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An Introduction to Flow Control Devices and the Potential Benefits to Geothermal Applications

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Outline

- Introduction
- Overview on Flow Control Devices (FCDs)
- FCD use in the Oil Industry (SAGD)
- Potential Benefits of FCDs to the Geothermal Industry
- Summary

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Introduction

- Uniform Distribution is Vital
  Uniform distribution of injected and produced fluids to & from the reservoir is critical
- SAGD Operators face Similar Challenges
  Oil operators, particularly those who use ***Steam Assisted Gravity Drainage (SAGD)*** are like geothermal
- FCDs Provide Effective Well Control (Significant Improvements Demonstrated)
  To address reservoir inefficiencies, SAGD operators have begun to employ FCDs as an effective means of ***well control*** and several operators have reported ***significant process improvements***
- FCDs may be a viable solution for Geothermal Wells
  Given the similarities between the challenges faced by SAGD and geothermal operators, ***FCDs may be a viable technology*** to help mitigate imbalanced reservoir flow in geothermal operations – and something to consider

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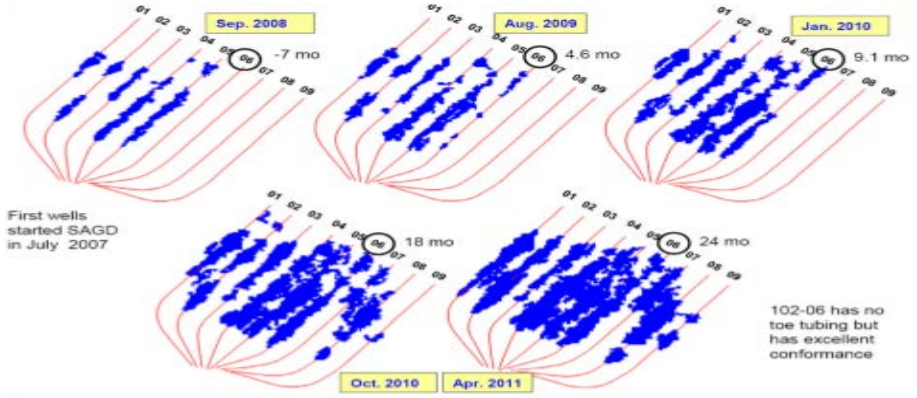
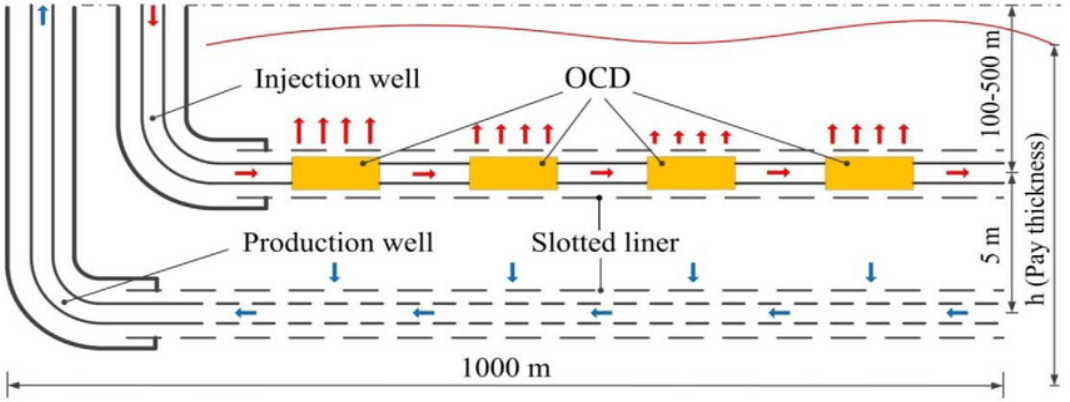
Overview of Flow Control Devices (FCDs)
Use in SAGD Wells

