Heat Recovery from Sedimentary Formations

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Motivation

- Studies show surface area for heat transfer crucial to energy production
  - Sediment A >> Fracture A
- Existing infrastructure reduces cost
  - Wells, Separators, Reinjection
- Potential to extend “EGS” to 6-10 new states

Summary of Cases Studied

- Single wellbore heat exchangers
- Advanced well technologies
- Single wellbore fluid extraction
- Injection/Production well pairs

Parametric Sensitivity Study in Wellbore Heat Exchangers

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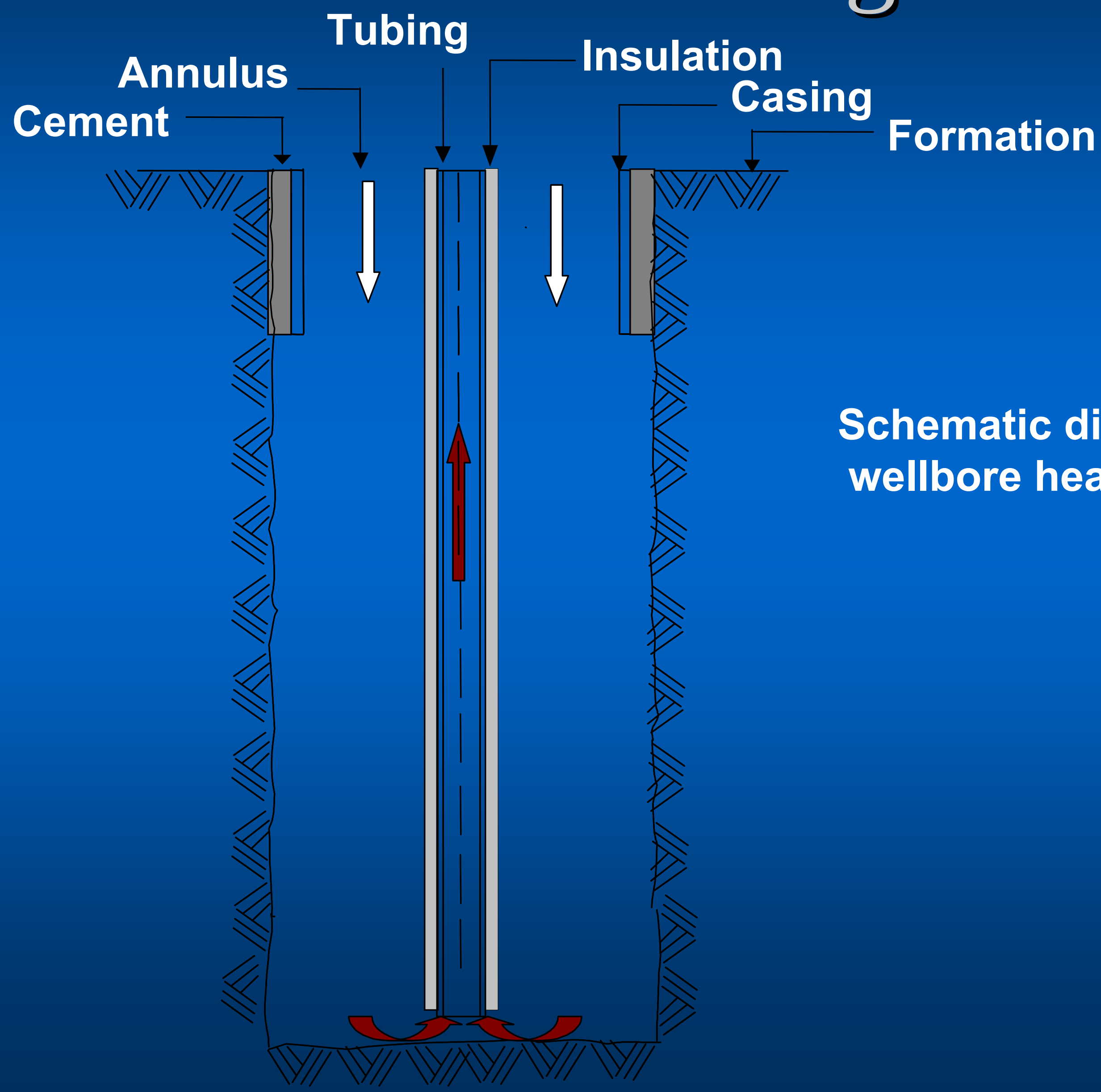
Wellbore Heat Exchanger Model



