Annular Circulation Co-Production System as an Alternative Design for Optimization of Total Energy Recovery from Oil and Gas Wells

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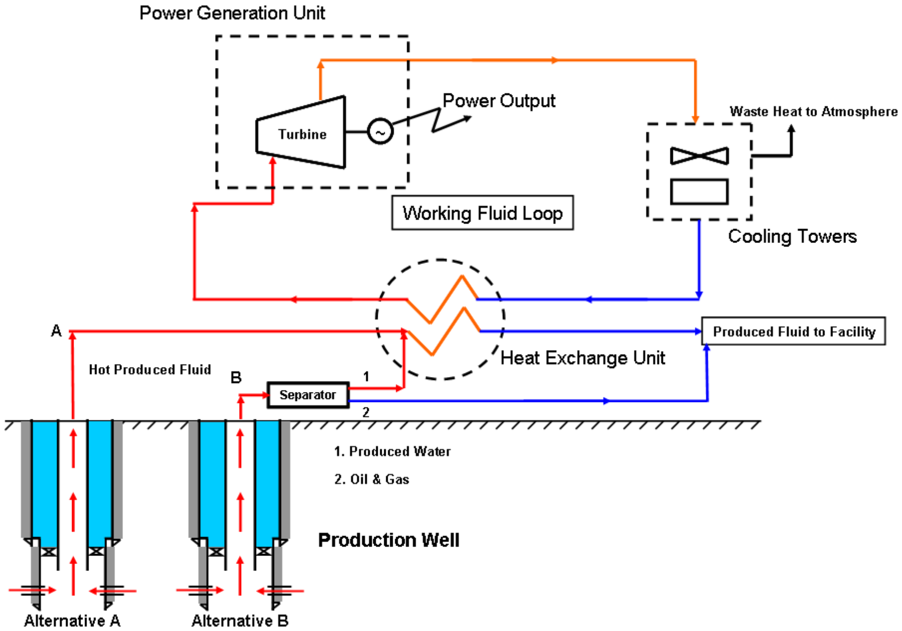
Geothermal Energy Utilization Associated with Oil & Gas Development

SMU, June 14 – 15, 2011

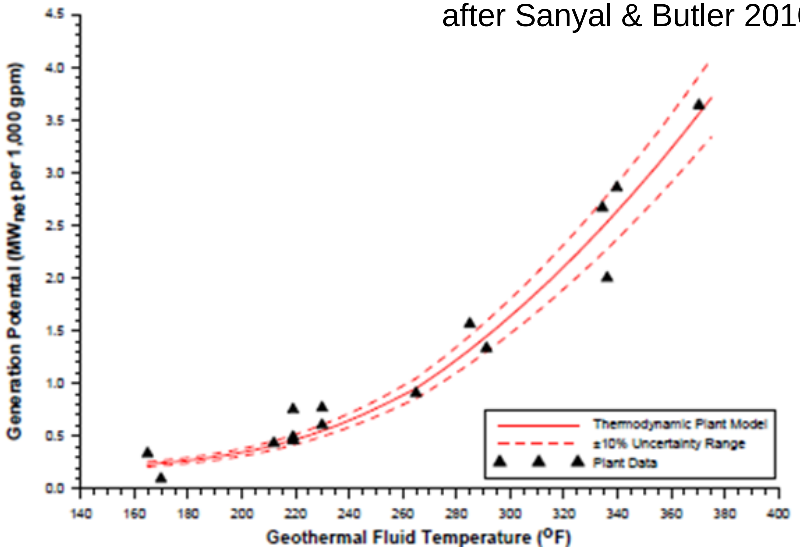
The Co-production Promise and Challenges

- Co-production of geothermal energy from oil and gas wells has significant potential in the US
  - 5,300 MW in Gulf Coast States alone (Tester et. al., 2006
  - 43 GW country-wide (Petty & Porro, 2007)
- Potential applications include
  - Currently sub-economic oil and gas fields that produce lot of water and have thermal potential
  - Currently economic oil and gas fields that have thermal potential that is wasted
- Complex problem requiring a systems approach to analysis and design:
  - Tolerance to decline in pressure and rate
  - Wellbore heat loss
  - Composition and pressure of hydrocarbons being produced
  - The loss of thermal energy in the separation process
  - Optimize total energy recovery
    - *Reservoir management*
    - *Well and completion design*

