D2.3 Simulation library with documentation

THEGREEFA

Thermochemical fluids in greenhouse farming
Rev 01

DISCLAIMER

Document references

Project Acronym	**TheGreefa**
Project Title	**Thermochemical fluids in greenhouse farming**
Project Coordinator	**Serena Danesi (ZHAW)**
Project Duration	**October 2020 – May 2024 (44 months)**

Deliverable No./Title	**D2.3 Simulation library with documentation**
Important Notice	**The full library is available online:** https://doi.org/10.5281/zenodo.12755245
Dissemination level [1]	**PU**
Work Package	**WP2**
Task	**Task 2.2 and Task 2.3**
Lead beneficiary	**LUH**
Contributing beneficiary(ies)	**ALL**
Due date of deliverable	**30/05/2024**
Actual submission date	**12/07/2024**

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Short description of contents and/or changes
0	12/07/2024	LUH	First release
0.1	09/10/2024	LUH	Clarified distinction between FDM method and statistical regression.

Contents

 This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

1. Introduction

This project is to develop a comprehensive absorber system for dehumidification of greenhouse coping the high temperature and humidity situation of greenhouse. Controlling humidity levels in greenhouses is crucial for optimizing plant growth, preventing diseases, and improving overall crop yields. By effectively dehumidifying the air, the absorber system helps maintain an optimal environment for plant development. In this task, an absorber system model composed of absorber model, controller, pump/fan and some other auxiliary equipment are established in the Dymola environment with Modelica language. The focus of this simulation is on an absorber model that utilizes a magnesium chloride solution for air dehumidification. The model is constructed based on the finite difference method, ensuring accurate representation of the physical processes involved in mass and heat transfer within the absorber. In this deliverable, the modelling library are listed and described including the fundamental physical equations used in main components and validation of them. Besides, library package name and usage introduction are also presented.

The Scope of this documentation covers the following areas:

- Detailed descriptions of the absorber model and its mathematical foundations.
- Descriptions of related models essential for the operation of the absorber system.
- An overview of the complete absorber system, including the control system.
- Guidance on extending the library to incorporate new features or models.

2. Component model descriptions

The simulation library developed for this project serves as a comprehensive tool for modelling and simulating an absorber system designed for air dehumidification in agricultural greenhouses. This section provides a general overview of the various models incorporated into the library, emphasizing their interconnected roles and the underlying principles that govern their behaviours. The core objective of this simulation library is to provide a robust framework for analysing and optimizing the performance of an absorber system. The absorber uses a magnesium chloride solution to effectively remove moisture from the air, thereby maintaining optimal humidity levels within a greenhouse. The models included in this library cover various aspects of the absorber system, from the physical and chemical processes involved in dehumidification to the control mechanisms required to maintain system stability and efficiency. The component models are listed in the table 1 including component name, icon, general description and source.

2.1 Library structure

The model of absorber, controller, system and other auxiliary models are presented in this document. In this section, the usage instruction is presented to help other engineers and researchers on using this model library. The library structure is shown in Fig. 1, which includes all of the models described in this report. Firstly, the ‘Fluid’ section includes the absorber model, where the dimension and various parameters can be tailored for your own absorber. Then the ‘ConModules’ is set for controller and its sub components, such as transition layer, time table, ordinary step model and etc. The last one is ‘media’ including the medium function for various properties change with different conditions, such as temperature, composition and pressure.

