International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Online International Journal Available at http://www.cibtech.org/jet.htm
2012 Vol. 2 (3) July-September, pp.14-17/Agarwal

Research Article

JET IMPINGEMENT COOLING OF HOT HORIZONTAL SURFACE THROUGH SHARP EDGE NOZZLE

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ABSTRACT

A hot stainless steel surface of 3 mm thickness was cooled with the round water jet of 2.5 mm diameter from a sharp edge nozzle. The target surface was initially heated up to 800 °C and the target surface to nozzle exit distance is kept in a range of z/d = 4-16. Water flow rate is varied such that the jet Reynolds number remains in a range of 5000-24000.

In present experimental investigation it has been observed that for the stagnation point the surface cooling is not affected by the change in nozzle exit to surface spacing. However, with the jet Reynolds number of 24000 the time taken to attain the 100 °C by the hot surface is 30% less as compare to the jet Reynolds number of 5000.

Key Words: *Jet Impingement, Transient Cooling, Stagnation Point, Surface Cooling Curve*

INTRODUCTION

Jet impingement cooling has been used in many industrial applications due to its simplicity and excellent heat removal capacity. The jet impingement cooling method has been applied expensively in electronic, metal and nuclear industries. Numerous analytical and experimental studies for the steady state and transient cooling condition are presented by many investigators (Wang *et al.*, 1989; Watson, 1964; Webb and Ma, 1995; and Mozumder *et al.*, 2005). The studies for transient cooling have been reported for different surface material, surface and fluid temperature, jet exit to surface spacing and jet configurations (Mozumdar *et al.*, 2005; Mozumdar *et al.*, 2006; Agarwal *et al.*, 2012; and Agarwal and Maherchandani 2012). The performance of transient surface cooling by an impinging jet has been evaluated on the basis of surface cooling rate, the rate of wetting front movement over the hot surface and the transient surface heat flux (Agarwal *et al.*, 2012; Agarwal *et al.*, 2012). Once the jet impinges normally on an upward facing hot surface, the jet fluid remains stagnate for a while at the impinging point (Stagnation point) before the progression in the downstream location. That movement of the wetting front depends on the jet fluid temperature, jet diameter, surface material and the surface temperature. In the present experimental investigation the surface cooling rate has been examined only for the stagnation point by the change in jet water flow rate and the nozzle exit to the test surface spacing. For developing a round water jet, a sharp edge nozzle having orifice diameter of 2.5 mm is used. Normal tap water has been used as jet fluid and flow was regulated to maintain the jet Reynolds number as 5000 and 24000. The nozzle exit to test surface spacing is kept at z/d = 4 and 16. The test surface is made of stainless steel of 3 mm thickness and heated initially up to 800 °C temperatures.

MATERIALS AND METHODS

Experimental Set Up and Procedure

The schematic of the experimental set-up has been shown in the *Figure 1*. Initially, the water was supplied to a straight pipe where a sharp edge nozzle was screwed at one of its end. This straight pipe having the sharp edge nozzle was mounted on a vertical slide (4) of the work table (2). The schematic and photographic view of the sharp edge nozzle used for the investigation is shown in Figure 2. The test-surface (5) was placed underneath to the nozzle and the nozzle pipe assembly. The vertical slide can be shift vertically to adjust the nozzle to test surface spacing. A turbine flow meter (6) was used to measure the jet flow rate and was controlled with a flow control valve (7). A single Ungrounded K-type thermocouples were attached at the geometric centre and the back side of the test-surface. This thermocouple was then connected to the Data Acquisition System (3). The back side of the test surface was insulated by using a Teflon sheet. The test-surface was heated slowly to the initial temperature of 800 °C with a high ampere and low voltage current, supplied from a step down transformer. Surface heating and water flow was remains operating during the experiments.