- FCDs have been commonplace in ***conventional oil*** wells since the ***early 90's***
- Since first being considered in SAGD wells by ConocoPhillips at Surmount – FCDs have now become a ***standard design element***
- FCDs improve ***Reservoir Conformance*** in SAGD with a ***steam blocking*** effect to:
  - Promote an even liquid level around the production well
  - Improving steam chamber uniformity
  - Stop "short-circuiting" between the injection and production well



4D Seismic Plots of first SAGD wells with FCDs
(Staldner 2012)



SAGD Well Completions with FCDs Deployed
(Li et al. 2017)

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Overview of Flow Control Devices (FCDs)
Types of FCDs in SAGD

In SAGD there are two types of FCDs

- **Outflow Control Devices (OCDs)**
  - Used in Injection Well(s)
  - Promote even distribution of steam, resulting in better steam chamber growth and a reduced Steam Oil Ratio (SOR)
- **Inflow Control Devices (ICDs)**
  - Used in Production Well(s)
  - Promote lateral inflow conformance and improves steam efficiency/recovery

FCDs Deployed in a SAGD Well
(Halliburton)

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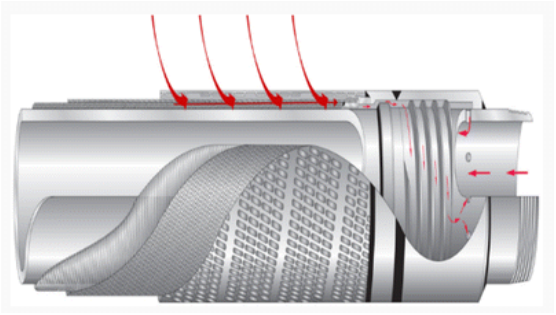
Overview of Flow Control Devices (FCDs)
Common Geometries of FCDs

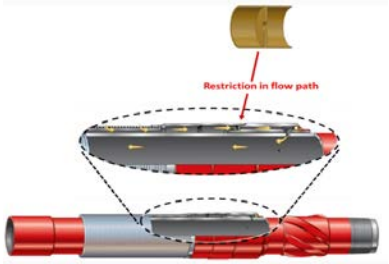
The underlying operating principle of an FCD is to ***restrict flow by inducing a pressure drop***.

FCDs can be categorized by three primary mechanisms:

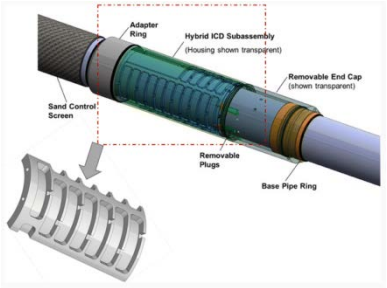
- **Channel-style**
  Frictional Drag
  - Directs flow through helical channels or tortuous pathway
- **Restriction-style**
  Bernoulli Principle
  - Typically an orifice or nozzle-based design
  - Changes in flow area create instantaneous pressure drops
- **Autonomous**
  Frictional Drag, Bernoulli Principle, Momentum Effects
  - Hybrid designs that use a combination of restriction and frictional pressure drop mechanisms



Channel-style FCD
Adapted from Bitto (2005)
(Banerjee 2016)



