Advanced Vehicle-level Thermal Management systems development enabled by 1D CAE

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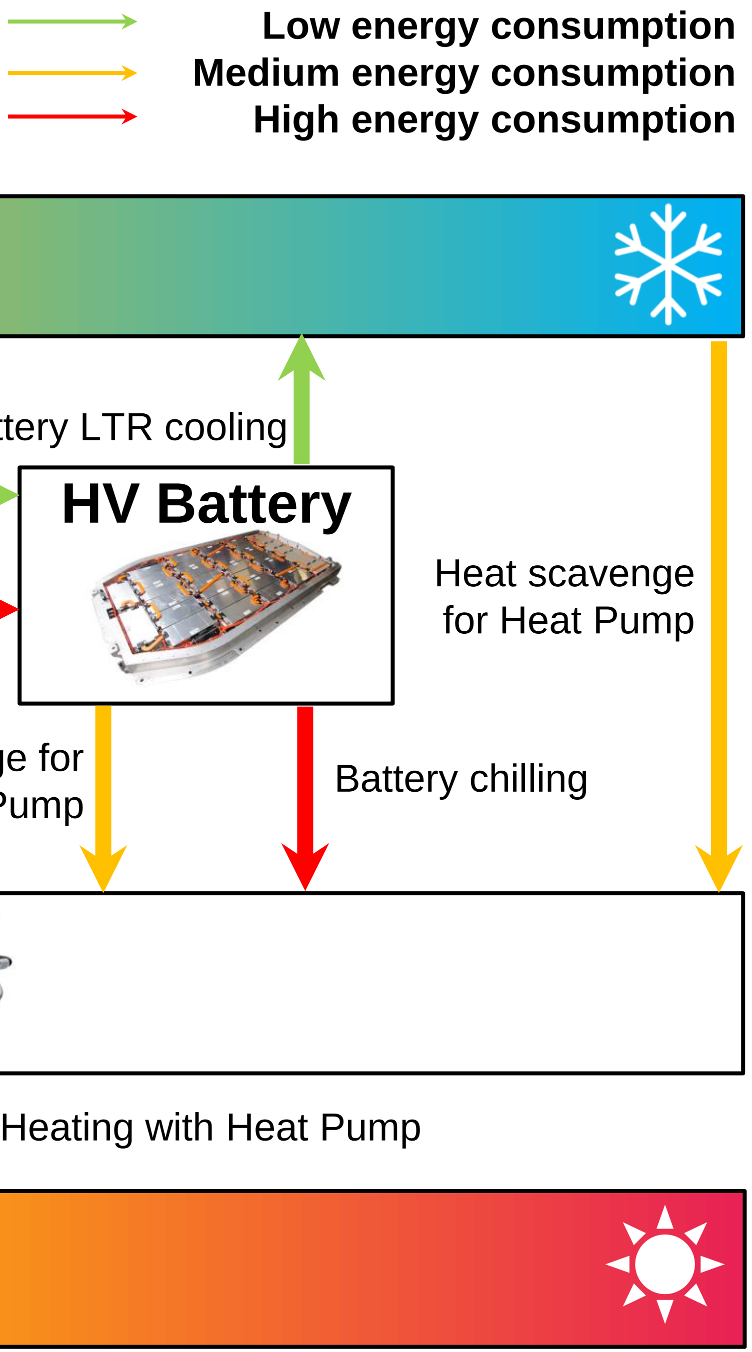
01 Introduction to the Heat Flux Management System

HFMS is JLR's Thermal Management Architecture that seamlessly integrates the 3 key thermal sub-systems in any Battery Electric Vehicle:

1. **Propulsion Thermal Management System** – Provides liquid heating and cooling functions to the High Voltage Battery, Electric Drive Units and Power Electronics.
2. **Climate Thermo-fluid System** – Provides heating and cooling functions to the Occupant Cabin.
3. **Air Flow Management System** –Provides cooling and heating air flow to the heat exchangers.

02 Heat Flux Map

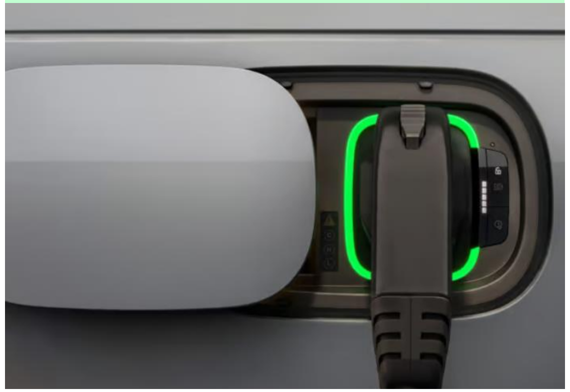


HFMS is designed to promote the mass adoption of Battery Electric Vehicles globally by addressing the most fundamental engineering challenges

Driving Range

- **+20 miles certified range increase.**
- **Up to 40% reduction on heating energy**.
- Propulsion system temperature controlled for maximum efficiency.
- **Range consistency** across ambient temperatures and driving conditions.
- Vehicle energy efficiency enhancer, **key part of JLR's sustainability vision.**

Charging Speed



- Enables **market leadership 800V fast charge** performance.
- **Charge time consistency** between across wide ambient temperature band.
- **Modern luxury Customer thermal comfort** maintained in all charging conditions with minimal impact to charging speed.