Schematic diagram of the wellbore heat exchanger

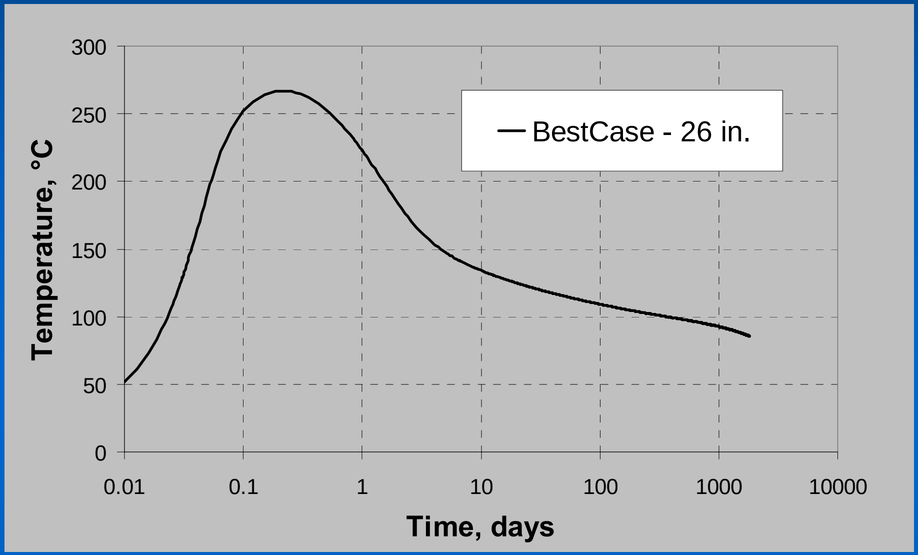
Parametric Sensitivity Study

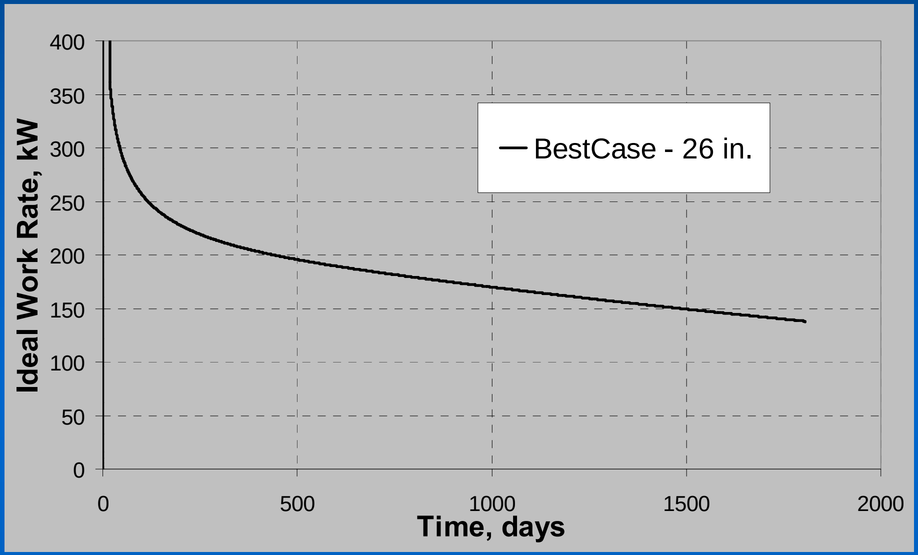
- Circulation Rate
- Wellbore diameter
- Tubing properties
- Working fluid properties
- Heat flux / wellbore depth
- Formation types

Optimal Parameters from Studies

Circulation Rate	100 gpm
Wellbore diameter	26 in.
Tubing properties	Secondary effect
Working fluid properties	water
Heat flux/ wellbore depth	0.1 $W/m^2 \rightarrow$ 5593 m
Formation types	Shale (K = 1.89 W/m°C, ρc_p = 1875.7 kJ/m^3°C)

Best Case Results





- Pseudo steady state fluid return temperature = 98 °C
- Pseudo steady state ideal work rate = 195 kW

Summary and Conclusions

- Comprehensive sensitivity study conducted
- Best Case below existing plant performance
- Wellbore heat exchanger not viable even with ideal energy conversion