The Conventional Approach: Binary Systems

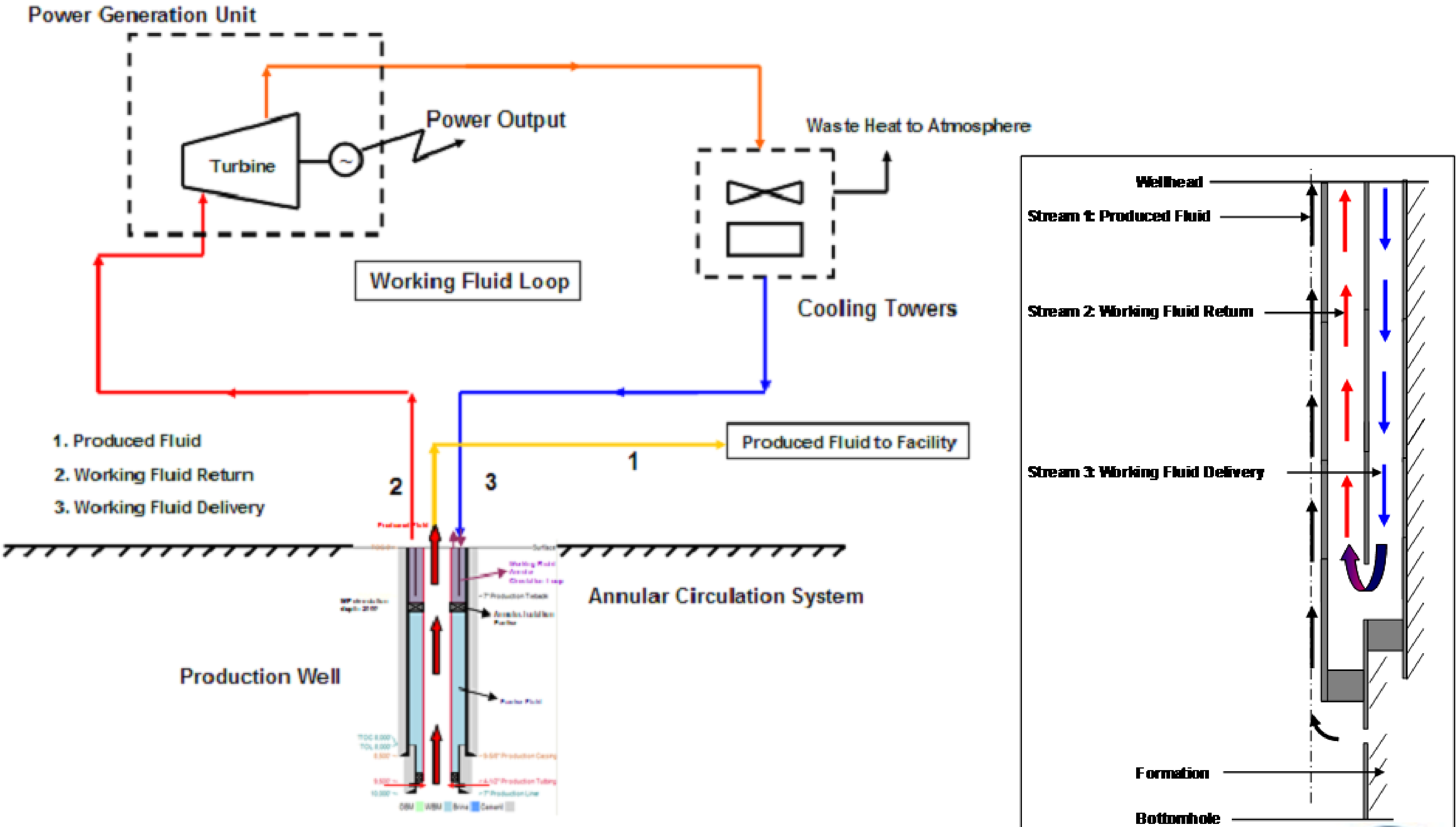


after Sanyal & Butler 2010



- Advantages
  - Familiar system
  - Off-the-shelf commercial systems
  - Ability to produce multiple wells into a single power plant
- Drawbacks
  - Production has to be dominated by water
  - Sufficiently low pressure to be within system limits
  - Non-sour, non-corrosive composition
  - Requires high per-well production rates to minimize wellbore heat loss

