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Transient Analysis of a Cylindrical Finned-tube Adsorber Reactor in a Solar Adsorption Refrigeration Cycle

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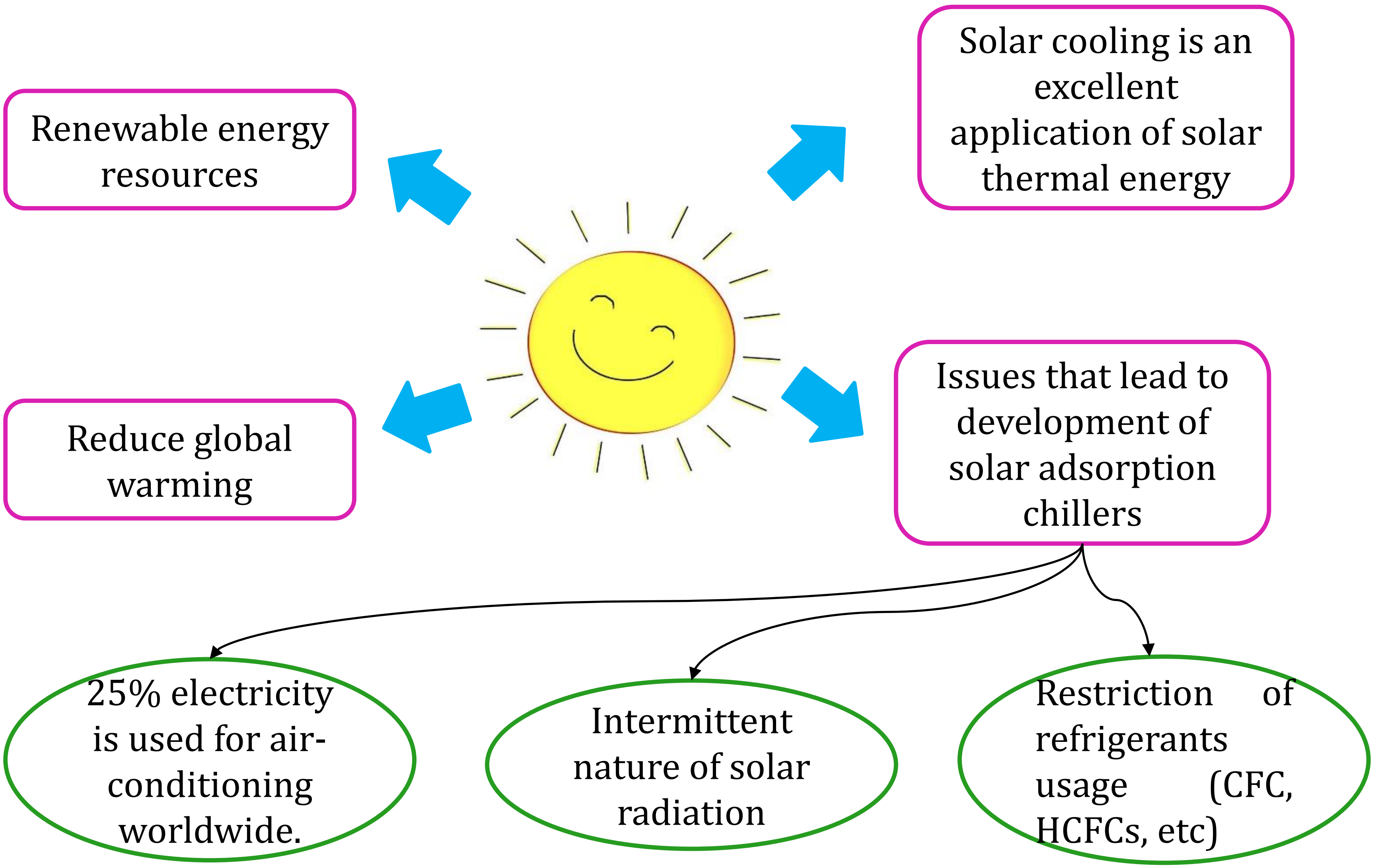
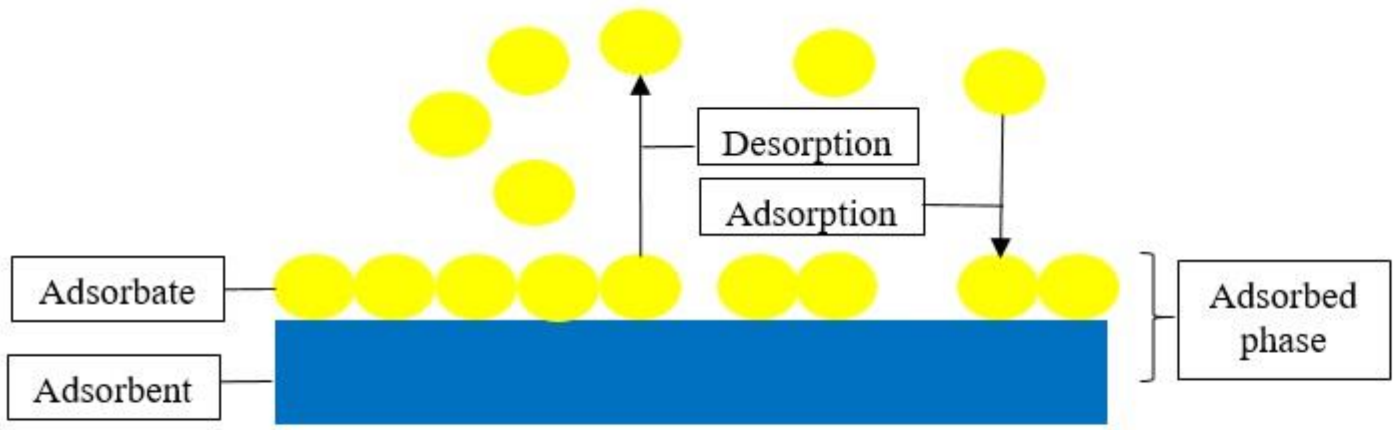
Presentation Outlines