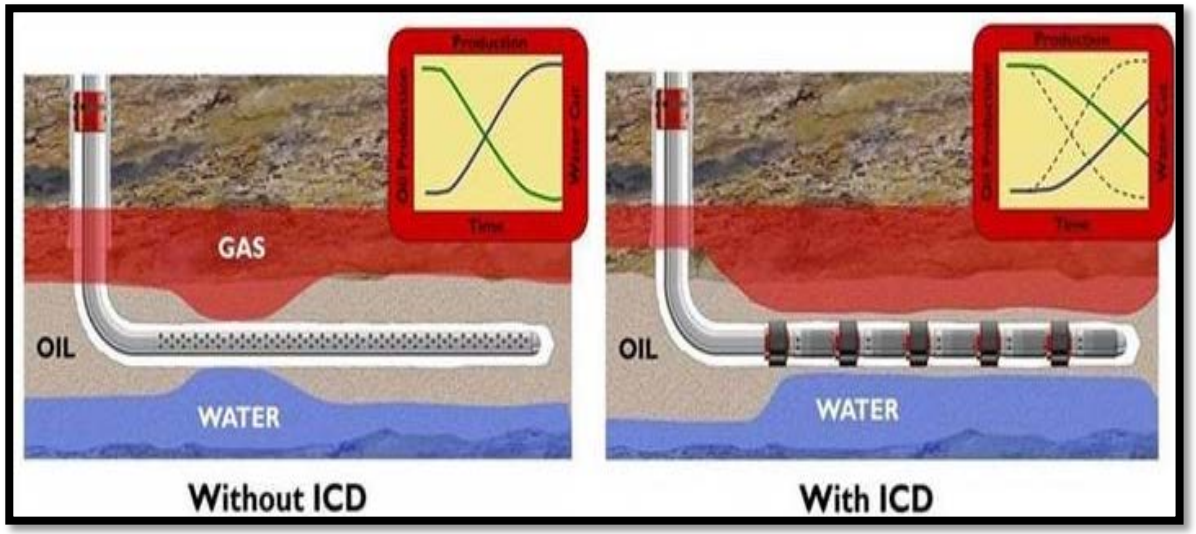
Restriction-style FCD
Adapted from Oyeka at al. (2014)
(Banerjee 2016)



Autonomous Hybrid FCD Assembly (with Transparent Housing)
(Banerjee et al. 2013)

Flow Control Devices in the Oil & Gas Industry
FCDs in Conventional Production

- FCDs have been used in conventional wells since the early 1990's
- FCDs can ***delay water or gas breakthrough*** in horizontal wells
- High rate of production in a localized zone may draw gas cap or aquifer to the production well ("***Drawdown***")
- Typically, Drawdown occurs at the heel of the well due to frictional pressure loss (i.e. heel-toe effect)
  - However, reservoir characteristics and other factors may cause breakthrough anywhere along the well



Localized Gas/Water Drawdown in a Conventional Horizontal Production Well (Halliburton)