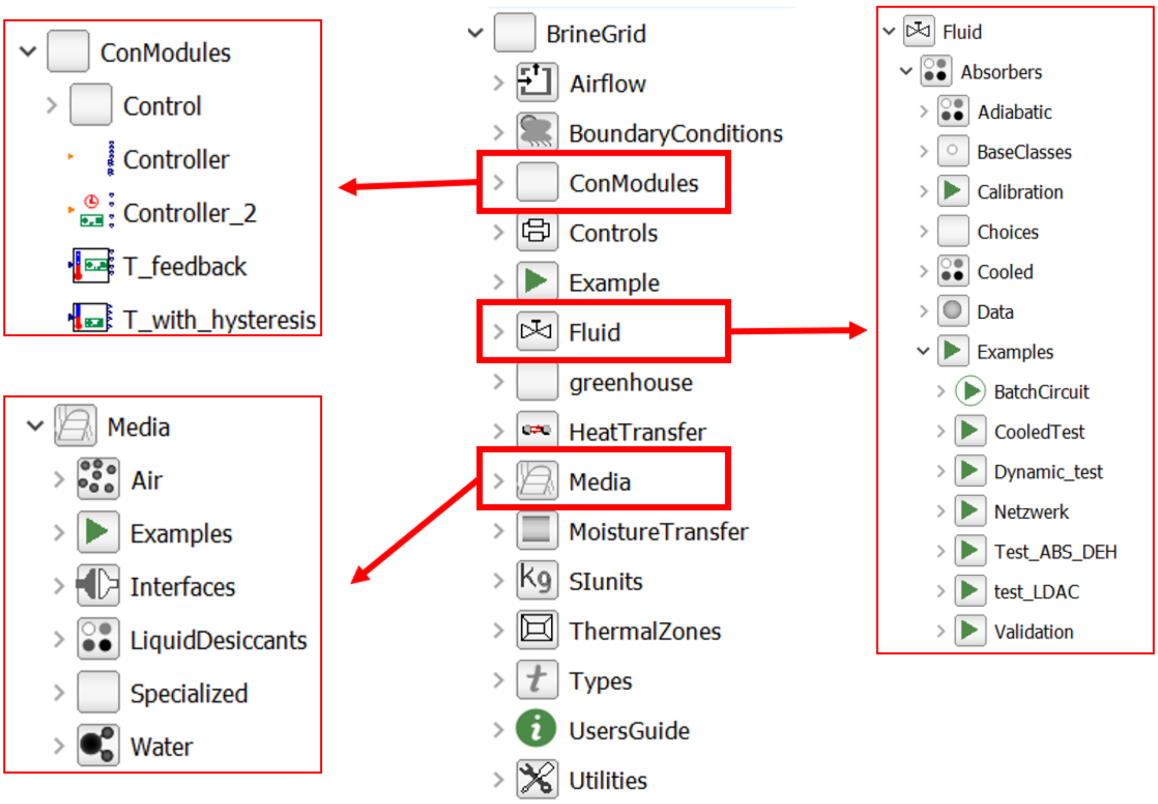


Fig. 1. Library structure of main part of model

2.2 List of component models

The component models are listed below corresponding to the context in table 1.

Modelica absorber model: This component was modelled by a finite volume model, with a counter-flow configuration, it was developed by Fürst and Kriegel [1]. The model was based on correlations developed for heat and mass transfer coefficients derived from experimental data. The theories and some core equations adapted in this model are explained in the next chapter. This absorber model is available in BrineGrid library[1].

Modelica TCF models: The dynamic medium Modelica model of $MgCl_2$–H_2O mixture was developed in H-DisNet project [2]. The experimental equations for the thermodynamic properties of temperature, concentration, and enthalpy were already validated in H-DisNet. The thermodynamic properties do not only depend on the pressure and temperature, but mostly on the composition. As the compositions changes significantly during absorption, very accurate media models are needed. This TCF models are available in BrineGrid library [1].

Modelica humid air source model: The parameters for air and solution used in the model are all from the demonstrator in Tunisia. The temperature and humidity range of air is 25℃ - 55℃ and 35% - 95%. The temperature range of solution is 25℃ - 42℃.

Controller: The controller is developed to achieve 3-stage control for absorber system based on the finite state machine, which is a mathematical model used to represent a system with a finite number of states and the transitions between those states. It was widely used in computer science, control systems, compiler design, network protocols, and various other fields. This controller model is consisted of some components including Initial step, Transition and Root of a StateGraph. These components are available in Modelica library [3]. The detailed control strategy is explained in the system model part.

Modelica fan/pump model: The fan and pump models are for a centrifugal pump or fan with ideally controlled mass flow rate or pressure. They are already available in the Modelica Buildings library [4].

Modelica temperature sensor: The Ideal Two-Port Temperature Sensor in Dymola measures the temperature of the medium flowing between its two fluid ports without influencing the fluid. It provides accurate temperature readings essential for system monitoring and control. This sensor is designed for integration into various thermal-fluid systems to ensure reliable performance.

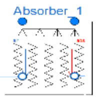
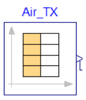
Modelica mass fraction sensor: The Ideal Two-Port Mass Fraction Sensor in Dymola measures the mass fraction of a specific substance in the medium flowing between its two fluid ports without affecting the fluid. It ensures accurate monitoring of composition in multi-substance or trace-substance flows. This sensor is essential for precise system analysis and control.

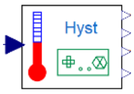
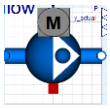
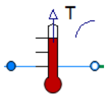
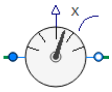
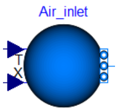
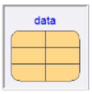
Source of inlet boundary: The Boundary with Prescribed Pressure, Temperature, Composition, and Trace Substances in Dymola defines specific values for these parameters at system boundaries. It allows precise control of boundary conditions for pressure, temperature, and composition, including trace substances. This component is crucial for accurate simulation and analysis of thermal-fluid systems.

