

Thermo-Fluid Systems for Fuel Cells

Contents



- Current expertise & capabilities
- Fuel cell applications
- Thermo-Fluid system solutions

Introduction

- WDL performs design, analysis & development of thermo-fluid systems, mainly for the automotive industry
- We work closely with OEMs & Suppliers on R&D and product development
- Here we explore how this capability can be applied to Fuel Cell thermo-fluid systems & applications

Background

- 25+ years in thermo-fluid systems
- 1D performance modelling (code writing & applications)
- Engine thermal loading R & D
- Programmes with automotive OEMs & Tier 1 suppliers
- Range of industries & markets:
 - Automotive
 - Motorsports
 - Aerospace
 - Military
 - Marine & Industrial
- Range of engine types:
 - Internal combustion (Otto & Diesel cycles)
 - Vapour cycle
 - Stirling cycle
- ***& Now FUEL CELLS....***

Expertise

- Thermo-fluid systems
- IC engine performance & emissions
- Cooling & lubrication systems
- Air management & EGR systems
- Technology strategy
- Programme planning & management

Capabilities

- Design:
 - Thermo-fluid systems
 - Heat exchangers
 - Turbo-machinery
- Analysis:
 - 1D IC engine performance (AMESim, WAVE, GT-Power)
 - 1D thermo-fluid systems (AMESim, s/state & dynamic)
 - Heat exchanger performance (WDL code)
 - Turbo-machinery performance (AMESim, WDL code)
- Manufacture:
 - Prototype fluid system components (partner)
- Test & Development:
 - Component/system test & analysis (partner)

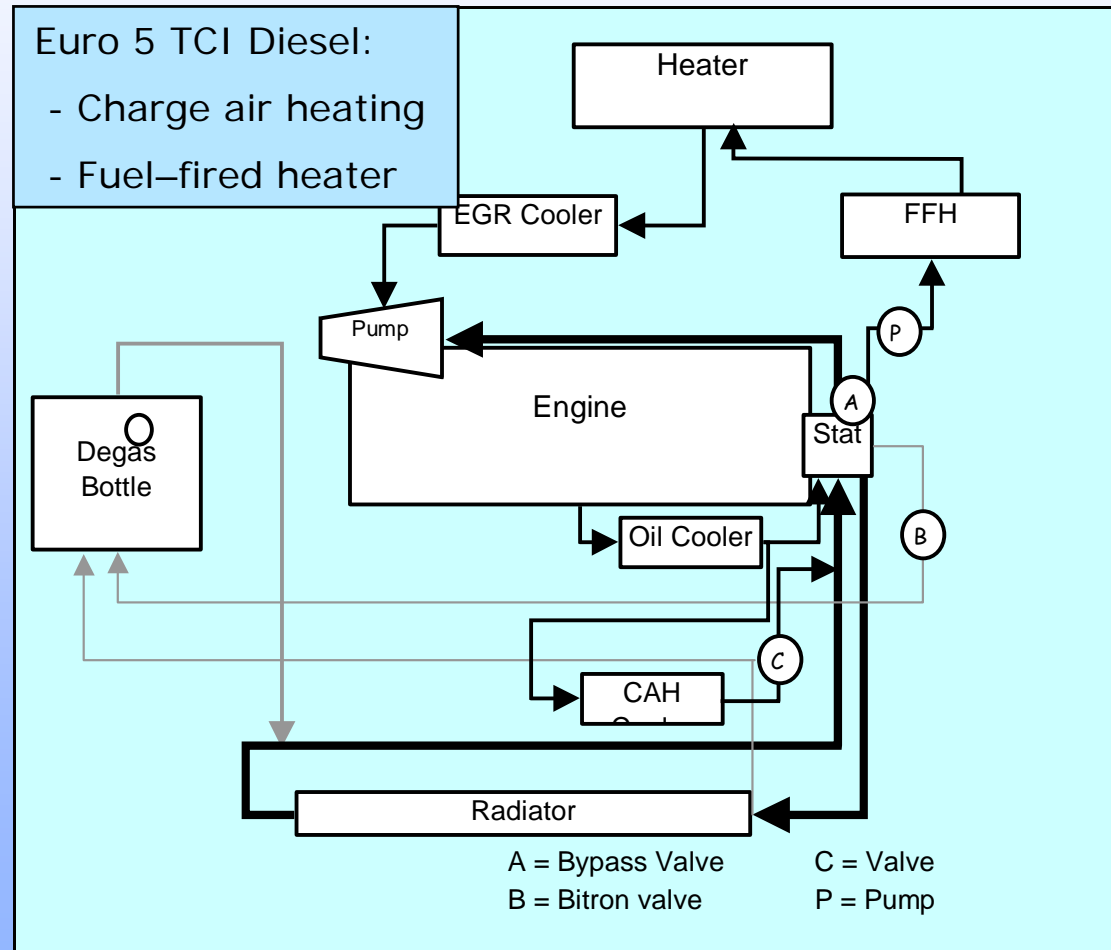
Completed Projects

- Cooling systems:
 - System development for a medium passenger car
 - Design & analysis of 'electric' cooling system (pump & flow control valve)
- Charge air cooling (CAC):
 - Design & development of new water-cooled CAC concept
 - Vehicle transient response modelling & testing
 - Advanced low temperature CAC concept
 - Combined CAC system for 2-stage boosted diesel engine
- EGR cooling:
 - Advanced low temp. EGR cooler
 - Thin-film surface nano-coating for corrosion resistance
- Air handling:
 - Turbocharger system design
 - Novel compressor-expander concept