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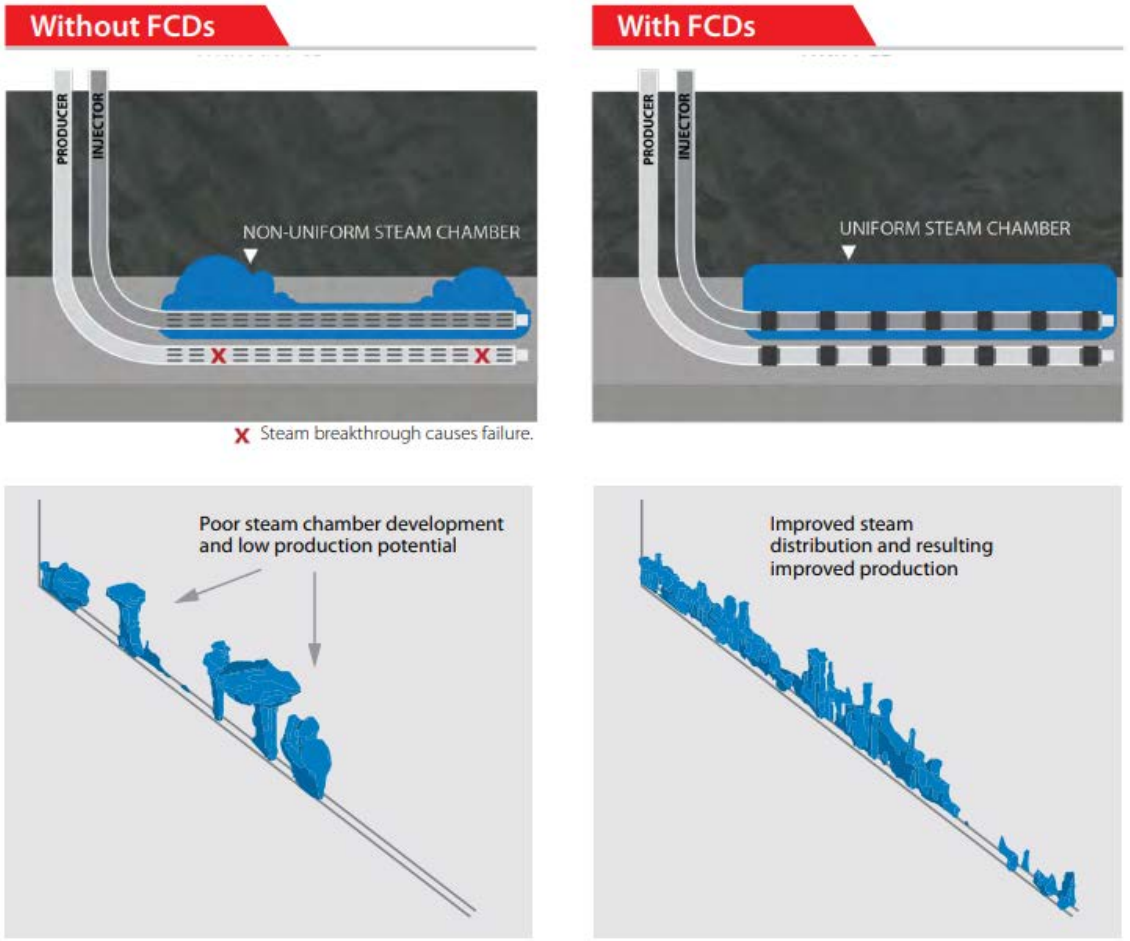
Flow Control Devices in the Oil & Gas Industry
Steam Assisted Gravity Drainage (SAGD)

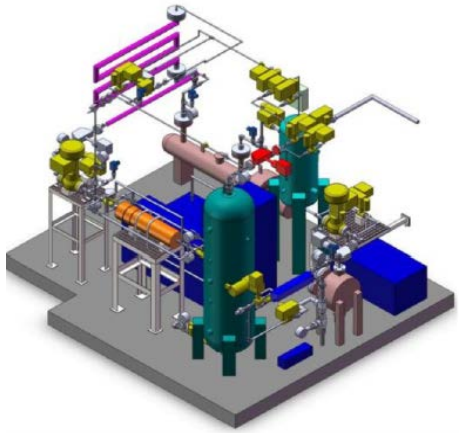
- A key step in SAGD recovery is the even formation of the steam chamber
- Recently, FCDs have been deployed in SAGD to mitigate localized breakthrough ("***Short-circuiting***")
- FCDs have been successful in lab testing at C-FER and field pilots with:
  - Higher production rates, without localized breakthrough
  - Reduced Steam Oil Ratio (SOR)
  - Improved ***reservoir conformance***

