Modeling Predictions of the Performance of Tube Bank Heat Exchangers with Phase Change Materials

Jared C. Williams   Casey J. Troxler
Faculty Advisors: Dr. Sandra Boetcher & Dr. Rafael Rodriguez

PCM Encapsulated Tube Bank Heat Exchanger Model

The analytical model used was from the paper "Analytical model of a PCM-air heat exchanger" by Dubovsky, Ziskind, & Letan. [1]

- Initially based off a thermal resistance network, progression is made from an analytical solution for a single tube to the complete heat exchanger through a series of partial differential equations

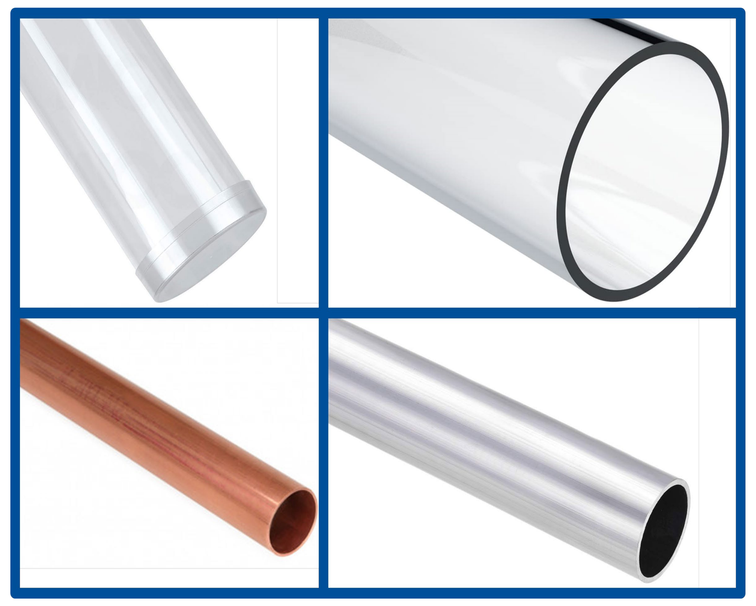
Governing Equation for total heat transfer of the tube bank

$$\frac{Q(\tau)}{Q_0} = \begin{cases} \frac{1}{1-e^{-b}} - \frac{1}{bN} * \frac{h_f}{h_0} \log\{1 + e^{-b\tau}(e^{b\zeta_f N} - 1)\}, \tau \le 1 \\ \frac{1}{1-e^{-b}} - \frac{e^{-b}}{1-e^{-b}} * \frac{h_f}{h_0} * \frac{\tau - 1}{N} - \frac{1}{bN} * \frac{h_f}{h_0} \log(\theta), 1 \le \tau \le \tau_0 \end{cases}$$

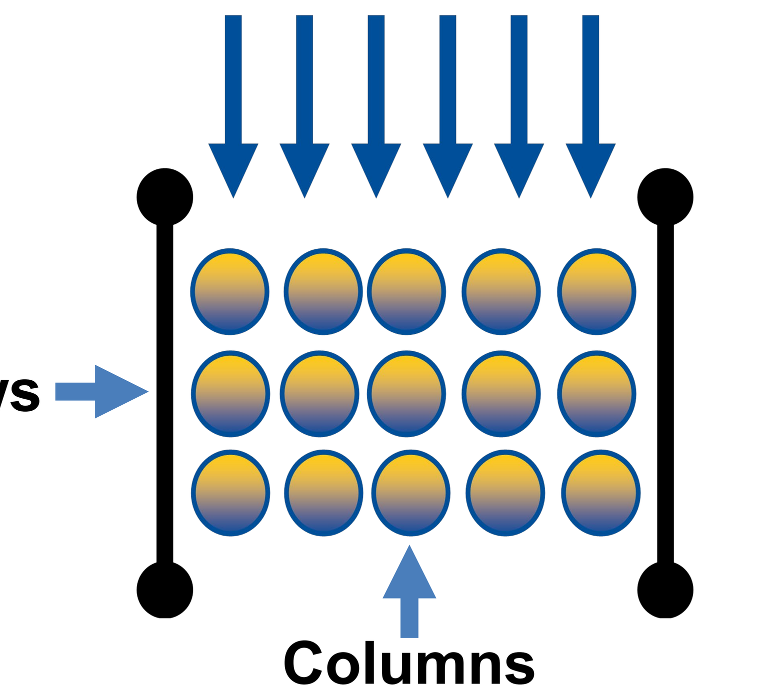
Variable	Variable Representation
Q_0	Energy required to be stored in PCM
τ	Dimensionless time
b	Constant based on thermal resistance calculations
N	Number of tube rows
h_f	Heat transfer coefficient from the tubes to the air
h_0	Overall heat transfer coefficient
ζ_f	Constant based on the heat transfer coefficients
θ	Constant calculated from b and ζ_f with h_f & h_0

