Contribution ID: **1** Type: **Oral**

Single-jet gas cooling of in-beam foils or specimens: Prediction of the convective heat-transfer coefficient

Thursday, 17 November 2016 09:00 (30 minutes)

Various applications utilize an impinging stream of gas for the cooling of metal foils and/or other material specimens while under bombardment in an accelerated particle beam. Helium is often used for this purpose but other gasses are also sometimes employed. Noble gasses can provide cooling as well as an inert environment for the protection of the foils or specimens.

At iThemba LABS, radionuclide production targets are bombarded outside the cyclotron and beamline vacuum. In addition to preserving the integrity of the vacuum, the ability to rapidly transfer targets to and from a target station is greatly simplified by eliminating the need to repeatedly break and restore the vacuum. The beamlines to the target stations have been provided with beam exit windows consisting of two closely-spaced thin metal foils (Havar) cooled by helium flowing between them. These gas-cooled, double-foil windows are thin enough to cause minimal energy degradation to the beam but provide a strong enough barrier to maintain the vacuum.

In this presentation, it will be shown that the so-called "duct equations" (in particular the Dittus-Boelter, Sieder-Tate and Petukhov-Kirillov formalisms) do not provide accurate estimates of the convective heat-transfer coefficient in applications where the beam spot is relatively small, even though their use for this purpose is not uncommon in the literature. These equations tend to underpredict the forced convection heat transfer, sometimes by as much as a factor of 3. Recently, calculations based on a description for single-jet impingement heat transfer (the Chang formalism) provided results in much better agreement with experimental values. The Chang formalism, however, assumes that the jet direction is normal to the heated surface, which is not the case in our beam-windows assemblies. An experiment was therefore performed at iThemba LABS to investigate the effect of the jet angle on the convective heat-transfer coefficient. Rather surprisingly, it was found that the dependence on the jet direction is indeed quite weak. This was also found in more advanced modelling using a commercial Computational Fluid Dynamics (CFD) code.

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Session Classification: Session 8

Track Classification: Plenary