

Conceptual framework for CHPM power plant

CHPM2030 Deliverable D4.1

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CHPM2030



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CHPM2030 DELIVERABLE D4.1

CONCEPTUAL FRAMEWORK FOR CHPM POWER PLANT

Summary:

This deliverable describes a model framework for a CHPM facility and the approach that will be used to develop a mathematical model that links the different components of the system in an overall system. The model will be used to simulate and optimise a CHPM plant.

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1 Executive summary

This deliverable is connected to Task 4.1, which will convert outputs of WP1-WP3 into an overall architecture design of the envisioned CHPM facility by creating a model framework based on component level models which enables linking downstream and upstream geothermal engineering subsystems. The components in the system are: (1) Underground heat exchanger, (2) Production wells, (3) Electrolytic metal recovery, (4) Geothermal binary power plant, (5) Gas diffusion electro-precipitation, (6) Salt gradient power generation and (7) Injection wells.

Sub-models within the components will describe the behaviour of each component and these will be combined in one overall mathematical model. Each component has an input from the previous component in the chain and an output to the following component. Data will be collected for each component so that a probabilistic model can be constructed in the python programming language using the selected approach. A list of fixed parameters of importance to describe the system has already been set up, although it may need modifications at later stages in the project.

The selected approach does fundamentally rely on successful data collection from the partners that develop the individual components in order to be able to describe mathematically what happens within the components and estimate the relevant uncertainties.

2 Introduction

The strategic objective of the CHPM2030 project is to develop a novel technological solution (Combined Heat, Power and Metal extraction from ultra deep ore bodies), which will help reducing Europe's dependency on the import of metals and fossil fuels, and at the same time, lower the environmental impact of the energy supply. In the envisioned technology, an Enhanced Geothermal System (EGS) is established on a metal-bearing geological formation, which will be manipulated in a way that the co-production of energy and metals will be possible. The project, at a laboratory scale, intends to prove the concept that the composition and structure of ore bodies have certain characteristics that could be used as an advantage when developing an EGS.

The specific objective of WP4 is to integrate downstream and upstream processes into a single system and develop optimisation strategies for energy and metals production. This task will combine the past experience of the consortium members with the design of medium and high-enthalpy geothermal systems and the outcomes of WP2 and WP3 to create one or more novel technology lines that will produce energy and valuable metals in an interlinked process. This knowledge will be utilised to adapt contemporary power plant design to the expected temperature and extreme salinity conditions that will occur under the CHPM2030 scheme.

This deliverable is connected to Task 4.1, which will convert outputs of WP1-WP3 into an overall architecture design of the envisioned CHPM facility by creating a model framework based on component level models which enables linking downstream and upstream geothermal engineering subsystems. The development of the conceptual framework builds on component level models for binary or flash geothermal power plants, but will be highly dependent on the outcomes of WP2 and WP3 to add metal recovery to the overall process flow.

3 Short description of the main components

The schematic diagram of the overall CHPM system, shown in Figure 3.1, was developed at an early stage of the project. However, the final version will be somewhat modified, for example by adding optional direct heat utilization.

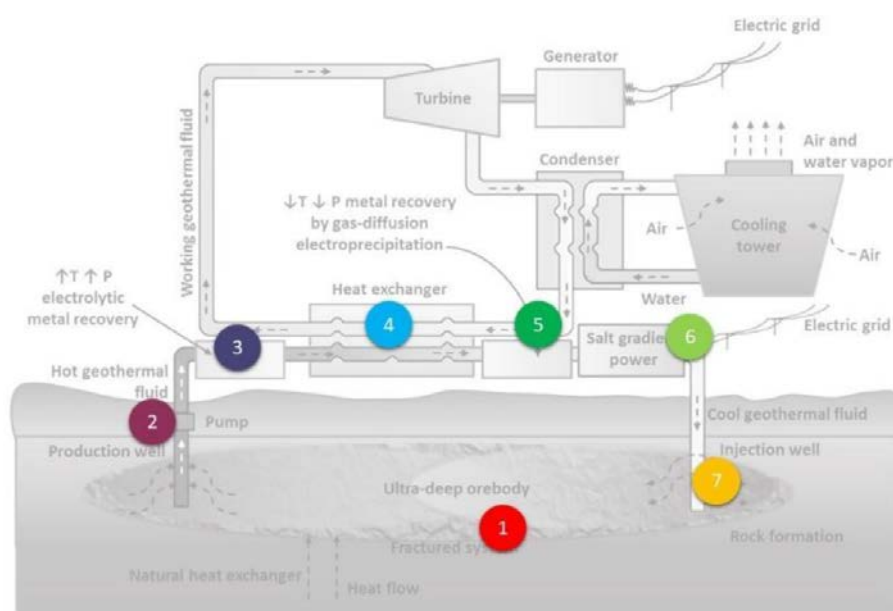


Figure 3.1 Schematic diagram of the overall CHPM system showing the links between the different components.