Outlet boundary: that boundary temperature, density, specific enthalpy, mass fractions and trace substances have only an effect if the mass flow is from the Boundary into the port. If mass is flowing from the port into the boundary, the boundary definitions, with exception of boundary pressure, do not have an effect.

Absorber geometry data: This package contains geometrical data of real absorbers. The parameters include dimensions (length, width, height and diameter), equivalent of diameter, specific area and void fraction.

Table 1. Component model description

Name	Icon	Description	Source
Modelica absorber model		Absorber model bases on the finite difference method depicting heat and mass transfer behaviour inside the absorption process.	Developed by BrineGrid [1] and further improved
$MgCl_2$	$MgCl_2$	The solution model employs experimental thermodynamic property equations that account for variations in temperature and concentration.	Developed by BrineGrid [1] and further improved
humid air source		Time-series based temperature and mass fraction for inlet boundary from demonstrator experiment.	Developed in Modelica library [3]

Controller		Controller model bases on the finite state machine implementing 3-stage strategy of system.	Developed in The Greefa
Pump/fan		Pump and fan used to define the mass flow rate of air and solution.	Developed in Building library [4]
Temperature sensor		This model measures the temperature of the medium flowing between its fluid ports. The sensor does not affect the fluid.	Developed in Building library [4]
Mass fraction sensor		This model measures the mass fraction of the air and solution flowing between its fluid ports. The sensor does not affect the fluid.	Developed in Buildings library [4]
source of inlet boundary		The source of inlet boundary defines prescribed values for boundary conditions for inlet of air and solution, including boundary pressure, boundary temperature, and boundary composition (applicable only for multi-substance or trace-substance flow).	Developed in Buildings library [4]
Boundary of outlet		The source of out boundary defines prescribed values for boundary conditions for inlet of air and solution, including boundary pressure, boundary temperature, and boundary composition (applicable only for multi-substance or trace-substance flow).	Developed in Buildings library [4]
Absorber geometry data		Geometry data includes dimensions and other parameters.	Developed by The Greefa

2.3 Absorber model

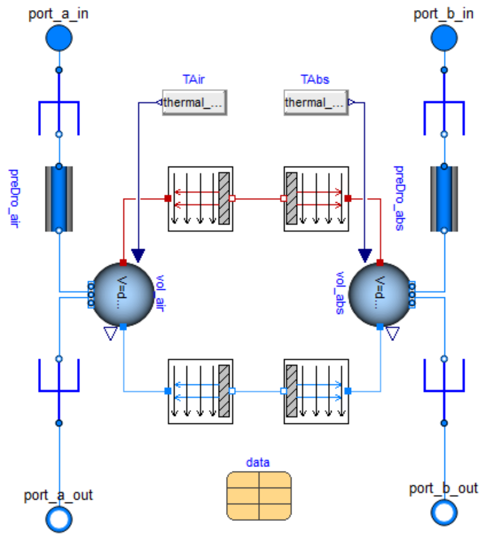


Fig. 2 Absorber model

The primary absorber model was constructed by Fürst and Kriegel [1] using mathematical and physical modelling, with parameters characterizing the absorber's geometry and structure. However, due to the complexity of describing the processes and interaction surfaces, the heat and mass transfer processes were not physically simulated in detail. Consequently, the absorber model is physically simulated with Finite Difference Method (FDM). The heat and mass transfer are calibrated and determined by using a statistical regression approach, without needing to know the details of the processes.

FFDM is a numerical technique used to solve continuous differential equations numerically. Its fundamental principle involves discretizing the continuous solution domain into a set of grid points and using difference formulas to approximate the derivatives in the differential equations. This method converts the differential equations into algebraic equations, which can then be solved using numerical techniques. Specifically, to create the absorber model, the described flow models need to be interconnected. The connections and quantities of these flow models depend on the flow configuration. In a counter flow configuration, a single flow model is used for both the moist air and the liquid desiccant. Fig. 3 illustrates the connections of the flow models with a discretization of n = 4. The fluids enter at the first node and exit at the last one, with heat and mass being exchanged at each node.

