Consiglio Nazionale delle Ricerche

National Council of Research

Institute for Advanced Energy technologies, " Nicola Giordano"

Adsorption heat pumps, research activitities at CNR ITAE

ANGELO FRENI

Workshop "Heat pumps in the Italian energy system"

IEA HPP ExCO meeting - Rome, 4 November 2009

Summary

Introduction

- Background
- Adsorption machines: current state of the art
- Key factors for further development

CNR-ITAE activity on adsorption chillers

- Materials,
- Heat transfer improvement
- Components
- Modeling
- Prototypes

Challenges for the future

Introduction

Background

Worldwide the cooling and air conditioning market is growing

Vapor compression units need a high amount of electric energy

The high consumption of electricity leads to peak loads, malfunction of the power grid etc

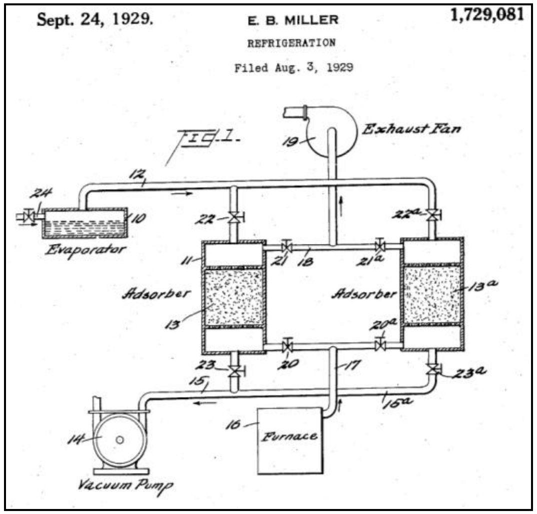
Thermally-driven cooling systems could be an answer

Two technologies:

CNR-ITAE ACTIVITY

absorption chillers	adsorption chillers
Cold is generated through the process of sorption by liquid solution	*Cold is generated through the process of adsorption on porous material*
LiBr/water and NH_3/water	Silica gel/water, zeolite/water, AC/ammonia
Mature technology	Developing technology
Several products on the market	Few products on the market

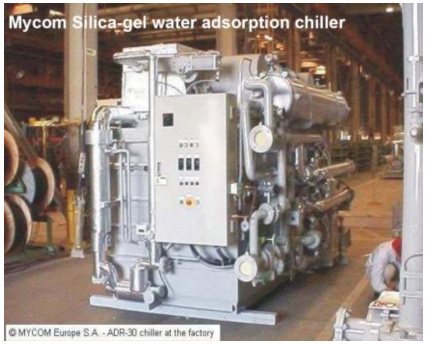
History of adsorption machines*



USA **1929**: Silica gel – SO2 adsorption refrigerator

Wait for 40 years…
Vapour compression units and CFC's are dominating the market

1980-1990: New interest in heat driven systems due to oil price shocks, resource limitations ….



