Fluid dynamics during forced convective quenching of flat-end cylindrical probes

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Abstract: - The hydrodynamic behavior of the quenchant around a flat-end cylindrical probe was studied to explain the anomalies observed when quenching this type of probe in a fluid moving at relatively high velocities. Both, physical and mathematical models were developed and compared with the observations made during the actual quenches which were conducted with water at 60°C flowing at 0.2, 0.4 and 0.6 m/s. The computed streamlines compared favorably with the measured ones which validated the mathematical model. The computed pressure field shows a significant gradient near the probe corner which produces backflow and an area of negative pressure which favors the occurrence of a localized thicker vapor blanket. Thus, the use of the flat-end cylindrical probe for wetting kinematics studies is not recommended.

Key-Words: - Wetting front; boiling; hydrodynamics; vapor blanket; pressure field; velocity field.

1 Introduction

During quenching of both ferrous and nonferrous metallic parts a number of complex phenomena interact to produce the final mechanical properties, distortion and residual stresses. Thus it is very difficult to design these processes using trial and error procedures. Standardized tests such as the Jominy end quench test [1] or cooling curve analysis [2] provide with relevant information but they are limited regarding distortion and residual stresses. Thus, the best alternative for process design is based on developing mathematical models to simulate the evolution of the thermal, microstructural and displacement fields during quenching; this methodology is known as Microstructural Engineering [3]. A critical parameter of the mathematical models is the heat transfer boundary condition at the part/quenchant interphase because the evolution of the heat extracted by the quenchant drives the thermal filed within the part and, therefore, the evolution of the microstructural and displacement fields. At that interphase, heat is extracted by a sequence of three different mechanisms: heat transfer through a vapor blanket ("film boiling"), heat transfer in the presence of bubbles ("nucleate boiling") and heat transfer due to pure convection [4], which often occurs simultaneously. The moving boundary between film boiling and nucleate boiling is known as the wetting front [5].

To either estimate the heat transfer boundary condition or to characterize the evolution of the wetting front, a number of investigations have been carried out using flat-end cylindrical probes [6-9]. Other researchers have used variations of this probe. Narazaki *et al.* [10,11] have shown results comparing the performance of flat-end, rounded-edge and spherical-end cylindrical probes. Based on the reproducibility of the cooling curves they concluded that the best probe would be that with the spherical-end. On the other hand, Frerichs et al. [12] reported that the spherical-end cylindrical probe produces a non-symmetrical wetting front; based on their results they propose the use of a cylindrical probe with chamfered edges. A recent study conducted by Vergara-Hernández and Hernández-Morales [13,14]