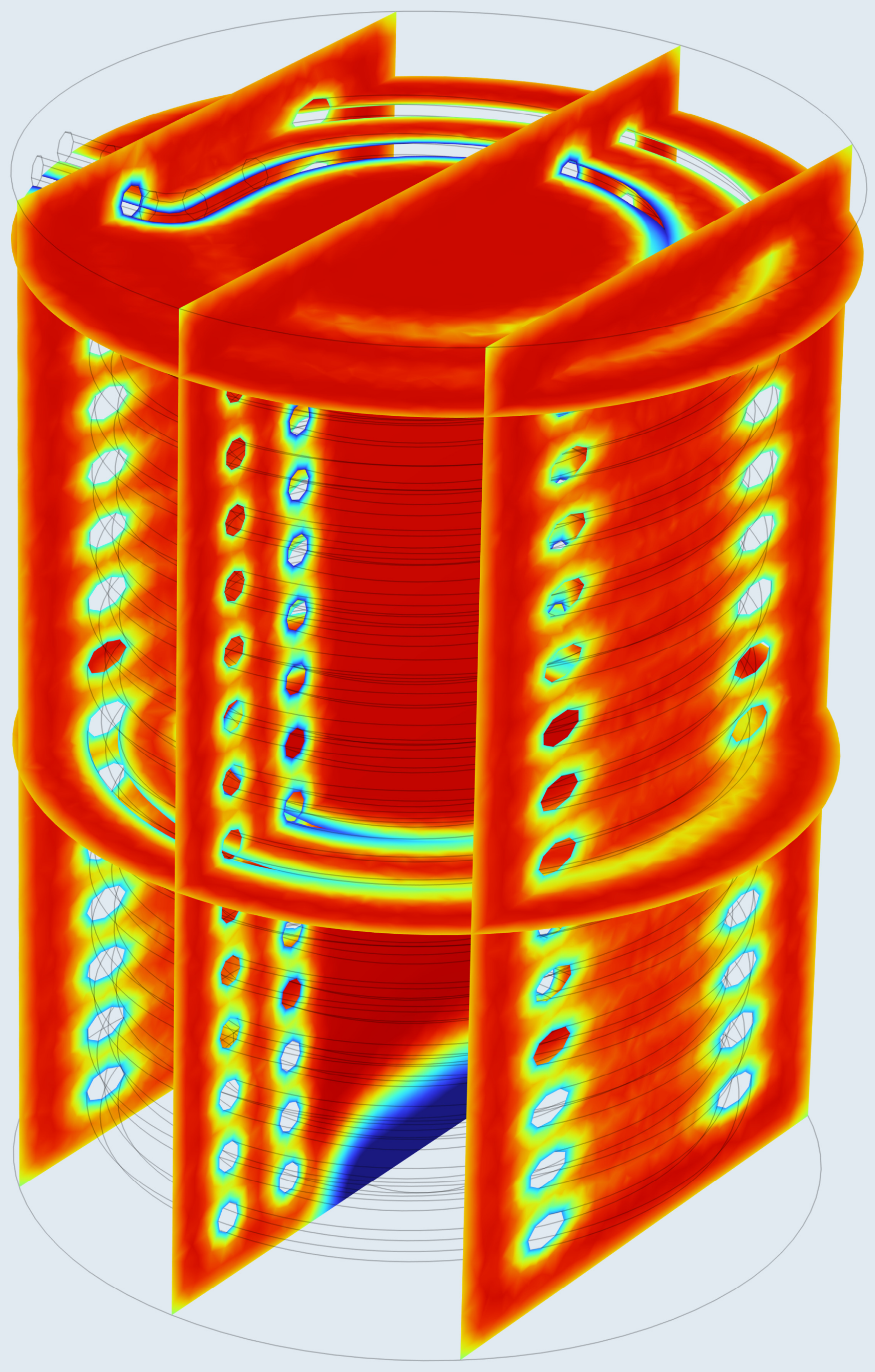

3-Dimensional Analysis of Coupled Heat and Mass Transfer in a Thermochemical Heat Storage System

This work investigates the impact of different parameters on the efficiency of the underlying ad-/desorption process of zeolite/water in a sorption thermal energy storage reactor.

