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TRANSIENT SPRAY COOLING OF TOP AND BOTTOM OF MOVING HIGH TEMPERATURE SURFACES

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ABSTRACT

Application of high pressure water spray cooling of, particularly, both top and bottom of heated surfaces (up to 1300 ^{0}K) has been common practice, in steelmaking, aluminium and metal powder production. In achieving consistent mechanical and metallurgical properties in the alloys, an accurate control of both surface temperatures is predominately the governing factor during the process operation. Moreover, the lack of knowledge in understanding the hydrodynamic and thermodynamic behaviour of the spray droplets on the moving surface, in for example, upstream steel manufacturing processes of the hot rolling, can reflects on the overall production costs and the final product quality.

An experimental investigation has been performed with a vertically downwards spray impinging from the top, onto the rotating test piece segment and also simultaneously spraying upwards onto the disk, from the bottom, with the surface temperature of up to 400 ^{0}C . Three full-cone atomisers with orifice diameters of 0.94-1.70mm were used. Measurements were made at vertical distances of 140 and 240mm from the atomiser tip to the test segment, using pressure up to 2.07MPa and with the speed of the rotating disk 60 and 120rpm, in studying the effect of the spray parameters on the cooling of rotating disk surface. The spray parameters considered were volume median drop diameter ($D_{v0.5}$), drop impinging velocity (U) and drop mass flux (G) with the range of 0.98 to 12.5 kgm^{-2}s^{-1} for mass flux, 49.0 to 230.4 µm for volume median drop diameter and 9.8 to 32.3 ms^{-1} for impinging velocity.

The pertinent finding of this work also includes that, the difference in the local heat flux between the top and bottom of the moving surfaces is about 35%, since the sprays on the bottom surface are subjected to gravity upon the impaction. Engineering correlation equations are also developed by using Excel software and presented as maximum local heat flux. Comparison of the measured maximum local heat flux, q_{max}, with the heat flux from the obtained correlation for both top and bottom surface are also presented.

INTRODUCTION

The industrial utilization of sprays and atomisation techniques are described by Nasr et al [1] which includes for example, spray forming, spraying molten metals, gas turbines, food manufacture, agriculture, diesel engines and steel making. High-pressure sprays are used effectively to cool hot objects in many processes due to their convenience of use and high heat dissipating ability. In particular water spray used in cooling of heated surfaces, for example during continuous casting and, hot and cold rolling process of steel making.

Although considerable work has been carried out in this field for dilute sprays, rather than the dense sprays, using low-pressure sprays or two-fluid atomization, which has more restricted industrial applications [2]. Nevertheless, much more is desired in terms of quantitative information with regard to the atomization parameters and their effects on spray cooling. Previous studies have been carried out on steady state and transients conditions [2-4], for example where the heat input is used to maintain a steady state surface temperature (about 1500 ^{0}K), or for the surface that is allowed to cool during the spraying. There is, however, a lack of information on the fundamental mechanisms of heat transfer to an array of impacting drops on the hot moving surface. Recent studies carried by Nasr et al [4] and Rho [5] present some of the results with relatively dense sprays on transient conditions, spraying *only* on the upper surface of the moving disk heated to 600 ^{0}C. There is, however, a growing concern in industry with obtaining systemic information on the effects of the spray parameters at high water pressure on the heat transfer characteristics for both sides of the moving hot surfaces in order to achieve the desired rate of cooling.

The main objectives of the present work are: (a) to study experimentally the heat transfer characteristics of vertical sprays impinging upon a top and bottom surface of a hot moving disk, heated up to 400 ^{0}C, where the sprays have a range of densities, produced by using full cone atomisers for water supply pressures up to 2 (MPa) with a range of exit orifice diameters (b) to study heat transfer using high-pressure water sprays and a rotating moving disk, with surface velocity of up to 1.4 m/s and (c) to examine and correlate, the parametric effects of mass flux, drop size and impinging velocity on heat transfer for temperatures up to 400^{0}C and (d) to provide and obtain comparison of the heat transfer characteristics of the upper with a lower moving surface.