Engineered Geothermal Systems using Advanced Well Technologies

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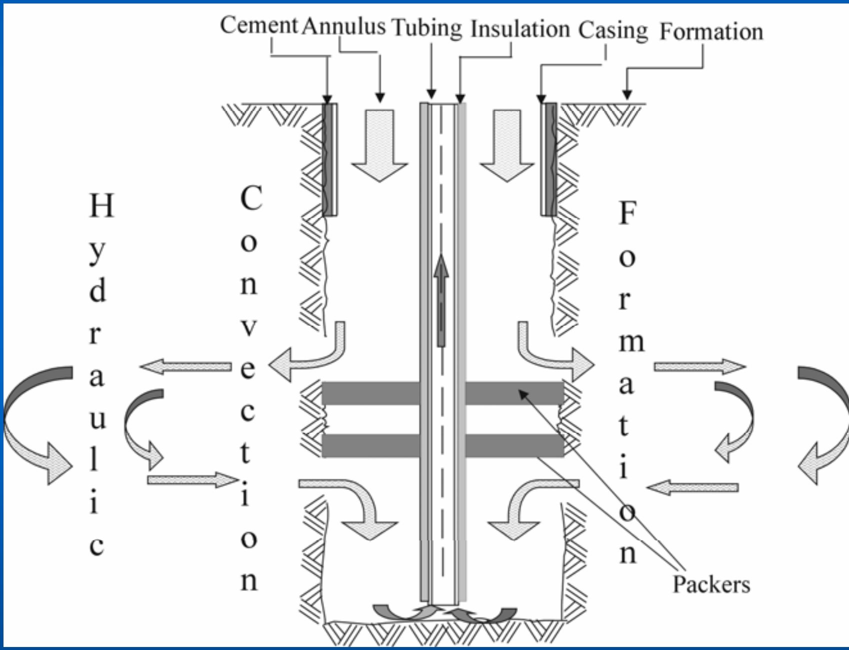
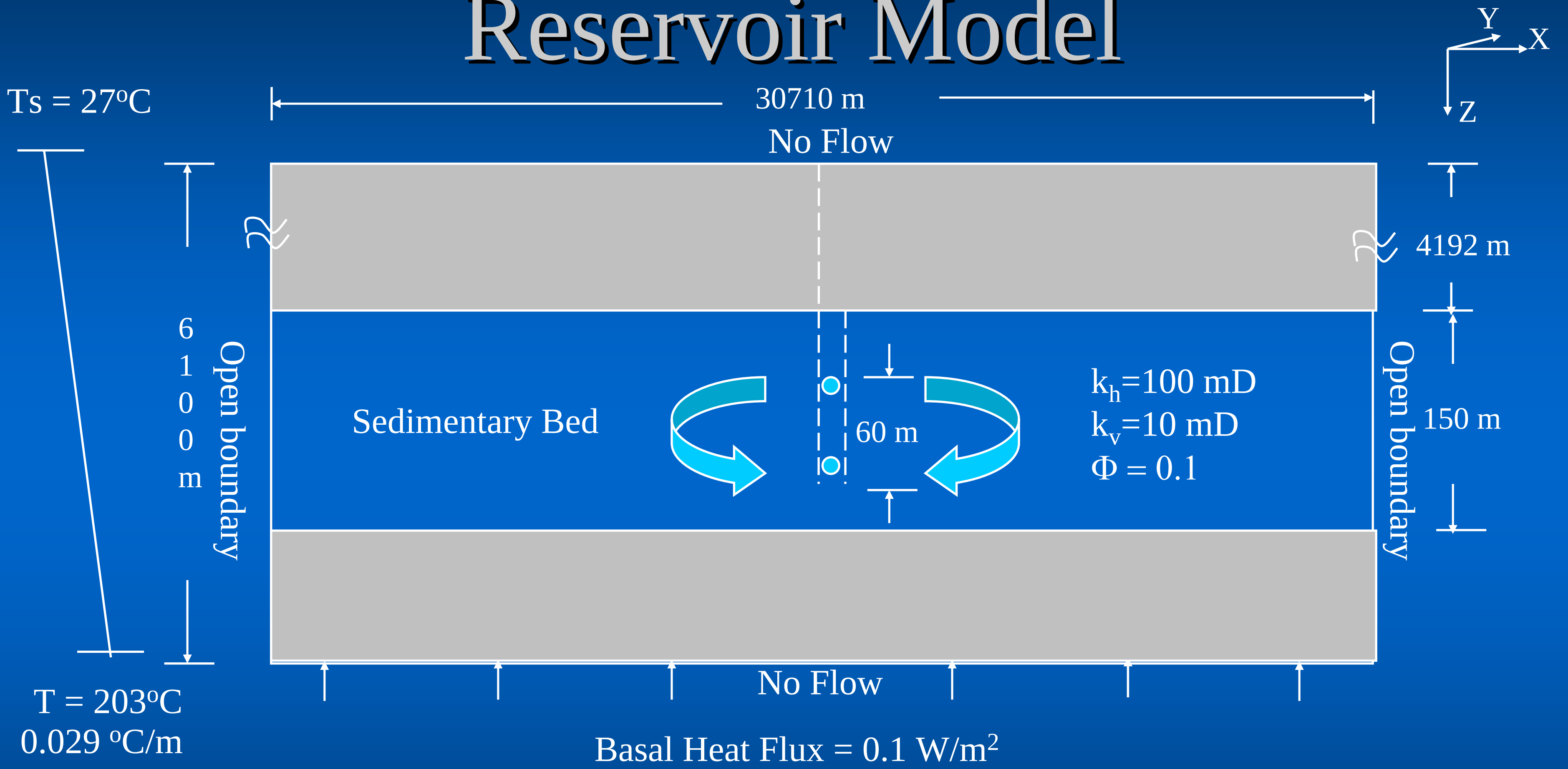
Vertical Well Dual Perforation (DP) System

