

Mathematical Modeling of Rotating Sorption Heat Storages

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Abstract

This paper focusses on developing a mathematical model for a seasonal thermal storage system based on sorptive materials. The storage has the shape of a continuously rotating drum and is filled with Zeolite as thermochemical storage material. The mathematical model is a particular realization of a model used to describe fixed bed reactors. The aim of the model is to use it in finding optimal operating strategies for an entire heating system. The resulting model consists of four coupled linear, constant coefficient differential equations. The simulation study presented here highlights the differences in operating conditions between a rotating drum reactor and a fixed bed storage system.

Keywords: sorption, seasonal storage, mathematical model

1. Introduction

In the current energetic scenario, it is crucial to store the large supply of solar energy available during summer and use it during winter, when the accessible quantity of energy is decreased. A seasonal storage system with both, high energy density and low thermal losses, is needed. Energy storage systems based on thermo-chemical materials like zeolite, such as the one developed in this study, are the most adequate option to achieve this goal, due to its potential to fulfill both of the requirements earlier described.

Efficient storage of heat is essential for solar thermal domestic heating systems in regions of the world with distinct weather periods. In large parts of Europe for example, space heating can be accomplished with solar installations of reasonable size in spring and autumn, however, the delivered heat is too less for comfortable heating in winter time while the abundant energy of the summer period is lost. Sorption storages offer the possibility to store heat over long periods without losses as long as they are kept dry. In an ongoing research project [OFFSORE] the development of such a seasonal heat storage system along with the required process technology is investigated.

The system here investigated is based on the concept of sorption, which is the phenomenon of fixation or capture of a gas or vapor (sorbate) by a substance in condensed state (solid or liquid) called sorbent and divided into absorption and adsorption processes [Tarik Kousksou et al., 2014].

Absorption is as a process in which molecules of a liquid or gaseous substance enters a solid or a liquid, changing its arrangement. The basic difference between absorption and adsorption is, that in the former there is the penetration of sorbate molecules into the sorbent material, while in the latter the interconnection between sorbent and sorbate is a surface based physical interconnection in the inter-facial layer [Mohamed Bachet, 2018].

Adsorption, on the other hand, is described as the binding of a gas or liquid phase of a substance on a surface of a solid or porous material, which creates a film of the adsorbate on the surface of the adsorbent. Adsorption processes are present in several physical, biological, natural and chemical systems and are widely used in industrial applications, for example, capturing and using waste heat to provide cold water for air conditioning (adsorption chillers), heterogeneous catalysis and water purification [Stavros Poupoulos et al., 2006]. Some applications of adsorption processes in closed and open storage systems are presented in the following sessions.

1.1. Closed systems recent applications

In a closed system, the reactor is under vacuum condition, in other words, isolated from the atmospheric environment, and consequently requires one or more condensers and evaporators. The entire system is sealed from the surroundings and only water can flow through the conduct passage that connects the reactor to the evaporator/condenser. The reactor contains the reactive sorbent and the condenser/evaporator is where the liquid water is collected.

A recent application is the HYDES project, in which, Günter Gartler et al., 2003, Andreas Hauer, 2007 and W. Wagner et al., 2003 developed a closed adsorption system with silica gel-H₂O as the working pair suitable for the long-term storage of low temperature heat. In this project, storage units combined with solar collectors were used as storage system and each storage unit had an absorber with an integrated heat exchanger, which was connected through a valve to a combined evaporator/condenser unit.

The subsequent project of HYDES was the MODESTORE project in which the storage prototype was improved by combining the condenser/evaporator in a single casing, presenting a better performance and a more compact design. The reactor consists of spiral heat exchangers with silica gel and a free channel in the center used for vapor diffusion [Dagmar Jähnig et al., 2006, Chris Bales et al., 2008].

1.2. Open systems recent applications

In an open system the reactor containing the sorbent material is at atmospheric pressure. One of the advantages of open systems is that they do not require the use of condensers, evaporators or working fluid storage reservoirs, having this way a simpler and cheaper design when compared to closed systems. Also, since the heat transfer fluid (air) is in direct contact with the solid reactant this system presents better heat and mass transfer conditions, while in closed systems the heat is transferred mainly by conduction, since this system configuration has a separate heat transfer loop and therefore, a heat exchanger in the reactor. The disadvantage of open systems is that they may experience a high (electric) energy consumption for overcoming pressure losses in the reactor [Gorazd Krese et al., 2018].

Among the recent applications is the MONOSORP prototype, which is an open adsorption heat storage system that uses zeolite 4A and water as adsorption pair and was developed for space heating in buildings [MONOSORP, 2006].