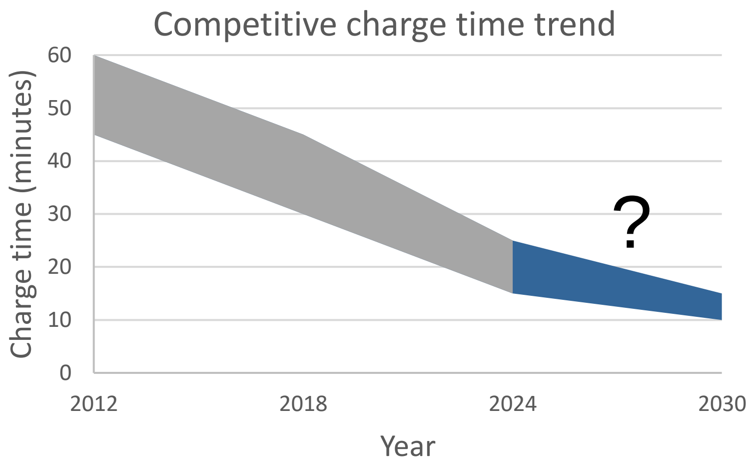
High Voltage Battery Longevity

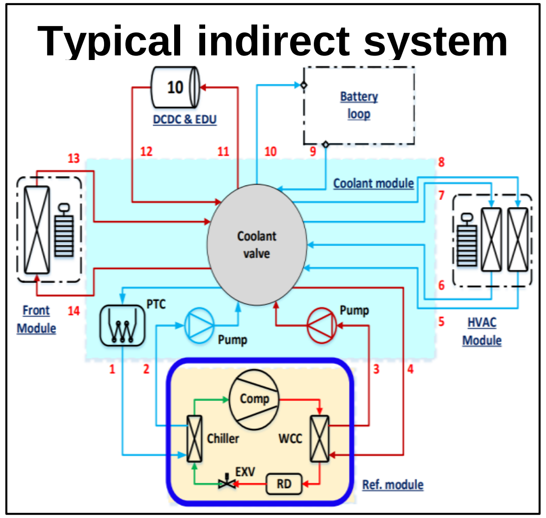
- Controls the High Voltage Battery Cells temperature in the optimum range to **maximize battery life**.
- Provides rapid battery heating and cooling reducing charge and discharge losses.

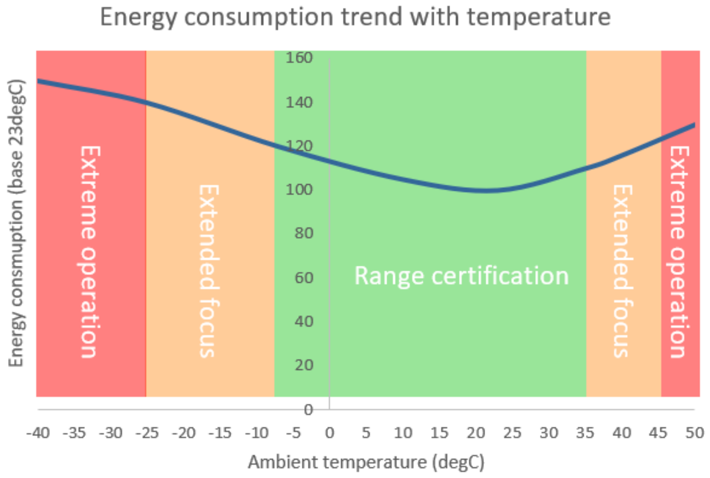
Extreme ambient Performance

- Enables **best in class off and on road sustained vehicle capability** in all weather and surface.
- Assists **vehicle start down to -40°C** ambient temperature.
- **Outstanding Customer thermal comfort** maintaining a tranquil sanctuary in all driving conditions.

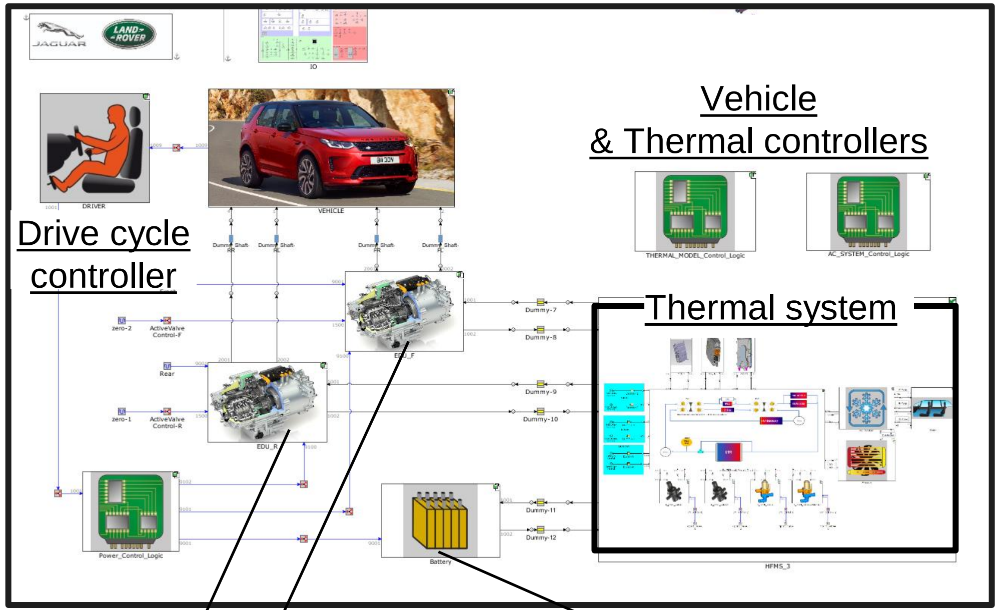
- **Continuous improvement in charge time** - Focus on miles/min.
- **Real world efficiency in all ambients**
- **Premium experience every time** – Thermal Comfort and NVH
- **Polyfluorinated Substances (PFAS) legislation:** R1234YF EU ban
  Expected move to either Propane (R290) or CO2 (R744).
- **Indirect HVAC (R290) opportunities for deep architectural changes**



