As fields become mature, operators are looking into different techniques and technologies to optimise and increase the oil recovery of the reservoirs. Horizontal wells have become a common practice for increasing the reservoir drainage area by maximising contact with the payzone. Drilling technology has made this possible, but with the opportunity new challenges in the completion have arisen.

A common challenge in the completion is the uneven production of the fluid along the length of the wellbore, which can occur both in homogeneous and heterogeneous formations. In a homogeneous reservoir, the fluid tends to enter the heel at a higher velocity than at the toe, also commonly known as the Heel-to-toe effect. Reservoir heterogeneity also contributes to uneven influx since reservoir fluids would tend to travel easier through high permeability sections, promoting water movement through the wellbore. Reservoir flow control is important to maximise hydrocarbon production and delay the production of unwanted fluids.

Inflow control devices (ICDs) integrated with a sand screen or debris filter have become a common technology to balance the influx and delaying water and/or gas breakthrough; while at the same time reducing operating costs, increasing the longevity and enhancing the oil recovery of the wells. For zonal isolation purposes, Inflow control devices (ICDs) are usually paired with swellable packers to optimise the management of the reservoir.

Traditional inflow control devices or passive ICDs are an intentional choke in the completion designed to balance the influx and delaying water and/or gas breakthrough; while at the same time reducing operating costs, increasing the longevity and enhancing the oil recovery of the wells. For zonal isolation purposes, Inflow control devices (ICDs) are usually paired with swellable packers to optimise the management of the reservoir.

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Halliburton’s EquiFlow® autonomous inflow control devices (AICDs) are the next generation of ICDs. An AICD has the ability to respond to changing well conditions without any action by the operator. When unwanted fluids reach the wellbore, the local AICD changes the way the fluid is moving inside. This results in a greater restriction to flow while other zones continue producing with a low restriction.

**Autonomous Inflow Control Devices Principles**

A traditional horizontal completion, exemplified on the left in Figure 1 (below), without inflow control devices naturally has an imbalanced influx rate across the length of the completion induced by frictional pressure drop in the tubing string. This problem becomes much worse with well length. Because of the high flow rate at the heel, water is able to quickly cone as shown in the left of Figure 1. Commonly water would invade the wellbore and this translates into very high water cuts at surface along with the decrease on hydrocarbon production.

AICDs are self-adjusting or active inflow control devices that act as traditional/pasive ICDs during oil production. However when low viscosity fluids breakthrough, the AICD choking slows down the flow from the zone producing unwanted fluids. This action occurs autonomously, using dynamic fluid technology to discern from desired and undesired fluids.

The well installation of AICDs is a simple operation and no control lines are needed. AICDs are run with the completion bottomhole assembly and installed in front of the reservoir. Therefore, reservoir fluid must pass through the AICD before entering the production tubing, and consequently reservoir zones can be controlled by AICDs. AICDs can also be run with swellable packers to create zonal isolation and prevent crossflow of fluids between zones at the wellbore.

![Figure 1: A comparison of completions in a homogenous reservoir prior to water breakthrough. ICD and AICD balance influx, delaying water breakthrough.](image-url)
Inflow control devices (ICDs) integrated with a sand screen or debris filter have become a common technology to balance the influx and delaying water and/or gas breakthrough; while at the same time reducing operating costs, increasing the longevity and enhancing the oil recovery of the wells.

The fluid mechanics behind the AICD must accomplish the following: a) determine if the reservoir fluid flowing through it is mostly oil or mostly water and/or gas; b) restrict the production when the fluid is mostly water and/or gas. The fluid identification and the fluid restriction capabilities are accomplished with the properties of the fluid and the geometry of the flow channels. Thus, directing the fluids (desired or unwanted) through different passages.

The two main constituent elements of the AICD are: 1) a viscosity selector that identifies the fluid; and 2) a flow restrictor that choking the flow of undesired fluids. These functions are accomplished by specially designed channels. These flow channels inside an AICD are optimized for different specific range of fluid viscosities.

The method used to generate the desired pressure drop depends on the fluid properties: density and viscosity, and a desired flow rate.