1990-2000 : First commercial products, no strong enough to survive

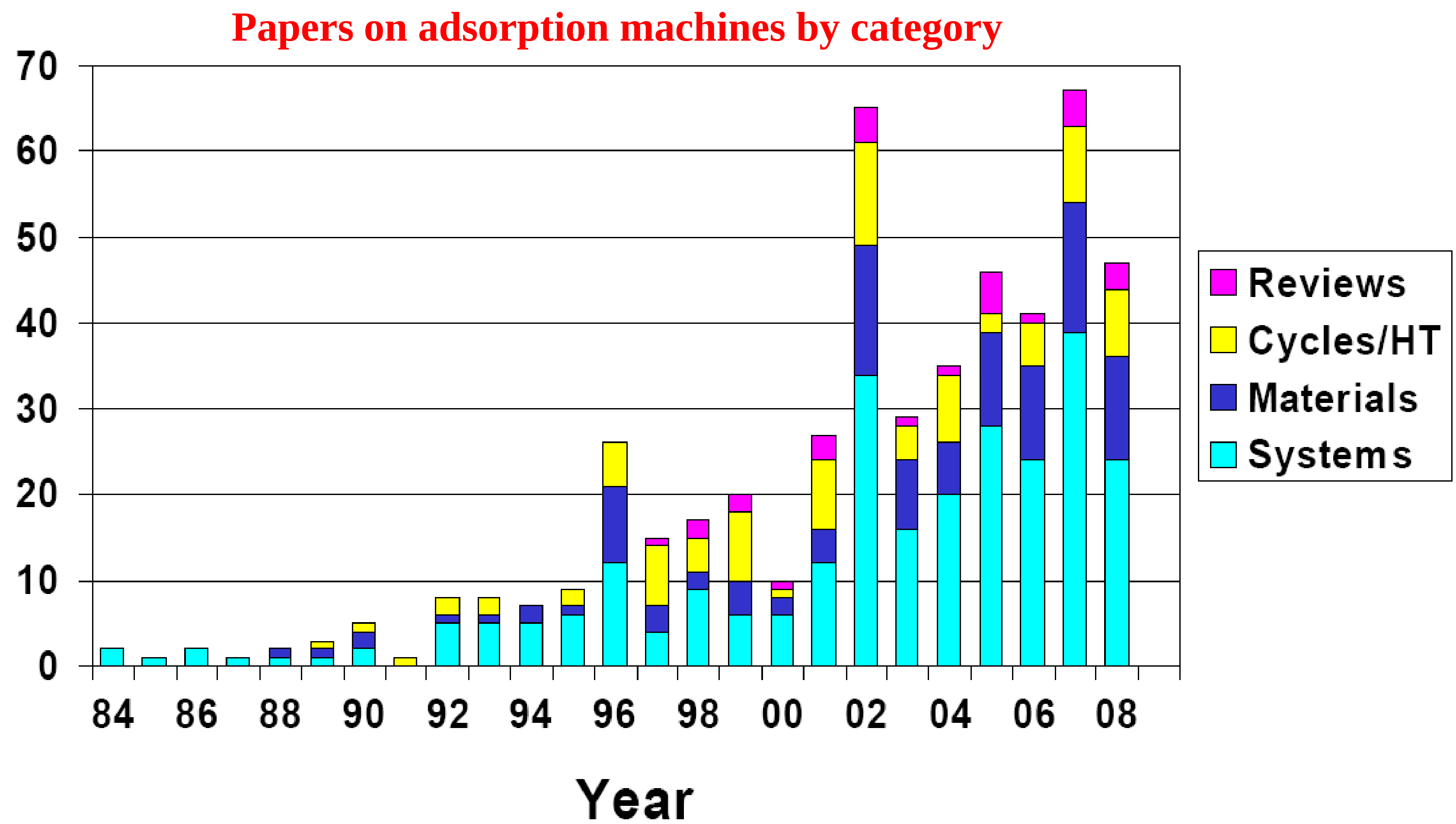
2000-today

Solid products developed in the EU

Many contributions from China and Japan

Still very little in USA

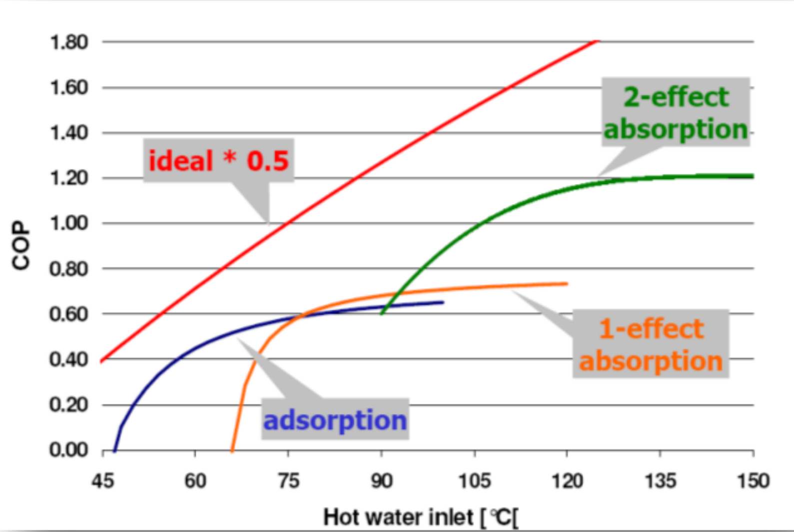
Scientific production



Source: Prof. R.E. Critoph, Un. Warwick, UK.

An overview on the market

Company	Nominal Cooling capacity (kW)	Useful effect (cold water), C	Working pair	Heat source (hot water) T_{in}/T_{out} (C)	COP
Nishiyodo (Japan)	70-1000	14/9	Silica gel/ water	85/79.4	0.6
SorTech AG (Germany)	8-15	10-18	Silica gel/ water zeolite/ water	75/67	0.6
Solarnext (Germany)	5-15	6-8	Silica gel/ water zeolite/ water	90/83	n.a.
DY Refrigeration (China)	14	n.d./≥-25 C	Zeolite/ ammonia	98/93	n.a.



Best adsorption chillers applications

(Low-grade) waste heat recovery

Solar cooling

Tri-generation

Automotive AC

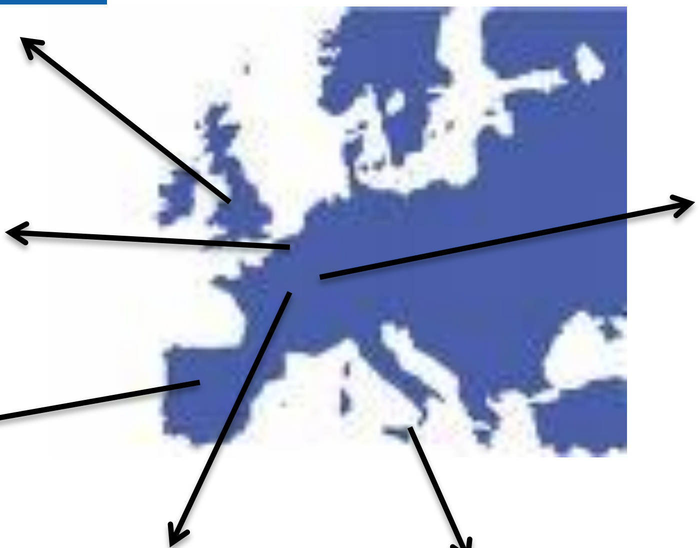
Main benefit: higher performance at low driving temperature

Main actors involved in adsorption chillers/heat pumps development

THE UNIVERSITY OF WARWICK

ECN

UNIVERSIDAD POLITECNICA DE VALENCIA



Cnam

ITAE

Vaillant

VIESSMANN

RWTH AACHEN UNIVERSITY

Fraunhofer ISE

green chiller.de

ASIA

- Nagoya University
- DENSO
- MITSUBISHI CHEMICAL
- 上海财经大学 Shanghai University of Finance & Economics

ITAE's national collaborations

-Università Politecnica delle Marche (Prof. F. Polonara)
-University of Messina (Prof. L. Bonaccorsi)
-University of Catania (Prof. L. Marletta)

Open issues to improve the machine performance

International R&D is mainly focused on the following subjects:

Improvement of adsorption capacity of adsorbent materials	-Higher COP and specific power -Volume and weight reduction
Heat transfer intensification through the adsorbent bed	-Shorter cycle time - Higher specific power
Engineering and control strategy	-Cost reduction -Machine reliability -Maximization of performance

