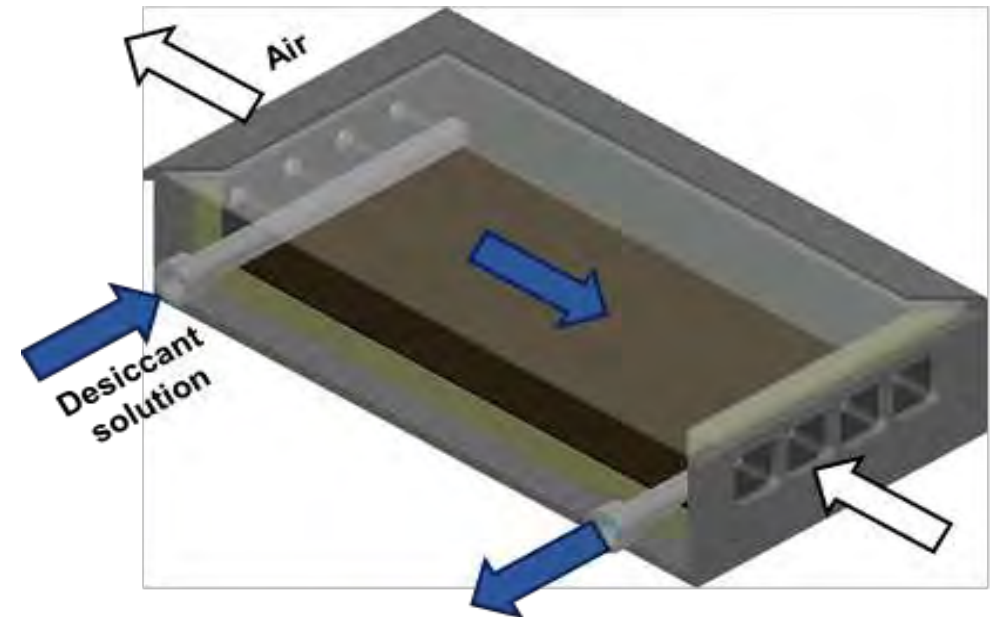
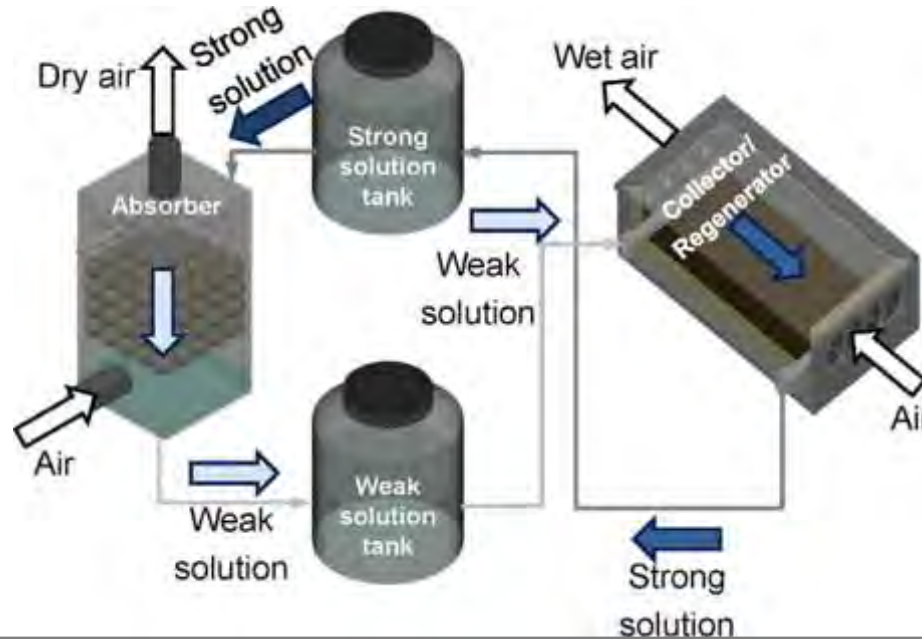