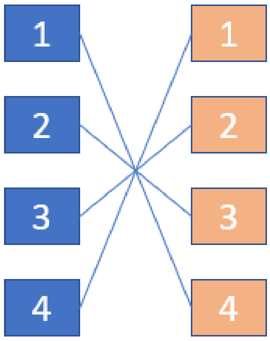


Fig. 3. Discretization counter current flow configuration (n =4 as example)

Figure 2 shows the absorber Modelica model scheme, which contains the main component models that describe the heat and mass transfer between the TCF and air. Before presenting the physical equations and theories employed in this absorber model, the assumptions are explained firstly:

- Throughout the heat and mass transfer process, the air and solution do not exchange heat with the external environment, assuming that the dehumidifier/regenerator is adiabatic.
- In the elemental control model, the thermal and physical parameters of air and solution (temperature, humidity, specific heat, concentration) are assumed to be uniform.
- The solution is uniformly infiltrated into the packing material, ensuring that the surface of the packing is completely wetted, and it is assumed that the heat and mass transfer area between air and solution are consistent.

The heat and mass transfer are described in these equations:

$$\dot{Q} = \alpha \cdot A \cdot \Delta T \ (1)$$

$$\dot{m} = \beta \cdot A \cdot \Delta X \ (2)$$

α and β are respectively the heat and mass transfer coefficients, which are defined by experimental data. A is the contact area of air and solution. $\dot{Q}$ and $\dot{m}$ are heat flow and mass flow between solution and air. ΔT and ΔX are the temperature difference and mass difference between air and solution, respectively. The logarithmic mean temperature/mass fraction difference method (LMSD/LMMD) is a calculation technique borrowed from heat transfer studies of adiabatic heat exchange processes between two fluids. It uses the logarithmic mean temperature difference of the solution and air at the

inlet and outlet of the control volume to replace the average heat transfer temperature difference in the coupled heat transfer process. The equations are shown as follows.
Current flow:

$$\Delta T = \frac{(T_{a,in} - T_{s,in}) - (T_{a,out} - T_{s,out})}{\ln \frac{(T_{a,in} - T_{s,in})}{(T_{a,out} - T_{s,out})}} \ (3)$$

$$\Delta X = \frac{(X_{a,in} - X_{s,in}) - (X_{a,out} - X_{s,out})}{\ln \frac{(X_{a,in} - X_{s,in})}{(X_{a,out} - X_{s,out})}} \ (4)$$

Counter flow and cross flow:

$$\Delta T = \frac{(T_{a,in} - T_{s,out}) - (T_{a,out} - T_{s,in})}{\ln \frac{(T_{a,in} - T_{s,out})}{(T_{a,out} - T_{s,in})}} \ (5)$$

$$\Delta X = \frac{(X_{a,in} - X_{s,out}) - (X_{a,out} - X_{s,in})}{\ln \frac{(X_{a,in} - X_{s,out})}{(X_{a,out} - X_{s,in})}} \ (6)$$

$\dot{Q}$ and $\dot{m}$ are heat and mass flow from air to solution or from solution to air. However, in this case, it is difficult to directly get these two values, so air is selected as a research object to determine the $\dot{Q}$ and $\dot{m}$ by calculating the heat and mass change of air inlet and air outlet of absorber based on equation (7)(8).

$$\dot{Q} = C_p \cdot m_{air} \cdot \left(T_{air,in} - T_{air,out}\right) \ (7)$$

$$\dot{m} = L_v \cdot m_{air} \cdot \left(X_{air,in} - X_{air,out}\right) \ (8)$$

Where C_p is heat capacity of air (kJ/kg·°C). L_v is latent heat of vaporization (kJ/kg) with respect to temperature. m_{air} is air flow rate (kg/s) inside absorber.

3. System model

The system simulation is based on Modelica language, which supports object-oriented declarative modelling methods of ordinary differential equations, allowing the use of classes and inheritance to create modular and reusable models of dynamic systems. Models can be extended and modified through inheritance, which helps in organizing and managing complex systems [3]. This absorber system model is composed of two parts, thermo-chemical (TC) part and air-side part. The main components of the TC model are the absorber, solution tank and pump. The air-side part includes greenhouse model, air fan and control system, etc.

The system model is established based on the structure and control strategy used in Tunisia demonstrator built by partners shown in Fig. 4. This absorber system is consisted of a small absorber and a big absorber in parallel structure. Each of absorber is equipped with a fan and a pump, as well as temperature and mass fraction sensors. The dimensions and parameters of two absorbers are shown in the Table 2. The component Air_TX and Solution_T are used to accept the measured data from Tunisia demonstrator as input parameters and boundary conditions containing the temperature and humidity of inlet air and inlet solution. Then the simulation data is compared with experimental data to validate the system model and control strategy. Last but not least, a controller based on the finite state machine is developed to achieve the control strategy employed in Tunisia demonstrator. The strategy is a three-stage control shown in Table. 3.

