Thermodynamic modelling and simulation of geothermal power plants: case studies and environmental impact

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Thermodynamic modelling and simulation of geothermal power plants: case studies and environmental impact

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The emissions associated with Geothermal power plant (GTPP) due to geothermal fluids represents a compelling challenge addressed in the last decades. The on-line measuring of pollutants generated by GTPP might result in a complicated task to handle. Simulation of GTPP has become an excellent tool to monitor and control the emission of pollutants. In the present work, the pollutant emissions of GTPP of Hellisheidi (Island), Chiusdino, and Castelnuovo (Italy) are modelled and developed with Unisim Design R480 using well understood thermodynamical models implemented in OLI. The presence of brine in the thermodynamical models has been taken into account. Carbon dioxide, methane, and hydrogen sulfide are the chemical pollutants considered for the process simulation. The AQ framework model in OLI is being used for binary mixtures and non-condensable gas. Furthermore, for liquid mixtures containing more than two components, the MSE-SRK Thermodynamic model is desirable depending on the original geothermal fluid source. The simulation process outcome agrees with experimental data for pressure between 30 and 100 bar within 5% deviation. A systematic study of the spatial distribution of the emissions has been made for the area surrounding the GTPP. Furthermore, an economic evaluation overview has been performed to highlight the equipment needed for maintenance and tool substitution.

UNIVERSITÀ DEGLI STUDI FIRENZE

DIEF Dipartimento di Ingegneria Industriale

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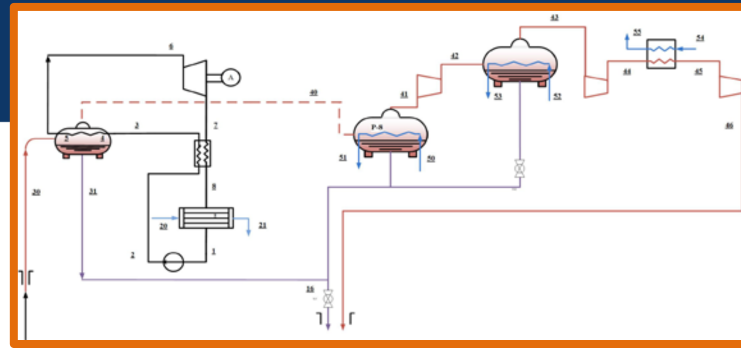

Introduction

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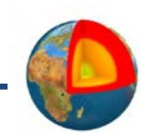


Geothermal energy: Sustainable and the environment

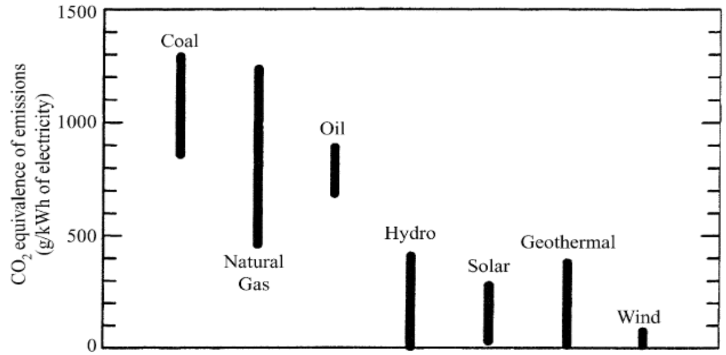
Definition of **Sustainability**: "To satisfy the needs of the present generation without compromising the needs of future generations "

- ✓ Geothermal resources can be considered **renewable**
- ✓ It is listed as alternative energy options in the Government R&D Programs;
- ✓ It is defined as environmentally friendly but within certain limits
- ✓ Geothermal resources are usually exploited by taking the fluid and extracting its heat content -> need for a balance guaranteed by charging speed and by the reinjection of fluids
- ✓ It depends on the technology in use and on the optimization of the processes: they influence the emissions into the atmosphere

Impact	Probability of occurring[b]	Severity of consequences[b]
Air pollution	L	M
Surface water pollution	M	M
Underground pollution	L	M
Land subsidence	L	L to M
High noise levels	H	L to M
Well blowouts	L	L to M
Conflicts with cultural and archeological features	L to M	M to H
Socioeconomic problems	L	L
Solid waste disposal	M	M to H

[a] Pollution can be chemical and/or thermal.
[b] L = low; M = medium; H = high.

