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Improving injected water conformance in fractured reservoirs

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Hart's E&P, June 2019

In many oil reservoirs, the ultimate recovery can be improved through the injection of water for both pressure support and flood of the reservoir to sweep residual oil towards the producer wells. To generate effective sweep, the injected water must be distributed uniformly into the reservoir structure. Reservoir heterogeneity, fractures and faults, and frictional pressure losses lead to inefficient sweep, bypassed oil and early water breakthrough into production wells.

Inflow Control Devices (ICDs), or in this case, Injection Control Devices (ICDs) can provide a cost-effective means of effectively distributing flow. Deployed as part of the lower completion or retrofitted into an existing well, the lower completion is segmented into multiple zones or compartments with one or more devices per zone.

The ICDs provide a flow restriction across the completion creating a pressure drop as a function of the flowrate into the zone. The relationship between rate and pressure drop can be engineered by changing the size or quantity of the ICDs. In high injectivity compartments, which have a higher rate capacity, the additional pressure drop provided by the ICD acts to limit injection into the compartment. Conversely, in a low injectivity zones the rate and therefore the pressure drop across the ICD is lower and as such, higher injection pressures in the formation is higher, resulting in increased water injection into this zone. Thereby flow distribution is achieved. For some applications, with a correctly designed completion, this technology has been proven to be highly effective in improving injection distribution.

To effectively manage flow distribution in a reservoir with highly conductive fractures, it is necessary to deploy highly restrictive ICDs in the compartments containing the fractures in order to accommodate the large injectivity contrast between the reservoir pore structure. The challenge for both production and injection application with ICDs is the detection and identification of such fractures during reservoir characterisation and logging of the wellbore prior to installation of the completion.

ICDs are fixed designs and once installed cannot be adjusted, except through well interventions in the case where slide sleeves are also deployed. An additional challenge in water injection applications is dynamic changes in the reservoir due to the injected water process. These include:

- Fracture propagation due to hydraulic pressure
- Thermal fracturing due to the injection of cold water to the relatively hot reservoir
- Formation impairment due to the injection of solids, oil in water, shale swelling or bacterial responses
- Any unexpected variations in fluid responses

Existing ICD technology can only accommodate these changes using highly restrictive settings throughout the completion. However, the high resultant pressure loss can have a significant impact on the topsides requirements and so does not offer a practical solution.

In response to the challenges of effective water injection in dynamically and naturally fractured reservoirs, Tendeka has developed a reactive or autonomous ICD technology that is able to adjust without intervention to a more restrictive setting when fractures or other reservoir features create thief zones. This allows the optimum setting to be maintained for both injection into the pore spaces and for effective fracture control while retaining the cost-effective benefits of ICD and the robustness of this technology for life of well operations.

The FloFuse System achieves this effect using a dual ICD set-up as shown in Figure 1. The ICDs are mounted into the completion base pipe, in this example a sand control screen. Injected water passes through the ICDs into a housing mounted at one of the screens, through the housing to the underside of the screen section and then out into the annulus between the screen and the formation. In normal injection mode, the ICD setting is the combination of the flow area of the FloFuse itself and the 'Fracture ICD' which is simply a highly restrictive ICD nozzle.

When the flow conditions are reached to activate the FloFuse, this device closes and the injection is restricted by the smaller resultant flow area of the Fracture ICD alone.

Figure 2 show the performance of the FloFuse system in more detail. In this chart, pressure drop across the system is shown

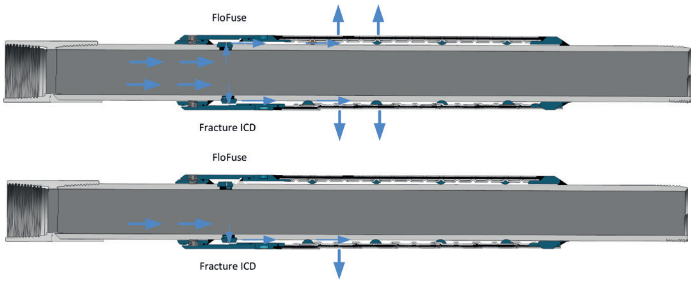

Figure 1

as a function of flow rate. The blue curve depicts the baseline performance created by the combined flow area of the FloFuse and the Fracture ICD, and the red curve depicts baseline performance of Fracture ICD. The green dotted line shows FloFuse performance as it switches between these two baselines. In this set-up, when the rate through the sand control joint exceeds 400 BPD, the FloFuse will trigger shifting the performance to the Fracture ICD. Conversely, when the rate through the Fracture ICD drops below 45 BPD the system will revert to the less restrictive baseline.

In application, the completion is designed so that effective conformance into the matrix or pore structure can be

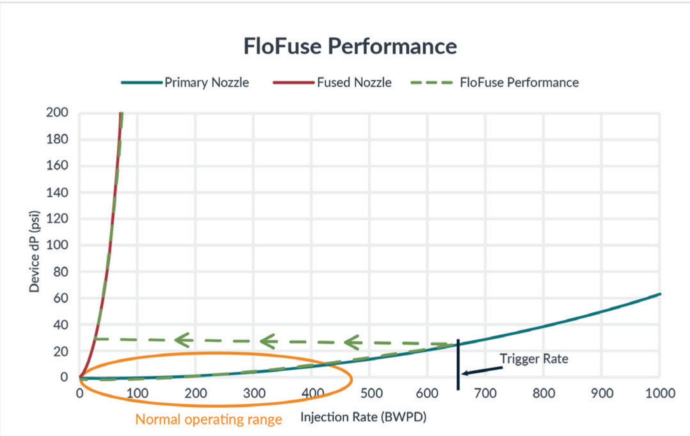

Figure 2

achieved in the 'normal operating range' with the combined flow area of the FloFuse and Fracture ICD. If a fracture is encountered which causes the flow rate to increase, the FloFuse will trigger to provide a more restrictive setting for effective control of flow into the fracture.

The valve remains dynamically reactive and will re-open if distributed flow can be achieved. The dynamic and reversible operation of the valve makes it suitable for applications where the permeability contrasts change over time, such as in thermally fractured water injection wells and where matrix stimulation is used to improve near wellbore permeability.

Matrix Stimulation

Designed initially to address the problems of providing a cost-effective, intervention free, life of well solution for water injection wells, the FloFuse can also provide an effective solution in reservoir stimulation operations. Matrix acidizing operations are common throughout the oilfield as a means of improving near wellbore permeability but if bull-headed into the well, it may only stimulate the highest permeability areas effectively. Diverter technology and/or high rates can aid distribution to lower permeability areas but are often not as effective.

The FloFuse provides an effective mechanical diverter which fuses once the treatment is effective in one zone diverting the flow to next zone and so on until the operation is complete. Once installed into the well, the FloFuse will work repeatedly to effectively distribute stimulation treatments as often as these are required, greatly simplifying operations over time.

The FloFuse rate limiting control device takes an inherent problem that hasn't been well addressed by industry and Tendeka's extensive experience in the design and implementation of ICD technology to adapt a technology from other industries to provide a solution that is simple and robust.

Tendeka is the world leader in ICD technology and has installed more than 7,000 passive ICDs and 34,000 Autonomous ICDs globally.

