Thermally Operated Mobile Air Conditioning Systems

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TOPMACS was part of the EU 6th framework program (STREP) research

Timeline: March 2005 – March 2009
The TOPMACS Initiative

Object: to develop innovative **Mobile Air Conditioning Systems** with a low to zero impact on the environment.

The Consortium:

- 1 Car Manufacturer
- 1 Truck Manufacturer
- 1 major A/C supplier
- 1 advanced material supplier
- 5 of the most acknowledged excellence Centres in the EU
The TOPMACS Focus

The innovative A/C System main Features

• Powered by the engine waste heat
• Use refrigerant with no GWP (compliant with the new EC regulation)

The core of the system is a sorption heat pump

Project Motivations

• To meet the new EC regulation on refrigerant
• To meet the EC new regulation on CO2 emissions target
• To significantly reduce the fuel consumption due to the A/C usage
• To lower the A/C impact on the engine
The use of waste heat to power the airconditioning has energy saving potential.
The TOPMACS Project major Outputs

- 4 First Generation Prototype Units with 4 different technologies
- 1 Demonstrator Car equipped with a silicagel-water cooling system
- 1 Demonstrator Truck equipped with a zeolite-water cooling system
- 1 Upgraded Activated Carbon-Ammonia cooling system bench prototype
- 1 MeH Mechanical Compression based cooling system bench prototype
- 1 Advanced Simulation Tool able to reproduce the overall system and all technologies
- 33 Papers and participations to international events
- 27 Students participated to the project, 3 Post-Dot Scholarship
The TOPMACS Sorption Cooling Systems main results

Key Results
• No GHG emission due to refrigerant
• Small CO2 emission due to A/C operation
• Low to zero fuel consumption due to A/C usage
• No impact on vehicle handling (no mechanical compressor attached to the engine)
• Coupled with a small fuel burner can provide the cabin preconditioning.

Compared to the state of the art TOPMACS Sorption Systems improve the Cooling Power Density up to 9 times!
A passenger Car with an air conditioning system working on the engine waste heat

A passenger Truck with a thermally operated air conditioning system

Adsorption cycle MAC powered by vehicle cooling loop
A passenger car with an air conditioning system working on the engine waste heat

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• The Thermally driven AC system concept
• Prototype sorption cooler development and laboratory tests
• On board installation and test
• Redesign and system integration study
• Conclusions and discussion
Sorption Cooling basic principle

A dry sorbent material (silica-gel) adsorb fluid (water) which evaporates generating the cooling effect.

Heat is needed to “dry” the sorbent material making it ready for a new cycle.

With 2 reaction bed a continuous cooling process can be realized.
Sorption Cooling System process scheme

Basically an heat pump working on 3 temperature levels

- **Condenser**
  - Cooling to ambient 35°C
- **Evaporator**
  - Cold to cabin 5-15°C
- **Thermal compressor**
- **Engine cooling water 90°C**
- **Input power engine waste heat**
- **Cooling to ambient 35°C**
Conventional mechanical compression A/C
The Thermal compression A/C System is based on the sorption cooling technology.

TOPMACS Grande Punto with Sorption cooling with indirect condenser/evaporator layout.
The Sorption cooler operation requires three process circuits:

- **Heating** circuit for the sorbent material regeneration
- **Cooling** circuit for the reaction beds and SC heat rejection
- **Chilling** to provide the cabin cooling useful effect

### Target operating conditions of the adsorption chiller

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<th>Temperature [°C]</th>
<th>Flow setpoint</th>
<th>Power</th>
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**Characteristics**

- Refrigerant: water
- Sorbent material: silica-gel
- HEXs + pipes + valves: stainless steel + aluminum
- Silicagel Weight: 9 kg
- Total Weight: 85 kg

ECN team: R. de Boer, S. Smeding...
Operating temperatures:

Thermal powers

Depending on the varying operating temperatures, the system can deliver 2.5kW cooling power COP 0.3 ±0.5.
SCS Laboratory tests results

Varying chilled water temp.