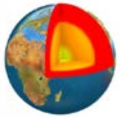
Potential environmental impacts of direct use of geothermal systems



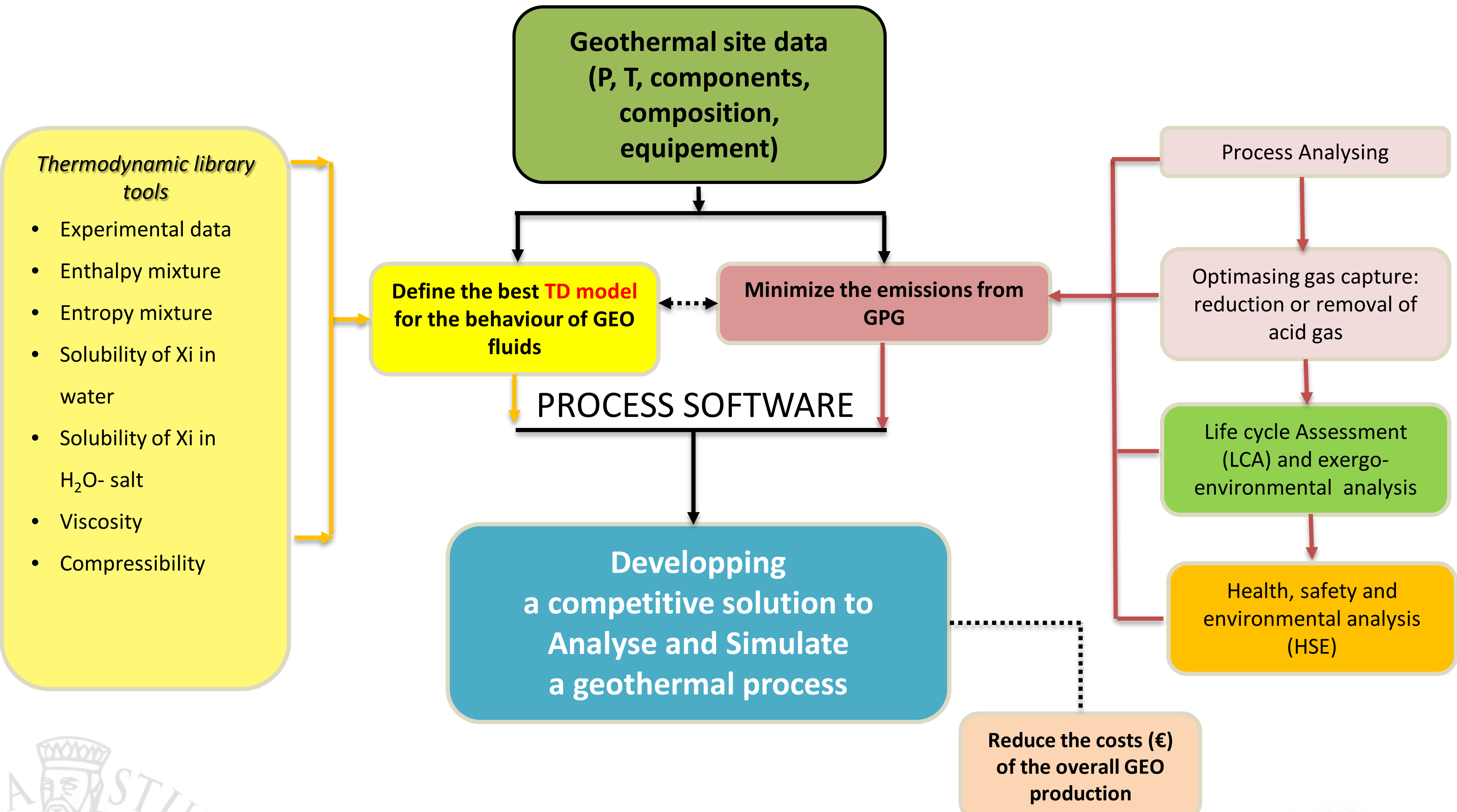
Geothermal like alternative energy to Gas&Oil

