Doctoral program Industrial engineering, cycle XL

Advanced adsorbent materials for low-grade thermal cooling applications

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Context & Motivation

Motivation

- Cooling & refrigeration account for **>10%** of global electricity
- Rising demand with climate change and digitalization
- Generation of **greenhouse gas emissions**
- Large availability of **low-grade thermal energy** (≈ 40–80 °C)

International Energy Agency: IEA

Research gap

- Adsorption cooling uses heat
- Performance limited by adsorbent **material**
- **Need:** High water uptake+ low regen temperature

Adsorption Cooling Systems: Sustainable solution

The system works through adsorption and desorption cycles, where **refrigerants** (water, methanol, ammonia..) are captured and released by **adsorbent materials** (porous materials) using heat.

Adsorption Phase: The adsorbent captures refrigerant vapor, releasing heat.

Desorption Phase: External heat drives the refrigerant to be released from the adsorbent material.

Cooling Cycle: The adsorbent captures refrigerant vapor, releasing heat.

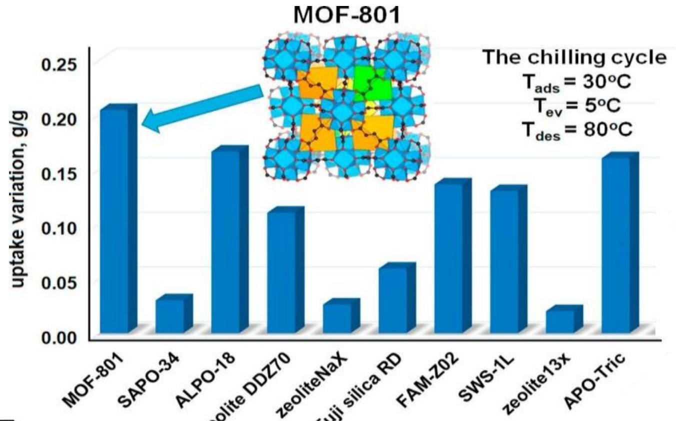
Regeneration: The adsorbent captures refrigerant vapor, releasing heat.

Materials & key properties

Key properties include:

- High surface area, high porosity
- Thermal & mechanical stability
- High adsorption capacity to store a significant amount of refrigerant
- Fast adsorption/desorption to enable efficient cycling

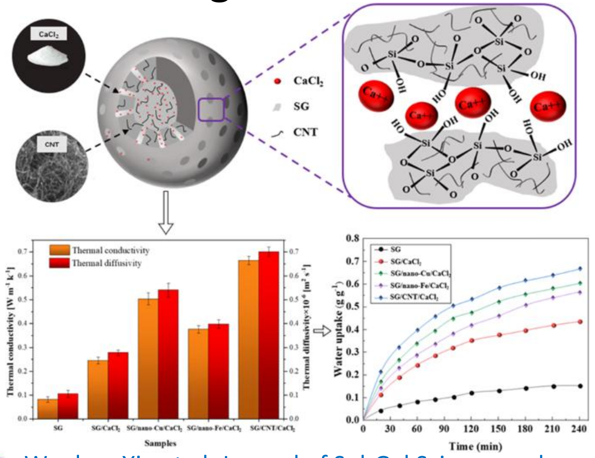
Metal-organic frameworks (MOFs)



M.V. Solovyeva et al. Energy Conversion and Management (2018)

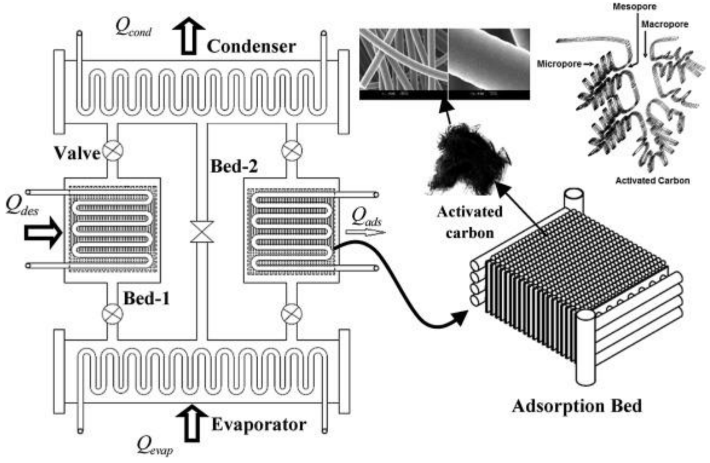
Examples:

Silica gel



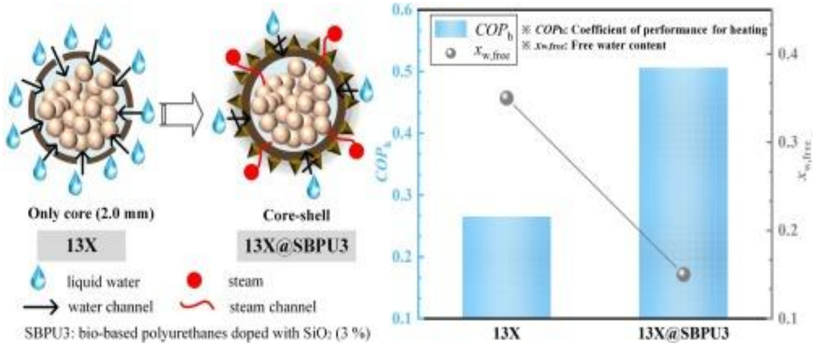
Wenhao Xie et al. Journal of Sol-Gel Science and Technology (2023)

Activated carbon



W. Fan et al. Energy 102 (2016)

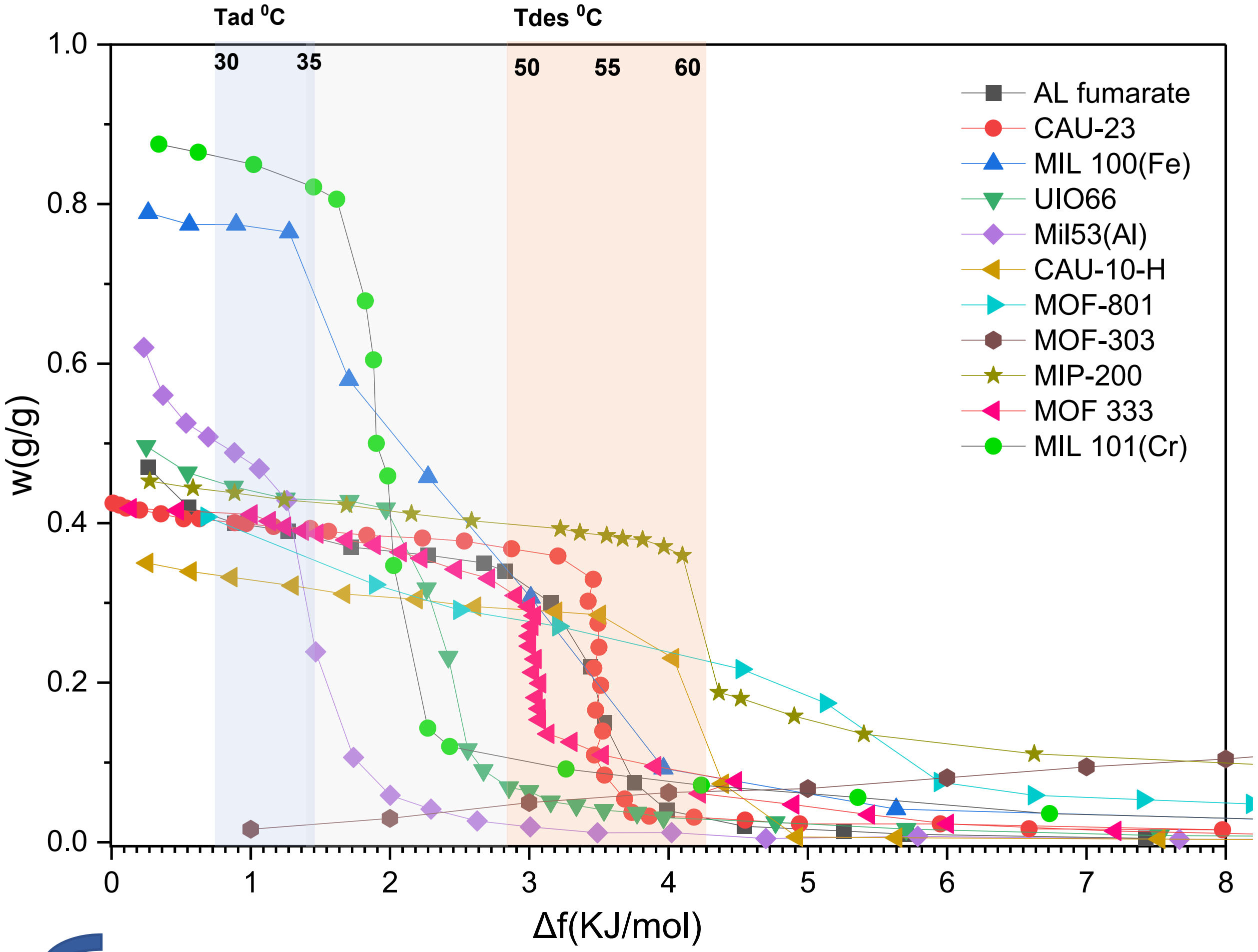
Zeolites



X. He et al. energy Conversion and Management (2024)

MOFs selection

Which MOFs can efficiently operate under low-grade temperature conditions?