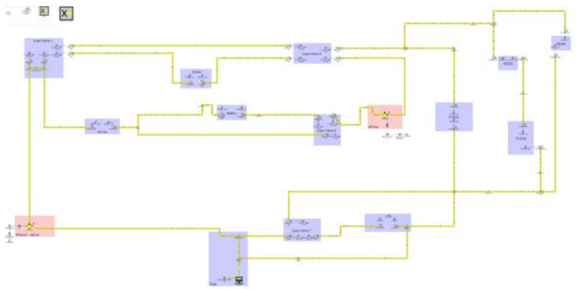




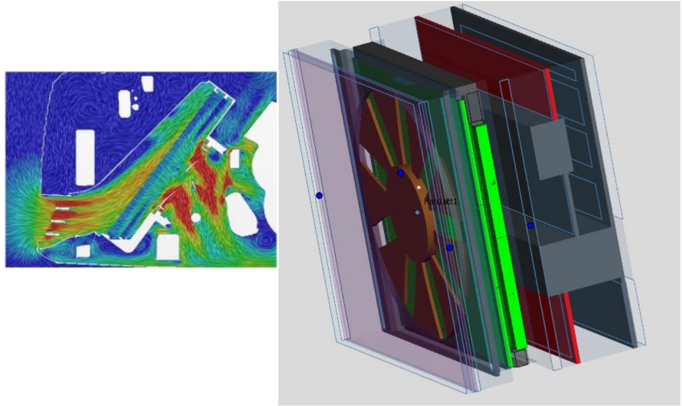
Vehicle Thermal Model (VTM)



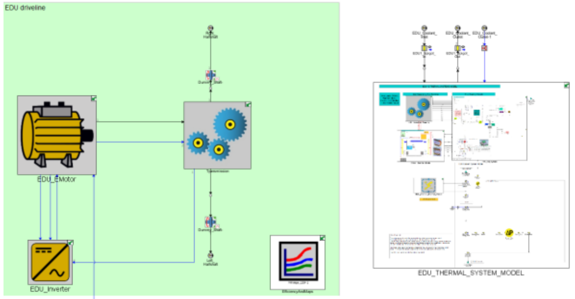
Cooling system Hydraulic sub-model



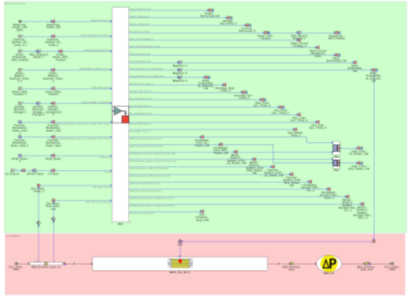
HX Cool 3D Thermal sub-model



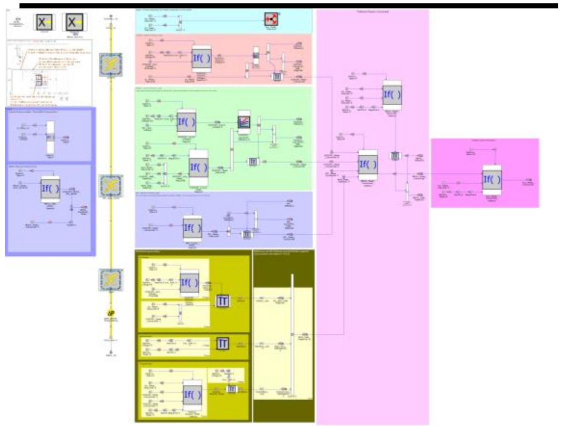
EDU models



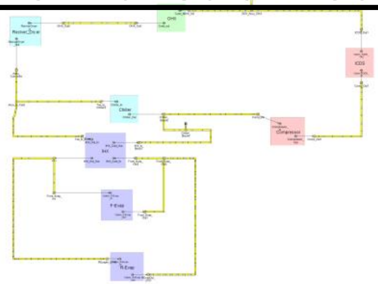
HV Battery Model



BEM and BMCM Model



Refrigerant system Thermal sub-model



Outer Heat exchanger (OHX) Modelling

Pablo Santirso Recio

Heat Exchanger Components in Automotive

1 phase

Both fluids have a unique phase (liquid or gas) during the heat transfer

2 phases

One of the fluid changes the phase during the heat transfer

Single Mode

The fluid always changes the phase in the same direction (evaporating or condensing)

