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## Development and multiscale characterization of a sensible/sorption bimodal heat storage for cooling tower application

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### *Abstract*

This study presents experimental results on so-called cTES (for cold Thermal Energy Storage), in the specific configuration of coupled heat and moisture storage. An effective improvement of coupled sensible/sorption energy storage is presented, by the development of a new sensible/sorbant material made of glass sphere coated with a mixture of AQSOA Z05 zeolith and PDMS Sylgard 184. The process of manufacturing and the characterization of the equilibrium isotherms of the coating are first presented. Main result show that the new coating is highly effective with more than 95% of the sorbant material being active. The experimental characterization of the thermal behaviour at prototype scale (>approximately 440 kg of coated spheres and 270 kg of uncoated spheres) is then presented. The results highlight effective operation of the cTES, i.e. water storage during adsorption and flattening of the ambient air temperature during desorption.

**Keywords:** sorption, cold Thermal Energy Storage, coupled storage, wet cooling alternative

### **Introduction**

Wet cooling towers are the most efficient choice for condenser cooling in thermal based power plants but are less and less compatible with the growing water-scarcity in numerous regions (Turchi et al. 2014). On the other end of the spectrum, the use of air-cooled systems reduces up to 80% of water consumption (Carter and Campbell 2009), but the efficiency of the turbine decreases significantly if the temperature of ambient air exceeds 20°C (Balogh and Szabo 2008).

Different hybrid or alternative cooling solutions with lower water consumption without prohibitive performance losses have been proposed as illustrated by the A.R.I.D. US program (ARID 2015). The use of thermal energy storage has also been proposed and already studied, with storage of the power block heat during the day and its evacuation during the night, when ambient temperatures are colder (Manglik and Jog 2016, WASCOP 2019, Bruch et al. 2021). An enhancement of such concept has been proposed by Rougé et al. 2021 with a coupled storage of heat and moisture from ambient air. Their experimental results have proven the effectiveness of the concept, with flattening of the air temperature during daytime near

night temperatures. However, the bi-granulometry used by the authors leads to significant of inactive adsorbent.

This paper presents an effective improvement of the concept of coupled sensible/sorption energy storage by the development of a composite storage material made of glass spheres coated with a mixture of adsorbent AQSOA Z05 zeolite and polymer binder. The material is first characterized at small scale, with experimental equilibrium curves. Then results obtained at prototype scale are presented and analyzed.

### **Fabrication and characterization of the composite material**

The composite material used for the coupled sensible-sorption storage has been obtained from the aluminophosphate FAM-Z05 sorbant combined with silicone binder PDMS, named Sylgard-184. The adsorbent FAM-Z05 has been chosen since it fulfils most of the study's requirements and notably the complete desorption at temperature around 40°C and the concentration of most adsorbed/desorbed water in a small temperature range. The procedure used for the fabrication of the SyZ05 material and the Gl-SylZ05 composite is schematically presented in Figure 1. It mainly consists in a dip coating procedure of adsorbent coating on a glass sphere substrate