- Geometry
  - Single vertical well
  - Two perforation intervals with isolation in annulus
  - Vertical hydraulic convection cell
- Previous Study (Herrling et al., 1990)
  - Sphere of influence dependent on anisotropy (k_H/k_V) and ratio of screen section lengths over aquifer thickness (a/H)



Reservoir Model



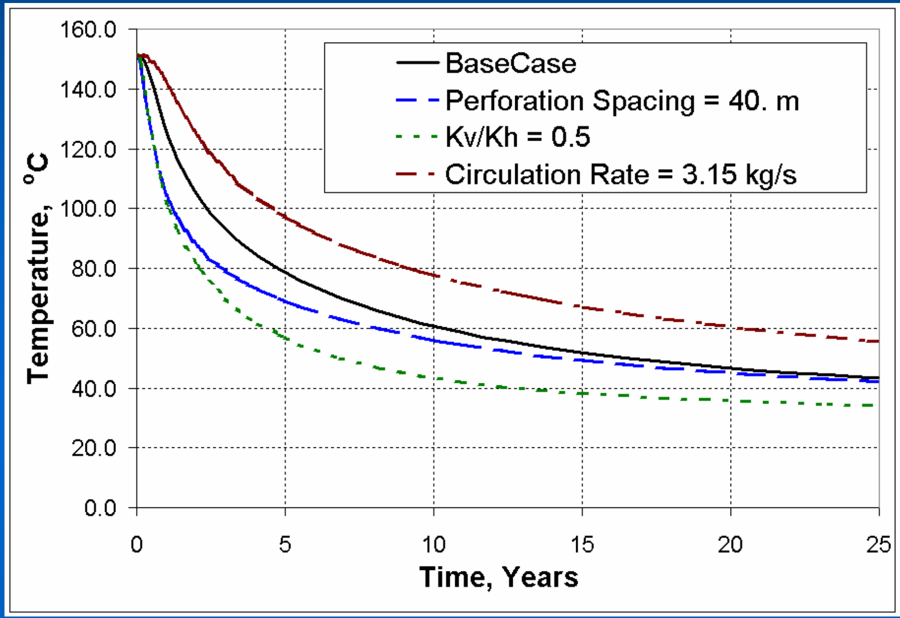
- **Circulation rate = 6.31 kg/s**
- **Injection Temperature = 27°C**

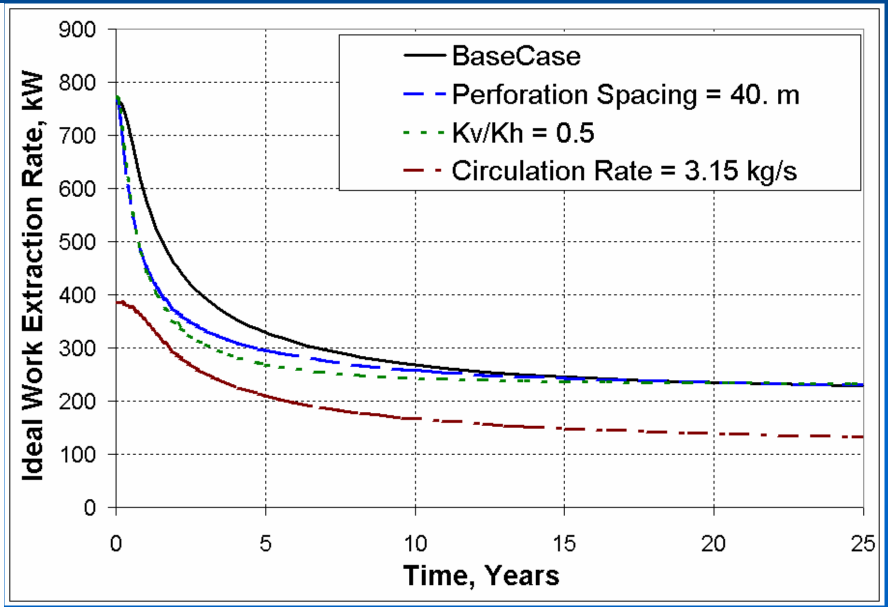
Sensitivity Study

- **Parameters**
  - Vertical/Horizontal Permeability
  - Circulation Rate
  - Injection/Extraction Perforation Interval Spacing

Case Identifier	Perforation Interval Spacing, m	Permeability ratio, k_V/k_H	Circulation Rate, kg/s
Basecase	60.	0.1	6.31
k_V/k_H	60.	0.5	6.31
Circulation Rate	60.	0.1	3.15
Perforation Spacing	40.	0.1	6.31