The CNR-ITAE activity on adsorption machines

MATERIAL LEVEL

1) Development of advanced adsorbent materials

COMPONENT LEVEL

2) Development of thermally efficient adsorbent beds

SYSTEM LEVEL

4) Realization of prototypes and system integration

3) Advanced characterizations of materials and components

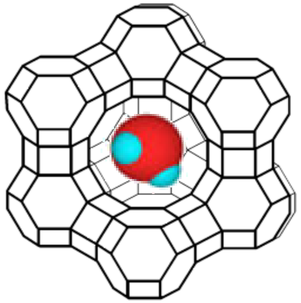
5) Mathematical modeling

MATERIAL LEVEL

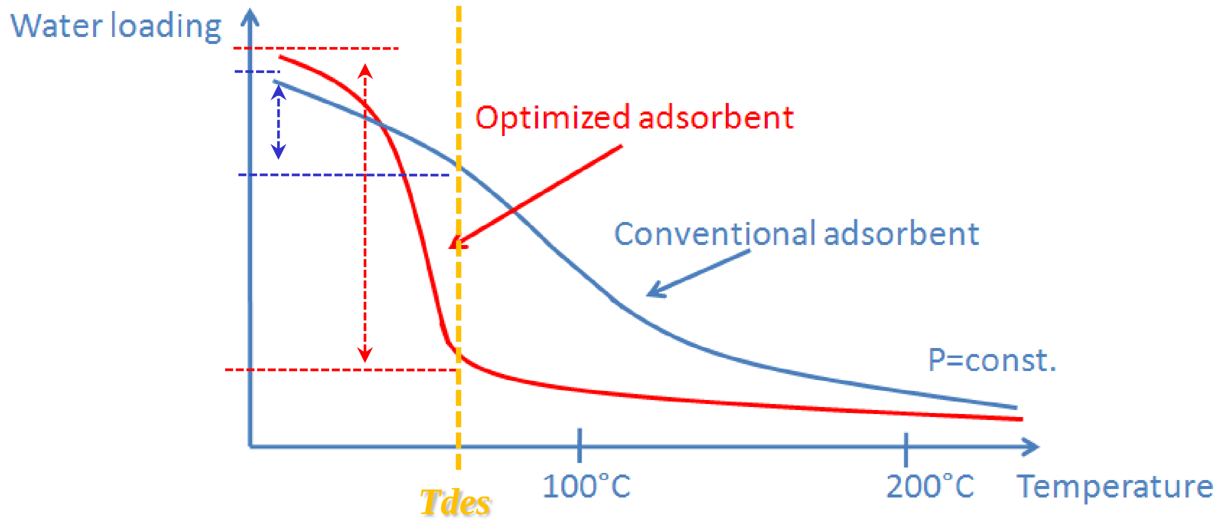
Development of advanced adsorbent materials

The adsorbent material is a key-element of an adsorpion machine

First adsoption heat transformers were realized usign adsorbents (Zeolite 4A, X, silica gel) not – optimized



New generation of adsorption machines requires novel adsorbent materials with optimal adsorption properties

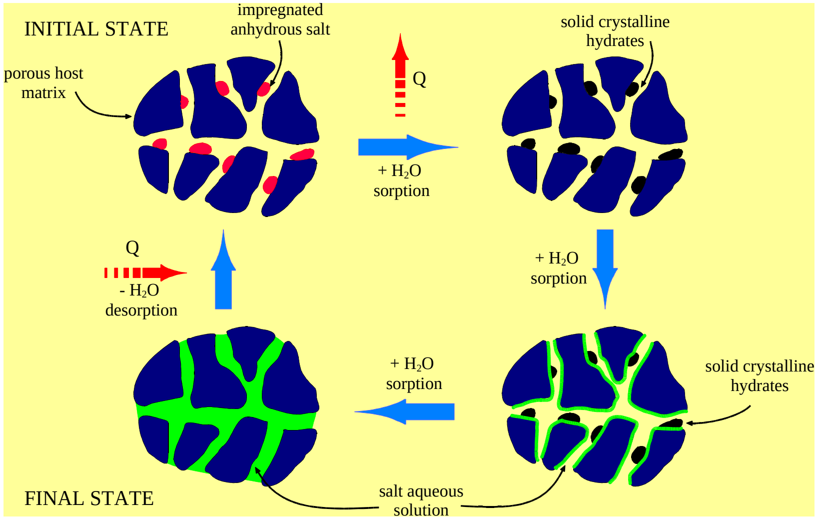


MATERIAL LEVEL

ITAE's activity: new composite sorbents

In collaboration with Boreskov Institute of Catalysis (BIC) – Russian Academy of Science

Selective Water Sorbents **SWSs**:
Two-component materials based on a porous host matrix with a salt inside its pores



Benefits:

Superior sorption capacity and low desorption T

Tailoring of the adsorption properties

Designation	SWS-1L
Host matrix	Mesoporous silica gel
Pore volume of the silica	1 cm^3/g
Salt	Calcium Chloride – $CaCl_2$
Salt content	33 wt.%
Max water loading	0.7 g/g
Optimal Tdes	100-110°C

Designation	SWS-8L
Host matrix	Mesoporous silica gel
Pore volume of the silica	1 cm^3/g
Salt	Calcium Nitrate - $Ca(NO_3)_2$
Salt content	45 wt.%
Max water loading	0.4 g/g
Optimal Tdes	80-90°C

Designation	CS-9L
Host matrix	Mesoporous silica gel
Pore volume of the silica	1 cm^3/g
Salt	Lithium Chloride (LiCl)
Salt content	30 wt.%
Max MeOH loading	0.7 g/g
Optimal Tdes	80-90°C