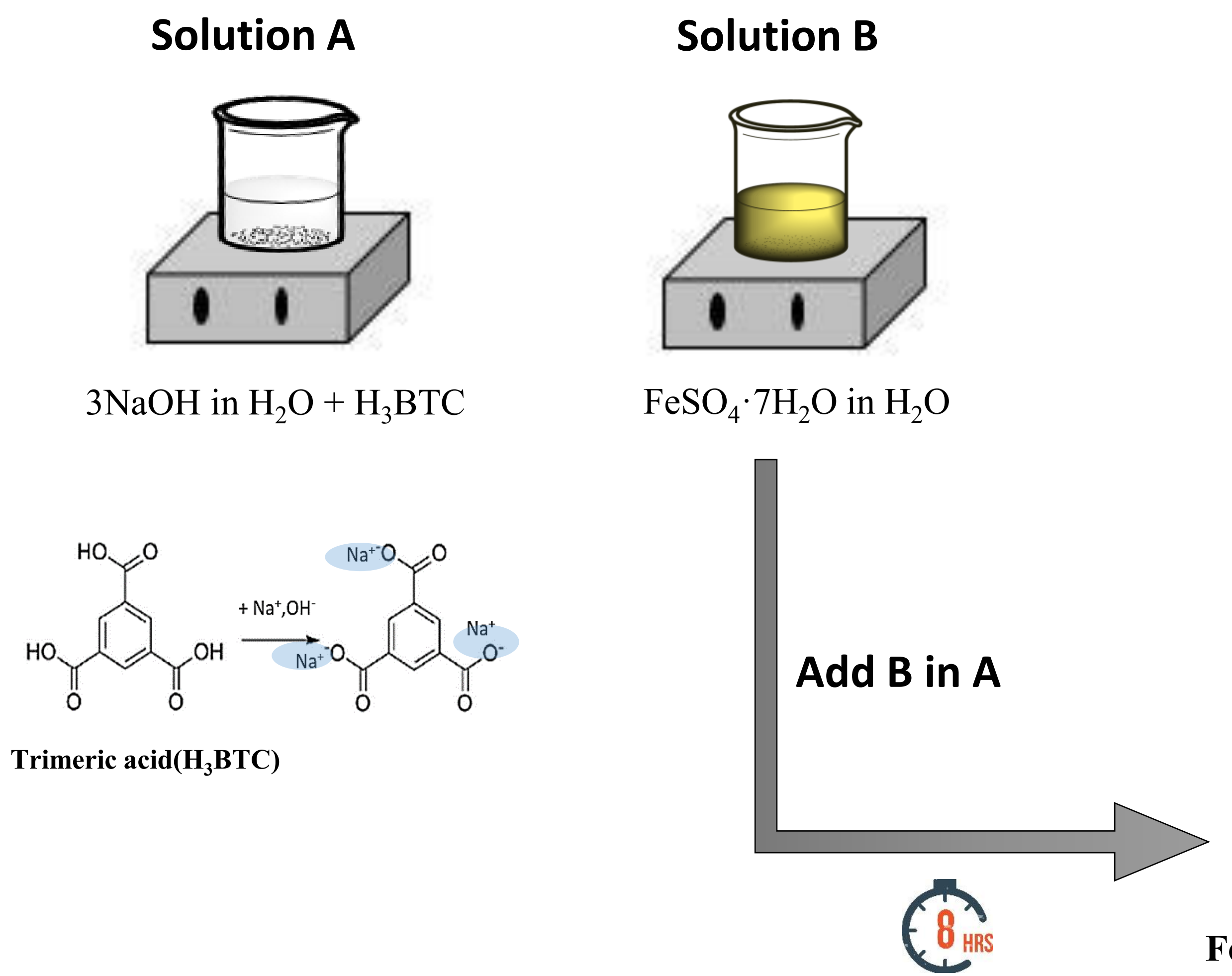
ΔF1	ΔF2	Ranking	MOFs	ΔW-adsorption
1.1	3.2	1	MIL-101(Cr)	0.7574
1.1	3.2	2	MIL 100(Fe)	0.5722
1.1	3.2	4	Mil53(Al)	0.4486
1.1	3.2	5	UIO-66(Zr)	0.3952