- Introduction
- Research Objectives
- Methodology
- Findings
- Conclusions

Introduction



Adsorption process

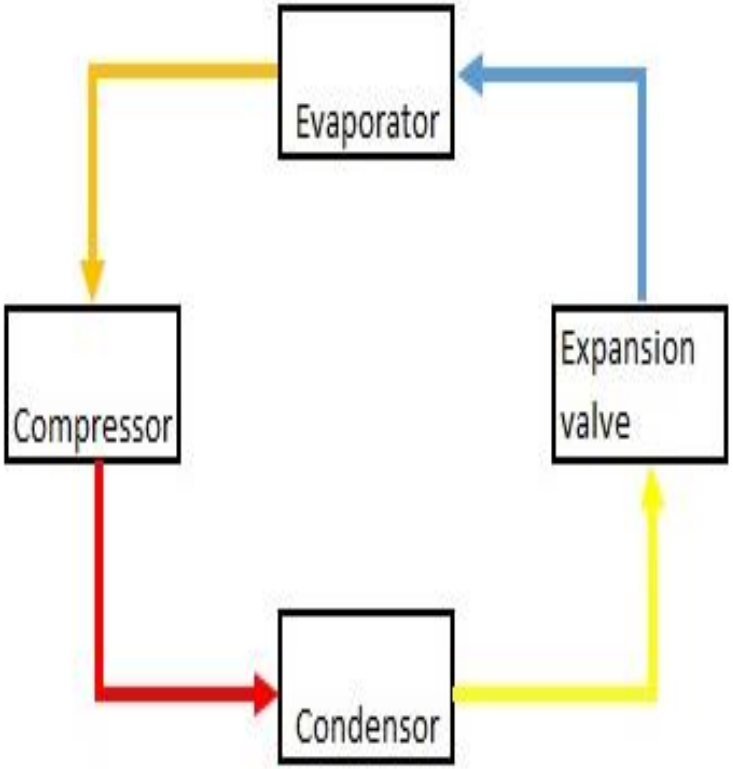


$$Adsorbent + Adsorbate \leftrightarrows Adsorbed\ phase$$

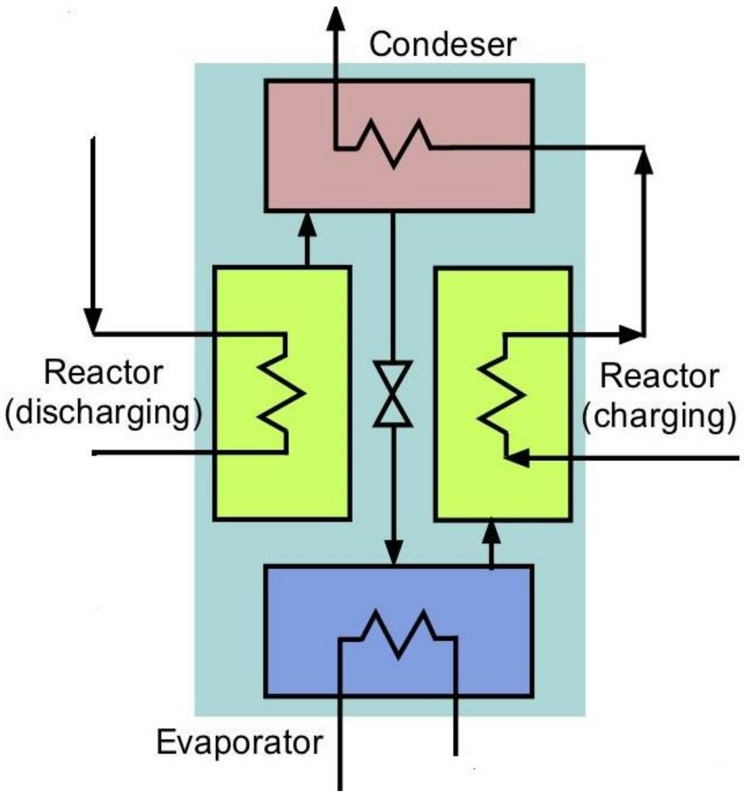
- **Adsorption**: attachment of adsorbate onto the adsorbent porous surface.
- **Desorption**: removal of adsorbate from the adsorbate porous surface.
- Solid adsorbent works with gaseous refrigerant (adsorbate) in this study.

Refrigeration cycle

- Basic refrigeration cycle



- Adsorption refrigeration cycle



Solar Adsorption Refrigeration System

Solar thermal energy → Adsorption refrigeration process → Cooling effects in evaporator