Best SWSs for cooling applications

MATERIAL LEVEL

ITAE's activity: new zeolites

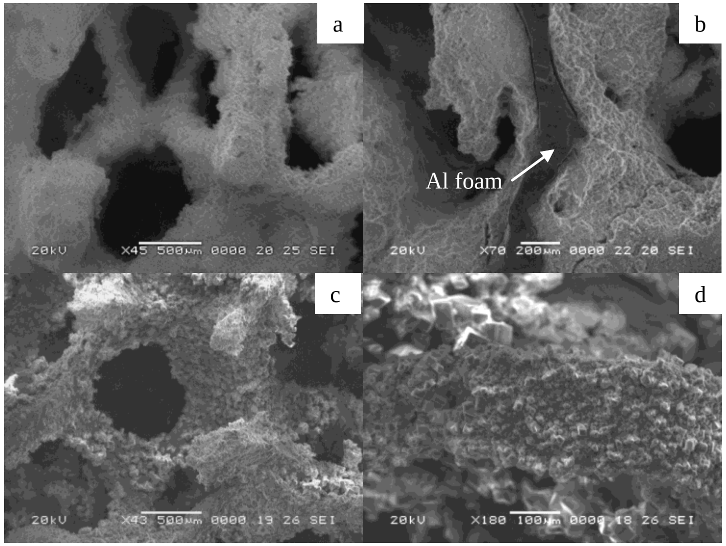
In collaboration with University of Messina

development of new zeolites and *(silico)*aluminophosphates (AlPO, SAPO)

-Hydrothermal synthesis

- Microwave synthesis

- Direct synthesis over metal substrates (finned tubes, foams, fibers, etc)

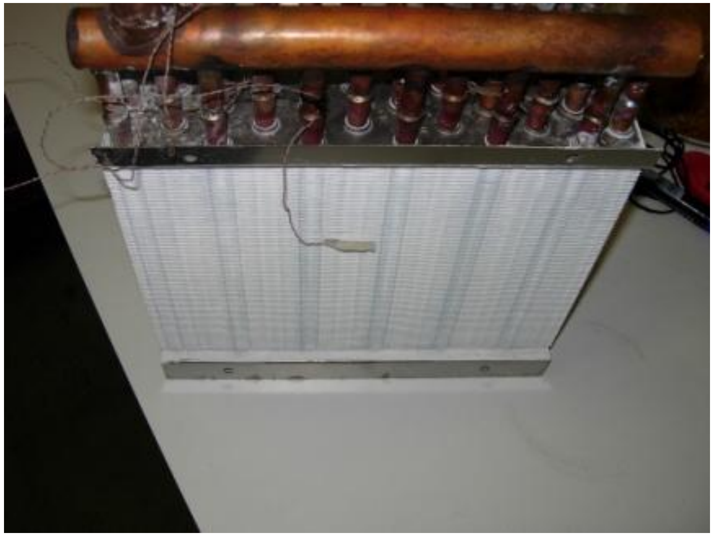


In collaboration with Mitsubishi Chemical – Japan

Characterization of novel AQSOA – FAM materials, specifically realized for utilization in adsorption machines.

-Measurement of adsortion kinetics and equilibrium curves

-Evaluation of the material thermodynamic and dynamic performance

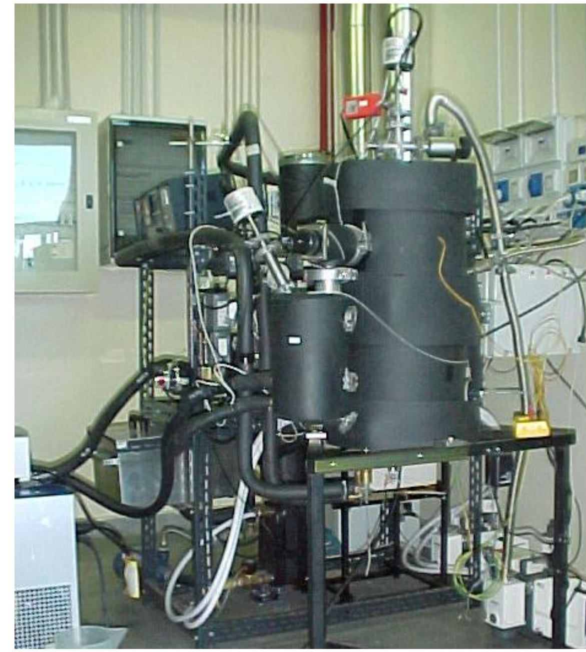


Material + Component LEVEL

ITAE's characterization activity

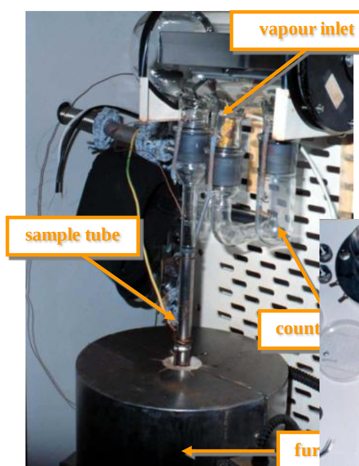
Standard equipments for analysis of adsorbent materials, such as XRD, DTA-DSC/TG, SEM, BET, Hg porosimetry

- adsorbent/adsorbate **equilibrium curves and kinetics** **(1 Chan Balance + 2 Rubotherm balances)**
- adsorbents **specific heat** **(calorimetric technique)**
- adsorbents **thermal conductivity** **(Transient hot-plate method)**
- adsorption **diffusion coefficients** and **permeability** **(self-made apparatuses)**
- adsorbents **hydrothermal stability** **(self-made apparatus)**



measurement of **COP and cooling capacity of full- scale adsorbent beds**

1 kW chiller test-rig



COMPONENT LEVEL

Development of thermally efficient adsorbent beds

Main problem of state-of-the-art of adsorbent beds:

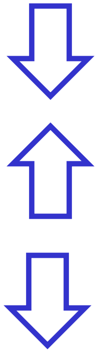
-Commonly, adsorbent beds are realized using the adsorbent in grains (low thermal conductivity).

