Phase Change Materials for Passive Cooling in Refrigerated Transport of Table Grapes under South African Climatic Conditions: A Comparative CFD Study

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Abstract:
The table grape cold chain in South Africa faces challenges, which include increased transit times due to deteriorating roads, increased fuel costs and increased fruit spoilage due to breaks in the cold chain, which leads to financial losses. Phase change materials (PCMs) are latent thermal energy solutions which enable passive cooling by absorbing and releasing heat during phase transitions. A transient computational fluid dynamics (CFD) model was developed in ANSYS Fluent to compare the performance of three commercial PCMs, RT0, RT2HC, and RT3HC (Rubitherm®), for refrigerated table grape transportation under representative dynamic South African climatic conditions. Thermal performance in terms of maintaining the recommended cooling range, fuel (diesel) consumption and carbon dioxide-equivalent ($CO_{2\text{-eq}}$) emissions were evaluated. The results showed that RT2HC was the most suitable PCM and maintained internal temperatures below 2 °C in a standard 40 ft container throughout the container for 2 hours and 11 minutes. RT 0, RT2HC and RT3HC reduced diesel consumption and $CO_{2\text{-eq}}$ emissions associated with refrigeration by 74.1 %, 78.8 % and 76.3%, respectively. Overall diesel savings of approximately 3.41 to 4.66 % were achieved when diesel consumed for vehicle propulsion was included in the analysis.

Keywords:
Phase change material, dynamic temperature variation, cold chain, transient study, latent heat storage, table grape transportation.