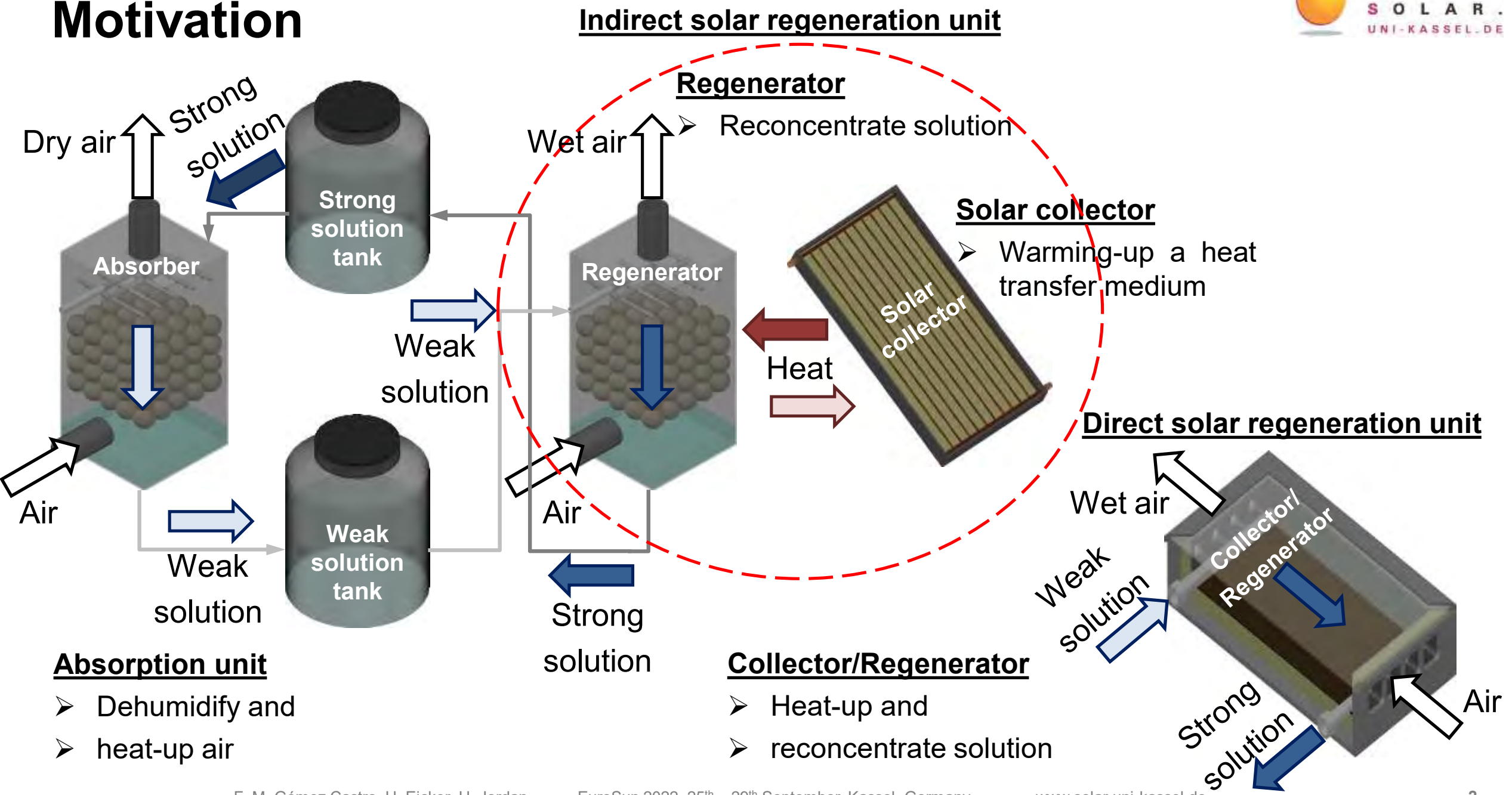


