Performance Analysis of Membrane Contactors Integrated into Absorber of Absorption Cooling Systems

Dr. Faisal Asfand

Power Engineering Centre
School of Water, Energy and Environment (SWEE)
Cranfield University, Bedfordshire, UK

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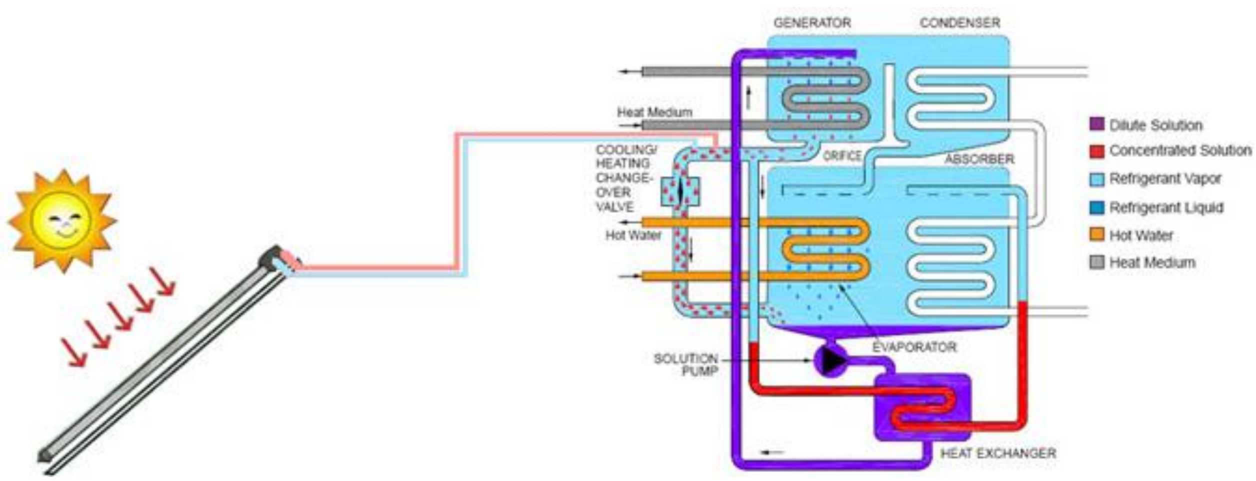
1.1 Introduction: Absorption Technology

Absorption refrigeration technology is gaining global acceptance because of

- Environmental friendly working fluid mixtures
- Do not contribute to ozone depletion and greenhouse effects
- Ability to efficiently utilize the renewable energy sources
- Does not depend on the costly mechanical energy

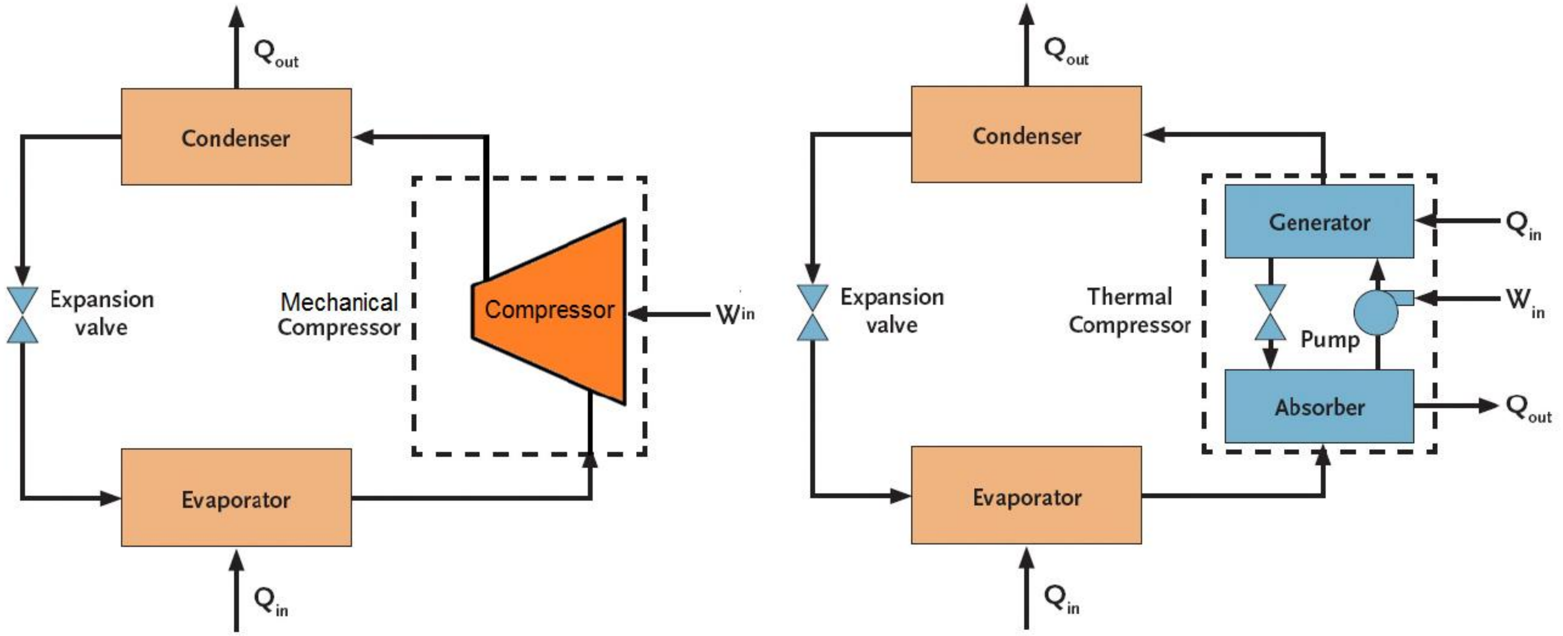
The absorption becomes attractive in specific applications when there are possibilities to use waste heat or thermal energy from renewable energy sources.



1.2 Introduction: Working Principle

In the absorption cycle, the role of the mechanical compressor in compression cycle is replaced by "thermal compressor" which consists of generator, absorber, solution heat exchanger, solution pump and throttling valve.

The "thermal" compressor of the absorption cycle uses a heat-driven concentration difference to move refrigerant vapour from the evaporator to the condenser.



Compression and absorption refrigeration cycles

2. Objectives & Methodology

The **main objective** of this work was to investigate the heat and mass transfer performance of a **membrane-based absorber** to **achieve a compact absorber** for absorption cooling systems.

Following objectives were accomplished in this work.

- ❑ **Developing a steady-state detailed numerical model** using CFD approach.
  - ➢ A CFD based solver was used to develop a **2-D numerical model** to carry out a detailed heat and mass transfer analysis.
- ❑ **Developing a steady-state** global model.
  - ➢ A steady-state **global model** was developed to investigate the effect of different operating and design parameters on the absorption performance.
- ❑ Both numerical models were **validated with the available literature data** and steady-state analyses were performed.

3.1 Membrane Contactors

Membranes can act as a **semipermeable barrier** to separate components or it can be used as a contactor between two components to enhance the absorption of a gas or vapour molecules in the absorbent.

Membrane contactors can be effectively utilized in the components of absorption refrigeration systems in order to design **compact components.**

Microporous membranes offer **higher area to volume ratio** which make it possible to provide enormous surface area to enhance heat and mass transfer processes in the membrane based components.