Sensitivity Study

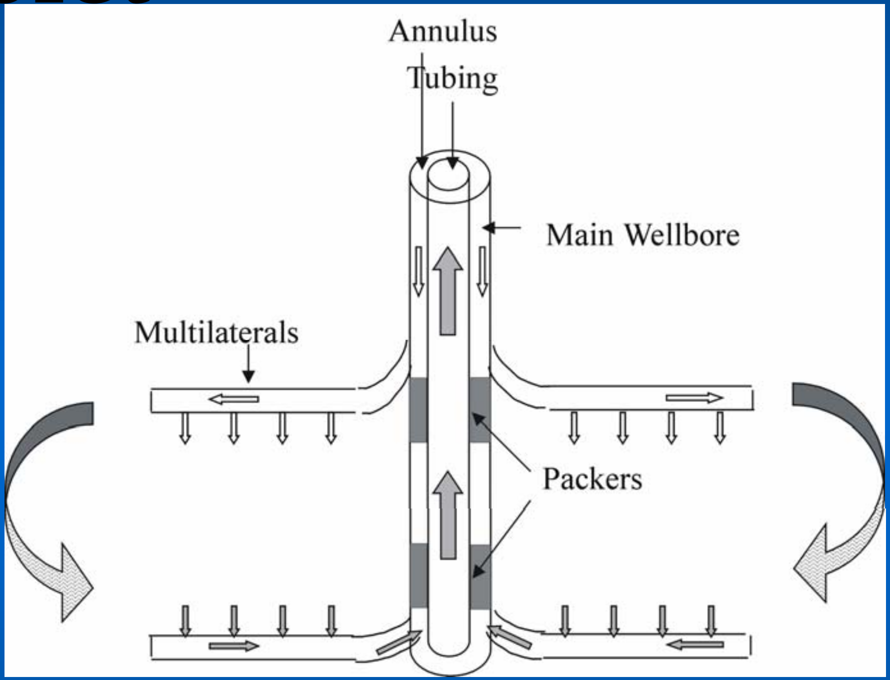




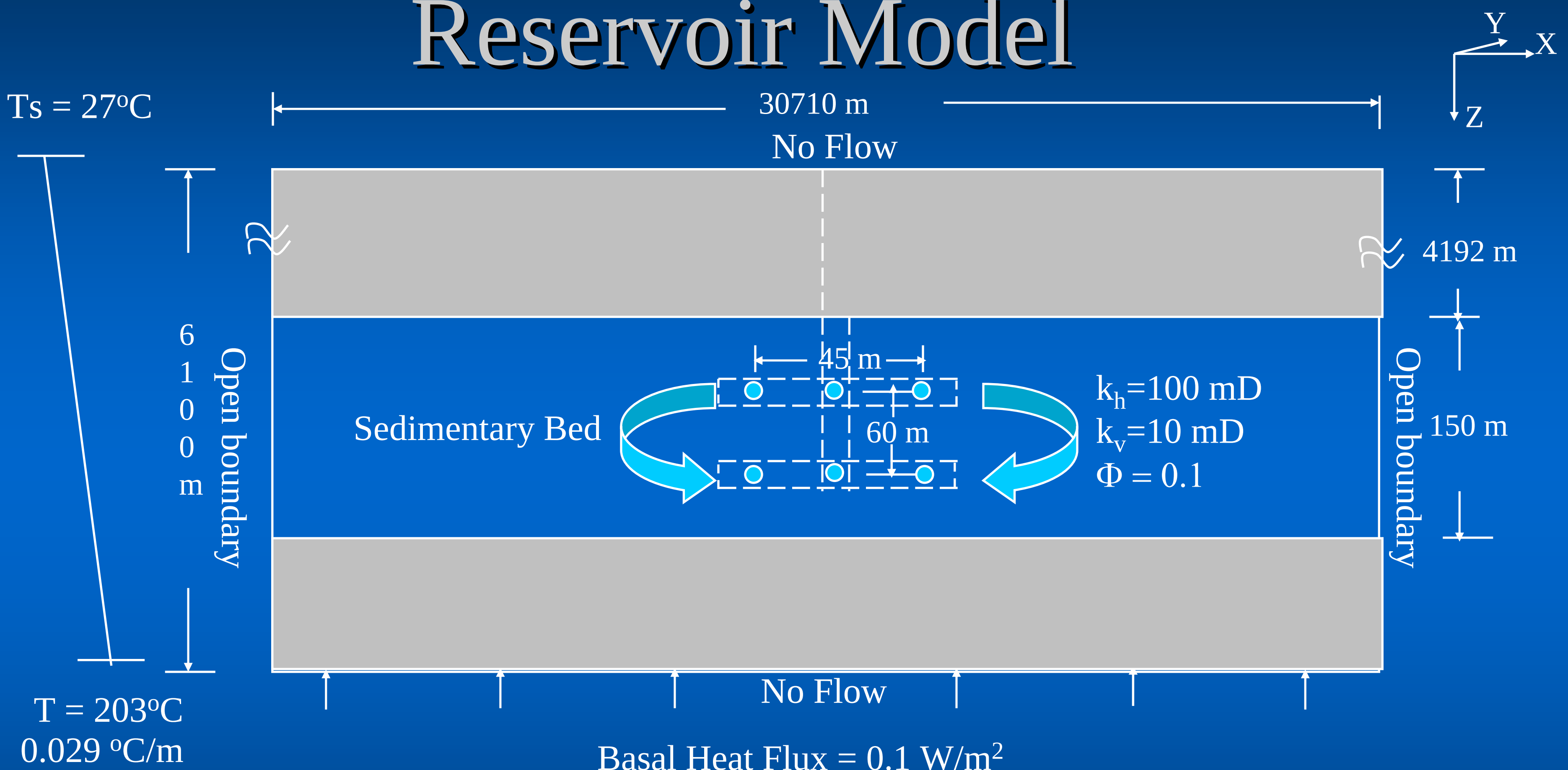
- Reduced vertical spacing → short circuit
- Increased k_v → crossflow & early BT
- Reduced circulation rate → high temperature but low ideal work rate