Within SolSpaces (a follow-up project of MONOSORP) a new solar heating system that includes an adsorption storage for seasonal energy storage with binderless zeolite 13X as adsorbent, was developed. The storage was subdivided into several segments to provide a better thermal performance. This system presents the same concept as the MONOSORP project, but it uses air solar collectors, which eliminates the need for a water to air heat exchanger and in the reactor, a packed bed of zeolite spheres is used instead of the honeycomb monoliths as in the MONOSORP project [Rebecca Weber et al., 2016].

1.3. Sorption storage systems alternatives

Regarding the physical storage principle, sorption storage systems are under the category thermo-chemical heat storage. Some alternatives for these systems are the sensible heat storage and the latent heat storage systems.

Briefly explaining, sensible heat storage utilizes the energy that was stored during a temperature change in the material, which can be in a solid or liquid form, and does not involve a material phase change during the process. The amount of heat stored depends on specific heat capacity, volume, material density, and the temperature variation. The most common sensible heat storage materials are water, thermal oils, liquid metals, earth materials and concrete blocks. It is desirable that the storage material has a high specific heat capacity, long term stability under the thermal cycling, good compatibility with its container and low cost [Lavinia Socaciu, 2012].

In the latent heat storage systems, on the other hand, the energy storage results from a change in phase of the material, which usually is from solid to liquid (fusion) or from liquid to vapor (vaporization). These materials are called phase change materials (PCM) and the phase change happens, theoretically, at an exact temperature point for pure PCM. One of the main advantages of the latent heat storage is the capacity to store a great amount of energy with a small temperature change, hence have a high storage density, and one of the major drawbacks is the poor thermal conductivity [Lavinia Socaciu, 2012].

2. Mathematical Model

The basis of the numerical model developed in this work is an open sorption storage system with a fixed zeolite 13XBF bed as discussed in [Barbara Mette, 2014]. An axial humid air flow drives the sorption process and allows direct charging/discharging of the sorption material. The cylindrical storage is divided into cylindrical segments (nodes) for numerical simulation purposes. The axial heat conduction between two neighbored store nodes is modeled using λ_{ax} , which represents the effective axial heat conductivity of the storage material. In order to perform the numerical simulations, the model is based on the following assumptions:

- The model assumes a one-dimensional approach, where no radial influence is considered
- A homogeneous model for storage material and air flow is used, i.e., it is assumed that the air leaves each store node with the node temperature $T_S(i)$, where (i) represents the node number
- The specific heat capacities of the solid and air are not function of the humidity or of the temperature in the system
- The sorption equilibrium is modelled by the Dubinin-Astakhov-approach and the reaction kinetics is described by a linear driving force ansatz.
- The specific heat capacity of the air is not a function of the humidity or of the temperature in the system; the specific heat capacity of the solid is only a function of humidity (water loading) but not of the temperature in the system.

The underlying assumption when modeling a rotating drum instead of a static cylinder is that the material is always ideally mixed. This means the water uptake of the material is equal for all particles, therefore the heat generated is also equal. Under this assumption, we can approximate the rotating drum by the model for a fixed bed with using just a single node. A multinode fixed bed model for open sorption processes was developed by IGTE within the SolSpaces project and implemented in the simulation software TRNSYS [Sebastian Asenbeck, 2016]. For the current research work presented here, the model has been re-implemented in MATLAB/Simulink™ by the ASIC team. Table 1 presents the variables used in the following equations adopted in the model.

2.1. Main equations

Table 1: Parameters Table

Parameter	Unit	Meaning
X_S	kg/kg	Water uptake of store node
m_{G0}	kg/h	Dry gas mass flow rate
M_{S0}	kg	dry mass of storage material
X_{Gin}	kg/kg	absolute humidity of inlet gas flow
X_{Gout}	kg/kg	absolute humidity of outlet gas ow
ρ_{S0}	Kg/m ³	Mean density of dry adsorbent material
A_S	m ²	Airflow cross sectional area
T_S	°C	Temperature of store node
T_{brd}	°C	Border temperature
cp_{S0}	kJ/kg/K	specific heat capacity of the dry zeolite
cp_{S1}	kJ/kg/K	specific heat capacity of the adsorbed humidity
l	m	Node length
K_{LDF}	1/s	Kinetic factor
t	h	Time
C_{border}	kJ/K	Thermal mass of store border node

As previously explained, the one node model with a fixed bed is used to approximate a rotating drum in this study. On the other hand, a multiple nodes model is used to replicate a cylindrical fixed bed reactor. The main differences between the equations used to describe these models will be now further detailed. In order to give a general view of the process, Figure 1 displays a simplified sketch of the storage system including the fluxes behavior and the subdivision into nodes. With multiple nodes, the system's equations will present slight differences depending on, in which node they are being implemented. For all the intermediate nodes, the

equations are always the same, but some terms will differ when compared to the equations employed in the input and output nodes. Each section will present the general equations and discuss how they are implemented in the one node and multiple nodes approaches as well as the differences between them.

