir pressure of 2490 psi and at temperature of 110°C. Since the water analysis data for X field is unavailable, the synthetic brine composition is used.

For this analysis, approximately 3 liters of synthetic brine were prepared using X field’s formation water composition. The initial 250 ml of brine was sent for water formation analysis to determine its salinity, pH, Total Dissolved Solids (TDS), anions and cations. This initial water analysis is considered as pre-CO₂ aging water composition, and is compared with the post CO₂ ageing water analysis result.

The remaining brine 240 ml was used to saturate the sample and to submerged the samples during static batch experiment. The two samples; namely A (core chip) and B (powder) were used in the kinetic study. Sample B was crushed from the core sample and weight for 12g.

After complete sample preparation for both samples, the samples are now ready for static batch reaction. The samples were taken from the same depths and zones. The samples were then carefully place into the accumulator before the sythetic brine is added into the accumulator using rock/water mass ratio of 1:20. The ratio is as reported in Alemu, et al.,2011. After the samples and brine were set
up, the accumulator’s pressure and temperature were increased until they reached X field’s reservoir pressure and temperature. Eventually, the samples were aged with supercritical CO₂ for 7 days.

After 7 days, the pressure and temperature were reduced back to ambient condition. Normally, minimum of 24 hours is needed for the accumulator to reach room temperature and pressure. After that, the samples were carefully taken out from the accumulator. The brine from accumulators from two experiments were collected and sent for post-aging water analysis.

**Injectivity Study**

Injectivity study is a study using core-flooding experiment equipment to determine the critical flow rate for CO₂ injection. For this study, the core plugs from X-wells were categorized into zones; low poro-perm, mid poro-perm, and high poro-perm. Since the low poro-perm category is comprised of very tight rocks (permeability less than 1 miliDarcy), it was decided that only sample from mid poro-perm zones is used for the study. This is because it is not recommended to inject CO₂ into a tight zone since the injection of CO₂ might cause the rock to fracture as the gas would not be able to migrate easily deep into the formation, making this zone is not suitable for CO₂ injection. One sample were taken from mid poro-perm zones (5831.53 ft) under Gas Water Contact (GWC) for this study.

**Reaction Kinetic Study**

The reaction kinetic study was conducted for 7 days which core chip/powder sample (Sample A and Sample B) was ageing in accumulator at reservoir temperature and pressure. At the end of ageing experiment, the brine from each of the experiment was sent for post-reaction water analysis.

The water analysis shows that there is indication of dissolution occur as it was reported that bicarbonate decreases from 7212 mg CaCO₃/L to 2005 mg CaCO₃/L for Sample A (core chip) and 2922 mg CaCO₃/L for Sample B (powder). The water analysis results were compared with XRD results in this section.

XRD analyses were also done for the sample prior to the ageing experiment and after ageing experiment for Sample A. The initial XRD analysis on the sample shown the rock was dominated with calcite with amount of 80.9%, follows by dolomite of 4.9% and K-feldspar of 2.9%. The comparison of bulk mineralogy and total clay of Sample A for pre- and post-aging experiments are shown in the pie chart in Figure 1 and Figure 2.
Figure 2: Bulk mineralogy and total clay of Sample A for post-aging experiment

The results for mineralogy analysis using QEMSCAN are shown in Figure 3 (i) and (ii).

(i) Initial (pre-aging)  (ii) Post-aging

Figure 3: Mineral Mapping and Weight Percentage of Sample A

Based on QEMSCAN analysis, sample A is dominantly made up of calcite (~91%) and ~3% of dolomite. The pre- and post- QEMSCAN analysis indicates minor reduction of calcite content of around 0.5%, whereas dolomite content shows a minor increase of 0.2%. The slight decrease of calcite content is consistent with the pre- and post- XRD analysis. However, the pre- and post-QEMSCAN analysis should be used with some caution due to the fact that the blade used to cut the core is thick. Hence, the two surfaces of pre- and post- samples might not be the identical. This pose some problems with heterogeneous carbonates as different surfaces might show differing mineralogy composition. Therefore, it is difficult to evaluate the mineralogy changes between the pre- and post-CO₂ treated samples. Thus, it is proposed that the precision cutting tool (with <1mm thick blade) is used for future QEMSCAN pre- and post- sample preparation. The precision cutting blade will ensure that a mirror image on both sides of the core could be obtained, so that an accurate assessment on the changes of mineralogy composition and mapping of its distribution between the pre- and post-samples could be made.
Injectivity study
CO₂ can be injected up to 100 MMScf/d for sample 5831.53 ft without making any changes to the core since it does not reach critical flowrate. Above 100 MMScf/d, the core permeability increases mainly due to combination of minimal mineral dissolution and fine flush-out. For sample 6018.7 ft, the CO₂ can be injected up to 97 MMScf/d without making any changes to the core since it does not reach critical flowrate.

Figures 4 and 5 show micro-CT scan for sample at depth 5831.53 ft prior to the injectivity (pre) and post of the injectivity study. The figures show that there is a micro-fracture on the sample, which is caused by minor dissolution of the carbonates in the core. This is aligned with water formation analysis results from the core-flooding experiments.

Conclusions
In conclusion, the integrated laboratory testing shows minimal changes to the formations due to CO₂ injection. CO₂ can be injected up to 100 MMScf/d for sample 5831.53 ft without making any significant changes to the core.

References