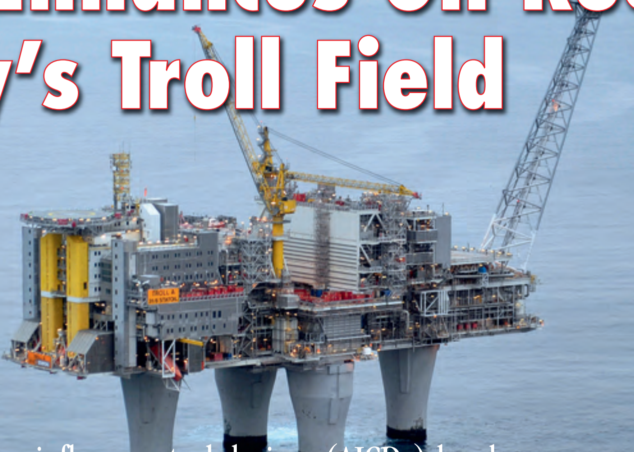
Troll A platform (photo: Harald Pettersen/Statoil ASA)

AICDs Aid Enhances Oil Recovery on Norway's Troll Field



The implementation of autonomous inflow control devices (AICDs) has been a success on the Troll field with the objective of limiting gas production for long horizontal wells in a thin oil column reservoir. First installed in 2008 and recently subjected to technical enhancements, the successful use of AICDs has led to them being adopted as part of the standard lower completion solution at Troll. To date, more than 30 wells have been completed with AICDs, demonstrating a significant increase in cumulative oil production.

BY MARTIN HALVORSEN, MARTIN MADSEN, AND MATHIAS VIKØREN MO, STATOIL; ISMAIL ISMA MOHD, AND ANNABEL GREEN, TENDEKA

Troll's multilateral horizontal wells are drilled with a total reservoir length typically of 3 to 5 kilometres within a thin oil column. The thin oil layer was originally between 22 and 26 metres in the western part of the field and 11 and 13 metres in the eastern part of the Troll oil field.

For more than a decade, production has been aided initially by passive inflow control devices (ICDs) and latterly AICDS to ensure contribution from all reservoir sections and limit gas production by postponing gas breakthrough and choking gas production after breakthrough.

AICDs provide the same functionality as passive ICDs in helping to create a more even inflow along the horizontal section of a well prior to gas breakthrough, but their added advantage is that they also have a self-regulating adjustable design to provide greater production choking where gas breakthrough occurs. This chokes production from reservoir sections producing large amounts of gas leading to greater oil recovery and lower gas production.

The AICD Device

The Autonomous inflow control device (AICD) that is installed at Troll was originally developed by Statoil and this type of AICD is referred to as the Rate Controlled Production (RCP) valve. The working principle is described by Mathiesen et al (2011) and Halvorsen et al. (2012) The function of the RCP is based on the Bernoulli principle by neglecting elevation and compressible effect, and expressed as:

$$P_1 + \tfrac{1}{2} r V_1^2 = P_2 + \tfrac{1}{2} \rho V_2^2 + \Delta P_{friction\ loss}$$

P_1 = static pressure

$\tfrac{1}{2} \rho V_1^2$ = dynamic pressure

ΔP = friction pressure loss

The equation states that the sum of the static pressure, the dynamic pressure and the frictional pressure losses along a streamline is constant. Figure 1 shows the RCP valve; the streamline or flowpath through the device is marked by arrows.

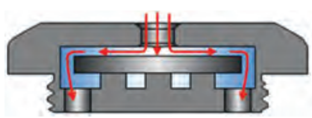


Figure 1. AICD flow path
(illustrations: Tendeka)

The RCP valve restricts the flow rate of low viscosity fluids. When gas or water flows through the RCP, the pressure at the flowing side of the disc will be lower due to the high fluid velocity. The total force acting on the disc will move the disc towards the inlet, and reduce the flow area and thus the flow. When more viscous fluids flow through the RCP, the friction loss increases and the pressure recovery of the dynamic pressure decreases. The pressure on the rear side of the disc will decrease resulting in lower force acting on the disc towards the inlet. Thus the disc moves away from the inlet and the flow area and the flow increases.