Cooling System ~ Case Study



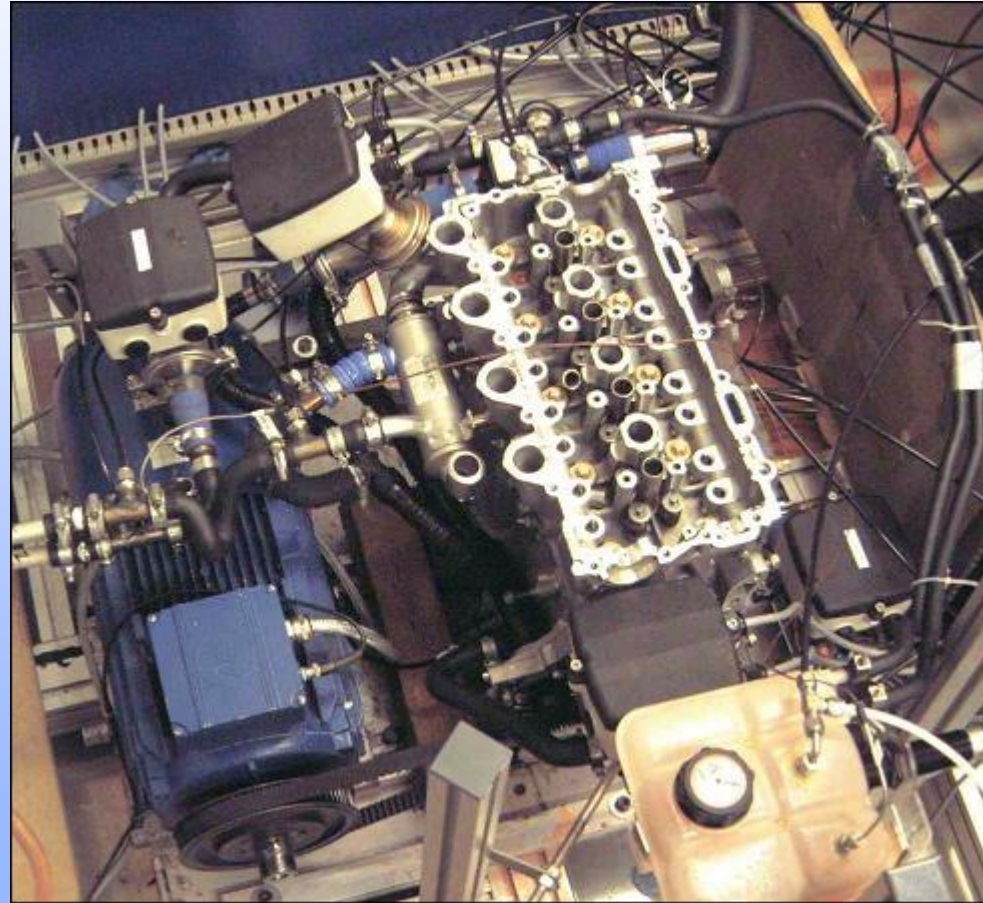
- Common car platform
- 5 engines (2 diesel, 3 gasoline)
- Fill, degas & performance validation



Cooling System ~ Case Study



- Full system installation
- Correct vehicle geometry
- Heated engine structure
- Motored coolant pump
- Instrumentation:
 - Pressures
 - Flows
 - Temperature
 - Sight glasses

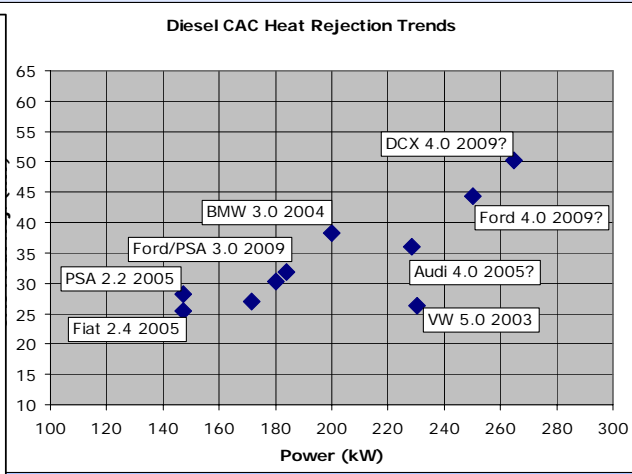
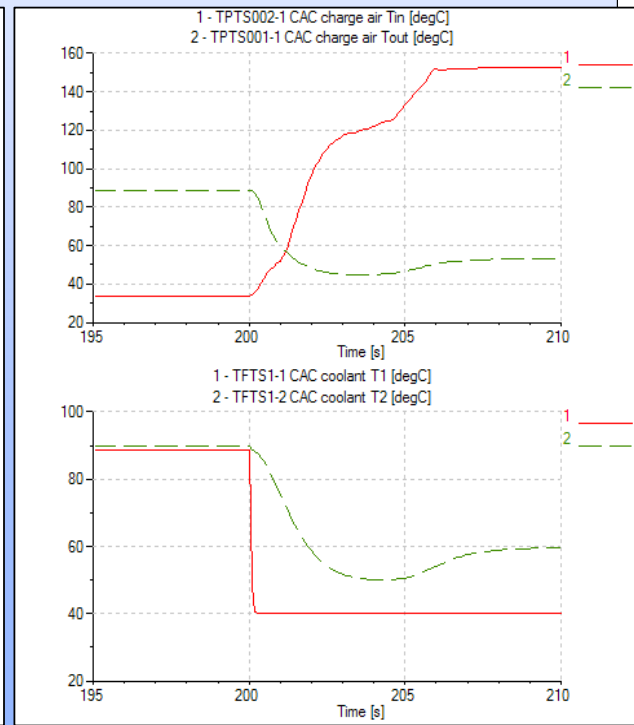
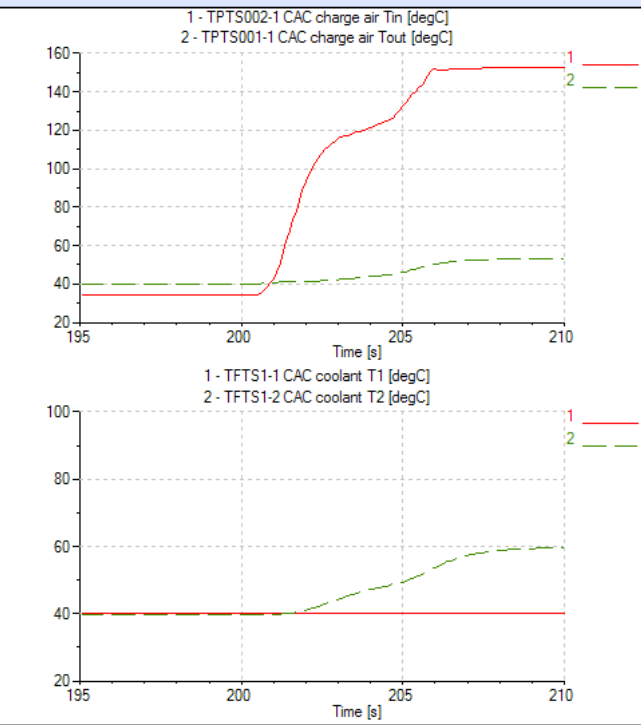
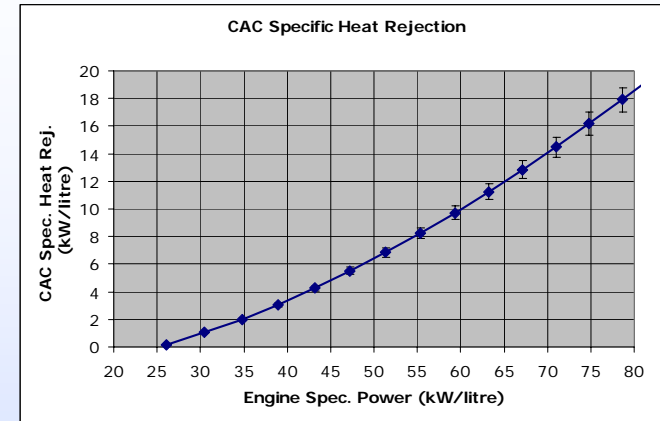


