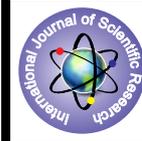


Effect Of Flow Rate On The Cooling Of Electrically Heated Hot Surface During Jet Impingement



Engineering

KEYWORDS : Impingement cooling, Stagnation point, Jet Reynolds number, Cooling curves

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ABSTRACT

The transient surface cooling of a hot stainless steel surface is done with the round water jet impingement cooling. The stainless steel surface of 3 mm thickness is electrically heated to obtain the initial temperature of 800 ° C. Water flow rate is varied to maintain the jet Reynolds number in a range of Re= 5000-24000 and nozzle exit to surface spacing has been kept constant at z/d=4. It has been observed that for same temperature drop surface cooling rate is higher with the jet Reynolds number of 24000, particularly for higher range of surface temperature. However, for lower surface temperature range surface cooling rate remains more or less invariable.

Introduction:

The jet impingement cooling provides a efficient way to obtain a higher rate of heat transfer from a hot surface. The jet impingement cooling methods is extensively being used in many industrial applications viz. steel, paper, textile, electronic, nuclear and many more. The Jet impingement is one of the methods to achieve the quenching with high rate of cooling. Many review papers for air and water jet impingement is available in the literature [1, 2]. These studies reveals that cooling and heat transfer performance from the hot surface to a great extent depends on the factors pertaining to the jet and surface properties. The experimental investigations reported that the jet configuration, jet size, fluid flow rate, jet fluid temperature, surface temperature, jet exit to surface spacing, surface orientation and roughness etc. affects surface heat transfer both under and transient and steady state condition [3,4,5].

There are several fluids that have been used as jet coolant; however, air and water are main fluid. Generally water as a jet fluid has been used in steel and nuclear application due to easy availability and higher heat removal rate capability.

Present investigation has been performed to explore the effect of jet fluid flow rate on the cooling of stainless steel surface at 800 °C temperature. The time varying surface temperature is recorded for the stagnation point with the jet of 2.5 mm diameter. The jet water temperature is maintained at 22 ± 1 °C and jet Reynolds number is maintained between 5000- 24000. The jet exit to test surface spacing is kept constant such that z/d = 4.

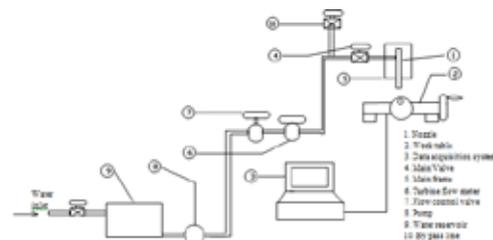
Experimental set up:

The experiments were performed with water of 22±1 oC temperature for cooling of a hot horizontal stainless steel surface. The schematic diagram of the experimental set-up is shown in Figure 1. Initially, collected water in reservoir (9) was supplied to the straight tube type nozzle (1) using a water pump (8). A flow control valve (7) and a turbine flow meter (6) were installed on the water supply line after the pump. The nozzle was mounted on a main frame (5) of a work table (2). The hot test surface was placed underneath to the nozzle on a work table (2). The test surface was placed concentric to the nozzle centre with the help of a lateral and transverse movement handle provided on the work table. The round water jet of 2.5 mm diameter was impinged on the upward facing hot test surface. A ungrounded minarally insulated K-type thermocouples was attached on the back side of the test surface and connected to the Data Acquisition System (3). The test surface was heated slowly up to 800 °C using a high current and low voltage auto-transformer arrangement. Two copper bus bars were attached from the auto-transformer to both sides of the test surface. Copper bus bars were used to minimise the voltage drop between the transformer and the test surface. The nozzle exit to test sur-

face spacing was maintained at z/d=4 by adjusting the vertical movement of nozzle. This movement was obtained with a rack pinion arrangement provided on the main frame and the corresponding nozzle position was observed on a vertical scale.

The test surface was a 3 mm thick stainless steel-316 surface. The test surface was made perfectly insulated by applying ceramic insulation and the Teflon at the back side of surface. The K-type ungrounded thermocouple of 0.25 mm sheath diameter was spot welded at the geometric centre of the test surface to record the variation of surface temperature. The resistance heating of surface was done up-to the initial surface temperature of 800 oC by regulating auto transformer. A digital voltmeter was used to measure the voltage drop across the sides of test surface and current supplied was recorded with the help of an ammeter and a current transformer (CT) arrangement. The surface temperature during transient cooling was recorded by using a data acquisition system at the rate of 100 samples per seconds. The flow of water to the nozzle was varied through flow control valve and the water flow rate was measured with the help of a turbine flow meter. The jet Reynolds number at the nozzle exit for a certain flow rate, jet diameter and water properties can be obtained by following equation (1)

$$Re = \frac{dU}{\nu} \text{ Where } U = \left(\frac{Q}{A_j} \right) \text{ (1)}$$



Where A_j is the nozzle exit area, Q is volume flow rate of water and U is the jet velocity exiting the nozzle.