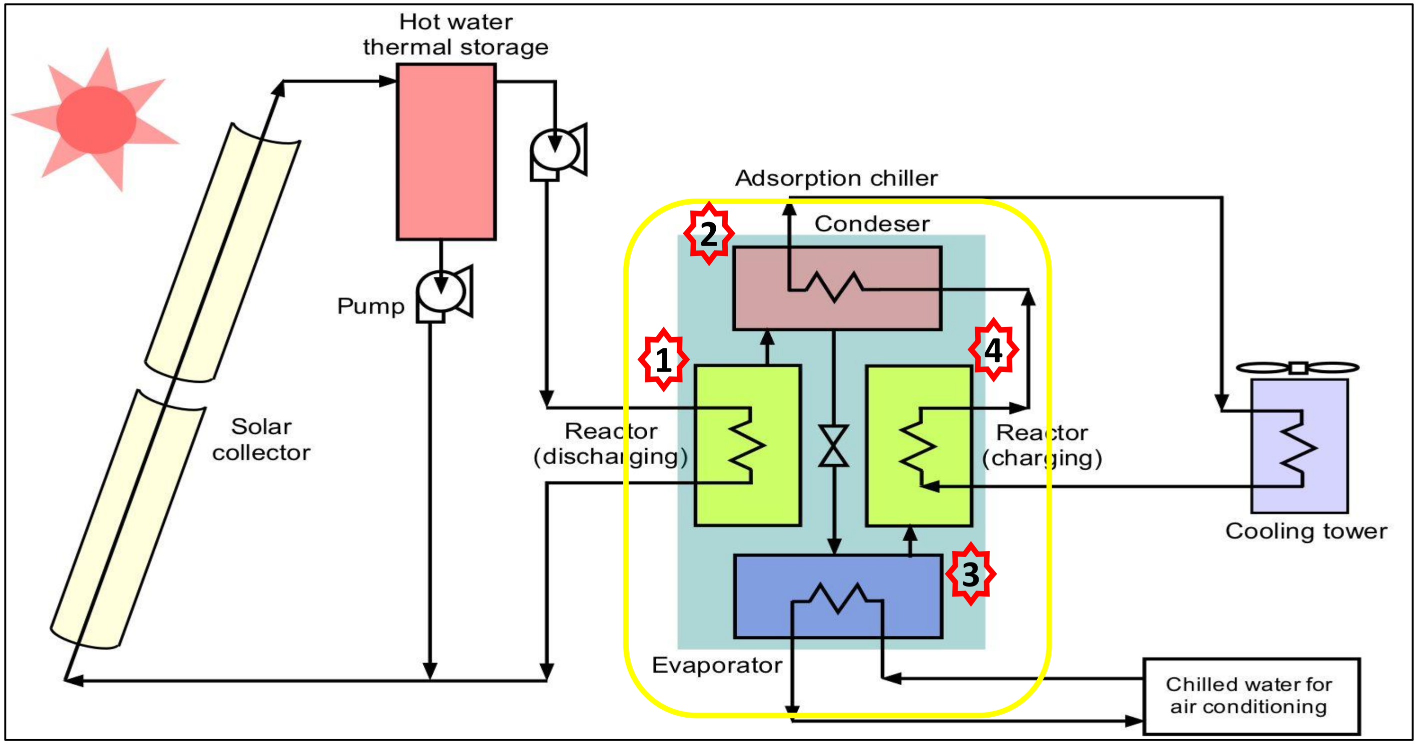


Fig. 1: Solar adsorption chiller system with hot water thermal storage

Research Objectives

Research Objectives

- To develop a methodology to model an adsorber reactor in adsorption refrigeration cycle.
- To study the temperature distribution inside adsorber reactor and its effects on adsorption capacity and system performance.
- To perform improvement on the adsorber reactor model to improve system performance.

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Methodology

1 Analytical works

- Adsorbent-refrigerant working pairs
- Solar adsorption refrigeration with thermal storages

2 Simulation activities

- 2D Adsorber reactor design
- Transient analysis of adsorber reactor

3 Optimization works

- 3D Adsorber reactor design with fins configuration
- Transient analysis of adsorber reactor
- Reaction rate and performance

Adsorber Reactor Modeling

Finite element analysis

- Time-dependent study
- Axisymetric 2D model
- Finless adsorber reactor

Materials

- Adsorber reactor: Stainless-steel
- Heat transfer pipe: Stainless-steel
- Adsorbent bed: Activated carbon
- Refrigerant: Methanol