Charge Cooling ~ Examples



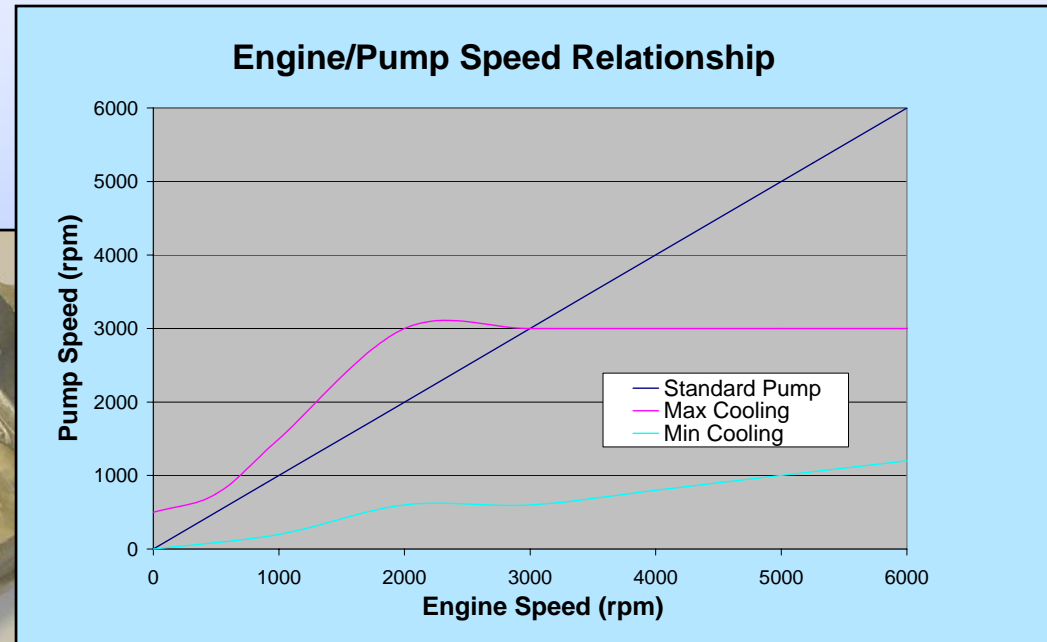
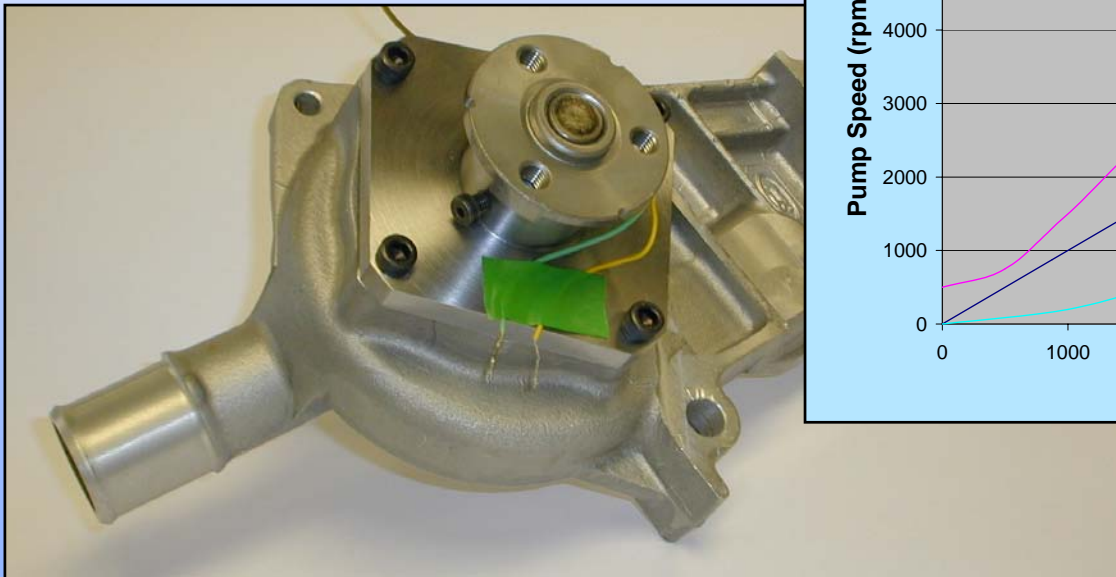
- Charge Cooling Trends