Binary type GPPs have minimal impact

These considerations led to the development of this doctoral thesis



Purpose of the Study



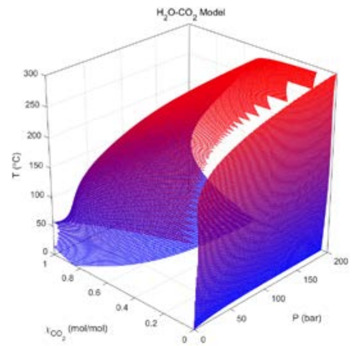
Thermodynamic models on geothermal fluid

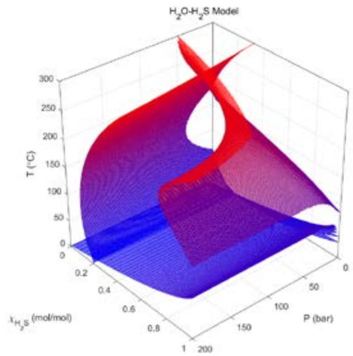
Considered Systems:

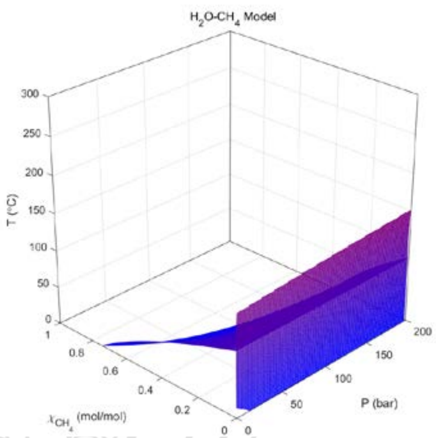
- H_2O-CO_2
- H_2O-H_2S
- H_2O-CH_4
- H_2O-CO_2-NaCl
- H_2O-H_2S-NaCl
- H_2O-CH_4-NaCl
- H_2O-CO_2-H_2S-NaCl

Development of a thermodynamic model valid for different geothermal mixtures applicable to one or more process software in view of an implementation of the geothermal plant for Castelnuovo, Hellisheiði, and Chiusdino GTPP.

AIM OF THE WORK

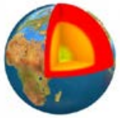






Thermodynamic models (EoS)