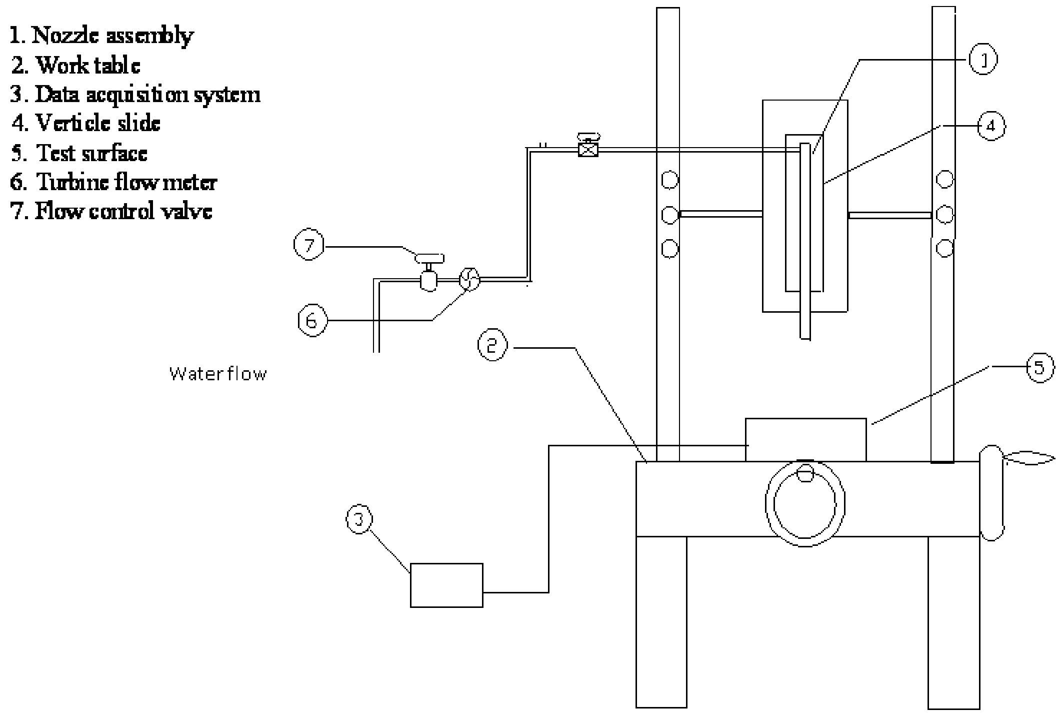

Figure 1: Schematic of experimental setup

Once the test surface attains desired temperature transient surface cooling was initiated with the impingement of the water jet. The change in surface temperature was recorded on the data acquisition system. The similar experiments were performed with the changed jet flow rate and nozzle o test surface spacing. The operating ranges of experimental parameters are shown in Table 1.

Table 1: Operating range of experimental parameters

Experimental Parameter	Operating Range
Reynolds number, Re	5000, 24000
Jet exit to surface spacing, z/d	4, 16
Nozzle diameter, d	2.5 mm
Thickness of test surface, w	3 mm
Water temperature, T_j	22 ± 1 ^oC
Initial surface temperature, T_i	800 ^oC

RESULT AND DISCUSSION

The transient surface cooling curve for the impinging point (stagnation point) is shown in Figure 3. These curves are for the investigated jet Reynolds number of 5000 and 24000 at nozzle exit to test surf ace spacing of z/d = 4 and 16.

It has been observed that at a fixed jet Reynolds number the change in nozzle exit to test surface spacing does not affect the surface cooling characteristics. This trend is in line with the result reported for the round water jet impingement cooling of a hot surface from a straight tube type of nozzles Agarwal *et al.*, (2012). The present result can be attributed that for a free surface water jet impingement air has no tendency of entrainment.

