Dynamic modelling of the steam generation system in the HPS2 CSP molten salt trough test facility

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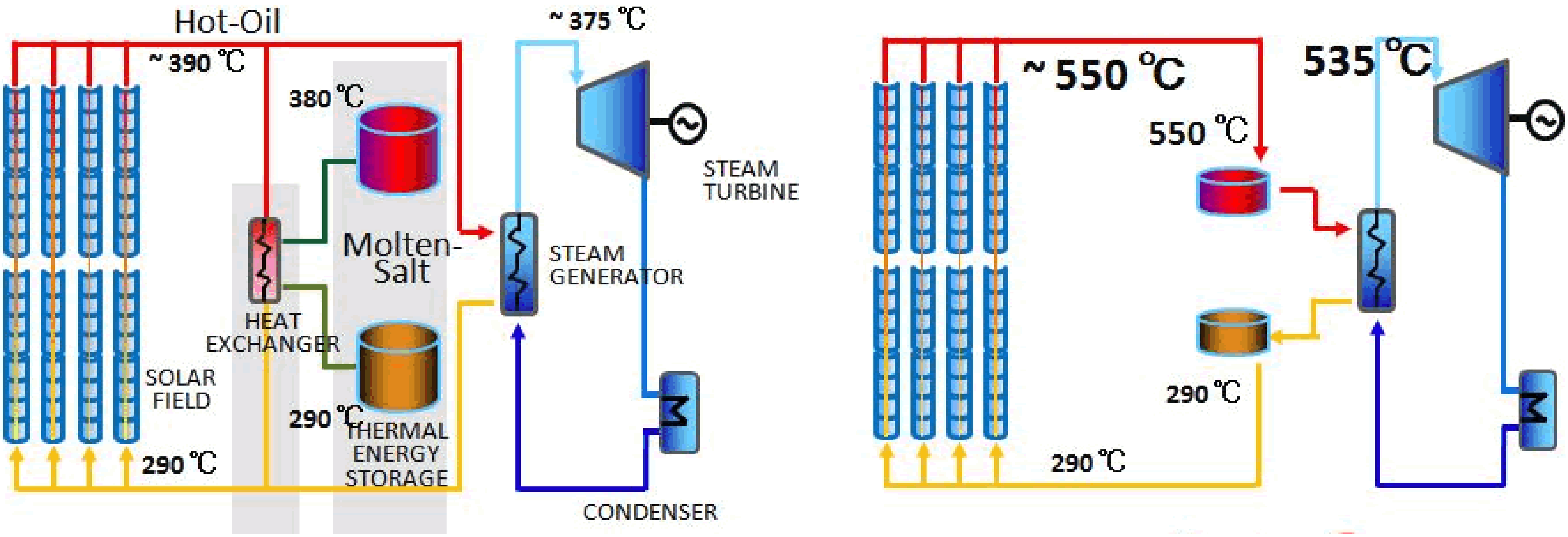
Introduction

- HPS2 is a Parabolic CSP (Concentrated Solar Power) test facility, where molten salt is being used as the heat transfer fluid.
- Advantages:
  - Plant simplification (Reduces cost due to less components)



Chiyoda Corporation. https://www.chiyoda-corp.com/technology/en/green_energy/solar_energy.html

Introduction

- HPS2 is a Parabolic CSP (Concentrated Solar Power) test facility, where molten salt is being used as the heat transfer fluid.
- Advantages:
  - Plant simplification (Reduces cost due to less components).
  - Higher heat transfer fluid temperatures which leads to higher steam cycle efficiencies.
  - Molten salt has a lower cost, non flammable.
  - Solar field is decoupled from the steam cycle.
- Disadvantages:
  - Molten salt has a high freezing temperature.
  - Corrosive at high temperatures.
- How to manage risks:
  - Operational strategy should be able to reduce the risk of freezing.
  - Using corrosive resistant materials will reduce the risk of corrosion.