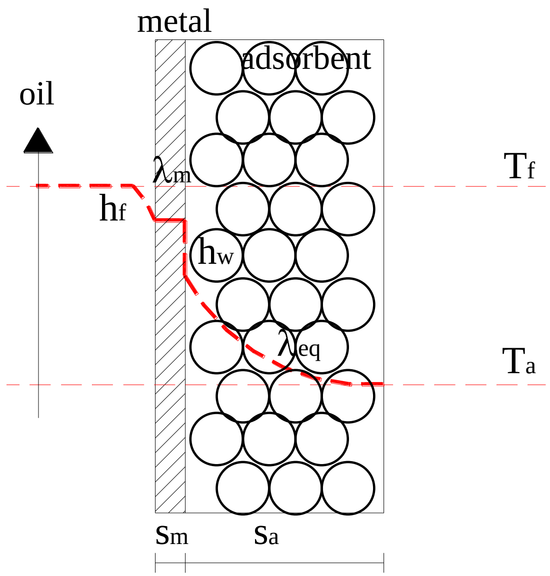
-Heat transfer is dominated by point-contacts

Heat transfer rate

Cycle time

Specific power



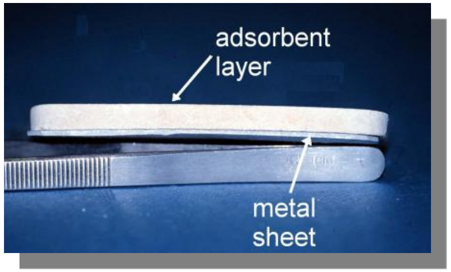


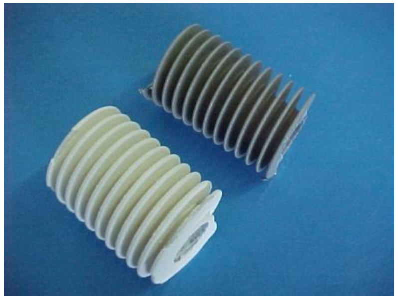
Modification of the adsorbent configuration is needed!

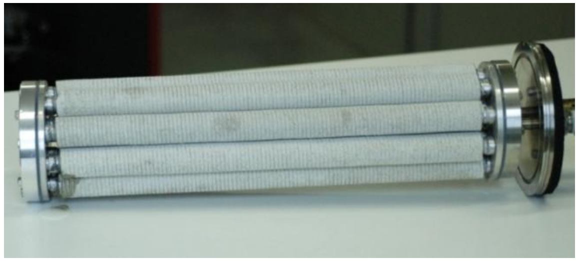
COMPONENT LEVEL

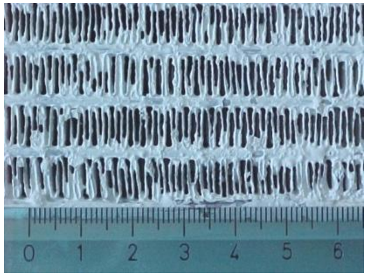
ITAE's coating technique evolution

L. Pino, Yu. Aristov, G. Cacciola, G. Restuccia, Composite materials based on zeolite 4A for adsorption heat pumps, Adsorption, (3), 33-40, 1996







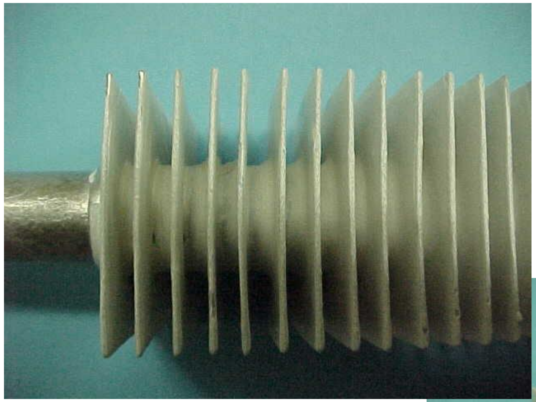


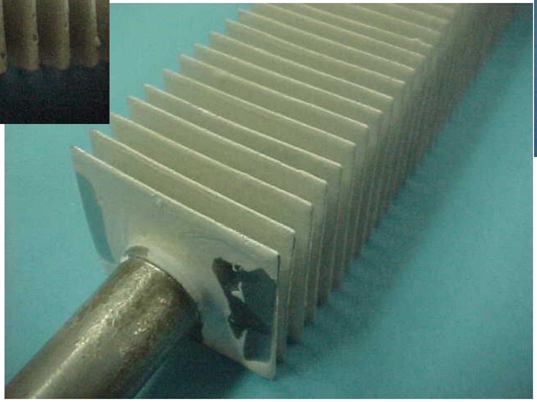
From simple supports…. To more sophisticated configurations…. To scale-up.

COMPONENT LEVEL

ITAE's coating technique today

Dip coating:





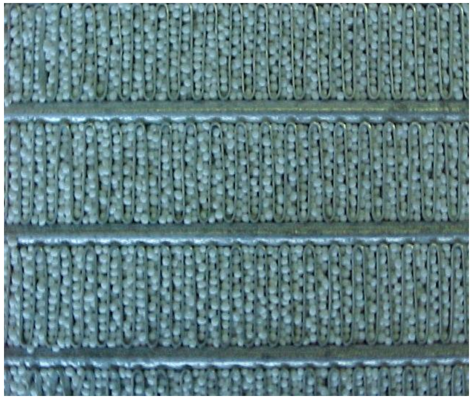
Spray coating:

thickness 0.2-1 mm

COMPONENT LEVEL

ITAE coating performance evaluation

HEX filled with grains



Coated HEX

HEX filled with grains		Coated HEX
20	Cycle time, min	8
10	Wall Heat Trans. Coeff., W/m^2K	150
20	Specific cooling power W/kg	300