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Abstract

Thermochemical heat storage technology has gained much attention recently, due to its remarkable advantages of high energy storage density and achievable long-term energy storage with negligible heat loss.

It is a step in solving the problem of daily and even seasonal mismatch between solar energy availability and heating demand in buildings.

To optimize the performance of these systems, critical factors such as system layout, material selection, and operating conditions are of great importance. Conducting numerical simulations prior to constructing prototypes can lead to time and cost savings.

In this study, COMSOL® software is applied to investigate the performance of a designed prototype numerically.

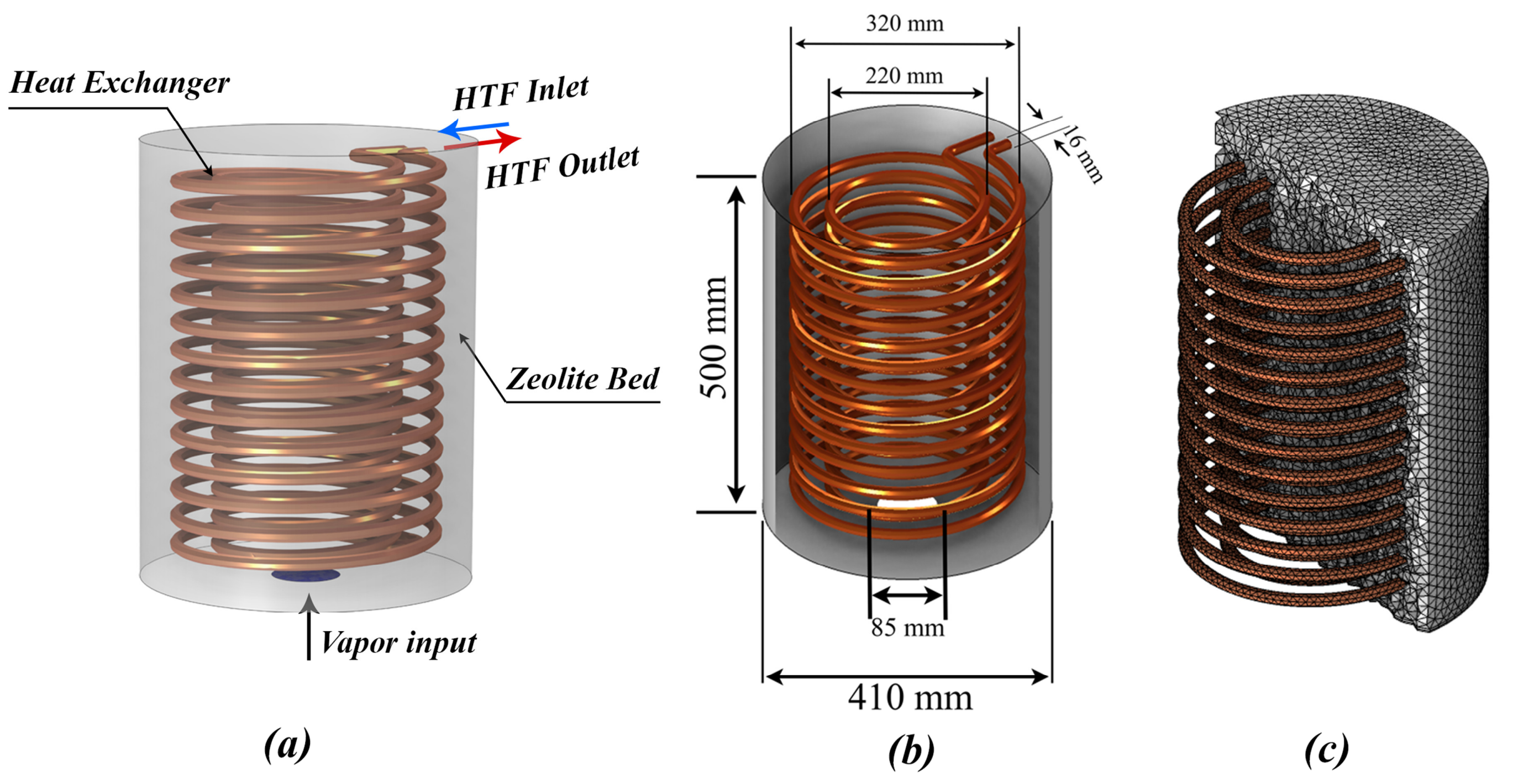

FIGURE 1. (a) Computational domain with HTF = heat transfer fluid. (b) Geometry. (c) Computational grid.