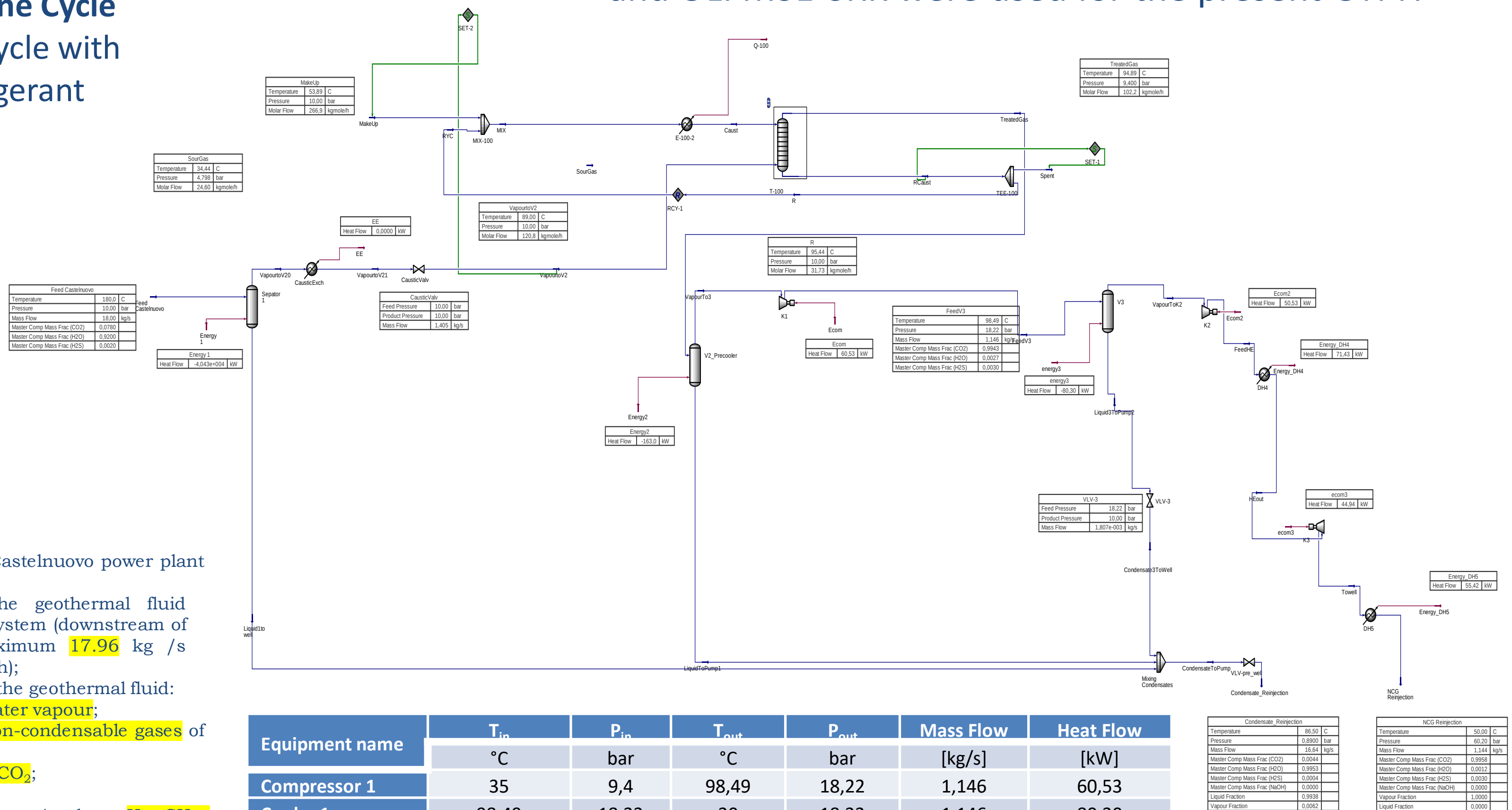
	Solubilities and Mixing Enthalpy			
	Mixtures without salt		***Mixtures with salt***	
	Yes	*No*	*Yes*	*No*
PRH	X		X	
Søreide e Witson	X		X	
CPA	X			X
Duan model	X		X	
Oli system AQ	X		X	
Oli system MSE	X		X	
Oli System MSE- SRK	X		X	
Sour-PR	X			X



Castelnuovo geothermal power plant

To perform the simulation about Castelnuovo GTPP, the Unisim Design® R480 software was used. Both Sour-PR and OLI MSE-SRK were used for the present GTPP.

Organic Rankine Cycle (ORC) binary cycle with R245fa refrigerant



The characteristics of the Castelnuovo power plant are:

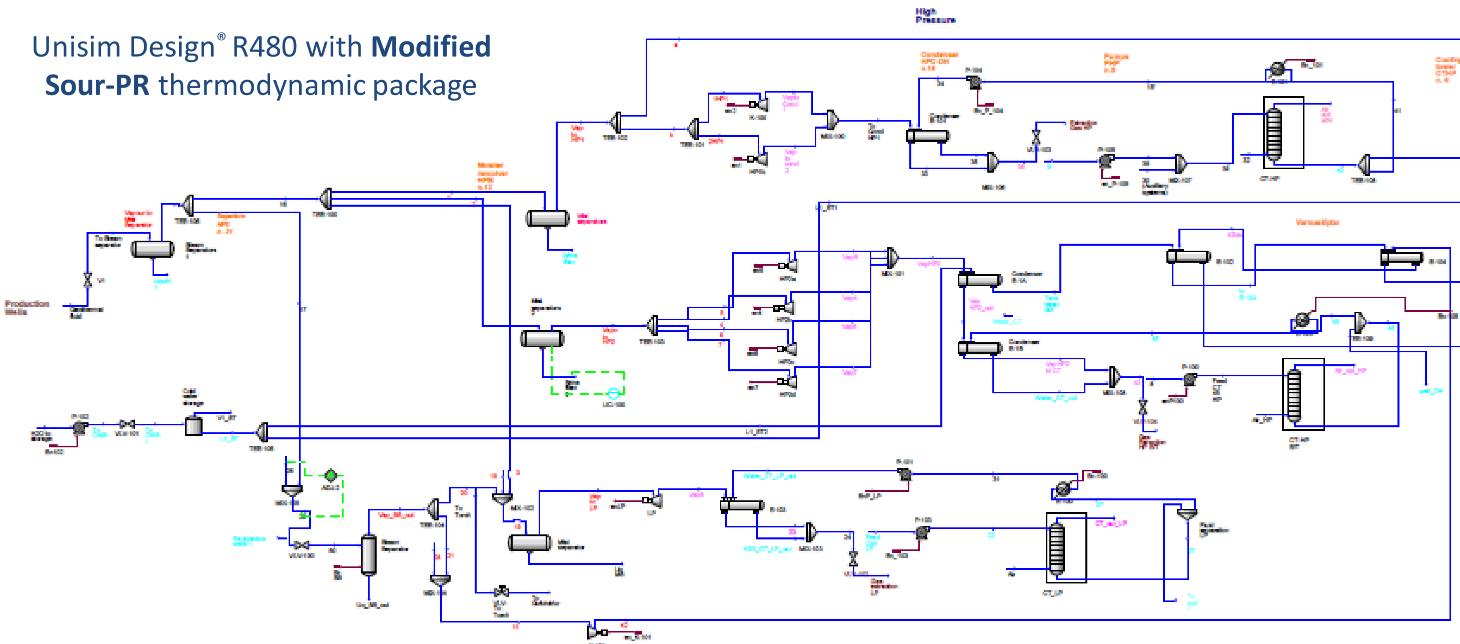
- A flow rate of the geothermal fluid entering the ORC system (downstream of the scrubber): maximum 17.96 kg /s (equal to 12,41 m^3/h);
- The composition of the geothermal fluid:
- 92% by weight of water vapour;
- 8% by weight of non-condensable gases of which:
- 97.5% by weight of CO_2;
- 2% by weight H_2S;
- 0.5% by weight others (such as H_2, CH_4, N_2, NH_3);
- chloride content (Cl-) maximum equal to 50 mg/l (on condensed sample);

Temperature/Pressure of the geothermal fluid entering the ORC system (downstream of the scrubber):461.65 K/10 bar - saturated steam.

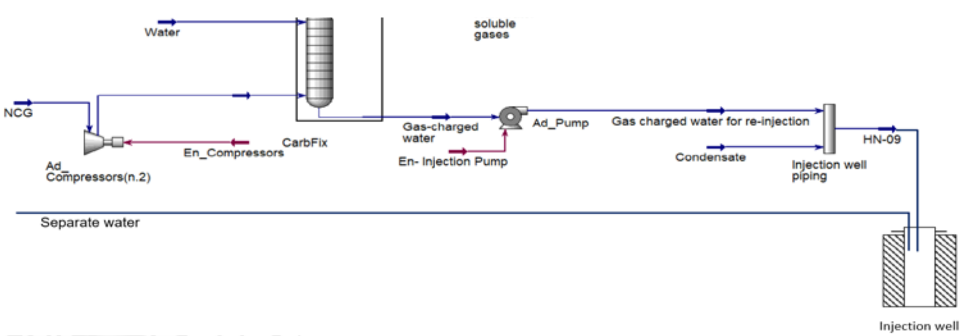
Equipment name	T_{in}	P_{in}	T_{out}	P_{out}	Mass Flow	Heat Flow
	°C	bar	°C	bar	[kg/s]	[kW]
Compressor 1	35	9,4	98,49	18,22	1,146	60,53
Cooler 1	98,49	18,22	30	18,22	1,146	80,30
Compressor 2	30	18,22	87,35	33,20	1,144	50,53
Cooler 2	87,35	33,20	30	33,20	1,144	71,43
Compressor 3	30	33,20	86,41	60,20	1,144	44,94
Cooler3	86,41	60,20	50	60,20	1,144	55,42