The RCP valve is a part of the sand screen joint. The screen joint is shown in Figure 2. The reservoir fluids enter the completion through the sand screen filter and flow along the annulus between 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 and flows to surface together with the production from the rest of the screens.

The AICD screen design is optimised to ensure identical outer diameter of AICD housing and filter section.

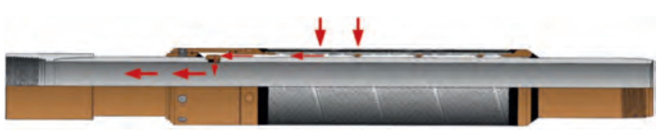


Figure 2. AICD unit mounted into sand screen joints – the flow path is marked by red arrows

Technology Advancements

The results of the first AICD installations on Troll from 2008-2011 concluded that cumulative oil production from one well was approximately 20% higher using AICDs compared with ICDs and that reduced GORs in wells enable the prognosed oil volumes to be produced in less time and with improved oil recovery. However it was believed that further performance improvements could be made by introducing significant mechanical design modifications for improved completion integration, robustness and longevity. The AICD that is installed in wells at Troll now comprises of only three components; valve body, nozzle and disc, as shown in Figure 3.

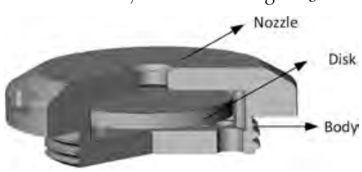


Figure 3. AICD construction

The nozzle and disc material have been upgraded to tungsten carbide with increased thickness for improved stability and erosion resistance.

The RCP has been downsized to prevent protrusion into the internal diameter of the completion to avoid interference with intervention tools and enable the deployment of intelligent completions within the sandface completion. The TR7 AICD is small enough to be installed within standard passive ICD housings, this has improved inventory utilisation as screens originally manufactured with passive ICDs were reworked to install AICDs. This has been achieved through a combination of a simplification of the fluid path through the RCP and modification to the fabrication of the device (as shown in Figure 4). The current TR7 RCP valve has less than half the diameter and the height of the original RCP installed in the first wells at Troll.

The range of AICD sizes, material options and configurations has

***Figure 4. Design evolution of the RCP AICD from original device AR2 (left), with revised fluid path TR7 (middle) and with a revised construction TR7-2 (right)** (photo: Tendeka)*

been increased to meet the demand of varying flow rates and inflow control requirements for different field applications.

Due to the reduced valve dimensions, the AICD can be threaded directly into the base pipe. In principle, the valve can be mounted or replaced anytime and also at the rig and it is possible to change the nozzle size of the AICD based on drilling results. Each screen joint may have up to four threaded ports compatible with AICDs, passive ICDs, chemical treatment valves or blanking plugs providing a high degree of flexibility to cater for reservoir uncertainty after drilling and inventory flexibility.

AICDs – Benefits Through Results

Based on the positive results from the original AICD-installed wells and the expected increased oil production simulated for new wells on Troll, it was decided to install AICDs in new wells on Troll and from the end of 2012 almost every well has been completed with AICDs (see Figure 5).

Taking one well, P-21, as an example, the well has now been in production for more than four years and the oil production achieved is shown in Figure 6.

The oil production is significantly higher than simulated/expected and the gas breakthrough (change in slope, start of decline) occurs much later than expected. The well was also producing at a beneficial GOR for a longer time than expected. It can be observed that the well has produced almost twice as much oil than expected at a given cumulative gas production.

A comparative study was performed between the production profile with AICDs, with ICDs and a completion without any inflow control. Simulations for most Troll wells show significantly increased oil production compared with other types of inflow control. The average of the increased oil production for a number of Troll wells are 31% for ICD and 46% for AICD compared to a no inflow case (see Figure 7).

The successful implementation of AICDs requires that the following criteria are met:

- No negative HSE effects.
- No problems during completion, startup or production that can be related to the AICD screens.
- No plugging or excessive pressure drop across the AICD screens with a negative effect on production.
- Favourable GOR development and cumulative oil production for the AICD completed wells.

The AICDs implemented in the Troll wells do not create added complexity compared to the previous wells completed with ICDs, yet the operation to complete a well is very similar.