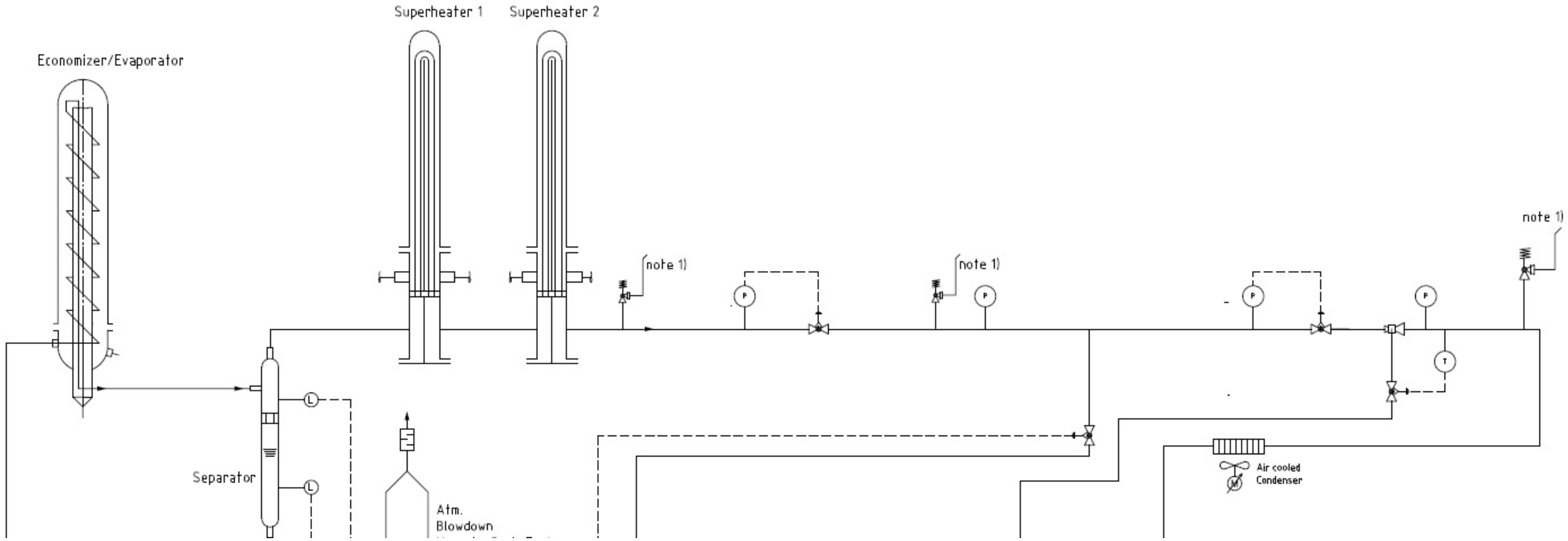
Introduction to the masters project

- The main objective is to create a dynamic process model of the molten salt storage system combined with the steam generator and cooling system in Flownex.

- Benefits of having a dynamic model:
  - Provides an understanding of the transient response of the test facility.
  - Pre-tune control loops for the test facility.
  - Train the plant operators.