Methodology

The ad-/desorption reaction of zeolite/water pair is simulated in a closed thermochemical heat storage system. For this purpose, the Linear Driving Force (LDF) model is used to calculate the adsorbed amount of water, and Dubinin's theory to calculate the equilibrium loading of zeolite (Ref. 1, 2).

Fig. 1 shows the dimensions of the system and the applied computational grid.

The influence of different operating conditions on the performance is studied. Parameters such as evaporator temperature (T_{Ev}) and zeolite initial loading (X_i) for adsorption and condenser pressure (P_c) and temperature of inlet HTF ($T_{in,HTF}$) for desorption are taken into account. Also, a case with a modified design (MD) is studied. In this case, the optimal diameter for the inner coil of the heat exchanger and the inlet opening from the evaporator is defined based on the parametric study, aiming to improve the heat transfer between the zeolite bed and HTF and the performance of the system.

Results

The influence of different operating conditions on the performance is presented in Fig. 2 and Fig. 3.

The simulation shows that with the right parameters the efficiency (η) of the system can be increased considerably as shown with some examples in the table below.

Operating Conditions		Q_{HTF}	Q_{source}	$Q_{Sensible}$	Q_{lost}	η	Loading Change
		$[Wh]$	$[Wh]$	$[Wh]$	$[Wh]$	[%]	$kg_{water}/kg_{zeolite}$
Adsorption	T_{Ev}=10°C, $X_i \approx 0.14$	3,595	5,188	424	1,169	69.3	0.105
	T_{Ev}=30°C, $X_i \approx 0.14$	4,084	5,837	432	1,320	70.0	0.114
	T_{Ev}=15°C, $X_i \approx 0.08$	5,803	7,772	209	1,759	75.0	0.156
	T_{Ev}=15°C, $X_i \approx 0.08$, MD	6,460	8,387	188	1,739	77.3	0.168
Desorption	P_C=1200 Pa, $T_{in,HTF}$=180°C	10,672	8,010	959	1,704	75.0	0.163
	P_C=1200 Pa, $T_{in,HTF}$=240°C	13,231	9,943	826	2,462	75.2	0.202
	P_C=2300 Pa, $T_{in,HTF}$=240°C	12,352	9,816	239	2,775	79.4	0.2

