Geothermal Energy (Week 10, 4 Nov)
- Power Generation

민기복

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Field trip (석모도 지열개발 프로젝트)

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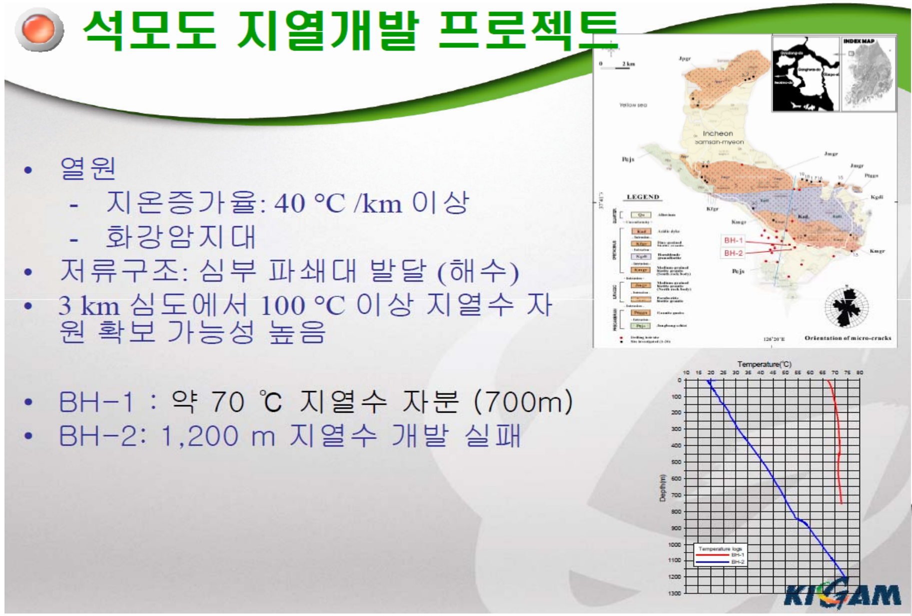
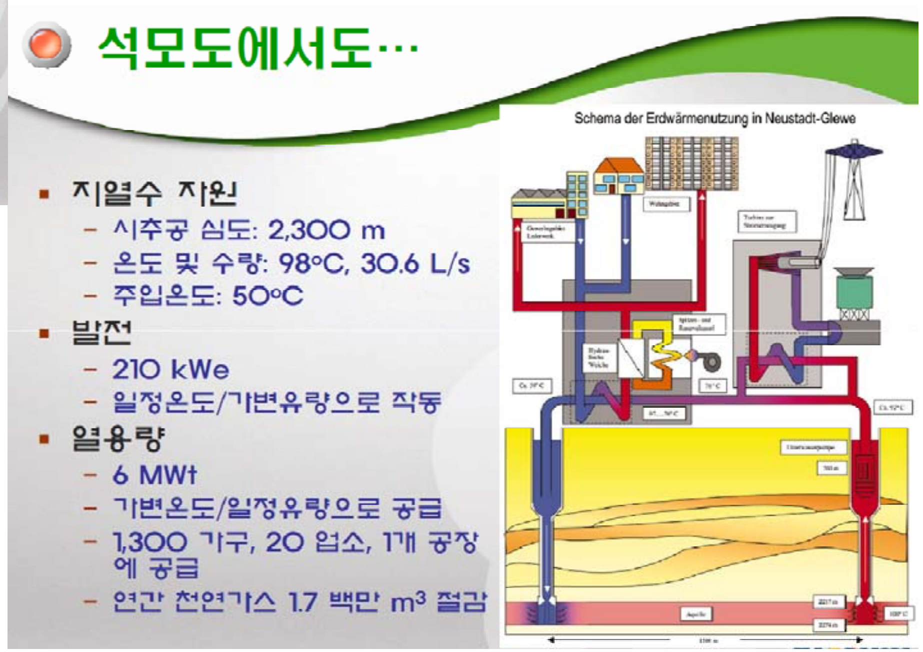


• 20 Nov 2009 (10:00 ~ 18:00)

Tae Jong Lee, 2009



Environmental Impact
General Impact of electricity generation

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- Gaseous emissions to the atmosphere
- Water Pollution
- Solid emissions to the atmosphere
- Noise pollution
- Land usage
- Land subsidence
- Induced seismicity
- Induced landslides
- Water usage
- Disturbance of wildlife habitat and vegetation

Environmental Challenges

- Land subsidence
- Induced seismicity

  } **Can be serious and careful study is needed**

- Induced landslide
- Noise pollution
- Disturbance of wildlife habitat and vegetation

