Thermal loop design aspects in Ultra Hot Geothermal Systems

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Abstract

The objective of this work is to make recommendations for the surface thermal loop of a deeper exploratory well to be drilled in Los Humeros, which is expected to tap a supercritical geothermal reservoir of pressures and temperatures much higher than the ones recorded in existing wells. Such a well should deliver highly more corrosive and abrasive fluids than standard high enthalpy wells, due to entrained acid gases (HCl and HF) and silica. Non condensable gases (CO_2 and H_2S) should be in much less concentration. Very few such wells are available worldwide, the most important of which are IDDP-1 and IDDP-2.

The thermal loop configurations for the exploitation of ultra-hot geothermal wells proposed in the literature are (i) central heat exchanger with binary plant, (ii) steam purification by wet scrubbing and condensing power plant and (iii) steam purification by dry scrubbing and condensing power plant, of which only wet scrubbing has been tested in IDDP-1 well and for limited time only.

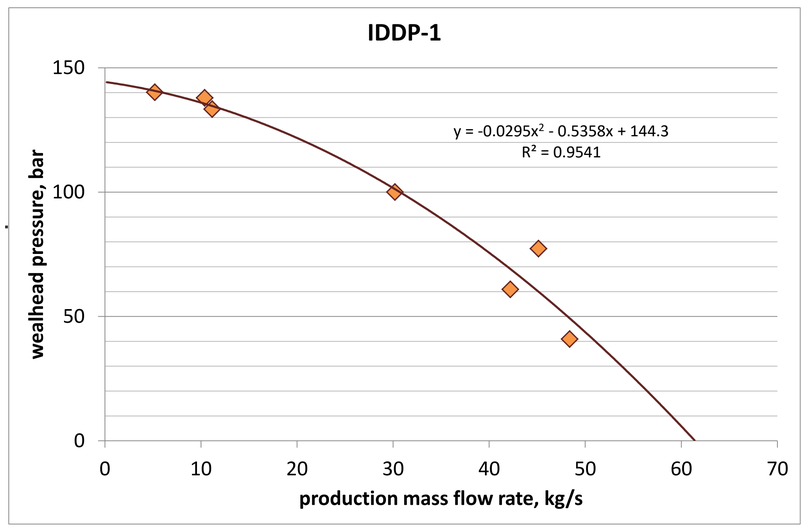
In Los Humeros geothermal system, the average well produces two phase fluid of 2600 kJ/kg specific enthalpy at 20 bar wellhead pressure, delivering 8 kg/s of steam with 3.86% non-condensable gasses (3.26% CO_2 and 0.37% H_2S) and steam condensate pH of 7.2.

The hottest well integrated in the power plant, delivers superheated steam of 283 ^oC temperature, 40 bar pressure and 2900 kJ/kg specific enthalpy. The steam condensate has a pH of 4.47, compared to 2.62 of IDDP-1. Continuous Injection of K_2CO_3 with Amine based inhibitor at the two phase pipeline, upstream of well line connection, has been successful, resulting in reliable operation with zero scaling and zero measured corrosion.

At present, there is no metal or alloy that can guarantee corrosion free operation with the aggressive superhot geothermal fluids. Aluminum is subject to intense pitting corrosion, copper and its alloys are attacked by H_2S, nickel is also attacked by H_2S and metal chlorides, while even the most exotic iron/steel stainless alloys are subject to corrosion above 150 ^oC. Titanium shows the highest resistance and corrosion free operation up to 300 ^oC. Plastic claddings are not stable at such temperatures. Therefore, development and testing of high temperature (>450 ^oC) corrosion inhibitors and/or cladding is compulsory.

As the ultimate goal is to achieve reliable electricity generation from stand-alone superhot geothermal wells, key challenges for the new superhot well are to demonstrate reliable long term fluid treatment and steam purification methods and surface equipment. Suggested field experiments and tests should include optimizing wet scrubbing method for higher conversion efficiency, downhole wet scrubbing, dry scrubbing, as well as new corrosion resistant materials and equipment for operation at extreme temperatures & pressures.