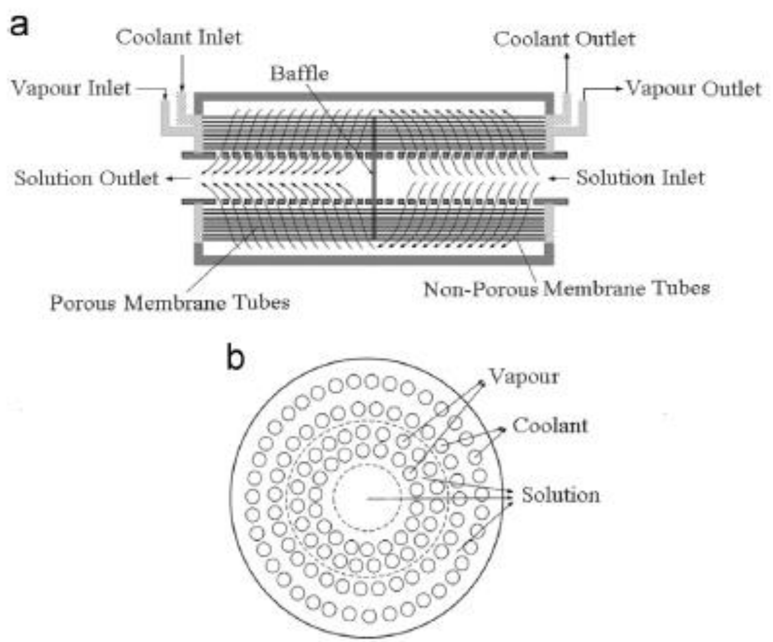
Membrane materials are **non-corrosive** and **compatible** with most of the materials and working fluids.

Hollow fibre membrane module and **plate-and-frame membrane modules** are the types most widely investigated in absorption refrigeration systems.

3.2 Membrane Contactors: Configuration

Plate-and-frame and hollow fibre membrane modules are mainly investigated for water-LiBr and ammonia-water working fluid mixtures, respectively.

The driving force for the refrigerant mass transfer in the case of ammonia-water and water-LiBr solutions is considered to be the difference in concentration and water vapour partial pressure, respectively.



Hollow fibre membrane module

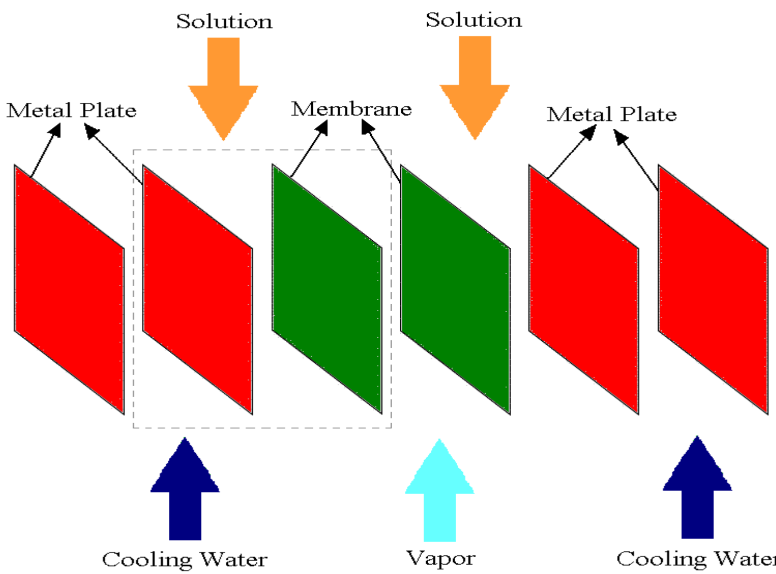


Plate-and-frame membrane module

4. Detailed numerical model

Numerical simulations were performed to study in detail the fluid dynamics behaviour and heat and mass transfer processes at local level.

Commercial code ANSYS/FLUENT which employs a finite volume approach to discretize the governing Navier-Stokes equations into a set of linear equations was used.

The continuity, momentum, energy and species transport equations were solved to perform steady-state heat and mass transfer analyses.

The effect of important parameters such as solution channel thickness, mass flow rate and coolant temperature on the absorption performance was evaluated.

Temperature, solution concentration , pressure profiles and thermophysical properties at local level along the channel length were studied in detail.

4.1 Absorber Configuration

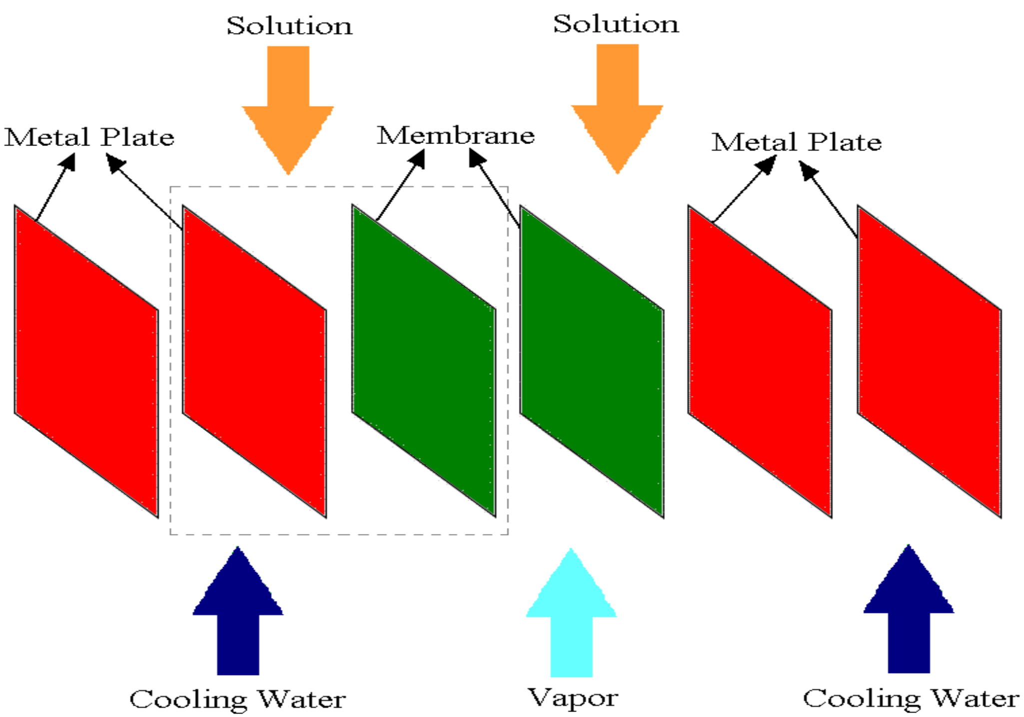
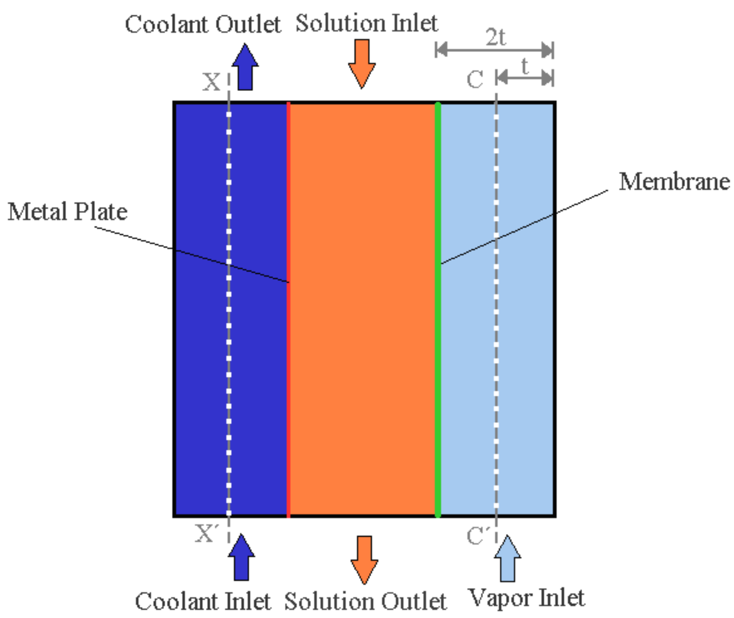