The restriction of the fluid in the AICD is accomplished by spinning the fluid around the exit. The amount of restriction on the device, DP (Pressure Drop), is related to the local velocity change in the fluid, i.e. the fluid near the exit will flow faster than at the entrance. The high rotational velocity near the exit hole creates a larger pressure differential. The AICD is designed so that the spinning velocity changes with the properties of the fluid, thus especially designed for causing a greater restriction for unwanted fluids.

Higher viscosity fluids flow more easily through the AICD than lower viscosity fluids. With low viscosity fluids, the high velocity of the fluid creates a vortex and a pressure drop that restricts the production of those fluids. With higher viscosity fluids, the amount of rotation decreases and the pressure drop through the AICD decreases.

Testing

Long-term production reliability and robustness are important characteristics for downhole equipment. Furthermore, fluid flow performance of the AICD is what truly distinguishes it from other ICDs. Therefore, extensive testing on flow performance, plugging and erosion has been made on EquiFlow AICDs.

Flow performance of the AICDs can be characterised by measuring the pressure drop vs the flow rate at different viscosities. The flow through the device has been validated by flowing test oil, water and gas as single phase, as well as by a mixed multi-phase flow.

As shown in the graph below (Figure 2, below), at a similar flow rate, the AICD shows in average 50% more restriction (pressure drop) for water than that of oil compared to a nozzle ICD. When comparing AICD vs nozzle with gas flow, the AICD shows a reduction of 54% less. Similarly at equivalent pressure drops, the AICD has at least 1.4 times more oil flow than water. The reduction of flow of gas and water represents significant savings in OPEX to operators, while at the same time more revenue from the oil production of the other zones.

![Figure 2: Fluidic diode Autonomous ICD Range 3B vs .085” nozzle flow performance comparison.](image-url)
In order to ensure that AICDs are able to withstand real well conditions, to which they can be exposed at downhole environments, they have undergone several plugging and erosion tests, circulated sand-water slurry through the AICD without any failure to the tool which simulated a 20-year lifetime.

**Modeling**

NETool™ software is Halliburton Landmark’s industry leading near-wellbore reservoir modeler and is used with reservoir input from the operator to determine the number of AICD inserts per joint, number of joints in a well, and quantity and location of swellable packers.

Characteristic equations, dependent on fluid properties, have been created based on testing flow data in order to describe flow performance. Those equations have been integrated into NETool simulation software for accurate well performance prediction of the designed completion.

NETool software is a steady-state, network-based simulator for quick calculation of multiphase fluid flow through a well completion and the near-wellbore region. The well completion and the near-wellbore region are represented by a distribution of nodes that may be interconnected by flow channels. Specification of the completion details leads to an appropriate pressure drop correlation for each flow channel, whether that is the formation, annulus or a range of completion paths.

Through interactive well placement and easy selection of completion components with built-in pressure drop correlations, the effects of well position, length, and completion configuration on production response are easily modelled. The effects of using an EquiFlow AICD completion can be seen by setting up the basic well parameters in the NETool software and running different completion designs with varying inflow parameters such as water cut, permeability, skin models, among others.

**Case Study**

An example of a successful installation was performed at the Ginta Field in Ecuador. The Ginta Field is a mature field, in production since 1996. Its location within the Amazonas jungle makes water handling process a delicate and expensive process. Water has to be treated and re-injected into the reservoir to minimize the impact to the environment. It has a very high mobility ratio and a strong aquifer which leads to very high water cuts, above 90% at surface. A big concern from this field was that much of the oil could be unrecoverable due to water breakthrough.

With the installation of EquiFlow AICDs in the Ginta field, the operator recovered 21,000 additional barrels of oil and reduced water production as much as 34%.

AICDs have proven to be a reliable technology to increase ultimate recovery and optimise reservoir sweep by equalizing influx along the wellbore.

**Conclusion**

AICDs have proven to be a reliable technology to increase ultimate recovery and optimise reservoir sweep by equalizing influx along the wellbore.

Operating under the combination of fluid mechanics, computer modeling, and measured performance data, the AICD is able to restrict the production of undesirable fluids, promoting the production of hydrocarbons.

AICD provides a robust, reliable solution without any control lines, moving parts, or electronics and relies on no intervention of any sort. It has predictable flow performance and has been proven through extensive testing and field installation success.

**References**

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