The Alternative:
Annular Circulation Co-Production System



ACCS Advantages and Limitations

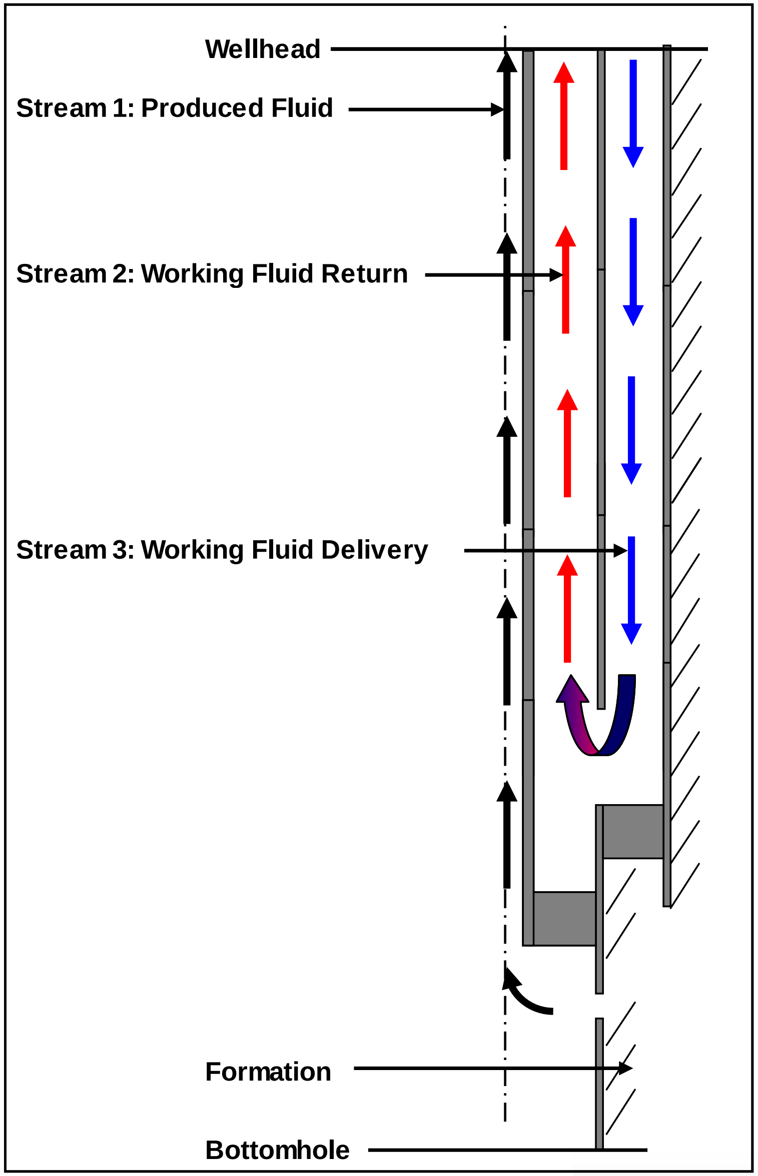
Advantages

- The geothermal system will be able to handle high pressure, nor sour or corrosive fluids.
- Long downhole heat exchanger for working fluid allows optimization of energy recovery.
  - Much greater tolerance to variations in produced fluid rates and composition
- Working fluid can be used to drive a downhole turbine pump to increase production rate