Table 1- Uncertainty in the measurements

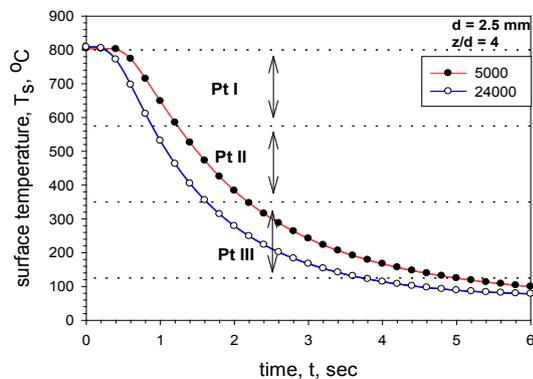
Parameter	Accuracy
water flow rate	0.10 lpm
time	0.01seconds
nozzle diameter	0.10 mm
test surface length and width	0.02 mm
test surface thickness	0.01 mm
temperature	1.5 °C @ 800 °C 0.5 °C @ 100 °C

Table 2- operating range of experimental parameters

Experimental parameter	Operating range
Reynolds number, Re	5000, 24000
Jet exit to surface spacing, z/d	4
Nozzle diameter, d	2.5 mm
Thickness of test surface, w	3.0 mm
Water temperature, T_f	22 ± 1 °C
Initial surface temperature, T_i	800 °C

Result and Discussion:

Initially, surface cooling curves are obtained with the recorded time varying surface temperature data during transient cooling of the hot surface. The cooling curves shown in Figure 2 are for jet Reynolds number of 5000 and 24000 at nozzle exit to surface spacing, $z/d = 4$. It has been observed that with the rise in jet flow rate or the jet Reynolds number, the surface cooling rate increases significantly. The cooling time to reach the surface temperature at 125 °C from its initial temperature of 800 is 30 % lower with 24000 Re as compare to 5000 Re.

**Figure 2 Surface cooling curves for different Jet Reynolds number**

If the complete cooling curve is divided in three equal parts of temperature ranges i.e. 800-125 °C in equal part of 225 °C temperature range. It is observed that for second part of tem-

perature range i.e. 575-350 °C, the cooling time is minimum. Whereas, the cooling time is the highest for the lower surface temperature range part (350-125 °C). The cooling time for the initial part of the temperature range is approximately 30 and 20 % higher than for the second part of the temperature range at 24000 and 5000 Re respectively. However, the lowest cooling time for the second part of the temperature range is approximately 65 % lower than the highest cooling time observed for the third part of the temperature range. This phenomenon remains unaffected by the change in jet Reynolds number.

The diverse behaviour of surface cooling time for different surface temperature range may be due to different mode of boiling heat transfer that may take place over the hot surface during the transient cooling. Agrawal et al. [3] and Islam et al. [6] has also witnessed the possibility of all the mode of heat transfer from the hot surface during transient cooling. Initial part-I of temperature range may correspond to the film boiling region and part-III corresponds to the nucleate and forced boiling regime. Whereas, part-II falls in the transient and the maximum boiling heat flux regime. Perhaps this is the reason for the minimum cooling time for the part-II temperature range as compare to the other temperature range.

The lower cooling time for the same drop in temperature with higher jet flow can be attributed by the rise in jet velocity for higher flow rate. For a given jet diameter or nozzle diameter with the rise in jet flow rate the exit jet velocity from the nozzle increases and it has been reported in literature that with the rise in jet velocity the heat transfer performance of the cooling surface increases [7]. Perhaps this is the reason for enhanced surface cooling at higher jet Reynolds number.

Conclusions:

The surface cooling rate of a hot stainless steel surface is experimentally investigated at the stagnation point. For same temperature drop at jet Reynolds number of 24000 the surface cooling rate is approximately 30 % higher as compare to at 5000 Re. The cooling rate is further higher for the mid range of surface temperature as compare to the higher and lower surface temperature range irrespective of the change in jet flow rate.

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