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Laboratory and numerical study on an enhanced evaporation process in a loess soil column subjected to heating

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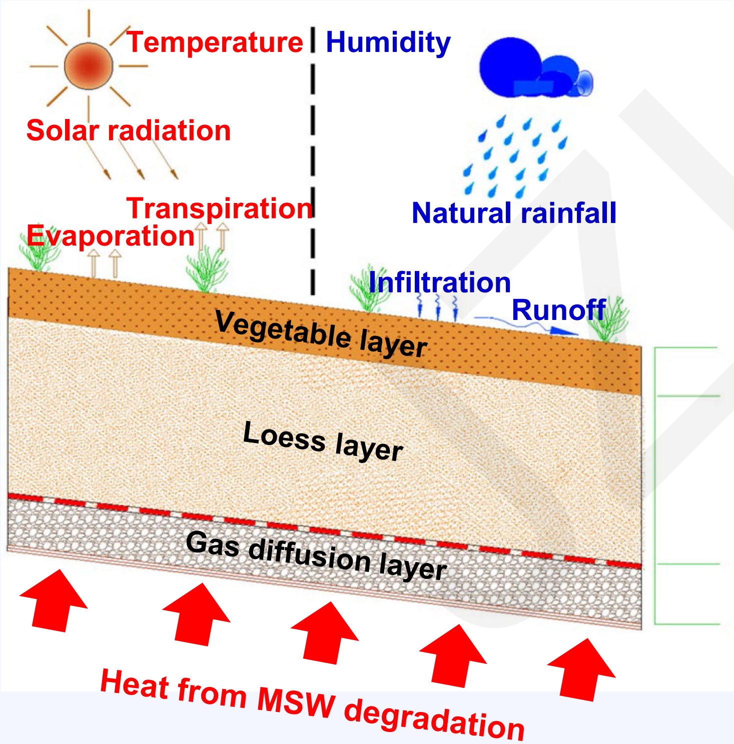
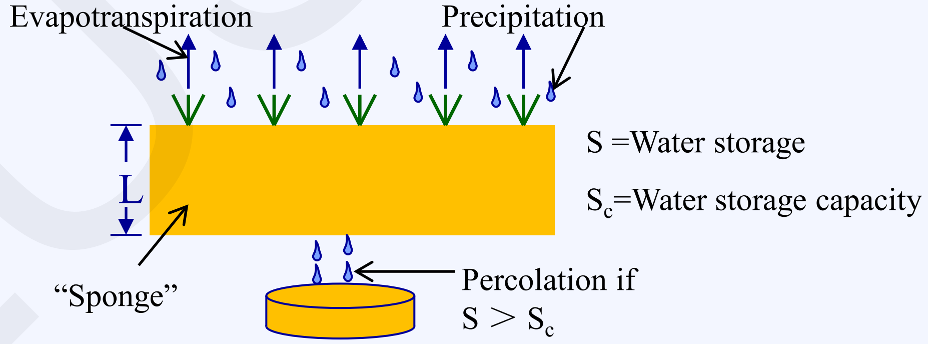
Introduction

□ Principles & advantages of earthen final covers

- The working principle of EFCs is like a sponge.
- The water vapor diffusion can be enhanced by the heating from municipal solid waste, and significantly impact the evaporation process in the earthen final cover.