- AMESim model:
 - HCCI charge air control system
 - Water-cooled CAC
 - WOT response



Advanced Cooling

- Design & development of variable speed mechanical pump:
 - Modelling
 - Performance development
 - Initial durability



Fuel Cell Technologies



Comparison of Fuel Cell Technologies

Fuel Cell Type	Electrolyte	Operating Temperature	Applications	Advantages	Disadvantages
Polymer Electrolyte membrane (PEM)	Solid organic polymer poly-perfluorosulfonic acid	60–100°C 140–212°F	<ul style="list-style-type: none"> electric utility portable power transportation 	<ul style="list-style-type: none"> Solid electrolyte reduces corrosion & management problems Low temperature Quick start-up 	<ul style="list-style-type: none"> Low temperature requires expensive catalysts High sensitivity to fuel impurities
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90–100°C 194–212°F	<ul style="list-style-type: none"> military space 	<ul style="list-style-type: none"> Cathode reaction faster in alkaline electrolyte so high performance 	<ul style="list-style-type: none"> Expensive removal of CO₂ from fuel and air streams required
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	175–200°C 347–392°F	<ul style="list-style-type: none"> electric utility transportation 	<ul style="list-style-type: none"> Up to 85% efficiency in cogeneration of electricity and heat Can use impure H₂ as fuel 	<ul style="list-style-type: none"> Requires platinum catalyst Low current and power Large size/weight
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600–1000°C 1112–1832°F	<ul style="list-style-type: none"> electric utility 	<ul style="list-style-type: none"> High efficiency Fuel flexibility Can use a variety of catalysts 	<ul style="list-style-type: none"> High temperature enhances corrosion and breakdown of cell components
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of yttria is added	600–1000°C 1112–1832°F	<ul style="list-style-type: none"> electric utility 	<ul style="list-style-type: none"> High efficiency Fuel flexibility Can use a variety of catalysts Solid electrolyte reduces corrosion & management problems Low temperature Quick start-up 	<ul style="list-style-type: none"> High temperature enhances breakdown of cell components

- Heat Transfer:
 - Low thermal inertia
 - High performance
 - Flow & pressure control
- Humidification:
 - Accurate control of condensation
- Waste heat recovery:
 - Low grade heat extraction (PEMFC)
 - High grade heat extraction (SOFC)
- Air & exhaust management:
 - CEM required for efficient high pressure operation

FC Cooling Requirements

- Low Temperatures Systems (AFC, PEMFC):
 - High specific heat rejection
 - Compact package
 - Corrosion resistance
 - Flow control
- High Temperature Systems (SOFC):
 - Heat resistance
 - Corrosion resistance
 - Flow control

BOP/System Challenges

- Most un-recovered energy is in the exhaust
- Operating & start-up temperatures
- Low temperature heat rejection
- Water vapour handling
- Operating pressure; balance of performance vs. losses
- Aggressive environments
- Turndown ratio (idle to max. power)
- Transient response

Cooling System (1)

Start-up of PEMFC Stacks From Sub-Freezing Temperatures

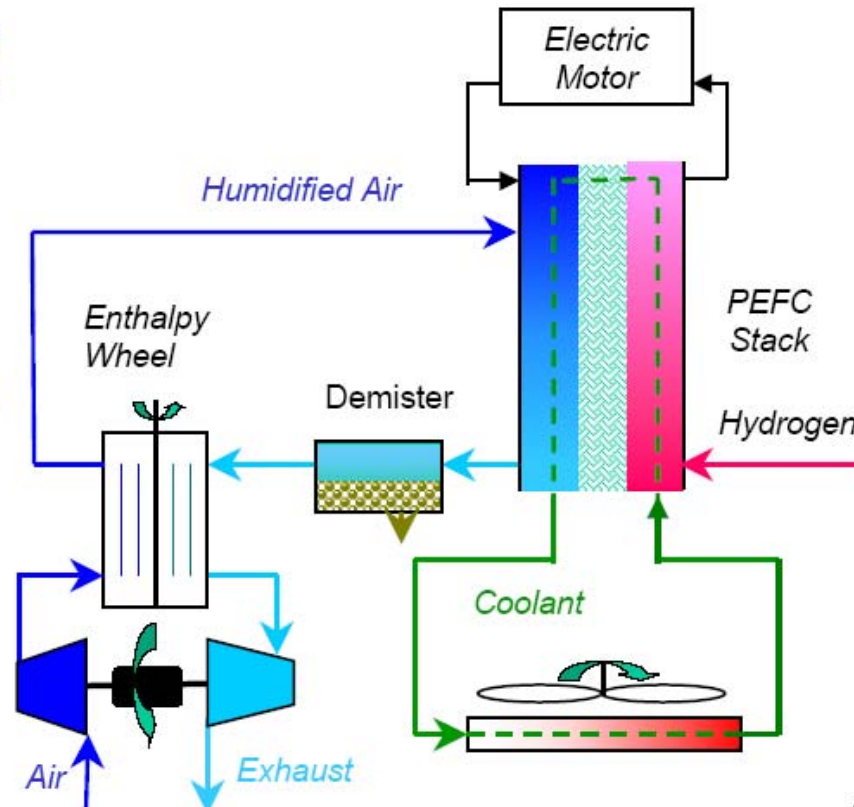
Pressurized FCS with Enthalpy Wheel Humidifier