Production features (indicative)



A 5-7 km deep well drilled in Los Humeros is expected to have similar production features with well IDDP-1 as an approximation

	Utilised Los Humeros wells	New dry steam wells	IDDP-1
Fluid type	88% steam 12% brine	superheated steam	superheated steam
Max pressure	68 bar	90 bar	150 bar
Max Temperature	340 ^oC	308 ^oC	450 ^oC
Steam flow rate	8 kg/s	10 kg/s	48 kg/s
Pressure	20 bar	40 bar	45 bar
Sp. Enthalpy	2600 kJ/kg	2900 kJ/kg	3100 kJ/kg

	Utilised Los Humeros wells	New dry steam wells	IDDP-1
Total NCG	3,88%	3,86 %	0,1081 %
CO_2	36150 ppm	32550 ppm	732 ppm
H_2S	1900 ppm	3700 ppm	339 ppm
N_2	300 ppm	1900 ppm	16 ppm
H_2	2 ppm	154 ppm	10 ppm

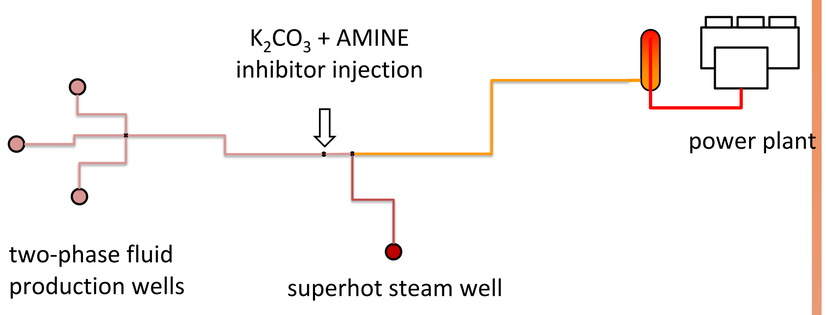
A 5-7 km deep well drilled in Los Humeros is expected to yield superheated steam of higher temperature, pressure, mass flowrate and enthalpy, but with much less non condensable gases.

Fluid chemistry (indicative)

	Utilised Los Humeros wells	New dry steam wells	IDDP-1
Condensate pH	7.2	4.47	2.62
HCl	-	n.a.	95.6 ppm
HF	-	-	7 ppm
NH_3	150 ppm	41 ppm	0.14 ppm
$FeCl_2$	-	19 ppm	19 ppm
B	130 ppm	958 ppm	1 ppm
SiO_2 (silica)	87 ppm	22 ppm	100 ppm
S_8 (sulfur)	-	-	72 ppm
	Moves to brine	Only steam phase	Only steam phase

IDDP-1 is the only ultra hot geothermal well which has been flow tested at present. It delivered fluid, which was extremely corrosive due to entrained acid gases of HCl and HF and had strong scaling tendency of silica and elemental sulfur.

Corrosion inhibition in dry steam well H43



In Los Humeros, injection of inhibitors at the two phase line before the intersection of the H43 steam line, effectively mitigated corrosion allowing the integration of superheated steam wells into the power plant

Materials

Metal alloy	Remarks
Aluminum & its alloys	Pitting and stress corrosion cracking (SCC)
Low carbon steel	Standard in present geothermal power plants
Cast iron	Cannot resist mechanical & thermal sock
Stainless steel	Needs oxygen to remain stainless. Immune to: crevice <20 ^oC; pitting <35 ^oC; SCC <150 ^oC
Nickel	H_2S immunity <65 ^oC; attached by metal chlorides
Copper, brass, bronze, …	H_2S attacks copper
INCONEL	Crevice & pitting immunity <85 ^oC
Silver	
Passivated stainless steel	Protective oxide layer will be eroded in oxygen free media. Immune to pitting corrosion <78 ^oC.
MONEL	Its copper is attacked by H_2S
Hastelalloy C22	Immune to: pitting <102 ^oC; crevice <150 ^oC
Titanium	Immune to corrosion up to 300 ^oC
Titanium grades 19 & 20	Recommended for geothermal brines

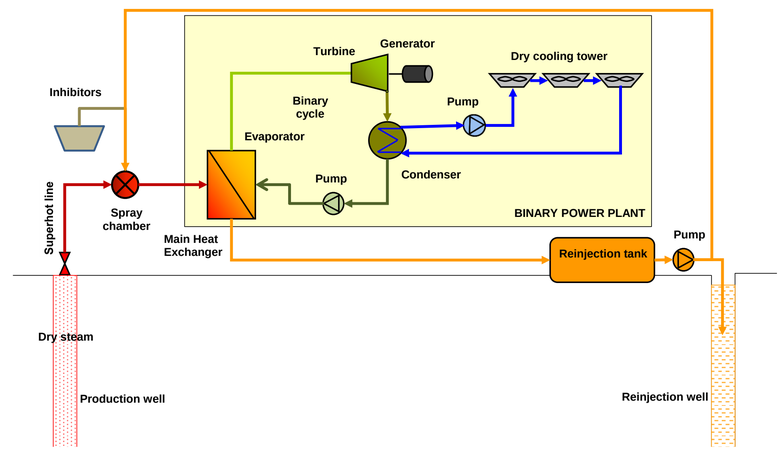
⇒ Increasing corrosion resistance in seawater 25°C