Analytical Model Design Conditions

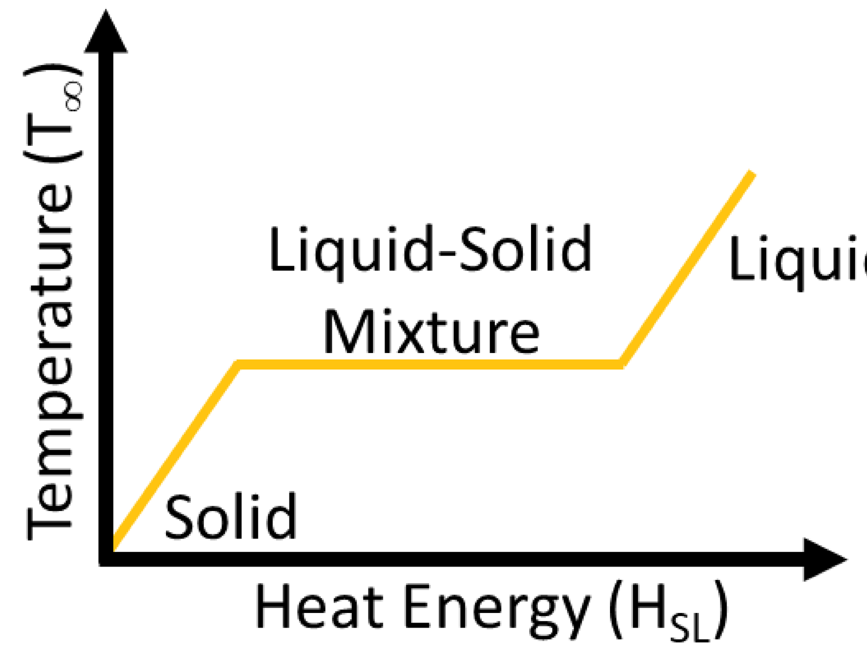
Encapsulation Method (k_{tube})



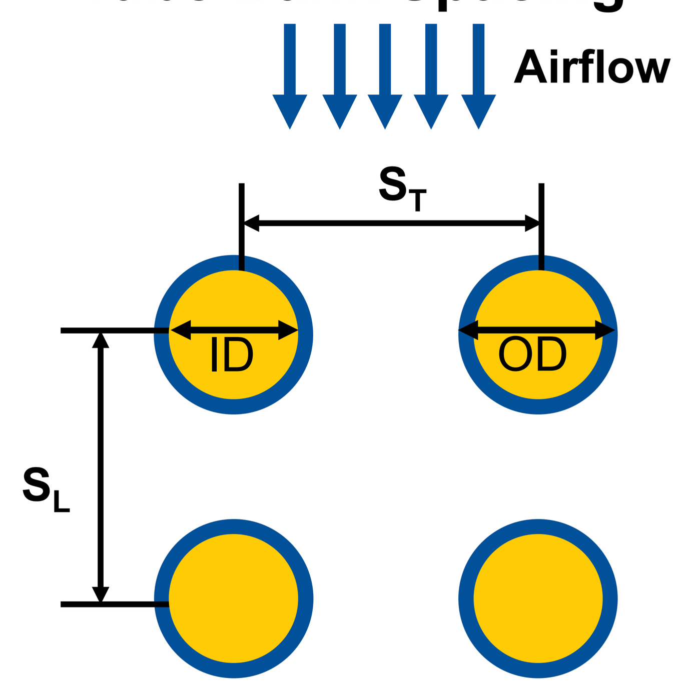
Air Temperatures (T_∞, ρ_{air})



PCM Used



Tube Bank Spacing



Abstract

As decarbonization of the power grid increases with renewable power generation sources, the intermittent nature of power generation also increases. With intermittent sources of power, there is a greater chance of excess power at specified parts of the day. To ensure that all power generated can be used rather than lost, ways to store excess energy need to be investigated. Currently the most prevalent form of energy storage is through electrochemical batteries. Electrochemical batteries however, are expensive and require added infrastructure for deployment. An alternative to electrochemical batteries is thermal energy storage (TES), that can aid in reducing buildings heating ventilation and air conditioning (HVAC) loads on the power grid. TES is commonly conducted by using phase change materials (PCM) which melt or solidify at specified temperatures. By taking advantage of the latent heat energy stored in the PCM, this energy can be used to condition a space later, reducing the peak thermal loads for a building.