Vertical Well Dual Lateral Doublet

- Geometry
  - Vertical well
  - Dual lateral doublet
- Improved wellbore productivity and increased reservoir exposure

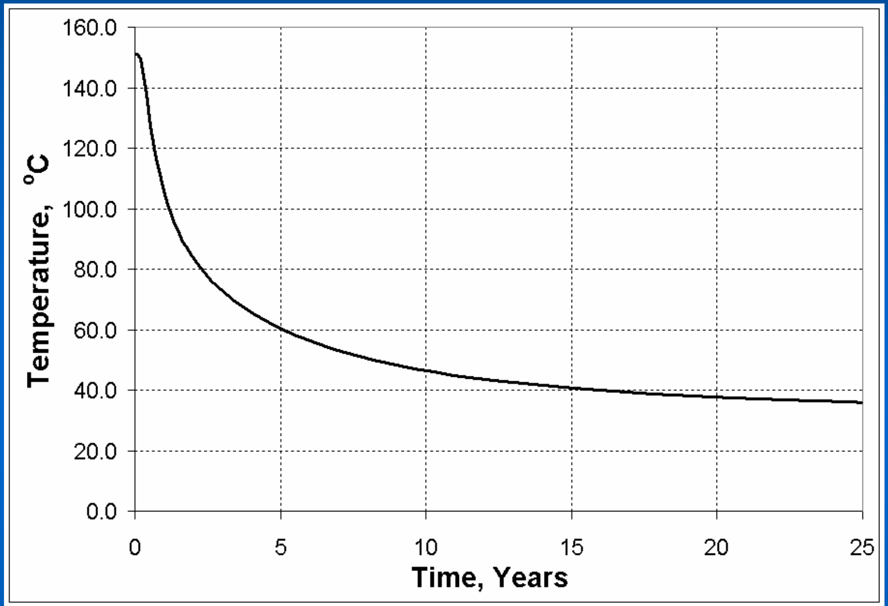


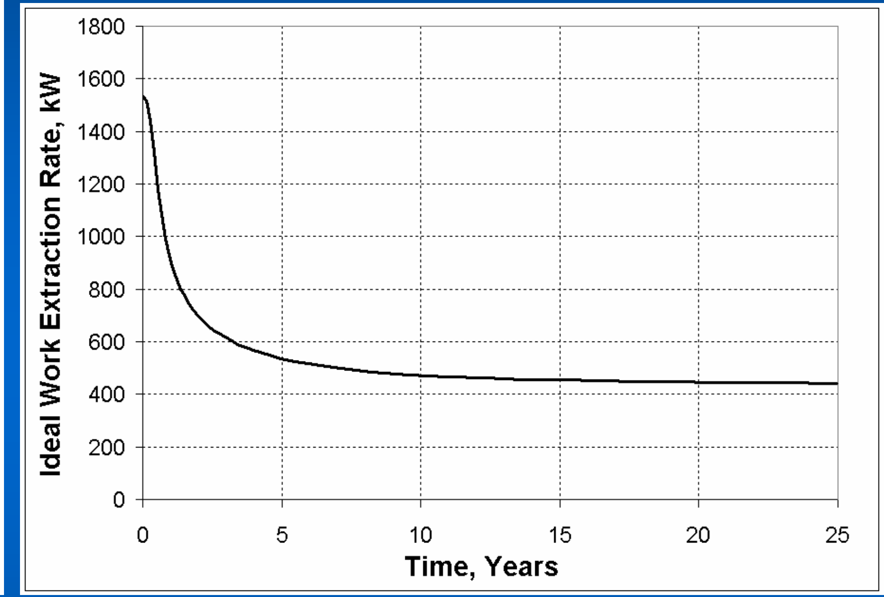
Reservoir Model



– **Circulation rate = 6.31 kg/s**
– **Injection Temperature = 27ºC**

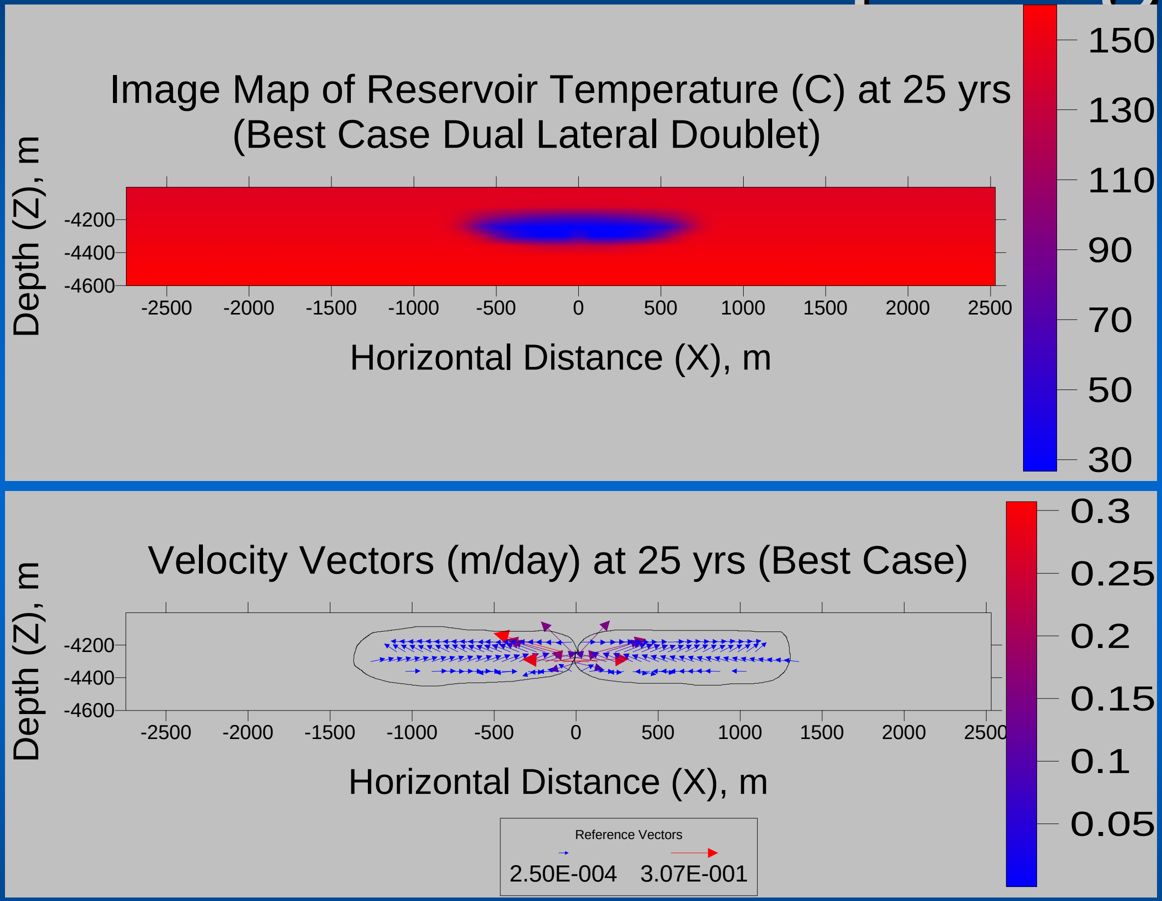
Best Case Dual Lateral Doublet Results



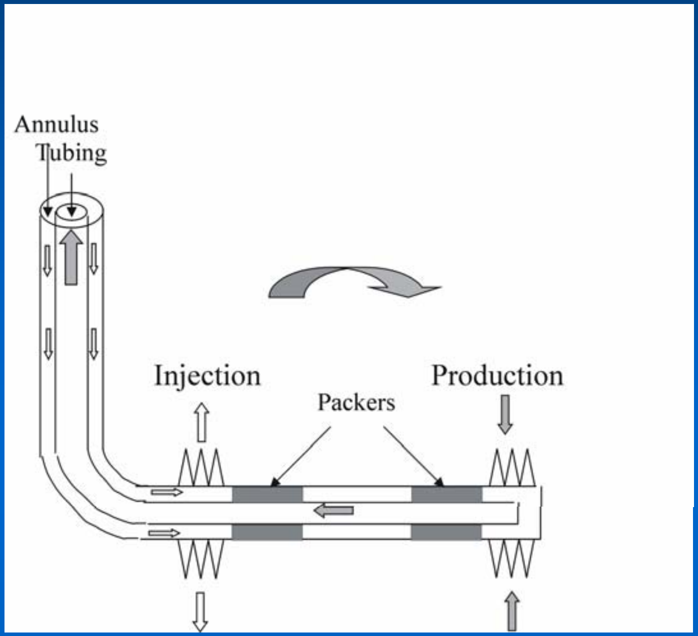


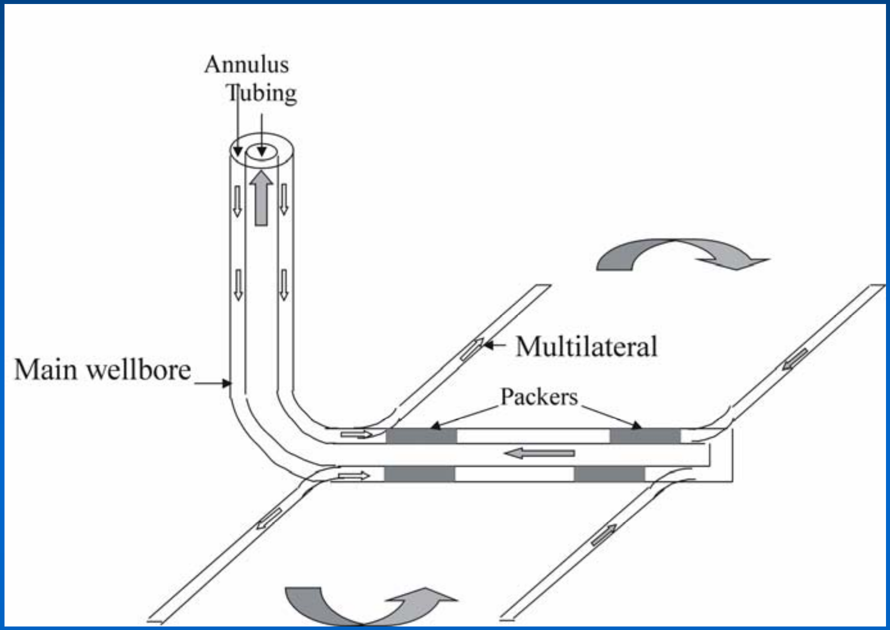
- Best case – Extraction Temperature : 60.4°C & Ideal Work Rate : 536 kW at 5 yrs
- Doesn't incorporate the temperature gain by conduction while flowing down
- Better technology than Dual Perforation for EGS

Thermal/Fluid Swept Region



Future Study





- Horizontal well dual perforation
- Horizontal well dual lateral doublet