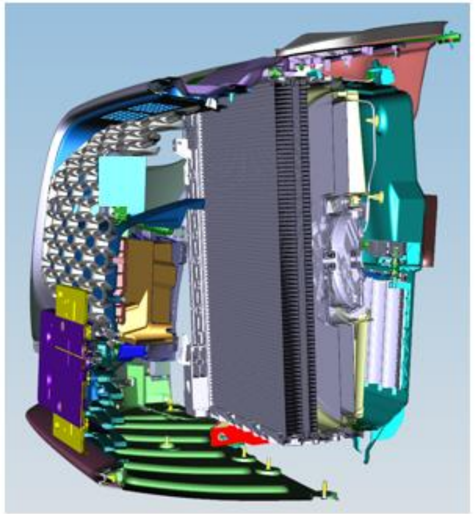
Dual Mode

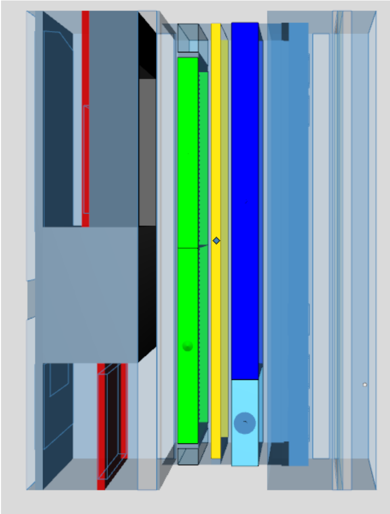
The Component has the ability to evaporate and condense the fluid

1phase → Re-Nu relationship found automatically by GT SUITE

2phase – Single mode → Multipliers found automatically by GT SUITE (check required)

2phase – Dual mode → Sometimes, manual optimization tool required

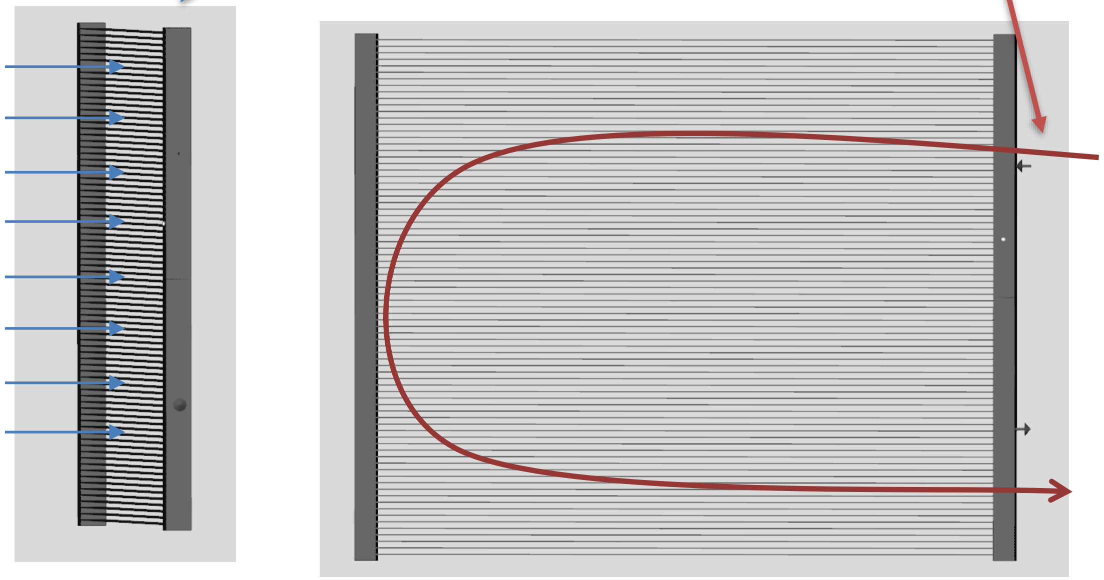




Component testing - 1phase Heat Exchanger

Air mass flow:
- Constant Temperature
- Constant Static Pressure
- Sweep Air mass flow rate (MFR)

Coolant Volumetric flow:
- Constant Temperature
- Constant Static Pressure
- Sweep volumetric flow rate (VFR)



Test results obtained

Q/ETD [W/K]		External MFR [kg/s]			dp Internal [kPa]
		0.5	1	1.5	
Internal VFR [L/min]	10	180	200	220	20
	20	195	237	274	25
	30	210	268	325	40
	40	225	296	373	60
dp External [Pa]		10	15	30	

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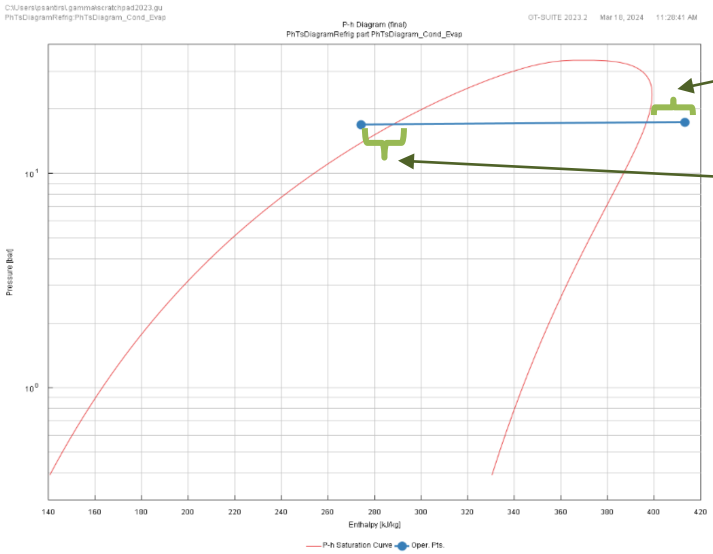
Component testing – 2phase Heat exchanger