Seismicity induced by fluid injection

shear slip induced by hydraulic pressure increase

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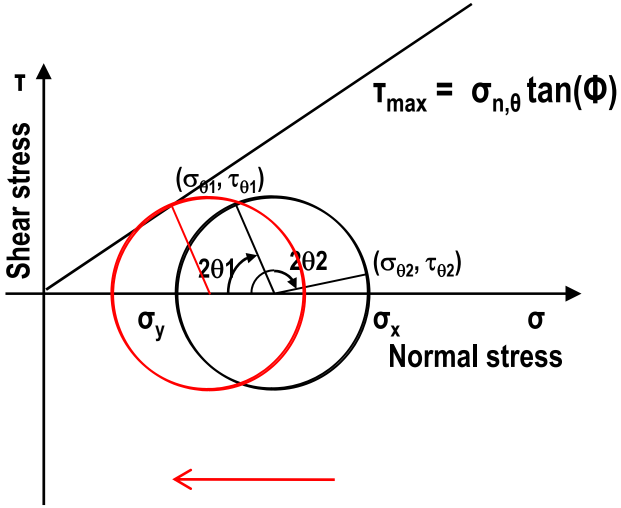
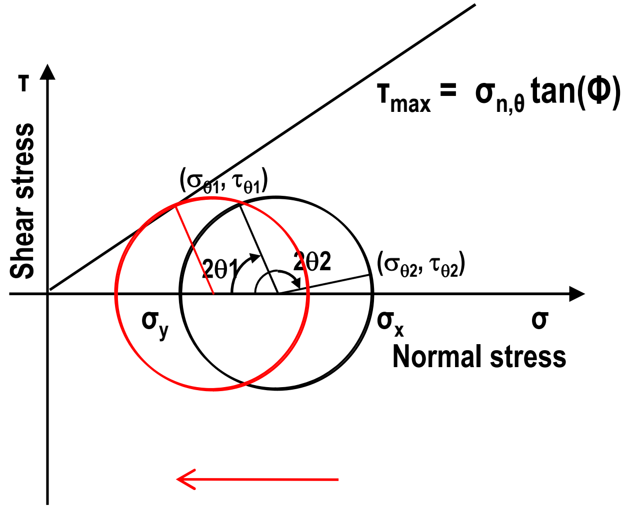
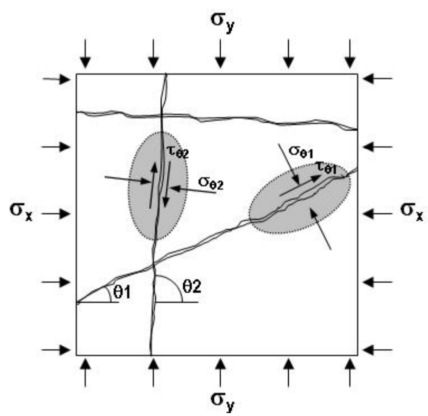


Increase of hydrauilc fluid pressure
← due to injection



Cooling of rock → shrinkage → decrease of stress

- Sources of seismicity – Microseismicity
  - change of hydraulic pressure
  - cooling of rock



Today

- Geothermal Power Generation
  - Power Generation technology cannot be considered in isolation from the geological aspects – we need to understand this.
  - Design consideration
  - Type of Geothermal power generation
  - Status

Types of power generation

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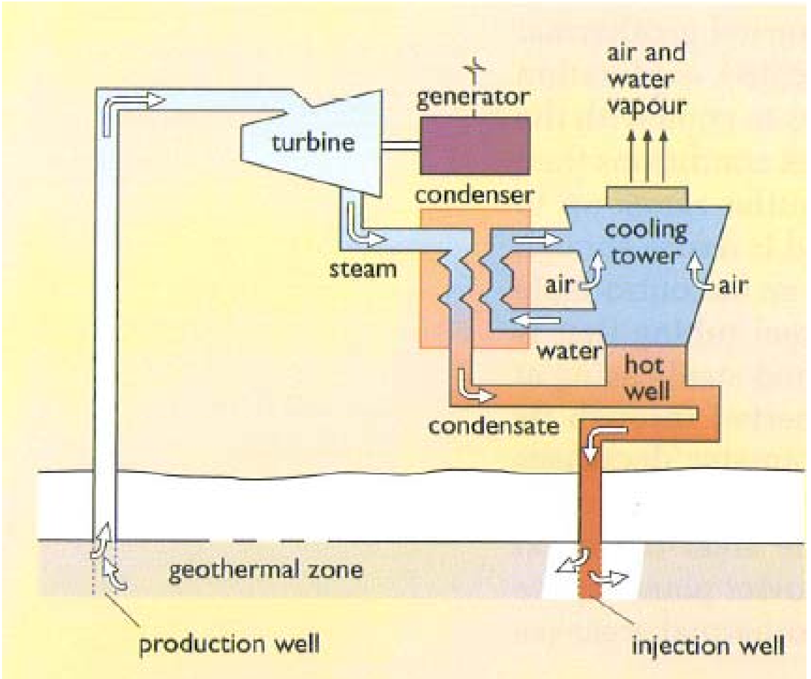
- Dry steam power plant
- Flash steam power plant
  - Single flash (1-flash)
  - Double flash (2-flash)
  - Triple flash (3-flash)
- Binary cycle power plant
  - Binary cycle
  - Combined flash-binary
- Hybrid fossil-geothermal systems
- Combined heat and power plant