The simulated oil production has been found to be favourable for AICD wells compared to ICD wells at Troll. Based on the oil production for the AICD wells, it has been observed that in total the actual oil production is on average slightly higher than the simulated oil

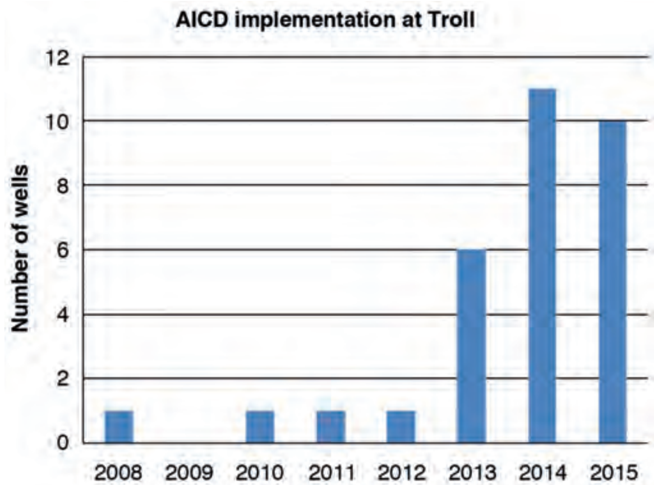


Figure 5. Number of Troll wells installed with AICD by year

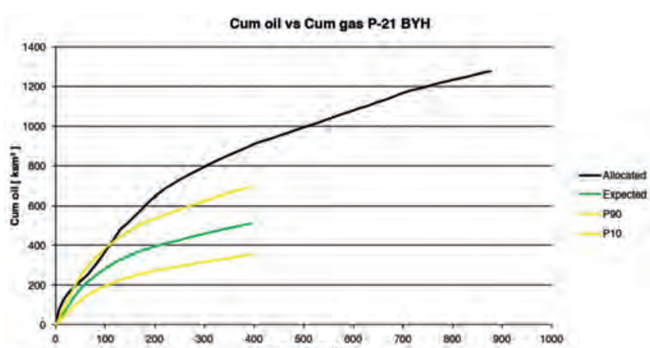


Figure 6. Comparison of modelled and actual cumulative oil production as a function of cumulative gas production

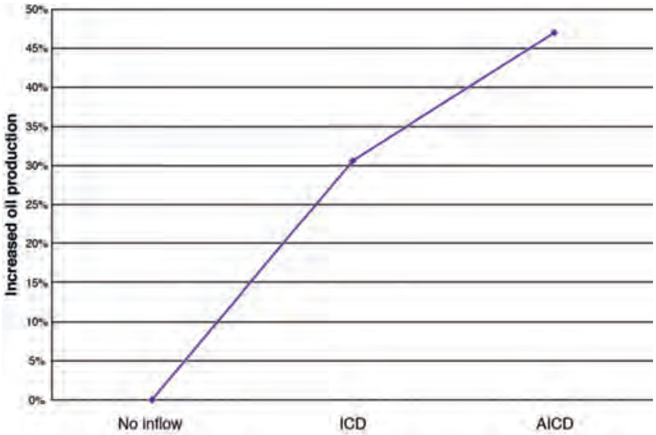


Figure 7. Simulated increase in oil production for ICD and AICD completions

production. The oil production from selected wells is show in Figure 8. Since the AICD wells are producing as expected, it is concluded that they have an increased oil production compared to if they were completed with ICDs.

AICD Selection and Evaluation

The Troll experience has proven that implementing AICD technology can significantly increase oil production, extend well life and ultimately lead to greater oil recovery in a wide range of environments and applications. All new wells at Troll are completed with AICDs and the selection is based on dynamic reservoir simulations on each individual well.

Enhanced well performance can be achieved with AICD-completed wells providing that acceptable production rates can be achieved through the AICDs throughout the life of the well, a viscosity contrast between the oil and the unwanted fluid is present at well conditions, some heterogeneities or non-uniformity in water or gas production is present along the wellbore and the ability to achieve adequate compartmentalisation of the wellbore annulus.

Well operability factors can determine the feasibility of the completion and any conflicting well objectives, these can include: compatibility with completion design, e.g. sand control, branch or zone control or monitoring; ability to deploy; effective well start-up; and flow assurance.

Conclusions

The AICD technology has been implemented successfully at the Troll oil field, based on the criteria of no negative HSE effects, no associated problems during completion, start-up or production, no negative effect on production, and a favourable GOR development and cumulative oil production.

