Wet Compression and Particle Dynamics in Axial Compressor

Motivations
- Gas turbines suffer for output work in dry and summer time, as compressor has to work more, so output decreases.
- NOx emission is reduced due to presence of water droplets.
- The following cost (2008 money) analysis shows mist cooling is preferred:
  - Standby Generator – $250–400/kW
  - Refrigerated cooling system – $150–250/kW
  - Mist Cooling – $35–50/kW

Specific Goals
- Develop a computer code (FogGT) to analyze inlet fogging and wet compression in the gas turbine.
- Implement the stage-stacking scheme in FogGT to analyze the compressor with one-dimensional mean line calculation of thermodynamics and aerodynamics across the rotor and stator.
- CFD Simulation for rotating stage (compressor stator and rotor) by
  - Using commercial code for rotating frame.
  - Particle dynamics including
  - Different forces (Thermophoresis, brownian, saffman lift, drag etc.)
  - Break-up and coalescence of particles
  - Heat transfer between main fluid and particle
  - Liquid particle erosion

Mesh for CFD
Structured O-mesh is applied to the boundary layer region of blades and unstructured triangular meshes are constructed elsewhere (top figures). Structured hexahedral meshes are used in the inlet area and on the blade surfaces; unstructured tetrahedral meshes are used in rotor and stator sub-domains for 3-D grid (right figures).
According to theory, a compressor is supposed to consume less power with fogging due to increased density, but our analysis shows otherwise because:

(a) As temperature reduces, pressure also reduces, the density reduces instead of increasing following $Pv^k = \text{constant}$.

(b) Recompression takes place at the location of interstage spray and consumes more power.

1. Compressor power increases with the increase of ambient temperature and decreases with the increase of water spray due to increased air density. But stage-stacking scheme surprisingly shows that even though the density increases at the inlet, it decreases than the hot ambient condition in later stages because decrease of temperature (due to inlet evaporation) reduces pressure faster than temperature, which results in the decrease in density according to the polytropic relation, $Pv^k = \text{Constant}$.

2. The local blade loading significantly increases immediately after the interstage spray. This significant increase of local blade loading induces rotating stall locally near the spray location. Overspray increases axial velocity, flow coefficient, the blade inlet velocity, the incidence angle and the tangential component of velocity.

3. Maximum erosion is found at the trailing edge of rotor suction side, which is $3.55 \times 10^{-9} \text{ kg/m}^2\text{s}$ equivalent to $14 \mu\text{m}$ loss of material per year.

4. Liquid droplets experience break-up and coalescence throughout the domain and affect wet compression process and compressor performance.

**CONCLUSIONS**

- The largest entropy change is observed during evaporation (6-7), which makes the wet compression curve flatter (10-11) during wet compression (10-11-12-13-14).
- 5-6-7-8-9 shows the entropy changes during different phase change of water due to compression.

The maximum erosion occurs near the leading edge on the suction side of the blade, where angle of attack is $30^\circ$ and pressure side of the stator. (Red arrows show the flow direction.)