To give an idea of the function of the main components in the system they are briefly described below, based on deliverables submitted by partners responsible for the individual components.

3.1 Electrolytic metal recovery

The Electrolytic metal recovery component (No. 3 in Figure 3.1) uses electrochemical reactions to deposit metals. The component is designed to perform at high temperatures and high pressures up to 200 bar and 300°C. The Working electrode design is shown in Figure 3.2.

The lab experiments performed in the context of CHPM2030 are performed in small batch reactors. In order to be applicable in a geothermal plant, the technology needs to be scaled by a factor of $10^4 - 10^6$. Preferably, the electrolytic metal deposition technology is implemented in a flow-through reactor that can be readily integrated in a geothermal loop with a high throughput (150 m³/h or more).

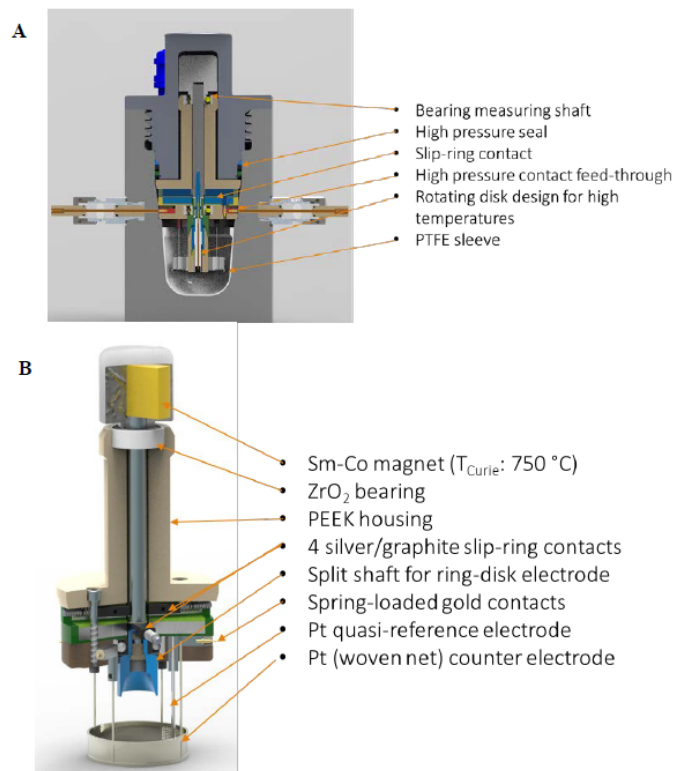


Figure 3.2 (A) Cross-sectional view of ETPER manufactured (B) High temperature and pressure rotating disk electrode designed to operate at 200 bar and 300°C.

3.2 Power and heat generation

Geothermal binary cycle power plants (ORC-Organic Rankine Cycle) (No. 4 in Figure 3.1) are commonly used when the temperatures of the geothermal resource is not sufficient for water flash systems, typically in the range 120-180°C. It uses a closed loop working fluid with lower boiling point than water that is vaporised using the heat from the geothermal fluid. The geothermal fluid releases its heat to the working fluid in a heat exchanger before it is reinjected to the reservoir. A schematic diagram of a geothermal binary cycle power plant is shown in Figure 3.3.

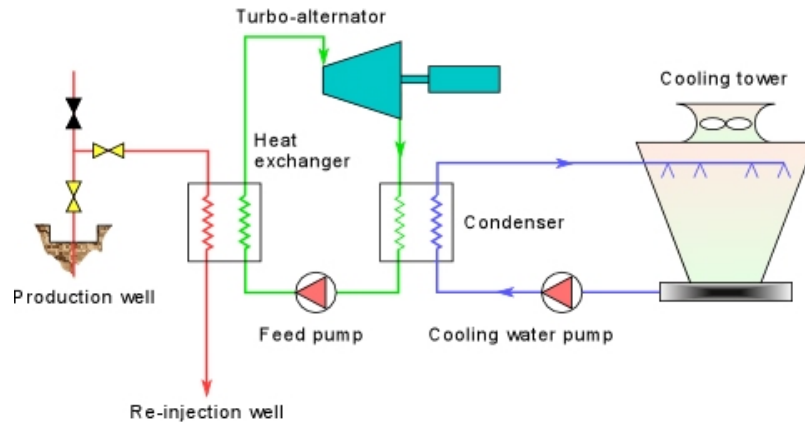


Figure 3.3 Schematic diagram of a geothermal binary cycle power plant.