FCS for hybrid family sedan

- 80 kW FCS + 40 kW ESS
- 50% FCS efficiency at rated power
- 50% O₂ utilization
- 0.7 V at design point
- 1000 W/L energy density
- 1000 W/kg specific power

CEM

- 2.5 atm at rated power
- 91 g/s rated flow
- Motor can be overloaded for 30 s
- 120% of design flow possible



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Cooling System (2)

Module 5- Fuel Cell Systems

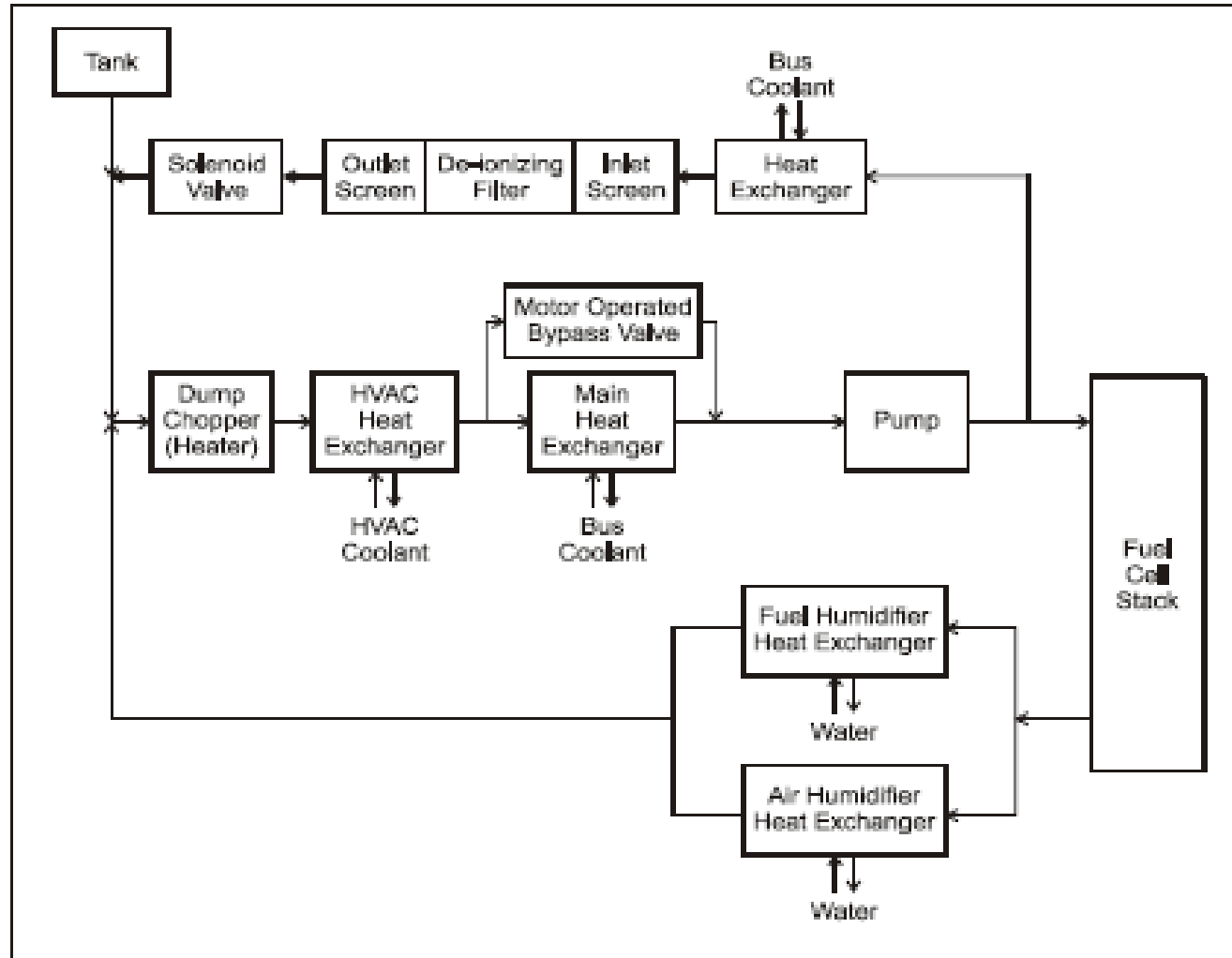


Figure 5-9 Stack Cooling System Flow Diagram

- Design & development of low cost, high efficiency, solutions for specific fuel cell power-plant thermal requirements
- Use a systems approach, not just a collection of components
- Design of thermo-fluid systems around automotive industry architecture, components & controls

Automotive Synergies & Benefits **WDL**

- Synergies:
 - Air management & cooling system demands for IC engines:
 - Heating & cooling (Bi-flow)
 - Electric assist compressor/expander (eBoost, TCS)
 - Delivery temperature control (HCCI)
 - HEX size constraints (on-engine WCAC)
 - Corrosion resistance (ECAC)
 - Close similarities with fuel cell needs
- Benefits:
 - Component performance
 - Package
 - Durability
 - Cost