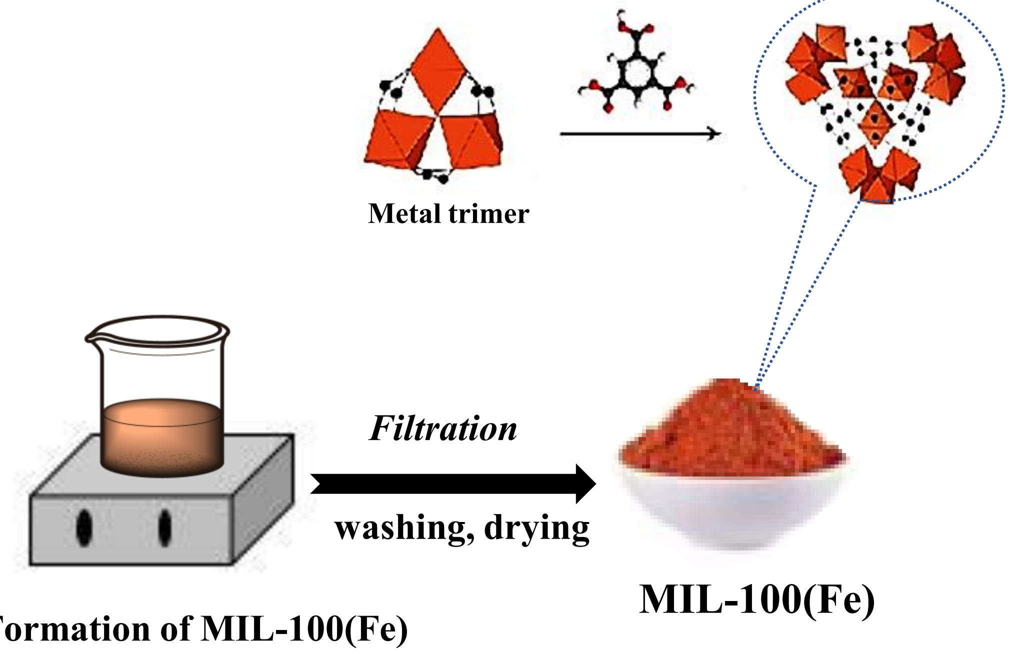
MIL-101(Cr), MIL-100(Fe), MIL-53(Al) and UIO-66(Zr) are the most suitable for adsorption cooling at low grade temperature.

Green synthesis strategy

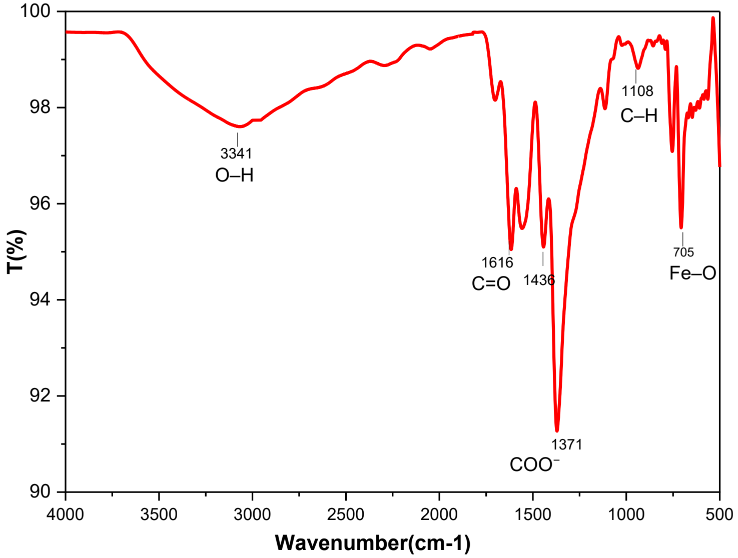
Green synthesis of MIL-100(Fe)

- Green synthesis (solvent water)
- Room temperature synthesis
- Simple and easy to operate