EXPERIMENTAL APPARATUS AND PROCEDURE

Test Apparatus

The test apparatus based upon the concept of a rotating disk has been previously described by Nasr et al [4] which , ideally meet the various conditions found in steelmaking and should be able to meet the specifications of providing (a) achieving high and uniform initial surface temperatures, in the range 100- 900 ^{0}C, (b) obtaining the required strip speeds up to 18 (ms^{-1}) (c) accurately measuring the temperature drop as the hot surface passes through the spray and (d) simultaneously spray bottom and top surfaces and adjustment of the moving surface to have an angle up to 45 ^{0} to horizontal. The spray angles can be related directly to the present conditions of the so-called inter-stand [1] cooling process where the angle of the steel strip in the hot rolling mill is changed between 18-45^0 with respect to the horizontal by a “looper”, which is installed between stands in order to maintain an appropriate strip tension. The rotating disk apparatus which is to fulfil a laboratory environment consists of a main frame constructed of tubular steel box section, and as shown schematically in Fig. 1, a heating system, a spray system, and a rotating test disk. The main frame supported the shaft on which was mounted the rotating disk, the slip ring commutator, the motor and the burner. The design allowed the possibility of the shaft and disk being tilted without significant deformation occurring. The atomizers mounted on a separate frame, thus allowing their orientation to be changed independent of the disk and with the “disk” being an annular mild steel ring, heated by gas burners, contains an instrumented test segment as shown in Figures 1 and 2 respectively. The present study sprayed simultaneously, vertically downwards onto the top and upwards onto the bottom of the horizontal rotating surface, thus simulating the condition which is directly related to the hot rolling process in the steel making. The mild steel test segment, similar to the hot rolling product, shown schematically in Fig. 2 was tapered10^0 to prevent of becoming loose upon centrifugal force whilst the disk is being rotated and was in two pieces, providing convenience in welding thermocouples to the bottom of their respective holes. There were nine holes on three planes to measure temperature differences between the thermocouples in order to derive heat fluxes in the metal as labelled thermocouple 1 to thermocouple 9 in Fig. 2. Each set of holes was staggered at around 45^o to minimise temperature distortion caused by having all three ceramic insulators in a vertical line. The top and bottom surfaces of the test segment was directly exposed to the sprays through a 40mm x 10mm slot in a protective canopy, made from stainless steel ‘thin plate’ product, and was a height of 100mm, placed above the upper and lower surface. The slots was thus intended to provide homogeneous central spray zone for impact on the surface. Homogeneous cooling of the surface also required, ideally, that the temperature was effectively uniform across any radius of the test segment.

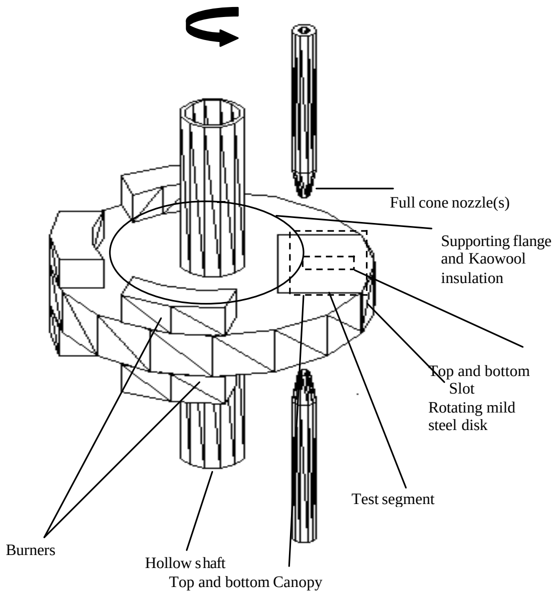


Fig.1 Schematic of transient apparatus

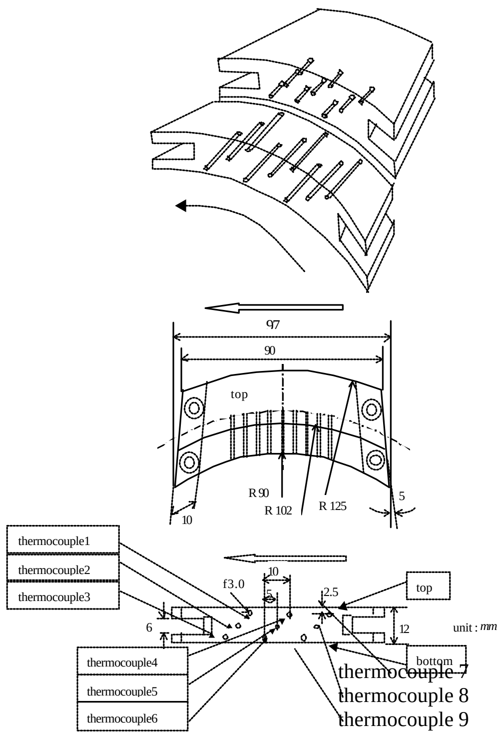


Fig.2 Detail of test segment

Six specially designed propane-oxygen SMST (surface mix surface tube) burners manufactured by Nordsea Gas Technology Ltd (NDT) are used with the maximum heat output of 34 kW. Three burners are mounted on the top of the disk and three underneath it. The intensity of the heat can be controlled in three ways, adjusting the regulators, using the control valve or moving the burners 10 to 50mm away from the corresponding heated surface.

Three different full cone atomizers, manufactured by “Spraying Systems Co. “, referred to as “TG0.5, TG1.0 and TG3.5” were used, providing maximum injection pressure of 12.0 MPa [4]. Water was supplied to these atomizers by a high-pressure plunger pump manufactured by Speck Triplex Ltd.).