Different set-ups are possible for combined power and heat generation. In most cases, a binary system is used for power production in geothermal CHP-plants. Different set-ups are possible for delivering heat as shown in Figure 3.4. The optimal set-up depends on the temperature and energy output of the geothermal wells and the requirements of the heat demand (temperature range and demand curve).

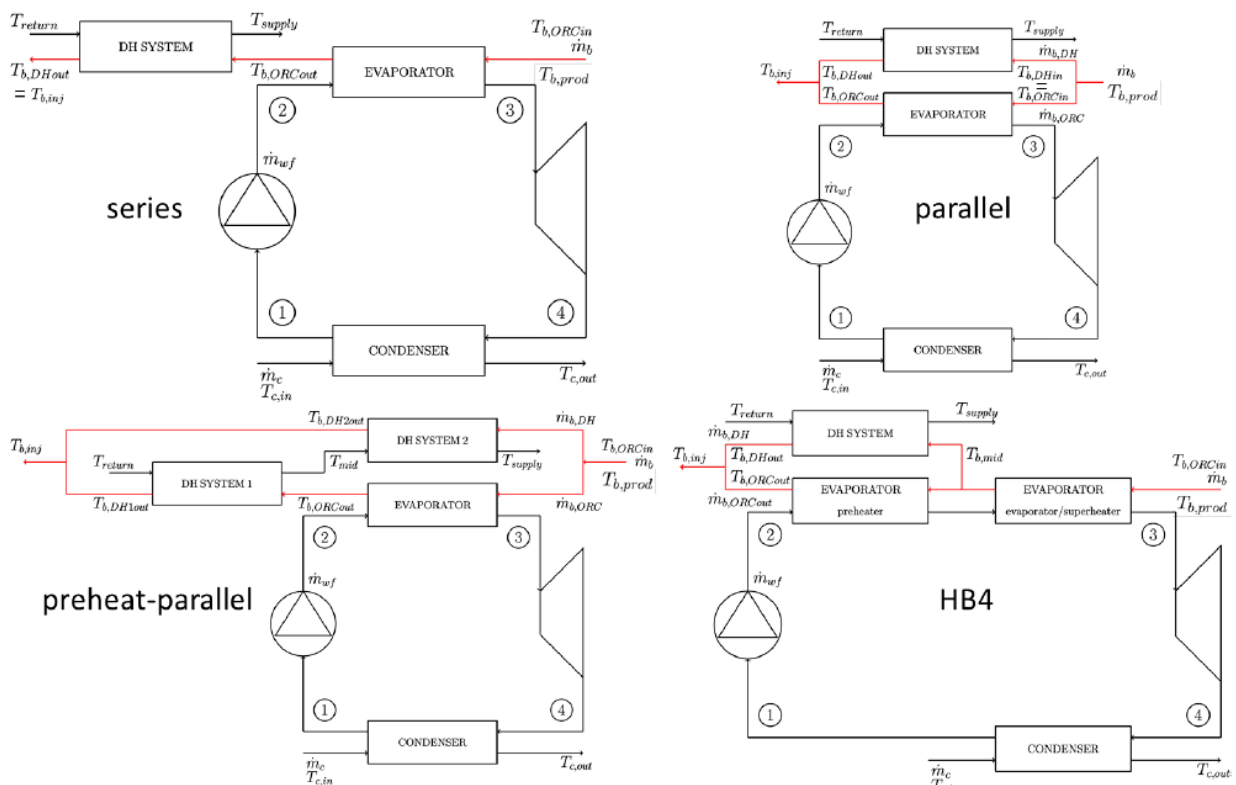


Figure 3.4 Schematic outline of geothermal CHP configurations. The red lines represent the geothermal brine (from S. van Erdeweghe et al., 2018¹).

¹S. Van Erdeweghe, J. Van Bael, B. Laenen, W. D'haeseleer, 2018. Optimal combined heat-and-power plant for a low-temperature geothermal source. *Energy* 150: 396-409.