Plate-and-frame absorber configuration with membrane contactor



Single unit of the plate-and-frame absorber

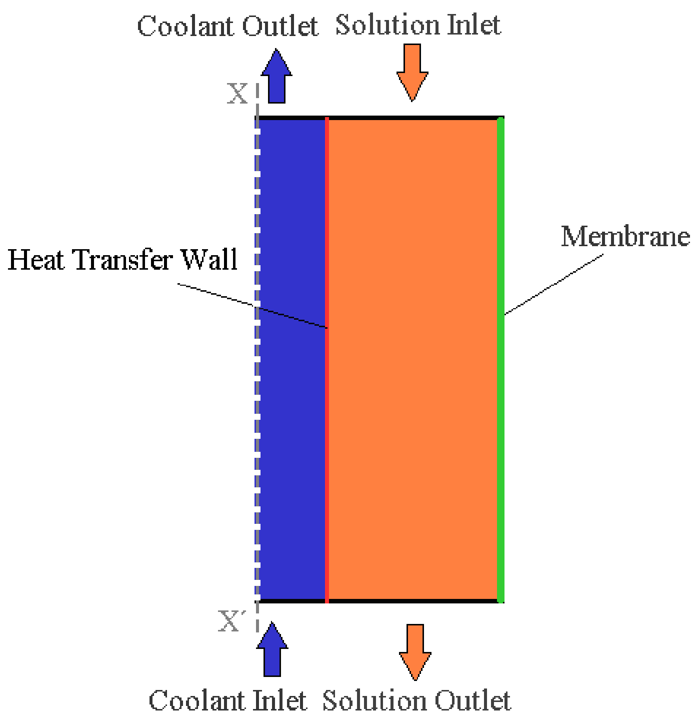
4.2 Computational Domain

A two-dimensional model was developed to simulate the flow, heat and mass transfer phenomena in a single unit of the plate-and-frame membrane module.

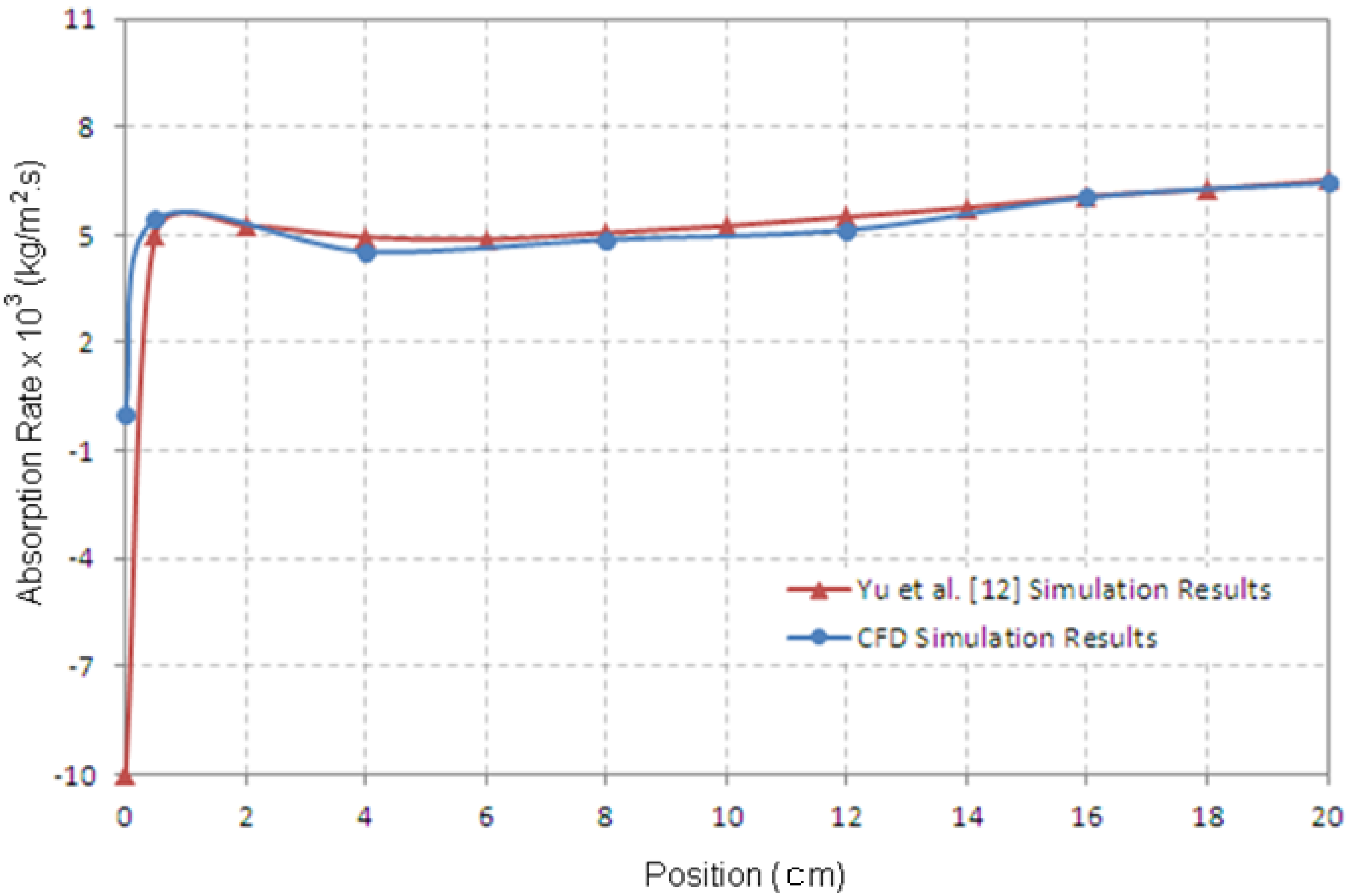
The heat transfer plate between the solution and coolant is considered as a wall boundary condition.

Symmetric boundary conditions are considered on the left side of the coolant flow channel to reduce the computational efforts.

The continuity, momentum, energy and species transport equations are solved to perform steady-state heat and mass transfer analyses.