Hellisheiði geothermal power plant

Unisim Design® R480 with **Modified Sour-PR** thermodynamic package



Double Flash Cycle



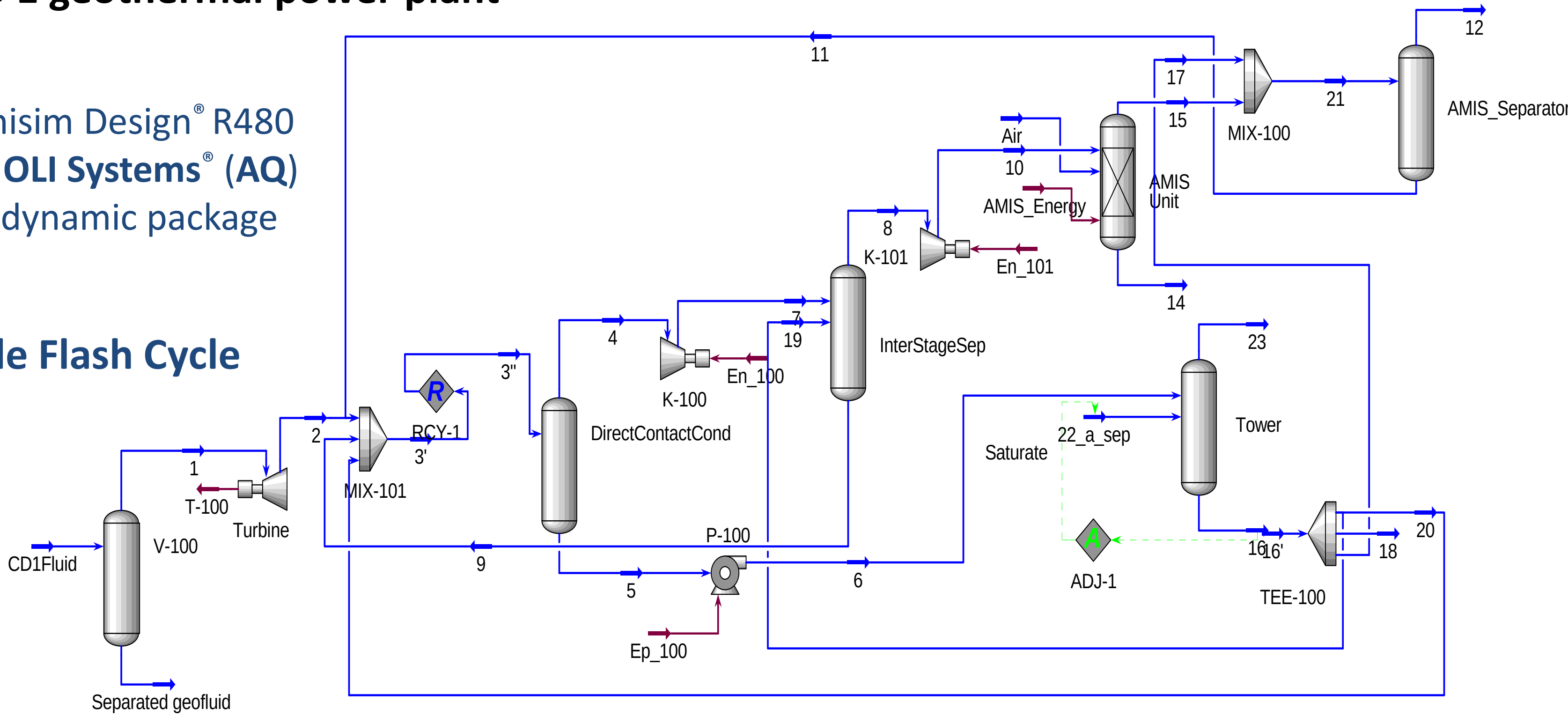
Gas	wt.% gas	tonnes/year	
		270 MWe	303.3 MWe
CO_2	0.37 ±0.07	60300	70770
H_2S	0.12 ±0.01	18900	21820.75
Ar	0±0	380	421.25
N_2	0.01±0.01	1650	1853.5
CH_4	0±0.0001	45	50.55
H_2	0±0.0007	640	210.63
wt.% total gas	0.51±0.07		

Process Simulation : Case Study 3

Chiusdino 1 geothermal power plant

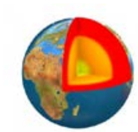
Using Unisim Design® R480 with the **OLI Systems**® (**AQ**) thermodynamic package