3.3 Gas diffusion electro-precipitation and electro-crystallisation

Gas Diffusion Electro-Precipitation and Electro-crystallisation (GDEX) (No. 5 in Figure 3.1) can remove metal and metalloid ions from an aqueous solution, transforming them into an amorphous or crystalline (nano) precipitate which can be easily recovered by sedimentation. The process uses porous activated carbon-based gas-diffusion electrodes, through which an oxidant gas is passed. The oxidant gas is electrochemically reduced at the cathode, forming peroxides (or polyatomic ions of the reduced gas), leading to crystallization or precipitation of composites between the metal ions and the oxidant-gas-reduction-product at the surface of the cathode. The precipitate is subsequently released into the aqueous electrolyte where it remains stable in a colloidal form during a certain period, but ultimately aggregates and precipitates. By varying the parameters of the electrochemical process, such as pH, ionic strength, metal/metalloid ion concentration, gas composition and electrochemical potential, not only selectivity can be tuned but also important properties of the product may be controlled such as morphology, particle size, crystal size and lattice parameter. The experimental setup for the component is shown in Figure 3.5.

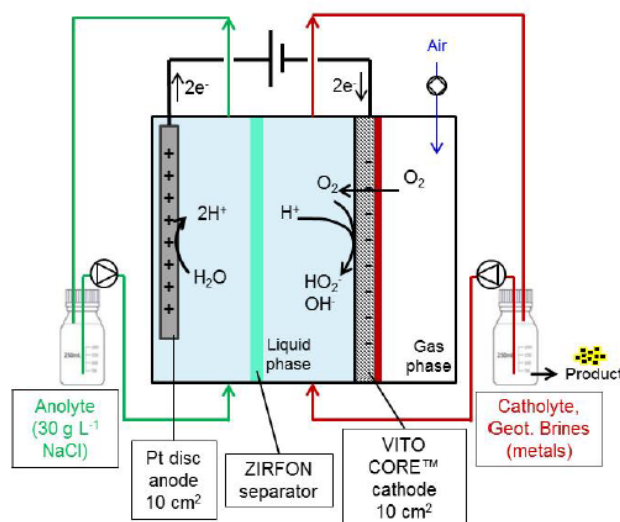


Figure 3.5 Schematic diagram of the GDEX technology for the treatment of geothermal brines.

3.4 Salt gradient power

The reverse Salt Gradient component (No. 6 in Figure 3.1) is composed of compartments separated by Cation exchange Membrane (CM) and Anion exchange Membranes (AM). Through these compartments brine solution (HIGH) and low salinity solution (LOW) flow, see Figure 3.6. The concentration gradients across the membranes cause the ions (Na^+ and Cl^-) to move in opposite directions, thus creating potential difference.

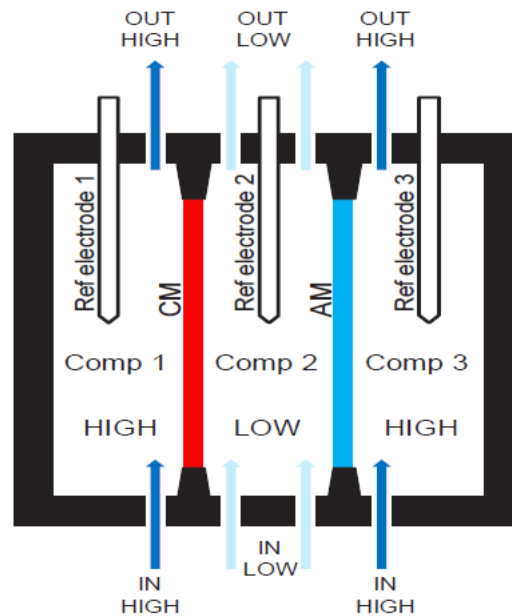


Figure 3.6 Schematic view of the 3-compartment set-up.

4 Selected approach

As shown in Figure 3.1 the overall CHPM system is composed of the following seven components:

- 1) Underground heat exchanger,
- 2) Production wells,
- 3) Electrolytic metal recovery,
- 4) Geothermal binary power and heat plant,
- 5) Gas diffusion electro-precipitation,
- 6) Salt gradient power generation and
- 7) Injection wells.