- Unconstrained spacing in horizontal wells, higher rock-fluid contact area and higher fluid residence times.

Summary & Conclusions

- **Advanced Well Technologies Evaluation**
  - Preliminary study conducted
  - Potential means of achieving EGS goals
- **Vertical Well Dual Perforation System**
  - Limited by sedimentary bed thickness
- **Vertical Well Dual Lateral Doublet System**
  - Better than Dual Perforation System but still limited sedimentary bed thickness
- **Horizontal Wells**
  - Unconstrained spacing → longer residence times, more rock-fluid contact area and higher temperatures
  - Horizontal well multilateral doublet is promising technology for EGS

Single Well Energy Production

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Governing Equations

- Single Phase, PSS, inflow equations
- Pump efficiency and parasitic load

$$P_I - P_{wf} = \frac{q\mu}{2\pi kh}\left[\frac{1}{2}\ln\left(\frac{4A}{\gamma C_A r_w^2} + \frac{2\pi kt}{\varphi\mu cA} + S\right)\right]$$

Example of Analysis Results

- **Depth = 6 km**
  - **T = 175ºC**
- **Reservoir properties**
  - r_e = 4000 m (V_p = 250 E6 m^3)
  - k > 50 md
  - h = 25 m
- **ΔP = 540 Bar**
  - P_I = 1005 bar
  - $\cong P_{HS}$ at 12 km
- **No Fluid Replacement option only feasible for geopressured formations**

Injection/Extraction Energy Production

- Primary production
  - Offshore production platforms
- Watered out (mature) fields
- Ongoing waterfloods

Summary

- **EGS attractive in sedimentary basins**
  - **Heat transfer A**
  - **Existing infrastructure**
- **No Fluid Replacement restricted to GP**
  - **$P_I >> P_{HS}$**
- **Conventional methods using existing petroleum technology good**
  - **Waterfloods, production platforms, etc.**