INVESTIGATION OF QUENCHING HEAT TRANSFER CHARACTERISTICS IN METAL OXIDE NANOFLUIDS

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Mechanical and Automotive Engineering Technology
UNIVERSITI MALAYSIA PAHANG

AUGUST 2022

ACKNOWLEDGEMENTS

This thesis became a reality with the kind support of many individuals. I would like to express my sincere thanks to all of them.

First and foremost, I would like to take this opportunity to express my sincere gratitude to my supervisor, Dr. Muhamad Zuhairi bin Sulaiman for the continuous support and guidance during my research in Universiti Malaysia Pahang for his patience, motivation, enthusiasm, and immense knowledge. He was helpful and generous with his time and expertise to evaluate and comment on my research and writing of this thesis. I could not imagine having a better advisor and mentor for my postgraduate studies.

I wish to express my gratitude to all the staff that was involved in obtaining data for my research, especially the staff from the Centre of Excellence for Advanced Research in Fluid Flow (CARIFF) UMP. I would also like to thank the Ministry of Higher Education for providing financial support under Fundamental Grant Scheme (FRGS) No. FRGS/1/2019/TK07/UMP/02/2 (University Reference RDU1901121) and Internal Research Grant (RDU160385).

I want to thank the rest of my labmates Muhammad Hadie Aizzat Asli, Nurul Adilah binti Abu Siroh and Chandraka Subramaniam for the stimulating discussions, the sleepless nights we were working together before deadlines and for all the fun we had during this research.

I would also like to thank my beloved family, my parents, Ismail bin Mt Daut and Fatimah binti Ismail for their devotion, understanding and support spiritually and financially throughout my life. They were always by my side at the times I needed them the most and helped me a lot in making this research a bearable one.

Last but not least, my thanks and appreciation also go to my colleagues and people who have willingly helped me out with their abilities.

ABSTRAK

Proses pelindapkejutan adalah salah satu proses penting dalam aplikasi penyejukan berkepadatan tinggi dan digunakan secara meluas dalam pelbagai bidang kejuruteraan seperti rawatan haba keluli dan keselamatan loji tenaga nuklear. Salah satu aplikasi proses pelindapkejutan yang ketara adalah ke dalam sistem pendinginan teras kecemasan sesebuah loji tenaga nuklear. Kini, cecair konvensional yang digunakan dalam proses pelindapkejutan adalah terhad dan tidak dapat mencapai kadar pemindahan haba yang diinginkan dalam jangka masa yang singkat. Oleh itu, cecair asas yang diubah suai yang disebut cecair nano dipercayai dapat mempercepat kadar pemindahan haba tersebut. Walau bagaimanapun, prestasi cecair nano dalam peningkatan pemindahan haba masih kurang dikaji dan menunjukkan beberapa kekurangan seperti masalah kestabilan. Dalam kajian ini, objektif awal adalah untuk mengkaji kestabilan cecair nano yang dihasilkan menggunakan beberapa teknik. Oleh itu, sebelum eksperimen pelindapkejutan, kestabilan cecair nano berasaskan partikel yang berbeza (Al_2O_3, SiO_2 dan TiO_2) dan campurannya (Al_2O_3–SiO_2 dan Al_2O_3–TiO_2 dengan nisbah 50:50) dengan kepekatan 0.001, 0.01 dan 0.025 vol% yang disiapkan disahkan menggunakan kaedah kualitatif dan kuantitatif. Lima teknik berbeza digunakan semasa penyediaan cecair nano tersebut iaitu: (i) sonikasi 1 jam, (ii) pengaduk magnetik 1 jam, (iii) pengaduk magnetik 0.25 jam dan sonikasi 1 jam, (iv) pengaduk magnetik 0.5 jam dan sonikasi 1 jam, dan (v) tanpa pengadukan dan sonikasi. Ketinggian pemendapan diperhatikan selama dua minggu dan saiz kluster nano yg terdapat di dalam sampel yang disediakan telah dibandingkan. Kemudian untuk objektif kedua, ciri pemindahan haba pelindapkejutan dari pelbagai jenis nanofluid dengan kepekatan berbeza dinilai melalui proses pelindapkejutan batang tembaga pada suhu tinggi yang dicelup dalam beberapa jenis cecair nano yang ditetapkan. Batang tembaga silinder dengan ukuran 50 mm panjang dan 15 mm diameter dicelup dengan cepat pada suhu 600 °C dalam cecair pelindapkejutan pada keadaan tepu dan di bawah tekanan atmosfera. Graf penyejukan (suhu vs masa) batang tembaga yang dicelup dalam cecair pelindapkejutan yang berbeza akan disiasat. Seterusnya, eksperimen yang sama juga dilakukan sebanyak 6 kali lagi dalam cecair pelindapkejutan tanpa membersihkan batang tembaga tersebut. Hasil eksperimen menunjukkan bahawa kaedah (iii) mempunyai kestabilan tertinggi pada setiap jenis dan kepekatan cecair nano yang diuji. Hanya sedikit pemendapan dan fasa berbeza yang dapat dilihat pada cecair nano tersebut. Penemuan ini dikukuhkan lagi dengan kaedah kuantitatif dengan menggunakan analisi penyebaran cahaya dinamik di mana ukuran kluster nano hanyalah bersaiz kecil. Seterusnya, lengkung penyejukan yang diperoleh semasa proses pelindapkejutan tunggal dalam cecair nano Al_2O_3-SiO_2 pada 0.01 vol% menunjukkan peningkatan yang ketara iaitu 27% lebih bagus berbanding dengan air suling. Walau bagaimanapun, eksperimen pelindapkejutan berulang menunjukkan bahawa cecair nano SiO_2 mempunyai peningkatan tertinggi setelah pelindapkejutan ke-7 berbanding jenis nanofluid lain. Setelah diamati, terdapat beberapa partikel nano yang melekat pada permukaan rod selepas setiap proses pelindapkejutan. Pada kepekatan cecair nano yang lebih tinggi, terdapat peningkatan yang lebih tinggi dalam kadar pemindahan haba semasa proses pelindapkejutan berulang, berbanding dengan kepekatan rendah. Oleh itu, penyelidikan ini memberikan bukti kukuh bahawa penambahan partikel nano dalam cecair pelindapkejutan dapat meningkatkan kadar pemindahan haba batang tembaga semasa fenomena penlindapkejutan tunggal dan berganda. Secara konklusi, maka wajar untuk menyimpulkan bahawa cecair nano mempunyai kesan positif terhadap prestasi pemindahan haba semasa proses pelindapkejutan.