A New Method for Determining the Nusselt and Sherwood Numbers in Simultaneous Heat and Mass Transfer in Solar Collector/Regenerators



Hochschule
für Technik
Stuttgart

Motivation



Experimental setup (with $\text{CaCl}_2\text{-H}_2\text{O}$)



800 – 1250 W/m^2

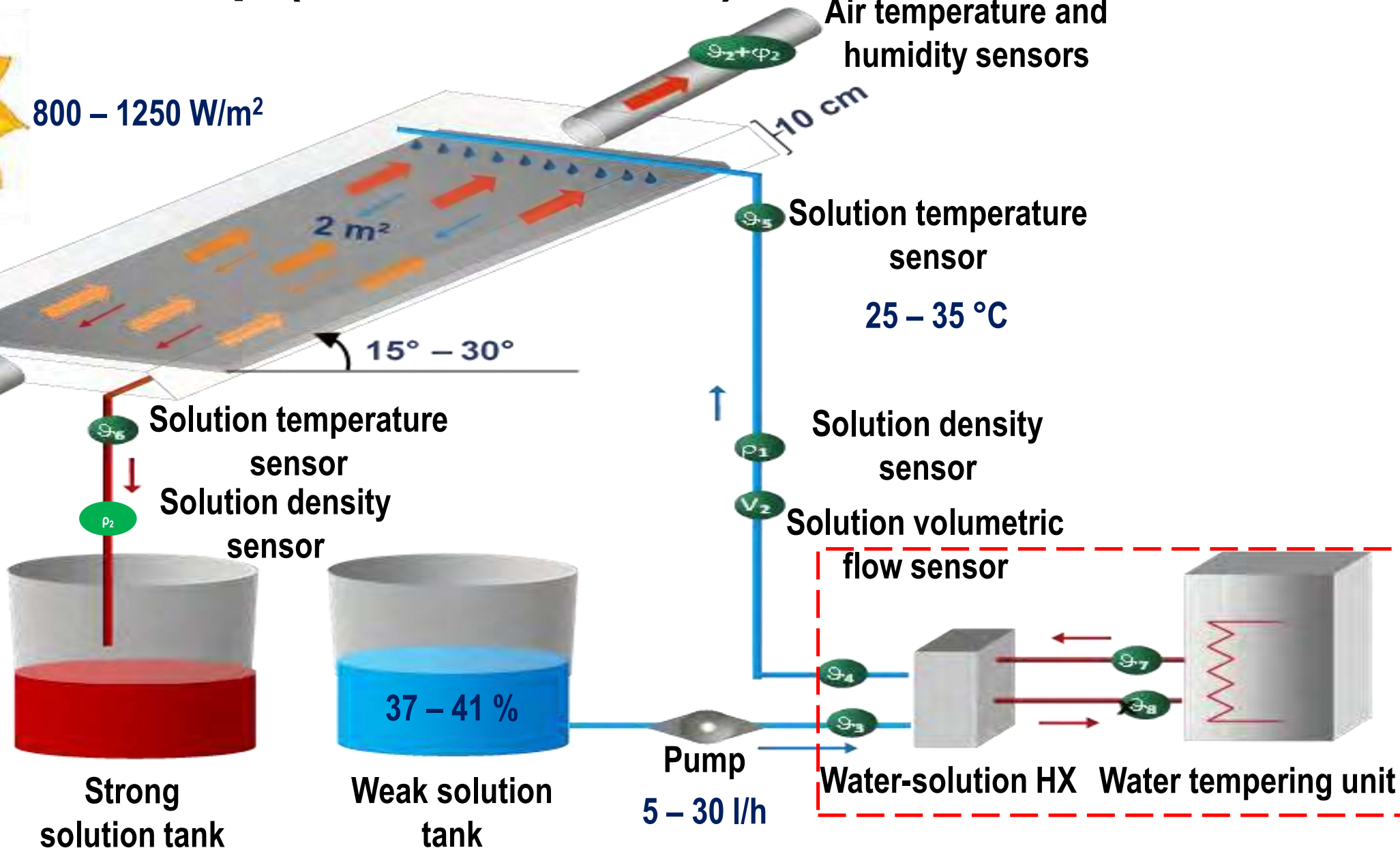
Air volumetric flow sensor

50 – 250 m^3/h

Air temperature and humidity sensors

31 – 33 %

39 – 43 % RH



Strong solution tank

Weak solution tank

Pump
5 – 30 l/h