4.3 Validation of the Detailed Numerical Model



Validation of detail numerical model with the literature results using water/LiBr

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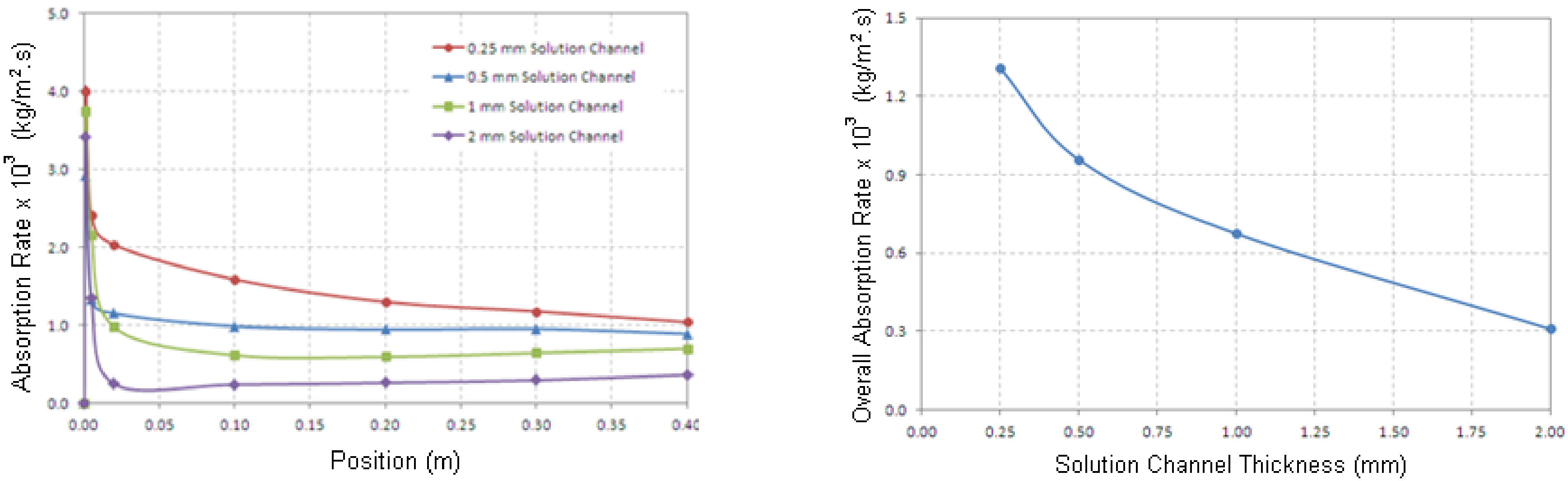
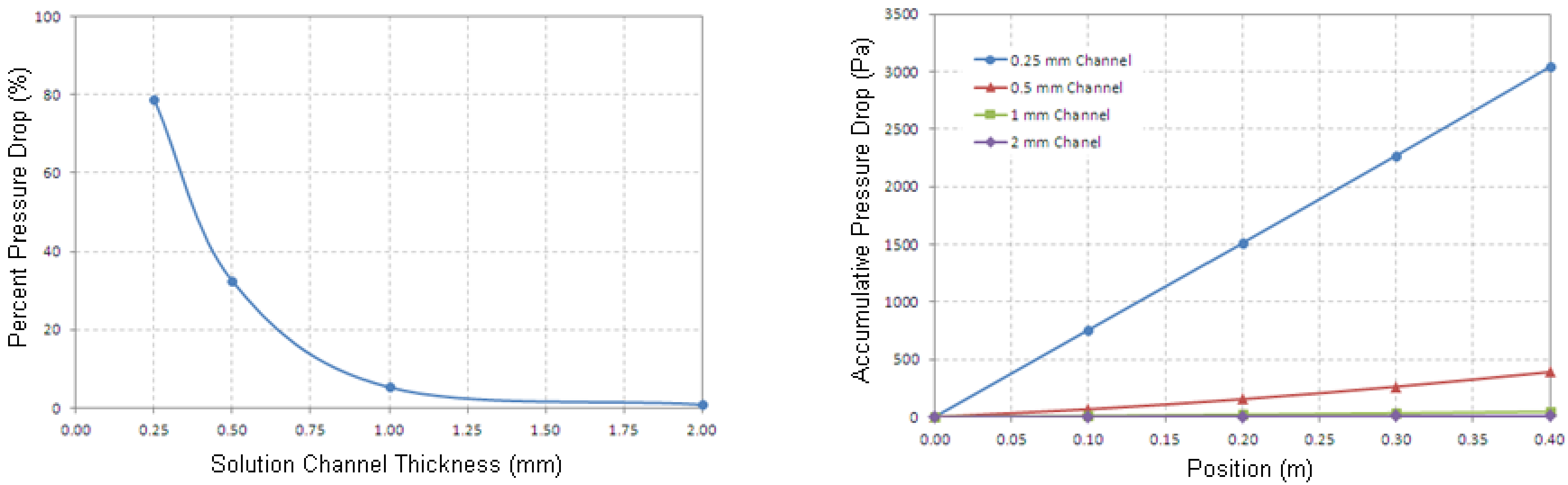
4.4 Results: Effect of Solution Channel Thickness

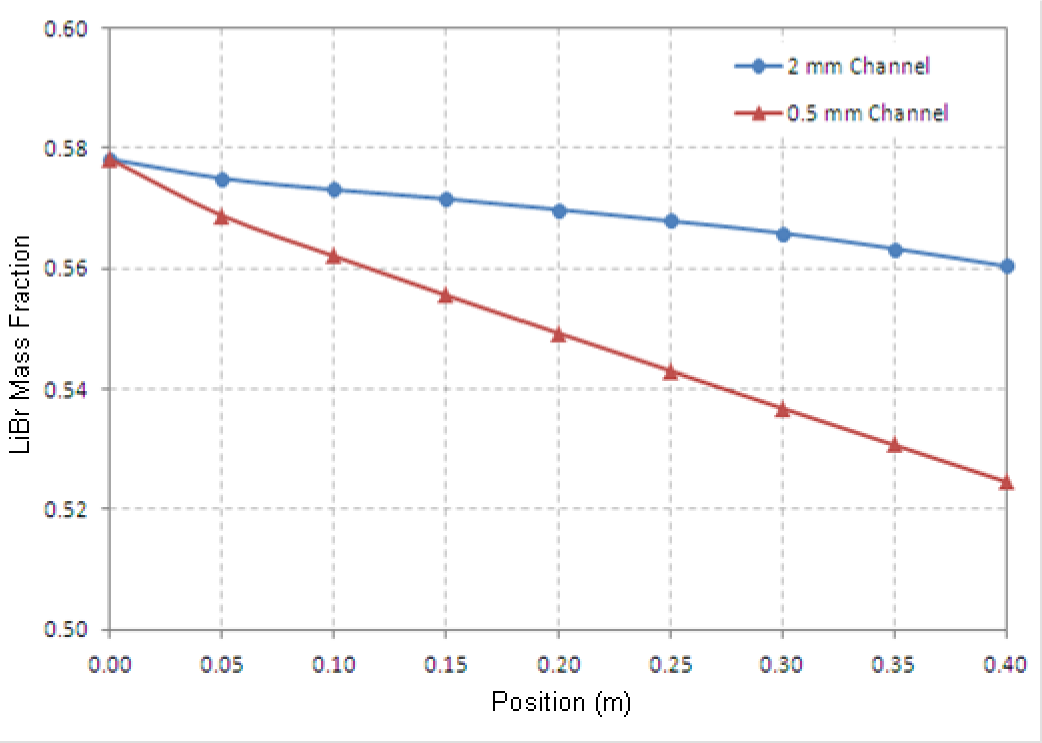


Effect of the solution channel thickness on the absorption rate along the channel