Initial conditions

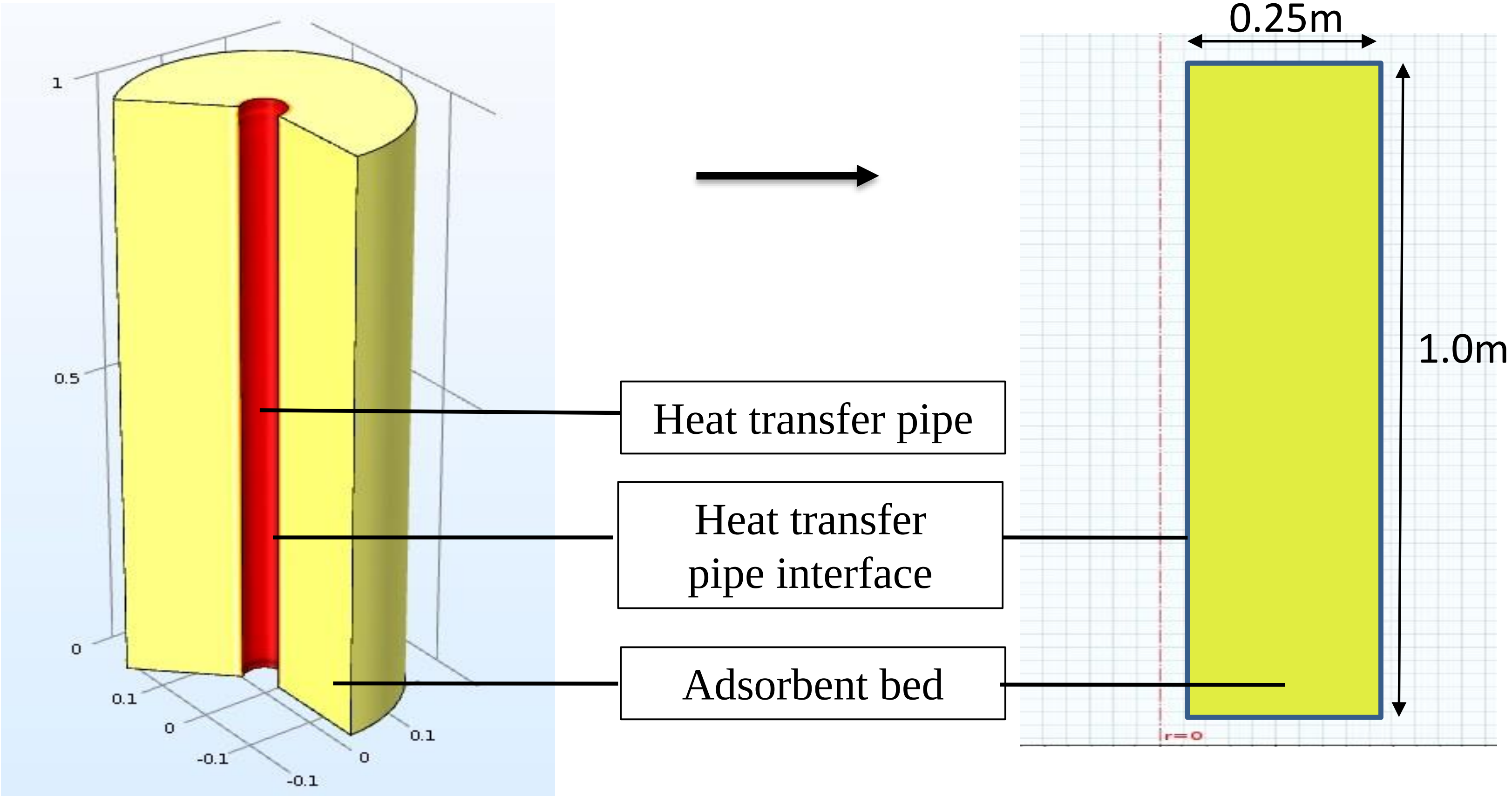
- Desorption process

$T = Ti = 40°C$
$P = Pc = 5898.5$ Pa
$X = X_0 = 0.290$ kg/kg

- Adsorption process

$T = Ti = 60°C$
$P = Pe = 880.3$ Pa

Adsorber Reactor Modeling



3D cross-section of the adsorbent bed

2D axisymmetry of adsorbent bed

Fig.2: Geometry model under study

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Adsorber Reactor Modeling

Heat transfer in porous media

- Conduction and convection of heat
- Between the heat transfer pipe and adsorbent

↓

Transport of diluted species

- Adsorption or desorption of refrigerant

↓

Coefficient form, PDE

- To solve for adsorption capacity, X (kg/kg)

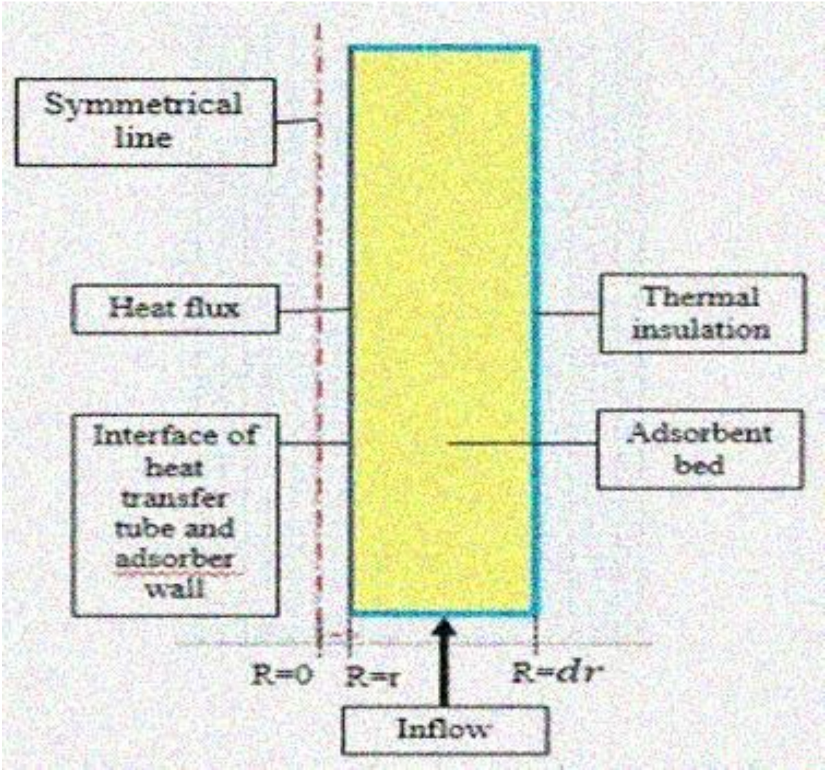
↓

Darcy's Law

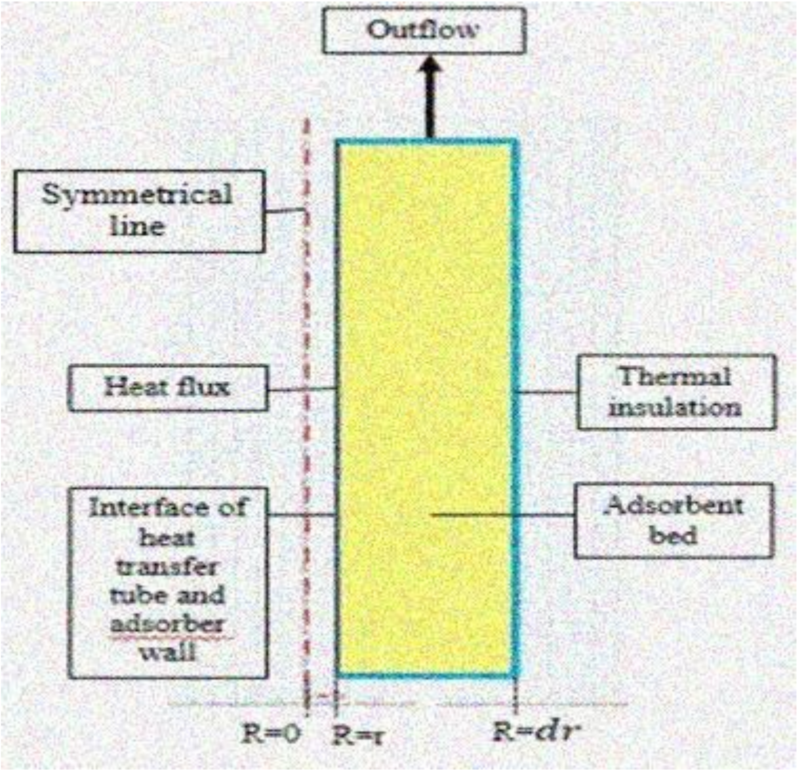
- To set the velocity of refrigerant in the porous adsorbent

