DESIGN AND DEVELOPMENT OF PHASE CHANGE MATERIAL INTEGRATED SOLAR AIR HEATER FOR DRYING APPLICATION IN AGRICULTURE

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CHAPTER 6

SUMMARY AND CONCLUSSIONS

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The research aims to design and develop phase change materials integrated solar air heaters for agricultural drying applications. All the set objectives were achieved, and the summary of the significant findings are provided below.

6.1 Selection, thermal stability, and compatibility study of PCMs for solar drying application

- The PCM selection process involved considering factors like melting temperature, toxicity, market price, corrosivity, and thermophysical properties. From 87 PCMs, a shortlist of 17 was created, and three (stearic acid, paraffin wax, acetamide) were selected through Multi Attribute Decision Making.
- Thermal stability was assessed using Thermogravimetric Analysis (TGA), confirming the selected PCMs' suitability for solar heating/drying. Differential Scanning Calorimetry (DSC) examined thermophysical properties after charging and discharging cycles, ensuring acceptable fluctuations for reliable performance.
- PCM compatibility with container materials (aluminium, copper, mild steel, stainless steel) showed varying corrosion rates. Despite differences, all materials met industrial corrosion limits for long-term use. Microscopic imaging revealed more significant deformations in copper and mild steel. Despite lower corrosion resistance, aluminium was selected as the container material, likely due to factors like cost, weight, and design considerations, supported by practical and corrosion test results.

6.2 Design, development, and performance assessment of PCMSAH

- This chapter focuses on optimizing design variables (absorber plate size, PCM quantity, air mass flow rate) for improved performance of the PCMSAH. The required PCM quantity is determined based on a uniform time constant (3 hours) and varying melting depths. PCM type significantly impacts outlet temperature, with acetamide achieving the highest (63°C), suitable for vegetable drying.
- Air mass flow rate changes influence outlet temperature, maintaining suitability for vegetable drying even with increased flow rates. The study emphasizes temperature gains during charging and discharging, with stearic acid exhibiting the highest gains. The PCMSAH offers uniform outlet temperatures during discharging and

higher temperatures than a PCM-less Solar Air Heater, benefiting crop drying and heating.

- Simulation results closely align with experiments, indicating effective predictive capabilities (2.32% to 4.50% mean relative errors). Thermal energy component distribution analysis reveals variations among PCMs, providing insights into energy efficiency. Thermal efficiency calculations show slightly lower efficiency for acetamide (~41%) compared to paraffin wax and stearic acid (~45%), with low uncertainty (±2.02%), indicating reliability.

6.3 Performance assessment of PCMSD with energy, exergy, economic and environmental considerations

- The PCMSD exhibits superior drying efficiency compared to open sun drying, evident in significantly lower final moisture content (dry basis) for all PCMs (acetamide: 1.89 g/g, paraffin wax: 2.89 g/g, stearic acid: 3.07 g/g) compared to open sun drying (4.09–5.19 g/g).
- The overall energy efficiency remains similar for paraffin wax (6.61%), stearic acid (6.84%), and acetamide (7.40%) in the PCMSD, showcasing PCM choice's minimal impact on the process.
- Specific Energy Consumption (SEC) varies among PCMs, with acetamide demonstrating the lowest SEC (9.56 kWh/kg), indicating superior moisture removal efficiency compared to paraffin wax (11.94 kWh/kg) and stearic acid (10.62 kWh/kg).
- Exergy analysis reveals marginal variations in overall exergy efficiency (2.66% to 2.94%) among PCMSD systems, but acetamide outperforms in the drying section, suggesting design improvements for enhanced exergy efficiency.
- Economic analysis indicates a higher capital cost for acetamide-integrated PCMSD, but annualized operational costs and potential income are marginally different, yielding a short investment payback period (approximately half a year) for year-round operation, supporting economic feasibility.
- Environmental sustainability assessment includes embodied energy, annual CO_2 emissions, CO_2 mitigation, carbon credit potential, and energy payback period. Embodied energy is highest for acetamide. Annual CO_2 emissions, mitigation, and carbon credit potential indicate positive environmental impact. The energy payback

period is estimated at 2.51 years for paraffin wax, 2.56 years for stearic acid, and 2.98 years for acetamide, emphasizing the environmental benefits of PCMSD.

6.4 Limitations of the present research

The current study provides insight into the investigation on selection of PCM for solar heating application and their characterization for thermal stability and compatibility. The study also provides the complete details on design, development and performance testing of PCM-based solar air heater and solar dryer. However, it is important to acknowledge the need for long-term testing and also testing at different geographical locations in order to fully comprehend the significance of the findings. While the research makes important advances, more research into long-term consequences is required for the knowledge of the impact and sustainability of the operation of PCM-based solar air heaters and solar dryers before transferring the technology to the market.

6.5 Suggestions for future work

1. Long term testing of the developed PCMSD in different days of the year and locations, with different agricultural products.
2. Study on integration of two or more PCMs to synthesis a composite PCM and to study their thermal stability and compatibility.
3. To extend the use of low or medium temperature PCMs in other applications like cold storage, building insulations and textile sectors.