Testing a 2-phase component presents certain challenges

Condenser



- Inlet Pressure
- Inlet SuperHeat

Outlet SubCool target

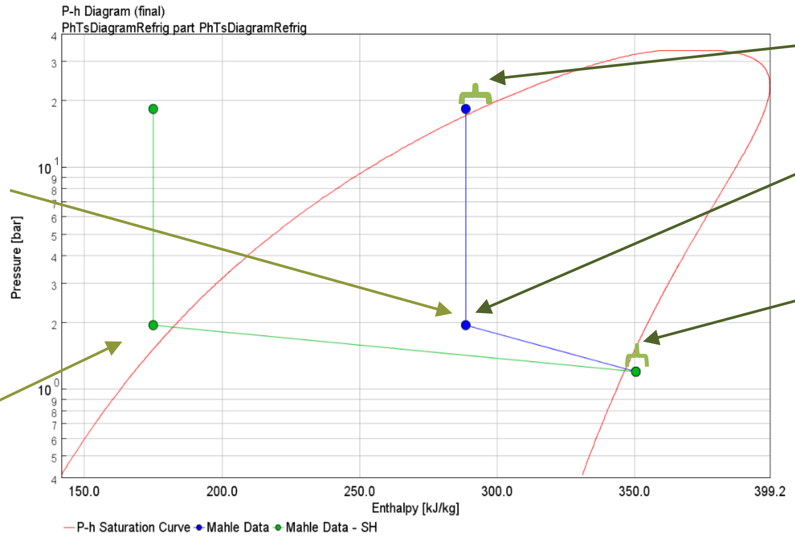
For air we define:
- Mass flow rate
- Inlet temp

Output:
- Refrigerant mass flow rate
- Refrigerant Heat rejection
- Pressure drop on Air and refrigerant

Evaporator

Saturation Temperature: Not suitable for measuring

Unrealistic operational point: Too much Subcooling in the Condenser outlet



- Subcool & Pressure pre-expansion valve
- Inlet Pressure post-Expansion valve

SuperHeat target

For air we define:
- Mass flow rate
- Inlet temp

Output :
- Refrigerant mass flow rate
- Refrigerant Heat rejection
- Pressure drop on Air and refrigerant

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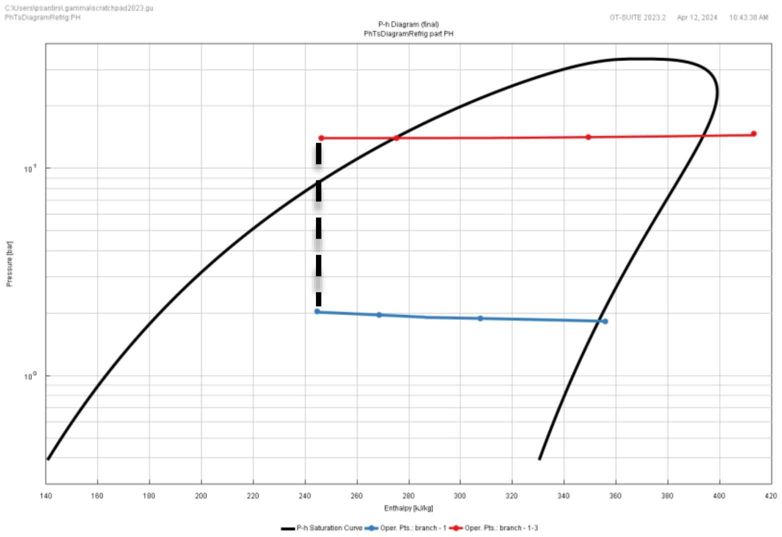
Enthalpy check