Water-solution HX Water tempering unit

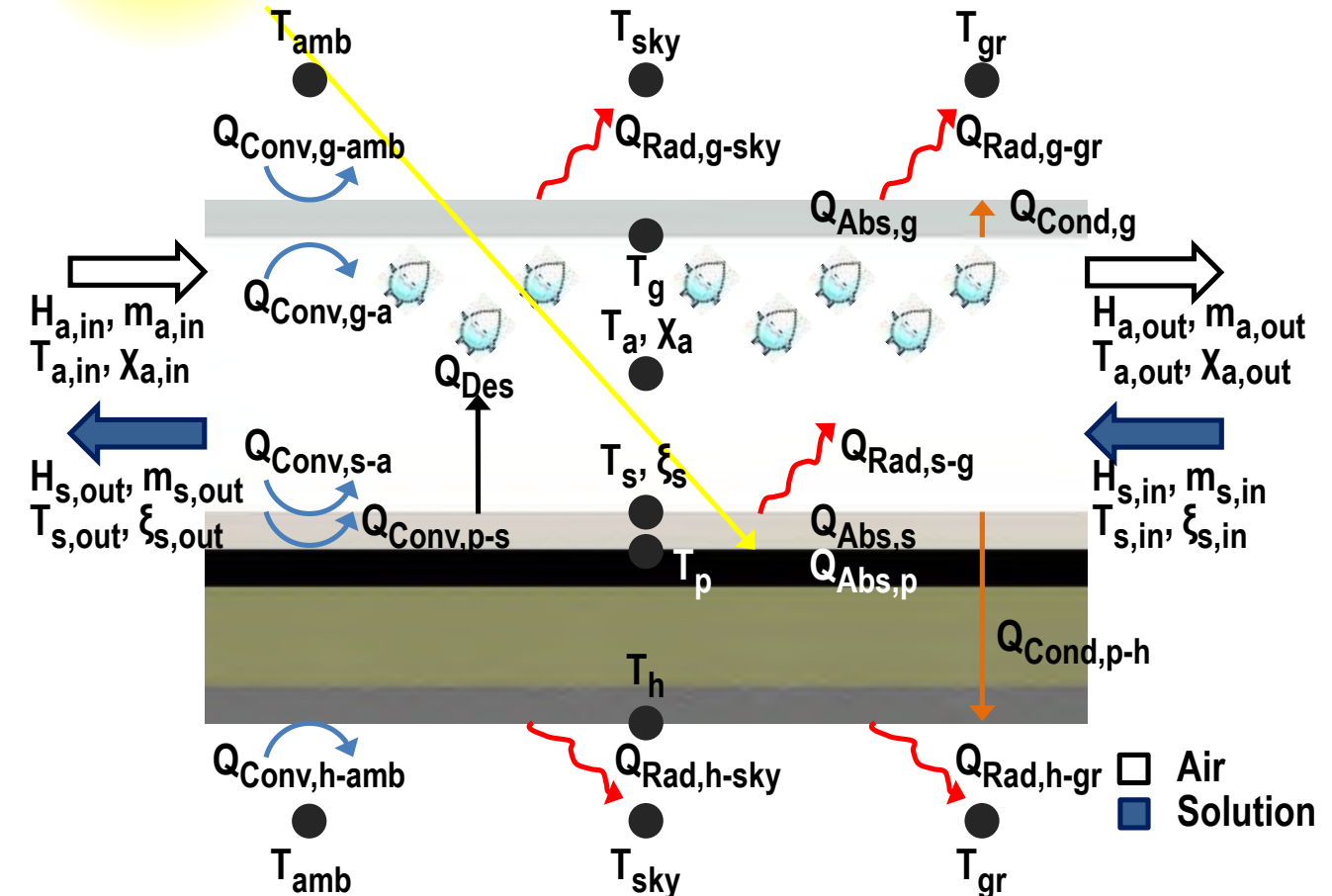
Aims

Assessing the Nusselt and Sherwood numbers.

- Developing a generalised method.
- Model validation.
- Benchmarking new correlations based on:
 - ✓ Own measurements and
 - ✓ Data from literature.

Heat and mass exchange through:

- Solar heating (Q_{Abs})
- mixed convection (Q_{Conv})
- longwave radiation (Q_{Rad})
- water desorption (Q_{Des})
- thermal conduction (Q_{Cond}) and
- enthalpy (H_a, H_s).