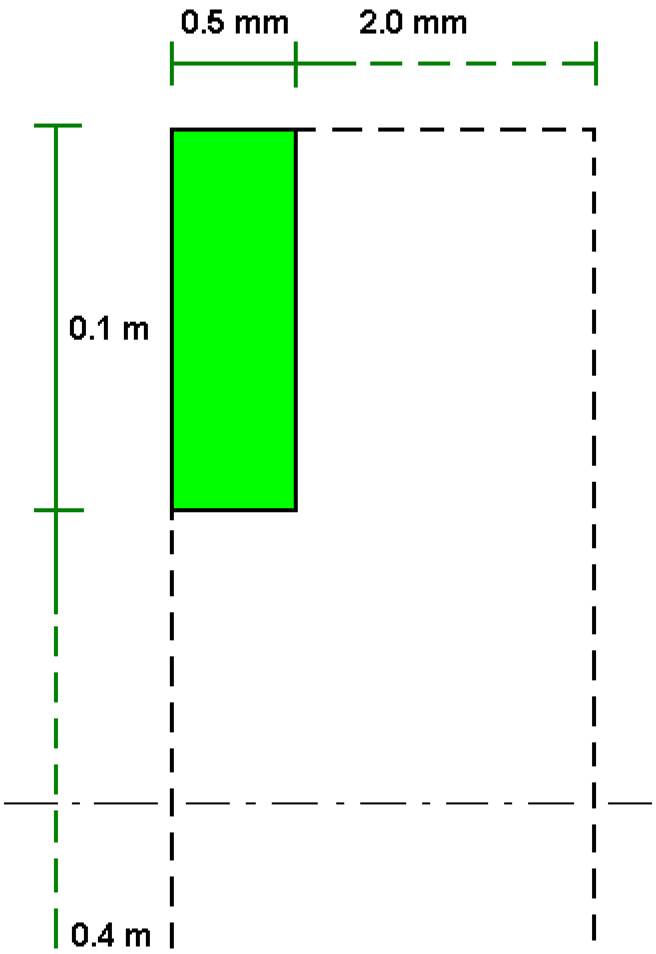


Effect of the solution channel thickness on the pressure drop

4.4 Results: Effect of Solution Channel Thickness on the Absorber Size



Concentration profiles in the bulk solution along the 0.5 mm and 2 mm solution channels



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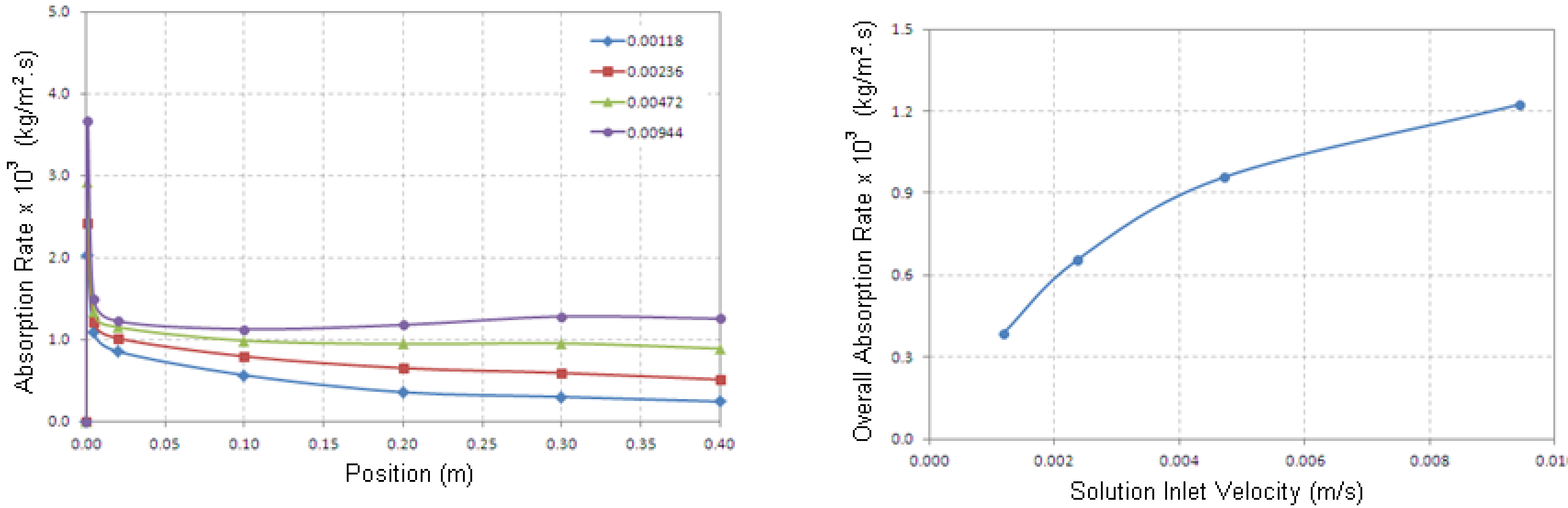
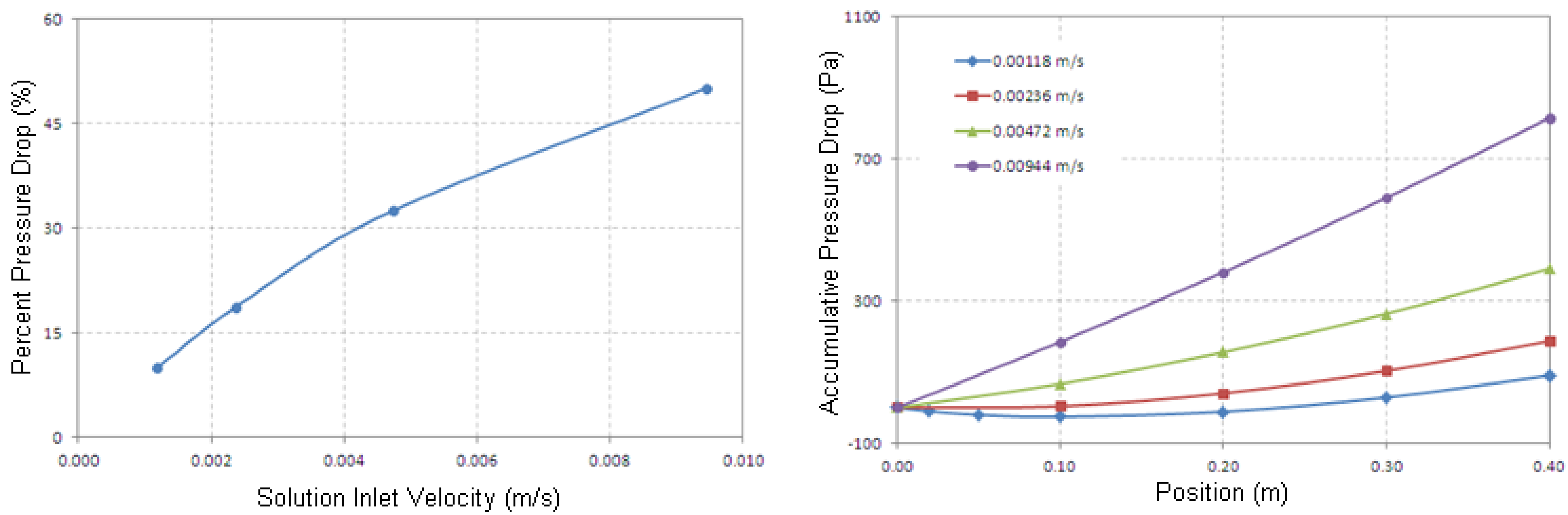
4.4 Results: Effect of Solution Flow Velocity