One way to use PCM for TES is through tube bank heat exchangers, which assembles a bundle of PCM encapsulated tubes in a particular spacing. Once the tube bank is configured, air would then pass over the tube bank exchanging heat with the PCM encapsulated tubes. This project focuses on optimizing the tube bank configuration to ensure the time taken to charge & discharge the TES would allow for the thermal battery to be used daily. Predictions for the heat exchangers performance is made through an analytical model while varying specified conditions including the tube bank spacing, encapsulation methods, the specified PCM used, and the incoming air temperatures. By modifying these conditions in the analytical model, estimations can be made before a physical test bed is produced for validation.

Model Motivation

Modeling was completed to aid in the design of the Ignite project "Investigation of Thermal Energy Storage-Heat Pump Integration for Residential Applications".

- Currently the test bed is in the final steps of construction, and model validation will begin before the end of the semester.

References

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Physical Test Bed Design Conditions

Encapsulation Material

Material	Thermal Conductivity [W/mK]	Price per foot
Acrylic	0.20	$2.79
PETG	0.20	$0.45
Aluminum	238.25	$23.47
Copper	404.68	$6.55

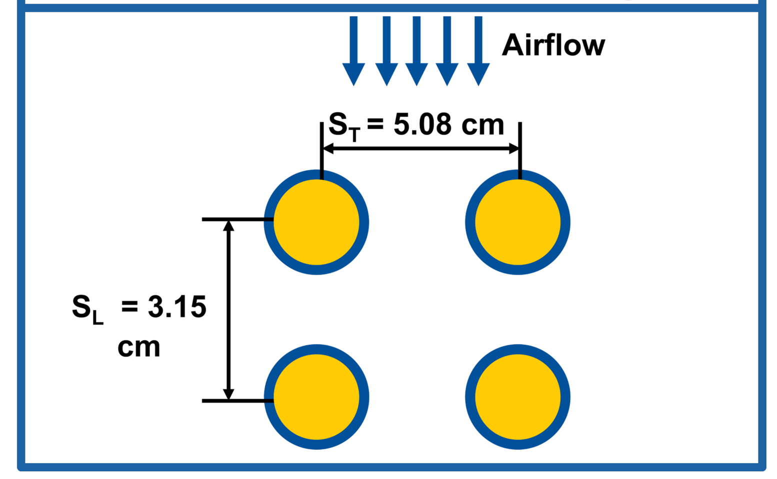
Incoming Air Temperatures

Fan Mode & Flow Rate [L/min]	Average Temperature [°C]
Medium – 6,711	7.7
High – 9,090	8.9
Super-High – 11,298	9.6