Adsorber Reactor Modeling

- Boundary settings



For adsorption process



For desorption process

Fig. 3: Boundary settings for the adsorber reactor modeling

Findings

- Temperature distribution inside the adsorbent (Desorption process)

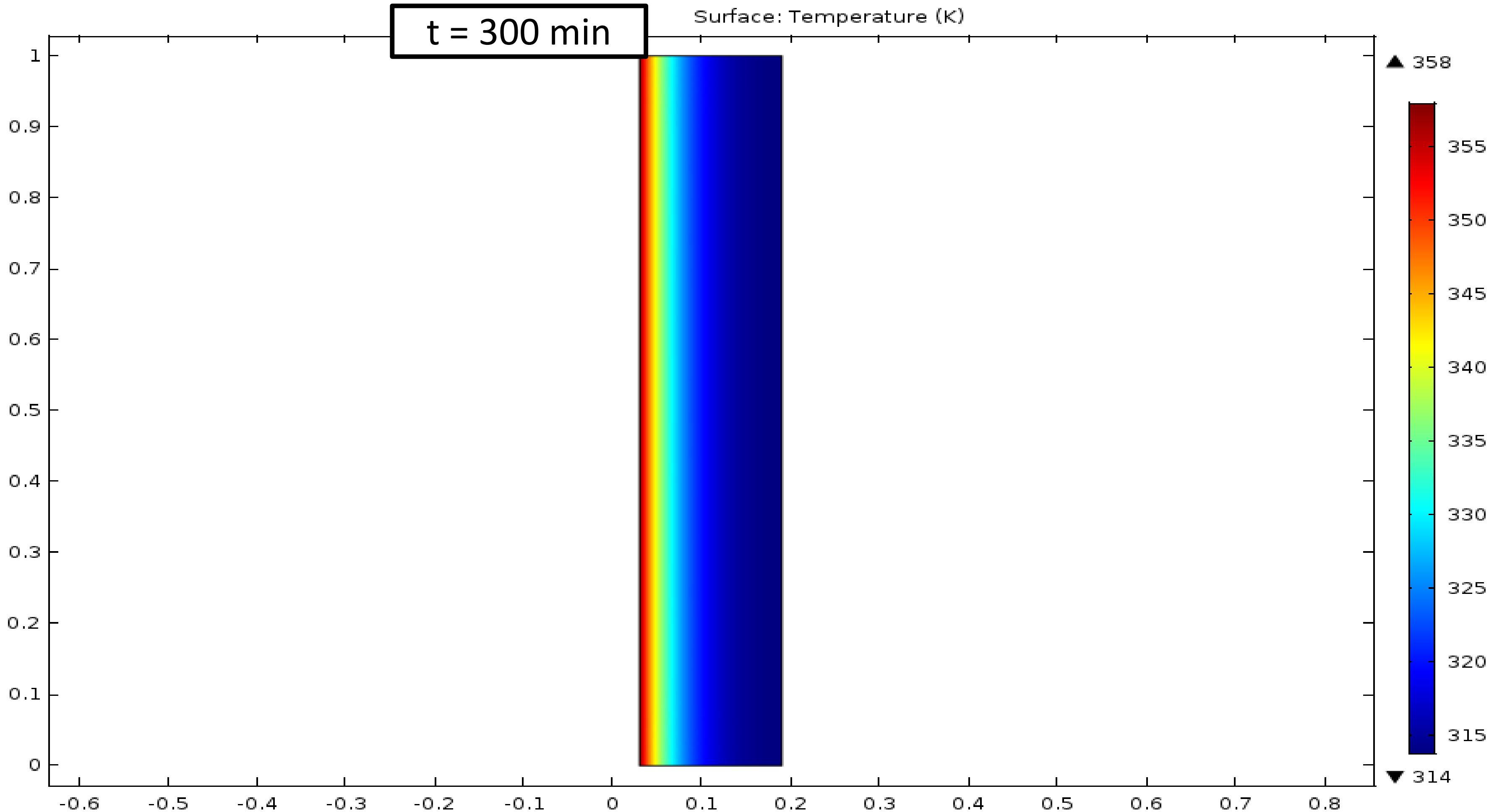


Fig.4: Temperature distribution inside the adsorbent bed

Findings

- Adsorption capacity inside the adsorbent (desorption process)