Subscripts:

g = glass cover a = air s = solution p = absorber plate
 h = housing amb = ambient gr = ground

Evaluation Method

Approach for coupled heat and mass fluxes: Nusselt number

$$\mathbf{Nu} = \mathbf{Nu}_{\text{lat}} + \mathbf{Nu}_{\text{sen}} \rightarrow \text{Sensible heat transfer: Gnielinski, 2010; Taler, 2017}$$

Latent heat transfer

$$\mathbf{Nu}_{\text{lat}} = [\mathbf{r}_0 + (\mathbf{r}_1 - \mathbf{r}_0) \cdot \mathbf{S}] \cdot \mathbf{Nu}_{\text{sen}}$$

Normalised output function

$$\mathbf{S} = \mathbf{LR}_1 + \sum_{i=1}^7 \mathbf{LR}_{2i} + \sum_{i=1}^7 \mathbf{LR}_{3i}$$

Multiple linear regression functions

$$1 \leq i \leq 7$$

$$\mathbf{LR}_1 = \mathbf{a}_0 + \sum_{i=1}^7 \mathbf{a}_i \cdot \mathbf{U}_i$$

$$\mathbf{LR}_{2i} = \mathbf{U}_i \cdot \sum_{j=1}^{8-i} \mathbf{b}_{i,j} \cdot \mathbf{U}_{j+(i-1)}$$

$$\mathbf{LR}_{3i} = \mathbf{U}_i^2 \cdot \sum_{j=1}^7 \mathbf{c}_{i,j} \cdot \mathbf{U}_j$$

Evaluation Method

Approach for coupled heat and mass fluxes: Nusselt number

Logarithmically normalised dimensionless groups

$$U_1 = \frac{\text{Log} \left(\frac{Re_a}{Re_{a,\min}} \right)}{4.675}$$

$$U_2 = \frac{\text{Log} \left(\frac{Gr_{ch}}{Gr_{ch,\min}} \right)}{8.839}$$

$$U_3 = \frac{\text{Log} \left(\frac{Le_{a,ev}}{Le_{a,ev,\min}} \right)}{1.552}$$

$$U_4 = \frac{\text{Log} \left(\frac{Ka_s}{Ka_{s,\min}} \right)}{3.15}$$

$$U_5 = \frac{\text{Log} \left(\frac{Re_s^*}{Re_{s,\min}^*} \right)}{4.691}$$

$$U_6 = \frac{\text{Log} \left(\frac{Gr_{m,ch}}{Gr_{m,ch,\min}} \right)}{6.26}$$

$$U_7 = \frac{\text{Log} \left(\frac{Nu_{sen}}{Nu_{s,\min}} \right)}{1.313}$$

Gas-phase

- Reynolds number (Re_a)
- Lewis number of evaporation ($Le_{a,ev}$)

Liquid phase

- Reynolds number (Re_s^*)
- Kapitza number (Ka_s)

Liquid-gas interface

- Channel thermal Grashof number (Gr_{ch})
- Channel solutal Grashof number ($Gr_{m,ch}$)

Evaluation method

Approach for coupled heat and mass fluxes: Sherwood number

- Same mathematical form as Nusselt number correlation.

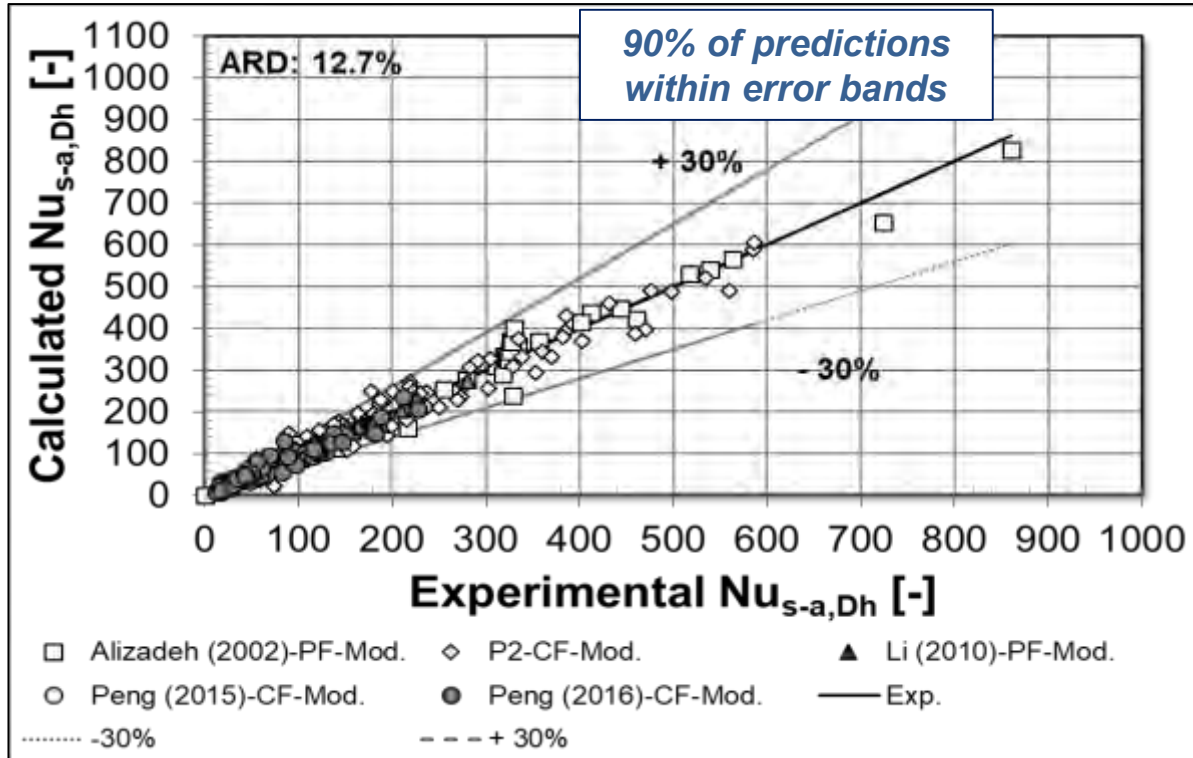
$$U_7 = \frac{\text{Log} \left(\frac{Sh_{sen}}{Sh_{sen,min}} \right)}{1.28}$$