Types of power generation
Dry steam power plant (건조증기방식)

- Dry steam spin the turbine
- The most efficient type
- However, dry steam reservoir is not common (~5% of reservoir >200ºC)



(a) dry steam power plant

Boyle, 2004, Renewable Energy

Types of power generation
Flash steam power plant (증발증기 방식)

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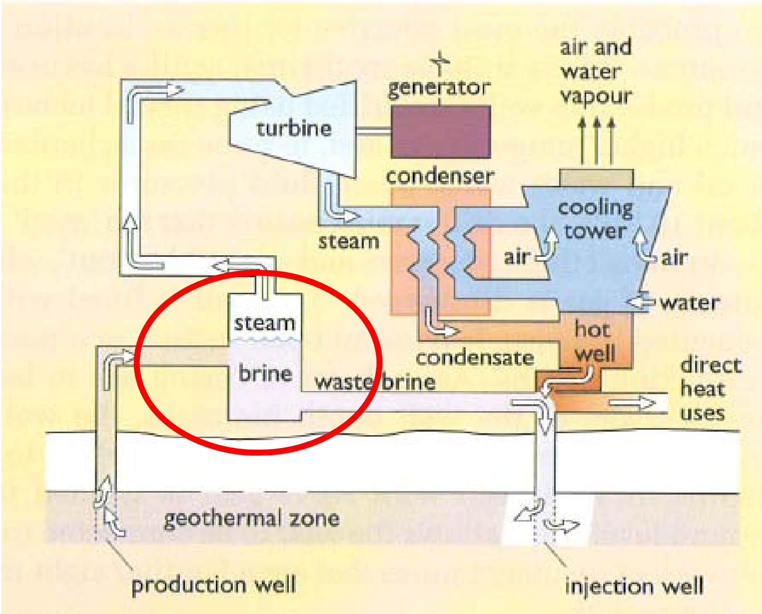
- Use separator to separate into distinct steam and liquid phase
- Mainstay of geothermal power industry
- Single/double/triple flash



(b) single flash steam power plant

Boyle, 2004, Renewable Energy

Types of power generation
Flash steam power plant

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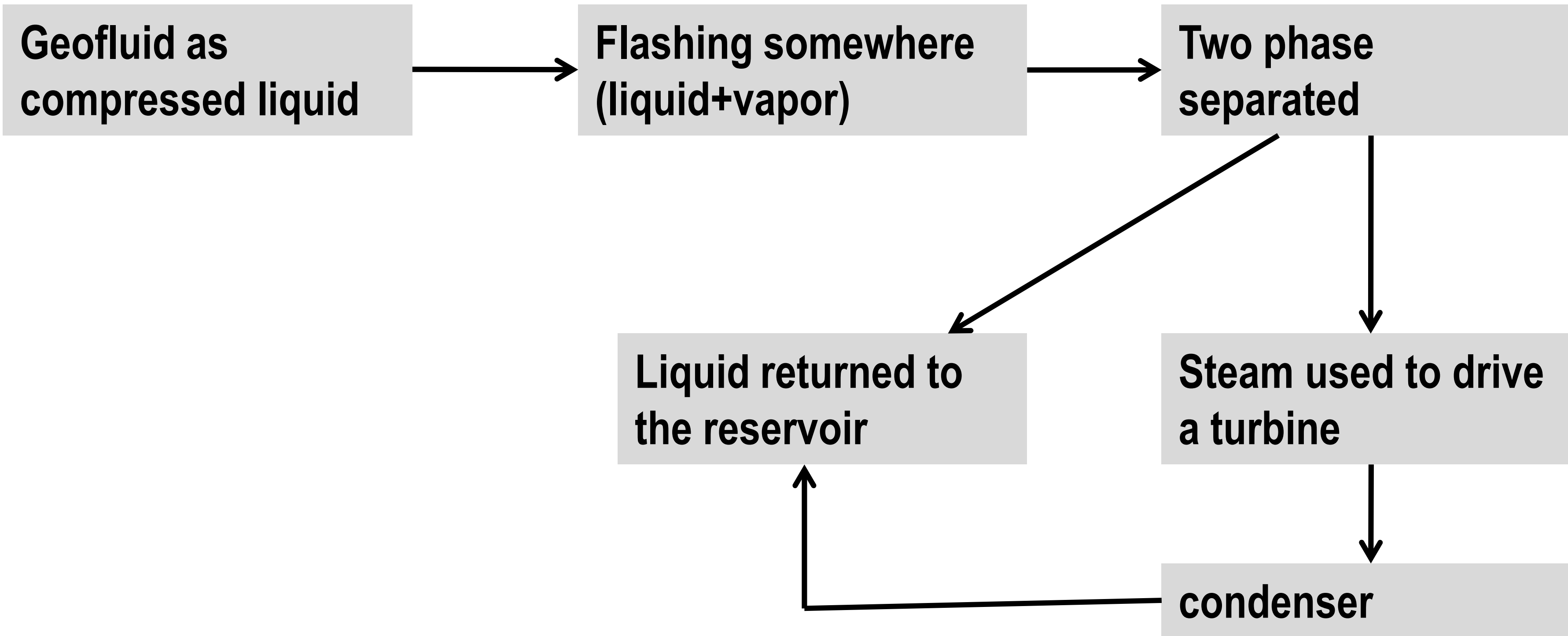
- General structure