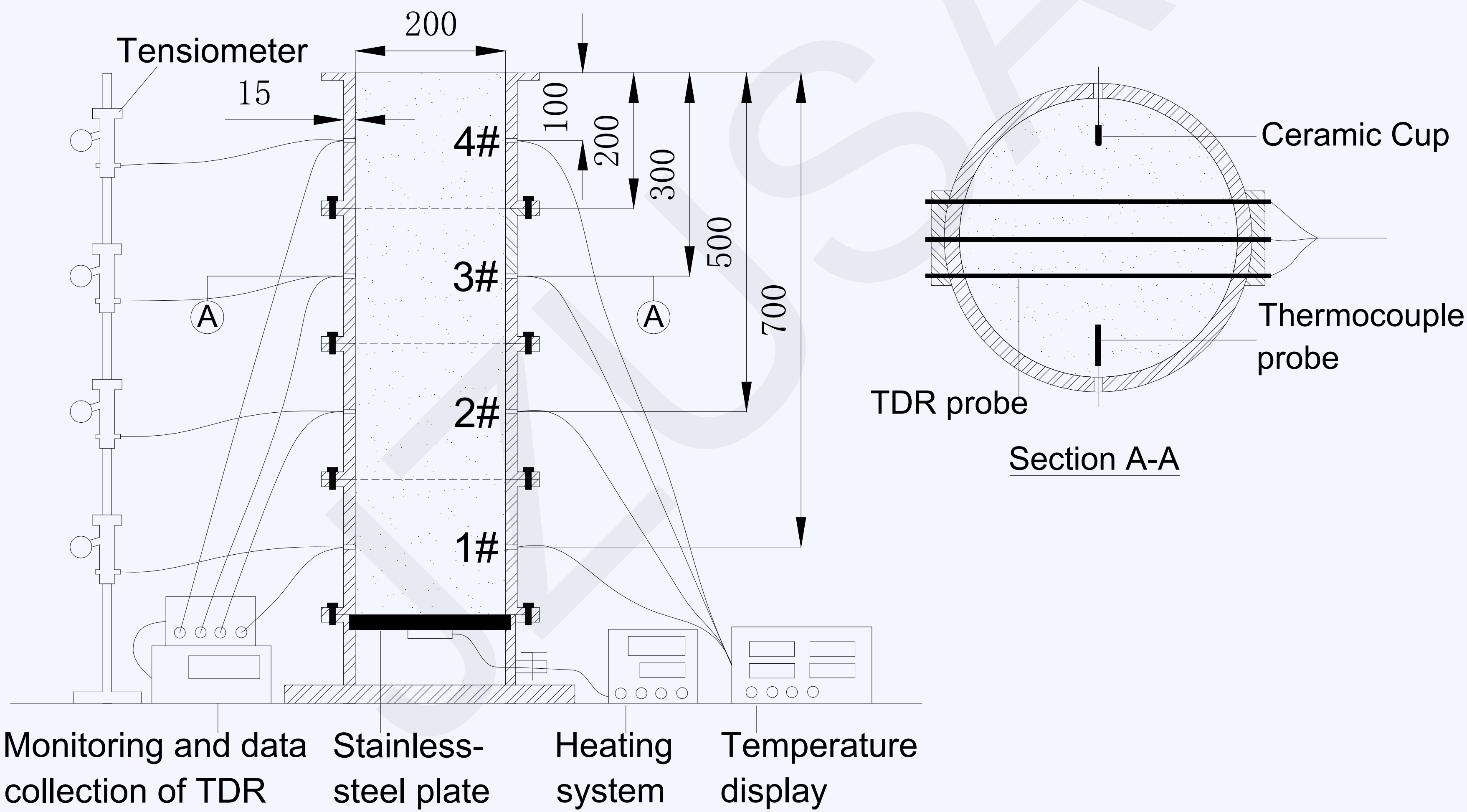


Sponge Concept



Laboratory experiment

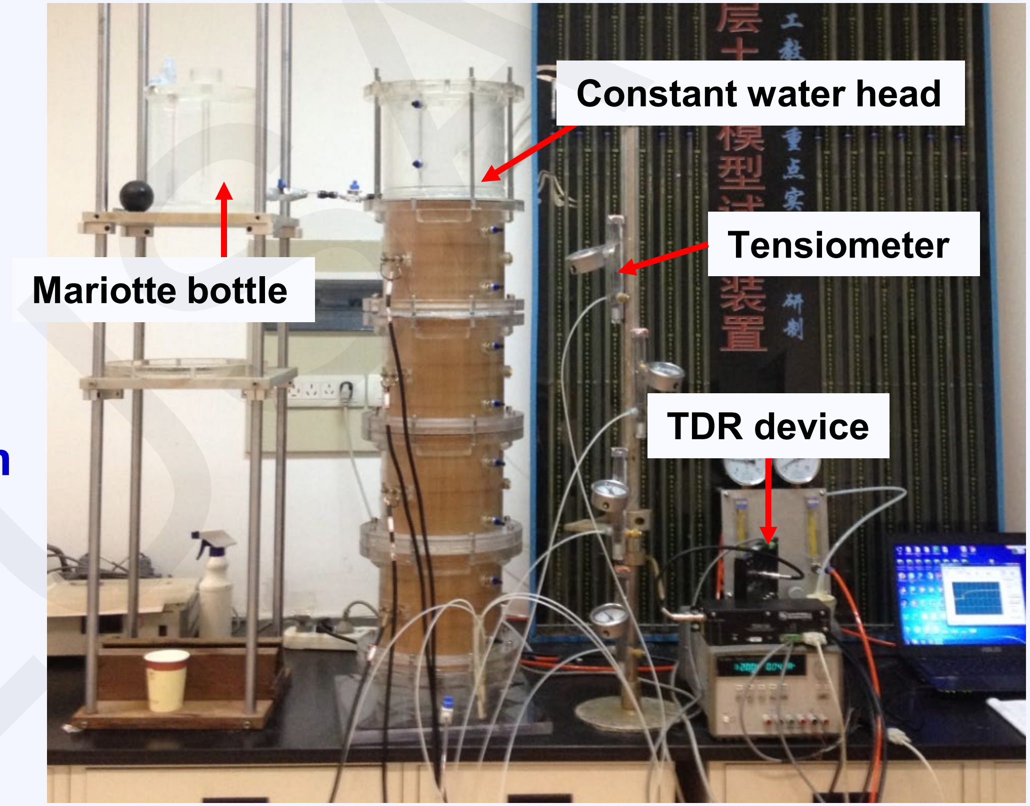
□ Instrumentation



Laboratory experiment

□ Testing procedure

- **Infiltration**
  - 5 cm constant water head
  - Opening bottom
- **Evaporation**
  - Open top and Sealed bottom
  - Constant temperature was controlled at 70 ℃



Numerical study

Governing equations

$$n\left(\rho^{\mathrm{w}}-\rho^{\mathrm{gw}}\right)\left(\frac{\partial S_{\mathrm{w}}}{\partial p^{\mathrm{c}}}\frac{\partial p^{\mathrm{c}}}{\partial t}\right)+\left(1-S_{\mathrm{w}}\right)n\left(\frac{\partial \rho^{\mathrm{gw}}}{\partial p^{\mathrm{c}}}\frac{\partial p^{\mathrm{c}}}{\partial t}\right)-\mathrm{div}\left(\rho^{\mathrm{g}}\frac{M_{\mathrm{a}}M_{\mathrm{w}}}{M_{\mathrm{g}}^{2}}\mathbf{D}\mathrm{grad}\left(\frac{p^{\mathrm{gw}}}{p^{\mathrm{c}}}\right)\right)$$

$$+\mathrm{div}\left(\rho^{\mathrm{w}}\frac{\boldsymbol{k}k^{\mathrm{rw}}}{\mu^{\mathrm{w}}}\left[-\mathrm{grad}(p^{\mathrm{g}})+\mathrm{grad}(p^{\mathrm{c}})+\rho^{\mathrm{w}}\boldsymbol{g}\right]\right)+\mathrm{div}\left(\rho^{\mathrm{gw}}\frac{\boldsymbol{k}k^{\mathrm{rg}}}{\mu^{\mathrm{g}}}\left[-\mathrm{grad}(p^{\mathrm{g}})+\rho^{\mathrm{g}}\boldsymbol{g}\right]\right)=0$$