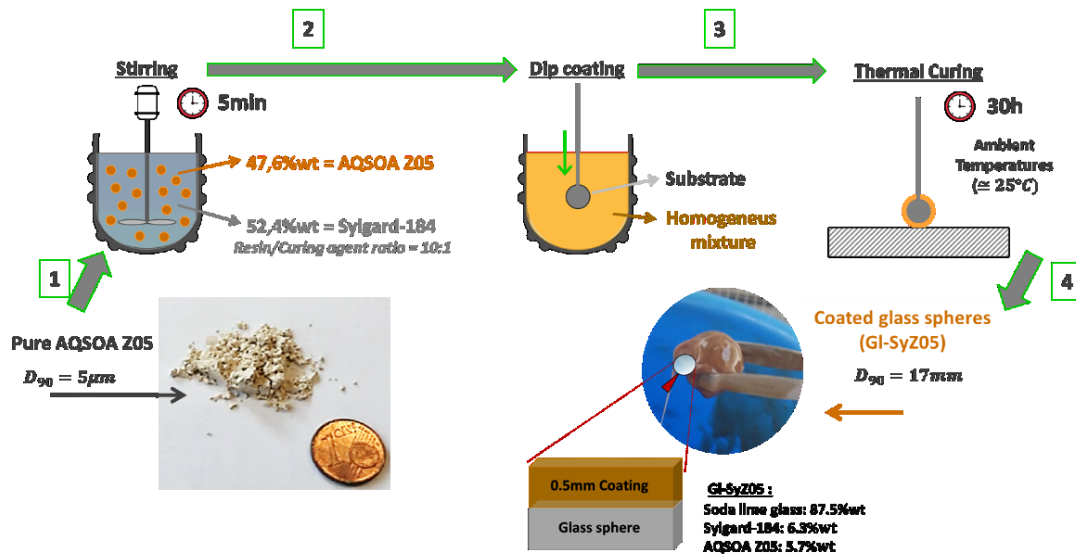


Figure 1: Scheme representation of the composite fabrication procedure

Figure 2 presents typical results obtained during adsorption of water vapor at 25°C and 60°C, with water vapor pressure up to 160mbar. The results highlight that the binder Sylgard-184 has little effect on the sorption reaction, since the composite maintains the same shape of the equilibrium isotherms. In addition, the AQSOA Z05 remains 95 to 100% active when embedded in the novel composite, with around 95% of the maximum uptakes when compared to its pure form. The authors believe that the 5% difference in uptake may be due to a proportion of inactive adsorbent, but there may be also some uncertainties in the material proportions during fabrication. A good agreement with literature data (Goldworthy 2014, Shimooka et al. 2007, Teo et al. 2017) is also observed.

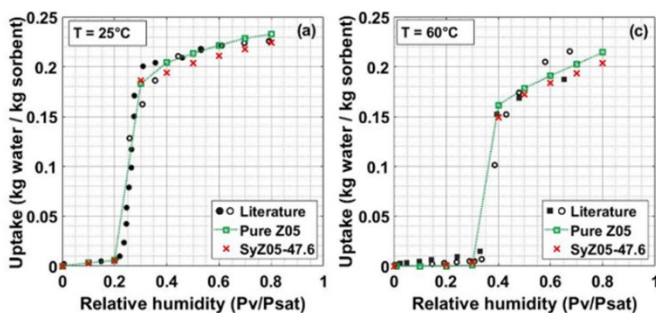


Figure 2: Typical equilibrium isotherms of pure Z05 and SyZ05 material, comparison with literature data.

## Experimental facility for reactor scale characterization

The experimental facility used for the characterization at reactor scale is schematically presented in Figure 3.

It consists mainly in an open air-loop, with controlled mass flow rate, temperature and relative humidity. It was designed to provide air at a maximal superficial and interstitial velocities of 0.3 m/s and 0.8 m/s respectively, temperature between 15 and 50°C and specific humidity between 2 and 20 g of vapour per kg of dry air at the inlet of the sensible-sorption module. More detailed description of the experimental facility is given in Rougé et al. 2021. The reactor tank is a cylindrical stainless steel tank surrounded by domed ends, with inner diameter of 0.61 m and total height of 1.7 m. A metallic honeycomb and a diffuser are installed at the two inlets of the reactor tank with the aim to smooth the air profile during the experiments and ensure transverse homogeneity.

The reactor was filled with a mixture of 17 mm spheres of glass and composite material GI-SyZ05. To ensure proper mix, the reactor height was divided into 30 equally thick layers, each layer being filled with homogeneous distribution of sphere glass and GI-SyZ05. At the end of the process, the tank is filled with approximately 440 kg of coated spheres and 270 kg of uncoated spheres.

The tank is finely instrumented with inlet/outlet Pt100 temperature and about 90 embedded thermocouples (type T, 1 mm diameter) to check the thermal behaviour (see Figure 4). Special attention has been paid to the inlet and outlet humidity sensors (with dedicated calibration sessions to highlight the influence of operating parameters of the humid air flow) to assess the relevancy and accuracy of the measurements.

