LIQUID AND GAS JETS IMPINGING ON A MOVING WETTED SURFACE

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Summary In continuous metal processing operations a cooling liquid is often applied to reduce the temperature of the strip. This liquid needs to be removed before downstream rolling operations can be undertaken. This paper contains the theoretical development and predicted results for both analytical and computational models of a combined liquid and gas jet wiping system designed to remove cooling liquid from the surface of a continuous moving strip.

The jetting system, shown in Figure 1, consisted of a liquid jet impinging onto a moving metal strip. A gas jet, located downstream of the liquid jet, is applied to the strip surface to remove undesirable liquid remaining on the strip surface. Both jets are configured in the symmetrical pattern and transversely span over the strip surface. Typical operating conditions are: strip velocity, v_s, of 18 m/s, strip width, W, of 1-2 m, and a plenum chamber clearance, H, of 22 mm.

An analytical approach was used to determine the average cooling liquid height on the moving strip upstream of the jetting assembly. The liquid height was obtained by relating the liquid draining over both sides of the strip to the head of liquid – a discharge coefficient of unity was assumed. It was found that the average height, h_f, varied between 20 – 30 mm as the strip width increased from 1 to 2 metres. This would suggest that the liquid build-up would be at least the same height of the clearance between the nozzle outlets and the top of the strip (i.e. 22 mm). The thickness and velocity profile of the cooling liquid boundary layer was also calculated, based on turbulent flow conditions. It was found that the thickness was in the range 5 – 15 mm, depending on the strip velocity and a cooling liquid injection point 0.5 m upstream from the jetting assembly. The overall cooling liquid velocity profile, therefore, was a moving boundary layer, above which was a pool of relatively stationary liquid.

A momentum balance was carried out to determine if the combined liquid and gas jet momentum were sufficient to prevent the cooling liquid from travelling downstream with the moving strip. Drainage in the direction of strip motion was also included. The analysis showed that the momentum of the liquid jet was an order of magnitude higher than that for the boundary layer flow on the strip, and should provide an adequate "dam" effect against the oncoming stream. It is thought that the action of the gas jet provided mainly a "wiping" effect to remove any gas jet liquid forced to travel in the direction of the strip motion.

Computational Fluid Dynamics (CFD) modelling of the jetting system was successfully developed based on the VOF technique. The governing equations included the continuity and momentum equations formulated in terms of the liquid volume fraction and the flow variables (velocity and pressure). Turbulence was incorporated using the standard k-ε approach in combination with the standard wall function. The finite volume scheme was used to discretise the governing equations which were solved using the commercially available Fluent CFD code. The computational boundary included the wall, the moving wall, the pressure/velocity inlets for the gas and liquid jets, and the pressure outlets. The gas-liquid interface shape was modelled based on the Laplace equation and the contact angle at the interface contact with the wall. The computational domain was meshed non-uniformly by the tetrahedral scheme, with strong grid clustering at the strip surface and along the direction of the liquid jetting.

The two-way coupling, involving an iterative approach, was used to obtain the interaction between the flow fields of the liquid and gas jets, and also the thickness of the liquid film remaining on the moving strip. The computational analysis was undertaken for a number of conditions to determine the effect of liquid and gas jet incident angle and plenum pressure, and strip speed, on the amount of liquid remaining on the strip surface. It was found that when no gas jet was applied a thin film of liquid remained on the strip surface, where the thickness of the film was most strongly influenced by the liquid jet incident angle. When the gas jet was applied it was found that the liquid film was removed in all cases tested (Figure 2). The distance downstream from the liquid jet stagnation point on the strip surface where the film was completely removed (Figure 3) was function of gas jet incident angle and plenum pressure. As expected, the trends observed were directly related to gas jet momentum parallel to the strip surface and opposing the motion of the liquid. Consequently, the optimum conditions to minimise the possibility of liquid remaining on the strip surface include maximising the gas plenum pressure and minimising the jet incident angle.

An insight into the liquid spray generated by the action of the gas jet on the moving liquid film can be gained by considering Figure 4. The boundary between the liquid (jet) and gas phase is shown as an inclined line. The velocity contours highlight the very high velocities generated within the liquid phase at angle not parallel to the moving strip. In practice it is highly likely that the momentum of the fluid would cause the film to breakup and be released from the film in the form of small droplets. A very general estimate of the trajectory angle and quantity of the ensuing liquid spray could be obtained from further analysis of the velocity field.

Finally, the computational analysis indicated significant recirculation of gas within the enclosed region between the two jets. The enclosed region was generated as a result of the two dimensional constraint imposed upon the computational domain. This condition would apply to the longitudinal axis of the strip where there would be little transverse motion of gas. However, the transverse motion would be expected to increase away from the centre of the strip and nearer to the sides. A fully 3D analysis would be needed to create a more realistic description of the flow in this region of the strip.