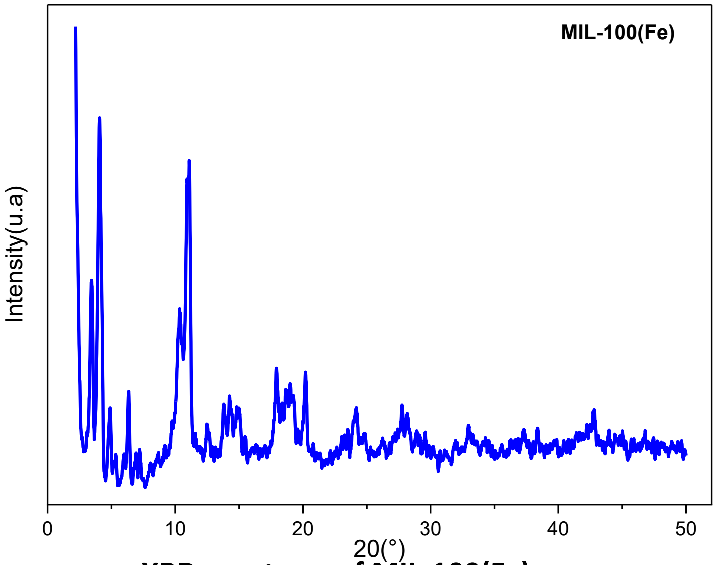




Characterization of MIL-100(Fe)



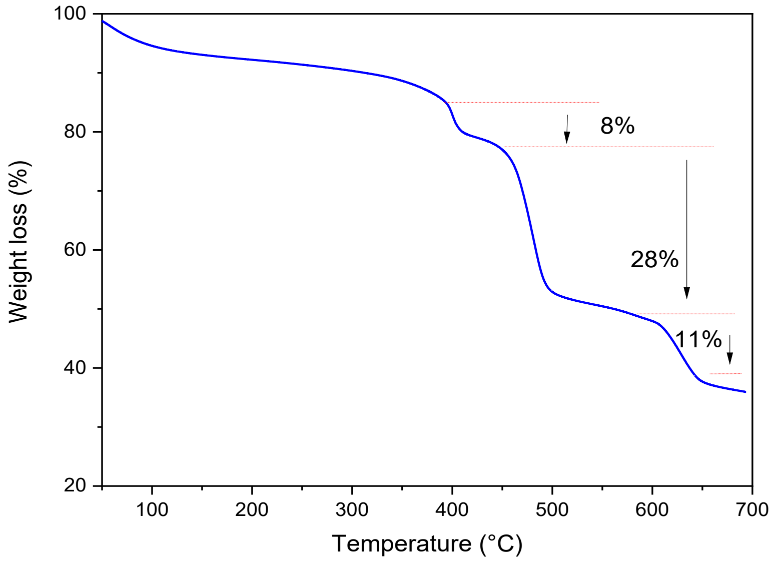
Ftir spectrum of MIL-100(Fe)



XRD spectrum of MIL-100(Fe)

Textural parameters of MIL-100(Fe) from DFT analysis (N_2, 77 K)

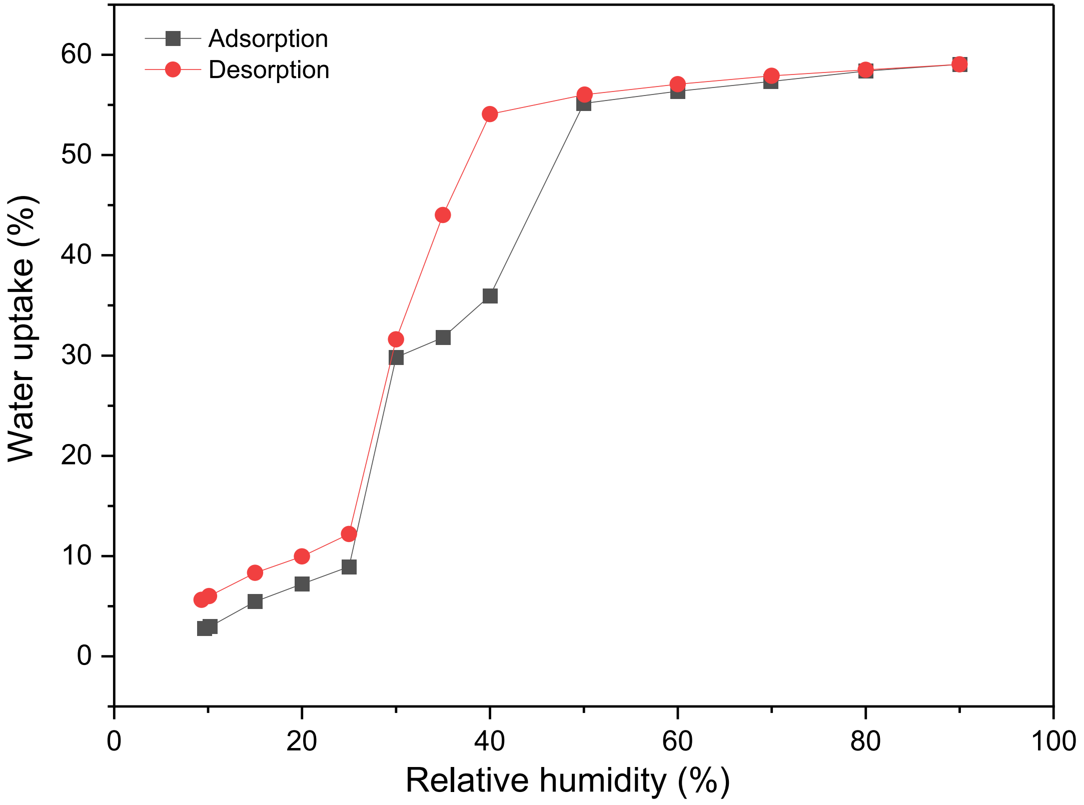
Sample	Surface area ($m^2\ g^{-1}$)	Total pore volume ($cm^3\ g^{-1}$)	Mesopore volume ($cm^3\ g^{-1}$)
MIL-100(Fe)	1549.7	0.579	0.18