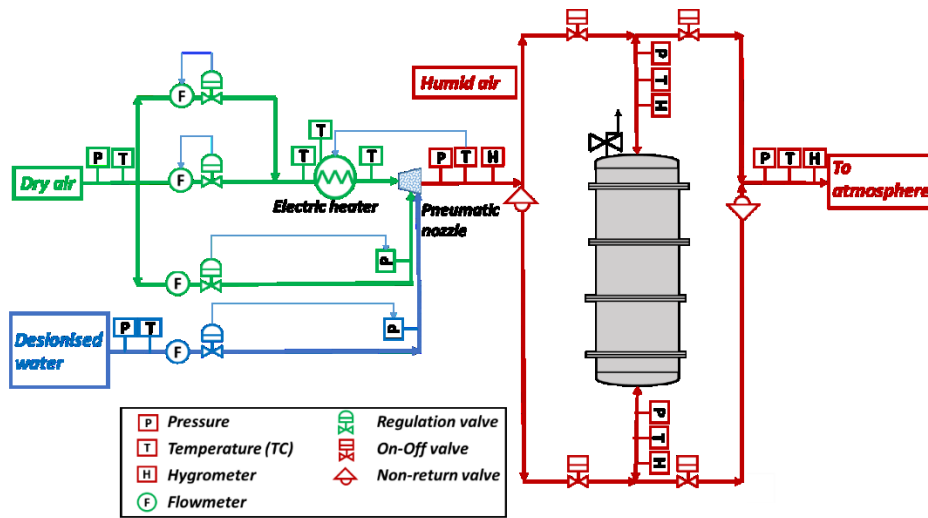


Figure 3: Scheme of the experimental set-up

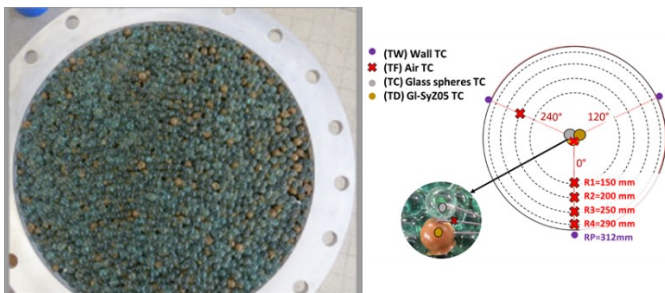


Figure 4: Left: Mixture of coated (orange) and uncoated (green) solid filler; Right: transverse distribution of thermocouples.

### Experimental characterization at reactor scale

Some simplified tests conditions have been first defined, to evaluate and characterize the thermal behaviour and try to highlight the contributions of sensible heat and sorption to the coupled phenomenon. Figure 5 presents typical results obtained in successive cycles with constant inlet air temperature (Type II tests) and constant inlet vapour pressure (Type III tests).

Type II tests allow to focus on the sorption effect since initial bed and inlet temperatures are constant. From Figure 5, the effect of the sorption is quantitatively limited but clearly observable: due to adsorption in charge, the outlet temperature is temporarily increased, which is linked to decrease of pressure vapour and increase of the stored water mass. A maximum of about 2 kg of water if adsorbed/desorbed from cycle to cycle. The opposite is observed in discharge (i.e. desorption). In all cases, an “established behaviour” is observed after 1 to 2 cycles only, i.e. the first cycle highlights a specific thermal behaviour due to initial conditions and next cycles exhibit behaviour independent of the cycle number. It should be noted that the difference on the inlet air temperature between charge and discharge can be attributed to regulation issues.

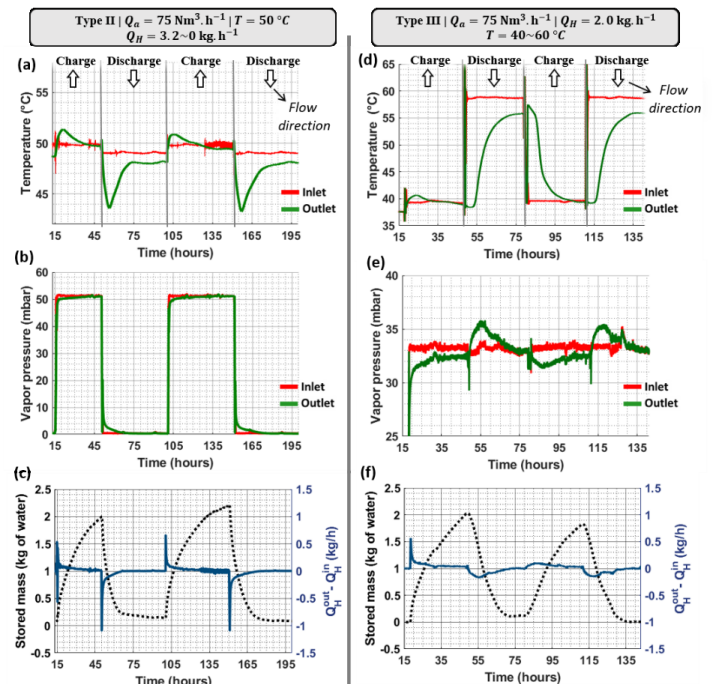


Figure 5: Typical results obtained in tests at constant inlet temperature (left) and constant inlet vapour pressure (left). Evolutions of inlet/outlet air temperatures (top), vapour pressure (middle) and water stored mass (bottom).

Considering constant inlet vapour pressure and varying inlet temperature, i.e. varying inlet relative humidity, is closer to the reality (Rougé et al. 2021) and leads to similar observations even if the results are more complicated to interpret due to sensible and sorption coupling.

Figure 6 depicts the influence of the air/water mass flow rate, considering similar conditions of temperature and relative humidity. The results highlight that the lower the air/water flowrate, the greater the thermal effects observed. Neglecting potential effects of thermal losses with varying mass



flow rate and cycle duration, this may be explained by the reaction kinetics which seems to be only slightly impacted by the air/water flow rate. Thus, the sorption thermal power is slightly affected by the flow rate and the observed thermal effects are proportional to the flow rate.