To measure the rapid temperature drop in the transient cooling test under rotating conditions, thermocouples were connected to a slip ring commutator manufactured by (I.D.M Electronics Ltd). The timer disk, attached to the top of the hollow shaft, with a hole and 126 slots, was specially made for the rig and it was used, not only to measure the speed of the rotating disk, but also to synchronise measurements with position of the instrumented segment of the disk relative to the spray centre. The two optical detectors connected to a tachometer provide indication for the disk speed and synchronisation pulses to a PC. The speed of the rotating disk was displayed digitally on the speed controller with an accuracy ± 2 (*rpm*). The synchronisation measurement device sent voltage signals of +10 (*V*) to the data acquisition system when the forepart of the test piece passed the vertical centerline of the nozzle exit.

The data acquisition (DA) system manufactured by National Instrument (NI) consisted of a Pentium PC, ADC, "LAB VIEW" for Window 2000/NT and Application Program Interface (API), the system uses devices that connect to the computer allowing the user to retrieve digitised data values. These devices typically connect directly to the computer through a plug-in slot, with "DA" devices, the hardware only converts the incoming signal into a digital signal that send to the computer. The computer receives the data through software and presents it in a form the user can understand. The maximum sampling data rate was 16kHz per channel. The outputs of the thermocouples from the test segment via slip ring were amplified to a maximum of ±10V and converted to temperatures via ADC and DA board through software signal conditioning. Common software signal conditioning includes amplification, cold junction compensation (for thermocouples) and filtering. The most common type of signal conditioning is amplification; amplify electrical signals to improve the digitised signal accuracy and to reduce noise. Signal conditioning systems can filter unwanted signals or noise from the measured signal. Overall, using the calibration data file in the “Lab View”, individual temperatures samples were measured to an accuracy of ±1 ^{0}C.

Test Procedure

It was decided as part of this ongoing investigation to carry out all tests at rotational speeds of 60rpm and 120rpm which were also used by Rho [5] and performed with a vertically downward sprays impinging onto top surface of the horizontal rotating disk. The current tests, however, performed by simultaneously spraying top and bottom surface of the rotating disk and measurements were made at vertical distances of 140 and 240 (*mm*) from the atomizer tip to the test segment, using pressure 0.69, 1.38 and 2.07 *(MPa)*.

The segment and the whole disk was heated first without the spray, until all thermocouples registered the initial preliminary temperature of 200, 300, 400 ^{o}C (within ± 2%). When these target temperatures were achieved, the burners were switched off and then the spray was turn on. The spray was not allowed to impact on the test specimen until it had achieved a stable spraying condition which took at least 10s. A sliding cover was used to cover the rectangular slot orifices, at both top and bottom disk surfaces, until the spray reached a steady state and then manually removed. Approximately 10s before the spray stabilised, the data acquisition system was then being triggered. As the specimen started to cool the time histories of the temperatures were recorded through the "LAB VIEW" processing facility.

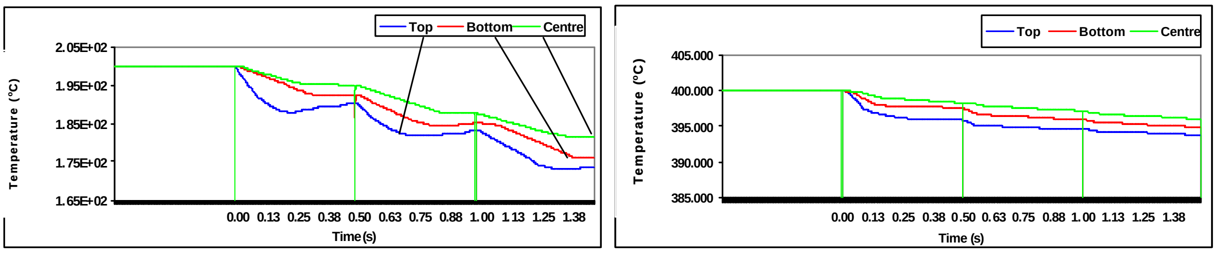
The test segment was polished before starting a test in order to minimise the effects of roughness of the surface, the time histories of the temperatures were recorded for the first traverse of the segment through the spray and, typically 4 further disk revolutions. Using different data rates and total sampling times thus enabled the detailed measurements for the first pass and multiple passes to be more accurately made. Heat flux from the surfaces was calculated as described in the next section.

