ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP035

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

M. Quispe†, J.J. Casas, C. Colldelram, D. Garriga, N. González, J. Juanhuix, J. Nicolàs, Y. Nikitin
ALBA-CELLS, Cerdanyola del Vallès, Spain
M. Rabasa, ESEIAAT, Terrassa, Spain

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).

INTRODUCTION

The new microfocus beamline BL06-XAIRA at ALBA, in commissioning phase, will have a chamber enclosing the goniometer that holds the sample, the detector, a cryostream, and other sample environment elements. The setup allows the experiments to be performed either in air or in helium atmosphere, and both at room temperature or under cryogenic conditions. The helium atmosphere not only reduces the background noise, thus increasing data quality for the whole energy range, but also prevents flux loss at low energies, providing the optimal conditions for anomalous phasing and elemental analysis experiments [1].

From the point of view of fluid dynamic engineering, a description of the design of this special chamber, as well as its adjacent gas circuit, is presented in the following sections. This design includes the possibility to recycle the helium, directing it to the ALBA Helium Liquefaction Plant.

PIPING AND INSTRUMENTATION DIAGRAM (PID)

Figure 1 shows the PID of the gas distribution. The design has been based on the requirement to operate in three modes: 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) [2]. For modes 1 and 2, a helium purity of 95% is required (experimental criterion).

The elements of the circuit are distributed inside and outside the experimental hutch (marked in green in Fig. 1) and regulate the different beamline components that blow helium into the helium chamber (bold black line). In the Fig. 1 the circuit for helium gas is highlighted with black lines (mode 1), while the distribution lines for air and nitrogen gas are marked in grey.

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. This component, has to be connected to a dry air (or nitrogen, or helium) source to avoid humidity and condensation damage. The gas first enters the detector (0.167 l/min, 296 K and 2.5 bar ABS), then is distributed inside the chamber; (2) Injection of pure helium gas from the cryostream to the sample, under nominal conditions 2.74 l/min, 95 K and 1.2 bar ABS; (3) Helium gas input from the goniometer. The rotation movement of this component requires helium gas under the conditions 5.61 l/min, 296 K and 5.5 bar ABS. 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. One of them is dedicated exclusively to supplying helium to the goniometer under its working conditions; the other compressor, located on the exit branch of the chamber, takes the exit gas and then distributes the helium in three branches: one towards the detector, another towards the aspiration of the other compressor (to recover the 5% of "lost" gas inside of the chamber), and the last one towards the Helium Liquefaction Plant, for recovery. Under ideal fluid balance conditions, the recovery line should recover the same amount of gas injected by the cryostream into the chamber.

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 (He pressure control unit), has been added to inject helium in case of gas losses during the operation.

† mquispe@cells.es.

