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Sujet de Thèse :

Thermal Storage using Phase Change Materials for Eco-Efficiency of Industrial Processes

Abstract :

Thermal waste emitted by industrial processes (smoke, heat exchangers (HEs), cooling processes, temperature stabilisation) often contains a large amount of energy in low-temperature heat, generally lost in the atmosphere. This waste heat (also known as excess heat) can be recovered to improve the overall energy efficiency of these processes. Thus, a large amount of energy is likely to be recovered and used to cover heat needs or optimise a process. Indeed, it is not easy to manage this heat upon its production. Latent Thermal Energy Storage (LTES) technology with Phase Change Materials (PCMs) has appeared as one of the most economically viable methods for recovering excess heat. The PCMs present a significant storage capacity that can be provided or stored at a nearly constant temperature.

The first challenge is understanding heat transfer mechanisms to bridge the lack of knowledge concerning thermal storage using PCMs. In particular, for PCMs with solid-solid and solid-liquid transitions, such as paraffins. For this, experimental and numerical studies of an annular LTES system allow us to understand the multiphysics phenomena of top, bottom, and horizontal configurations. Also, a new method is presented to calculate the storage density and distribution of energy storage rate in the different regenerator components (PCMs, HTF, and HEs).

The low power density of LTES systems limits large-scale PCM applications. For this, twoapproaches were tested to improve the heat transfer of LTES systems. Act on the PCM to enhance its thermal conductivity and solve PCM leaks. In that sense, two new shape stabilisedPCMs are developed. The first one is based on the paraffin as PCM, Low-Density PolyEthylene (LDPE) as supporting matrix and Multi-Walled Carbon Nanotubes (MWCNTs) asthermal conductivity enhancer. The second involves the Poly-Ethylene Glycol (PEG) as PCM and MWCNTs as a shell matrix and thermal conductivity enhancer. The second method acts on the HE to improve convective heat transfer. This method focuses on an inexpensive and practical solution, the annulus eccentricity of a horizontal LTES system, in which natural convection enhance the PCM heat transfer.

According to the thesis methodology, the sulphuric acid industry was chosen as a real-life case of excess heat recovery. This process releases a large amount of energy below 200 °C, exceeding 30 MW for 1500 tons.day-1. In that sense, the closed loop of an industrial sulphuric acid plant is modelled, simulated, and validated with the plant data. The last section provides a new approach to assessing and comparing the performance of LTES devices. This method is based on thermal rate capability and Ragone plots. For this, a simplified model has been developed for industrial design purposes. This tool shows the influence of PCM properties, operating conditions, and HE geometries on the storage capacity, power density and HTF outlet temperature.

Keywords: Thermal Energy Storage; Phase Change Materials; Computational Fluid Dynamics; Phase Change Modelling; Chemical Process Modelling; Excess Heat Recovery.