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Design and Fluid Dynamics Study of a Recoverable Helium Sample Environment System for Optimal Data Quality in the New Microfocus MX Beamline at the ALBA Synchrotron Light Source

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Abstract

XAIRA is the new microfocus MX beamline under construction at the ALBA Synchrotron Light Source. For its experiments, data quality will be optimized by enclosing all the end station elements, including the diffractometer, in a helium chamber, so that the background due to air scattering is minimized and the beam is not attenuated in the low photon energy range, down to 4 keV. This novel type of chamber comes with new challenges from the point of view of stability control and operation in low pressure conditions while enabling the recovery of the consumed helium at the ALBA Helium Liquefaction Plant. Besides, the circuit includes a dedicated branch to recirculate the helium used by the goniometer bearing at the diffractometer. This paper describes the fluid dynamic conceptual design of the Helium chamber and its gas circuit, as well as numerical results based on one-dimensional studies and Computational Fluid Dynamics (CFD).

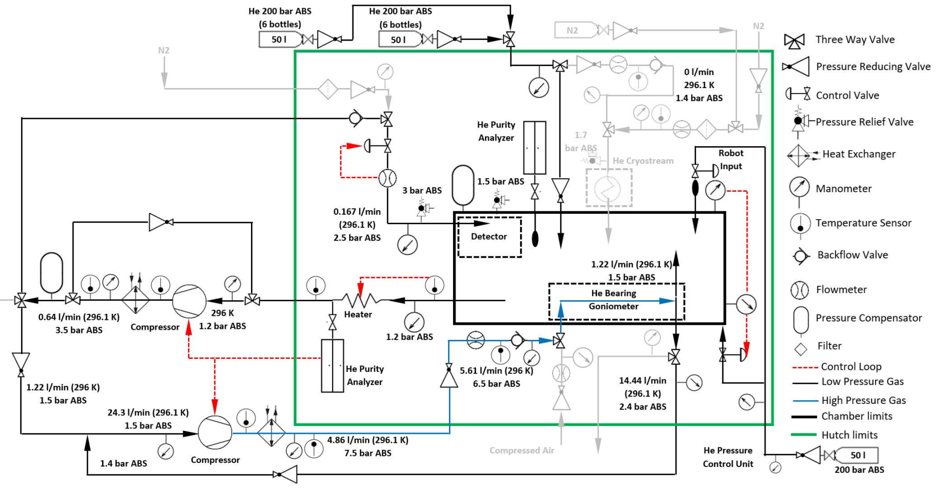
Piping and Instrumentation Diagram (PID)

Model Description

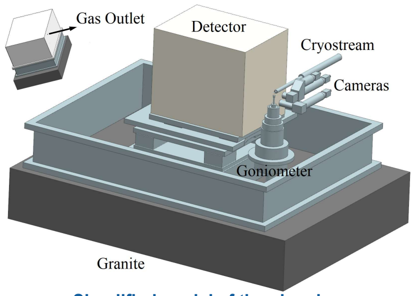
The PID has 3 modes of operation: sample in helium atmosphere at a nominal cryogenic temperature of 95 K (mode 1), sample in helium atmosphere at room temperature (23 ºC, mode 2); and sample surrounded by nitrogen gas at a nominal cryogenic temperature of 100 K (mode 3). For modes 1 and 2, a helium purity of 95% is required.

Under steady state regime, the balance of helium gas inside the chamber is conserved according to the following input and output conditions: (1) Gas input to the chamber from the detector. The gas first enters the detector, then is distributed inside the chamber; (2) Injection of pure helium gas from the cryostream to the sample; (3) Helium gas input from the goniometer. The rotation movement requires helium gas. During its operation, the goniometer "loses" approximately 5% of gas, which becomes a gas supply to the chamber; and (4) A single output is fixed, represented in the PID with an output arrow on the left side of the chamber.

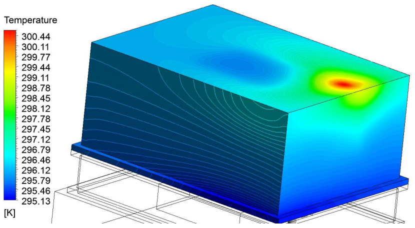
For the circulation of helium gas, two compressors are required. The system has 12 bottles of pure helium gas, each of 50 litres at 200 bars of pressure. This assembly will feed gas directly to the cryostream during experimentation. An individual bottle of helium gas, connected to the chamber, has been added to inject helium in case of gas losses during the operation. The operation of the beamline includes a sample mounting system (marked as robot in the PID diagram) to mount and unmount the samples on the goniometer head.



Helium Gas Distribution in the Chamber: CFD Studies



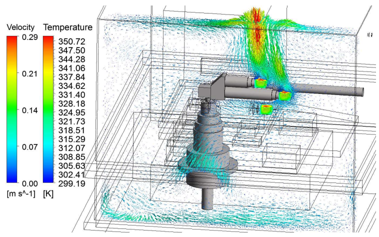
Simplified model of the chamber



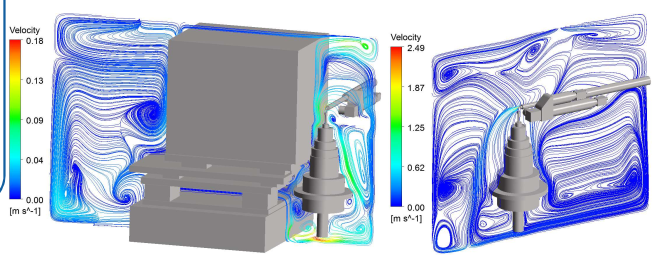
Temperature on the chamber walls

CFD Model

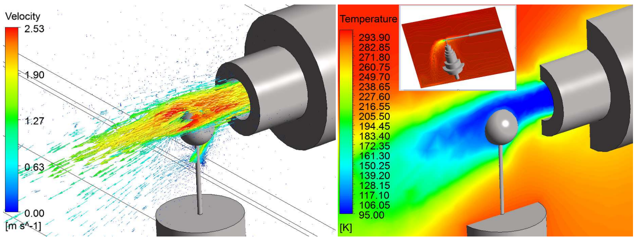
Stainless-steel chamber with dimensions 1345 x 1010 x 844 mm. The gas outlet, a 12 mm inner diameter tube, is located on the same wall of the chamber where the cryostream is fixed. The helium gas has been simulated under conditions of forced convection, assuming 100% purity and imposing these inlet flowrates as detailed in the PID. The gas injected by the cryostream has been simulated at 80 and 95 K. The gravitational effect has also been introduced. The properties of helium gas as a function of temperature have been introduced. A laminar regime has been assumed for the fluid dynamics and the incompressibility approximation for the gas. The internal heat input has also been implemented: 3.66 Watts in each of the three cameras. For external heat transfer to the chamber, air in natural convection at 23ºC has been applied, with a convective heat transfer coefficient equals 5 W/m²K.



Distribution of the velocity vectors towards the upper zone, due to the thermal load of the three cameras



Streamlines of velocities around the sample



Temperature and velocity distribution around the sample

Conclusions

This work describes the design details and results of the fluid-dynamic simulations obtained for the experimental helium gas chamber and its adjacent piping of the new microfocus beamline BL06-XAIRA at ALBA. The results of the one-dimensional and CFD simulations confirm an optimal fluid dynamic behaviour of the proposed design.

The piping and instrumentation configuration and the chamber have been designed to recover the helium gas used in the experimentation, which, under ideal conditions, should be equal to the gas injected by the cryostream. The purity of the recovery gas will depend on many factors, such as the action of the automated robot and the tightness of the piping and attached components.

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