Types of power generation
Flash steam power plant

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- Flashing process: transition from a pressurized liquid to a mixture of liquid and vapor, as a result of lowering the geofluid pressure below the saturation pressure* corresponding to the fluid temperature (DiPippo, 2008)
- The flashing process occur in (flashing point may change though);
  - reservoir as the fluid flow through the permeable formation with an accompanying pressure drop
  - production well anywhere from the entry point to the wellhead
  - Inlet to the separator as a result of a throttling (조절) process by a control valve

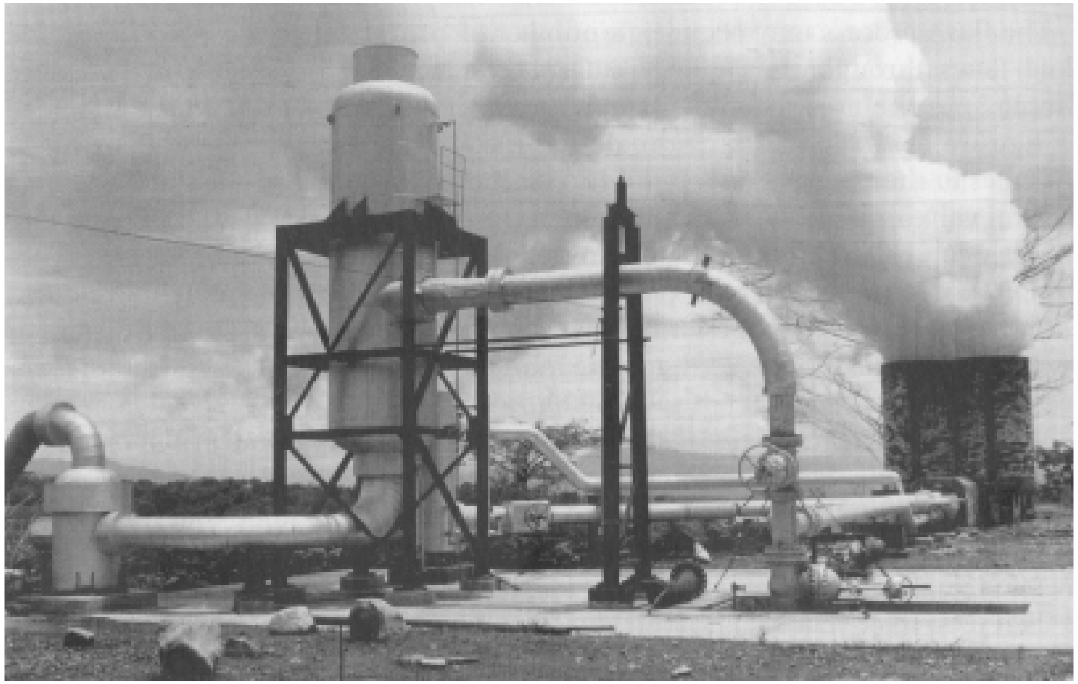
***Saturation pressure: the pressure for a corresponding saturation temperature at which a liquid boils into its vapor phase**

Design consideration

- Separator
- Gathering system
- Pressure losses
- Turbine blade integrity
- condenser

Design consideration
Separator

- Separator:
  - Important to separate two phase efficiently - liquid entrained in the steam can cause scaling and/or erosion of piping and turbine component



Wellhead separator system at Ahuachapan, El Salvador (DiPippo, 2008)