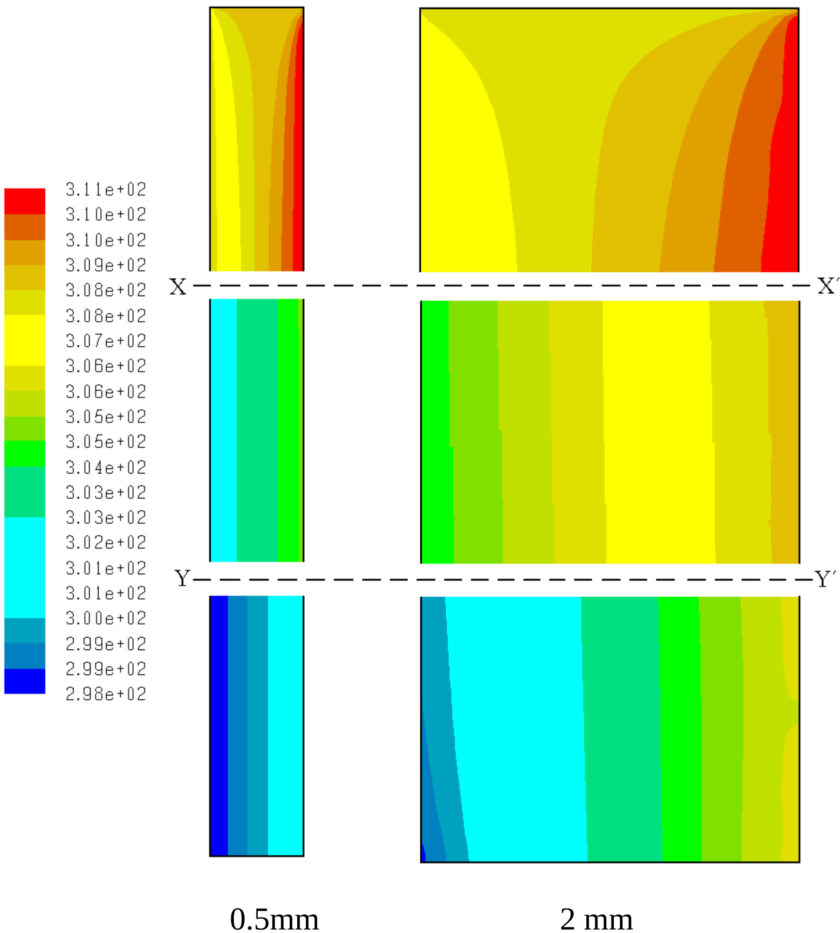


Effect of the solution flow velocity on the absorption rate along the channel

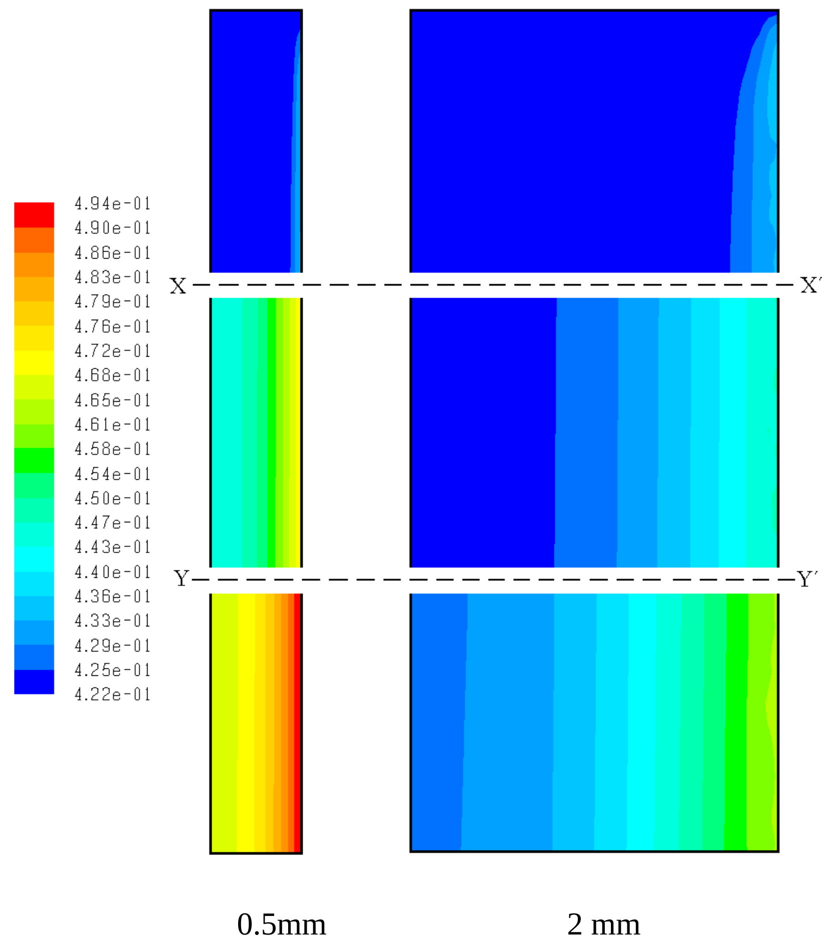


Effect of the solution flow velocity on the pressure drop

4.4 Results: Solution Temperature & Concentration Profiles



Solution temperature profile along the channel

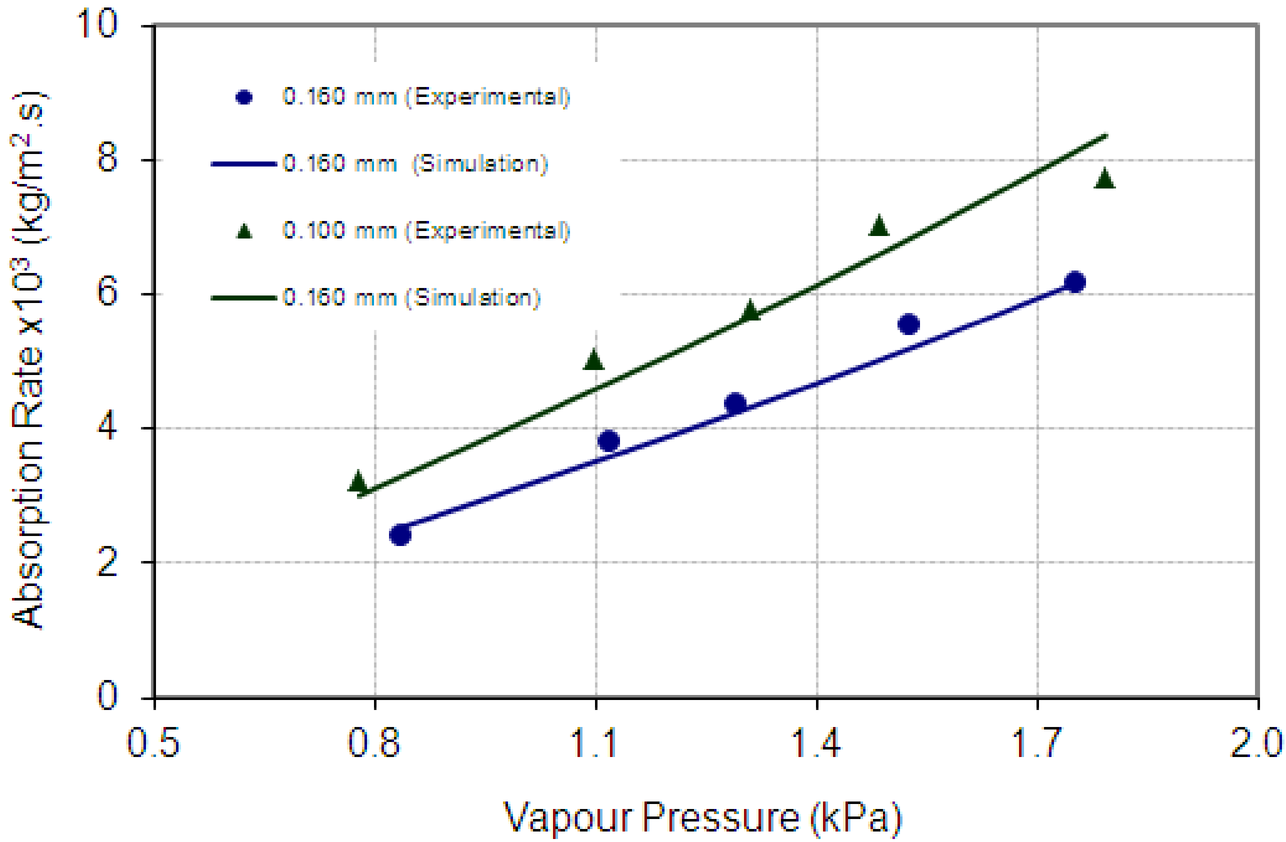


Mass fraction of refrigerant (water) in the solution

5. Global Numerical Model

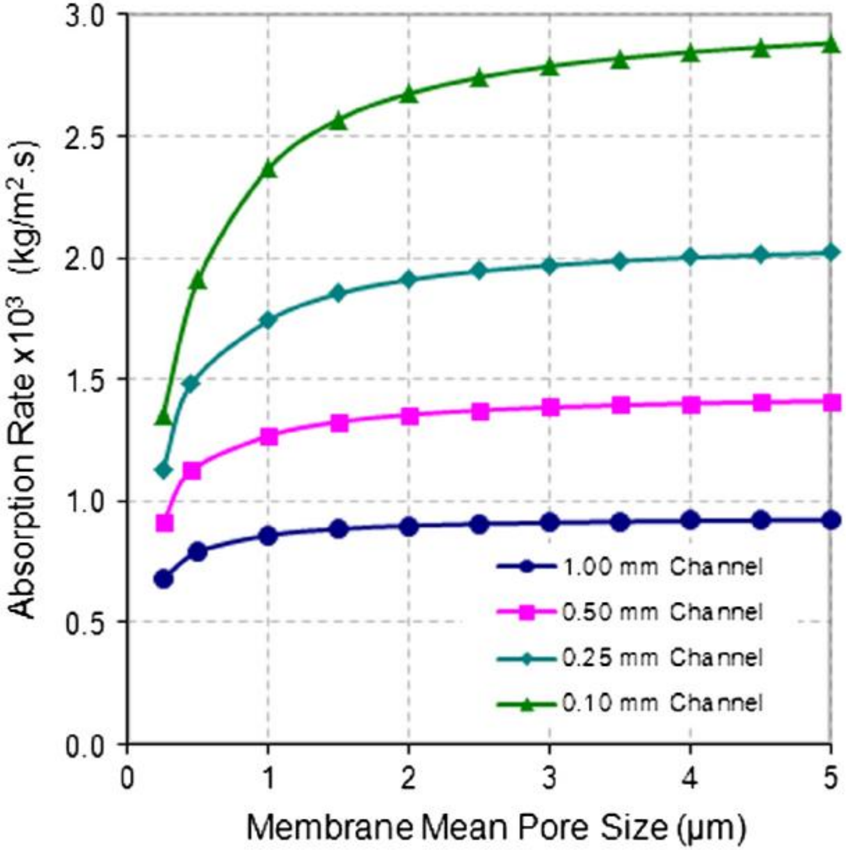
- **Coupled heat and mass transfer** model was developed in **MATLAB code.**
- **Energy and mass balance equations** were solved in each cell along the channel.