→ Gnielinski (2010) and Taler (2017)
 ✓ Prandtl number → Schmidt number

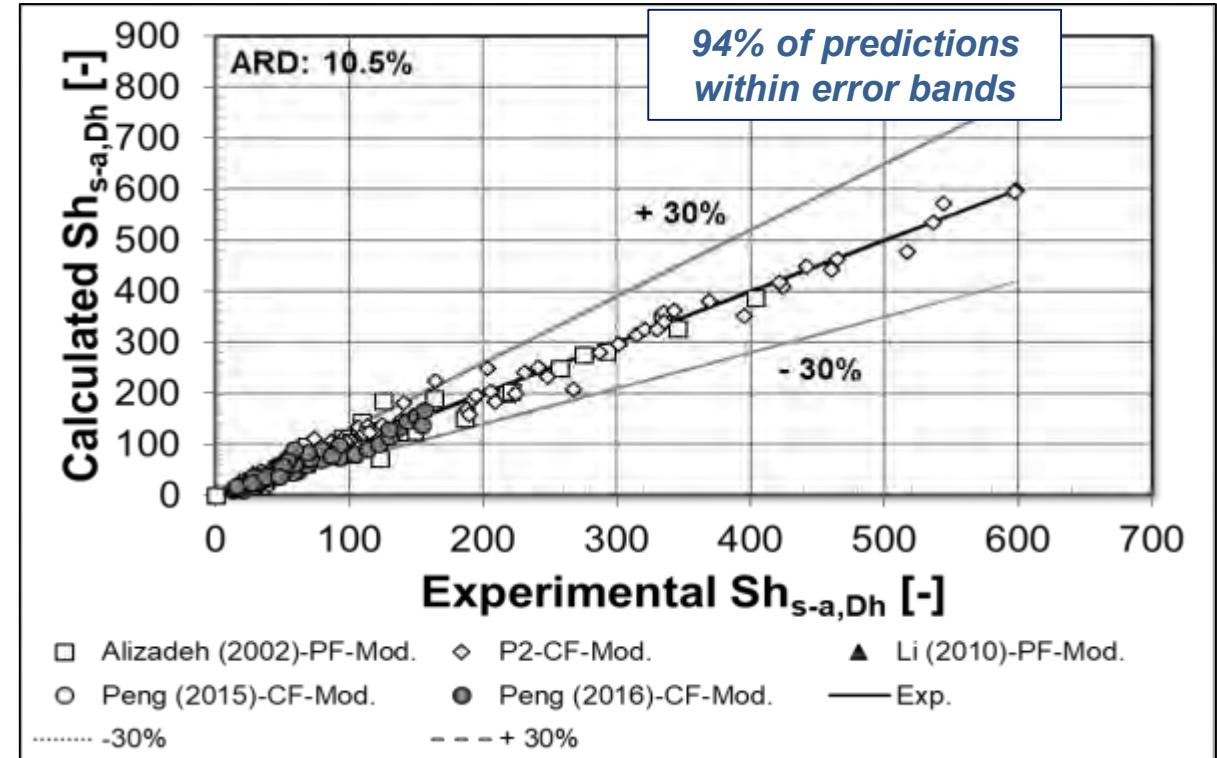
- Coefficients r_i , a_i , $b_{i,j}$ and $c_{i,j}$ → Fit with data from test rig and literature.
- **Domain of applicability**
 - $\text{CaCl}_{2\text{aq}}$, LiBr_{aq} and LiCl_{aq} solutions.
 - Re_a in the transitional and turbulent flow regimes.
 - Re_s^* in the smooth and wavy laminar flow regimes.