Design consideration
Gathering system

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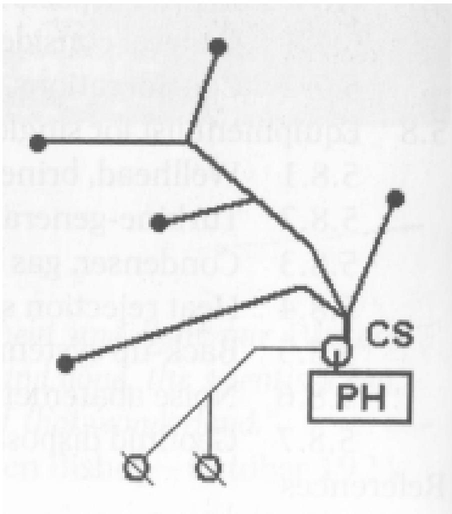
- Gathering system design:
  - A typical 30MW 1-flash power plant needs 5-6 production wells

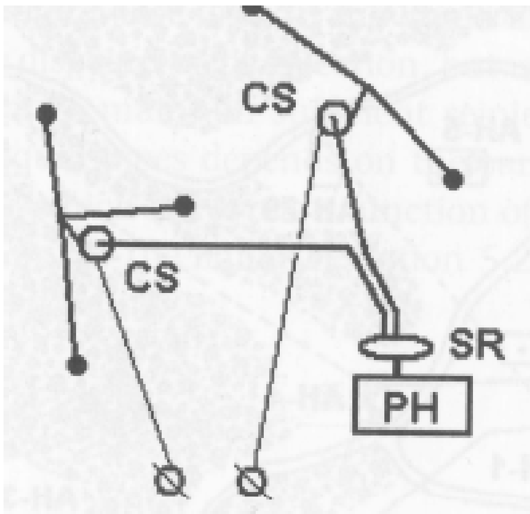
DiPippo, 2008

● : production wells
○ : injection wells

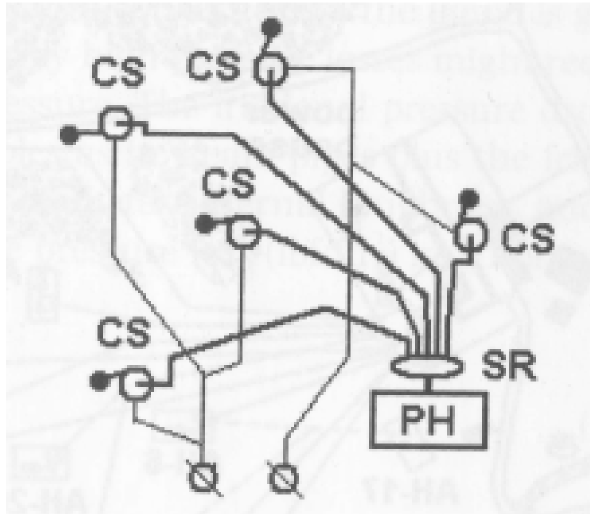
PH: powerhouse
CS: cyclone separator
SR: steam receive



Separator at the power house



Satellite separator



Individual wellhead separaator

Design consideration
Pressure losses

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- Frictional pressure loss in the steam line

$$\Delta P_f = 0.8 \frac{L\dot{m}^{1.85}}{\rho D^{4.97}}$$

  - L: length of the pipe (ft)
  - m: mass flow rate (lbm/s)
  - ρ: density (lbm/ft^3)
  - D: inside diameter of the pipe (in)
- Diameter plays a huge role in the pressure drop
  - Balance between larger pipe and extra cost (thermodynamic-economic optimization study)

Design consideration
Pressure losses

- Frictional pressure loss in the liquid line

$$\Delta P_f = 1.75 \times 10^{-4} \frac{fL\dot{m}^2}{\rho D^5}$$

  – f: friction factor affected by pipe internal roughness, Reynolds number and Diameter