ABSTRACT

Quenching heat transfer is one of the significant processes in high-density cooling applications and are widely used in various engineering fields, such as heat treatment of steel and safety of nuclear power plant. One of the significant quenching process applications is an anticipation into the Emergency Core Cooling System (ECCS) of a nuclear power plant. At present, conventional fluids used in quenching are limited and are unable to achieve the desired rate of heat transfer in a short amount of time. Thus, an engineered base fluid called nanofluids are expected to accelerate the heat transfer rates. However, the performance of the nanofluids in heat transfer enhancement is still undiscovered and exhibits some drawbacks, such as stability issues. In the present work, the initial objective was to elucidate the dispersion stability using several techniques in order to ascertain the stability of the newly prepared nanofluids. Hence, prior to the quenching experiments, the stability of three different water-based nanofluids (Al_2O_3, SiO_2 and TiO_2) and their hybrids (Al_2O_3–SiO_2 and Al_2O_3–TiO_2 of 50:50 volume ratio) with prepared concentrations, C = 0.001, 0.01 and 0.025 vol% were verified using qualitative and quantitative methods. Five different methods were implemented during the preparation of the water-based nanofluids, which are (i) 1 hour of sonication, (ii) 1 hour of magnetic stirring, (iii) 0.25 hour of magnetic stirring and 1 hour of sonication, (iv) 0.5 hour of magnetic stirring and 1 hour of sonication, and (v) without magnetic stirring and sonication. The height of sedimentation was observed for two weeks and the nanocluster sizes of the prepared samples were compared. Then, for the second objective, the quenching heat transfer characteristics of various types of nanofluids and their concentrations were evaluated using experimental work consisting of a high-temperature copper rod that were quenched in several types of nanofluids, such as Al_2O_3, SiO_2 and TiO_2 nanofluids as well as their hybrids. Here, a 50-mm cylindrical copper rod with diameter of 15 mm were rapidly quenched at an initial temperature of 600 °C in the quench media at saturated conditions and under atmospheric pressure. The cooling curves of the copper rod quenched in different quench media were investigated. Successively, a multiple quench experimentation was also conducted by re-quenching the same rod for 6 more times in the quench media. Experimental results on the dispersion stability of the nanofluids showed that using method (iii) had the highest colloidal stability despite the types and concentrations of nanofluids tested. Only slight sedimentation and phase separation could be observed in the nanofluids that were prepared using method (iii). The findings also correlated with the quantitative method by using dynamic light scattering (DLS) where there is a reduction in nanocluster sizes in the samples tested. In respect of the heat transfer performance, the cooling curves obtained during single quenching heat transfer in hybrid Al_2O_3-SiO_2 nanofluids showed a significant enhancement as compared to distilled water with the highest enhancement of 27 % at C = 0.01 vol%. However, the results obtained after multiple quenching experiments using a quenched surface showed that SiO_2 nanofluids had the highest enhancement after the 7^{th} quench as compared to other types of nanofluids. It was observed that some of the nanoparticles were deposited on the surface of the rod after each quench. At higher concentrations of nanofluids, there was a greater enhancement in heat transfer rates during multiple quenching, as compared to low concentrations. Hence, the present research provides strong evidence that the addition of nanoparticles in a quench media could enhance the heat transfer rates of a copper rod during the single and multiple quenching phenomena. Thus, it is reasonable to conclude that the nanofluids have a positive effect on the quenching heat transfer performance when used as a quench media.

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