Coupled Nusselt and Sherwood numbers

a) Nusselt number



b) Sherwood number



Average relative deviation:

$$ARD = (1/n) \cdot \sum_{i=1}^n \left| \frac{P_{\text{Exp}[i]} - P_{\text{Mod}[i]}}{P_{\text{Exp}[i]}} \right| \cdot 100$$

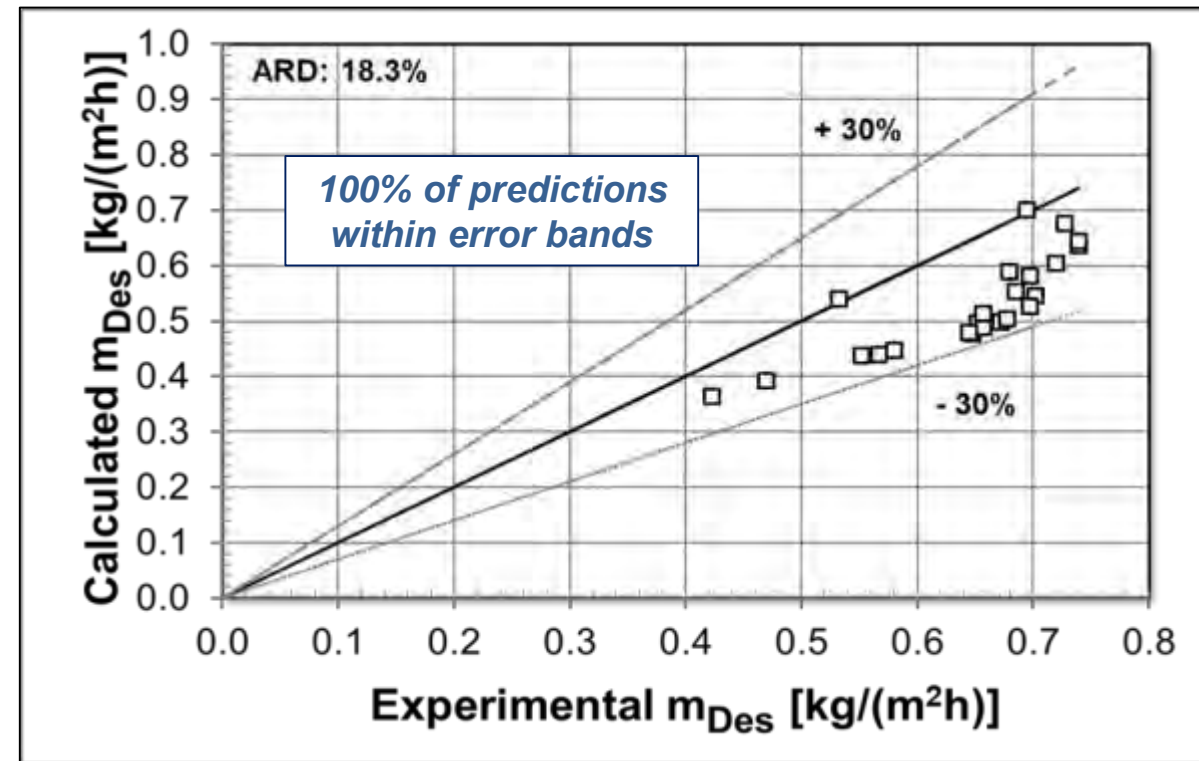
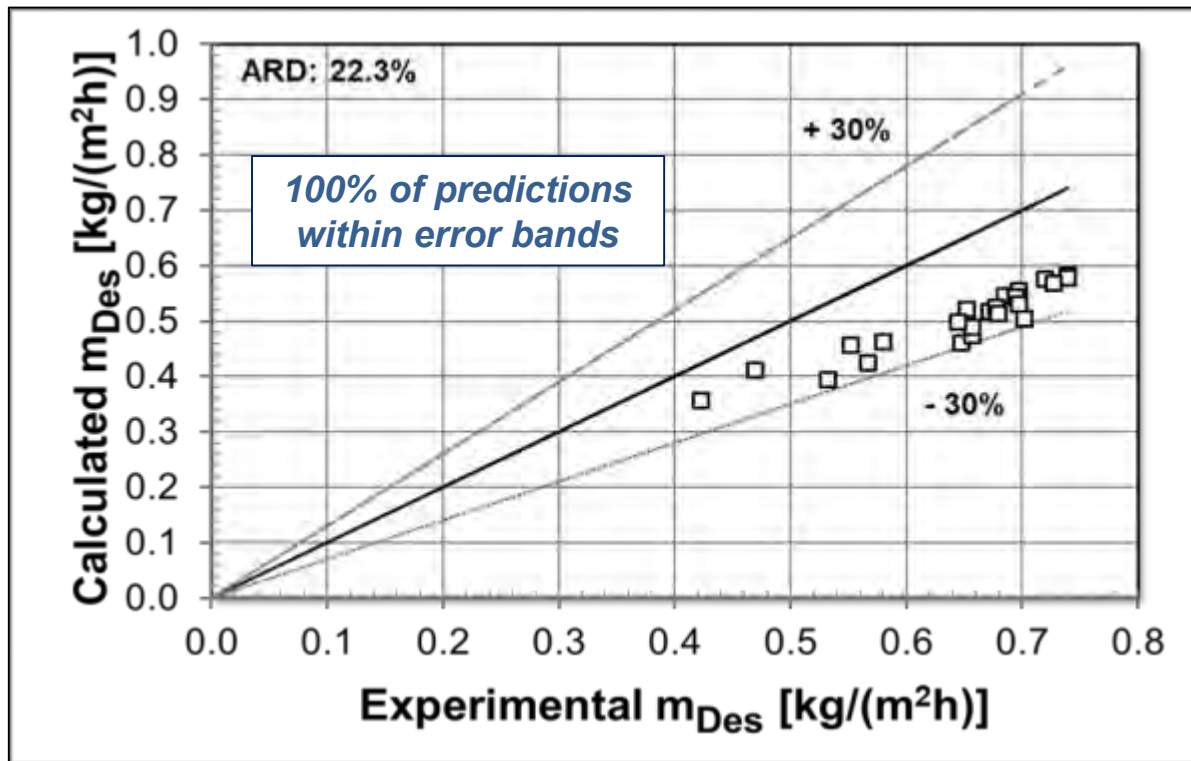
← exp. ← modelled

