TRANSIENT HEAT TRANSFER ANALYSIS OF DIMPELED ROD

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Abstract. The considerable heat transfer increase that the dimple causes has led to an interest in its technology recently, with pressure drop penalties lesser than other heat augmentation types. The increase in heat transfer using dimples is based on the fact that the scrubbing of cooling fluid occurs within the dimple and intensifies the delay of flow separation over the surface. The researchers have used different dimple-shaped geometries from all the research studied, such as triangular, ellipsoidal, circular, square, from which the ellipsoidal shape offers better results than other shapes because of prior vortex development. The present work mainly aims to study the dimpled specimen's transient properties and determine their influence on heat transfer.

1. INTRODUCTION

In several fields of application, such as microelectronic cooling, gas turbine internal airfoil cooling, nuclear power plant fuel components, and biomedical equipment, there is a relentless attempt to find ways to increase heat transfer. Two methods are generally adapted for enhancing the heat transfer: Active techniques and Passive techniques. In passive methods, the heat transfer rate is increased by producing surface modifications such as protrusions, dimples, and pin fins. The dimples (surface indentations) are considered necessary because the material is significantly reduced in dimple production, while excessive material is used in pin-fin or rib tabulators, which increases the equipment's weight and cost. A variety of Computational and experimental work has been carried out to enhance the transfer of heat. In 1971, the first person to try using dimples on the surface for heat transfer enhancement was Kuethe[1]. According to him, the dimples would help promote vortexes' creation, resulting in heat transfer improvement [1]. V.N Afnasyev[2] performed an experimental analysis on surfaces formed by spherical cavity networks and observed that, relative to the plane surface, heat transfer improved by 150 percent. Nikolai Kornev[3] investigated vortex structure and heat transfer enhancement in turbulent flow over the staggered dimple array in the narrow channel.
using Large Eddy Simulation. The impact of the dimple aspect ratio, temperature ratio, Reynolds number, and flow structure in the dimple channel was studied by Mahmood and Ligrani [4]. A numerical simulation of laminar channel flow over the dimpled surface was conducted by Wang [5], and within a single dimple, an asymmetric 3D horseshoe vortex was found. Experimental research was performed by S.L. Borse and I.H Patel[6] on the influence of dimples on heat transfer under forced convection over a flat surface. They claimed that surface dimples contributed to a lower pressure drop in heat transfer enhancement and indicated that heat transfer enhancement in staggered arrangements is more efficient than inline arrangements. The channel height effect on the heat flow over the dimpled surfaces was studied by Moon [7].

The heat transfer coefficient and friction factors were computationally explored in rectangular channels with dimples on one wall. Pisal and Ranaware[8] have experimented to determine whether dimples on a heat sink fin can enhance heat transfer for laminar airflow. It was carried out using two distinct types of circular dimples (spherical) and oval dimples (elliptical). These dimples were located on both sides of the copper plate; it had a relative pitch of S/D=1.20, and a relative depth of δ/D=0.2. The Nusselt number and overall heat transfer coefficient are calculated for these configurations. Between the 600 and 2000 scale, heat transfer improvements were observed. Katkhaw et al. [9] analyzed the flat surface with an outer flow ellipsoidal dimple with ten types of different arrangements and dimple intervals. For such a dimpled surface, the heat transfer was measured and contrasted with a smooth surface's heat transfer. Results revealed that for staggered arrangement, the heat transfer coefficients were 15.8% more than that for a smooth surface and 21.7% more for inline arrangement. By the transient wide band liquid crystal process, an eight-by-eight jet array will affect a staggering array of dimples at Reynolds number 11,500 as investigated by Kanokjaruvijit Martinez-Botas[10]. Two dimple geometries were tested for hemispherical and cusped elliptical shapes. The study of dimple geometry's effect showed that hemispherical and cusped elliptical dimples did not behave differently significantly. However, compared to the economy, production, and loss of pressure, the hemispheric type should be preferred. Various similar studies can be found in [11-29].

From the literature, it is clear that dimples play a significant role in heat transfer enhancement. However, the unsteady heat transfer analysis for different dimple orientation and material is scarce; this is the primary motivation behind this paper. The main objectives were to find the cooling curve, rate of convective cooling at any instant, and the total amount of heat transfer at a given time. Additionally, the effect of dimple orientation on the heat transfer rate, the cooling medium's influence on the heat transfer rate, and the heat transfer coefficients for different cooling mediums and different dimple orientations were also discussed.

2. EXPERIMENTAL METHODOLOGY

2.1. Experimental setup

The apparatus is a large insulated water bath with a volume of approximately 30 liters (Fig 4.1). A 3 kW electric heater powered by a thermostat to achieve a constant bath temperature is at the bath's bottom. A rotary switch located in the front of the bath regulates the water temperature. The water bath cover assembly is designed to allow the test specimen to be quickly placed into the bath while maintaining the flow conditions. The test sample is connected to the carrier assembly, and for uniform heat transfer through the water bath, the water bath is stirred continuously. The thermocouple labeled T1 indicates the brass temperature, and the thermocouple labeled T2 indicates the water bath temperature.

2.2. Preparation of test specimen

Brass is the material considered for testing, and the dimples have been machined with the assistance of CNC end milling on the surface of the material. The dimples were machined with a diameter of 4mm and a total depth of 4mm in which 2mm depth has a cylindrical profile, and the remaining 2mm has a concave profile. Two types of orientation were considered to study the influence of dimple orientation on the transient properties, which are inline configuration and circumferentially Staggered orientation. The inline configuration has the dimples located at 90° apart with a spacing of 10cm along the length
(as shown in Fig 2). Circumferentially staggered orientation has the dimples located 90° apart but are provided with an offset along each corner's length (Fig 4.3).

3. RESULTS AND DISCUSSION

The study presents the experimental results of a cylindrical brass specimen with dimples machined with two configurations: 1) Inline configuration and 2) Circumferentially staggered configuration. The study presents the cooling curve, rate of convective cooling at any instant of time, the total amount of heat transfer at a given time. It also provides the effect of dimple orientation on the heat transfer rate, the cooling medium's influence on the heat transfer rate, and the heat transfer coefficients for different cooling mediums and different dimple orientation.

The following graph (Fig. 4(a) and 4(b)) illustrates the decay rate in temperature and heat transfer coefficient with time. The decay rate is higher in the dimpled rod than the ordinary rod in air cooling. We can also notice that the better results are obtained for inline when compared to the random arrangement.
Figures 5(a) and 5(b) illustrate the change in temperature and heat transfer coefficient when the cooling medium is water. It can be seen that the decay in temperature is almost the same for both the dimpled orientations. However, significant heat transfer enhancement can be seen in the dimpled surface compared to the ordinary rod.
The following graph (Fig. 6(a) and 6(b)) shows the variation of temperature and heat transfer coefficient with time for a radiator coolant. It illustrates that there was no significant heat transfer enhancement when the cooling medium was a radiator coolant. It is because of the reason that a coolant circulation system is required to remove heat effectively.
4. CONCLUSIONS
From the results obtained, we can conclude that there was considerable heat transfer enhancement with dimples' introduction. Heat transfer enhancement concerning dimples' inline configuration was more than the staggered arrangement of dimples. The convective cooling and total heat transfer rate also increased after the introduction of dimples for air cooling. When the cooling medium was water, there was no distinction between the heat transfer from specimens with inline and staggered configuration. Surprisingly, when a coolant was used, there was probably no heat transfer enhancement seen.

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