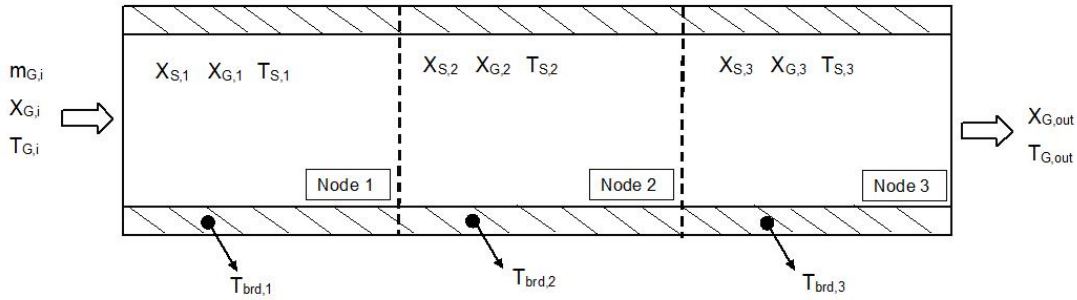


Figure 1: Sorption storage system simplified sketch

- Water mass balance within the storage material:

(Eq. 1) represents the temporal change of the water loading of the zeolite due to the adsorption or desorption processes. In other words, it represents the reaction rate, also characterized by the symbol m_{ads} and is implemented as follows for the one node model:

$$\frac{dX_S}{dt} = \frac{mG0}{M_{S0}} * (X_{Gin} - X_{Gout}) \quad (\text{Eq. 1})$$

Multiple nodes model: Regarding the input node, the (Eq. 1) is implemented as previously stated, but for the intermediate and for the output node, the absolute humidity of outlet gas flow (X_{Gout}) from one node becomes the absolute humidity of inlet gas flow (X_{Gin}) for the subsequent node ($X_{Gout}(i-1) = X_{Gin}(i)$). Thus, (Eq. 1) can be rewritten as follows:

$$\frac{dX_S}{dt} = \frac{mG0}{M_{S0}} * (X_{Gout}(i-1) - X_{Gout}(i)) \quad (\text{Eq. 2})$$

- Air humidity along the node length

(Eq. 3) results in the air humidity at the outlet of the store node (X_{Gout}) that allows the calculation of the reaction rate (m_{ads}), which measures how fast the water mass flow is adsorbed from the air flow.

$$\frac{dxG}{dl} = \frac{\rho_{S0} * A_S}{mG0} * K_{LDF} * (X_S - X_{S,eq}) \quad (\text{Eq. 3})$$

For the one node model and for all the nodes included in the multiple nodes model (input, intermediate and output), the calculation of the air humidity along the node length will remain the same, hence, (Eq. 3) is implemented in all the models as previously presented.

- Energy Balance Equations

(Eq. 4) represents the heat transfer in the system. It can be noticed that the specific heat capacity of the zeolite is divided into two terms: the specific heat capacity of the dry zeolite ($cpS0$) and the specific heat capacity of the adsorbed humidity ($cpS1$). For both terms a constant value was assumed in this model.

$$\frac{dT_S}{dt} = \frac{\Sigma dQS}{(M_{S0} * cpS0 + M_{S0} * xS * cpS1)} \quad (\text{Eq. 4})$$

Where ΣdQS represents the sum of the heat ow rates into the store node (i), and can generically be expressed by (Eq. 5):

$$\Sigma dQS = dQ_{brd} + dQ_G + dQ_{ax}(i) - dQ_{ax}(i+1) + dQ_{ads} \quad (\text{Eq. 5})$$

Where dQ_{brd} corresponds to the heat flow from the border node to the store node, dQ_G is the sensible heat gas flow into the store node, dQ_{ax} is the axial heat flow coming from the neighbor store node and dQ_{ads} represents the heat of the reaction.