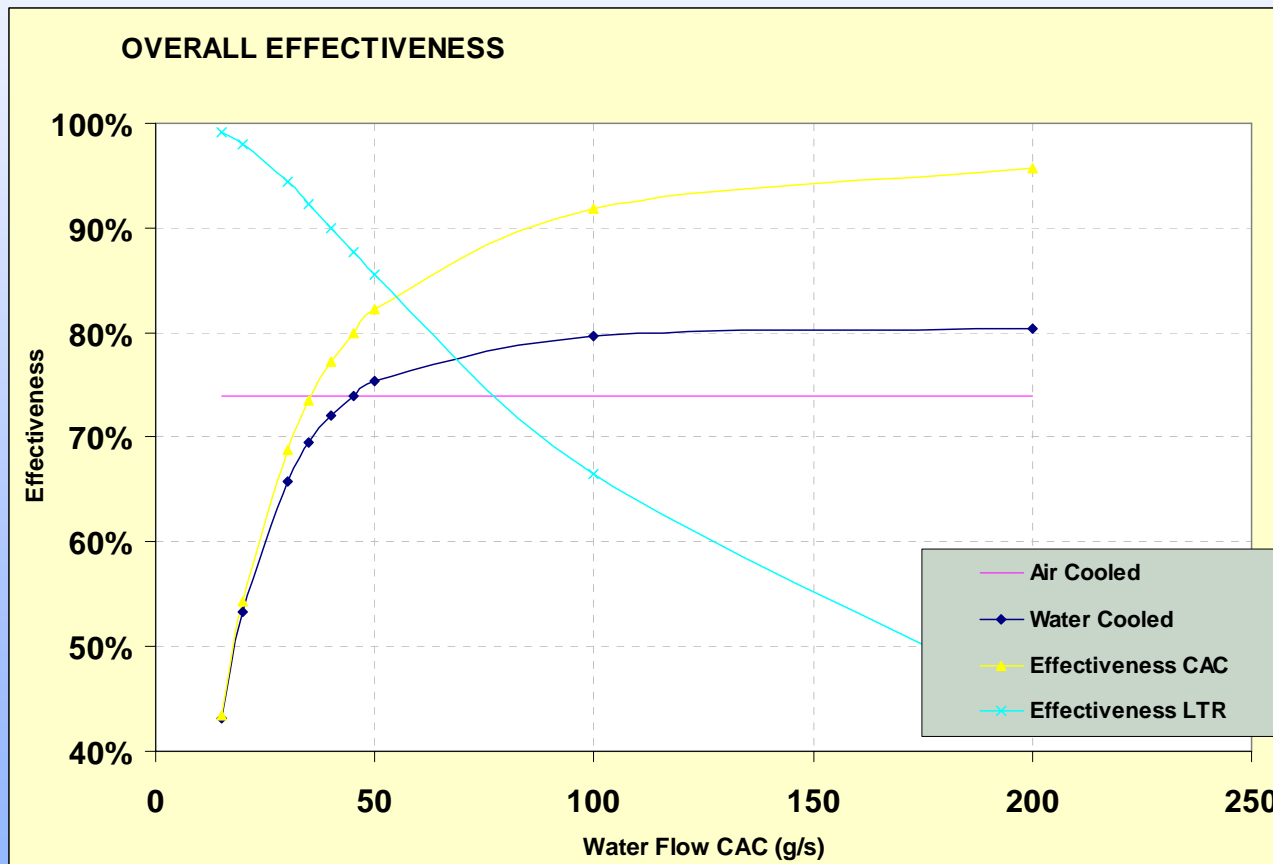
Heat Transfer Solutions

- High temperature:
 - EGR Cooler Technology
 - Stainless steel
 - Tube-shell design
 - Optimised heat transfer
- Heat recovery:
 - Automotive EHRS
 - Bypass flow control
- Low temperature:
 - Charge air cooler technology
 - Aluminium
 - Plate-fin design
 - Anti-corrosion coating
 - All-plastic design feasible



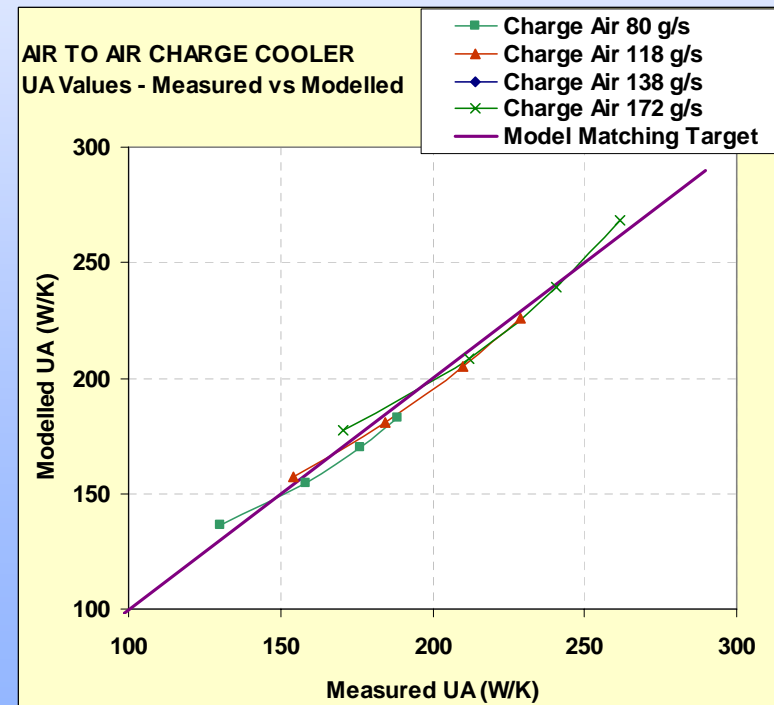
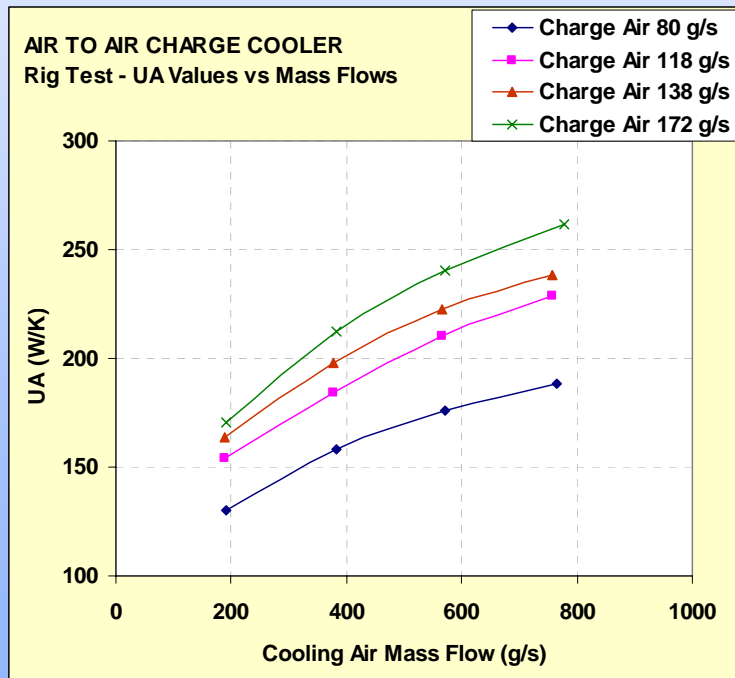
Cooling System Analysis