Single Flash Cycle



Well	Depth [m]	Flow rate [t/h]	T [K]	P [bar]	NCG [%]
Montieri 5	3447	78.8	473.95	16.2	6.0
Montieri 5A	4137	22.4	473.96	16.1	4.2
TravaleSud 1B	3361	26.4	471.75	15.5	6.1
TravaleSud 1C	3713	25.2	472.05	15.4	4.5
TravaleSud 1D	4432	24.5	491.95	15.4	4.5

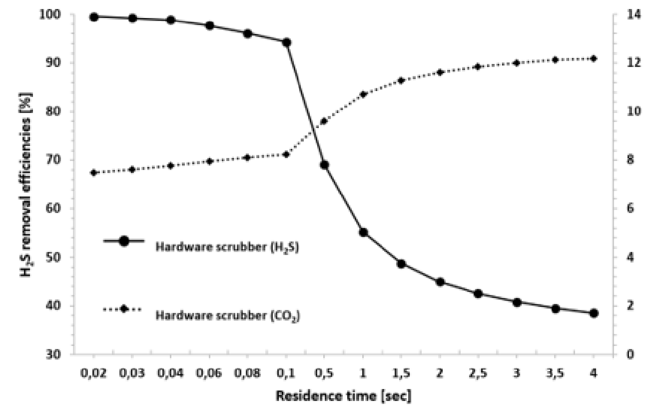
Composition of the geothermal fluid (130 t/h)		
Dissolved gasses (NCG) mass fraction	4.00 %	
CO_2	5100	Kg/h
CO	0.4	Kg/h
CH_4	79	Kg/h
H_2S	90	Kg/h
NH_3	11.6	Kg/h
Hg	5.6	g/h
Trace elements		
As	0.042	mg/l



Environmental Impact: Emissions Reduction

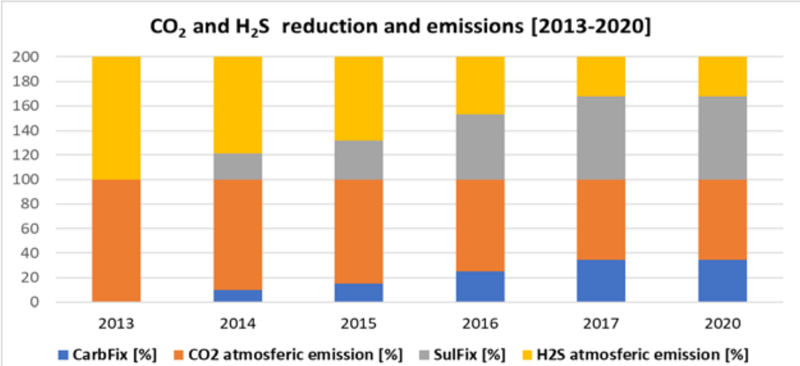
Work objective:
- ❑ To implement methods to reduce the Emissions for all the studied cases.
- ❑ Energy recovery and re-injection of geothermal fluids.

Case 1 (Castelnuovo GTPP) :



- ❖ *Solution 1* : H_2S and CO_2 removal using a caustic scrubbing system.
- ❖ *Solution 2* : H_2S, removal with sulfatereducing bacteria (*Desulfovibrio desulfuricans*).

Case 2 (Hellisheiði GTPP) :



- ❖ geothermal gas injection of CarbFix pilot plant.

Case 3 (Chiudino 1 GTPP) :

- ❖ AMIS® emission treatment system.

NCG emissions treatment system (AMIS)	
H_2S removal efficiency	99.8%
Hg removal efficiency	82.2%
NH_3 removal efficiency	87%
CO_2 removal efficiency	0%
As removal efficiency	99%

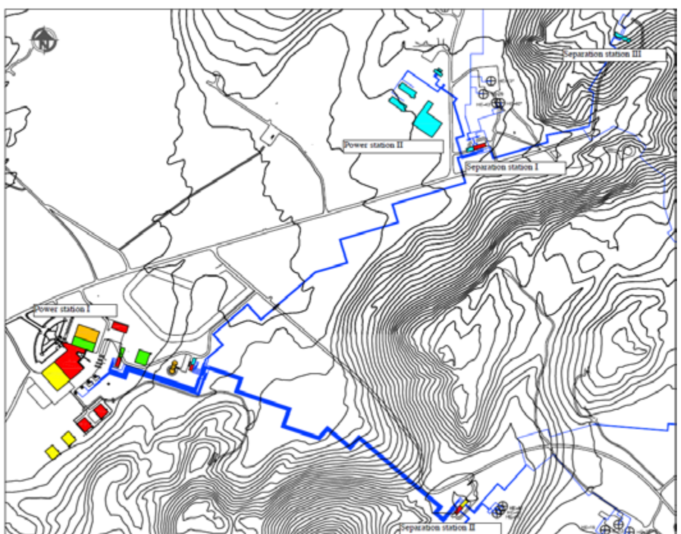
Environmental Impact: H_2S dispersion modeling for the Hellisheiði GTPP