A second energy balance equation takes into account the store border temperature heat transfer and can be expressed by (Eq. 6). Where $dQ_{ax,brd}$ is the axial heat flow, in the borders of the nodes coming from the neighbor store node and dQ_{amb} represents the heat loss from the system to the ambient.

$$\frac{dT_{brd}}{dt} = \frac{[dQ_{ax,brd}(i) - dQ_{ax,brd}(i+1) - dQ_{amb} - dQ_{brd}]}{C_{border}} \quad (\text{Eq. 6})$$

It is important to notice that all heat flows (UA-values) are related to the length of one node only and for simplicity the index (i) is skipped here. (Eq. 7) express the axial heat flow coming from the left neighbor store node.

$$dQ_{ax}(i) = UA_{ax} \cdot (T_S(i-1) - T_S(i)) \quad (\text{Eq. 7})$$

(Eq. 8) represents the axial heat flow, in the borders of the nodes, coming from the left neighbor store node.

$$dQ_{ax,brd}(i) = UA_{ax,brd} \cdot (T_{brd}(i-1) - T_{brd}(i)) \quad (\text{Eq. 8})$$

Where $UA_{ax,brd}$ is the effective axial heat transfer rate between two border nodes:

$$UA_{ax,brd} = \frac{\lambda_{ax,brd}}{L_{node}} \cdot A_{brd} \quad (\text{Eq. 9})$$

(Eq. 10) represents the heat of the reaction, where the heat of adsorption h_{ads} is approximated to a mean value and kept constant during the simulations.

$$dQ_{ads} = m_{ads} \cdot h_{ads} = m_{Go} \cdot (X_{Gin} - X_{Gout}) \cdot h_{ads} \quad (\text{Eq. 10})$$

The sensible heat gas flow into the store node is described by (Eq. 11), in which T_{Gin} is the gas temperature entering the store node.

$$dQ_G = m_{Go} \cdot cp_G \cdot ((1 + X_{Gin})T_{Gin} - (1 + X_{Gout})T_S) \quad (\text{Eq. 11})$$

(Eq. 12) corresponds to the heat flow from the border node to the store node and UA_{brd} represents the effective heat transfer rate from storage material to border

$$dQ_{brd} = UA_{brd} \cdot (T_{brd} - T_S) \quad (\text{Eq. 12})$$

(Eq. 13) calculates the heat loss from the system to the ambient, and UA_{amb} express the heat loss rate.

$$dQ_{amb} = UA_{amb} \cdot (T_{brd} - T_{amb}) \quad (\text{Eq. 13})$$

One node model: In this approach, since the system is formed by one node only, there will be no axial heat being transported from one node to the other, thus, the axial components ($dQ_{ax}(i)$ and $dQ_{ax}(i+1)$) in the sum of the heat flow rates (Eq. 5) are disregarded. Hence, (Eq. 5) is implemented in the model as showed below:

$$\Sigma dQS = dQ_{brd} + dQ_G + dQ_{ads} \quad (\text{Eq. 14})$$

Regarding the second balance equation (Eq. 6) once again the axial components are neglected. After replacing (Eq. 12) and (Eq. 13) into (Eq. 6), it will be expressed as follows:

$$\frac{dT_{brd}}{dt} = \frac{[-UA_{amb} \cdot (T_{brd} - T_{amb}) - UA_{brd} \cdot (T_{brd} - T_S)]}{C_{border}} \quad (\text{Eq. 15})$$

Multiple node model: Since the system is subdivided into several nodes, (Eq. 6) and (Eq. 7) will present different terms depending on the node in which it is applied:

- Input node: the term $dQ_{ax,brd}(i)$ will be neglected and (Eq. 6) will be written as:

$$\frac{dT_{brd}}{dt} = \frac{[-UA_{amb} \cdot (T_{brd} - T_{amb}) - UA_{brd} \cdot (T_{brd} - T_S) - UA_{ax,brd} \cdot (T_{brd}(i) - T_{brd}(i+1))]}{C_{border}} \quad (\text{Eq. 16})$$

$$dQ_{ax}(i) = -UA_{ax} \cdot (T_S(i) - T_S(i+1)) \quad (\text{Eq. 17})$$

- Intermediate node: For this node, axial heat and axial border heat are coming into and out of the store node from the previous and subsequent nodes respectively. Thus, (Eq. 6) and (Eq. 7) are defined as below:

$$\frac{dT_{brd}}{dt} = \frac{1}{C_{border}} \cdot [-UA_{amb} \cdot (T_{brd} - T_{amb}) - UA_{brd} \cdot (T_{brd} - T_S) + UA_{ax,brd} \cdot (T_{brd}(i-1) - T_{brd}(i)) - UA_{ax,brd} \cdot (T_{brd}(i) - T_{brd}(i+1))] \quad (\text{Eq. 18})$$

$$dQ_{ax}(i) = UA_{ax} \cdot (T_S(i-1) - T_S(i)) - UA_{ax} \cdot (T_S(i) - T_S(i+1)) \quad (\text{Eq. 19})$$

- Output node: Regarding the last node, axial heat and axial border heat are only coming into the store node from the preceding node, hence, (Eq. 6) and (Eq. 7) can be expressed as follows:

$$\frac{dT_{brd}}{dt} = \frac{1}{C_{border}} \cdot [-UA_{amb} \cdot (T_{brd} - T_{amb}) - UA_{brd} \cdot (T_{brd} - T_S) + UA_{ax,brd} \cdot (T_{brd}(i-1) - T_{brd}(i))] \quad (\text{Eq. 20})$$

Regarding (Eq. 7) the only difference will be that this node presents the axial heat and the axial border heat only coming out of it, thus only a negative sign will be added in the beginning of (Eq. 7). Next section presents the results obtained with the one node and multiple nodes models and a sensitivity analysis performed on the inputs and some selected parameters based on the results achieved.