- Individual heat exchangers cannot be considered in isolation
- System analysis essential



Heat Exchanger Modelling

- Flow rate/heat transfer relationship of compact heat exchangers is complex
- WDL modelling method accurately predicts effects of changes in:
 - Hot and cold side flowrate
 - Core size and shape



- Current turbocharger technology & components:
 - Lightweight materials
 - Flow controls
- Electric assisted compressor-expander:
 - eBooster based design
 - Expander added

Compressor-Expander Module

Expander Module

Results

A novel system architecture has been developed that exploits a simple pressure-operated relief valve to permit a fixed-geometry turbine to provide stack

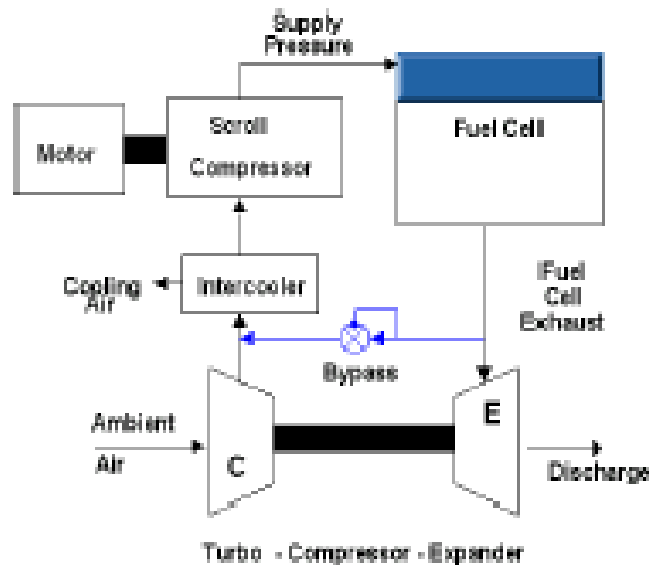


Figure 3. Hybrid TurboScroll System Architecture

pressure control tailorable to a wide variety of possible pressure-flow profiles. The system feeds both the turbocompressor output and any bypass gas into an intercooler for rejection of heat and densification of the process gas prior to compression to final operating pressure through the scroll compressor. Based on detailed preliminary designs, substantial improvements in system weight and volume, relative to previous generation machines, have been achieved by the hybridization of turbo-

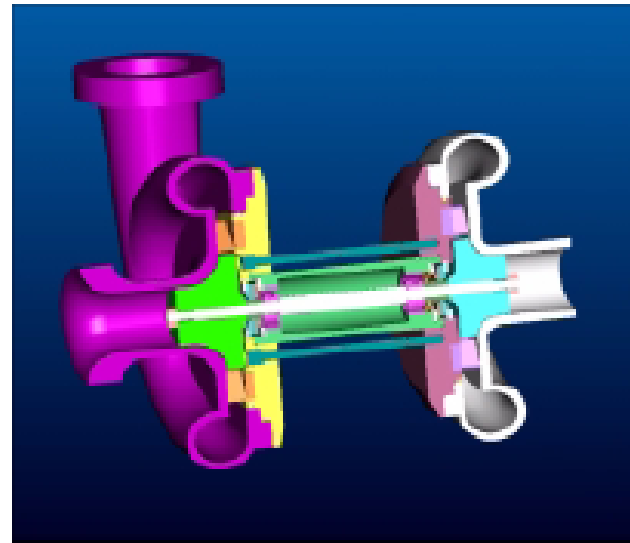
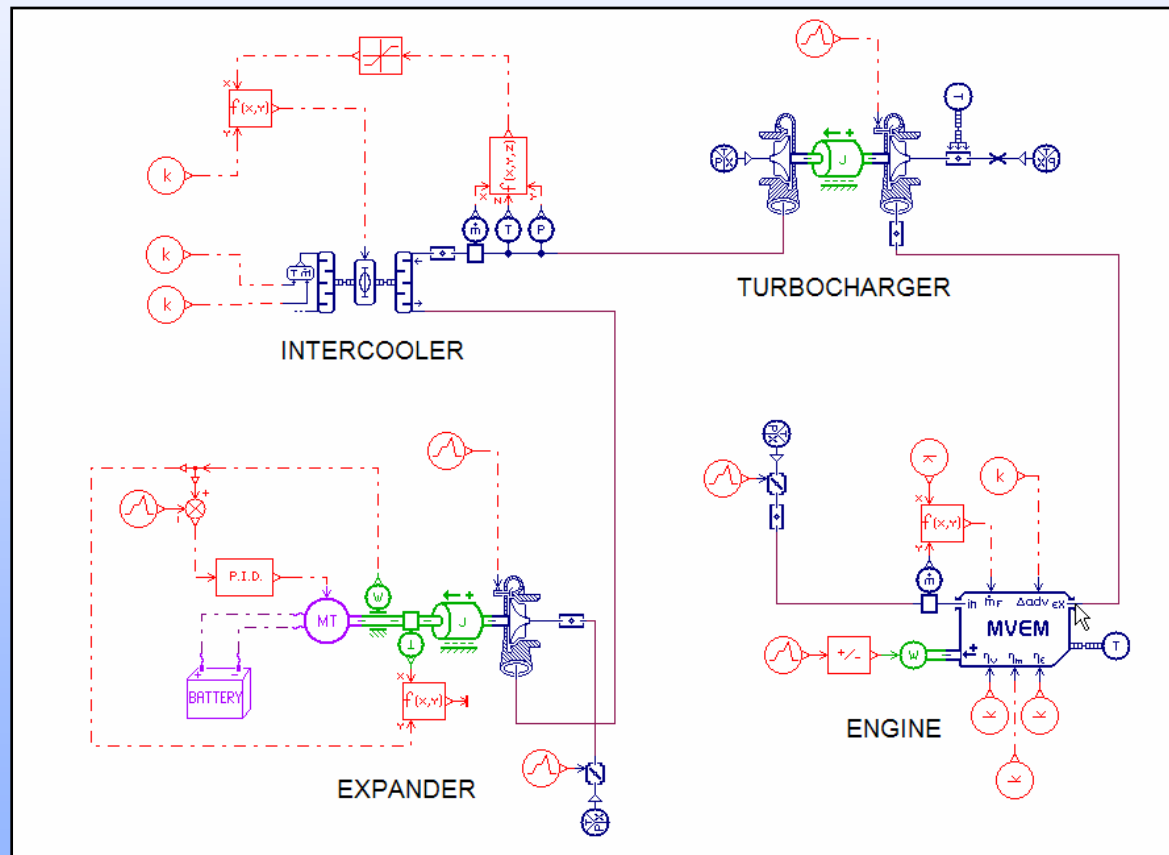