Water/Steam Cycle

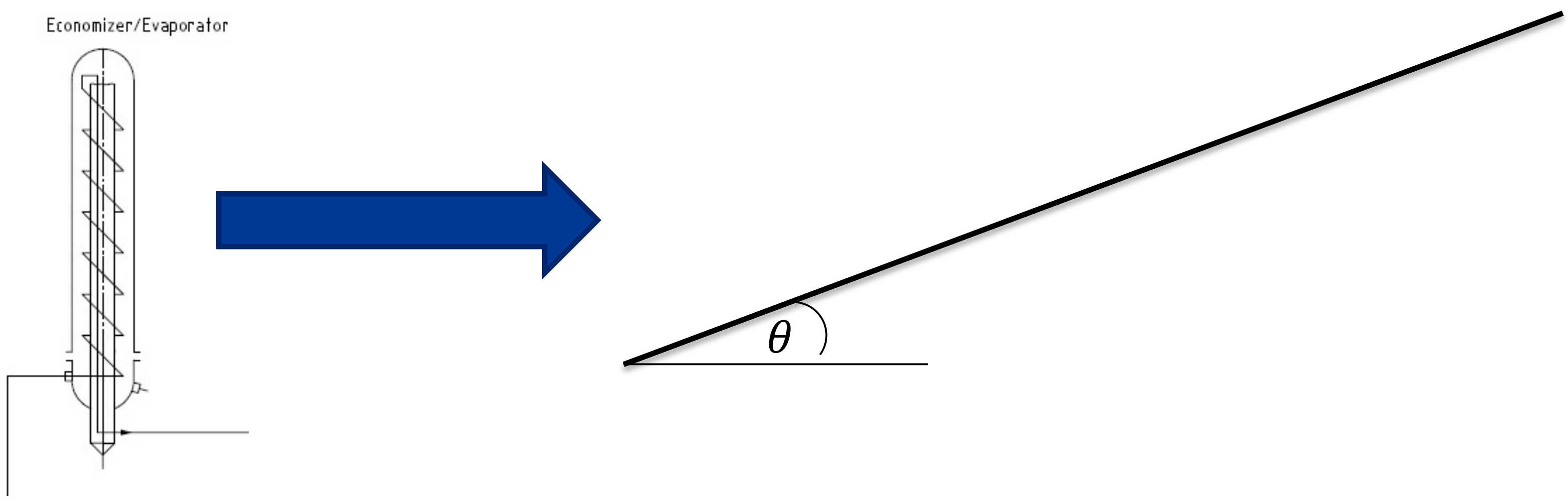
- Main components:
  - Helical Coil Economizer and Evaporator.
  - Separator (only used in start up).
  - Two straight tube super heaters.
  - Series of valves to bring steam temperature and pressure down.
  - Air cooled condenser.



Flownex Modelling Approach

Flownex Simulation Environment:

- Integrated system modelling code used for design, simulation and optimization of complete thermofluid systems.
- System is discretized into spatial or conceptual volumes in one dimension for which mass, momentum and energy are solved.
- Two phase regions are modelled using a homogeneous approach.
- Helical coil simplification:



Heat Transfer Correlations Used

- In the economizer section of the helical coil steam generator, the Reynolds numbers achieved by the flow under different plant loads are represented well by the following Nusselt number:

$$Nu = 0.328Re^{0.58}Pr^{0.4}$$
$$6000 < Re < 180{,}000$$

- For the evaporator section the Reynolds number is always greater than 1.9×10^5 and thus the standard straight tube Dittus-Boelter equation was used.
- The molten salt flow over the helical coil is assumed to be cross flow and thus a correlation for cross flow over tube banks was used.
- For the superheaters the standard Dittus-Boulter equation for the steam on the tube side was used.
- For the superheaters the following correlation was used which was developed for single phase heat transfer on the shell side.

$$Nu = 0.2Re^{0.6}Pr^{0.33}\left(\frac{\mu}{\mu_w}\right)^{0.14}$$

Frictional Losses

- For the helical coil tube side a standard straight tube pressure correlation is used with a multiplication factor added to enhance the pressure drop seen in the helical coil.
- For the shell side in the helical coil steam generator and the super heaters a flow resistance element was used, where the equation for the pressure drop is given below. The flow admittance is adjusted to give expected pressure drops from design values at 100% load.

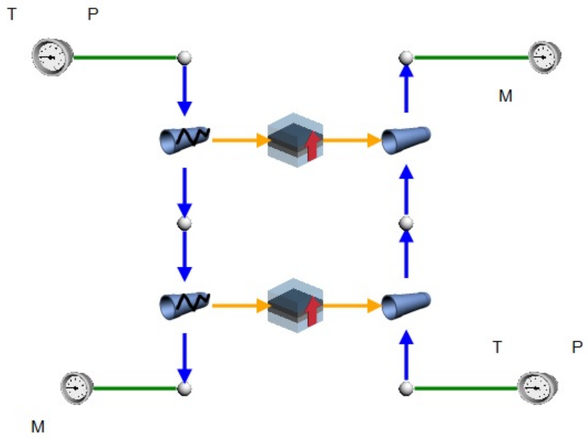
$$\Delta p_0 = \frac{|\dot{m}|\dot{m}}{\rho A_f A_{sf} A_0} + \rho g \Delta z$$

Where:

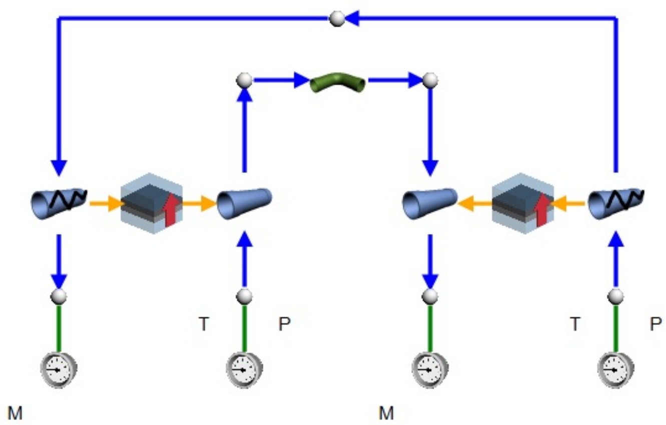
$$A_f = flow\ admittance$$
$$A_{sf} = admittance\ scaling\ factor$$
$$A_0 = opening$$

Flownex Model For Each Component

Economizer/Evaporator

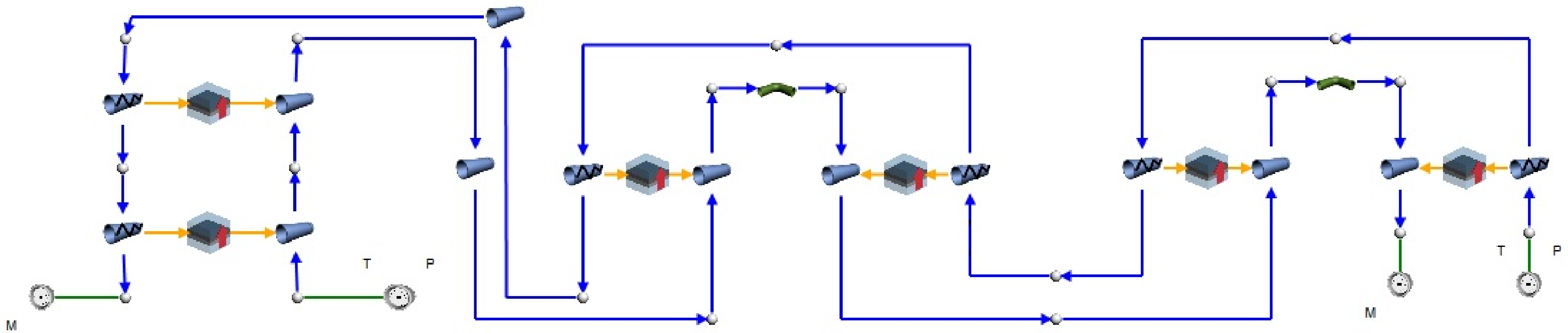


Superheater



Flownex Model of Components Connected

Economizer/Evaporator   Superheater 1   Superheater 2



Steady State Results For Each Separate Component

- Table below shows the results as a percentage error against expected results obtained from the design description and operating manual, for each component tested separately at 100% load.

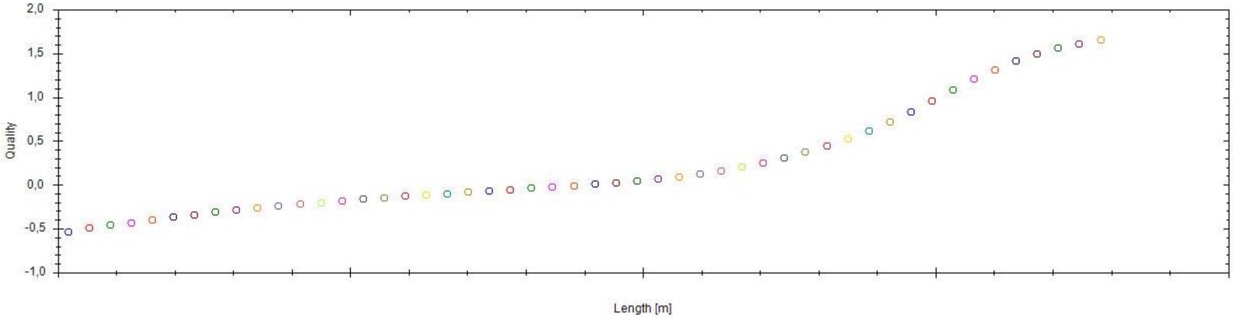
	Economizer	Evaporator	Superheater 1	Superheater 2
Salt outlet Temperature	-0.49%	-0.66%	+1.17%	+0.98%
Salt Outlet Pressure	+1.3%	+1%	-0.654%	-0.26%
Water/steam outlet temperature	+0.17%	+6.05%	-0.269%	-0.78%
Water/steam outlet pressure	-0.19%	+0.8%	+0%	+0.34%