Water phase balance

$$-n\rho^{\mathrm{ga}}\left(\frac{\partial S_{\mathrm{w}}}{\partial T}\frac{\partial T}{\partial t}+\frac{\partial S_{\mathrm{w}}}{\partial p^{\mathrm{c}}}\frac{\partial p^{\mathrm{c}}}{\partial t}\right)+\left(1-S_{\mathrm{w}}\right)n\left(\frac{\partial \rho^{\mathrm{ga}}}{\partial T}\frac{\partial T}{\partial t}+\frac{\partial \rho^{\mathrm{ga}}}{\partial p^{\mathrm{c}}}\frac{\partial p^{\mathrm{c}}}{\partial t}+\frac{\partial \rho^{\mathrm{ga}}}{\partial p^{\mathrm{g}}}\frac{\partial p^{\mathrm{g}}}{\partial t}\right)$$

$$-\mathrm{div}\left(\rho^{\mathrm{g}}\frac{M_{\mathrm{a}}M_{\mathrm{w}}}{M_{\mathrm{g}}^{2}}\mathbf{D}\mathrm{grad}\left(\frac{p^{\mathrm{ga}}}{p^{\mathrm{c}}}\right)\right)+\mathrm{div}\left(\rho^{\mathrm{ga}}\frac{\boldsymbol{k}k^{\mathrm{rg}}}{\mu^{\mathrm{g}}}\left[-\mathrm{grad}(p^{\mathrm{g}})+\rho^{\mathrm{g}}\boldsymbol{g}\right]\right)=0$$

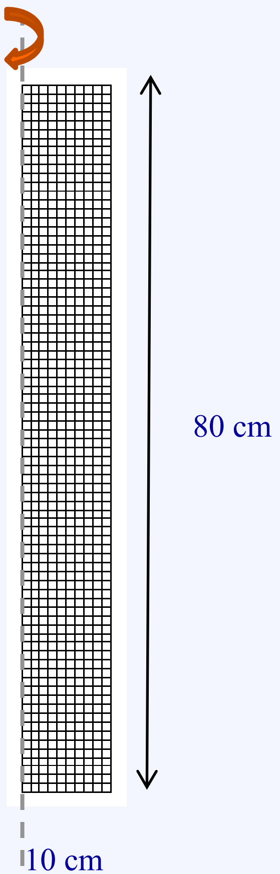
Gas phase balance

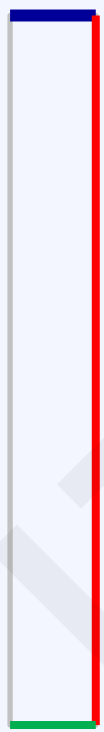
$$C\rho\frac{\partial T}{\partial t}+(C^{w}\rho^{w}\mathbf{v}^{w}+C^{g}\rho^{g}\mathbf{v}^{g})\mathrm{grad}T-\mathrm{div}\left(\boldsymbol{\lambda}\mathrm{grad}T\right)=q_{th}$$