The temperatures of the specimen were obtained from the thermocouples 7, 8 and 9 (see Fig.2). Although the temperatures of up to 1300 ^{0}C were possible, they were however , at this stage, restricted to maximum of 400 ^{0}C and it is intended to move to higher temperature in future investigations. The others were significantly affected by water penetration of the gap between the test segment and the reminder of the rotating disk. The rotational speeds of the disk 60 and 120 (*rpm*) provided tangential velocities of 0.7 and 1.4 (ms^{-1}), the velocities although relatively low, are commonly found in steel making which can also be up to 18 *m/s*, particularly in hot rolling mills.

EXPERIMENTAL RESULTS AND DISCUSSION

Application of "LAB VIEW" allows the removal of noise through filtration, by smoothing the data during data processes. Fig.4 shows an example of the temperature-time curves of the top and bottom surfaces consist of four regions: the non-spray zone, and the 1st, 2nd and 3rd spray zones. The non-spray zone occurred because of a typical time delay between opening the aperture and the spray reaching the test piece, estimated to be a maximum 1.4 (*s*) through all the tests. Furthermore The non-spray period was useful for confirming that thermocouples were operating satisfactorily and that temperature was homogeneous in the test piece to within ?1^{o}C. When the forepart of the test piece passed a vertical centreline through the nozzle exit, the first synchronising pulse was recorded and used to define “zero-time”, as shown in Fig.4. After synchronising pulses were recorded, a small time gap, estimated to be within 0.05s at 60rpm and 0.025s at 120 rpm, was found until the starting point of cooling because of the difference of a circumferential alignment angle, between the first synchronising pulse position and the thermocouple position.

Temperatures were maintained at relatively constant values in the non-spray zone, and they then dropped rapidly after impaction of the water spray. After the test piece left the cooling area, temperatures recovered to some extent (due to heat redistribution in the metal), until it entered the next cooling stage. The repeated cooling and heat recovering signals were very similar in their patterns, which is an additional check on experimental accuracy.



(a) (b)

Fig. 4 Temperature-time histories using 1.70mm nozzle at 2.07 MPa, (a) initial temperature 200 ^{0}C, 60rpm, x=140mm, (b) 400 ^{0}C, 120rpm, x=240mm

Fig. 4 shows the representative temperature-time histories in the three different positions of thermocouples 7, 8 and 9. At initial temperatures from 200 to 400 °C pressure 2.07 (*MPa*), nozzle diameter, 1.70 (*mm*), different rotating speeds, 60 and 120 (*rpm*), and surface-nozzle distances, 140 and 240 (*mm*), are shown in order to review temperature drop according to changes of surface-nozzle distances and rotating speeds. The temperature at position 7 and 9, which lies near the surfaces, drops rapidly after impaction of the first water spray, and reaches a minimum before it recovers when the heating (conduction) from within the test piece overcomes the cooling. The temperature then continues to recover slowly, by means of heat redistribution from all parts of the test piece, until the segment enters the next cooling stage, giving repeated cooling and heat recovering, as shown in all the conditions.

It is also observed that the temperature drops at the top (thermocouple 7) more than the temperature drop at the bottom (Thermocouple 9), the difference of about 35 % can be observed as typically shown in Fig. 4. This is an expected trend, as experienced by Nasr [1] at Corus Ltd, UK. This could be due to the gravitational effects on the sprays, impacting on the lower surface of the rotating disk, which tends to pull the spray down.

At low speed, (the rotating disk at 60 (*rpm*)) the temperature drop relatively higher than at 120 (*rpm*). This can be attributed to the fact that less residence time of spray is experienced in the cooling zone for the higher speed. Naruhito [6] and Klinzing [7] also experienced adverse effect of the speed of moving objects.

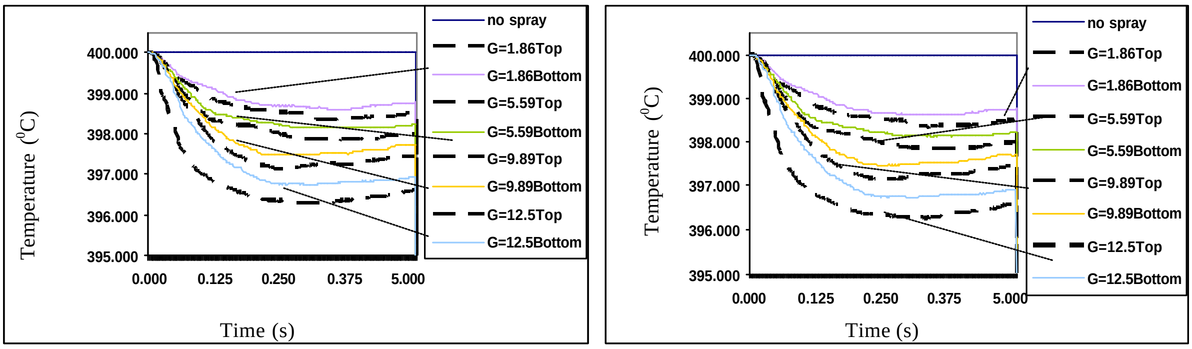
The changes of spray characteristics, due to the different surface-nozzle distances, also affect the cooling rate of the test piece, for stationary surfaces, as described by Fry [8]. For example, increasing the surface-nozzle distance causes less temperature drop on both sides of the test piece, mainly due to the decreasing of mass flux. It is noted that the actual surface temperature in both surfaces (top and bottom) in the region of direct contact with the water spray are lower than middle thermocouples position of the test piece, because the thermocouples 7 and 9 were under direct contact with the spray from both sides. Temperatures in the central part of test piece (thermocouple 8) generally are without rapid temperature drops (see Fig.4).