Limitations

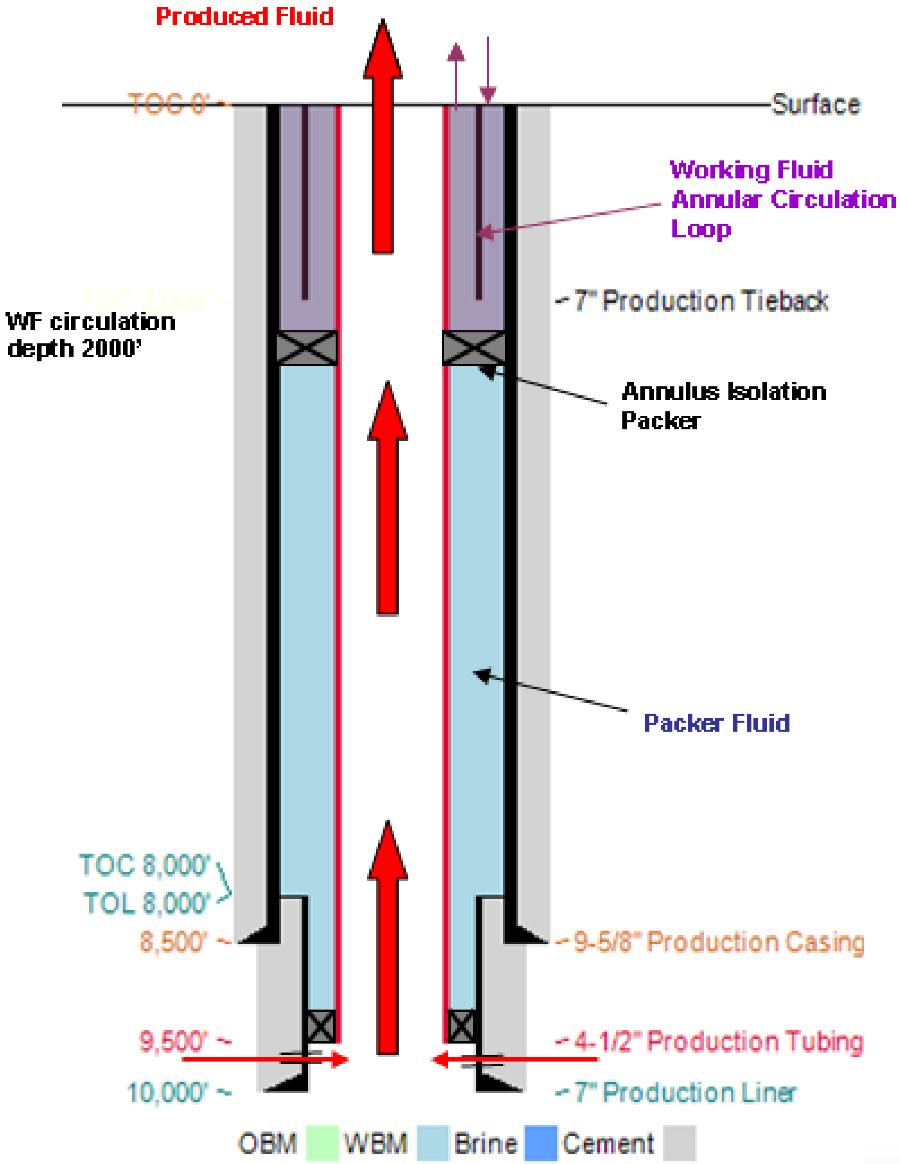
- Need for distributed single-well surface energy system
- Need for a well workover to create the annular circulation loop (for an existing well)
- Cost of working fluid in the wellbore
- New downhole equipment designs

ACCS Model



- Mass, momentum and energy balance
- Three flow streams and the formation interact thermally
- EoS and transport property data from NIST REFPROP
- Standard viscous correlations for pressure drop
- For heat transfer
  - NTU-effectiveness for the heat transfer between the fluids
  - 1-D quasi-steady thermal response in formation (Ramey, 1962)
- Surface system modeled thermodynamically with turbine and system efficiencies, and parasitic pump power
- Can also model classical surface binary co-production system
- Model validated against benchmark solution – Neotec Wellflo 8 and RMOTC Ormat unit

