Introduction

This paper presents a methodology that investigates completion design options for Carbon Capture and Storage (CCS) wells, particularly focusing on multiple reservoir zones. It explores advanced strategies, such as the use of Flow Control Valves (FCVs), which challenge the industry's conventional preference for design simplicity. This study evaluates the project benefits and impact of surface-controlled selective multizone completions aiming to enhance CO_2 storage capacity, reduce the Area of Review (AoR) extension, improve reservoir efficiency, and manage operational risks.

Key areas of analysis include:

- Challenges in CCS completion design
- Fill-up strategy of multiple reservoir zones
- Project impact of advanced completions
- Risk management approach
- Completion design workflow optimization.

This paper advocates for a fundamental shift in industry design practices suggesting that, in certain cases, advanced completions can yield superior outcomes, promoting more efficient and sustainable carbon storage.

Based on the subsurface identification of two or more prospective CO_2 storage zones, the key challenge lies in distributing mass flow across these zones to minimize the overall area of review.

The main design drivers include:

- Assessing the potential to inject into both zones simultaneously using a single well
- Determining if the zones can be effectively isolated within the well completion
- Preventing crossflow between zones
- Controlling the injection balance from surface to optimize overall performance.
- Assessing dynamic operation.

Method and/or Theory

The completion design methodology to achieve project objectives comprises six elements:

1. **Data collection:** Gathering information on reservoir and source fluid composition, mass flow, pressure, and temperature, well profile.
2. **Modeling:** Creation of reservoir-specific models and calibration with well-test data.
3. **Scenario creation:** Development of multiple operational cases were developed based on the two prospective storage zones, incorporating the following variables:
    - Completion Configuration: With or without flow control valves (FCVs)
    - Project Life cycle: Early-life (low pressure) and late-life (high pressure)
    - Cases:
        - Hydraulic Performance:
            - Steady-state CO_2 injection
            - Optimization of valve quantity, positioning, and injection targets
        - Thermodynamic Operation (CO_2 expansion)
            - Well clean-up with CO_2
            - 24-hour shut-in periods
            - Blowout case involving uncontrolled CO_2 release to the atmosphere.

Figure 1 summarizes all the variables in a single view

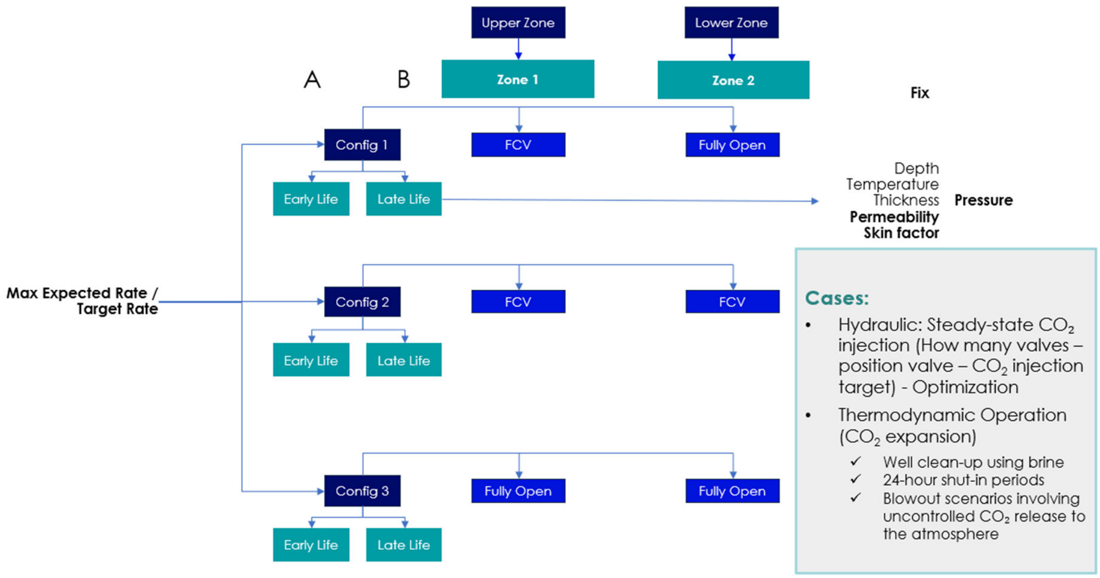

***Figure 1** Scenario Creation*

4. **Simulations:** Simulation of both steady-state and transient conditions to evaluate the hydraulic performance of the well system, including zonal injection distribution, flow instabilities, and a comparative analysis of FCV versus non-FCV configurations. Both thermodynamic behavior and wellbore-reservoir interactions are considered in the assessment.