Energy balance

Numerical study

FEM model and boundary conditions





Evaporation BC

$$E_a = E_p \frac{H_s - H_r}{1 - H_r}$$

$$= (a + b \cdot n_{wind})(100 - H_r)\frac{H_s - H_r}{1 - H_r}$$

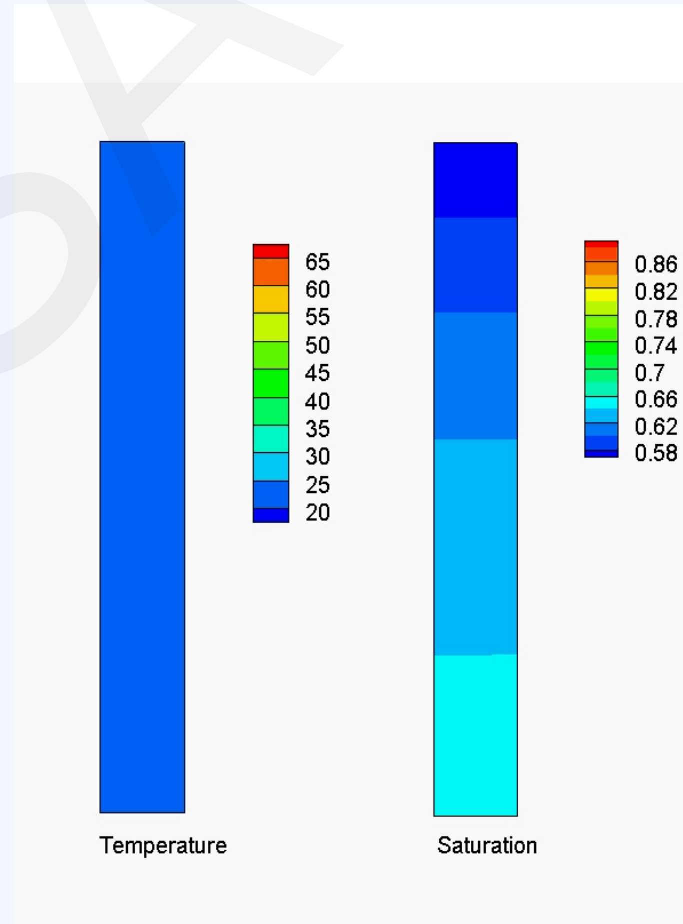
Heat transport BC

$$q_{th} = h(T_a - T_s)$$

Temperature BC

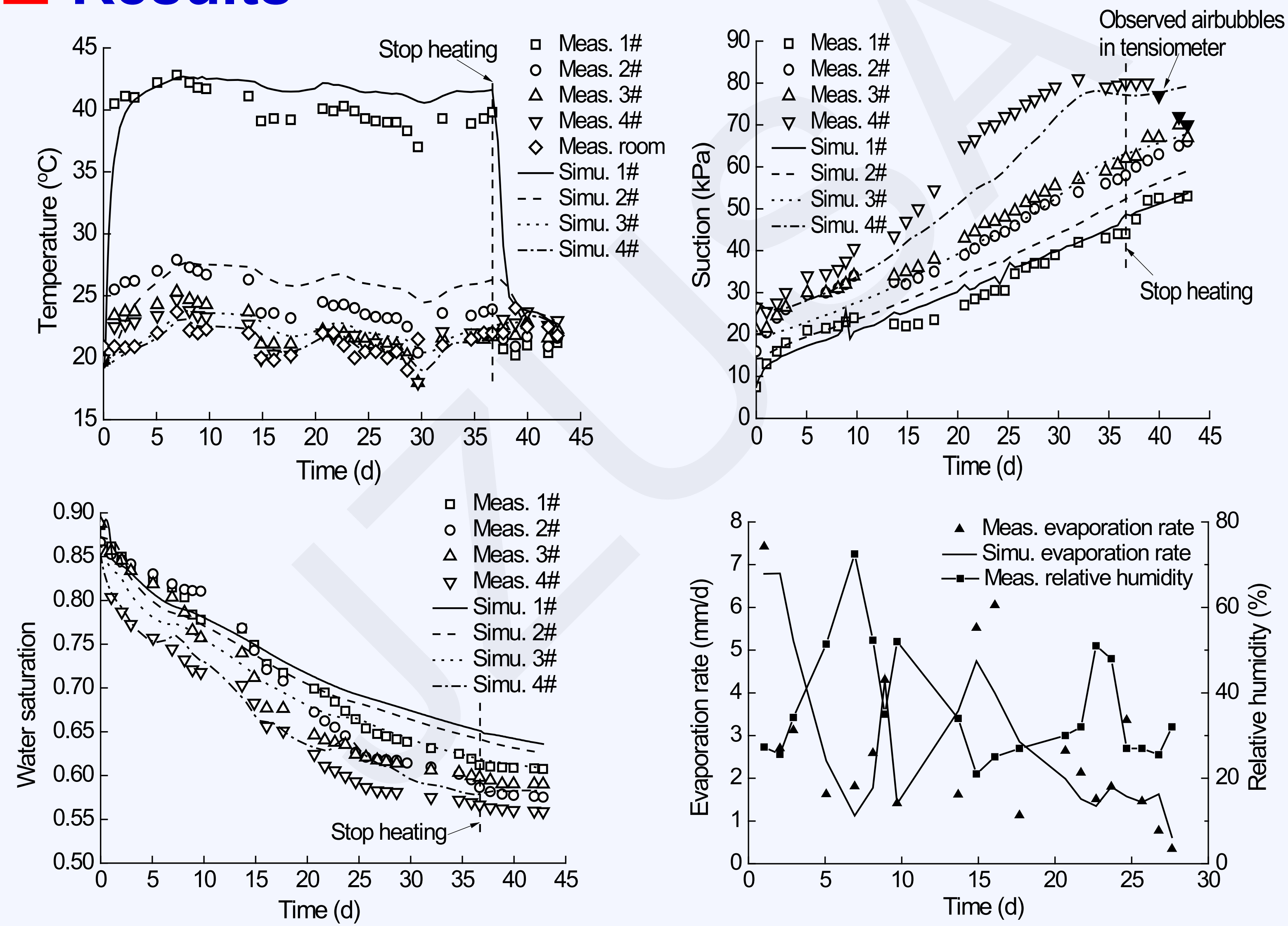
$$T = 70\,°C$$

when Time < 880 *hours*



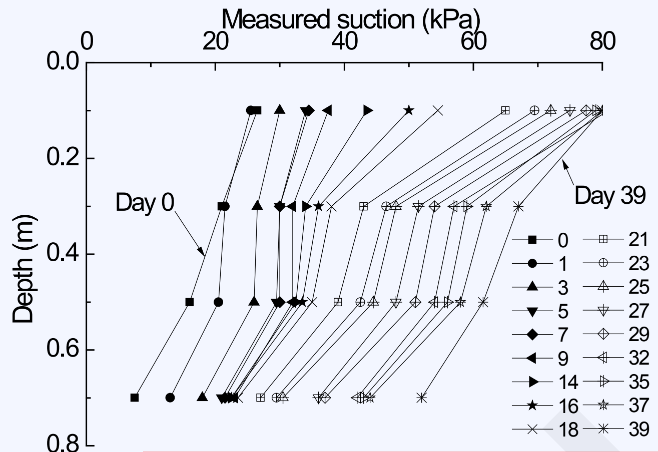
Numerical study

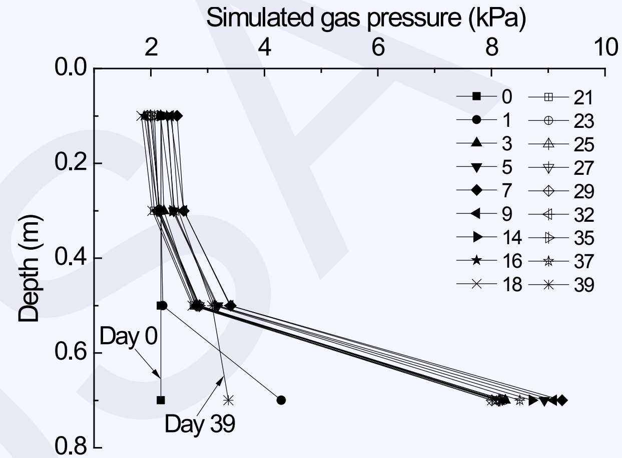
Results



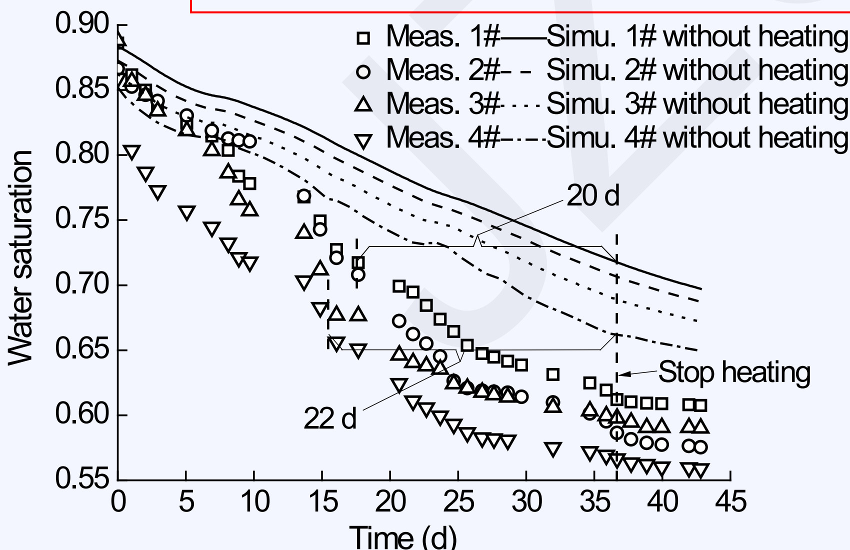
Numerical study

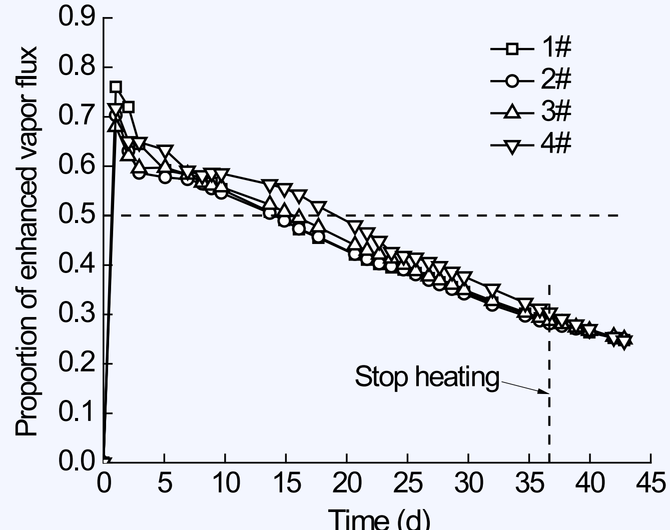
Results





$$W_{\text{Heating}}^{t}=\frac{(S_{\text{w}}^{0}-S_{\text{w, heating}}^{t})-(S_{\text{w}}^{0}-S_{\text{w, non-heating}}^{t})}{S_{\text{w}}^{0}-S_{\text{w, heating}}^{t}}=\frac{S_{\text{w, non-heating}}^{t}-S_{\text{w, heating}}^{t}}{S_{\text{w}}^{0}-S_{\text{w, heating}}^{t}}$$





Conclusions

- **The tortuosity τ of the tested loess for vapor diffusion and the parameter a of the empirical evaporation function were obtained by back analysis using the proposed numerical model. Finally, the tortuosity τ and parameter a were defined as 0.65 and 0.022 mm/d, respectively.**
- **The heating of the bottom accelerated the drying process of the soil column by almost 22 d compared with the conditions without heating, which indicated that the proposed new method is time- saving. The water vapor diffusion was significantly enhanced by the bottom heating.**
- **Before Day 15 the proportions of enhanced vapor flux in the total water loss with heating were always higher than 50%, which indicated that water vapor diffusion dominated the evaporation process at this period. After Day 15, the proportions decreased from 50% to 25%.**