- Each channel was **discretized into 200 cells** along the length and a convergence criterion of 2×10^{-07} was used to obtain steady-state converged solution.
- The governing non-linear and differential equations were solved simultaneously in each cell using the **Newton-Raphson method and finite difference method,** respectively.
- Following **assumptions** were considered in the analytical model for the simulation
  - Steady state conditions.
  - One dimensional transfer in the flow direction along the length.
  - No heat losses to/or gained from the surroundings to the absorber cells.

5.1 Validation of the Global Numerical Model

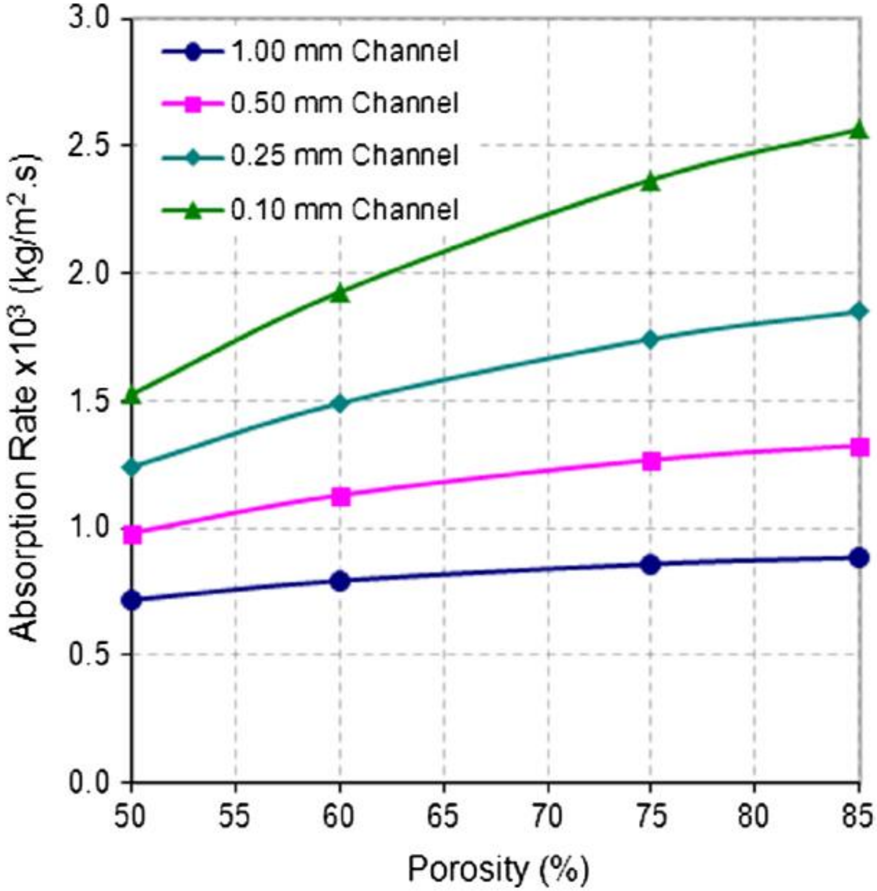


Validation of global numerical model with the literature results using water/LiBr