Table 2. Parameters of absorber

Type	Small absorber	Big absorber
Length (m)	0.84	1.68
Width (m)	0.7	0.7
Height (m)	1.0	1.0
Equivalent diameter (m)	0.0026	0.0026
Specific area (m^2/m^3)	246	246
Void fraction (%)	92	92

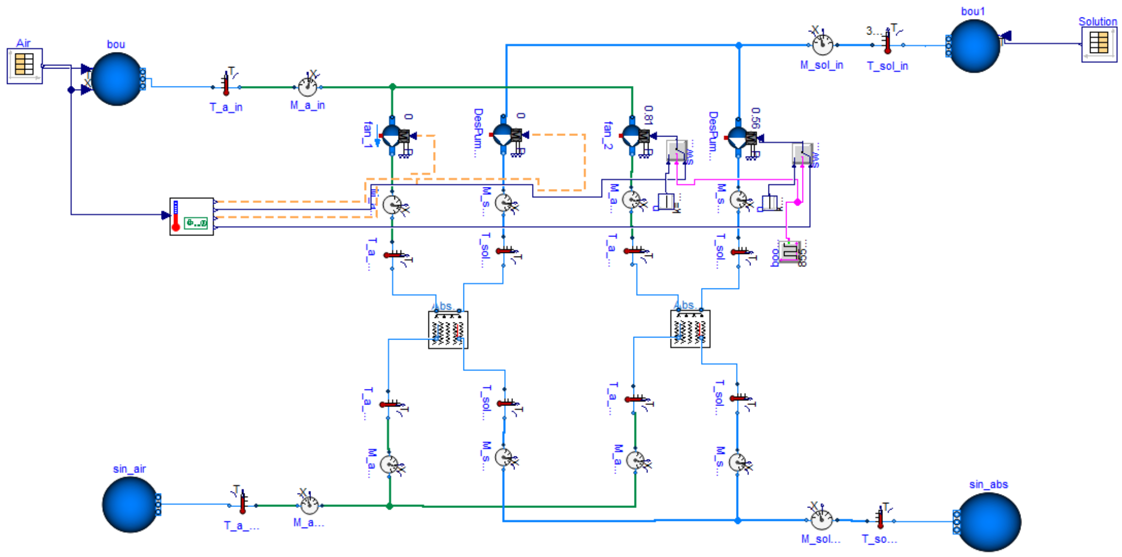


Fig. 4. System model with controller
(This is a system model including inlet and outlet of air and solution, one small absorber, one big absorber, two pumps, two fans, one controller and some humidity and temperature sensors)

3.1 Control strategy

The demonstrator in Tunisia is developed with absorber and control system for greenhouse. The absorber is similar to that described above. The innovative point is the control strategy shown in Table 4. There are two size absorbers, fans and pumps. When the greenhouse temperature is low then 39℃, all the fan and pump are off, which called 0 stage. The first stage will start at 39℃, and stop at 38.5℃. The second stage will start at 41℃, and stop at 39.5℃. The third stage will start at 42℃, and stop at 41.5℃. The difference between the start temperature and stop temperature introducing the hysteresis effect is for avoid vibration of the system. The control box for system monitoring is presented in Fig. 7.

Table 3. Control strategy

Stage	Trigger temperature (℃)	Stop temperature (℃)	Small Fan (kg/s)	Large Fan (kg/s)	Small Pump (kg/s)	Large pump (kg/s)
0	<39	N/A	Off	Off	Off	Off
1	39	38.5	On	Off	On	Off
2	41	39.5	Off	On	Off	On
3	42	41.5	On	On	On	On

Fig. 5. Control box

Reference

[1] Fürst Y, Kriegel M. ADIABATIC ABSORBER MODEL FOR THE LIQUID DESICCANT DISTRIBUTION NETWORK AT THE TECHNOLOGY PARK BERLIN ADLERSHOF USING MODELICA. n.d.

[2] Intelligent Hybrid Thermo-Chemical District Networks. Https://Www.h-DisnetEu/ n.d.

[3] https://modelica.org/language/. Modelica n.d.

[4] Modelica Buildings Library. Https://SimulationresearchLblGov/Modelica/ n.d.

[5] Chen Y, Zhang X, Yin Y. Experimental and theoretical analysis of liquid desiccant dehumidification process based on an advanced hybrid air-conditioning system. Appl Therm Eng 2016;98:387–99. https://doi.org/10.1016/j.applthermaleng.2015.12.066.

 This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.