Effect of Impinging Jet Diameter on the Transient Cooling of Electrically Heated Stainless Steel Surface

Chitranjan Agarwal[#1], J. K. Maherchandani[#2]

#1 Department of Mechanical Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur-313001, Rajasthan, India, +912942470510 (O),

#2 Department of Electrical Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur-313001, Rajasthan, India, +912942470510(O),

ABSTRACT

The transient surface cooling of a hot stainless steel surface is investigated for different jet diameter on a electrically heated hot stainless steel surface. The surface of 3 mm thickness is initially heated to the temperature of 800 °C. Water flow rate is varied to maintain the jet Reynolds number at 5000 and nozzle exit to surface spacing has been maintained at z/d=4.

It has been observed that for same temperature drop surface cooling rate is higher for the larger jet diameter even though the jet velocity with larger jet diameter is low in comparison to lower jet diameter.

Key words: Impingement cooling, stagnation point, jet Reynolds number, Cooling curves.

Corresponding Author: Chitranjan Agrawal

INTRODUCTION

The use of jet impingement cooling is being employed extensively in various industrial applications such as material processing, electronic cooling, and emergency cooling of nuclear reactors due to its high heat removal capacity. The surface cooling not only depends on the thermal response of the material but also parameters pertaining to the cooling jet. These parameters include jet flow rate, jet diameter, jet configuration, jet temperature and the jet fluid [1, 2, 3].

The water jet impinging cooling of flat hot surfaces has been employed in a wide range of practical applications where cooling generally takes place under transient conditions. Therefore, the main objective of this work is to study the effect of jet diameter on transient conditions of a hot horizontal stainless steel surface exposed to an impinging water jet. The test surface is heated up to initial temperature of 800 °C. The jet diameter has been varied in a range of 2.5 mm-4.8 mm with maintaining the jet Reynolds number at 5000. The impinging water jet temperature is 22 ± 1 °C, which is correspond to the normal water temperature used in the industries. The jet exit to test surface spacing is kept constant at z/d = 4.

EXPERIMENTAL SET UP

The schematic diagram of the experimental set-up is shown in Figure 1. A water reservoir (9) was used to collect the water which was supplied to the straight copper tube nozzle (1) with a water pump (8). A flow control valve (7) and a turbine flow meter (6) were used to control the jet flow on the water supply line. The nozzle was mounted on a main frame (5) of a work table (2) and the test surface was mounted on work table (2) concentric to the nozzle centre. The position of the test surface underneath to the nozzle was obtained with a transverse and lateral movement handle provided on the work table. Two nozzles of 250 mm length were used to produce the round jet of 2.5 mm and 4.8 mm diameter. The nozzle positions were varied with the help of rack-pinion arrangement provided on the main frame of the nozzle assembly. The nozzle was positioned such that for each jet diameter the nozzle exit to test surface spacing should remain at z/d=4.