➤ **Suitable selection of dimensionless groups → High accuracy.**

Comparison with correlations from literature

(a) Correlations of Peng and Zhang (2016).

(b) Proposed correlations.



Liquid desiccant: LiCl-H₂O

3. Improved description of buoyancy effects (Grashof numbers) and of different types of liquids by the Kapitza number
 ⇒ Improved accuracy + flexibility

Operating conditions:

$G_{28^\circ} = 420 - 790 \text{ W/m}^2$

$T_{a,in} = 29 - 37 \text{ }^\circ\text{C}$

$X_{a,in} = 9 - 20 \text{ g/kg}$

$V_a = 70 - 350 \text{ m}^3/\text{h}$

$T_{s,in} = 25 - 32 \text{ }^\circ\text{C}$

$\xi_{s,in} = 24 - 26\%$

$V_s = 12 - 18 \text{ l/h}$

Conclusions and Outlook

- **New method** for evaluating the **Nusselt and Sherwood numbers** for solar collector/regenerators.
- The selected **dimensionless groups** adequately emulate the **coupled heat and mass fluxes** within the device.
- The **proposed correlations outperform** those of Peng and Zhang (2016)
 - ***Thermosolutal buoyancy + solution properties*** → ***Improved accuracy + flexibility***

Outlook: Extending the method to other liquid desiccants, feasibility analysis of collector/regenerators,...