It has been decided to focus on a few specific scenarios regarding site location in the CHPM2030 project. Thus, limited emphasis will be placed on the geothermal reservoir and the wells (components No. 1, 2 and 7) in the overall system description since the reservoir conditions will be known (or estimated) for the specific sites. Thus, the overall system description will focus on the surface components No. 3, 4, 5 and 6.

A model framework has been created based on component level models, which enables linking downstream and upstream geothermal engineering subsystems. The different system components will be integrated into a single system by a mathematical model. This model will be used to develop optimisation strategies for heat, energy and metal production.

A brief overview of the approach is given below:

- The main task is to develop a mathematical model of the overall system.
- The overall model will be made up of elements or sub-models describing the behaviour of each component (component models).

- Each component has an input from the previous component in the chain and an output that will feed the following component.
- The overall simulation model will be used to study different scenarios, find optimal solutions and perform sensitivity analysis.
- The most important design parameters have already been identified. However, some component models may require additional parameters.
- Mathematical descriptions of what happens within the different components in the system are needed. This is the task of the partners responsible for the respective components.

Sub-models within the components will describe the behaviour of each component and these will be combined in one overall mathematical model. Each component has an input from the previous component in the chain and an output to the following component as shown schematically in Figure 4.1. Data will be collected for each component so that a probabilistic model can be constructed in the python programming language using the selected approach. Data for the individual components will be mainly derived from the experiments performed in WP3.

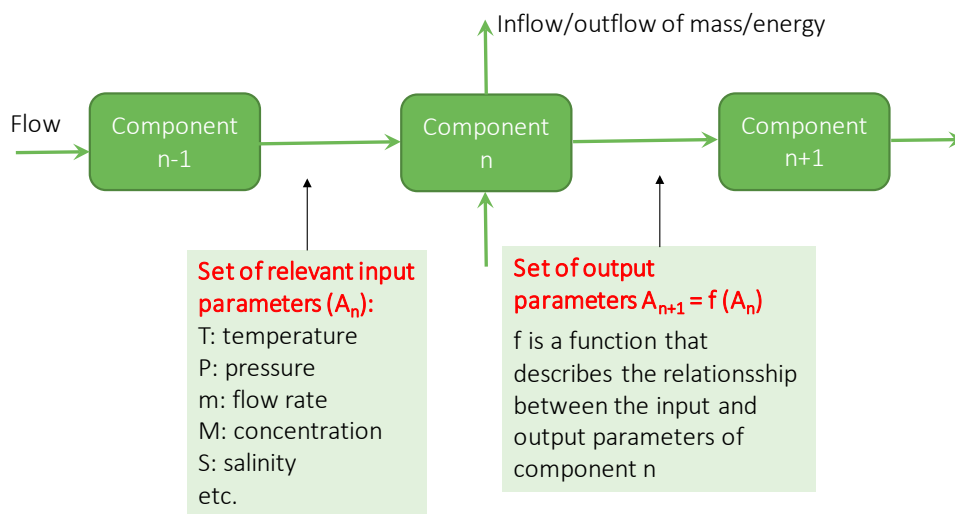


Figure 4.1 Schematic presentation of a component model.

At this stage the type and scope of the mathematical model is being developed at ISOR with inputs from other partners. The approach in the overall model is to consider each component as a “black box” into which a list of parameters is feed and out comes a new list where the list has been altered according to the inner workings of each component. Also from the input parameters, the energy input or output of each component is calculated.

The work on Task 2.4 (Overall systems dynamics and data for environmental assessment) on collection of critical parameters for the technological elements and the overall system dynamics provides important inputs to the work on system integration in WP4. It identifies the key parameters for the CHPM technology and feeds them into WP4 (optimisation and performance). The proposed set of parameters that the current work is based on is as follows:

| | |
|--------------------------------|-----------------------|
| Temperature: | T [°C] |
| Pressure: | P [bar] |
| Acidity/basicity: | pH [-] |
| Redox condition: | Rd [eH] |
| Oxygen fugacity: | fO ₂ [bar] |
| Carbon dioxide: | CO ₂ [bar] |
| Conductivity: | si [S/m] |
| Flow rate: | q [L/s] |
| Salinity: | S [g/L] |
| Oxidizing compounds: | O _x [mg/L] |
| Concentrated suspended solids: | Css [mg/L] |

This list of parameters is not considered to be fixed and parameters can be added or removed as deemed necessary. Most of the components are still in active development and data is being accumulated. Detailed knowledge on the interplay of various parameters within most of the components is therefore missing. Due to this uncertainty, the model approach in consideration is a probabilistic Monte Carlo model. In a Monte Carlo model, each uncertain parameter is given a probability distribution according to the certainty of its value. The model is then run multiple times using randomly selected set of parameters for each run. In the end a probability distribution for energy use and metal extraction is created.