We need to check the robustness of the data before the calibration

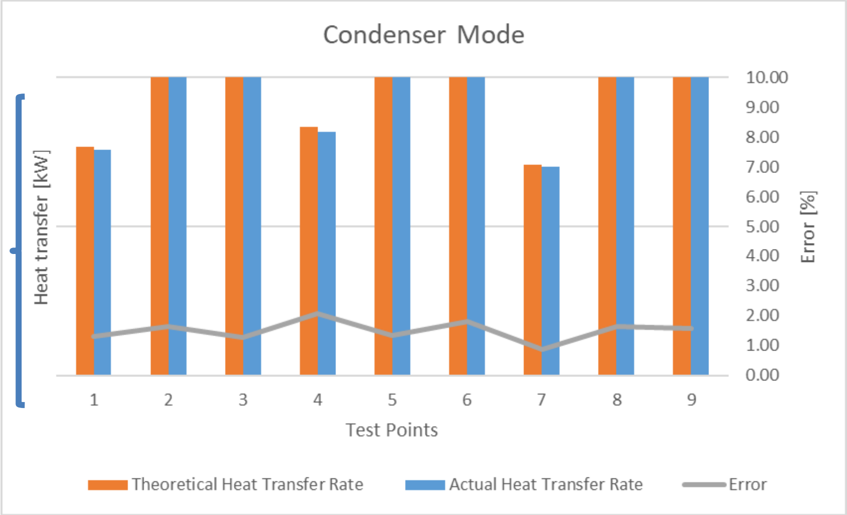
$$\dot{Q} = \dot{m}\Delta h$$

$$h \rightarrow f(P,T)$$



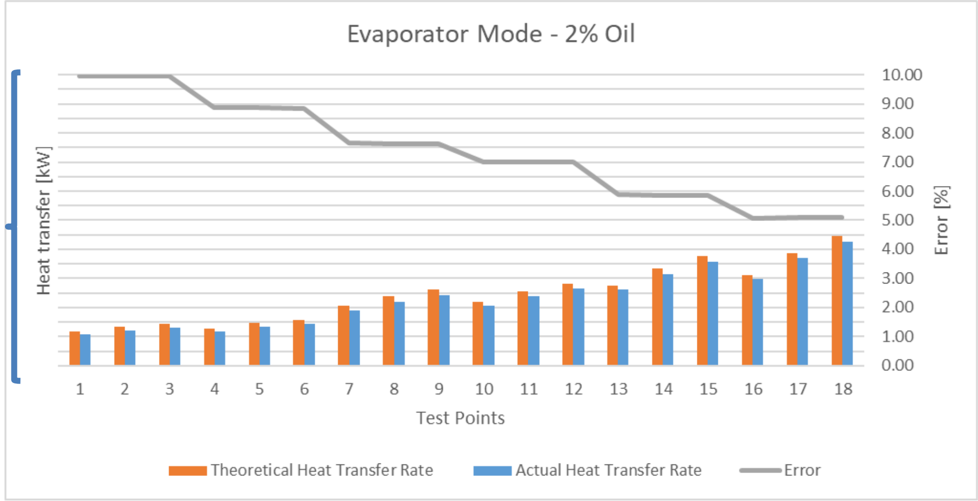
Condenser

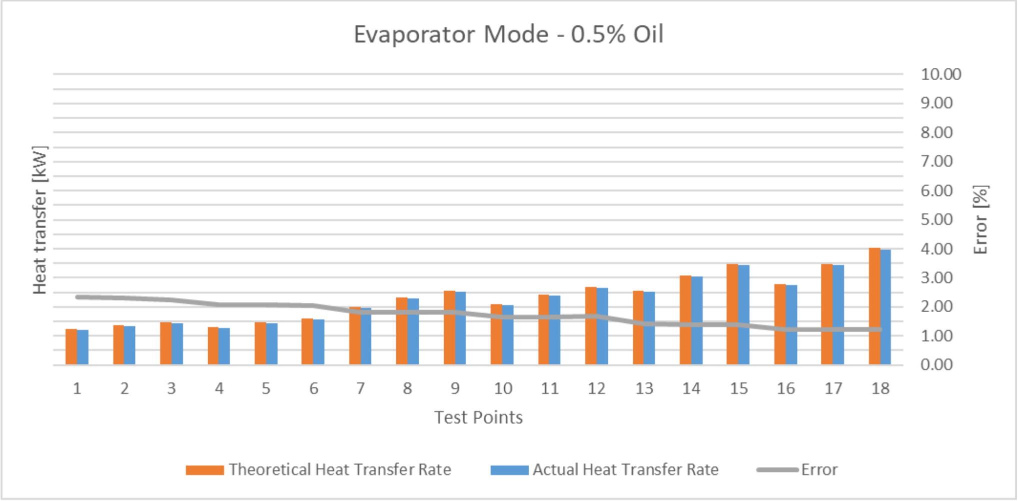
10kW - 20kW



Evaporator

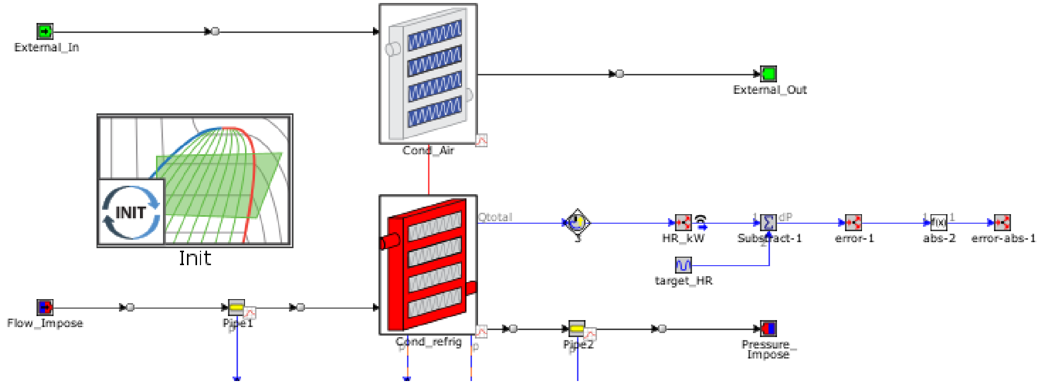
1kW - 5kW





2phase model calibration parameters

GT SUITE is not capable to automatically calibrate the component
We need to prepare a specific model



Cases:
30-50 Individual test cases

Parameters:
10 Individual parameters

Outputs:
5 Individual outputs

Genetic algorithm optimization tool

~10.000 iterations
~300.000 simulations
~72 hours

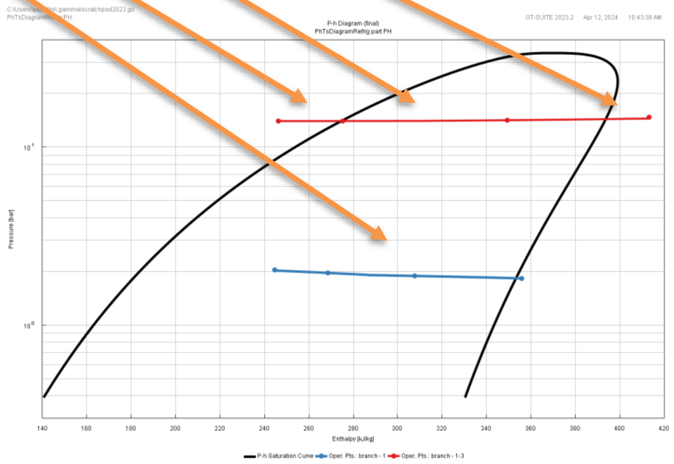
Parameters

Heat Released

- Refrigerant: Evap. phase, Liquid phase, Cond. phase, Gas Phase
- Air: Gas phase