- Pressure loss due to gravity

$$\Delta P_g = \rho g \Delta H$$

- Pressure loss in a two-phase, steam-liquid pipeline is far more complex

Design consideration
Blade & Condenser

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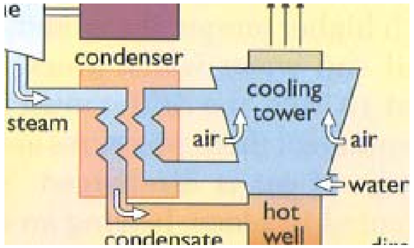
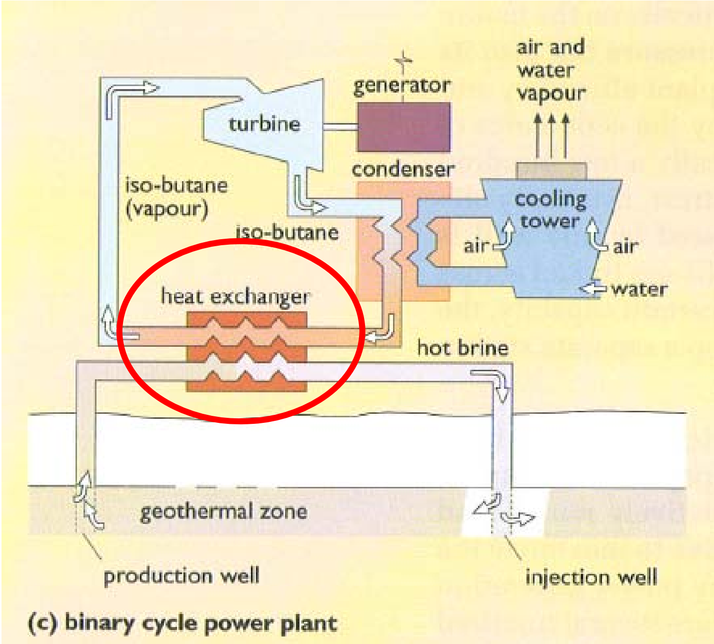
- Blade integrity:
  - Typical geothermal turbine inlet steam conditions are saturated with pressures that range from 0.5 – 1 MPa. As a result significant amounts of moisture appear in the steam path → significant amount of moisture → blades erosion
- Condenser:
  - Geothermal steam condenses when it passes through cooling water
  - CO_2, H_2S in steam do not condense → need to be removed (otherwise increase overall condenser pressure)



Types of power generation
Binary cycle power plant

- Uses a secondary working fluid with a lower boiling point than water: pentane, butane
- Well established technology for utilizing low- to moderate temperature geothermal fluids
- Also known as Organic Rankine Cycle (ORC) plant
- With geofluid temperature < 150°C
- 162 units in operation which is 32% of all geothermal units (DiPippo, 2008*). But this generate only 4% of the total power



Boyle, 2004, Renewable Energy

*As of May 2007 and slight change occurred

Types of power generation
Hybrid combined flash-binary

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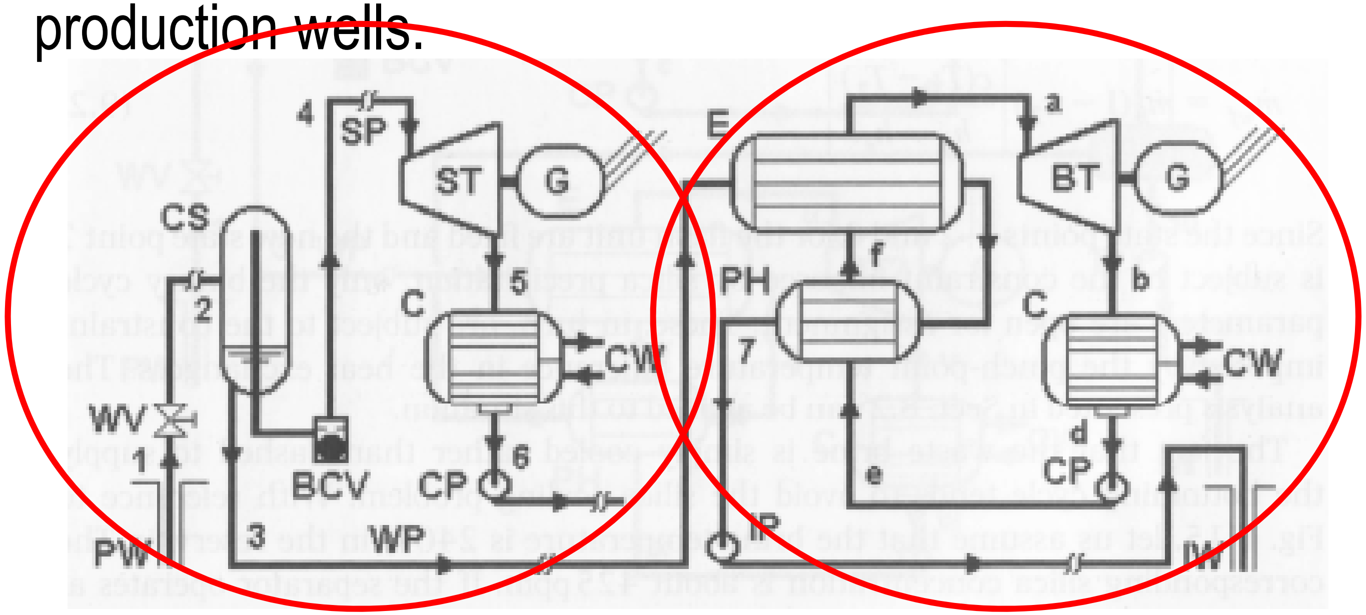
- Combined flash-binary
  - add a binary unit between the separators and the reinjection wells
  - Additional power generated by the binary cycle without any new production wells.



flash **binary**

DiPippo, 2008

Types of power generation
Hybrid fossil-geothermal systems

- Combine fossil and geothermal energy inputs
- Fossil-superheat system
  - Fossil fuel is used to enhance the performance of geothermal plants
- Geothermal-preheat system
  - Use geothermal fluids to enhance the performance of fossil-fueled power plants
  - Geothermal resource must be located close to the site of the fossil plant

Types of power generation
Combined heat and power plants

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- Combine power generation and direct heat usage in a single geothermal plant
- Overall utilization efficiency of the resource is enhanced
- When heat is provided to the community adjacent to the plant, it demonstrates to the community that the plant is a ‘good neighbor’.

