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Numerical Investigation of the Emergency Release of a Crogenic Gas into a Confined Space

The sudden release of cryogenic fluid into an accelerator tunnel can pose a significant health and safety risk. For this reason, it is important to evaluate the consequences of such a spill. Previous publications of CERN and the Wroclaw Universtiy of Science and Technology concentrated on either Oxygen Deficiency Hazard or the evaluation of mathematical models using experimental data; no studies to date have focussed on the influence of cryogen inlet conditions on flow development. In this paper, the stratification behaviour of low-temperature Helium released into an air-filled accelerator tunnel is investigated for varying Helium inlet diameters. A numerical model was constructed using the OpenFOAM Toolbox of a generalised 3D geometry, with similar hydraulic characteristics to the CERN and SLAC tunnels. This model has been validated against published experimental and numerical data. A dimensionless parameter was then determined for the onset of stratification, taking into account the Helium inlet diameter; a dimensionless parameter for the degree of stratification was also employed. The simulated flow behaviour is described in terms of these dimensionless parameters, as well as the temperature and oxygen concentration at various heights throughout the tunnel.

Keywords: cryogenics, stratification, accelerator tunnel, unexpected helium release, ODH hazard

Summary

This paper used a modified Bakke number, Ba”, and a Degree of Stratification Parameter, DS, to describe the stratification behaviour of a helium release into an accelerator tunnel for various helium inlet diameters. The modified Bakke number was determined from dimensional analysis to be dependent on 8 parameters: the tunnel diameter, the helium inlet diameter, the ventilation air velocity, the air density, the helium inlet mass flow rate, the initial helium density, the density difference between the air and the helium-air mixture and gravitational acceleration. The degree of stratification was defined as a weighted normalised standard deviation of gas concentration.

Data from nine unsteady OpenFoam numerical simulations was used to quantify the above parameters for different hole sizes, time steps and (up- and) downstream locations. Oxygen and temperature profiles for various cross-sections were also produced and flow visualisations were created using Paraview.

Flow cases were compared to the observations of M. Chorowski, G. Konopka-Cupia, G. Riddone, Safety oriented analysis of cold helium-air mixture formation and stratification (2006) and T. Koettig, J. Casas-Cubillos, M. Chorowski, L. Dufay-Chanat, M. Grabowski, A. Jedrusyna, G. Lindell, M. Nonis, N. Vauthier, R. van Weelderen, T. Winkler, J. Bremer, Controlled cold helium spill test in the lLHC tunnel at CERN (2015). Chorowski et al. (2006) identified 5 different flow patterns of stratification behaviour. Using the modified Bakke number, the 9 considered cases were classified as being flow types 1 through to 3.

The degree of stratification parameter allowed these three flow types to be distinguished further. Flow behaviour of the first type took the form of a turbulent jet, which ejected the released helium onto the ceiling of the tunnel where it readily formed a stratified layer. Type 2 behaviour was such that the helium jet no longer had the momentum to deposit the released cryogen on the ceiling of the tunnel. A great degree of mixing occurred, and it was found that the degree of stratification was highly sensitive to changes in the helium inlet diameter. Flow behaviour of the third type was such that any further increases in the helium inlet size did not affect stratification behaviour. The discharge did not form a jet, but merely spilled to the floor of the accelerator tunnel where it slowly rose as it mixed with the warmer air of the tunnel.

A further observation was that for large times after the initiation of the helium release, particularly for long distances downstream, the degree of stratification converges for all hole sizes. It suggests that the stratification behaviour is most important for the time directly following the start of cryogen release.

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