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Study on boiling heat transfer of water–TiO_2 and water–MWCNT nanofluids based laminar jet impingement on heated steel surface

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ABSTRACT

The present study aims at investigating the boiling heat transfer aspect of water–TiO_2 and water- multi-walled carbon nanotubes (water–MWCNT) nanofluids based laminar jet cooling of heated horizontal steel surface. Experimental results show that cooling rate is enhanced by using nanofluids when compared to water. A one-dimensional finite volume inverse heat transfer model is developed to predict the total heat flux removal rate from the hot steel surface. It is also observed in the present case that the shift from "film boiling" to "transition boiling" regime occurs earlier for nanofluid than that of water jet cooled surface. An order of magnitude analysis shows that the shift may be attributed to the vapor film instability in presence of nanoparticle deposition. However, only marginal variation of critical heat flux (CHF) is observed in case of nanofluid jet when compared to water jet.

1. Introduction

Run out table (ROT) cooling is an integral part of rolling operations in any steel industry where conventionally laminar jet of sub-cooled water is impinged on the horizontally moving hot steel strip, which is being rolled continuously. The cooling rate of steel is an important parameter for obtaining the desired mechanical and metallurgical properties. The strip enters at an initial temperature of about 1100 K and exits at around 800 K. As the temperature of the steel strip is higher than 373 K, the heat transfer predominantly occurs through boiling of water. Thus, research in this field involves an extensive study of laminar water jet impinging on horizontal hot plate (either stationary or in motion), to understand the various phases of boiling *viz.* film, transition and nucleate and the factors affecting CHF.

There have been efforts to develop a correlation for CHF for jet impingement of saturated liquids *viz.* water, ethanol, R-11 and R-113 on heated surface based on nozzle diameter, impinging fluid velocity and fluid temperature [1]. Liu and Wang [2] studied film boiling heat transfer with water jet impinging upon a horizontal flat plate. They concluded that transition boiling occurs for sub-cooled jets and the incipience of film boiling is strongly influenced by degree of the sub-cooling. Krishna Kumar et al. [3] developed a one-dimensional finite difference heat transfer model for ROT cooling process by assuming heat transfer coefficients for different cooling zones. Sikdar and Mukhopadhyay [4] predicted the exit strip temperature based on actual plant data using a one-dimensional finite difference method based heat transfer model.

Nanofluids are particles with size less than 100 nm dispersed in a base fluid such as water. They are known to have higher thermal conductivity when compared to that of the base fluid and hence have been a topic of great interest in research ([5,6]). A number of studies have been performed to understand the effect of nanofluids in phase change heat transfer; however the studies have been predominantly in pool boiling regime where several researchers have reported anomalous findings ([7–10]). The application of nanofluid in laminar jet boiling and the study of heat transfer aspects during jet impingement is an emerging area of research. Recently, Liu and Qiu [11] studied the boiling heat transfer for water–CuO nanofluid impinged on plate surface. They have reported a significant decrease in boiling heat transfer of nanofluid as compared to water and formation of a thin sorption layer of nanoparticle on the surface. Chakraborty et al. [12] reported that using laminar jet of water–TiO_2 nanofluid for cooling hot steel plate results in significant enhancement in cooling rate as compared to water which leads to changing the microstructure of the steel. However, heat transfer analysis and the reason for observing such a phenomenon are not discussed in details.

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