3. Simulation Results

A comparison between the simulations performed with one node and 4 different variations of the multiple nodes model (namely, 3 nodes, 5 nodes, 7 nodes and 10 nodes models) was carried out. The investigation targeted the final output temperature of the system [T_s (°C)], energy [kWh] and power [kW]. In these simulations, 5 kg of zeolite 13X was used, with an initial water uptake of 0.1 kg/kg and an absolute humidity of the inlet air of 0.008 kg/kg.

3.1. Temperature, Power and Energy

Figure 2 presents the output temperature of the air in the last node of each model. As predicted, the node temperatures start at ambient temperature (20 °C) and then increase (up to 50 °C) while the adsorption is happening. After some time, the temperatures in the store nodes decrease, implying that the adsorption no longer

occurring. Here it is possible to observe that the one node model presents a smoother function than the multiple nodes approaches, and that it achieves lower maximum temperatures, but, on the other hand, it keeps a higher ΔT for longer times in comparison with the multiple nodes model. Same behavior happens with the power output of the system (Figure 3).

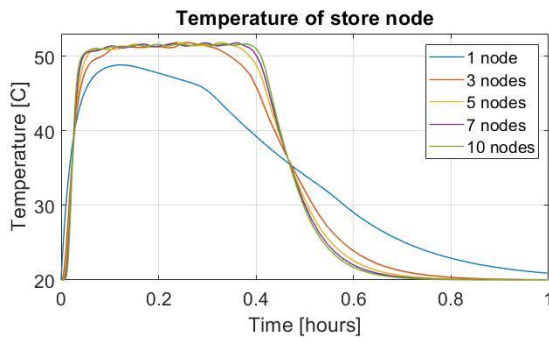


Figure 2: Output temperatures for different nodes simulations

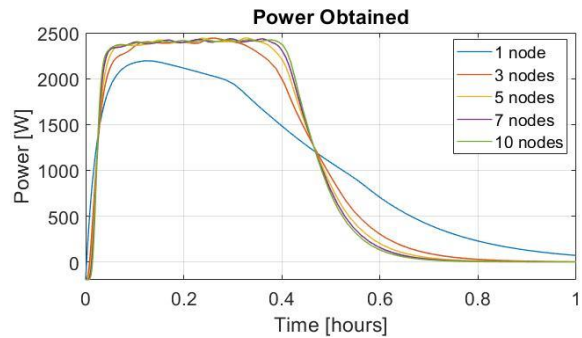


Figure 3: Power obtained in the different simulations

Figure 3 represents the power obtained with the system for each simulation. It is possible to observe that a higher amount of power is obtained in the beginning of the simulation, representing the time period when the adsorption process is taking place, and with time the power decreases, which indicates the period when the adsorption has ceased.

In both figures it is possible to notice that the one node model differs from the multiple node models, but that in general all models present the same curves shapes, meaning that the model developed in this work can well fit the one node and the multiple nodes models. The amount of energy obtained with the one node model was around 1.1 kWh, while with the multiple node approach it was 1.15 kWh, which proves that the difference in the final energy achieved with both approaches is not substantial.

3.2. Water uptake of storage material

- One node model

The material has an initial water uptake of 0.1 kg/kg and as expected, the water uptake increases till it reaches the maximum possible uptake of the material, which in the simulation is around 0.33 kg/kg, under the maximum water load of the sorption material (0.34 kg/kg) as can be seen in Figure 4. The water uptake depends on the temperature and humidity of the inlet air-stream which were respectively 20 °C and 0.008 kg/kg.