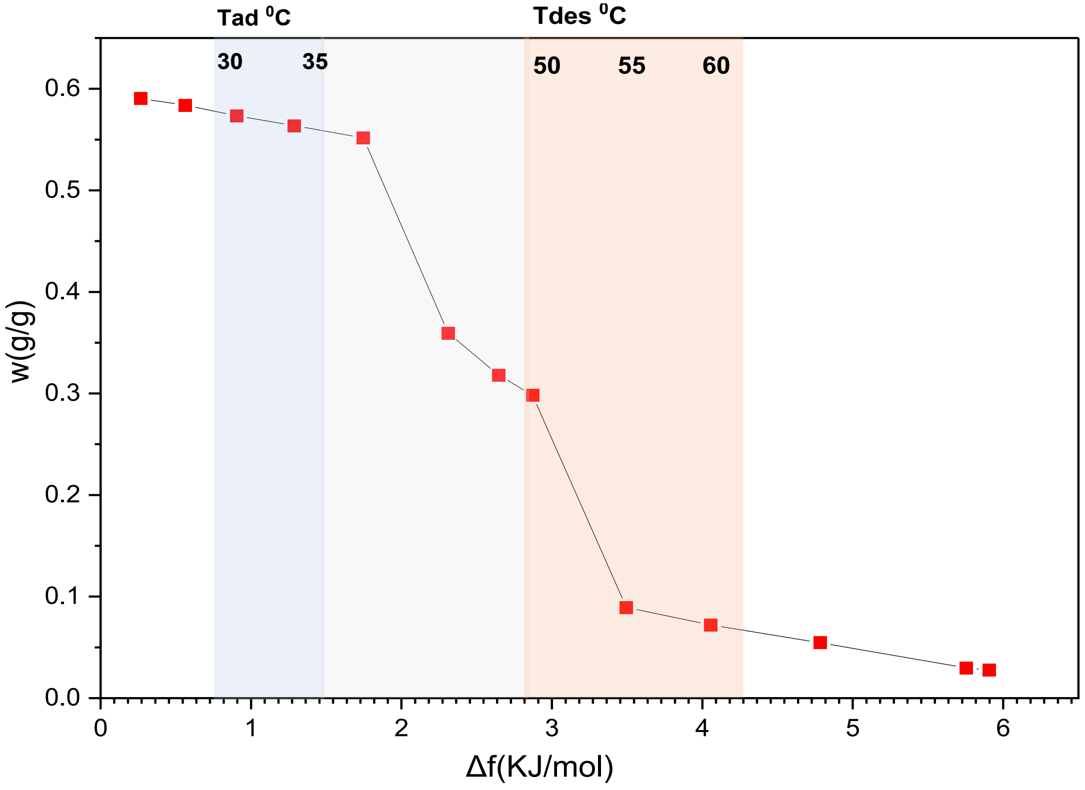
TGA/DTG curves of MIL-100(Fe)

- ✓ FTIR and XRD confirm successful formation and crystallinity of MIL-100(Fe).
- ✓ BET reveal high surface area.
- ✓ TGA shows good thermal stability up to ~300 °C.

