Conjugate Heat Transfer

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The controlled transfer of heat from a component to its surroundings is critical for the operation of many industrial processes. For example, cooling of electronics components is needed to maintain safe operation and extend operating lifetime, while quenching of materials from elevated temperatures is often required to develop specific microstructural features that provide prescribed properties.

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The conjugate heat transfer problem can be analyzed using COMSOL Multiphysics and applied to conditions with and without phase transformation. For the simple case when no phase transformation occurs in the coolant media, the rate of heat dissipation is a function of conduction and convection to the flowing fluid. The flow conditions and component geometry may give rise to turbulent flow that affects the heat dissipation over the surface.

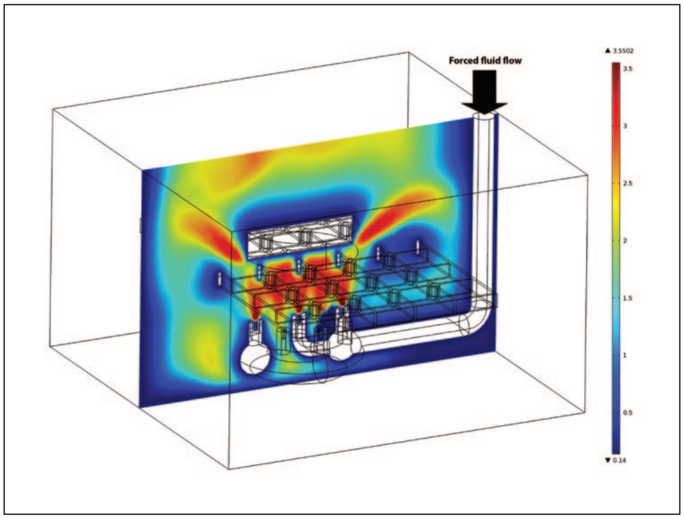

Figure 2: Results of variation of thermal conductivity developed under conditions of turbulent flow that combines multiphase flow, due to forced fluid flow, and flow due to buoyancy effects associated with bubble formation due to fluid boiling.

Analysis of heat transfer under conditions where phase transformation occurs in the cooling fluid is more complex and must consider the range of near-wall effects arising from film boiling, transition boiling, nucleate boiling and pure convection. The near-wall boiling processes that strongly influence heat transfer from the part to the quenching medium operate on a scale that is many orders of magnitude smaller than the component size. To accommodate these different scales, the complex 3D physics near the wall are analyzed here using sets of equations that are solved only on the walls of the component. Under these conditions, accurate analysis of the heat transfer can be obtained for the differential heat transfer rates into the gas or liquid phase and the effect of gas formation on the flow behavior (see Figure 1).

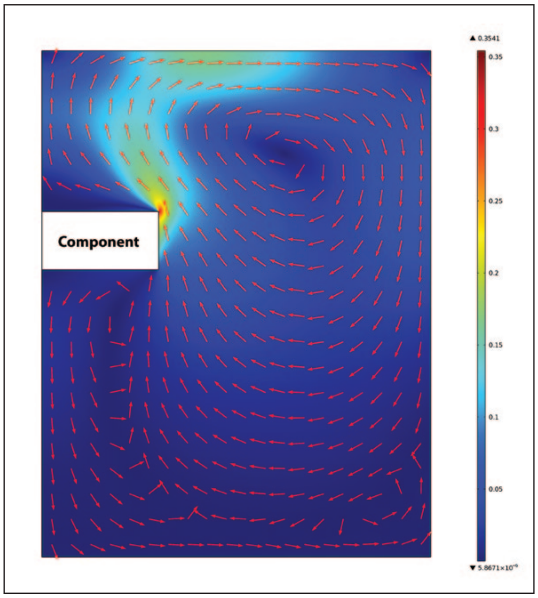

Figure 1: Fluid flow velocity vector resulting from bubbles evolving along the surface of a hot component during quenching.

In practice, commercial quenching during heat treatment includes forced fluid flow as well as fluid flow introduced by the phase transformation from liquid to gas. To provide a complete analysis of the flow pattern within a commercial quenching tank and the resulting thermal distribution in the specimen, the effect of the two fluid flow components must be integrated. The analyses developed here used a multiphase flow model that included forced convection due to mechanical pumping, agitation caused by gas bubbles and vapor formation in complex geometries. The turbulent flow models were modified to account for the two-phase flow. Figure 2 shows the results of analyses of a commercial quench tank in which fluid is forced through nozzles and impinges on the bottom surface of a hot component lowered into the tank.

The results show the variation in the thermal conductivity due to the multiphase flow resulting from forced fluid flow and flow due to the liquid to gas phase transformation caused by the fluid boiling at the specimen surface. Using these analytical approaches the fluid flow conditions can be modified to produce a more regular distribution of heat extraction from the hot component. This allows the development of quench conditions in which an even temperature gradient can be maintained leading to more homogeneous microstructural variability within the final component shape and limited development of residual stresses in the component. ■