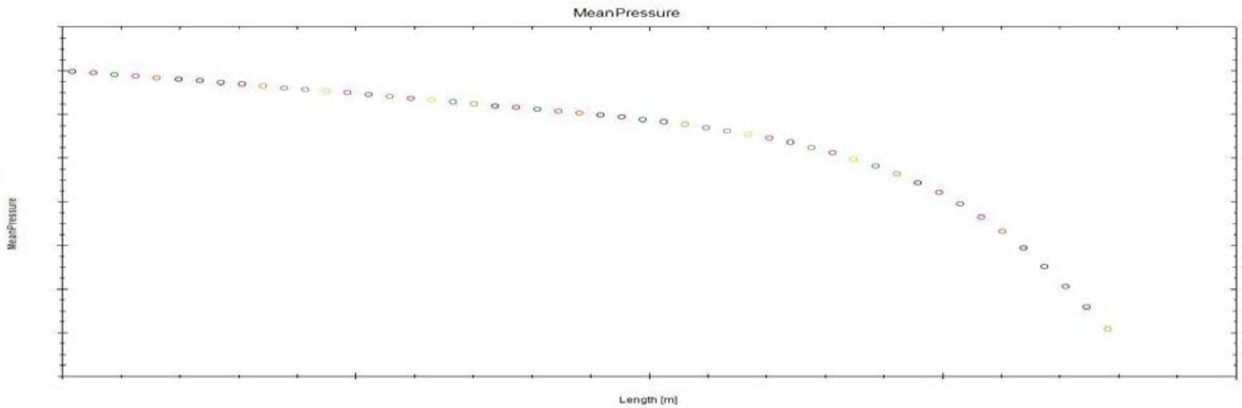
Steady State Results For Whole Steam Generation Section

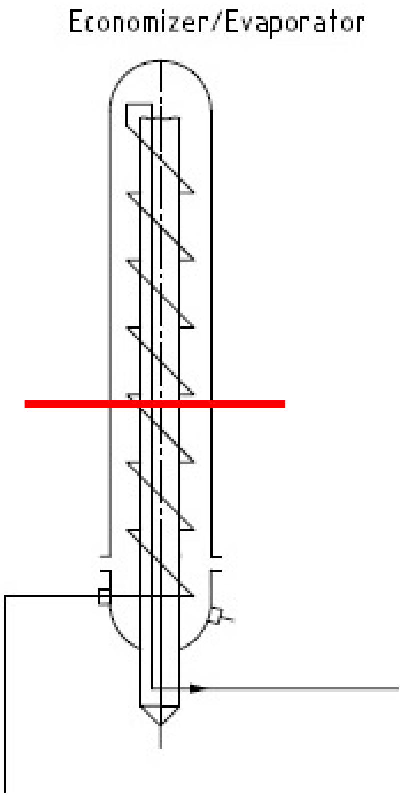
- Table below shows the results as a percentage error against expected results obtained from the operating manual, for the entire steam generation system.

Plant Load:	35%	100%	115%
Salt Exit Temperature	+7.3%	+3.09%	-2.04%
Steam Exit Temperature	+0.06%	+2.74%	+2.87%
Steam Pressure	-16.85%	-57.25%	-75%

