Thermal Design and Analysis of Battery Electric Vehicles

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Thermal Design and Analysis of Electric Vehicles

InDesA Competence

Simulation and Design Analysis of complex systems for engineering and industrial applications

Fluid Flow & Heat Transfer
Hydro & Aerodynamics
Thermal & Energy Management
Air-borne Acoustics & Sound Design
Thermal Design and Analysis of Electric Vehicles

Integrated Design Analysis

Development Environment of customer

1D Simulation

3D Simulation

3D Virtual Test Bench
e.g. for performance prediction of water pump for low coolant temperatures
Why did I hesitate to order a Battery Electric Vehicle?
- High price
- Low range
- Long recharge time

What can I improve as a Thermal Management expert?
- Range
- Recharge

Why is Thermal Management significant?
HV components are temperature sensitive with regard to efficiency and need “thermal comfort” – just like passengers in the cabin.

Get the most out of it!
- Battery
- E-Motor
- Cabin comfort
Simulation Methodology

1. Build system to predict vehicle energy consumption for arbitrary drive cycles with 1D methodology.
2. Solve Fluid Flow and Heat Transfer problems for vehicle and HV components with 3D CFD/CHT solver STAR-CCM+
3. Feed back results to 1D system model for calibration.
4. Validate filling and degas function for coolant system with 3D CFD solver STAR-CCM+
Pandora Electric Vehicle

... designed to demonstrate thermal simulation techniques with options for different thermal management technologies.

**Specification MY 2019:**

- Rear wheel drive with 160 kW/360 Nm E-Motor
- Battery 72 kWh, 448 V
- Battery Cell: 50 Ah; 3.7 V\text{nom}

**InDesA Design** includes

- Exterior
- Radiator/Condenser and Fan Module
- Cabin and HVAC unit
- Battery and E-Drive Coolant System
- Refrigerant Circuit
- HV components (Battery, Motor, Inverter)
Thermal Design and Analysis of Electric Vehicles

Schematic of Pandora Thermal and Electric System

- Refrigerant Circuit
- Cabin Ventilation
- System Control
- Drive Cycle Power Demand
- Electric Circuits

- Coolant Circuit #1
- Coolant Circuit #2
- Cooling Air
- Cabin Climate Power Demand

- Temperature sensor
- Pressure sensor
- Actuator
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The Pandora Thermal System

Cabin
3D flow/thermal

E-Drive
3D flow/thermal

U-Hood
Aero
3D flow/thermal

Coolant Circuit
3D fill/degas

Battery
3D flow/thermal
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Aerodynamic and Underhood Flow

**Exterior and Underhood Flow Simulation**
- Vehicle Aerodynamics
- Flow through Condenser/Radiator and Fan Module (CRFM)
- Vehicle underfloor Flow

**Prediction of**
- Aerodynamic drag
- Mass flow rates and losses through CRFM
- Heat Release from Radiator/Condenser
- Heat Transfer Coefficients (Cabin, E-Motor)

**Relevance for 1D System Simulation**
- Aerodynamic drag
- Calibration of cooling air flow model (CRFM)
- HTC’s for cabin exterior
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Cabin Flow and Heat Transfer with Solar Radiation

Cabin Thermal Comfort Simulation
- CFD Cabin flow
- CHT Cabin Structure (body frame, windows, seats, etc.)
- Solar Radiation

Prediction of
- Cabin warm-up / cool-down
- Thermal comfort
- Thermal Balance Analysis

Relevance for 1D System Simulation
- Calibration of multi-zone cabin model
- HTC’s at windows, walls and other boundaries
**Warm-up Scenario:**

01/08/2018 11:00 CET
Parking lot @ InDesA office
Site elevation 490 m
N 48° 13’ E 011° 40’
sun shine; no clouds

Simulation time 2 hours
Cabin start temp. 28°C

*animation not visible in pdf*
Cool-Down Scenario:

01/08/2018 13:00 CET
Parking lot @ InDesA office
Site elevation 490 m
N 48° 13’ E 11° 40’
sun shine; no clouds

Simulation time 2 minutes
Avg. cabin start temp. 62°C
Vent temp. 10°C
Vehicle speed: 0 kph
E-Drive Thermal Analysis

➢ E-Motor (water cooled)
➢ Inverter (water cooled)
➢ Transmission (air cooled)

Prediction of

➢ Local component temperatures
➢ Heat transfer analysis

Relevance for 1D System Simulation

• Heat release from component to coolant
• Calibration of 1D models for e-motor and inverter with regard to thermal inertia (transient behavior)
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E-Drive Thermal Analysis

- E-Motor (water cooled)
- Inverter (water cooled)
- Transmission (air cooled)

Prediction of

- Local component temperatures
- Heat transfer analysis

Relevance for 1D System Simulation

- Heat release from component to coolant
- Calibration of 1D models for e-motor and inverter with regard to thermal inertia (transient behavior)
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Battery Thermal Analysis

- Battery packs
- Cold Plate (water cooled)

Prediction of

- Local component/cell temperatures
- Heat transfer analysis

Relevance for 1D System Simulation

- Heat release from battery to coolant
- Calibration of 1D models for battery with regard to thermal inertia (transient behavior)
Fill and Degas Simulation

- Battery Coolant Circuit
- E-Drive Coolant Circuit

Simulation of

- Gravity fill
- Vacuum fill (2000/20000 Pa)
- Degas through bleed points
- Degas with active pump and valve control

with the following goals:

- Identification of remaining air pockets
- Removal of remaining air in system
- Control strategies
- Identification of degas potential (design optimization)
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E-Drive Coolant Circuit Vacuum Fill @ 20000 Pa
Open bleed point at cabin heater

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E-Drive Coolant Circuit Degas of Cabin Heater

Animation not visible in pdf
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E-Drive Coolant Circuit - Gravity ReFill

Refill at ambient pressure

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E-Drive Coolant Circuit – Degas with Pumping

*valve closed at cabin heater return*

*valve closed to radiator*

*pump speed 2500 rpm*

*degas through swirl tank below expansion tank*

*animation not visible in pdf*
valve closed at cabin heater return

degas through swirl tank below expansion tank

valve closed to radiator

pump speed 2500 rpm

animation not visible in pdf
Simulation Methodology presented for
Thermal Design and Analysis of Battery Electric Vehicles

Demonstrator Vehicle Pandora VEV presented
to demonstrate simulation techniques
with refrigerant and coolant circuits as well as HV components.

STAR-CCM+ 3D CFD/CHT simulation application shown
for vehicle and various HV components to
• prove concepts and functions
• derive, optimize, and calibrate 1D objects for thermal system simulation

STAR-CCM+ 3D CFD Fill and Degas simulation presented
to validate functioning of coolant system.