As an example the input and output probability distribution for the current version of the geothermal binary plant component are shown in Figure 4.2. Here the temperature range is taken to be in the range from 70°C to 200 °C with the probability distribution taken to be a triangular distribution with the mode at 120°C. The output distribution shows the range of power to be expected from the input temperature distribution and the most likely value, which in this case is around 8 MW.

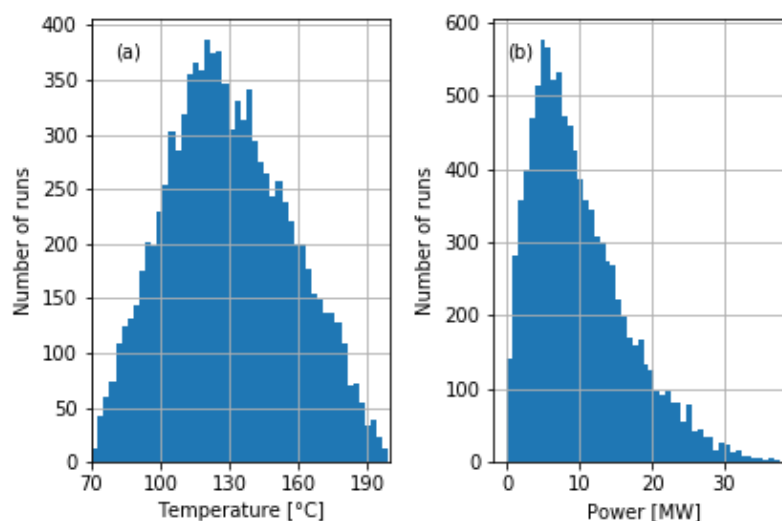


Figure 4.2 (a) Input probability distribution for temperature for the binary power plant component.
(b) Output probability distribution for power production for the binary power plant component.

The models for each component relating the input and the output values can also involve uncertainty. For example for the relation of energy use as a function of Ca and Mg concentrations and salinity for the Gas diffusion electro-precipitation component is currently based on the blue data points in Figure 4.3.

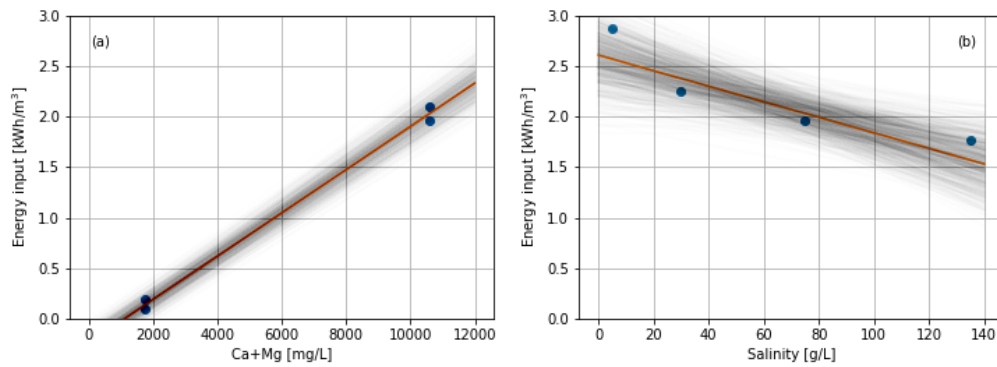


Figure 4.3 Relation between energy use of the Gas diffusion electro-precipitation component as a function of (a) Ca and Mg concentration and (b) salinity.

The relation for energy use as a function Ca and Mg concentrations and salinity is deduced from a linear regression analysis, shown as orange solid lines in Figure 4.3. With more data points nonlinear regression would also be considered. The linear regression analysis gives uncertainty ranges that can be used in the Monte Carlo modelling. In Figure 4.3 one thousand lines that are randomly selected from the uncertainty range of the parameters from the linear regression analysis are drawn in black. For each run in the Monte Carlo modelling one such line would be randomly chosen.

The selected model approach for the CHPM plant does fundamentally rely on successful data collection from the partners that develop the individual components in order to be able to describe mathematically what happens within the components and estimate the relevant uncertainties.