It is seen that in the case of T = 200 °C Fig. 4(a), temperature drops are relatively higher than in the other, for example, extreme of cooling rate, shown in Fig. 4(b). This is because the surface at temperature 200 *°C* is regarded as in the transition regime, and has a much higher heat transfer coefficient than the other temperatures, that are in the film regime (300 ^{0}C to 400 ^{0}C). For the same sprays, Jeong [9] observed that the surface temperature dropped rapidly, during transient cooling tests between 150 and 204 °C, and regarded this as the transition regime, with a stationary surface. Naruhito et al [6] concluded that, so called, the "quenching point", (the Leidenfrost point) occurred in the temperature range between 230 - 240°C, in their experimental results. Thus the temperatures from 300 to 400 °C in the present experiments can all be regarded as being the film- boiling regime.

In order to minimise temperature distortion, caused by having ceramic insulators in a vertical line, the thermocouples were staggered. The phase (time) differences due to stagger were under 0.007 (*s*), both between thermocouples 7 and 8, also between thermocouples 8 and 9, at 60 (*rpm*), and half this time at 120 (*rpm*). The data files have thus not been corrected for these phase differences because they are small relative to the time scales of temperature variations.

From the general results obtained, temperature-time curves display relatively repetitive curves of the cooling and restoring process in and after the spray zones. The present study is focused on the first spray zone and with reference to Fig. 4 which show the temperature-time histories on expanded scales at the top position (thermocouple 7), at the center position (thermocouple 8) and bottom position (thermocouple 9) during the first spray, with four different mass fluxes from 200 to 400°C. The four mass fluxes, 1.86, 5.59, 9.89 and 12.50 ($kgm^{-2}s^{-1}$), are selected as reported previously [4].

Fig. 5 shows a typical trend of temperature-time response for four different mass fluxes at both 60 and 120 (*rpm*) for top and bottom surface, Figures 5 (a) and 5 (b) respectively**.** The present results for the top surface are in close agreement with those found by Rho [5] with the same adopted conditions herewith. From the results, the temperature drops generally increase with increasing mass flux for temperatures 200 to 400°C as shown in Fig. 5. This confirmed that the mass flux is one of the main parameters, determining heat transfer in both transition and film regimes, as it was also observed with work using stationary surfaces [3].



(a) (b)

Fig. 5 Surface temperature time histories at four different mass fluxes, *G* ($kgm^{-2}S^{-1}$), at (a) 200 ^{0}C with rotating disk at 60*rpm*, and at 400 ^{0}C at 120*rpm*

LOCAL HEAT FLUX

One dimension heat flux calculation procedure was used here for calculating the "evaporative heat flux" which treats the test piece as an infinitive plate moving [4] with a velocity which is that of the tangential velocity of the center of the test segment [4]. The "evaporative heat flux" can therefore be represented as $q_w = \frac{\rho VDC_p(\Delta T_{av} - \Delta T_{nospray})}{2\pi L}$ (Wm^{-2}), Where $V = dL/dt$, L is maximum distance (**L = 675 *mm***).

The variations of evaporative heat flux according to the distance during the first revolution of the test piece segment under the spray were obtained by applying the equation of the "evaporative heat flux". The typical results are shown in Fig. 6 for the two full cone atomises (TG1.0 and TG 3.5) at different conditions. Note that the synchronisation pulses shown the graphs represent the points where the forepart of the segment passed under the spray centre-line. Fig. 6 also shows the heat flux curves for 200 ^{0}C initial surface temperature, where each figure shows the results for the pressure of 0.69 MPa for both top and bottom surfaces and two different nozzle-surface distances at 60rpm. Similar trends were also obtained for 300 ^{0}C and 400 ^{0}C surface temperatures and other operating conditions and for the rotational speed of 120rpm. The pertinent finding which shows on Fig. 6 is that, there is a *35%* difference in local heat flux of top surface compared with the bottom surface. This is an expected trend as experienced by Nasr[1], which is mainly due to gravitational behaviour, which pulls down the corresponding sprays from bottom [9] surface upon or before impacting onto the moving surface. This was also found when all other surface temperatures were examined. Broadly speaking, the local heat flux increases just after the impaction of the water sprays and reaches maximum around 75 (*mm*) from the beginning of the first spray, and after that starts to come down with the increase of the distance. The test segment can be seen to be cooling prior to passing the spray for the second time, it is also observed that the heat flux as shown in the Fig. 6 at temperature 200 ^{0}C (in transition regime) are high than at the other temperatures 300 and 400 ^{0}C (in film boiling regime). This is expected due to the region associated with film boiling, a vapour layer insulates drops from the heated surface and small drops rebound from the surface. Nasr et al[4] and Jeong achieved the film-boiling regime using the same atomisers with stationary finned test segment in steady state cooling. In general the heat flux: (a) increases with increasing nozzle orifice diameter, (b) increases with increasing supply pressure, (c)decreases with increasing the distance between nozzle tip and the test surface and (d) decreases with increasing the rotational speed.

