

# Enhancing EOR

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As the heavy oil reservoirs age and fields become mature, the optimisation of oil recovery becomes essential if oil production targets are to be met.

For many years, inflow control devices (ICDs) that restrict flow by creating additional pressure drop, have been used to mitigate this problem. They are, however, passive in nature and once water or gas breaks through, the choking effect cannot be adjusted without intervention. The viscosity difference between heavy oil and water gives an unfavourable mobility ratio, which results in quicker water breakthrough. The velocity difference between water and oil allows water to flow much faster and will flood the wellbore and impair the oil production from oil producing zones. The Autonomous Inflow Control Device (AICD) is designed to choke back flow of less viscous fluid, and therefore chokes back the flow of water compared to oil, thus resulting in reduced water cut.

The functionality of an AICD is similar to passive ICD in that it helps to create a more even inflow along the horizontal section prior to water breakthrough. Moreover, the AICD also has a self-regulating, adjustable design to provide greater production choking where water breakthrough occurs. This chokes production from compartments producing large amounts of water, leading to greater oil recovery and lower water cut. The AICD can also be retrofitted and deployed as an inner string in an existing well that has already being flooded to control the inflow of the water. This leads to greater oil recovery by reducing water production.

## Applications

In sandstone reservoir applications, the AICD valve is typically assembled as part of the sand screen joint in the lower completion. However, for carbonate reservoir applications, the AICD can act as a standalone sub with a debris filter assembled before the inlet of the valve. The reservoir fluids can enter the completion through the sand screen filter and flow along the annulus between the filter and base pipe into the inflow control housing where the

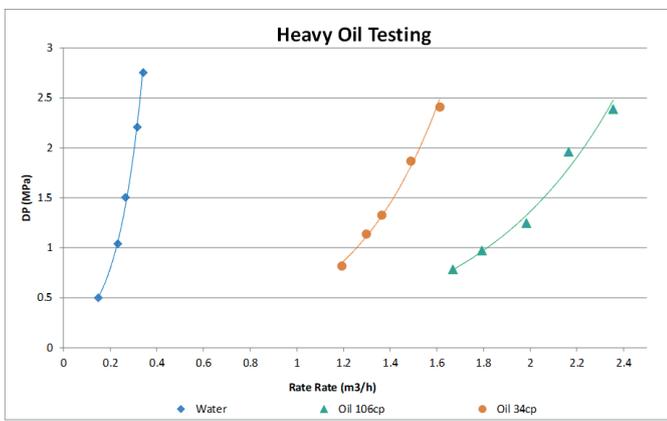
AICD is mounted. The fluids then flow through the AICD and into the production stream, moving to the surface together with the production from the rest of the wells.

An experiment with oil, water and gas was performed to define the performance of the AICD in heavy oil operations. The performance is shown through the differential pressure across the AICD versus the flow rate through the device. The experiment was carried out using 106cp oil, 34cp oil and water. Figure 1 shows a typical flow rate profile for heavy oil and water through an AICD. It illustrates flow rate through the valve increasing with oil viscosity ranging from 1cp water to 36cp heavy oil and 106cp heavier oil. The mobility ratio between water and heavy oil in this test ranges from 36 to 100 times. This implies that water travels faster at a similar pressure gradient compared to oil and leads to a reduction in water flow at a similar pressure drop.

There is stringent due diligence to be performed before the implementation of the AICD. Reservoir simulations are used to evaluate the potential of an AICD application. A segmental dynamic and static model is commonly produced to simulate representative reservoir properties and allow evaluation of the well with and without the AICD.

Commonly, for wells without inflow control, the water is channelled from the down-dip through to the high permeability section, to the producer well and bypasses the oil up-dip. The AICD will improve the water sweep by balancing the inflow from high permeability section and creating the pressure drop at high mobility water sections. Furthermore, the AICD will allow a low mobility heavy oil to be produced and recover the oil up-dip.

Not all heavy oil horizontal well applications will show benefits from this technology. However, a sizeable mobility contra caused by permeability difference and good pressure support normally will benefit from these technologies.



**Figure 1:** Single phase volume flow of oil, water and gas through the AICD as a function of differential pressure.



**Figure 2:** AICD oil rate and water cut performance in an existing / retrofit well

Annular isolation is critical in AICD completions to compartmentalise the reservoir. This allows for different choking pressures at high mobility water sections or compartments and more production from low mobility heavy oil sections or compartments. Generally, the swell packer placement is dependent on the permeability contrast and saturation contrast that exists between intervals in the wells. Limitations on the number of compartments may be imposed by well operability factors, such as zone length, open hole drag and previous operational experience. Sensitivity analysis to optimise the quantity and location of zonal isolation devices is essential for this technology.

The flow rate and the well length will determine the total flux rate through a single AICD valve. The flow rate through the valve for a given pressure drop increases with viscosity, as it is dependent on fluid mobility. The initial / maximum oil / liquid production targets are used along with the reservoir

fluid data to determine the quantity and size of AICDs required to ensure the maximum well deliverability is achieved. This will favour applications in longer horizontal wells compared to shorter vertical wells.

The evolution of water cut over time, typically low water cut levels are seen at the initial stages of the well, is a critical factor for maximising the oil production. During this time, AICDs should be used to optimise the drainage and reduce the likelihood of water coning and ensure that inflow between the zones is balanced. Generally, heavy oil reservoirs have a high Darcy permeability. This provides a period window to extract oil from high saturation pockets until the water saturation increases highly along the entire wellbore. At this later stage, operating the well at higher total liquid rate will help in the attempt to recover more oil.

As a field's water cut increases, this can cause the formation of emulsion in its wells. It will increase the flowing pressure loss and consequent reduction in the well production rate. Due to viscous properties of emulsion, the AICD will not apply a higher pressure drop to flow the emulsion if it forms in the annulus. A bypass valve will be needed if downhole chemical injection is planned to treat the emulsion and scaling. The bypass valve can be installed as part of screen assembly in the lower completion or run as a separate sub.

## Case Study

AICDs have been implemented in many brownfield wells as a retrofit solution after water cut increases are experienced. Retrofit installations to date have been in wells where the water cut has typically reached up to 96%. One of the first AICD retrofit installations in a heavy oil environment was to control water cut, it also showed a significant increase in oil recovery (Figure 2).

The results of the installation from 2014 have shown significant water cut reduction from an average 96% water cut before the AICD string installation to around 93.6% water cut after the AICD installation. This is a significant reduction in water cut for a well that is producing a total liquid rate of 1000m<sup>3</sup>/d.

The water cut reduction has increased the oil production from 43 m<sup>3</sup>/d to 55 m<sup>3</sup>/d. The results of these wells have shown an increase of oil production of approximately 28% after installing the AICDs. Based on the positive results of the initial well, there have been many more wells within the field completed with AICDs as a retrofit solution or primary completion for new wells.

## Conclusion

The implementation of AICDs in various heavy oil fields worldwide to control water has shown a general trend of reduced water cut. The viscosity difference between heavy oil and water provides a favourable mobility ratio well suited to this technology and has been shown to enhance oil production. As the water is restricted upon breakthrough, the overall recovery of the well is improved when compared to operations using conventional methods and passive ICDs.