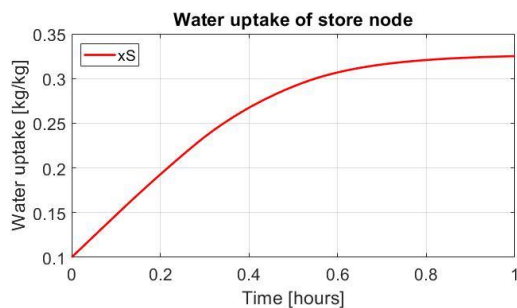


Figure 4: Water uptake of storage material with one node model

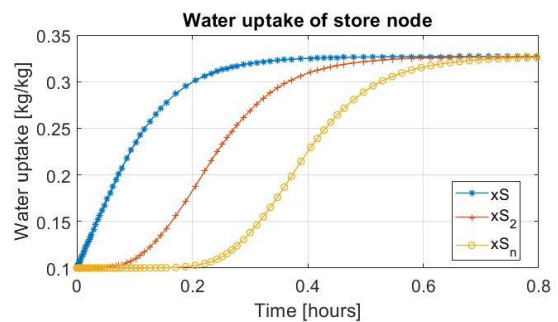


Figure 5: Water uptake of storage material for multiple node model

- Multiple nodes model

Figure 5 displays the water uptake of the storage material after each one of the nodes. One can notice that the water uptake in the last node presents a time delay in comparison with the first node, this happens because the water contained in the humid air is mostly retained by the first node and then when the air reaches the next node, less humidity is available to be absorbed by the storage material.

3.3. Sensitivity Analysis

During the sensitivity analysis study, the impact of the inlet gas mass flow rate m_{Gi} and the absolute humidity of inlet gas flow X_{Gi} on the final results was analyzed. The investigation was performed on the multiple nodes model with a total number of 3 nodes. The main goal of this analysis was to understand how the change in the inputs affects the final results of the model. This investigation targets the final power [W] and temperatures [°C] outputs. Both inputs had their values changed in a range of 4 different values that were combined between each other. The vectors of values used to run the new simulations can be checked below:

- $m_{Gi} = [200, \mathbf{300}, 400, 500]$
- $X_{Gi} = [0.006, 0.007, \mathbf{0.008}, 0.009]$

Inside the vectors the values in bold represent the ones used initially in the simulations. The other values in the vector were chosen by increasing and decreasing the original value in steps of 100 and 0.001 for the m_{Gi} and X_{Gi} respectively. Figure 6 till Figure 9 display the temperatures outputs with the input changes.

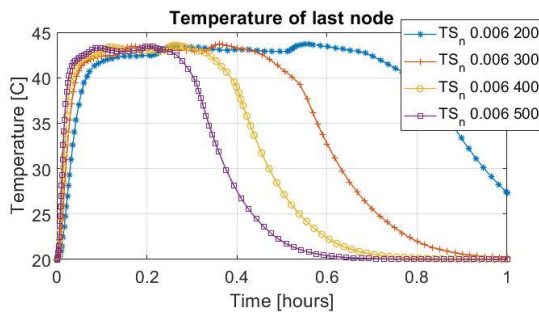


Figure 6: Case 1: X_{Gi} fixed as 0.006 kg/kg and m_{Gi} varying

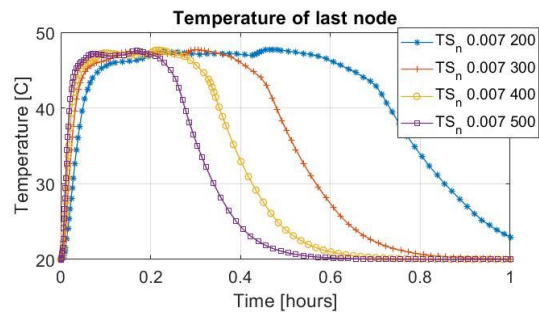


Figure 7: Case 2: X_{Gi} fixed as 0.007 kg/kg and m_{Gi} varying

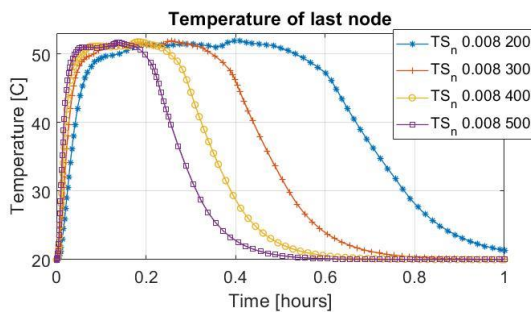


Figure 8: Case 3: X_{Gi} fixed as 0.008 kg/kg and m_{Gi}

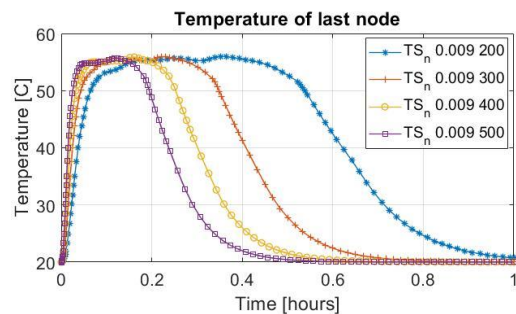


Figure 9: Case 4: X_{Gi} fixed as 0.009 kg/kg and m_{Gi}

For case 1, presented in Figure 6 the absolute humidity of inlet gas flow X_{Gi} is fixed with a value of 0.006 kg/kg, while the inlet gas mass flow rate (m_{Gi}) changes. For the cases 2, 3 and 4 the same procedure was adopted, but at this time, the absolute humidity of inlet gas flow is fixed at 0.007 kg/kg, 0.008 kg/kg and 0.009 kg/kg respectively. From this study some conclusions were achieved:

- For the same absolute humidity of inlet gas flow, the lower the mass flow rate, the longer is the period

of time while the high temperatures in the system were kept. The reason for this behavior is that, with a lower gas flow rate, the time that the adsorbent material will have to perform the adsorption processes increases, enabling the release of heat due to the adsorption process to happen for longer times.

