Process flow and steam gathering system

Session VI

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Presentation overview

• Presentations reviewing different cycles and design process
• Demonstration of thermodynamic models for different working cycles
• Calculated example showing methods used within geothermal steam gathering system design
Lindal diagram

- Industrial (e.g. drying)
- Power generation
- Greenhouses
- Space heating
- Fish farming
- Soil heating
- Snow melting
- Balneotherapy
Geothermal power generation

Power Generation Technology

- Supercritical
- Dry steam, flash
- Binary

Temperature, °C

Plant power, MW
Geothermal in Iceland
Process flow

• A review of thermodynamic cycles used in geothermal energy production. Flash steam cycles with single flash and double flash as well as different binary cycles as ORC and Kalina Cycle are introduced and compared
Binary technology

Main features:

• Power generation by means of closed thermodynamic cycle
• Geothermal fluid loop and power cycle are completely separated
• Nearly zero emission plant
• Suitable for integration with other energy sources (solar, biomass, waste....)
Low enthalpy fluid gathering

- Doublet: (1 production well, 1 injection well) is the typical layout
- Triplet is also used
- Multi-well, with several modules is being discussed
The geothermal fluid loop
The downhole pump: lineshaft (LSP), submersible (ESP), hydraulically driven (HTP)

Main issues: depth, pumping head, temperature, reliability and availability

Source: TP-Geoelec) “Strategic Research Priorities for Geothermal Electricity»
Power cycle: the reference ideal cycle for all liquid heat source, with constant heat capacity.

\[ P = \dot{Q}_{IN} \cdot \eta \]

REMIND: the cycle efficiency depends only on the geothermal source and ambient temperatures.

\[ \eta = 1 - \frac{T_{amb}}{(T_{geoth,source} - T_{reinjection})} \cdot \ln \left( \frac{T_{geoth,source}}{T_{reinjection}} \right) \]
Power cycle: the real cycle
Concepts for binary cycle design

• **Objectives:**
  - high efficiency
  - => second law analysis: minimize second law losses
  - low cost, €/kW
  - => optimize component design
  - Critical choice: the cycle working fluid
Concepts for binary cycle design
The heat introduction process
ORC Cycle working fluid selection

• The fluid must be suitable for the selected geothermal source and plant size (Fluid critical temperature and pressure, molecular complexity are relevant)
  
• Hydrocarbons
• Refrigerants
• Others

Important issues: environmental, toxicity, flammability
Cycle selection: simple or recuperative subcritical or supercritical
Kalina plant
working fluid: ammonia-water mixture
Cost & component sizing

- Turbine sizing
- Selection of $\Delta T_{\text{pinch point}}$ for the heat exchangers: the smaller the $\Delta T_{\text{pinch point}}$, the higher the efficiency but also the heat exchanger cost
Component sizing and performance

Example for heat recovery case (Diesel engine)

Source: C. Pietra et al. 2010
Demonstration of model

• ORC preliminary evaluation
The plant power balance

Net plant power = (turbine power – pump power) - auxiliaries power consumption
Binary plant performance

Geothermal binary power plant efficiencies

Cycle efficiency

Geothermal fluid temperature, °C
Back Pressure Steam Power Plant

2 phase flow

Steam separator

Vapor

Turbine

Generator

P_{high}

P_{low}

Production wells

Reinjection wells
Back pressure unit - layout
Steam Power Plant with Condenser

- Geothermal fluid
- Production wells
- Steam separator
- Mist eliminator
- Steam generator
- Silencer
- Turbine
- Condenser
- Condensate
- Vacuum pump
- Cooling tower
- Reinjection wells
- Condensate
- Generator
Hellisheiði-Single flash

Hellisheiði power plant
Steam Power Plant – Double Pressure

Production wells

Two phase flow

Steam separator

HP steam

Turbine - generator

LP steam

Condenser

LP Steam separator

Two phase flow

Reinjection wells

Cooling system

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Svartsengi – the “Octopus”
Steam Power Plant – Double Flash