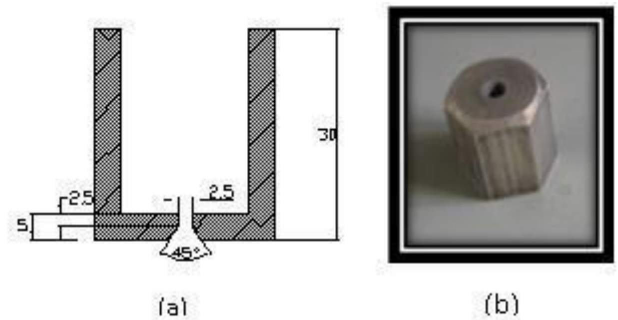

Figure 2: Sharp edged nozzle (a) Schematic view **(b)** Photographic view

The high density water jet is surrounded by relatively low density air, thus the shear forces act on water jet by the surrounding air is negligible. Therefore, the structure of the free surface water jet does not deformed before reaching to the target surface. Since, other operating parameters pertaining to the jet and the test surface remains the same, therefore, surface cooling is not affected by the change in nozzle exit to surface spacing.

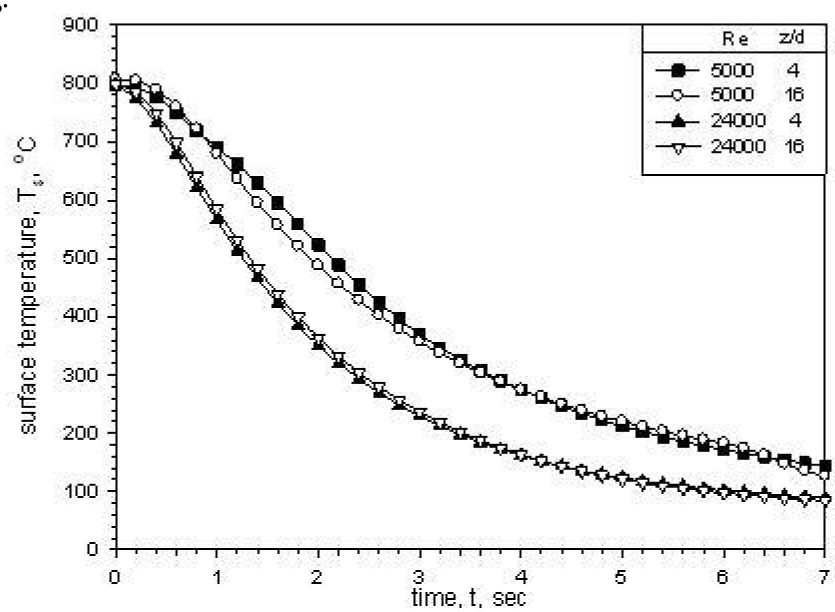

Figure 3: Transient surface cooling curves for the stagnation point

With the Figure 3 it has also been observed that with the increase in jet flow rate or the jet Reynolds number the surface cooling is increases. Although the rise in surface cooling is not as proportionate to the rise in jet Reynolds number. With the rise in jet Reynolds number by 4 fold (5000 to 24000) the reduction in surface cooling time is only 30 % to attain the surface temperature of 125 °C from its initial value of 800 °C. This result is also in line with the result reported for the surface quenching through jet impingement from straight tube type nozzle Agarwal and Maherchandani (2012). The reduction in surface cooling time with higher jet Reynolds number can be attributed by the rise in coolant flow rate and the rise in jet velocity. Whereas, the reduction in surface cooling time which is not in proportion to the rise in jet Reynolds number may be due to the splashing of jet strikes the hot surface. The higher jet flow impinging on the test surface leads to higher splashing of jet fluid, thus the rise in jet fluid volume with the increase in jet Reynolds number is not utilized completely to cool the surface.

CONCLUSION

The results of transient cooling of electrically heated hot surface with the jet impingement from a orifice type sharp edge nozzle is in line with the jet impingement cooling from a straight tube type nozzle. With the sharp edge nozzle also the surface cooling rate increases by the rise in jet Reynolds number. Although the percentage rise in jet Reynolds number is not reduces the surface cooling time in equal proportion. The effect of rise in nozzle exit to surface spacing on surface cooling has also not witnessed with the sharp edge nozzle jet impingement cooling also.

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