The capacity of the AICDs is seen to be sufficient to produce the plateau liquid rates prior to gas breakthrough. The AICD wells are produced towards a lower bottom hole pressure due to added pressure drop across lower completion (AICD screens), but this extra pressure drop is not seen as a problem in Troll wells.

Significantly, the AICD wells are producing at better than expected rates, and have contributed to an increase in oil production from the Troll field. ■

Acknowledgements

The authors are grateful to the Troll license partners Petoro, Shell, Total, ConocoPhillips and Statoil, for allowing this work to be published.

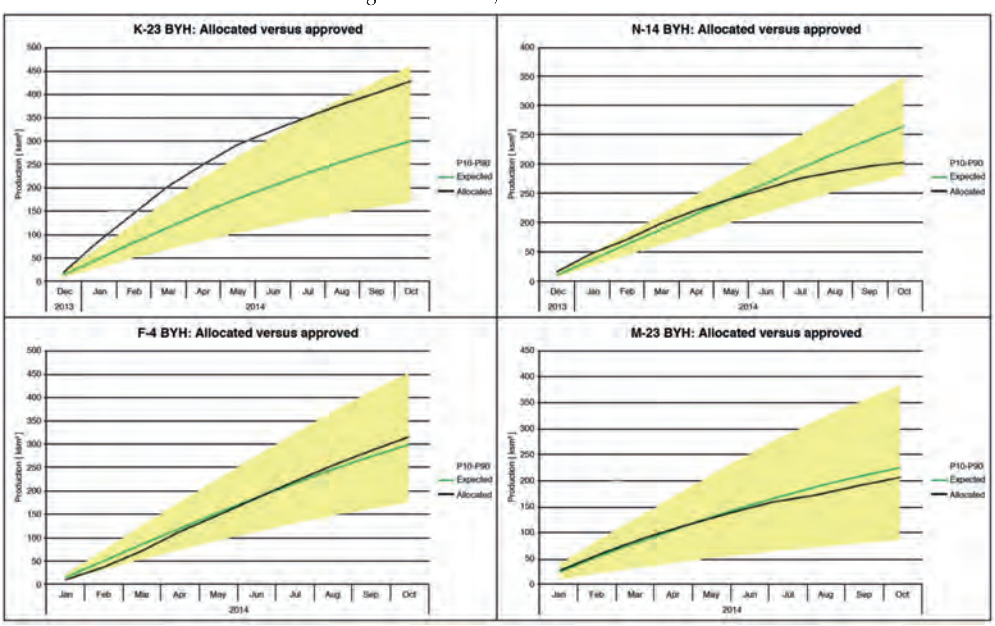


Figure 8. Comparison between actual and expected oil production over time for selected well examples

The Authors:

Martin Halvorsen is working for Statoil ASA and the current position is Leading Advisor in Production Technology. He earned a MS degree in Physics from the University of Bergen, Norway. More than 20 years of experience from the oil industry working within R&D, product development, technical services and production engineering. With Statoil ASA since 2006.

Martin Madsen, Discipline Leader Petroleum Technology in Troll Petech, Statoil ASA, has a Master's degree from the Norwegian University of Science and Technology (NTNU) in Production Technology. He comes from a background which includes reservoir engineering, well operations and production technology. Martin has gained over 20 years' experience in the oil industry and has been with Statoil since 1986.

Mathias Vikøren Mo works for Statoil ASA as a reservoir engineer, where he is involved in the evaluation of inflow control devices as well as other production technologies . He has a Master's in reservoir engineering from the Norwegian University of Science and Technology (NTNU).

Ismail Isma Mohd is the Product Line Manager for Sand Control / Inflow Control for Tendeka based in Aberdeen, United Kingdom. He is responsible for sand control and inflow control product development, material selection and subsurface modelling. He holds a PhD and MSc. in Mechanical Engineering from University of Leeds, United Kingdom specialising in Oilfield Sand Erosion and Corrosion.

Annabel Green is Chief Technology Officer at Tendeka. She has broad experience in sand control, reservoir completions and general completion technology across global markets and holds several patents and is the co-author of a number of SPE papers. Annabel graduated from Leeds University with a degree in Mechanical Engineering.