Pressure drop

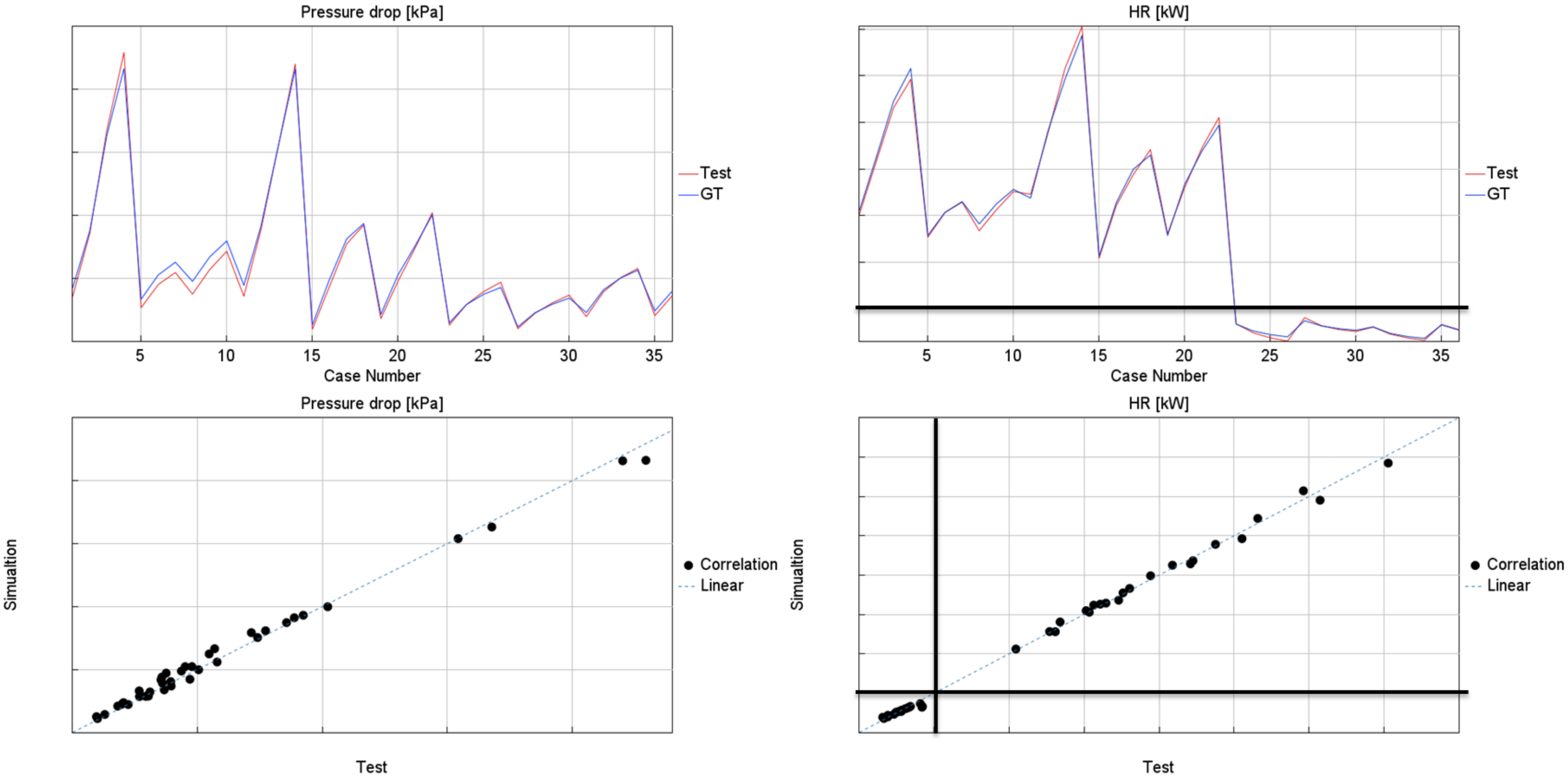
- Refrigerant: Liquid phase, Gas phase, Two phase



Outputs

- Heat transfer
- Internal dP
- Fraction of dP at inlet
- Fraction of dP at outlet
- Simulation Convergency

Results for the latest Hx



Complexity during Evap calibration – Reversing of Heat flux

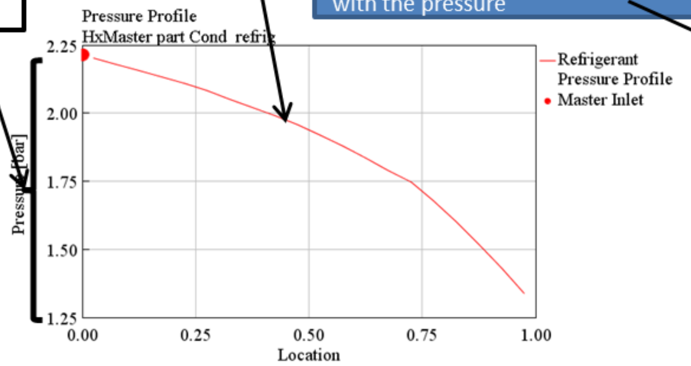
When we analyse the test conditions in evaporator mode, we realise that the OHX is rejecting heat in the first section

