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Energy Efficiency of Secondary Refrigeration with Phase Change Materials and Impact on Greenhouse Gases Emissions

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Abstract : Secondary refrigeration consists of splitting large-size direct-cooling units into volume-limited primary cooling units complemented by secondary loops for transporting and distributing cold. Such a design reduces the refrigerant leaks, which represents a source of greenhouse gases emitted into the atmosphere. However, inserting the secondary circuit between the primary unit and the 'users' heat exchangers (UHX) increases the energy consumption of the whole process, which induces an indirect emission of greenhouse gases. It is thus important to check whether that efficiency loss is sufficiently limited for the change to be globally beneficial to the environment. Among the likely secondary fluids, phase change slurries offer several advantages: they transport latent heat, they stabilize the heat exchange temperature, and the formerly evaporators still can be used as UHX. The temperature level can also be adapted to the desired cooling application. Herein, the slurry {ice in mono-propylene-glycol solution} (melting temperature T_m of 6°C) is considered for food preservation, and the slurry {mixed hydrate of CO_2 + tetra-n-butyl-phosphonium-bromide in aqueous solution of this salt + CO_2} (melting temperature T_m of 13°C) is considered for air conditioning. For the sake of thermodynamic consistency, the analysis encompasses the whole process, primary cooling unit plus secondary slurry loop, and the various properties of the slurries, including their non-Newtonian viscosity. The design of the whole process is optimized according to the properties of the chosen slurry and under explicit constraints. As a first constraint, all the units must deliver the same cooling power to the user. The other constraints concern the heat exchanges areas, which are prescribed, and the flow conditions, which prevent deposition of the solid particles transported in the slurry, and their agglomeration. Minimization of the total energy consumption leads to the optimal design. In addition, the results are analyzed in terms of exergy losses, which allows highlighting the couplings between the primary unit and the secondary loop. One important difference between the ice-slurry and the mixed-hydrate one is the presence of gaseous carbon dioxide in the latter case. When the mixed-hydrate crystals melt in the UHX, CO_2 vapor is generated at a rate that depends on the phase change kinetics. The flow in the UHX, and its heat and mass transfer properties are significantly modified. This effect has never been investigated before. Lastly, inserting the secondary loop between the primary unit and the users increases the temperature difference between the refrigerated space and the evaporator. This results in a loss of global energy efficiency, and therefore in an increased energy consumption. The analysis shows that this loss of efficiency is not critical in the first case (T_m = 6°C), while the second case leads to more ambiguous results, partially because of the higher melting temperature.The consequences in terms of greenhouse gases emissions are also analyzed.

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