5.2 Results: Effect of membrane characteristics on the absorption performance

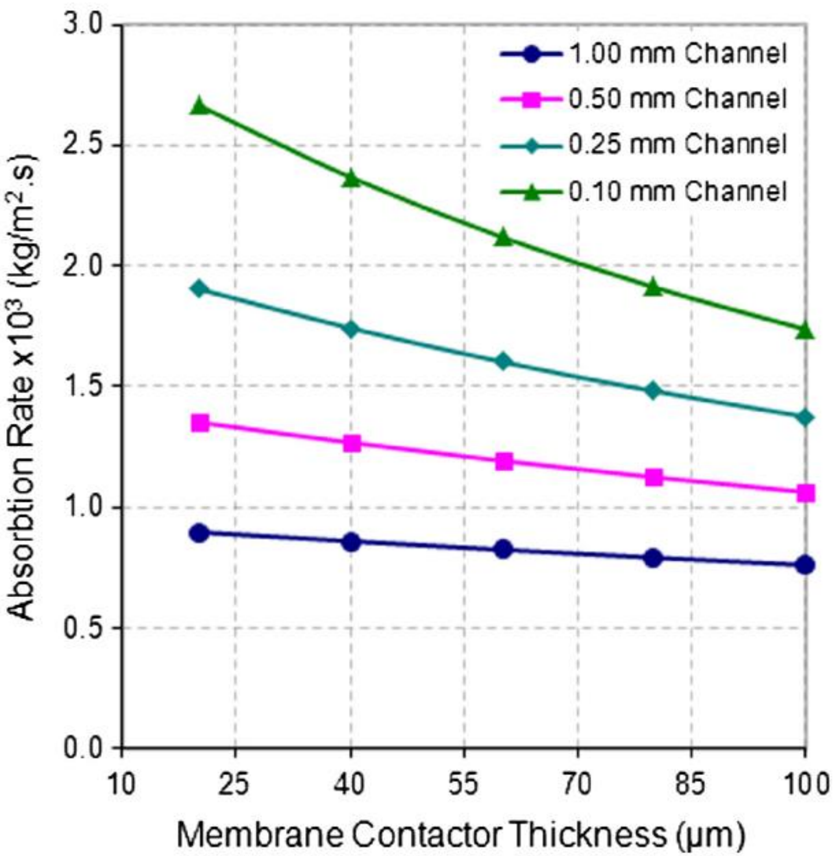


Effect of membrane mean pore size

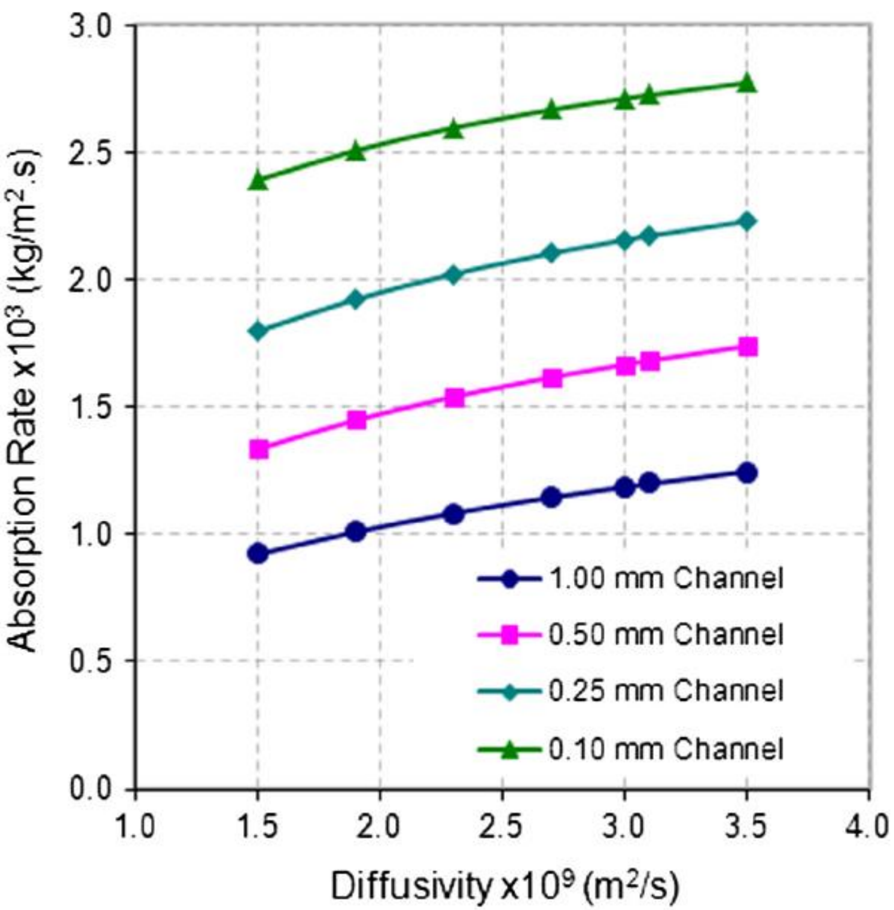


Effect of membrane porosity

5.2 Results: Effect of membrane characteristics on the absorption performance



Effect of membrane thickness



Effect of solution diffusivity

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6. Conclusions

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- The current research lead to the development of an advanced absorber which would be more **efficient, compact and competitive.**

- Very promising application are **transport sector, residential buildings and small scale** applications.

- Velocity and solution film thickness can be **independently controlled** in plate-and-frame membrane absorbers which can allow design of compact absorbers with enhanced heat and mass transfer.

- A **three-fold increase** in the absorption rate is achievable when the solution channel thickness is **reduced from 2 mm to 0.5 mm.**

- More than **50% increase** in the absorption rate is possible if the solution **masflow rate is doubled.**

- The solution **pressure drop** along the channel **increases exponentially** with decrease in solution channel thickness and increases linearly with increase in solution mass flow rate.

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6. Conclusions

- It is concluded from the results that the **membrane characteristics do not effect significantly on the absorption performance**.

- Membrane characteristics have a less prominent effect on the absorption rate and the **solution resistance** is the **dominant resistance** in refrigerant mass transfer in the case of thicker solution channels.

- For a plate-and-frame membrane configuration where the solution channel thickness is around 0.5 mm, a compromise can be made to select a membrane contactor with characteristics that will not negatively affect the mechanical strength of the membrane.

- It is recommended that the membrane contactor with a **pore size between 0.5 µm and 1 µm, a thickness in the range of 40 µm to 80 µm and porosity in the range of 70% to 80%** should be selected to achieve higher absorption rate with enhanced mechanical strength.

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7. Future Work

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- Further research is needed to explore the **long term operation** consequences of membrane contactors in absorption and desorption processes.
- **Fouling** of membrane contactors means that more need for research is necessary with regard to absorption refrigeration components employing membrane contactors, so that durability and life span cost of the absorption refrigeration system can be evaluated more precisely.
- Membrane contactor **surface properties** need to be studied further for more efficient use in absorption refrigeration components.
- Membrane contactor modules are available in different types hence, membrane modules other then plate-and-frame membrane module and hollow fiber module should also be investigated.
- Numerical analysis of **membrane based desorber** to investigate in detail the fluid dynamics behaviour and heat and mass transfer mechanisms both in **direct diffusion mode and boiling mode.**

Acknowledgement

I am thankful to the ‘British Council’ and ‘National Natural Science Foundation of China for granting me the opportunity to attend this workshop.