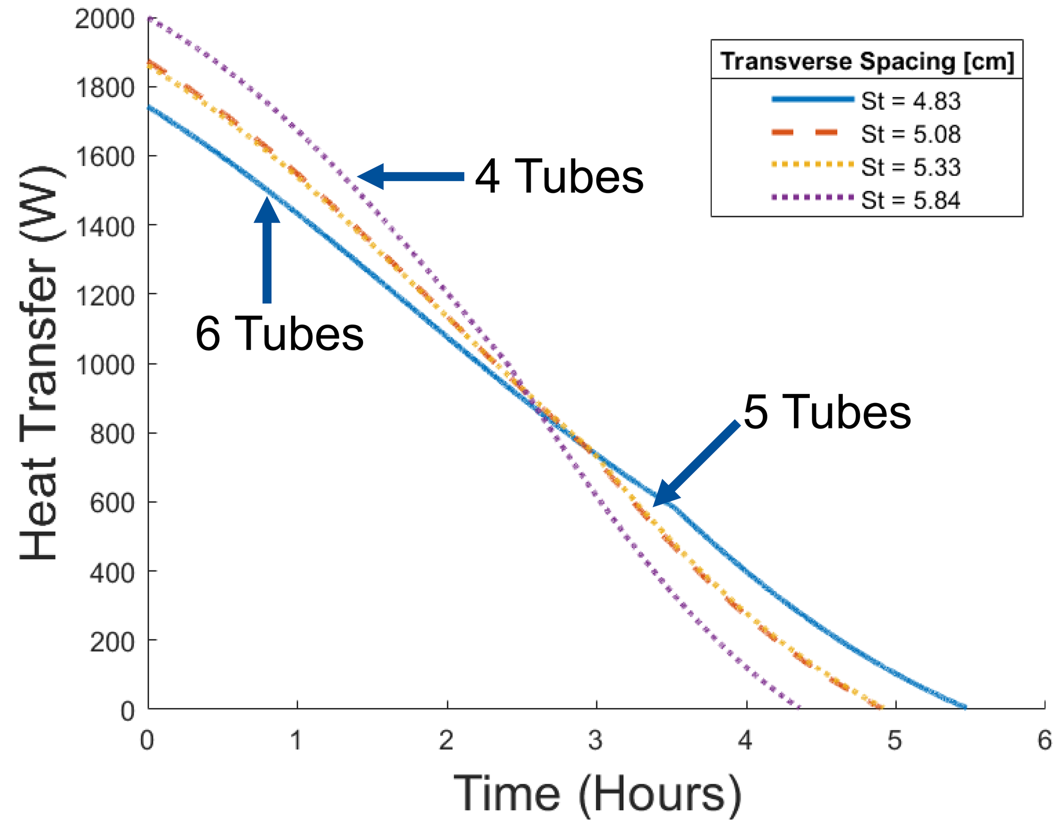
PCM Selected

PCM Product	Phase Change Temperature [°C]	Heat Storage Capacity [kJ/kg]
PureTemp20	20	171
Rubitherm21	21	165
Rubitherm22	22	190

Tube Bank Spacing

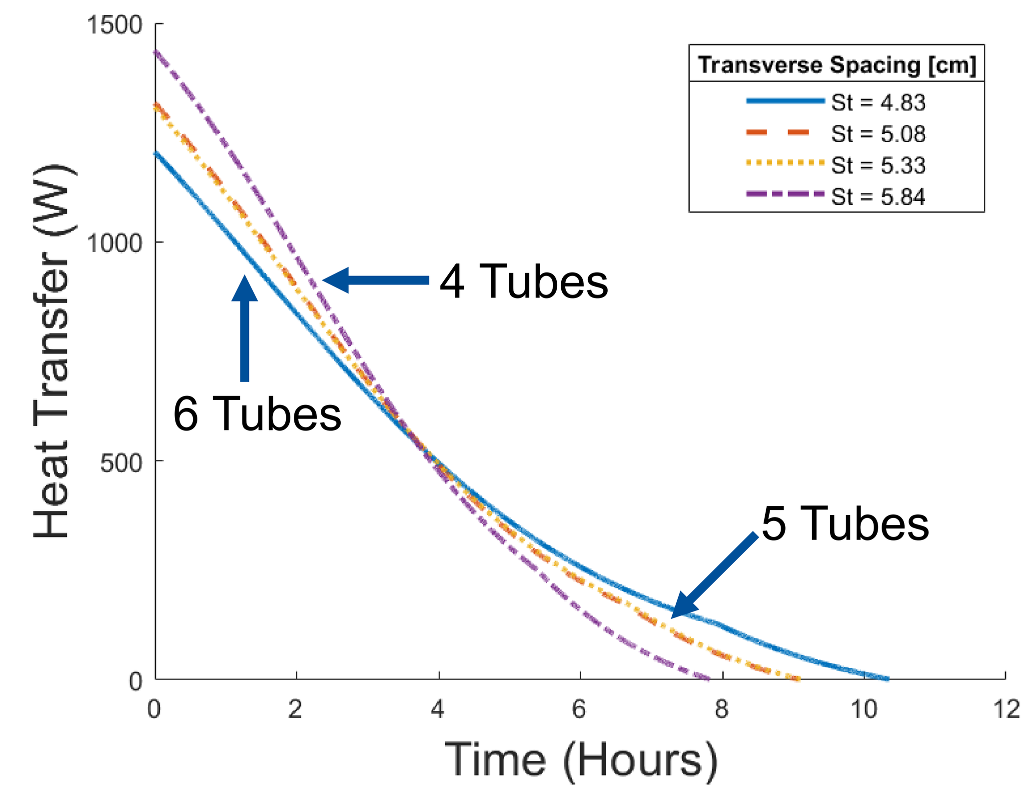


Analytical Results from Test Bed Conditions – Time to Charge



Tube Bank Characteristics
Ideal: 5 Tube per Row
112 rows

Design Condition Changes



Tube Bank Characteristics with Hexadecane
Ideal: 5 Tube per Row
84 rows