Figure 4. TurboCompressor Preliminary Design

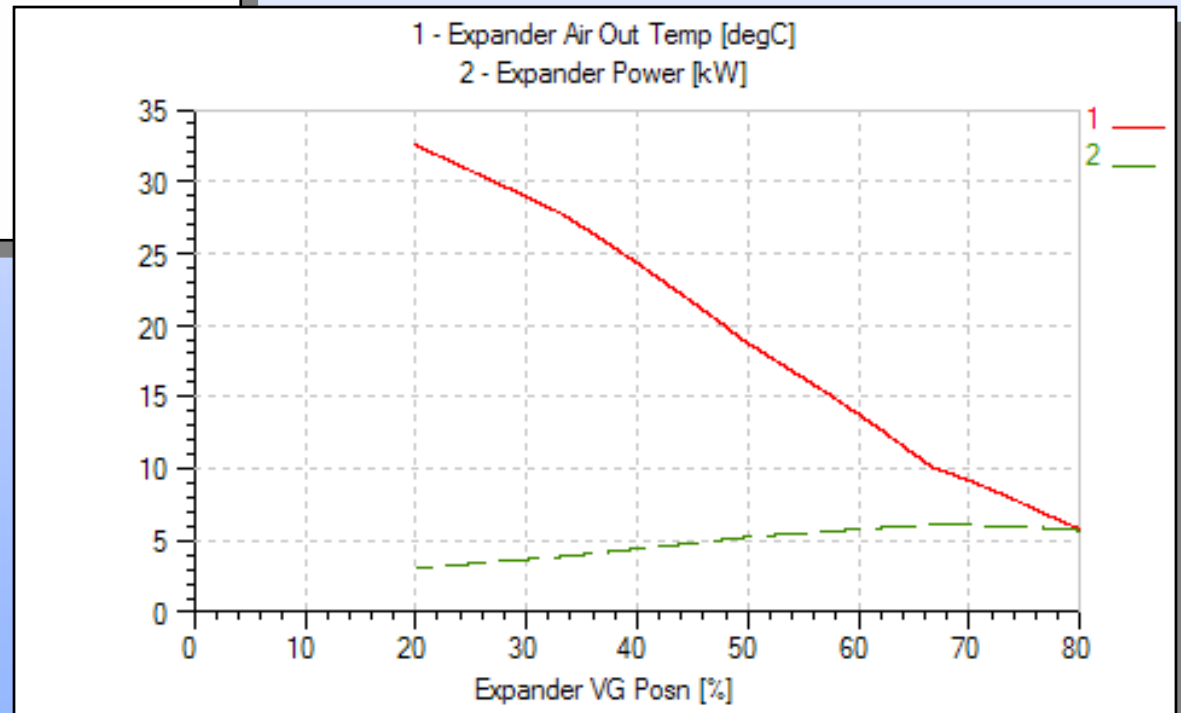
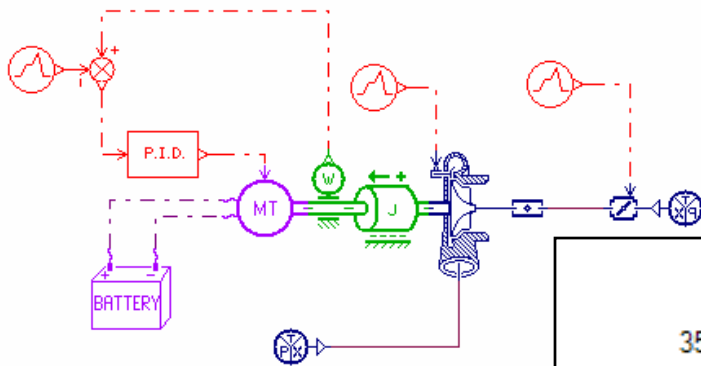
Turbo-Cooling System Model

- WDL work on turbo-expanders for charge air cooling in IC engines has significant potential for FC applications
- AMESim model shows combines CEM (turbocharger) & electric expander:



Expander

AIR EXPANDER



Summary

- WDL has wide ranging of skills & experience in thermo-fluid systems
- We have a portfolio of heat transfer & air handling system customers, suppliers & projects
- We are well placed to provide design & development related services for Fuel Cell thermal systems
- We are flexible & cost-effective