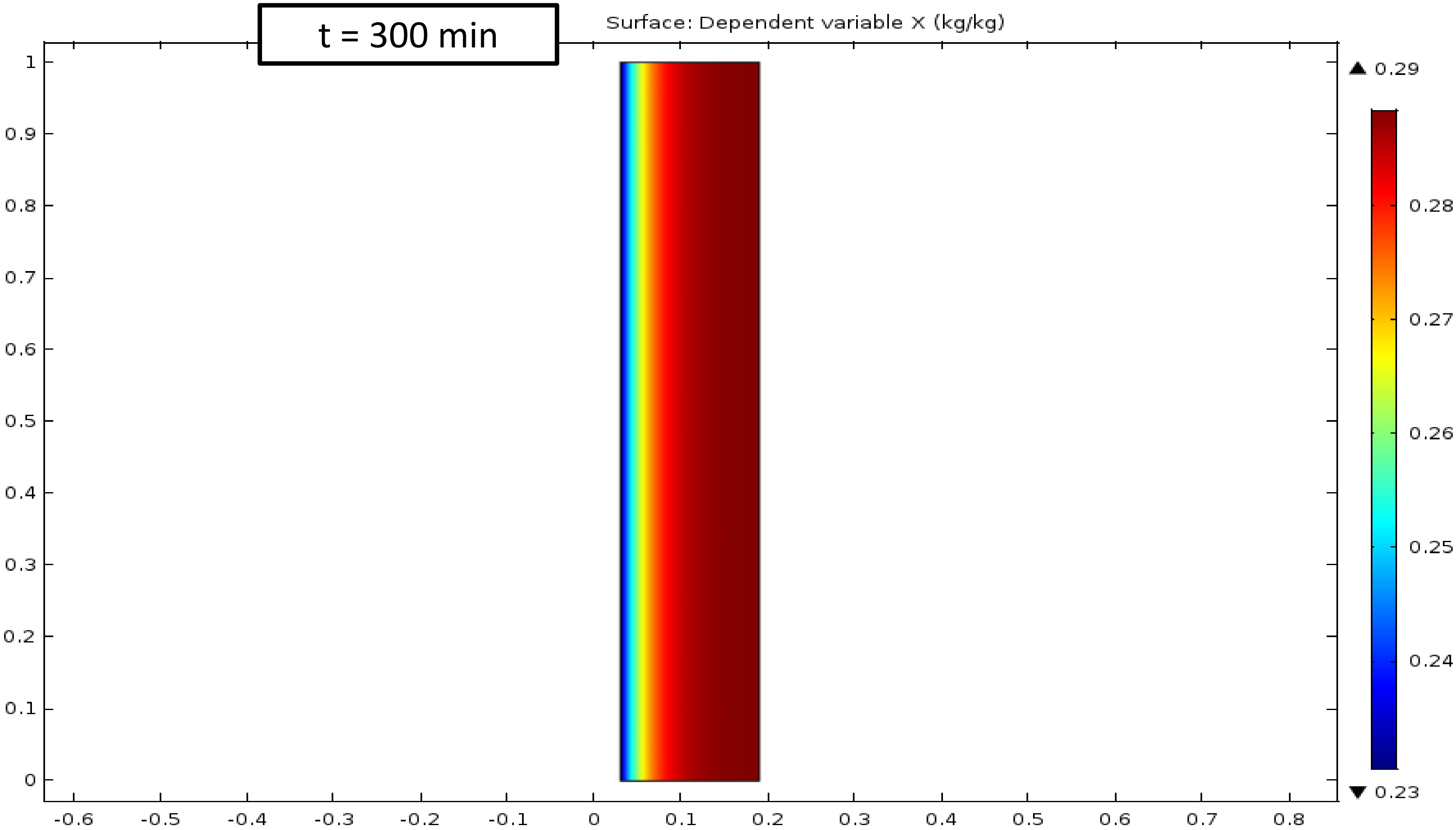
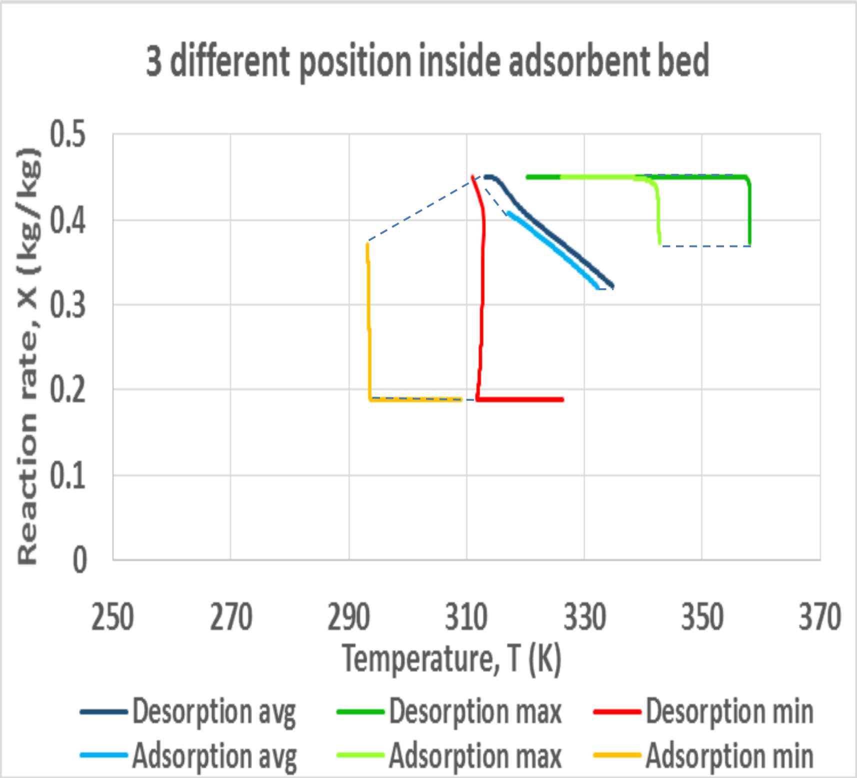
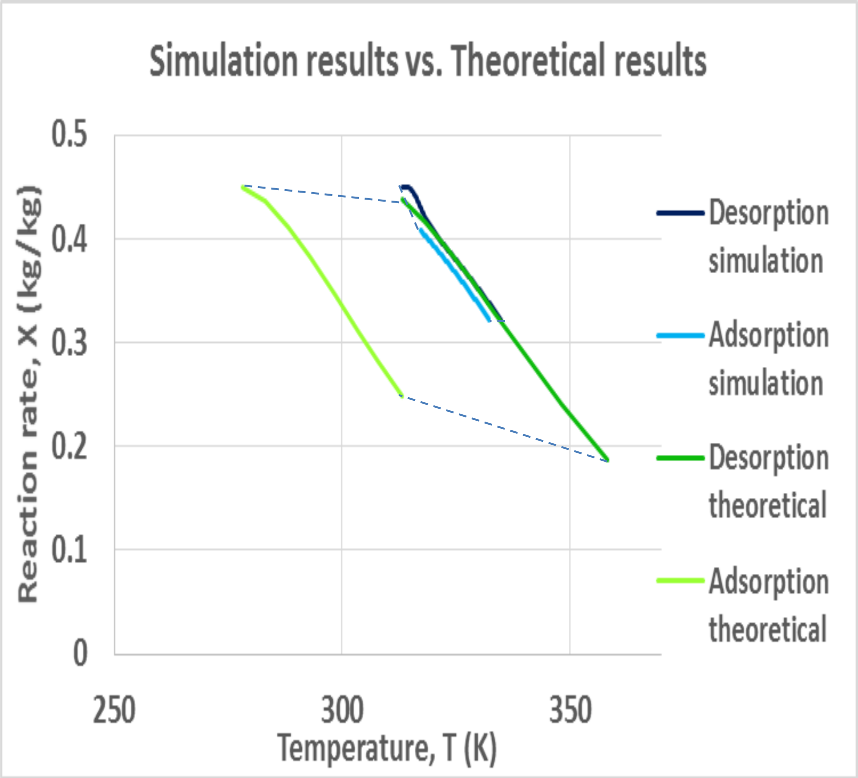


