Droplet Trajectories in a Turbine Rotor

The study of droplet trajectories will help to improve the design of blade profiles and provide more accurate performance calculations of **Energent's** Variable Phase Turbine (VPT)*. Past design practices assumed the impact of all droplets; we are now looking at the impact difference of small verses large droplets.

Figure 1 indicates the likely paths of large droplets (> 25 µm) moving through the blade passage of the VPT. Nearly all of the droplets impact the blade surface, separating from the two-phase flow. Losses are encountered due to the momentum loss of the impact at an angle with the surface and due to friction losses in the liquid film as it flows along the surface. The smaller the droplet the more it will follow the flow of gas.

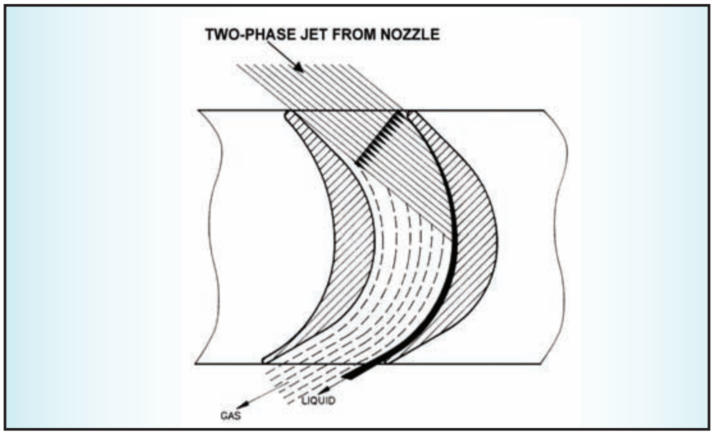

Figure 1 Schematic of large liquid droplets moving through the blade passage of the VPT.

By modeling the droplets as solid particles, their trajectories through the turbine rotor were calculated using CFD software from Numeca.

Figure 2 shows the location of the boundary of the inlet and the mid-span surfaces with respect to the rotor blade. Noting where the boundary of the inlet surface is relative to the blade will help you understand the plots on the right side in later figures.

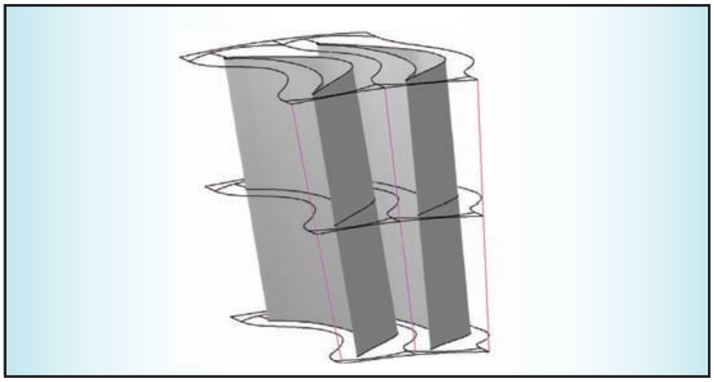

Figure 2 The location of the inlet and mid-span surfaces.

The left side of Figures 3 - 6 shows the trajectory of particles that start on the inlet surface at mid-span. The trajectories of droplet diameters of 1 and 10 microns, typical of cryogenic and refrigerant flashing expanders, are shown. For each diameter, the trajectories were calculated both ignoring and including the effect of the gas flow turbulence on the particle trajectory.

The right side of these figures shows the variable "Destination_outlet," with a range between 0 and 1. "Destination_outlet" is the fraction of the droplet trajectories that start on the inlet surface and leave through the outlet surface. 0 indicates that the particles hit a wall: hub, shroud or blade. 1 means that the particles moved through the blade passage without hitting a wall. The consequence of including the effect of the gas flow turbulence on the droplet trajectory is that all the particles that start at a particular point on the inlet surface do not follow the same trajectory. This is reflected in the intermediate values of "Destination_outlet".

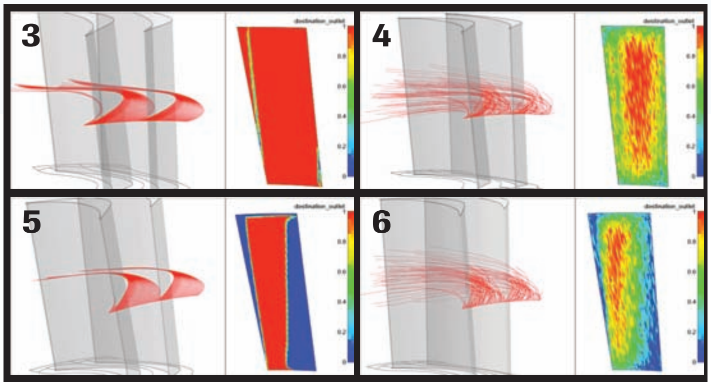

Figure 3 1 micron particles without turbulence.

Figure 4 1 micron particles including the effect of turbulence.

Figure 5 10 micron particles without turbulence.

Figure 6 10 micron particles including the effect of turbulence.

For the 1 micron diameter, the narrow strip where the variable destination_outlet is not equal to 1 corresponds to the droplets that hit the leading edge and pressure surface of the blade.

The larger diameter droplets are more likely to hit a wall than the smaller ones which are more likely to follow the gas flow. The effect of turbulence on the droplets is to scatter them. Fewer reach the outlet without hitting a wall.

For the conditions analyzed, including the effect of turbulence, the results show that only 27 % of the 1 micron droplets impact the surface whereas 50 % of the 10 micron droplets impact the surface.

Figures 7-8 show the average impact angle of particles hitting the blade wall, measured from the plane tangent to the wall. For both sizes, the droplets impact the same region of the blade surface on the pressure side and at the leading edge.

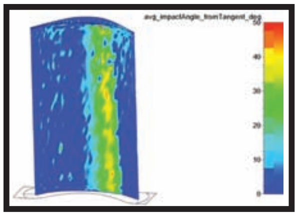

Figure 7 Average impact angle for 1 micron particles on the blade surface, including the effect of turbulence.

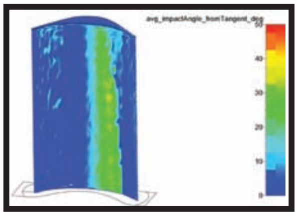

Figure 8 Average impact angle for 10 micron particles on the blade surface, including the effect of turbulence.

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* Lance Hays, "The Energent Variable Phase Turbine expands liquids or supercritical fluids used in refrigeration," FrostByte, Summer 2009, pages 1, 4.