Status

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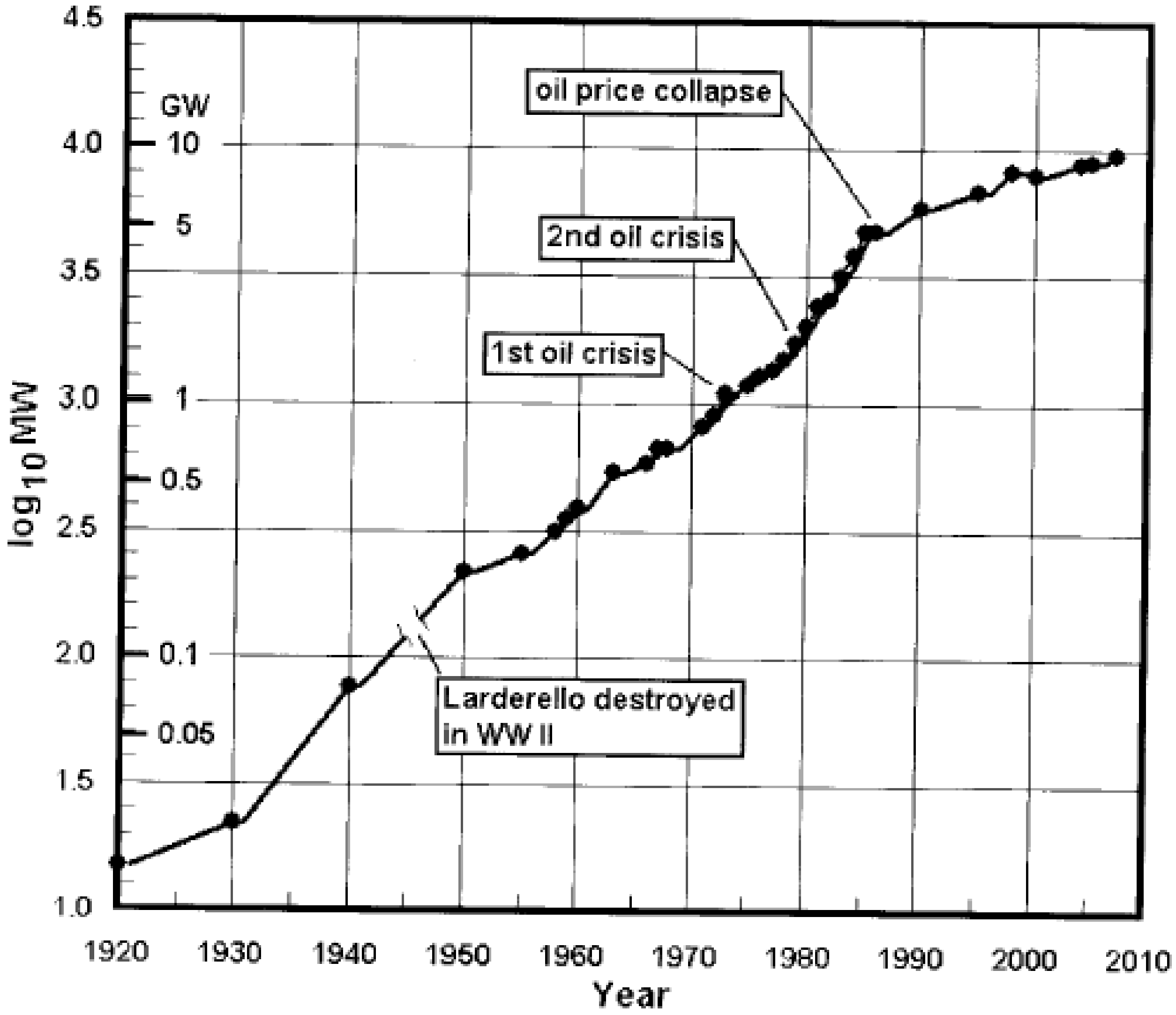

DiPippo, 2008

Status of geothermal power plant

DiPippo, 2008

Rank	Country	No. units	MW
1	USA	193	2556
2	Philippines	58	1980
3	Mexico	37	953
4	Italy	33	811
5	Indonesia	15	807
6	New Zealand	39	572
7	Japan	22	538

- Total: 504 units, 9513 MW, Average MW/unit: 19
- Ex) Australia: 1 unit, 0.15 MW → in ten years???
- In the next 50 years, 100 GW in US alone (MIT, 2006)

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Table A.3 Geothermal power plants: by installed MW for each type of plant.