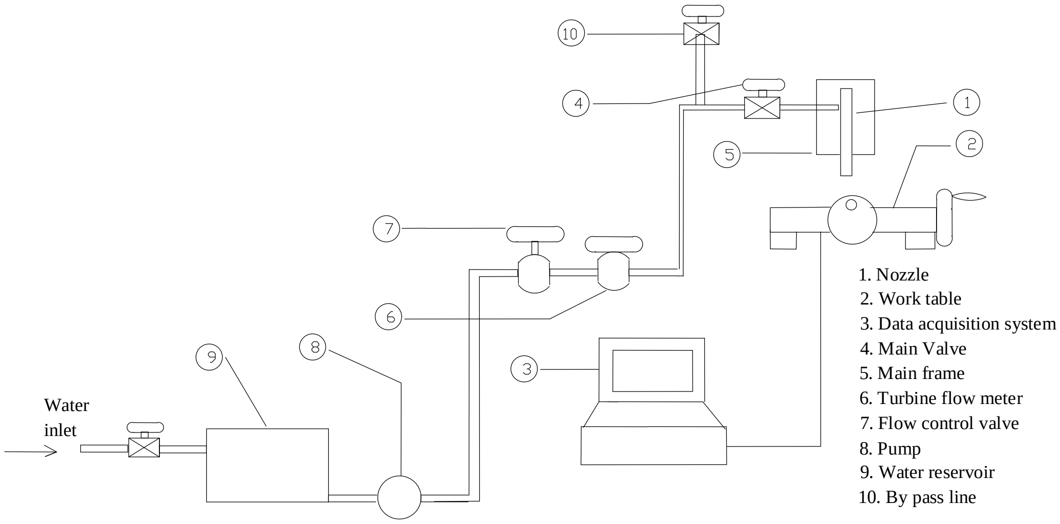

Fig 1: Schematic of experimental set-up

A SS-316 surface of 130 mm length 30 mm wide and 3 mm thickness was used as test surface. A ungrounded mineral insulated K-type thermocouples of 0.25 mm sheath diameter was spot welded at the centre of test surface on the reverse side and connected to a Data Acquisition System (3). The test surface was attached to an auto transformer through two copper bus bars and heated slowly up to 800 °C by using high current low voltage AC supply. The back side of the test surface was made perfectly insulated by using 50 mm thick Teflon sheet and a layer of ceramic insulation and the Teflon at the back side of surface. The resistance heating of surface was done up-to the initial surface temperature of 800 ^{o}C 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)

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

Where Aj is the nozzle exit area, d is jet diameter, Q is volume flow rate of water and U is the jet velocity exiting the nozzle. The uncertainty in each of the measurement is shown in Table-1. The uncertainties in the radial position of thermocouples were 0.1mm, since, the thermocouple diameter was 0.25 mm, the uncertainty in the thermocouple position became 0.25 mm. Experiments were performed for jet Reynolds number of 24000 and 5000 keeping nozzle exit to surface spacing, z/d = 4. The operating ranges of experimental parameters have been shown in the Table -2.

Table1. Uncertainty in 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

Table2. Operating range of experimental parameter

Experimental parameter	Operating range
Reynolds number, Re	5,000
Jet exit to surface spacing, z/d	4
Nozzle diameter, d	2.5 mm, 4.8 mm
Thickness of test surface, w	3 mm
Water temperature, T_j	22 ± 1 ^{o}C
Initial surface temperature, T_i	800 ^{o}C

RESULT AND DISCUSSION

The curves for the surface cooling are obtained with the temperature data recorded data during transient cooling of the hot SS surface at the stagnation point. The cooling curves shown in Figure 2 are for jet diameter, d, of 2.5 mm and 4.8 mm for a constant jet Reynolds number of 5000 and nozzle exit to surface spacing at z/d = 4. It has been observed that with the rise in jet diameter the rate of surface cooling rises. The cooling time required to obtain the surface temperature of 125 °C from its initial temperature of 800 °C is more than twice for jet of 2.5 mm diameter as compare to time required for the same temperature drop with jet of 4.8 mm diameter.

If this temperature ranges i.e. 800-125 °C is divides in three equal parts then it is observed that for lowest range of surface temperature (350 C-125 C) the effect of change in jet diameter on the surface cooling is more significant as compare to the temperature drop for the other higher ranges (Figure 2). It is also observed that the surface cooling time for the same temperature drop is highest for the lower range of surface temperature (Pt III). This observation remains the same for both the investigated jet diameter. The increase in surface cooling time with 2.5 mm jet diameter as compare to 4.8 mm jet diameter for various ranges (Pt I, Pt II, Pt III) having the same magnitude of temperature drop is shown in Table 3. The lower cooling time for the same surface temperature drop with higher jet diameter can be attributed by the increase in coolant flow rate for 4.8 mm jet diameter as compare to 2.5 mm. Though, the jet velocity with 4.8 mm jet diameter is approximately 90 percent lower than the jet velocity with 2.5 mm jet diameter. Since, it has been reported earlier that with the rise in jet velocity the surface cooling rate increases [4,5]. However, present results witnessed that the rise in coolant flow rate play an important role in the effective surface cooling rather than the rise in jet velocity.