ACCS Model Results: The Base Case

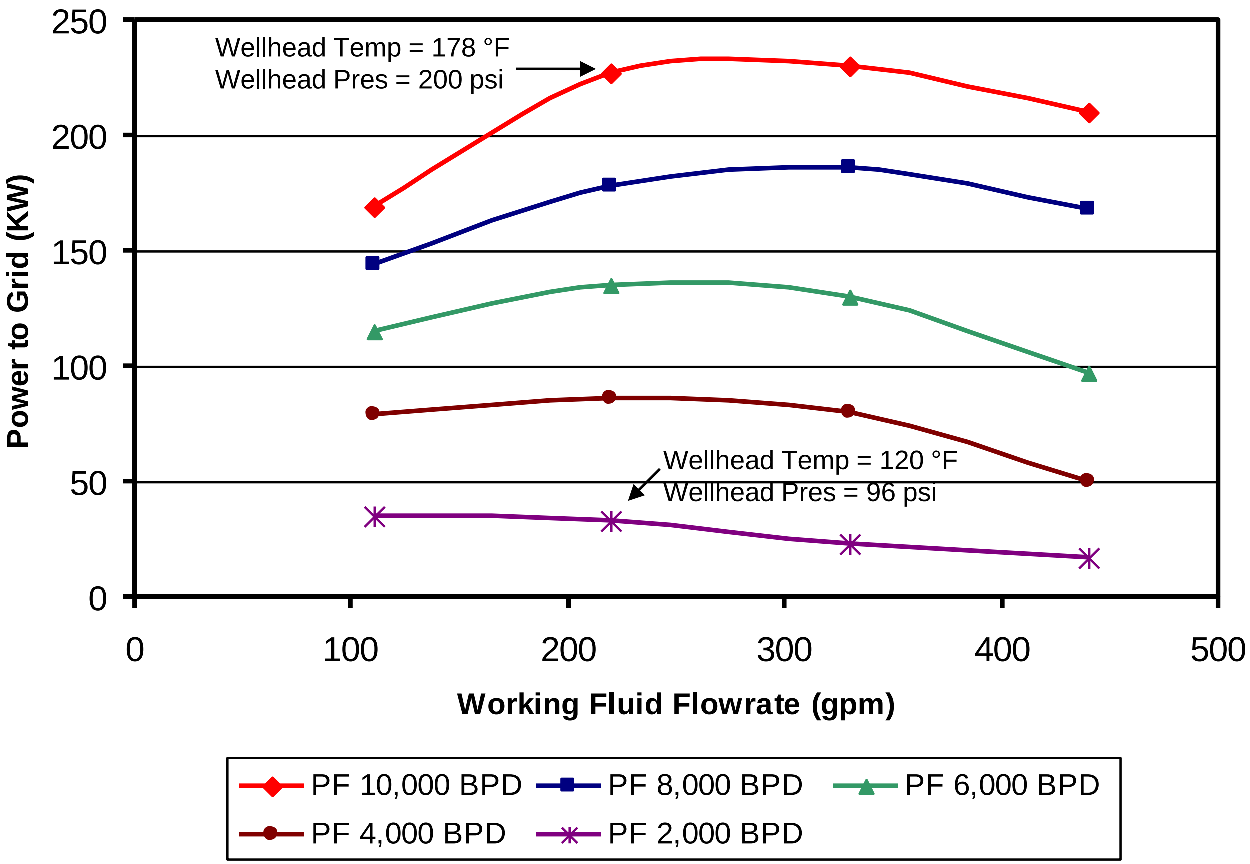


Reservoir Depth (ft)	10,000
Circulation Depth (ft)	2,000

Tubular	OD (in)	ID (in)
Tubing (PF)	4.500	3.826
Working Fluid Return	7.000	6.538
Working Fluid Delivery	9.625	8.535
Bottom Section (PF)	7.000	6.538