Varying cooling water temp.

Varying heating water temp.

Varying cycle time.

- Varying chilled water temp.
- Varying cooling water temp.
- Varying heating water temp.
- Varying cycle time.
Grande Punto A/C Overall System layout

On board system overall characteristics:

- **ECN Sorption Cooling System**
- **Heating loop** connected with the engine coolant + heat recovery from the exhaust gas
- **Cooling loop** connected with an additional radiator
- **Chilling loop** connected with the air cooler placed into the standard HVAC module
The Grande Punto installation

CRF Team: S.Mola, D.Magnetto, W.Ferraris, L.Cancedda, A.Secondi, S.Sandri, F.Cavallaro
The Grande Punto installation

Sorption Cooling System

Heat rejection module

Air cooler installation in the HVAC module

Air cooler

ST Evaporator
Control and acquisition system

ECN PLC
Sorption System control BOX

CAN C
(Sorption System information)

CAN B
(vehicle information)

NI Compact Field Point

To the sensors and actuators:
- Thermocouples
- Mass Flow Sensors
- Pumps ON/OFF
- Fan ON/OFF

LabVIEW Software

PCMCIA CAN Card

Labview interface
On board tests

Test conditions
Ambient temperature 20°C & 28°C
Vehicle speed constant & NEDC

Average Cooling Power 900W
DT to air 12.5°C
On board performance comparable to bench scale tests
Conclusions

- World first passengers car with sorption cooler working on waste heat of engine is installed and working

- The present prototype peak cooling power is unable to provide the Standard Cool-Down Performance, but it is suitable to maintain the steady state conditions

- Powering heat to the System with a small fuel burner could provide the car cabin preconditioning and allow the cooling system downsizing

- The system is able to maintain the cooling power for the time of the cycle (good option for stop&start powertrain)
Conclusions

- The chosen switching control works properly in fluctuating flow and temperature conditions.
- During dynamic driving conditions the system provide constant cooling power.
- The additional radiator to reject the heat of the Sorption System has limited performance.
- The cabin heat exchanger could perform better.
- Design study indicates the possibility for location in the engine bay.
Sorption cooling system reactors redesign

Current cooling system reactors design

- Two reactors + Check valves
- Indirect condensation & evaporation
- Use of serial exchangers
- Stainless steel + aluminum
- Dimensions: 900 x 400 x 500
- Weight: 85 kg
- Silicagel: 9 kg

New cooling system reactors design

- Integrated sorption reactors, Vapor and liquid distribution valves
- Direct condensation & evaporation
- Molded plastic + aluminum
- Dimensions: 460 x 220 x 420
- Estimated weight: 15 kg
- Silicagel: 4 kg
Current design: 3 exchangers by sorption reactor bed

Mechanical tubes and fins exchangers

Water tank

Coated fins

Tubes

Reactor housing

Assembly of exchangers and reactor bottom housing

- **Sorption Reactor Design**
  - One mechanical tubes and fins exchanger by reactor bed
  - 4 rows tubes by exchanger
  - Fins coated with sorbent sheet material
  - Common molded plastic housing for the two reactor beds
Fiat Punto vehicle integration
Fiat Punto vehicle integration summary

- Use of sorption cooling system with direct condensation and evaporation
- Implementation close to engine and dashboard
- No major interferences with vehicle structure and with engine
- Minor interferences with some components of the engines compartment (tubes, ducts…)
- Expansion vessel & battery need to be repositioned
Next steps

The development of adsorption cooling technology for MAC application requires further research and development effort. These efforts should include:

- purposely developed heat exchanger
- further reduction of system volume and weight
- application of an air cooled condenser and a direct driven evaporator
- increased integration in the car/engine system is an important issue to improve performance, volume weight
Thanks for your attention