Conjugate Heat Transfer

J. Crompton[1], Luke Gritter[1], Sergei Yushanov[1], Kyle Koppenhoefer[1]

[1]AltaSim Technologies, Columbus, OH, USA

Abstract

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. Heat transfer can occur by natural or forced convection, conduction into adjacent material or supports and, if the temperature is high enough, by radiation to the surrounding environment. In some cases, heat transfer may be accomplished while maintaining the fluid as a single phase, in others heat transfer may be sufficiently high to cause a phase transition from liquid to gas. 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. An example of the flow behavior over the surface of a heated component is shown in Figure 1 for the simple case of forced flow from a single point below the component. For this case, the existence of stagnated flow regions is observed and produces limited heat transfer compared to the corners, where high flow rates produce maximum cooling. Using analyses of this type, a more even distribution of heat transfer can be produced by providing a uniform flow of air over the surface and focusing concentrated flow on areas in which higher heat transfer is required. 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. 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.