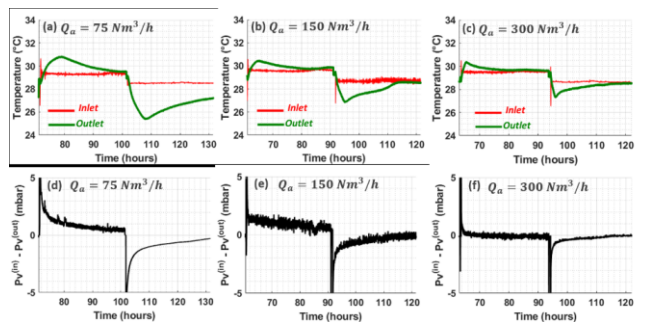


Figure 6: Influence of air/water mass flow rate, Type II tests.

It should be noted that the observed effects presented in Figure 5 and Figure 6 are quantitatively rather small, with temperature variations due to sorption of only few degrees. The authors explain this by the behaviour of the PDMS binder used during the fabrication of the composite material, whose permeability seems to be much lower than expected. As a consequence, the sorption process is lowered, cycle durations are increased and thermal effects are being diluted over time.

## Conclusion

The preparation and the characterization of an innovative composite material made of glass spheres coated with AQSOA Z05 zeolite mixed with polymer binder has been presented. It appears that the addition of AQSOA Z05 powder into the polymer matrix demonstrates to be a favourable approach since the AQSOA Z05 remains 95 to 100% active.

At reactor scale, the composite material highlights the expected behaviour, i.e. water storage during adsorption and flattening of the air temperature during desorption.

However, even if additional experimental campaign are needed to properly characterized the material and the storage set-up, the observed thermal effects are quite lower than expected, typically about few °C only. This has been explained by the permeability of the polymer binder which seems to be quite lower than expected.

Next steps include the characterization of the kinetics of the composite material and the search for more efficient polymer matrix.

## References

- Rougé S., Soriano O., Bruch A., Largiller G., Bentivoglio J., Experimental characterization of coupled sensible heat and moisture storage for dry cooling enhancement, *Applied Thermal Engineering* 192, (2021), 116922.
- Balogh A. and Szabó Z., “HELLER System: The Economical Substitute for Wet Cooling - to avoid casting a shadow upon the sky,” *Therm. Eng.*, p. 45, 2008
- Turchi C.S. Wagner M.J., and Kutscher C.F., “Water Use in Parabolic Trough Power Plants: Summary Results from WorleyParsons’ Analyses,” NREL/TP-5500-49468, 1001357, Dec. 2010. doi: 10.2172/1001357.
- Carter N.T. and Campbell R.J., “Water Issues of Concentrating Solar Power (CSP) Electricity in the U.S. Southwest,” p. 20, 2009.
- ARID, [https://arpa-e.energy.gov/sites/default/files/documents/files/ARID\\_ProgramOverview.pdf](https://arpa-e.energy.gov/sites/default/files/documents/files/ARID_ProgramOverview.pdf), 2015
- Manglik R.M. and Jog M.A., “Resolving the energy–water nexus in large thermoelectric power plants: a case for application of enhanced heat transfer and high-performance thermal energy storage.,” *J. Enhanc. Heat Transf.*, vol. 23, no. 4, 2016, doi: 10.1615/JEnhHeatTransf.2017024681.
- WASCOP project, 2016-2019, Grant Agreement 654479.
- Bruch A., Bourdon D., Dumas C., Blaise A., Chouvel-Saye A., Experimental characterization of a water/rock thermocline cold thermal energy storage for optimization of condenser cooling, *Journal of energy storage* 44, 2021, 103426.
- Goldsworthy M.J. 2014. “Measurements of Water Vapour Sorption Isotherms for RD Silica Gel, FAM-Z01, FAM-Z02, FAM-Z05 and CECA Zeolite 3A.” *Microporous and Mesoporous Materials* 196, 2014.
- Shimooka S., Kazunori O., Hideto H., Takahiko T., Hiroyuki K., Akio K., Mitsuhiro K., and Hitoki M. 2007. “The Evaluation of Direct Cooling and Heating Desiccant Device Coated with FAM.” *JOURNAL OF CHEMICAL ENGINEERING OF JAPAN* 40 (13): 1330–34.
- Teo W.B., Chakraborty A., and Fan W.. 2017. “Improved Adsorption Characteristics Data for FAM Types Zeolites and Water Systems under Static and Dynamic Conditions.” *Microporous and Mesoporous Materials* 242 (April): 109–17.