Fig.5: Adsorption capacity inside the adsorbent bed

Findings

- Activated carbon-methanol working pair (in system with hot water thermal storage)





- Highest COP obtained from finless theoretical is 0.618, while the simulation results show a lower COP of 0.266 .
- The low heat transfer inside the adsorbent bed caused the non-uniform temperature distribution inside the adsorbent bed.

Adsorber Reactor Optimization

Finite element analysis

- Time-dependent study
- 3D model

Materials

- Adsorber reactor: Stainless-steel
- Solid fins: Aluminium alloy
- Adsorbent bed: Activated carbon
- Refrigerant: Methanol

Adsorber reactor optimization

- Constant volume of adsorbent
- Design variables:
  - No. of fins
  - Fins thickness
  - Radius of adsorber
- Transient simulation to improve its COP, by:
  - Starts with 2 fins with 0.001m thickness
  - Fin thickness: 0.001m, 0.002m, 0.003m
  - No. of fins: 2, 4, 6, 8, 10, 12, 14 fins.

Adsorber Reactor Optimization

- Design for optimization of adsorber reactor

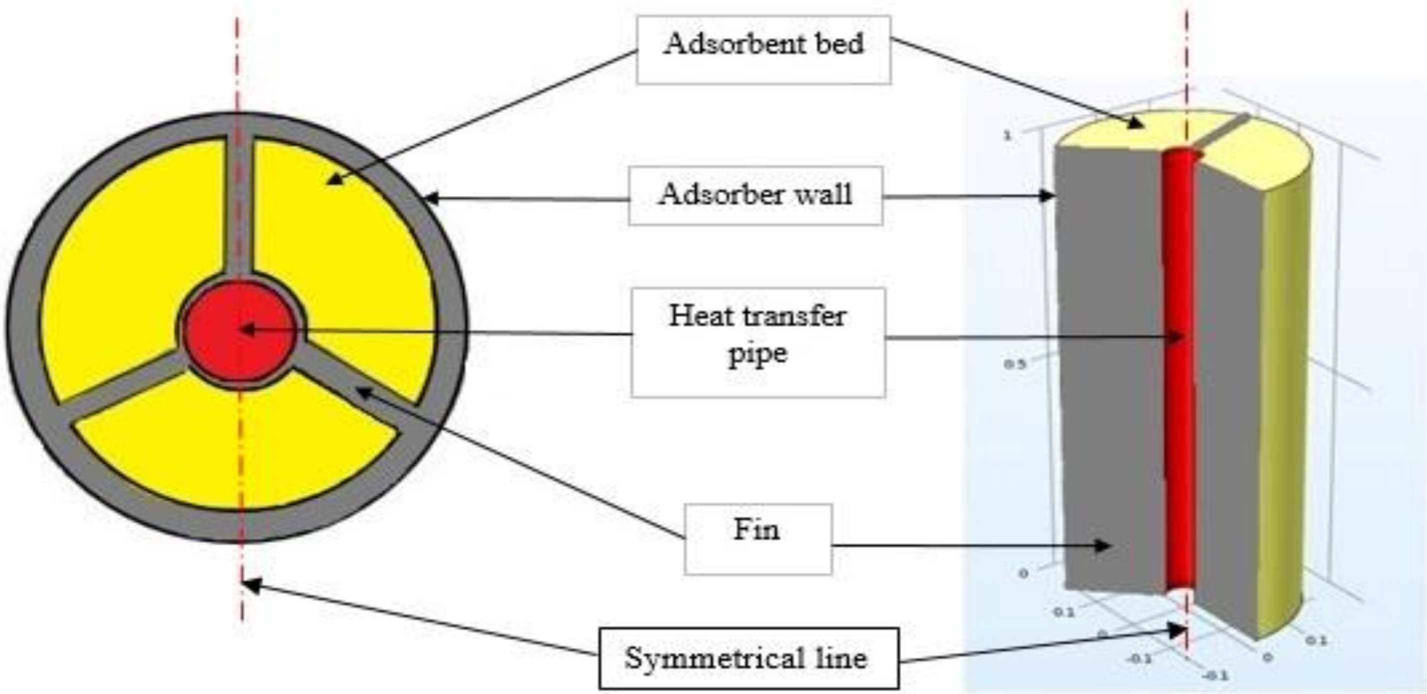


Fig. 6: Cross-sectional of adsorber reactor with three fins configuration

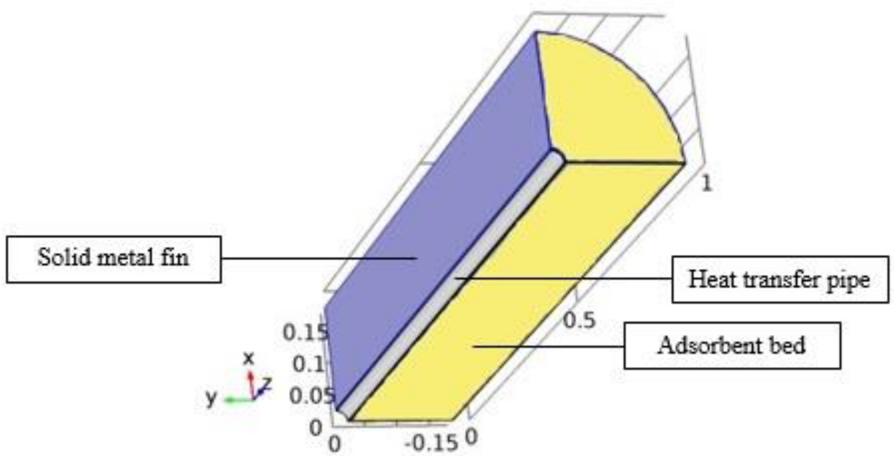
Adsorber Reactor Optimization

Governing equations

- Convection, conduction, and mass transfer

- Heat transfer in solid fins

$$q_{htp} = -kT_{htp}$$



- Heat and mass transfer in porous media