Work objective:

- To assess the air dispersion plume of H_2S from the Hellisheiði power plant area
- To evaluate plumes affect air quality in the Reykjavík area.

- Geothermal Energy contributes to the emission of H_2S to the atmosphere
- Influences on the city of Reykjavík and plant workers

Hellisheiði GPP is located at a distance of 30 km southeast of Reykjavík city.



H_2S release points

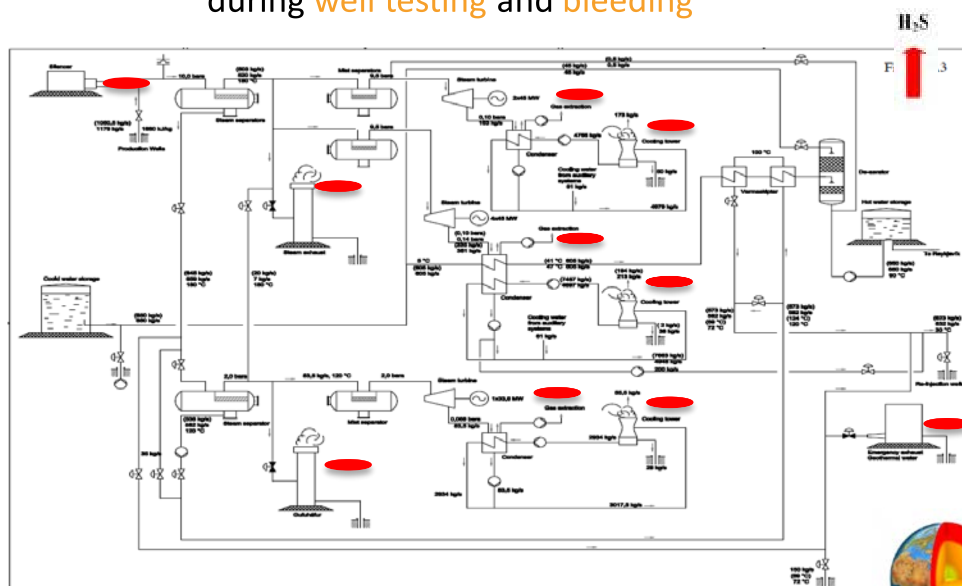
H_2S is released through the steam from geothermal groundwater during the process of electricity generation.

Average velocity of steam release: 180 kg/s

54 kg/s is H_2S

Extraction of geothermal groundwater from wells HE-11 and HE-17 at temperatures of 190°C.

The steam is released through the cooling tower, condenser gas removal, condensate, in geothermal water discharge, in steam stacks during shutdown, and during well testing and bleeding



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Conclusions

The sustainability of geothermal energy for the purpose of decarbonisation and the quality of life of the population depends on the size of the plant, the technology used and the methods of reducing / eliminating the pollutants produced.

The design and optimization of geothermal processes require accurate thermodynamic models through the study of solubility and enthalpy, with a small margin of error from real values.

The different thermodynamic models are applicable: PRH, OLI-AQ and Sour-PR for geothermal mixtures without salts, while Duan Model, Soreide-Witson, and particularly MSE, MSE-SRK for salt mixtures and Hg Metal.

The results obtained made it possible to highlight a strong reduction in the environmental impacts caused by gaseous emissions from the optimization and treatment systems of the gaseous effluents

For each type of GTPP cycle different methodologies for H_2S - CO_2 reduction are shown: CarbFix® for Hellisheiði, caustic scrubbing system and H_2S removal with sulfatereducing bacteria for Castelnuovo, and finally AMIS emission treatment system for Chiusdino 1.