Water Sorption Performance



Water Vapor Isotherm of MIL-100(Fe) at 30°c



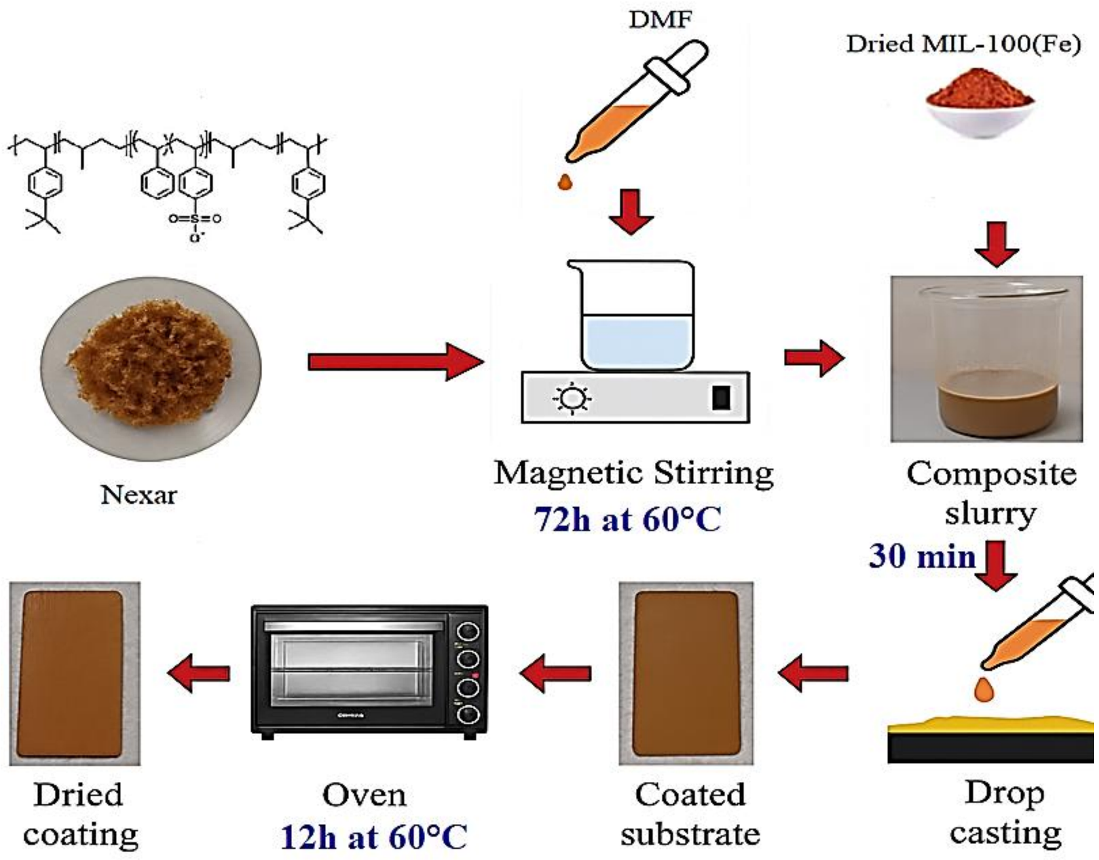
Thermodynamic operating window of MIL-100(Fe)

✓ Fast uptake at moderate RH confirms strong hydrophilicity.