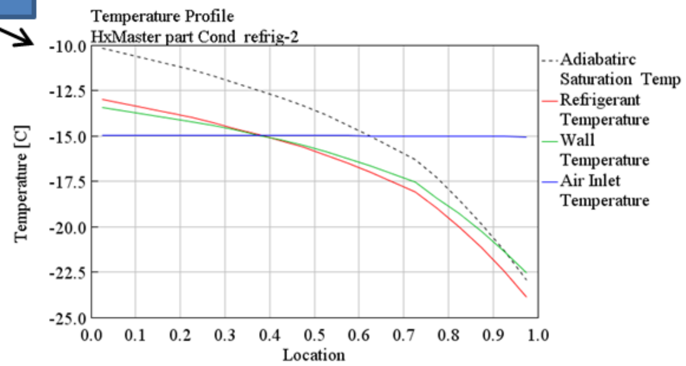
Total dP

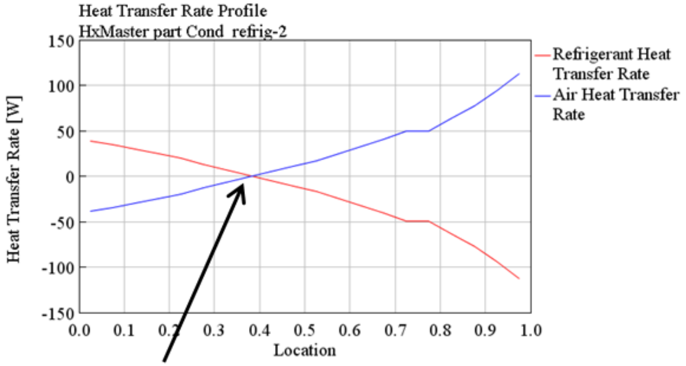
The Internal pressure changes inside the OHX

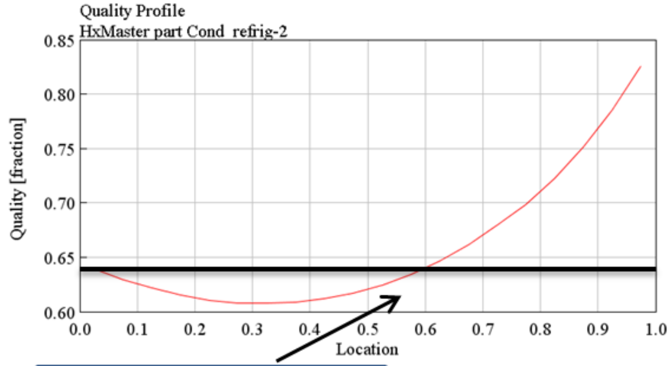
The saturation temperature changes with the pressure

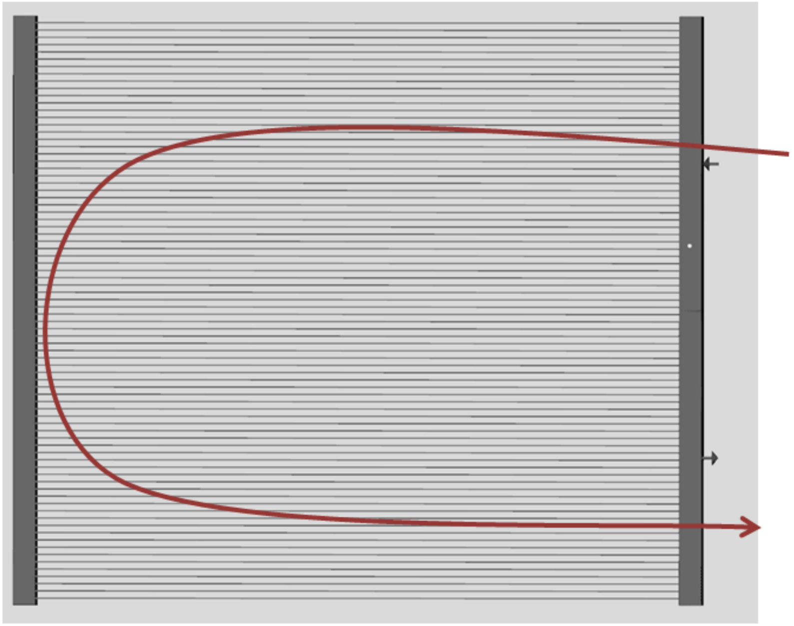
In addition, there is heat transfer in the OHX that impacts on the temperature











We change the heat flux direction at 35% of the OHX

We have positive work/energy balance at 60% of the OHX

Fortunately, this is a standalone test condition, when the component will be placed in the vehicle, the control system will avoid this effect

Conclusions

- The difficulty of the process increases exponentially between 1 phase and 2 phases and between single mode and dual mode
- It is important to define properly the test conditions to properly characterise the Hx without duplicated data
- The calibration is not just an interpolation/extrapolation on the data, it uses physic formulas and empirical methods
- It is important to check the test conditions before start with the CAE calibration to be sure that the test has been conducted properly
- The process is automatic for all cases, except for an outboard Heat Exchanger (OHX) where we need to use a manual process due to its complexity

Next steps

- Optimise the number of points required for the testing to save time and cost
- Optimise the genetic algorithm to reduce the number of iterations
- Using the method continuously to evaluate its robustness and reliability

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