- The greater the absolute humidity of the inlet gas, the higher the temperatures achieved in the process and also the smaller the amount of time while the high temperatures in the system were kept. This happens because with a high air humidity, more water will be available to be adsorbed by the storage material and more heat will be released in the process, allowing the temperature in the nodes to increase. On the other hand, the storage material achieves its maximum water uptake faster and the higher the humidity in the air, the shorter the process time.

Figure 10 till Figure 13 represent the change in the power obtained in the system, due to the changes in the inputs parameters.

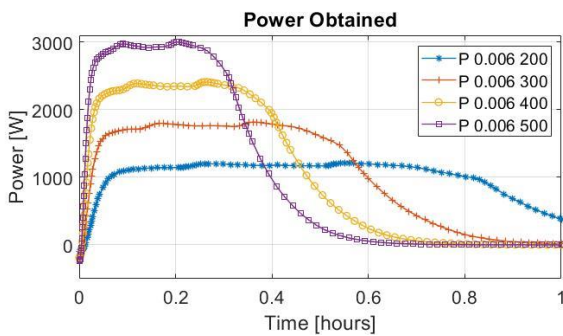


Figure 10: Case 5: X_{Gi} fixed as 0.006 kg/kg and m_{Gi} varying

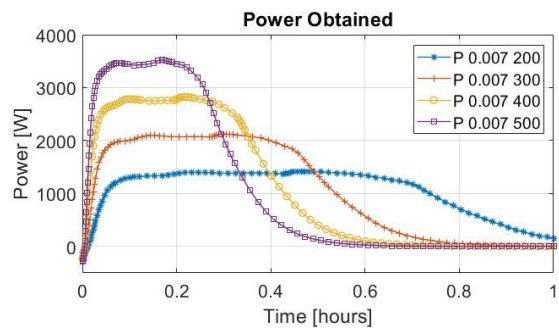


Figure 11: Case 6: X_{Gi} fixed as 0.007 kg/kg and m_{Gi} varying

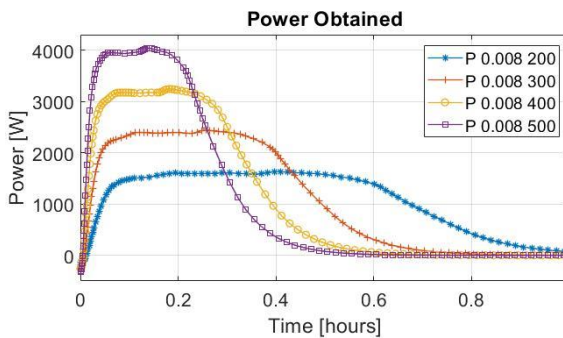


Figure 12: Case 7: X_{Gi} fixed as 0.008 kg/kg and m_{Gi} varying

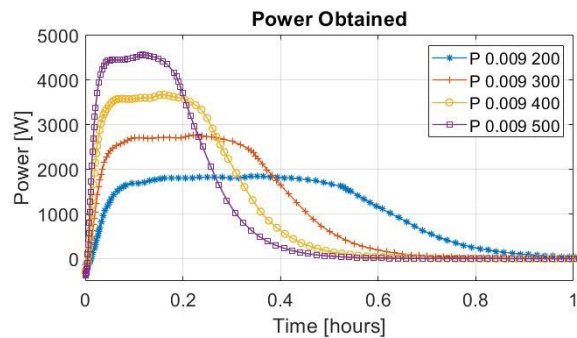


Figure 13: Case 8: X_{Gi} fixed as 0.009 kg/kg and m_{Gi} varying

Similarly, to the previous cases, for cases 5, 6, 7 and 8, the absolute humidity of inlet gas flow (X_{Gi}) is fixed with values of 0.006 kg/kg, 0.007 kg/kg, 0.008 kg/kg and 0.009 kg/kg respectively, while the inlet gas mass flow rate (m_{Gi}) varies. Comparing the results, the following observations can be made:

- When integrating the results for each of the cases, the amount of energy obtained will be the same. This happens because the amount of material and the humidity in the air are constant in each individual case.
- For the same absolute humidity of inlet gas flow, the higher the gas flow rate, the higher the amount of power obtained in the system, but also the smaller the period of time while the maximum power is held. When comparing to the previous cases, it is possible to observe that with a higher gas flow rate, the maximum temperatures are achieved in a shorter period of time. Therefore, since the possible amount of energy that can be obtained in each case is always the same; the system will reach a maximum power output faster for higher gas flow rates.