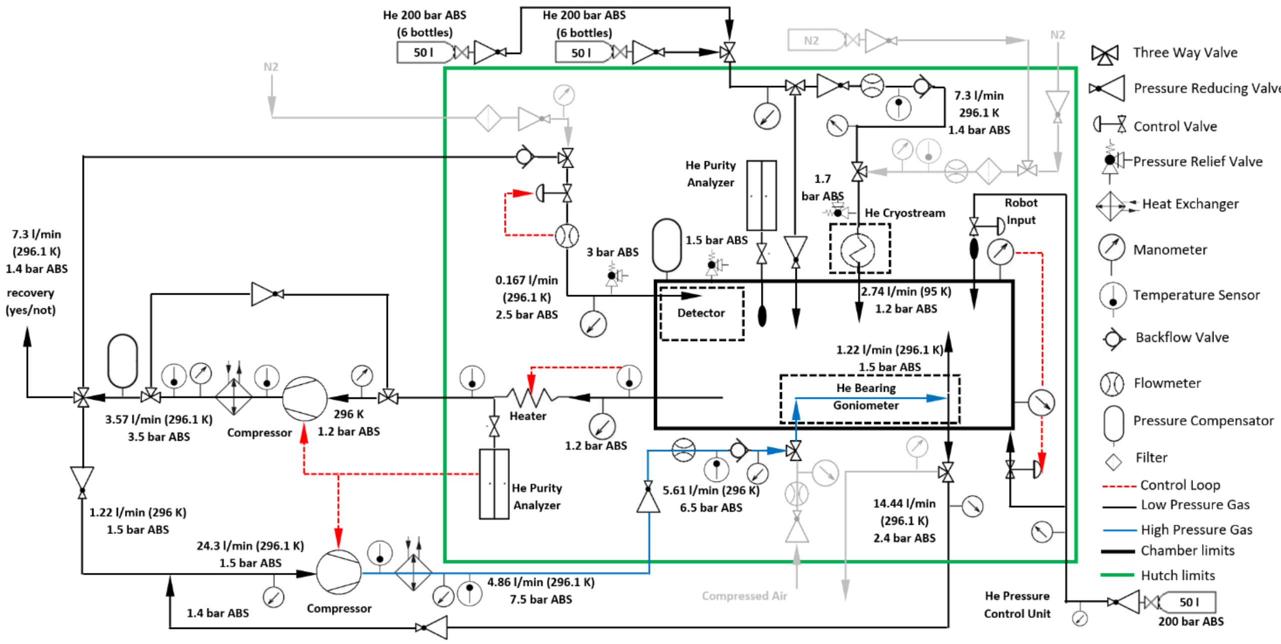

Figure 1: XAIRA PID operational mode 1: Helium gas with Cryostream on.

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. This is one of the critical points where the purity of the helium in the chamber can be affected, because the access valve must be opened and there will be direct contact with the outside air. The chamber is sealed when the robot is inside the chamber (typically for ~ 4 sec) by the gripper itself, which has a diameter that matches the aperture of the gate valve. The effect on purity of the helium will be assessed during the commissioning of the He circuit in 2024.

One-Dimensional Modelling

All pipes with their components have been simulated with the one-dimensional software PIPEFLOWEXPERT [3] to determine the pressure drops. In all cases the pressure drops are very low and fluid dynamics is guaranteed. There is a branch where fluid dynamics has a high dependence on the nominal operating points. This is the branch that connects the outlet of the chamber with the suction area of its respective compressor. On the one hand, the design pressure of the chamber must be maintained below 1.2 bar ABS, which is a requirement of the detector manufacturer to protect its membrane. On the other hand, the nominal working pressure of the compressor suction is 1.2 bar ABS, however, it can be operated up to the limit of 1.1 bar ABS. In a better scenario we would have a gradient of 100 mbar between the chamber and the compressor. In this branch the pressure drop is 4 mbar, calculated with PIPEFLOWEXPERT. During commissioning we must ensure the appropriate working points to always have a gradient > 4 mbar.

HELIUM GAS DISTRIBUTION IN THE CHAMBER: CFD STUDIES

CFD Simplified Geometry

Figure 2 shows the simplified model of the stainless-steel chamber, located on a granite base, and some of its main components. Its dimensions are 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.

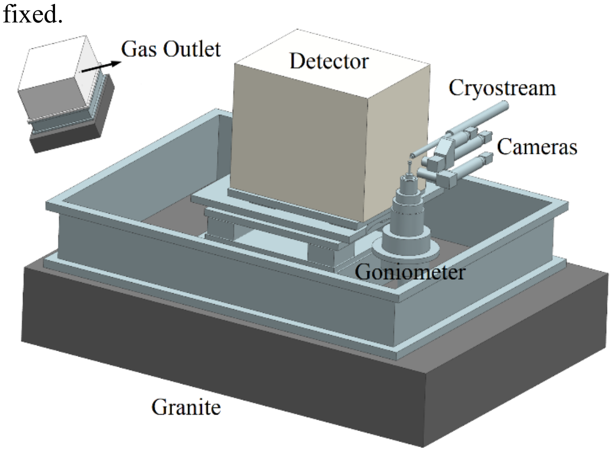

Figure 2: Simplified model of the chamber, showing some of its internal components.

CFD Model

The helium gas has been simulated under conditions of forced convection, assuming 100% purity and imposing three inlet flowrates as detailed in the previous section. The gas injected by the cryostream has been simulated at 80 and 95 K. The gravitational effect has also been introduced. In this case, the effect of gravity is relevant due to the high sensitivity of the density of helium gas with respect to

ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP035

temperature, especially under cryogenic conditions. 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/m^{2}K. The optimal mesh generated has been around 8 million elements, which ensures the asymptotic result of the simulations. The ANSYS WORKBENCH software has been used for the calculations [4].

CFD Results

The temperature distribution around the sample is shown in Fig. 3. The sample is completely immersed in helium gas at 95 K. In the same figure, in the upper part, the temperature distribution in a vertical plane at the position of the sample is presented. In this plane it is observed that the cold zone of the gas has an influence on a small space around the sample, and close to the wall of the chamber the temperature is around 294 K.