✓ Thermodynamically suitable for low-grade adsorption cooling

From powder to application

MIL-100(Fe)-Polymer Composite Coatings

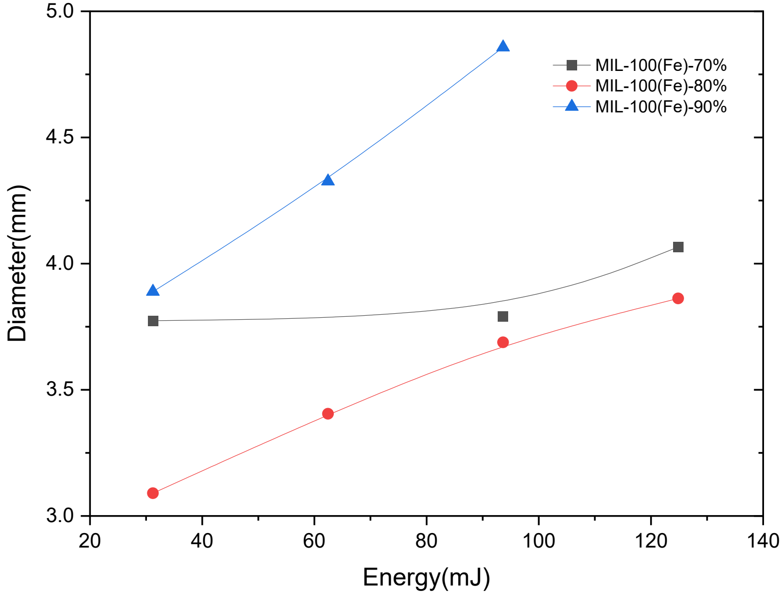


Composite coating characterization

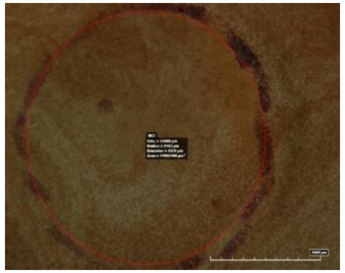
- ❖**Scratch Test**: Surface resistance
- ❖ **Impact Test**: Toughness
- ❖**Pull-Off Test**: Adhesion strength

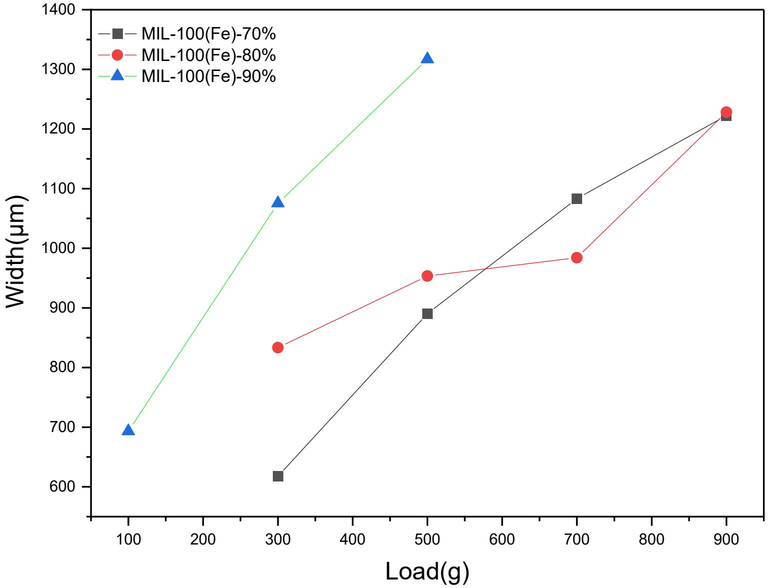
Coating performance

Scratch test

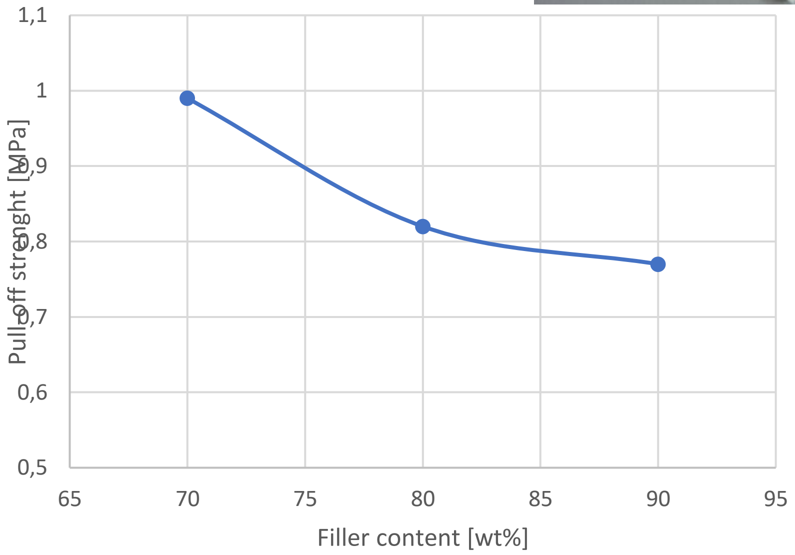


Impact test





Pull-Off Test



Mechanical tests show acceptable coating performance across different MOF loadings and further optimization is in progress.

Conclusions and Outlook

- ✓ Green and simple synthesis successfully achieved
- ✓ Promising water sorption demonstrated
- ✓ Composite coatings show acceptable mechanical performance
- ➢ Evaluation of the **sorption performance of composite coatings**
- ➢ Cycling stability assessment
- ➢ Heat exchanger integration

Thank you for your attention

Acknowledgments

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DIPARTIMENTO DI INGEGNERIA

Consiglio Nazionale delle Ricerche

ITAE

Sorption Technologies