Table3. Change in surface cooling time

Temperature range	**% Increase in time**
Pt I (800 °C-575 °C)	60
Pt II (575 °C-350 °C)	120
Pt III (350 °C-125 °C)	135

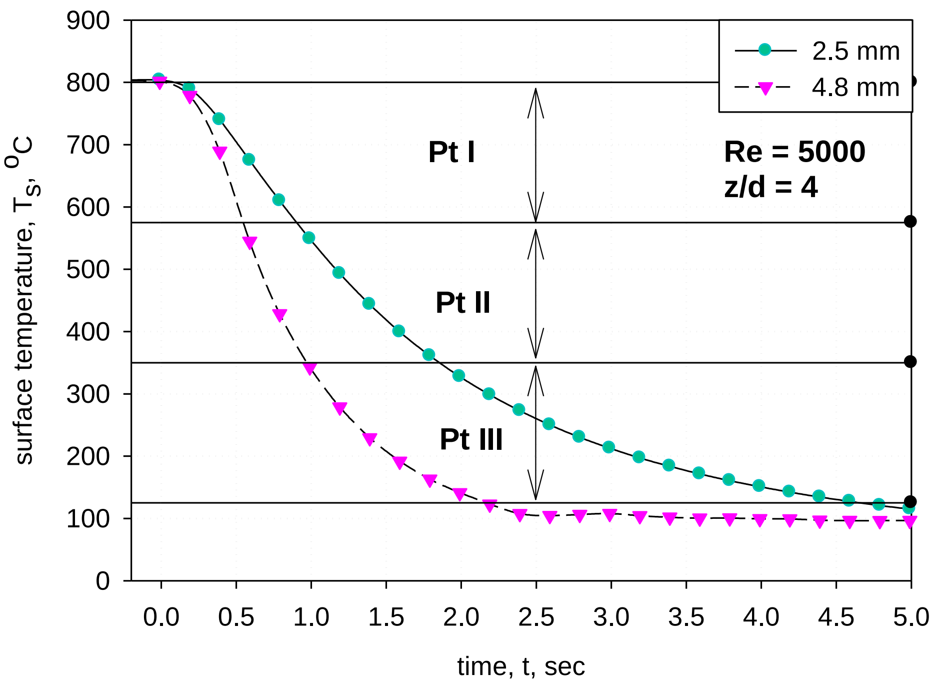

Fig 2: Surface cooling curves for different Jet Reynolds number

CONCLUSION

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.

REFERENCE

[1] M. A. Islam, M. Monde, P. L. Woodfield, and Y. Mitsutake, Jet impingement quenching phenomena for hot surfaces well above the limiting temperature for solid–liquid contact, International Journal of Heat and Mass Transfer, Vol. 51, pp. 1226–1237, 2008.

[2] C. Agrawal, R. Kumar, A. Gupta, B. Chatterjee, Rewetting and maximum surface heat flux during quenching of hot surface by round water jet impingement, International Journal of Heat and Mass Transfer, Vol. 55, pp. 4772-4782, 2012.

[3] C. Agrawal, R. Kumar, A. Gupta, B. Chatterjee, Effect of jet diameter on the rewetting of hot horizontal surfaces during quenching, Experimental Thermal and Fluid Science, Vol. 44, pp. 25-37, 2012.

[4] A.K. Mozumder, M. Monde, P.L. Woodfield, and M. A. Islam, Maximum heat flux in relation to quenching of a high temperature surface with liquid jet impingement, International Journal of Heat and Mass Transfer, Vol. 49, pp. 2877–2888, 2006.

[5] M. Akmal, A.M.T. Omar, and M.S. Hamed, Experimental investigation of propagation of wetting front on curved surfaces exposed to an impinging water jet, International Journal of Microstructure and Material Properties, Vol. 3 (4/5), pp. 654-681, 2008.