   Results were analyzed to determine the FCV opening configuration that optimally maintains zonal control while minimizing operational risks. Additionally, the analysis identified the critical temperature and pressure conditions based on the previously defined scenarios

5. **Sensitivity analysis:** Examine the impact of FCV positioning through adjustment to the flow area to control the percentage of injection per zone. This analysis considers the maximum pressure rates observed and evaluates 7 Cases different with valves setup in different position to assess system performance.

   Figure 2 below summarizes mass distribution across both zones, offering key insights related to & of injection to support the optimization of injection strategy and completion design.

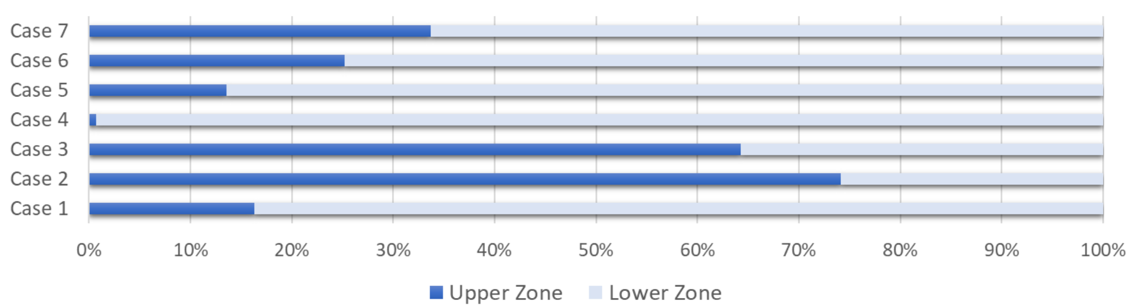

***Figure 2** Injection distribution with FCV Position*

6. **Results comparison:** Analysis of FCV performance across the defined cases to determine the most suitable configuration for controlling the zonal injection rate, while minimizing or

preventing adverse events during both normal (steady-state) and critical cases defined throughout the project lifecycle. Additionally, evaluation of the thermodynamic conditions (maximum/minimum pressure and temperature) for each case to ensure the selected completion materials are fit for purpose.

Based on the cases analyzed in this study, the configuration with two flow control valves—one per zone—proved to be the most suitable for the following reasons:

- It effectively prevents crossflow between zones during steady-state injection.
- During shut-in periods, only a minimal crossflow from the upper to the lower zone was observed.
- The maximum and minimum temperature conditions were identified under the "blowout case," which simulates uncontrolled CO_2 release to the atmosphere.

Sensitivity analysis demonstrates the ability to adjust the injection rate per zone by changing the position of the flow control valves, enabling more effective injection management across both zones.

Figure 3 summarizes the methodology used to analyze the technical feasibility of implementing Flow Control Valves (FCVs) as part of the field development strategy.