$$\left[(1-\varepsilon)\rho_{ads}c_{ads} + (\varepsilon+\alpha)\rho_{ref}c_{ref} + \alpha\rho_{adsorbed}c_{adsorbed}\right]\frac{\partial T}{\partial t} = [\lambda_e\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}] + \frac{\partial}{\partial t}\left[(\varepsilon-\alpha)\rho_{ref}\right]\frac{P}{\rho_g} + \frac{1}{2\pi r dr}\left(\frac{P}{\rho_{adsorbed}} + \Delta H_{ads}\right)\left(\frac{\partial m_{adsorbed}}{\partial t}\right)$$

- Reaction rate

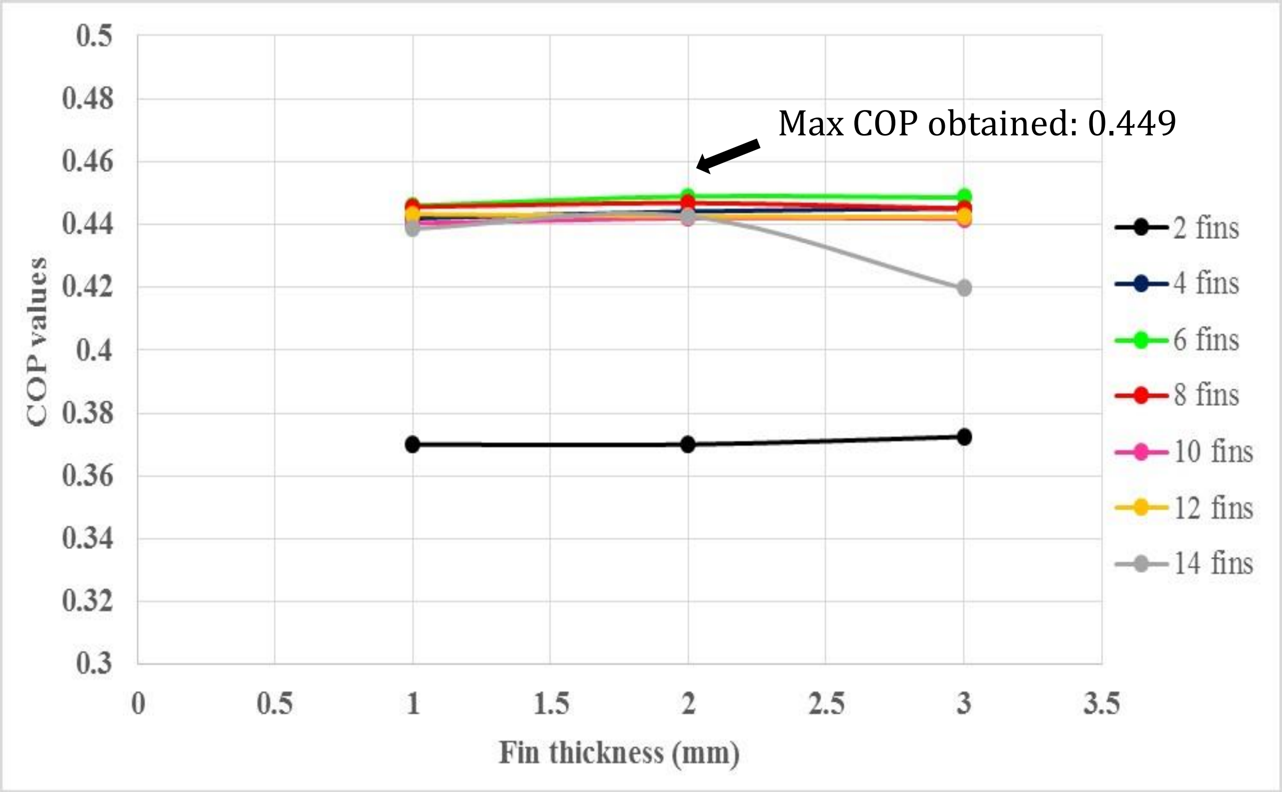
$$R_X = (1-\varepsilon)\rho_{ads}\frac{\partial X}{\partial t}$$

- Darcy's law

$$\upsilon = -\frac{\kappa}{\mu}\Delta \mathrm{P}$$

Findings

- COP of the systems in adsorber reactor with fins configuration



- The higher the number of fins, the better the COP obtained.
- The adsorber with 6 fins of having 2 mm thickness shows the highest improved COP of 0.449.

Conclusions

- Finless adsorber reactor simulation suffers from a low COP of the system due to temperature gradient inside the adsorbent bed.
- Low heat transfer cause a low system performance.
- Too many fins configuration reduce the COP. Extra heat is required to change the fin material temperature.
- The adsorber with 6 fins of having 2 mm thickness shows the highest improved COP of 0.4489, from finless COP of 0.266.
- Nevertheless, this value obtained is still lower than that of the theoretical COP, 0.618.

THANK YOU