- The greater the absolute humidity in the air, the greater is the amount of power achieved in the system. The reason is that with more water vapor in the air, the amount of water available to be adsorbed by the storage material is higher and consequently, an increase in the node temperature will happen, leading to a higher power output in the system. On the other hand, the material reaches its maximum water uptake in a shorter period of time, decreasing the adsorption process rate and which causes the power output decrease.

3.4. Desorption Process

In order to simulate a desorption process, the following parameters were used:

- Initial water uptake of storage material (X_S) = 0.3 kg/kg
- Absolute humidity of inlet gas flow (X_{Gi}) = 0.006 kg/kg
- Inlet gas temperature (T_{Gi}) = 200 °C

All the other parameters remained the same as used in the previous simulations. Figure 14 displays the behavior of the water uptake with time, during a desorption process. In this case, the zeolite 13X starts the simulation already saturated with water (0.3 kg/kg) and the results show that, only after a period of around 10 hours, the material would reach a water uptake of 0.1 kg/kg.

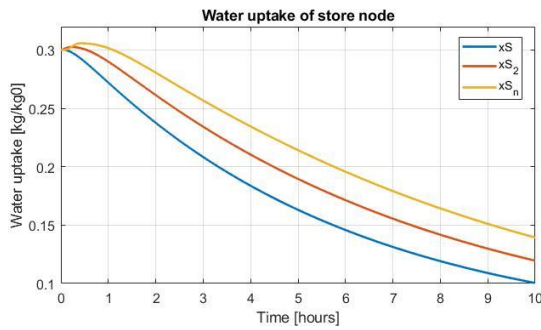


Figure 14: Water uptake of store node during desorption (X_S)

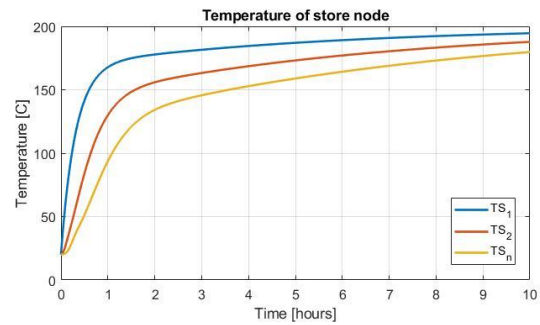


Figure 15: Output temperature during desorption (TS_{out})

In order to perform a desorption process, a hot and dry air should be the inlet air to the system, therefore, $T_{Gi} = 200$ °C was chosen. In this process, the zeolite begins with an ambient temperature of 20 °C and during the desorption the storage temperature increases, and after a period of almost 10 hours, it reaches nearly 200 °C, which corresponds to the inlet temperature of the air (Figure 15)

4. Conclusions

This paper focused on developing a mathematical model of a seasonal sorption storage system with a rotating drum. The model uses as dynamic inputs the inlet gas mass flow rate (m_{Gi}), absolute humidity of inlet gas flow (X_{Gi}) and temperature of inlet gas flow (T_{Gi}).

The simulations suggest that under similar operating conditions, the rotating drum is able to provide a temperature increase to the process air for a longer time, compared to the fixed bed reactor. This is at the cost of a decreased maximum temperature. The total energy is, however, the same for both setups since the equilibrium conditions of the storage material are precisely the same at the end of the simulation. When comparing the results achieved with multiple nodes models, basically no difference could be noticed between the models with > 5 nodes, which means that with a 5 node model, the system can be already fully described with no more need to increase the number of subdivisions (which also increases the computational time).

Studies performed and simulation models developed by Barbara Mette et al., 2014 and Rebecca Weber et al., 2016, were used as base and also as a validation method of the system here designed. The final results were

really satisfactory, and proved that the mathematical model here presented can be used in any further applications.

4.1. Future Work

With a fully functional model, one of the subsequent objectives of the project is to implement the sorption storage system into a passive house, in order to keep its room temperature at a certain desired level. Further recommendations for the enhancement of the results and better understanding of the system are:

- Execute a validation of the model using measurements from the experiments with the real system developed in [Bernhard Zettl et al., 2018].
- Creation of a model that takes into account the full system developed by Zettl et al., 2018 including the desorption of the material in the furnace, the heat exchangers included in the system and the material transport throughout the system.

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6. References

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