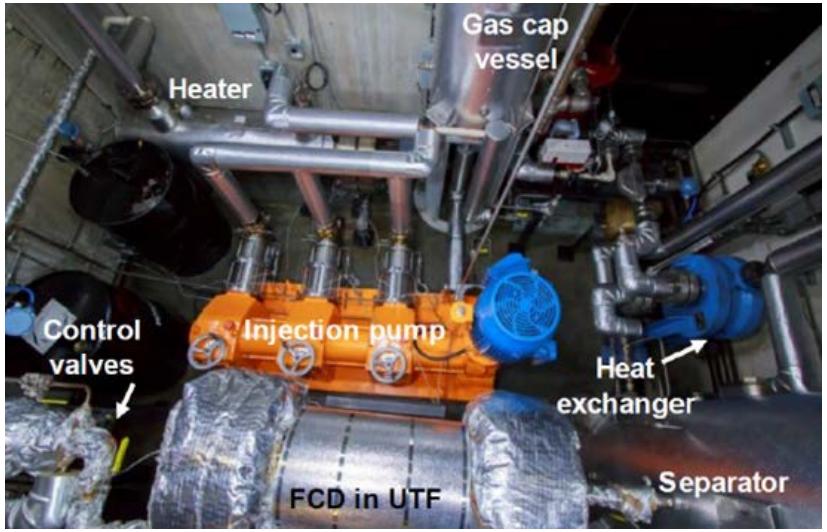


Steam Chamber Development Geographical Representation
(ConocoPhillips)

Flow Control Devices in the Oil & Gas Industry
Challenges (and path forward) in SAGD

- Identifying optimal ICD types to maximize performance in a SAGD well is challenging
  - There are few ICDs specifically designed for SAGD
- Other key factors to consider include:
  - Number of FCDs per well (and optimal spacing/deployment)
  - Likelihood of erosion and wear over life of well (15 to 25 years)
- SAGD operators and C-FER have invested significant effort into evaluating FCD technology for SAGD
  - C-FER and ConocoPhillips designed and built a unique high temperature flow loop and Erosion Apparatus
  - They also devised a protocol for characterizing the performance and reliability of ICDs under SAGD-representative conditions





High Temp ICD Testing Loops at C-FER
(C-FER)

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Potential Benefits to Geothermal Applications
Imbalanced Reservoir Flow

- There are many parallels when comparing conditions experienced by geothermal operators and SAGD – such as imbalanced reservoirs
- Short-circuiting (or "Flow Channeling") is a widespread issue in the Geothermal industry; impacting both hydrothermal and EGS operations
  - Chemical precipitates injection is sometimes possible – but in other cases geothermal operators need to drill a new injection well
- Thermal Drawdown is another major issue; it is detrimental to the produced heat capacity of the resource and a factor which may induce thermal stresses in the surrounding rock (i.e. leading to further short-circuits)
- Controlling flow through the reservoir may maximize heat exchange and mitigate Short-circuiting

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Potential Benefits to Geothermal Applications
Possible Benefits of FCDs

- Short-circuiting and Thermal Drawdown in the Geothermal industry share many commonalities with SAGD operations
- Considering the similarities between the mechanisms, we suggest FCD technology may help to mitigate Short-circuiting and Thermal Drawdown in geothermal applications
  - OCDs in geothermal wells could promote balanced distribution of injected fluids
  - ICDs in a production well would mitigate Short-circuiting by preventing high rate production from a preferred path; possibly preventing Thermal Drawdown from produced fluid through localized zones
- FCDs may provide increased confidence in new EGS projects

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Potential Benefits to Geothermal Applications
Limitations and the Bottom Line

- Although FCDs have been successful in the Oil & Gas industry, there is little information on the use of this technology in geothermal applications
- Differences between Oil & Gas and geothermal operations may pose challenges to existing FCD designs, including:
  - Higher flowrates (i.e. SAGD operations exhibit lower flowrates than geothermal applications)
  - Scaling/Plugging (i.e. FCDs induce a pressure drop and flashing may lead to increased scaling)
  - Advancing completions (i.e. FCDs require advanced completions such as liners or tubing)
- ***Bottom Line***: FCDs have potential but they are an unproven technology in the Geothermal Industry; development and refinement is required

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Summary

- FCDs have provided SAGD operators with improved reservoir conformance
- Short-circuiting, flow channeling and thermal drawdown can be critical issues for both SAGD operators and geothermal operators
- Potential challenges remain regarding the implementation of FCDs due to the unique conditions of geothermal wells – but the benefits may be large

Further collaboration between the oil and the geothermal industries would be beneficial to accelerate the understanding of how FCD technology may benefit both groups

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