COMPONENT LEVEL

Direct synthesis of zeolite over metal

In collaboration with University of Messina

Advantages

No binder required

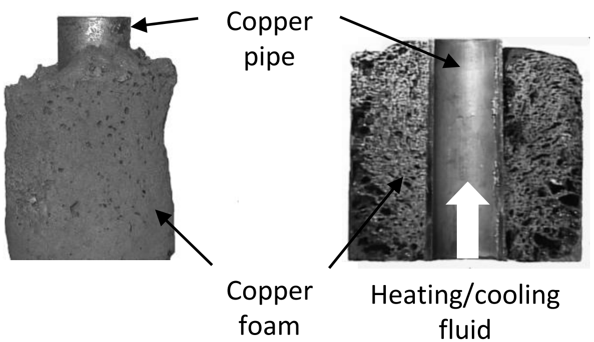
Perfect contact zeolite – metal

Drawbacks

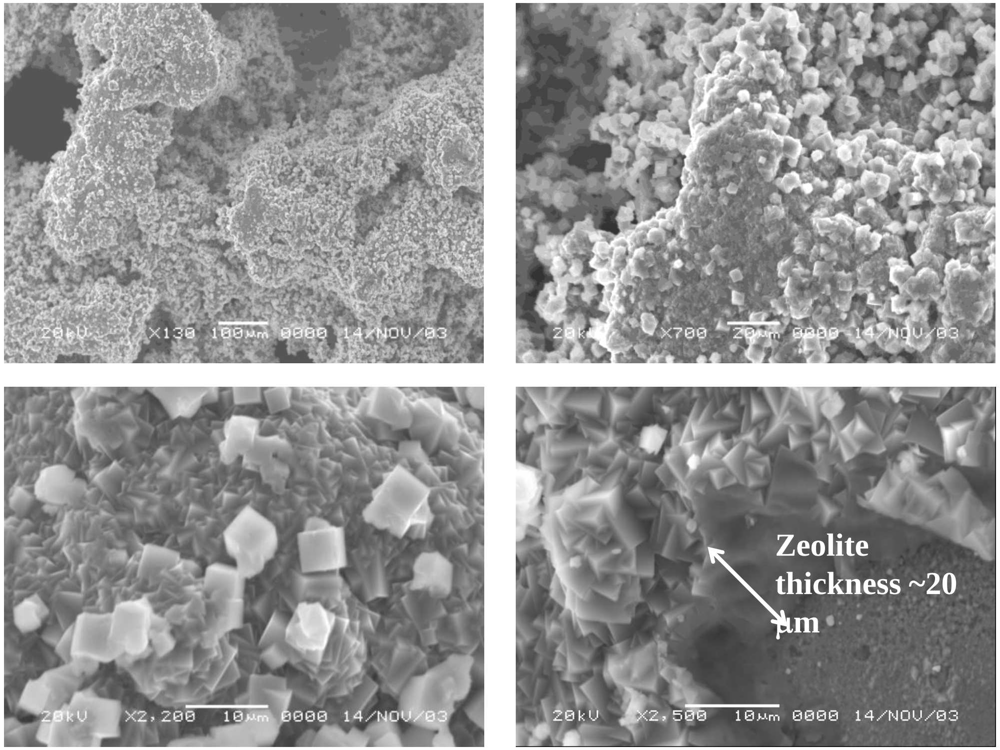
Zeolite layer thickness < 0.1 mm

Low zeolite loading

Zeolite A synthesized on copper foam



Zeolite SAPO synthesized on Aluminium foam

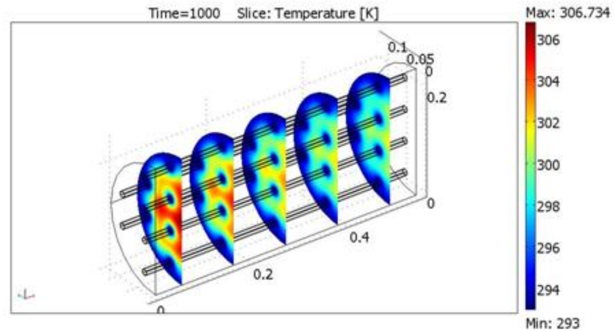


Material + component + system

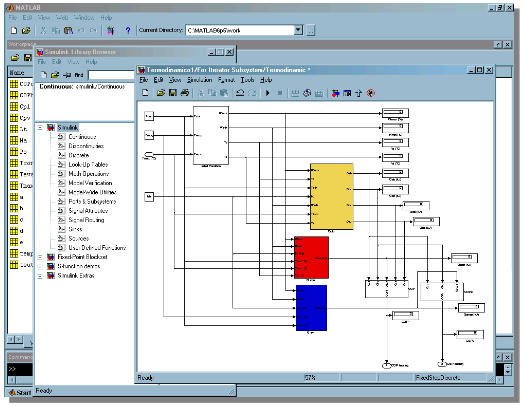
ITAE's activity on mathematical modelling

Three levels:

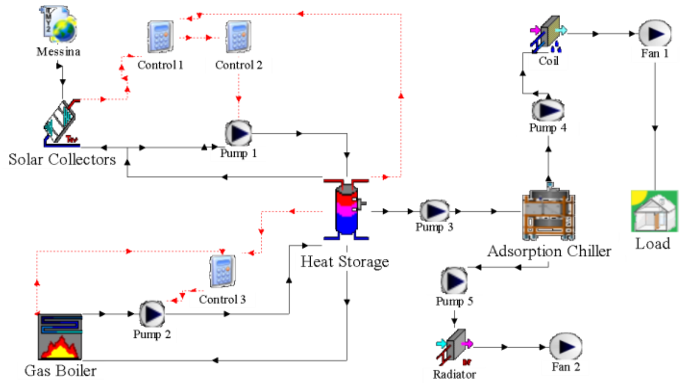
Detailed simulation of the adsorption process
Main aim: Optimization of the adsorber configuration
Coupled H&M transfer through the adsorber
Accurate knowledge of **H&M diffusion coeff**.
Implementation: numerical methods for PDE (Fortran), FEM analysis by COMSOL