Economizer Sub Element Results







Operating Condition Adjustments

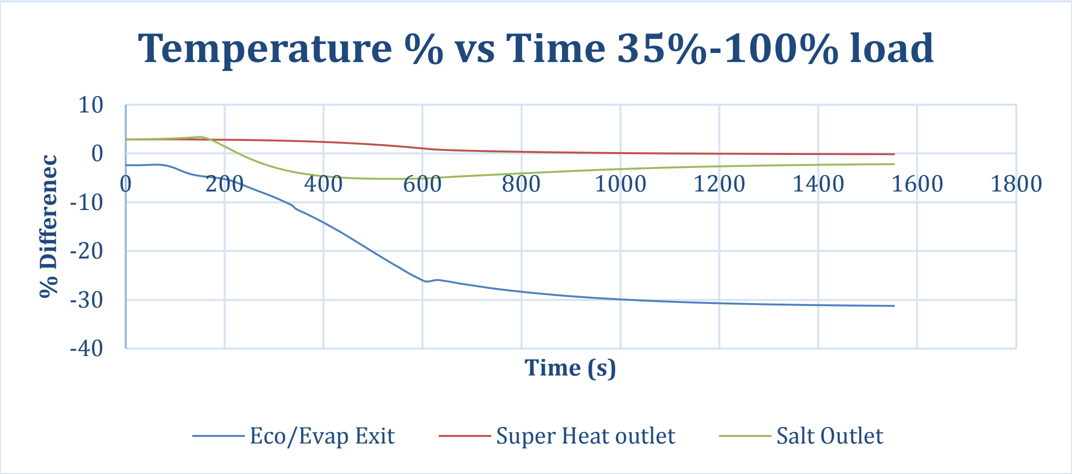
Plant load:	35%	100%	115%
Salt mass flowrate	0%	-0.53%	-3.4%
Water/Steam mass flowrate	+6%	+9.7%	+13.6%
Feed water pressure	0%	+0.625%	+0.6%

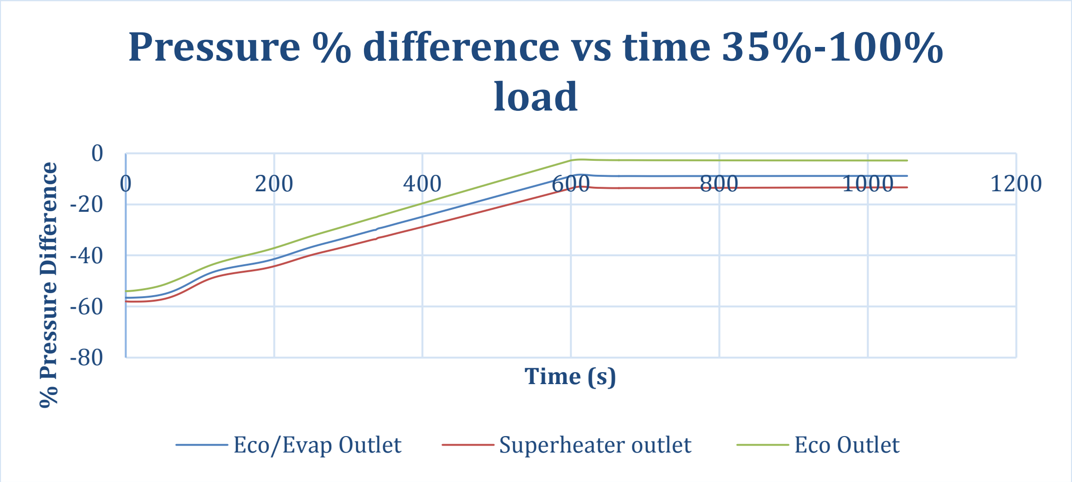
Steady State Results With Adjusted Operating Conditions

- Table below shows the results as a percentage error against expected results obtained from the operating manual, for the entire steam generation system after operating conditions were adjusted.

Plant Load:	35%	100%	115%
Salt Exit Temperature	+2.15%	-1.95%	-2.38%
Steam Exit Temperature	-0.12%	-0.16%	+0.62%
Steam Pressure	-3.42%	-0.28%	-4.085%