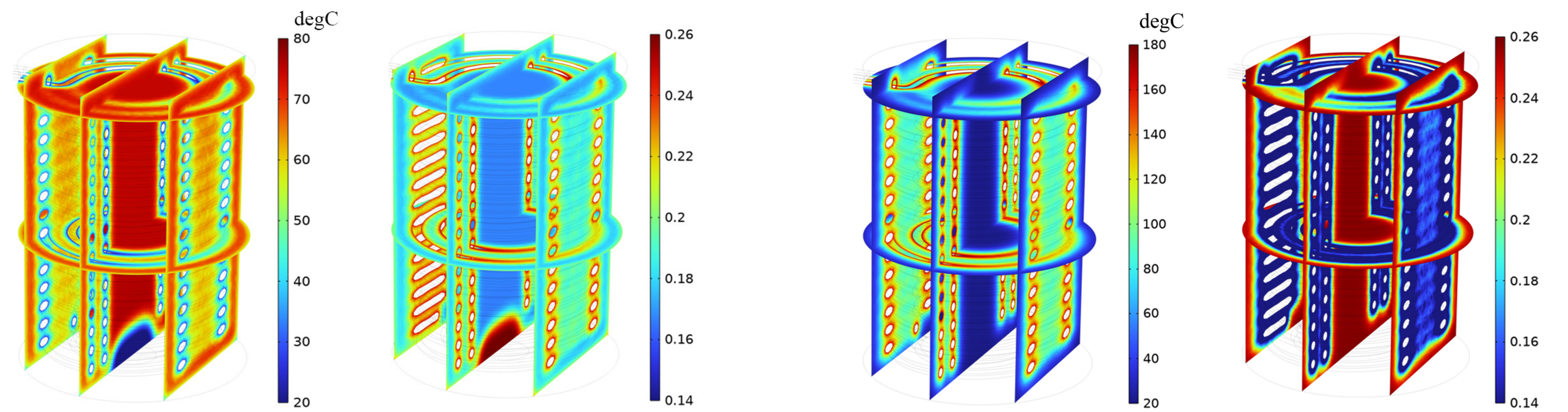

FIGURE 2. Bed temperature (°C) and loading ($kg_{water}/kg_{zeolite}$) variations for Left: Adsorption (T_{Ev}=10°C, $X_i \approx 0.14$) and Right: Desorption (P_C=1200 Pa, $T_{in,HTF} \approx 180$°C) at 100 Min.

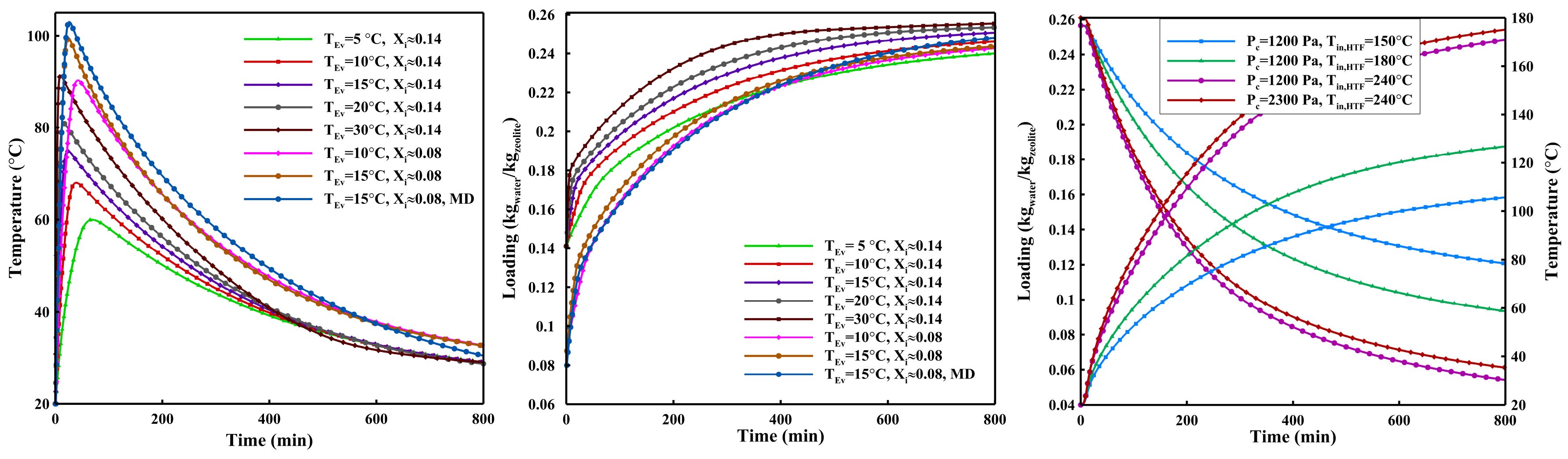

FIGURE 3. Left: Bed temperature (adsorption). Middle: Water loading (adsorption) and Right: Bed temperature and loading (desorption) for different cases.

REFERENCES

[1] Çağlar, Ahmet. "Design and experimental testing of an adsorbent bed for a thermal wave adsorption cooling cycle." (2012).

[2] Abou Elfadil, Mazen. "Investigations and technical development of adsorption thermal energy storage systems with simulation and different control strategies." (2021).

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