Simulation of the adsorption machine
Main aim: Design of efficient machines
Energy and mass balance for machines components
Lumped parameters: Global heat and mass transfer coefficients
Implementation: Matlab- Simulink



Simulation of the whole energetic system
Main aim: System performance, control strategy
Performance-map of the system components
Super-lumped parameters
Implementation: Trnsys

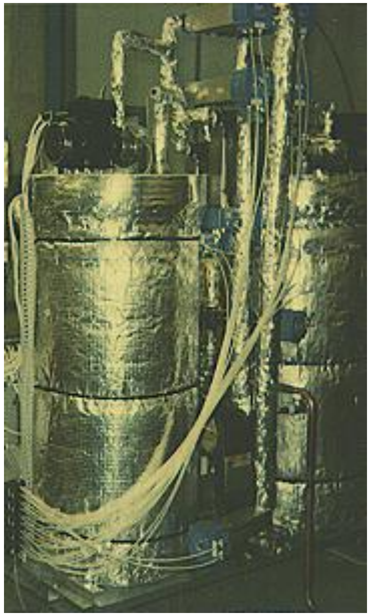


SYSTEM LEVEL

Evolution of ITAE's prototypes

Early '80 | Early '90 | 2007 | 2009

First ITAE zeolite-water heat pump – 1kW



20 kW zeolite-water heat pump

3.5 kW zeolite-water refrigerator for stationary applications

2.5 kW zeolite-water chiller for automotive applications

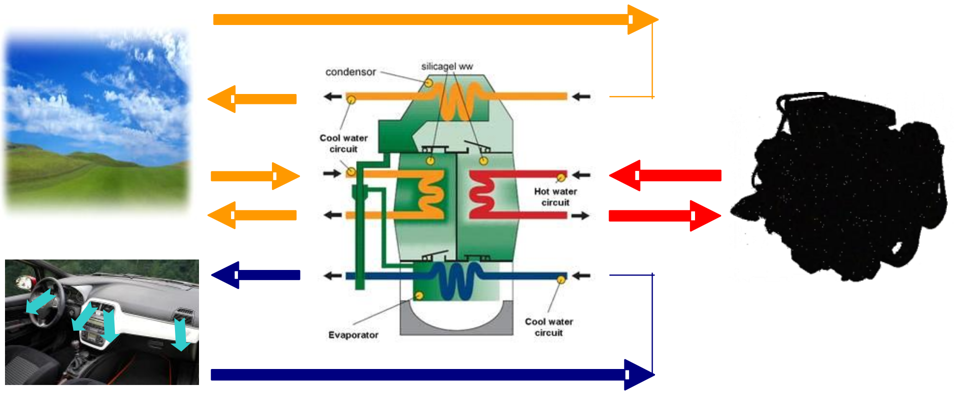
SYSTEM LEVEL

The ITAE on-board air conditioner

Realized within the EC PROJECT TOPMACS

Thermally
OPerated
Mobile
Air Conditioning
Systems

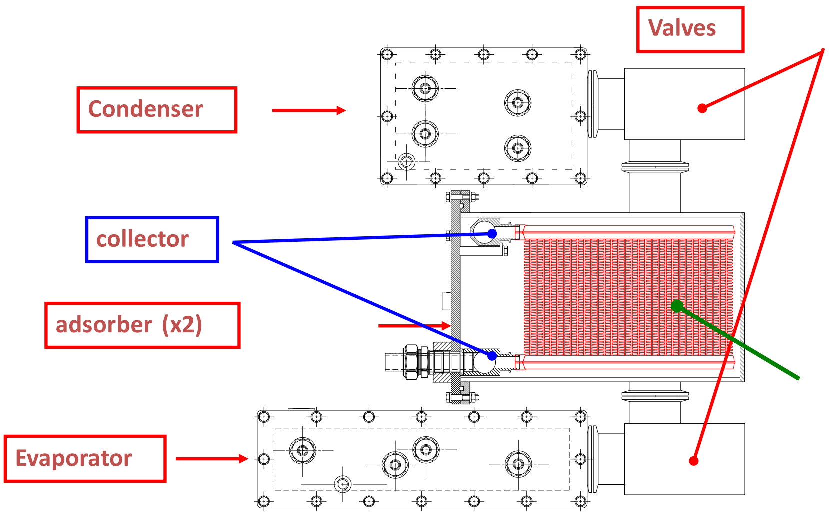
The engine waste heat is used to drive the chiller for the cabin air conditioning



CNR-ITAE role: Installation of a 2.5kW adsorption cooling system in a heavy truck (Iveco Stralis)

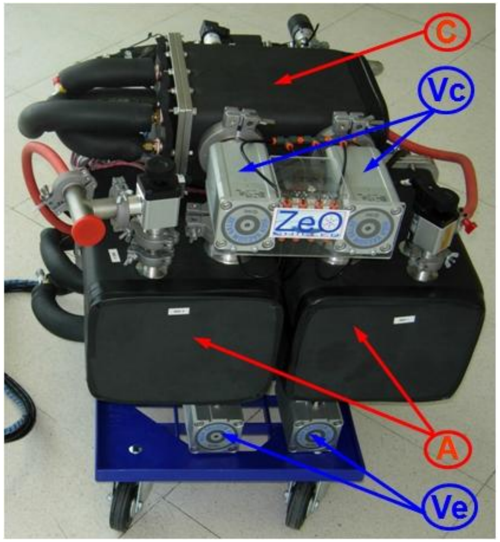
SYSTEM LEVEL

The ITAE on-board air conditioner



Innovative features

- Novel double-bed adsorber
- Adsorbent material: AQSOA – Z02 (Mitsubishi Chemical)
- Compact aluminium HEX
- Compact design of condenser and evaporator



volume ~ 200 liters

weight ~ 60 kg

SYSTEM LEVEL

Testing in a real IVECO truck cabin

Performance evaluated:

Delivered cooling power: 1-2.3 kW

Cooling COP: 0.25-0.4

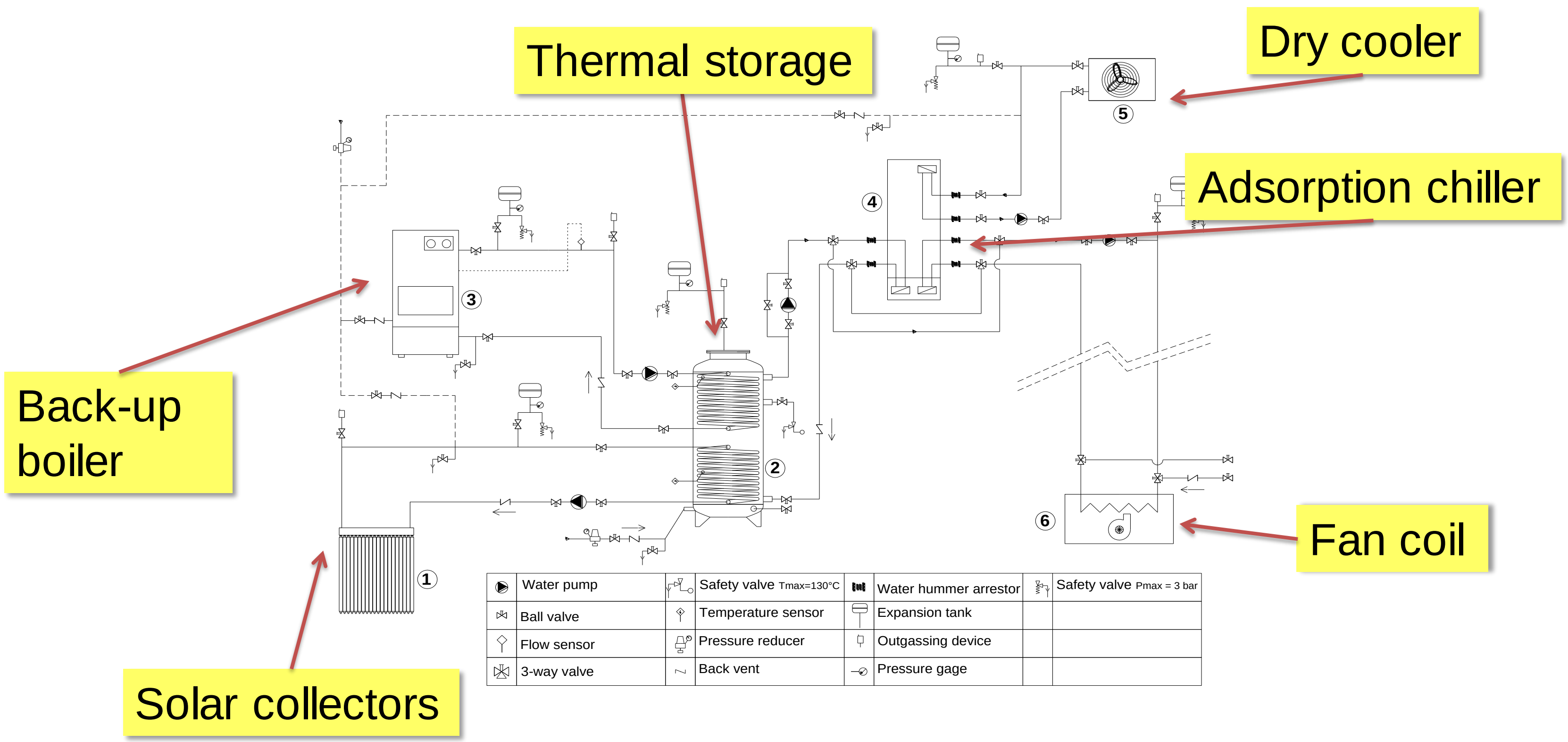
Specific Cooling Power: up to 600 W/kg

SYSTEM LEVEL

The ITAE solar-assisted air conditioner

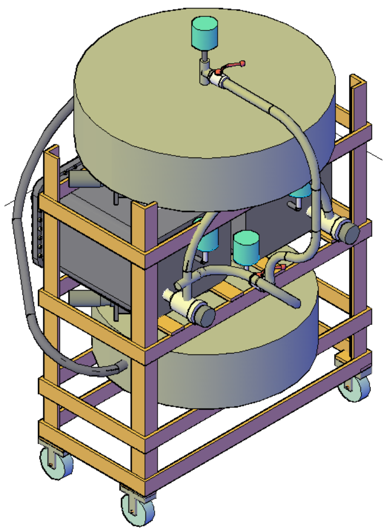
Project "solar cooling" (founded by Ministero Attività Produttive):

design and the realization of a demonstrative solar cooling system using a self-made adsorption chiller



SYSTEM LEVEL

The ITAE solar-assisted air conditioner



Key features

Double-bed adsorption machine with heat recovery
Thermally driven by low temperature heat source (70-90°C)
Adsorbent bed: compact plate-fin type HEX
Evaporator/condenser: copper finned coils
Fully automatic

Performance evaluated:

Delivered cooling power: 2.5-3.5 kW

Cooling COP: 0.43-0.55 for T_{des} = 78 °C – 90 °C and T_{amb} = 30-35°C

Challenges for the future

KEYWORDS for a further development

Materials:
-Database
-Cheap adsorbents
-Stability

Components:
- Scale-up of coating techniques
- Evaporator design

Machine:
- Advanced cycles
- Control strategy
- System integration

THANK YOU!