Reservoir Fluid	Temperature (°F)	SIBHP (psi)	PI (gpm/psi)
Water	260	4,500	2.5

ACCS Model Results: Fluid Rates



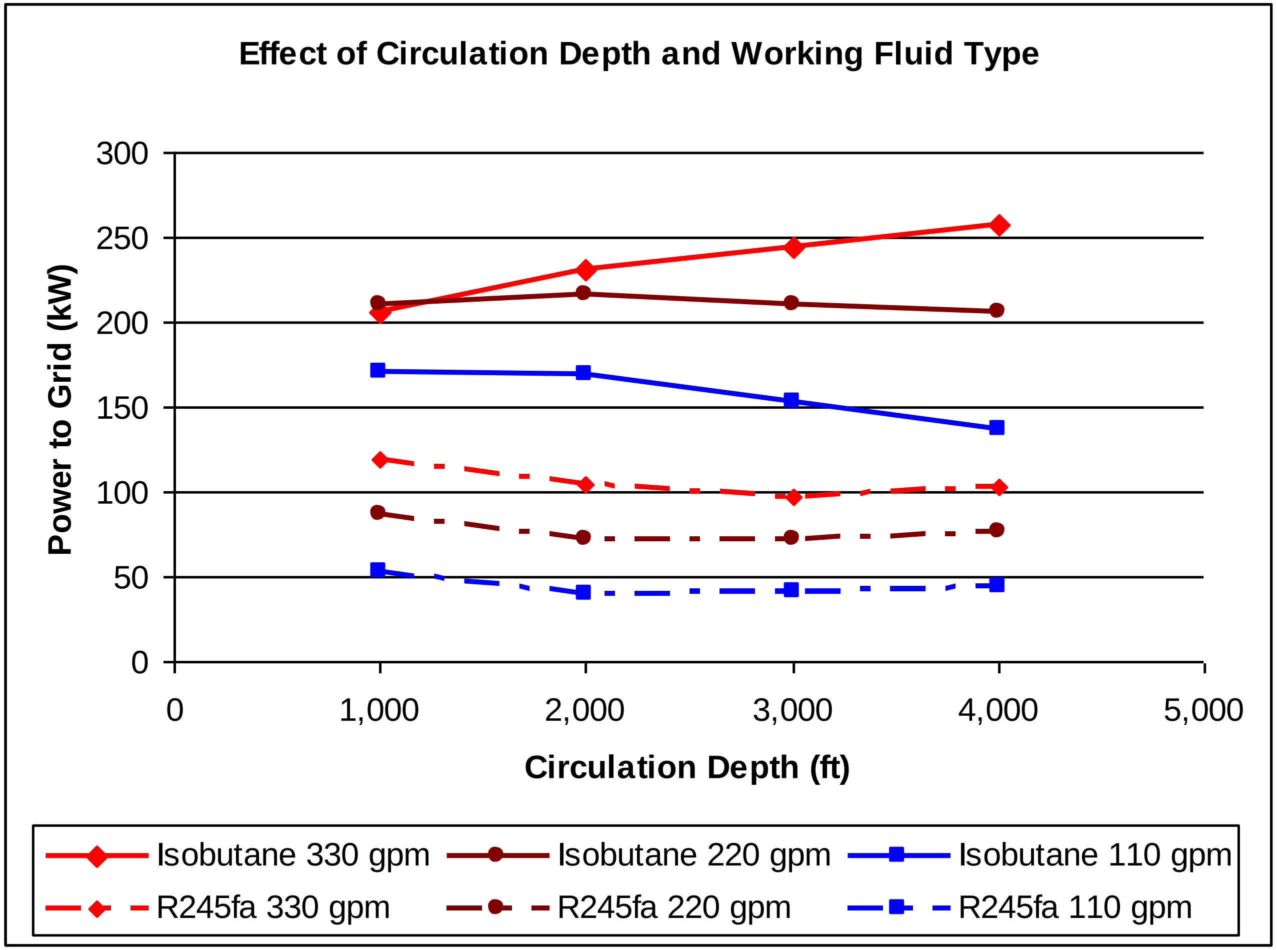
An optimum WF rate exists for a given production rate.

Further optimization possible by changing circulation depth or WF

ACC System	
WF WH Temp (°F)	178.3
WF WH Pres (psi)	200
PF WH Temp (°F)	200.8
PF WH Pres (psi)	173
Conventional Binary Plant	
PF WH Temp (°F)	244.6
PF WH Pres (psi)	229
PF BH Temp (°F)	260
PF BH Pres (psi)	4500

24W / BPD at 10,000 BPD; compares to 26 W / BPD for Classical System (Sanyal and Butler, 2010); Further optimization is possible

ACCS Model Results: Circulation Depth and WF Type



Isobutane is better WF for this specific application.

There is an optimum circulation depth for each case.

Results likely to be different for different cases.

ACCS Option: Downhole Pump

- Extracts pressure energy from working fluid and creates additional drive for produced fluid
  - Takes advantage of the thermo-siphon effect
  - Impact on thermal energy is minimal
  - Enhances vaporization of working fluid in return path
- First proposed by Hugh Mathews in the 1980’s in his “Gravity Head” System
- A commercial application is currently under development by **Geotek Energy** of Midland, TX.

Summary

- Designed the Annular Circulation Co-Production System (ACCS) as an alternative for co-production of thermal energy.
- Developed a rigourous thermal-hydraulic model to study this system.
  - Energy recovery comparable to conventional binary-cycle approach
  - Offers several attractive features:
    - *Greater tolerance to decline in reservoir rates*
    - *Greater range of application*
    - *Potential for continuous optimization of energy*
    - *Ability to extract thermal energy from produced oil and gas, in addition to water*