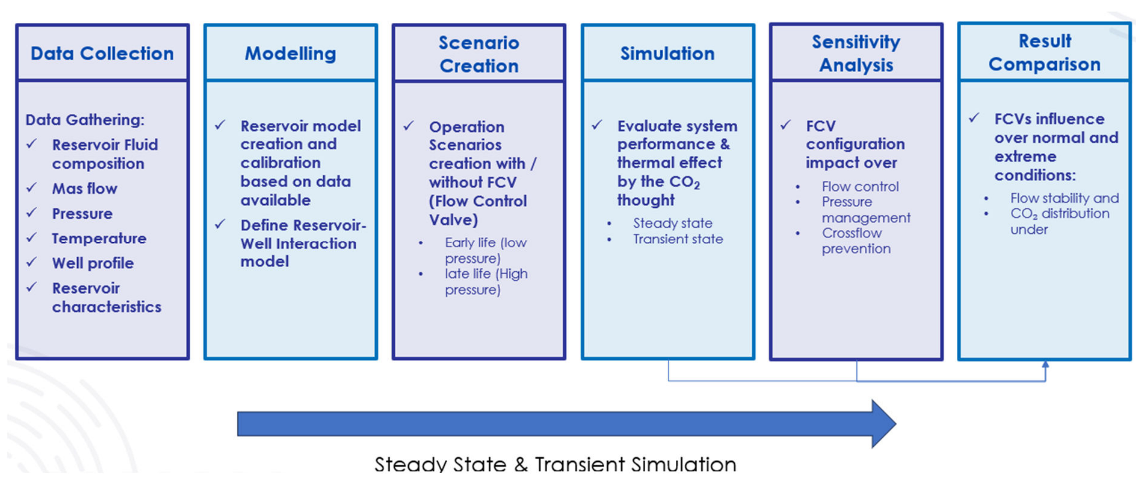

Figure 3 *Summary of the methodology applied to assess the feasibility of incorporating flow control valves into well completion design*

Flow Control Valve:
Flow Control Valves (FCVs) are engineered to regulate fluid injection into distinct, isolated intervals within the reservoir. In injector wells, they are typically used in conjunction with packers to manage flow across multiple zones within a single wellbore.

FCVs can be operated either remotely or from the surface through control lines that extend along the wellbore. These valves offer multiple opening positions, which can be adjusted by varying the pressure in the control line, enabling precise control of injection rates based on reservoir needs.

The main advantage of FCVs in CO_2 injection operations is their ability to balance flow across zones, minimize crossflow, and reduce the Area of Review. The number of FCVs deployed is directly related to the number of isolated zones defined by packers.

Figure 4 below represent the schematics for the Flow Control Device using to control a multizone well. (Follow the arrow to observe the fluid distribution).

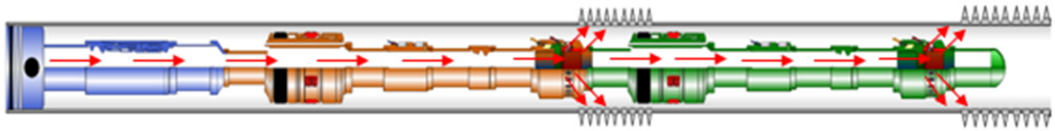

Figure 4 *Injection - Two Zones Well*

Conclusions

The study reveals that FCVs enhance control of injection volumes and pressure across multiple reservoir zones, preventing crossflow, and contributing to operational stability during extreme conditions, such as uncontrolled release. The placement and optimization of FCVs configuration result in better pressure management and increased operational efficiency. Despite their complexity, FCVs offer a more effective alternative to conventional completion designs, enhancing multiple zone reservoir performance, and overall project value. Additionally, the estimation of the thermal effects during injection generates insights needed to determine the most extreme temperature conditions that the well must withstand.

This paper introduces advanced well completion design, particularly the application of FCVs, in multiple reservoir zones. It challenges the industry's inclination towards simpler designs by demonstrating how more complex approaches can optimized reservoir fill-up, reduce Area of Review (AoR) extension, and optimize cost. The sensitivity analysis provides new understanding into FCV utilization, encouraging a shift in industry standards regarding more effective and sustainable reservoir management.

References

Shu, D.Y., Deutz, S., Winter, B.A., Baumgärtner, N., Leenders, L. and Bardow, A., 2023. The role of carbon capture and storage to achieve net-zero energy systems: Trade-offs between economics and the environment. Renewable and Sustainable Energy Reviews, 178, p.113246.

Khan, M., Inam, S., Hussnain, S.U., Aijaz, M.J., Ullah, R., Shafee, I., Haider, M., Ahmad, H., Qureshi, H.A. and Bashir, I.A., 2023, November. Smart Well Completions: A Comprehensive Review of Technologies, Applications and Challenges. In SPE/PAPG Pakistan Section Annual Technical Conference (pp. SPE-219507). SPE.