Fig.7 (a) shows the heat flux at temperature 400 ^{0}C with the lower speed of the rotating disk 60 (*rpm*), which are relatively higher than at 120 (*rpm*) as typified in Fig.7 (b). The heat flux decreases with increasing in the rotational speed for all cases, due to:(a) less residence time of the surface in the spray in the cooling zone at high rotational speed, and (b)tangential velocity gives a different relative spray angle when the spray impacting on the heated segment. This was also observed by Yao et al [10] in which, the increase of the speed of the rotating disk affects in the droplet impact angle, due to the entrained air.

(a) (b)

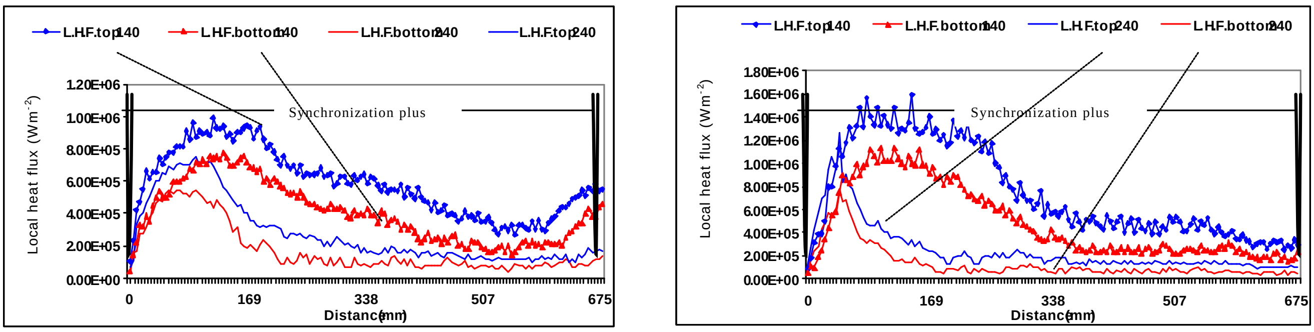


Fig. 6 Effect of nozzle distance on Local heat flux, q_W at temperature 200 ^{0}C with 0.69 (*MPa*) with atomiser-surface distance (d), 140, 240(*mm*) and speed of rotating disk 60 (*rpm*) for top and bottom surface and for nozzle (a) TG1.0 and (b) TG 3.5.

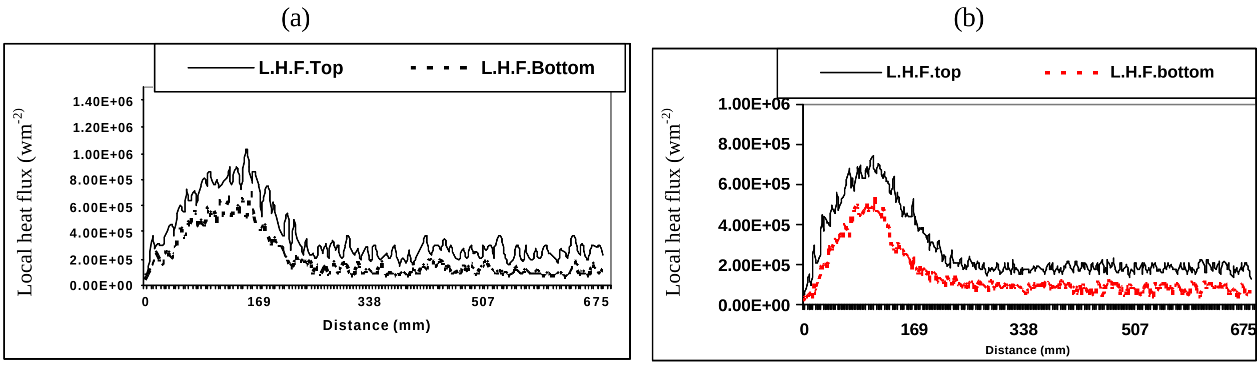


Fig.7 Local heat flux q_w at temperature 400 ^oC with three different pressures at atomiser-surface distance 140mm for (a) at speed of rotating disk 60rpm and nozzle TG3.5 and (b) at speed of rotating disk120rpm for nozzle TG1.0.