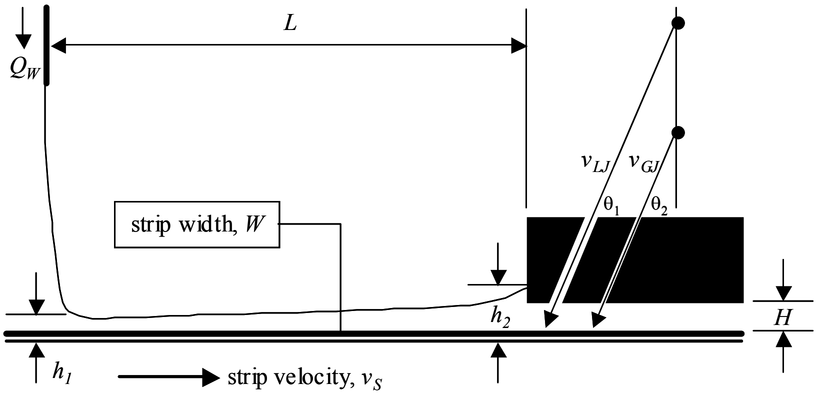

Figure 1: Basic Geometry for the Analytical Model

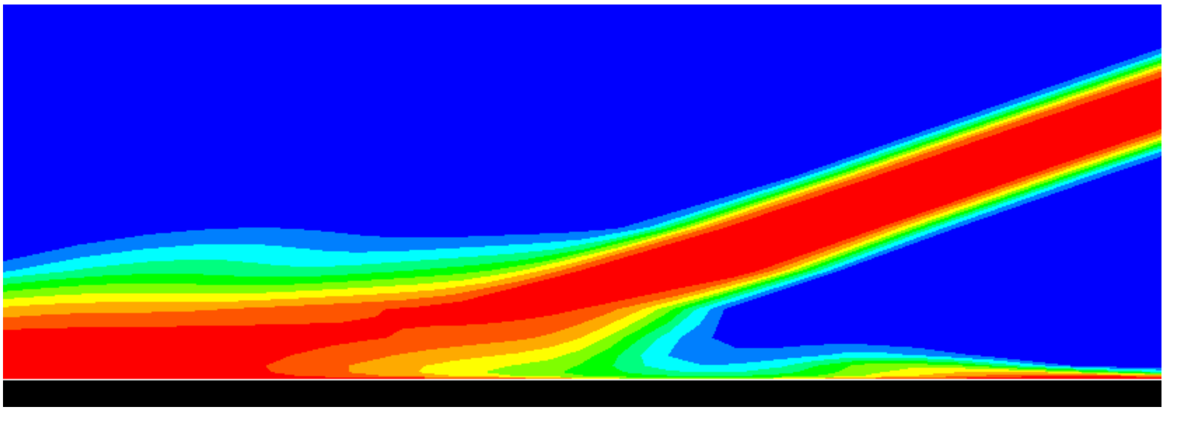

Figure 2: Magnified view of liquid jet with gas jet interaction under normal operating conditions
(Colour contours: liquid fraction = 1 (red), = 0.5 (green) = 0.0 (blue))

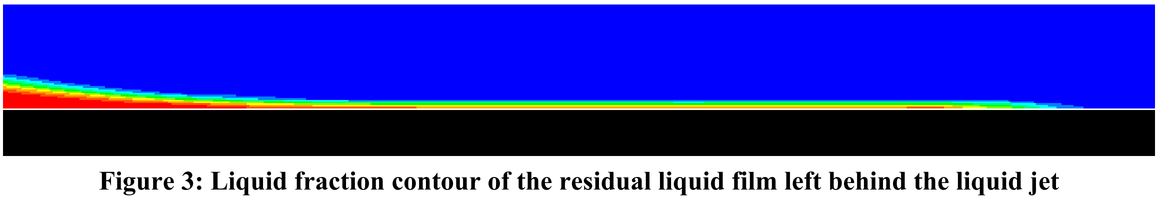

Figure 3: Liquid fraction contour of the residual liquid film left behind the liquid jet
(Colour contours: liquid fraction = 1 (red), = 0.5 (green) = 0.0 (blue))

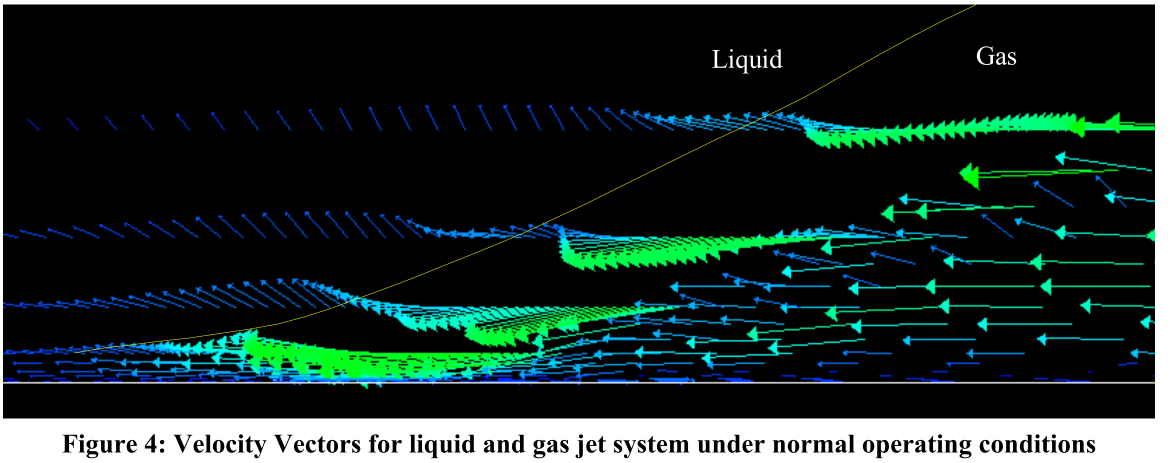

Figure 4: Velocity Vectors for liquid and gas jet system under normal operating conditions
(Colour contours: velocity = 200 m/s (green), = 30 m/s (blue))