Corrosion free operation with geothermal fluids above 300 °C cannot be guaranteed by even the most resistant alloys

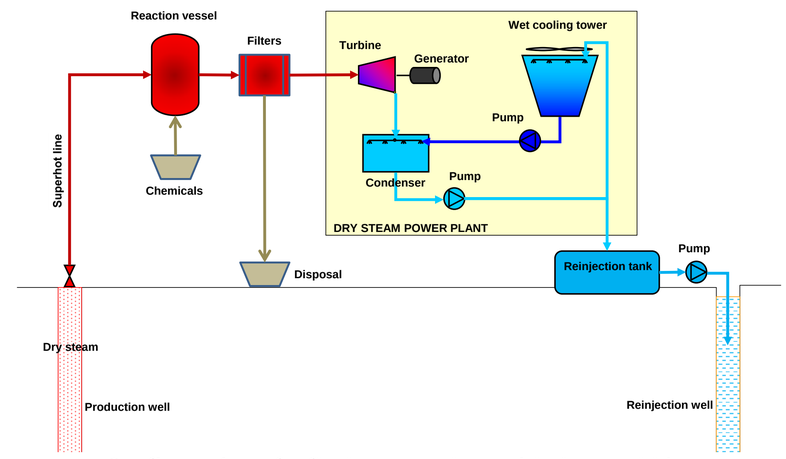
Pipe lining	Remarks
Organic, Epoxy	Max service T < 60-90°C
Cement mortar	Max service T < 100°C
Glass lining	Max service T < 250°C
Zirconium Alumina Ceramic	Limited corrosion resistance
Cast Basalt	Max service T < 450°C; Thermal shock resistance up to ΔT=150°C almost absolutely acid/alkali resistant
Alumina Ceramics	Max service T < 1700°C Limited corrosion resistance
Nitride or Reaction Bonded Silicon Carbide	Max service T < 1500°C Limited corrosion resistance
Aluminum-zircon-silicate cast	Max service T < 1000°C Thermal shock resistance up to ΔT=950°C High chemical resistance
Sintered Silicon Carbide	Max service T < 1750°C Outstanding corrosion resistance

Internal wall pipe linings that seem promising for ultra hot geothermal fluids are cast basalt, cast aluminum-zircon-silicate and sintered silicon carbide

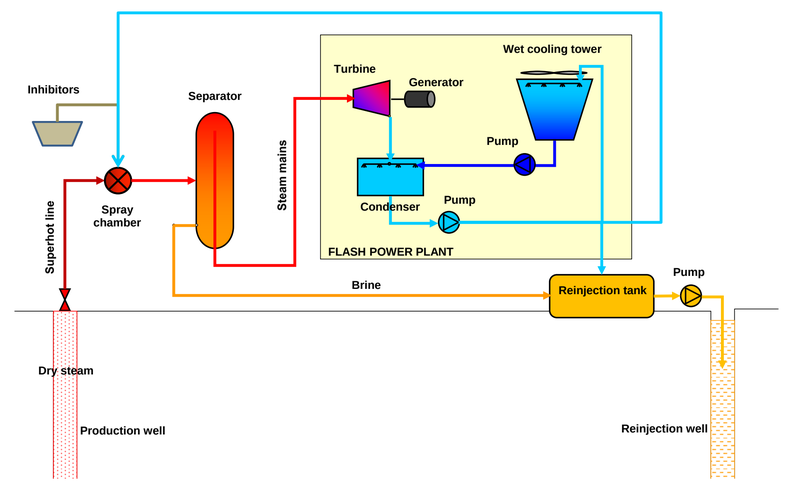
Surface plant



Configuration of a binary plant with main heat exchanger and wet scrubbing with brine



Configuration of a flash steam plant with dry scrubbing



Configuration of a flash steam plant with wet scrubbing with steam condensate

IDDP-1 wet scrubbing experience:

- The acid gas in the steam could effectively be scrubbed away with brine, condensate or cold groundwater.
- The silica dust and the dissolved silica in the steam precipitated when the pressure was reduced and was effectively washed from the steam into the scrubbing water.
- The sulfur in gaseous form, in IDDP-1 steam however, could only be scrubbed from the steam with alkaline water.

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