- Steam supply system
- Production wells
- Reinjection wells
- Primary steam
- Secondary steam
- Steam separator
- LP Steam separator
- Condenser
- Turbine - generator
- LP Turbine - generator
- Cooling system
- T_{cw}
Hellisheiði – low pressure unit
Steam Power Plant w. District Heating

Steam supply system → Steam separator → District heating system → Primary steam → Turbine-generator

Condenser → To district heating

Cooling system → $T_{cw}$

Production wells → Reinjection wells → Freshwater wells

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Hellisheiði - Districh heating plant
The Hellisheiði Power Plant
Steam Gathering System

- This session will present an overview of the design process of a geothermal steam gathering system with emphasis on particularities of the geothermal fluid.
Steam Supply - Preliminary P&ID

- Production wells
- Geothermal water
- Re-injection wells
- Two phase flow
- Steam separators
- Mist separators
- Steam
- Pressure relief
- Emergency exhaust
- Turbines
- Generators
- Cooling towers
- Condensers
Nesjavellir Power Plant

- Cooling towers
- Steam pipelines
- Power Plant
- Well
- Two phase flow
- Steam vent station
- Separation station

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Steam Supply - Design

- Design standards
  - Standards i.e. Pressure directive 97/23/EC
- Pressure selection
  - Chemical constraints
  - Power generation
  - Productivity curves
Typical productivity curves
Steam Supply – Design load

• Constant load
  – Weight
  – Pressure

• Variable load (depending on location)
  – Wind
  – Snow
  – Earthquake
  – Ash

• Frictional load
  – Thermal expansion
  – Friction
Steam Gathering System - Pipelines

- Pipe laying
  - Under ground
  - Above ground
- Material selection
- Pipe size
  - Pressure/temperature
Steam Supply System – Pipelines

![Graph showing the relationship between pipe diameter and flow for 7 bar-a and 20 bar-a systems.](image-url)
Steam gathering system – route selection

- Public safety
- Environmental impact
- Restriction on land
- Cost efficiency
Steam pipelines
Steam Supply - Layout

- Central separation station
- Satellite separation stations
- Individual separators

Source: Di Pippo
Power plant layout
Steam Supply - Separators

- Cyclone separators
- Gravity separators

- Efficiency
  - Steam separator and moisture separator should together achieve 99.99 % bw. liquid removal or better
Calculated example

• The presenter will go through a calculated example to show methods used for basic engineering within steam gathering system design. The example taken will be connected to the special conditions encountered in geothermal energy.
Example

• Example for 1200 kJ/kg well enthalpy
  – 40-50°C condensing temperature
  – Back pressure

• Objective
  – Maximize the power production
• Assumptions
  – Assume that we know the reservoir enthalpy
  – We know the condenser temperature
  – Assume that separation pressure does not influence the well flow
Example, condensing unit

![Graph showing power generated vs separated temperature for condensing units at 40°C and 50°C.](image-url)
Example, condensing unit

• The maximum power will be 12,4 MW
  – Entalpy = 1200 kJ/kg
  – Condesing pressure 0,075 bara / temperature 40°C
  – Separation pressure 6 bar\textsubscript{a}
  – Flow 100 kg/s

• What if we selected backpressure instead?
Example, back pressure

![Graph showing generated power vs separated temperature for back pressure and condensing, 40°C.](image)
Example, back pressure

• The maximum power will be 6,4 MW
  – Entalpy = 1200 kJ/kg
  – Separation pressure 12 bar$_a$
  – Flow 100 kg/s
Example

• Optimum separation pressure is 6 bar, is that ok?

• Saturation temperature for 1200 kJ/kg is 273°C
Bibliography


• Technology Platform on Geothermal Electricity (TP-Geoelec) “Strategic Research Priorities for Geothermal Electricity» available on the Internet at: www.egec.org


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