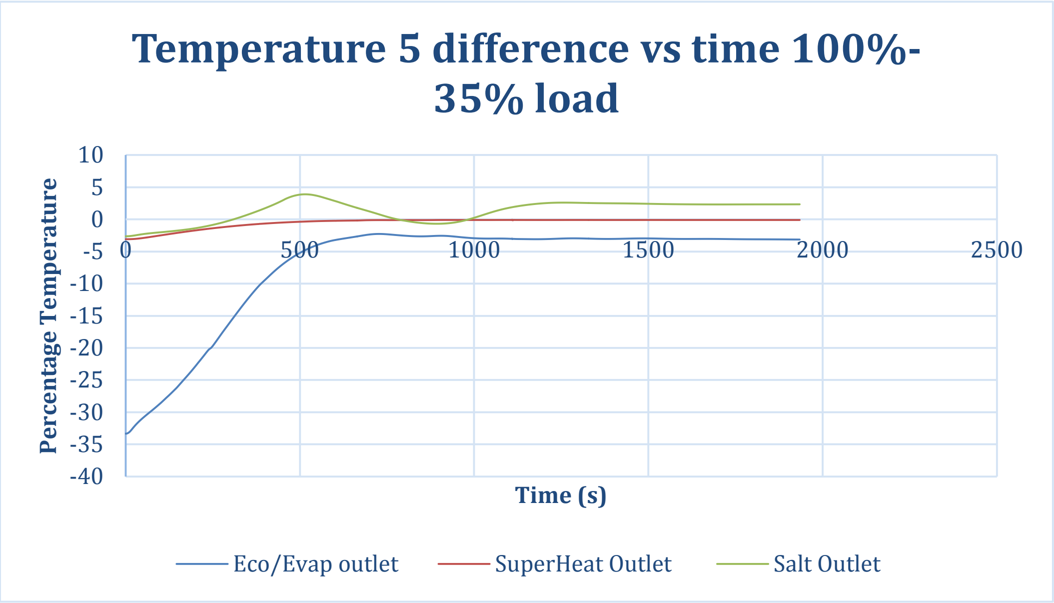
Transient Results

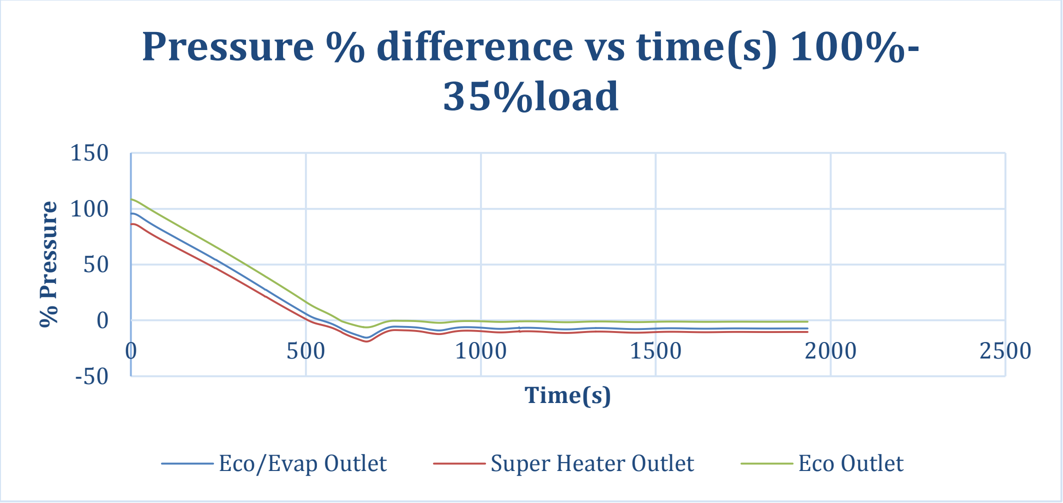




- % difference against a reference temperature or pressure.
- Eco/Evap and Superheater outlet reference temperature was the expected outlet temperature of the outlet of superheater 2.
- Salt outlet temperature was referenced against the expected salt outlet temperature.
- Pressure was referenced against the feedwater inlet pressure.

Transient Results





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Conclusions

- For each separate component the model produces results which correlate well with expected results.
- Unexpected large pressure drops for the whole steam generation system is due to the boiling point in the helical coil steam generator.
- Small changes in the operating conditions move the boiling point further up the helical coil steam generator significantly, thus reducing the pressure drop.
- Decreasing the salt mass flowrate and increasing the water/steam mass flow rate moves the boiling point up.
- Final outlet temperature of the steam generation system does not fluctuate by much through transient scenarios.
- Temperature outlet of the salt changes quickly and there is a lag in response.

Questions