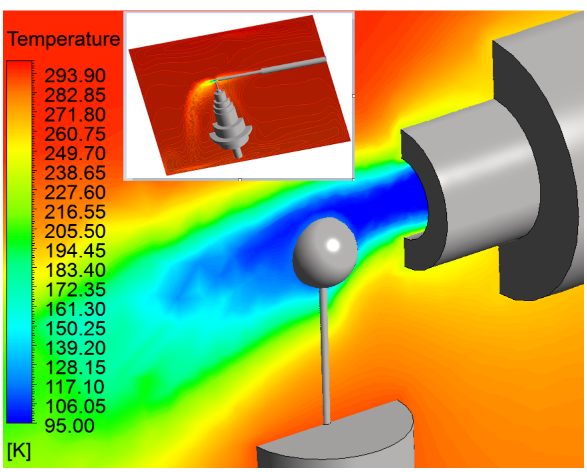

Figure 3: Temperature distribution around the sample and in a vertical plane at the position of the sample.

Figure 4 shows the distribution of the velocity vectors around the sample. A maximum velocity of the gas on the sample equals 2.53 m/s is obtained.

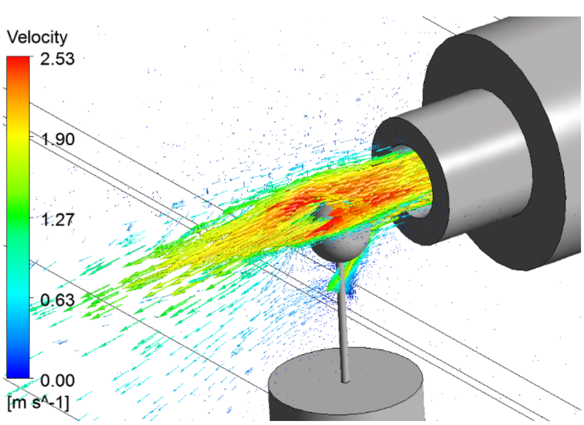

Figure 4: Velocity vectors around the sample.

The temperature value of the helium gas at the exit of the chamber has been evaluated under the conditions presented in Table 1. It can be concluded that the temperature values are close to the external air. This behaviour is due to the significant influence of heat transfer from the outside air to the chamber. It is also observed that the influence of the heat generated in the cameras on the gas outlet temperature is negligible.

Table 1: Average Helium Gas Temperature at the Exit of the Chamber, for Different Conditions

Temp. Cryostream (K)	**Cameras**	**Temp. Outlet (K)**
95	On	296.81
95	Off	295.86
80	On	296.74
80	Off	295.79

The CFD results also show high temperature values in the three cameras, around 350.7 K. This temperature peak enhances the movement of the fluid in a vertical direction due to the high difference in densities in this region, as can be seen in Fig. 5.

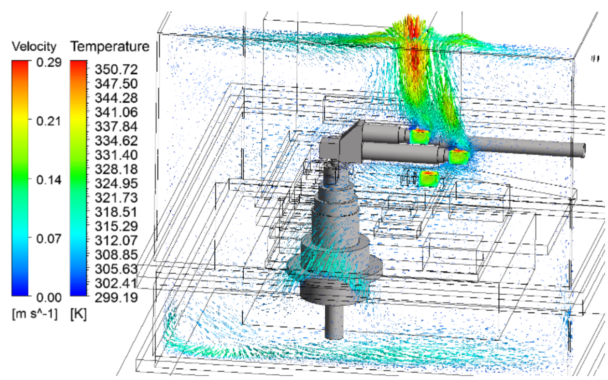

Figure 5: Distribution of the velocity vectors towards the upper zone, due to the thermal load of the three cameras.

Another significant result is that for the cryostream injection conditions, at 80 and 95 K, the values of the temperature distribution on the external wall of the chamber remain in the range of 295 to 300 K, for both cases.

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.

ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP035

REFERENCES

[1] D. Garriga, "XAIRA End Station: Conceptual Design Report", unpublished.

[2] M. Quispe, "Detailed Design Report: XAIRA Helium Gas Circuit", unpublished.

[3] PIPEFLOWEXPERT, https://www.pipeflow.com/

[4] ANSYS, https://www.ansys.com/products/fluids