Spray characteristics of the central zones of full cone nozzles are function of are functions of supply pressure (*P*), exit orifice diameter of atomizer (d_o) and atomizer surface distance (*x*). When the distance from the atomizer tip to the heated surface increased, all three parameters, mass flux, impinging velocity and drop median diameter, are decreased. The effects of mass flux (*G*), median droplet diameter ($D_{v0.5}$) and the mean droplet velocity (*U*), it is difficult to discriminate by visual inspection of the data, which thus requires correlation methods. However, it is difficult to vary one parameter at a time, although it can be seen that the clearest correlation, with the least scatter, is between the maximum heat flux and mass flux. This in turn confirms the importance of the mass flux in determining the heat transfer. Fig. 8 shows the maximum heat flux against individual spray characteristics for the 200 ^0C for top and bottom surfaces for 60rpm cases. At 60 (*rpm*) the ranges of maximum local heat flux are from 4.0 ? 10^5 to 2.6 ? 10^6 (Wm^{-2}) and at 120 (*rpm*) from 4.8 ? 10^5 to 1.6 ? 10^6 (Wm^{-2}).

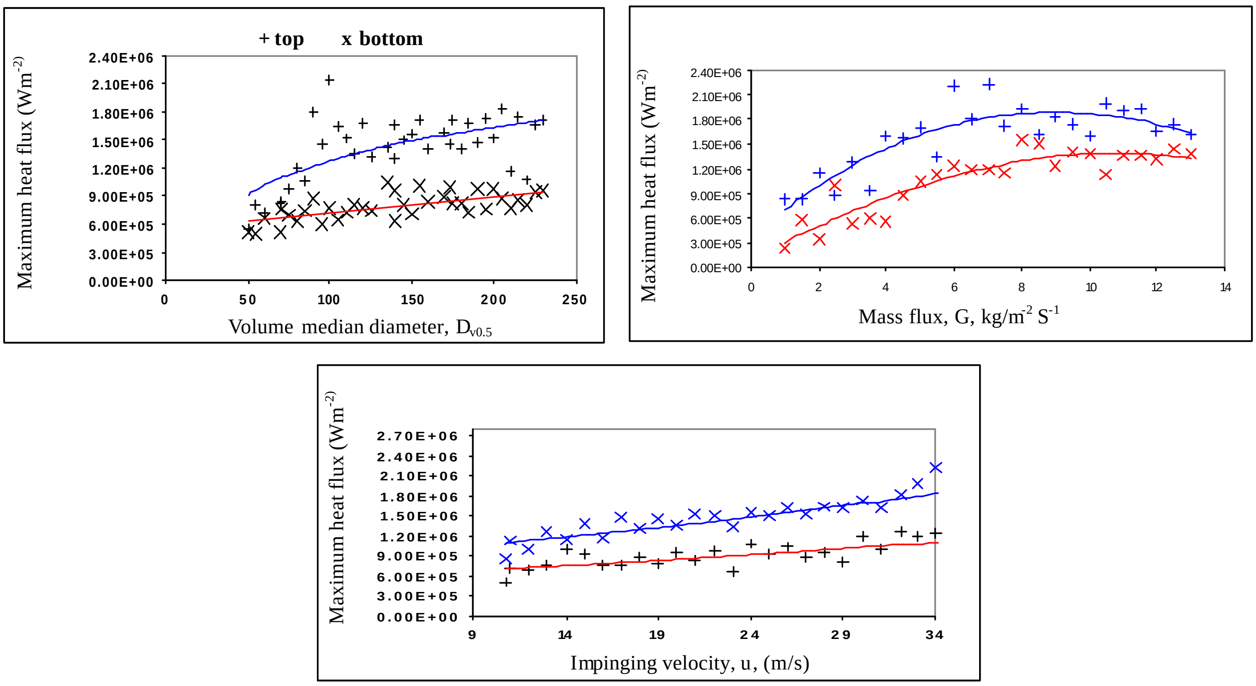


Fig. 8 Effect of spray characteristics on maximum heat flux at temperature 200 ^0C (*G*, and $D_{v0.5}$ were not varied independently of each other)