Country	Dry steam	1-Flash	2-Flash	3-Flash	Binary	Flash-binary	Hybrid	Total
United States	1462	49	707.3	49	257.2	25	6	2555.5
Philippines	0	1325.44	496.74	0	15.73	142	0	1979.91
Mexico	0	480	470	0	3.3	0	0	953.3
Italy	790.5	20	0	0	0.7	0	0	811.2
Indonesia	140	667	0	0	0	0	0	807
New Zealand	55	85	226.8	44.8	21.5	139	0	572.1
Japan	23.5	351.75	160	0	2.49	0	0	537.74
Iceland	0	351.7	60	0	10.7	0	0	422.4
El Salvador	0	160	35	0	9.3	0	0	204.3
Costa Rica	0	144	0	0	19	0	0	163
Kenya	0	116.4	0	0	1.8			
Nicaragua	0	101.4	0	0	7.5			
Russia	0	79	0	0	0			
Papua-New Guinea	0	56	0	0	0			
Guatemala	0	0	0	0	0			
Turkey	0	20.4	0	0	7.4			
China (Tibet)	0	0.6	26	0	1			
Portugal (San Miguel)	0	3	0	0	13	0	0	16
France (Guadeloupe)	0	4.7	10	0	0	0	0	14.7
Austria	0	0	0	0	1.25	0	0	1.25
Thailand	0	0	0	0	0.3	0	0	0.3
Germany	0	0	0	0	0.2	0	0	0.2
Australia	0	0	0	0	0.15	0	0	0.15
Totals	2471	4015.39	2191.84	93.8	372.52	362.6	6	9513.15
Percent of total	25.97	42.21	23.04	0.99	3.92	3.81	0.06	100.00

Dry steam: 26%
Single flash: 42%
Double flash: 23%
Binary: 8%

DiPippo, 2008

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Table A.4 Geothermal power plants: by number of units for each type of plant.

Country	Dry steam	1-flash	2-flash	3-flash	Binary	Flash-binary	Hybrid	Total
United States	25	3	28	1	125	10	1	193
Philippines	0	37	10	0	6	5	0	58
New Zealand	1	3	9	4	6	16	0	39
Mexico	0	29	5	0	3	0	0	37
Italy	31	1	0	0	1	0	0	33
Iceland	0	14	2	0	8	0	0	24
Japan	1	16	3	0	2	0	0	22
Indonesia	3	12	0	0	0	0	0	15
China - Tibet	0	2	10	0	1	0	0	13
Russia	0	12	0	0	0	0	0	12
Guatemala	0	0	0	0	0	9	0	9
Kenya	0	6	0	0	1			
El Salvador	0	5	1	0	1			
Nicaragua	0	6	0	0	1			
Costa Rica	0	4	0	0	1			
Papua-New Guinea	0	6	0	0	0			
Portugal (San Miguel)	0	1	0	0	0			
Turkey	0	1	0	0	1			
France (Guadeloupe)	0	1	1	0	0	0	0	2
Austria	0	0	0	0	2	0	0	2
Thailand	0	0	0	0	1	0	0	1
Germany	0	0	0	0	1	0	0	1
Australia	0	0	0	0	1	0	0	1
Totals	61	159	69	5	162	46	1	504
Percent of total	12.10	31.55	13.69	0.99	32.14	9.13	0.20	100

Dry steam: 12%
Single flash: 32%
Double flash: 14%
Binary: 41%

DiPippo, 2008

statistics

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Summary of geothermal power plants: by # of units and installed MW (DiPippo, 2008)

Type	Dry Steam	1-flash	2-flash	3-flash	Binary/flash-binary	hybrid	Total
No. unit	61	159	69	5	208	1	504
No. unit,%	12	32	14	1	41	0.2	100
MW. totals	2471	4015	2192	94	735	6	9513
MW, %	26	42	23	1	8	0.06	100
MW/unit	41	25	32	19	2.3/7.88	6	19

– MW/unit: Dry steam>2 flash > 1 flash> binary

Today

- Geothermal Power Generation
- Design consideration:
  - Separator
  - Gathering system
  - Pressure losses
  - Turbine blade integrity
  - condenser
- Type of Geothermal power generation
- Status

References

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- DiPippo, 2008, Geothermal Power Plants, 2nd Ed., Elsevier
- MIT, 2006, The future of geothermal energy - Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st century, US Department of Energy, http://www1.eere.energy.gov/geothermal/future_geothermal.html