ILASS 2008
Sep. 8-10, 2008, Como Lake, Italy
Paper ID ILASS08-13-12

HEAT TRANSFER COEFFICIENT IN SPRAY COOLING QUENCHING

G.P. Celata, M. Cumo and A. Mariani

ENEA - Institute of Thermal-Fluid Dynamics,
S. Maria di Galeria, Rome, Italy
celata@casaccia.enea.it, mariani_a@casaccia.enea.it

ABSTRACT

The paper is dealing with the prosecution of a research carried out at the Institute of Thermal-Fluid Dynamics of ENEA to investigate the rewetting of a hot surface. In the previous work attention was paid on the cooling of a hot surface with drop impingement. In this paper the previous test section is replaced by a new one designed to allow the measurement of the heat flux in 2-D. After the drop impingement, the liquid film falls along the surface. The reference situation is the external surface of a tank which, after a fire, is subjected to flames or high temperature anyway, and is cooled with water or an extinguishing liquid. The experiment was characterized by a 1-D liquid spray, i.e., drops having a uniform, constant diameter, impinging on the heated surface. The working principle of such a spray is based on the varicose rupture of a liquid jet (Rayleigh-Weber instability): imposing a periodic perturbation of appropriate amplitude and frequency on the jet surface, the flow is "constrained" to break soon after leaving the nozzle, eventually obtaining constant diameter drops, depending, for a given liquid, on the nozzle diameter and liquid velocity.

The heat flux is calculated from the response of the thermocouples placed on the heated wall at different depth and different lateral position. The heat flux has been found to increase with the coolant mass flow-rate. A higher initial wall temperature is associated with higher values of the heat flux, while the spray drop diameter seems to play a significant role in the heat transfer, considering the different positions which the heat flux has been calculated at. This behaviour is confirmed in the analysis of the maximum heat flux.

An inverse method model, suggested by Woodfield et al. [1], is also used to calculate the surface temperature and the heat flux in the material, providing a very good prediction of experimental results.

From the value of the heat flux it is possible to calculate the value of heat transfer coefficients during the quenching process. Heat transfer coefficient has been found to increase with the coolant mass flow-rate. The wall temperature has a little effect on heat transfer coefficient.

INTRODUCTION

Rewetting of high temperature walls has received a significant attention since the 1960's with reference to the safety analysis of LWRs. More recently, such a process has increased its demand with reference to other applications (rewetting of high temperature walls after fires, quenching of steel, etc.). Consequently, the most recent research has aimed not only to a wider investigation of complex heat transfer phenomena associated but also to the achievement of an estimation of the most significant physical parameters. The availability of an informative tool based on the measurement, both direct and indirect, of fundamental parameters, such as the rewetting time and velocity and the wall-coolant heat flux, turns out to be extremely useful in the design and assessment of plant safeguard systems as well as in the emergency management of accident conditions. Data analysis of experiments carried out in the present work is finalized to the evaluation of the wall heat flux, q", during the rewetting of an overheated metallic plate by liquid sprays.

As is known, when a liquid is impinging on an overheated surface the instantaneous formation of a vapour cushion prevents the liquid from wetting the surface, thus avoiding a consistent heat removal from the surface itself. After a while, thanks also to the heat removal by the liquid-vapour mixture, the wall temperature decreases below a 'critical' value (rewetting temperature). From this point on the solid-liquid contact is restored and a liquid film will cool the surface while falling down.

The velocity of the front liquid film, also known as rewetting (or quench) velocity, u_{rew}, is mainly controlled by the heat conduction from the dry region towards the wetted region (heat conduction is opposite to the film flow), and it is often said conduction controlled rewetting.

Analytical models available in the literature, such as Oliveri et al. [2], Yamanouchi [3], Blair [4], Duffey and Porthouse [5], Tien and Yao [6], aiming at describing the rewetting phenomenon and calculate the rewetting velocity, are based on the solution of the Fourier equation inside the heating wall as well as on the heat transfer at the liquid solid interface.

The exact solution, starting from which it is possible to derive the rewetting velocity, requires the knowledge of the heat transfer coefficient and the wall temperature at the rewetting or quench front, ideal boundary between the wetted region (in contact with the liquid film) and the dry region, [2].

Many authors, in order to take into account the complex phenomenon occurring in the region of boiling nearby the quench front, known as sputtering, and the possibility of precursory cooling of the dry region thanks to the drops generated in the sputtering region, assume a heat transfer coefficient with an associated wall heat flux, changing along the vertical direction of the hot wall. Other authors, on the basis of their experimental data, believe that the assumption of a coefficient which is constant in the wetted region and is equal to zero in the dry region may be a reasonable approximation. In both cases the analytical study of the phenomenon can be tackled according to a 1-D, [3], or 2-D approach [4] [5] [6]. From the above considerations it appears how, for a better understanding of a complex phenomenon such as the rewetting, further experimental indications may be needed to provide a more accurate estimation of fundamental parameters characterizing the phenomenon, such as the heat transfer coefficient and the wall heat flux, which is the objective of the present work.

TEST FACILITY AND MATRIX

The experimental facility, schematized in Fig. 1, is extensively described in [7] e [8], where authors have investigated the cooling of a vertical metallic (stainless steel) plate, electrically heated by Joule effect from 200 to 700 °C, by means of water sprays with a uniform distribution of drop diameter. The spray system is also described in [9] and is based on the application of a perturbation wave to the coolant (before leaving the nozzle) which yields a uniform drop diameter depending on the liquid velocity and on the perturbation frequency (some kHz).