Empirical correlations for maximum heat flux were obtained by using *"MS"* software the experimental for the range of the spray parameters is 0.98 to 12.50 ($kgm^{-2}s^{-1}$) for mass flux (*G*), 49.03 to 230.40 (*µm*) for volume median drop diameter ($D_{v0.5}$) and 9.77 to 32.32 (ms^{-1}) for drop impinging velocity (*U*). The software did not allowed calculations with more than four variables, which are impinging velocity (*U*), volume median diameter ($D_{v0.5}$) and mass flux (*G*). Superheat $?T_e$ was excluded due to no spray correction raised to different powers. The calculated data, using SI units for G, U and $?T_e$, but using *µm* for $D_{v0.5}$, are those obtained by the equation shown in the following:

$$q_{\max\ Top\ 60rpm} \ ?\ 2.0\ ?\ 10^6\ ?\ G^{0.229}\ ?\ U^{0.271}\ ?\ D_{v0.5}{}^{0.173}\ ?\ ?\ T_e{}^{?0.496} \qquad (1)$$

$$q_{\max\ Top\ 120rpm} \ ?\ 1.5\ ?\ 10^6\ ?\ G^{0.226}\ ?\ U^{0.270}\ ?\ D_{v0.5}{}^{0.173}\ ?\ ?\ T_e{}^{?0.577} \qquad (2)$$

$$q_{\max\ Bottom\ 60rpm} \ ?\ 1.9\ ?\ 10^6\ ?\ G^{0.228}\ ?\ U^{0.272}\ ?\ D_{v0.5}{}^{0.172}\ ?\ ?\ T_e{}^{?0.58} \qquad (3)$$

$$q_{\max\ Bottom\ 120rpm} \ ?\ 1.4\ ?\ 10^6\ ?\ G^{0.225}\ ?\ U^{0.264}\ ?\ D_{v0.5}{}^{0.169}\ ?\ ?\ T_e{}^{?0.675} \qquad (4)$$

Fig. 9 shows the typical comparison of the measured local heat flux for top and bottom surface using the correlation equations 1 to 4. The maximum heat flux increase with increasing mass flux (*G*) and impinging velocity (*U*), the effects of the mass flux and impinging velocity on maximum heat flux for 60 (*rpm*) tend to be more significant than for 120 (*rpm*). The main effects factor in the correlations is the surface superheat temperatures, and the drop size has the smallest effect on the heat transfer. The difference in heat transfer between the upper and lower surface, as has been described, is about 35%, which can also be seen in Fig. 9.

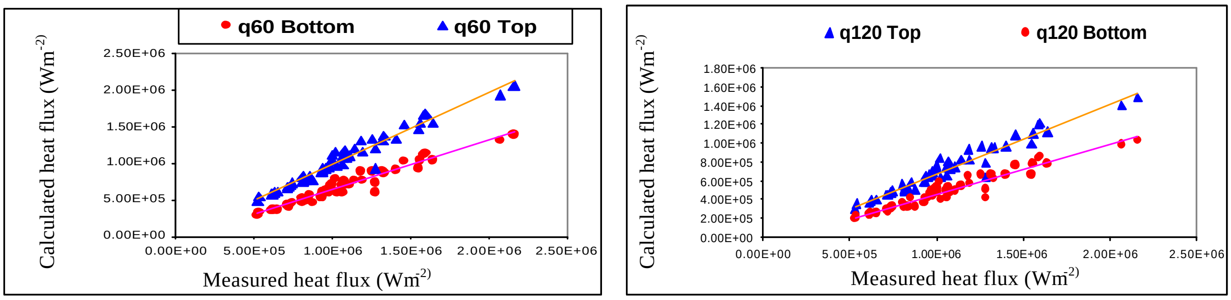


Fig.9 Comparison of the measured maximum local heat flux with the heat flux from correlation equations 1-4.

CONCLUSIONS

Rotating disk technique has been proved a convenient method to determine surface heat transfer during spray in both upward and downward directions. Care is required during smoothing the rotating surface results, especially beyond 90 ^{o} of rotation. Local heat flux increases just after the impaction of the water sprays, and reaches a maximum around 75 (*mm*) up and downstream for both surfaces. Heat fluxes at temperature 200 ^{0}C (in the transition regime), are higher than the other temperatures 300 and 400 ^{0}C (in the film boiling regime). The heat flux generally increases with increasing, nozzle orifice size, supply pressure, decreasing with the nozzle surface distance and decreasing with the rotational speed. In film boiling regime, maximum heat flux at rotating disk 60 (*rpm*) decreases significantly in comparison with the transition regime from 4.0 ? 10^5 to 1.4 ? 10^6 (Wm^{-2}), and at 120 (*rpm*) from 4.8 ? 10^5 to 1.1 ? 10^6 (Wm^{-2}).

The local heat flux decreases by up to 35%, when the top and bottom moving surface are compared together, since the bottom sprays is subjected to gravitational effects.

Whilst recognising that the corresponding correlation equations are not dimensionally correct, they are very useful in revealing features of the physics of the flows. For each rotational speed, using the correlation equations, maximum heat flux found to be increasing with mass flux, *G* and impinging velocity, *U* raised to similar powers, thus indicating the importance of droplet momentum flux.

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