The Numerical Simulation of a LAr Thermostat

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Abstract

Our experiment is designed to search for dark matter WIMPs scattering off 1500L liquid argon (LAr) in an ultra-low background cryostat. The cryostat will be located in JINPING Mountain, China. To prepare for this experiment we developed a LAr thermostat, with a self-circulation argon liquefaction system that uses two pulse tube cryocoolers (80W@80K). Because these cryocoolers form fewer bubbles and maintain a stable temperature gradient within 1.0 K in the inner cylinder an actively-cooled LAr shield is used to intercept heat radiation. A temperature gradient greater than 1.0 K is detrimental for proper functioning of the detector. To analyze the flow and heat transfer characteristics of LAr in the inner cylinder we create a numerical model. These characteristics play a role in making the detector work stably and efficiently. We present an overview of the modeling and the simulations with the commercially software FLUENT.

Objectives

- To analyze the flow and heat transfer characteristics of LAr in the inner cylinder.

Conclusion

- A LAr cryostat with temperature uniformity and minimizing the number of gas bubbles, is being developed.
- An actively-cooled LAr shield is used to surround the cryostat to intercept heat radiation.
- Applying reverse heat flux at the thermostat is beneficial to maintain a uniform liquid phase with the numerical simulation to analyze the flow and heat transfer characteristics of LAr in the inner cylinder.
- our future work will investigate the impact of the amplitude of heat flux density on the flow and heat transfer of LAr in the thermostat under the condition of reverse heat flux.

Methods

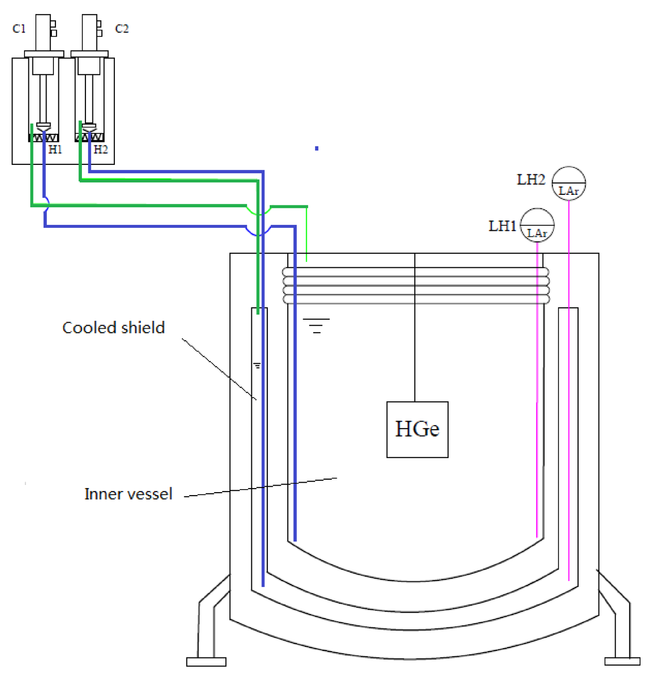
The scheme of the cryostat

A cryostat with LAr, aimed at searching for WIMPs, is being developed in China.

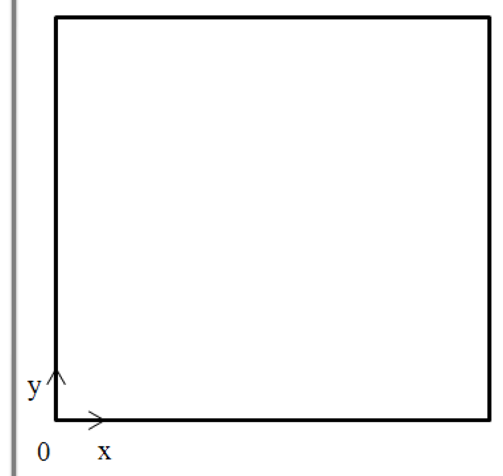
The key technology of the associated cryogenic system lies in two requirements:

maintaining temperature uniformity within 1K due to the temperature dependence of the energy measurements;

minimizing the number of gas bubbles which have detrimental effects on the detector.



The thermo-hydraulic analysis model



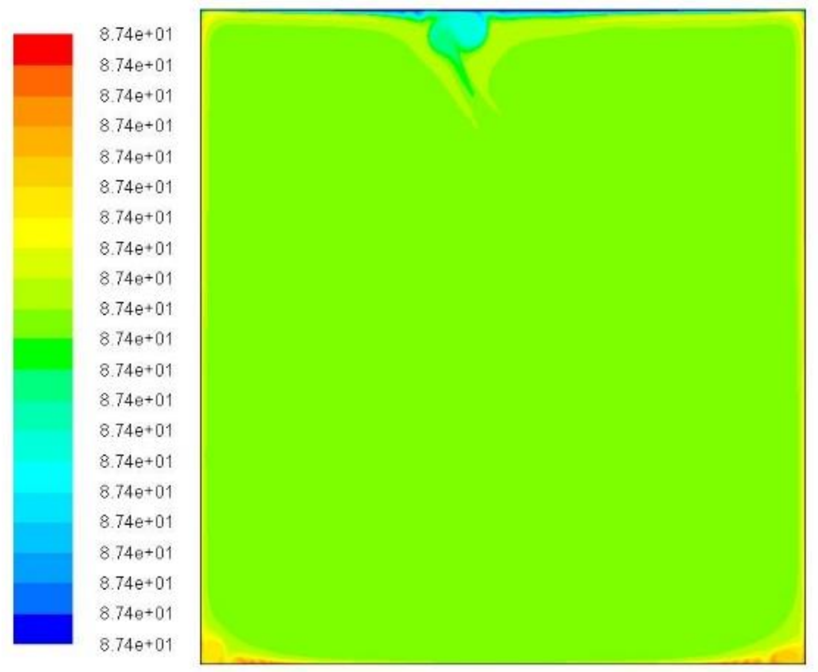
A two-dimensional double-precision solver is used.
the Semi-Implicit Method for Pressure Linked Equations (SIMPLE) algorithm is applied.

Boundary conditions :
- the top is a thermostat wall
- the side and bottom maintain a constant heat flux
- a first-order implicit algorithm is used

two sets of numerical calculations are performed: one for the forward heat flux and one for the reverse heat flux.

Results

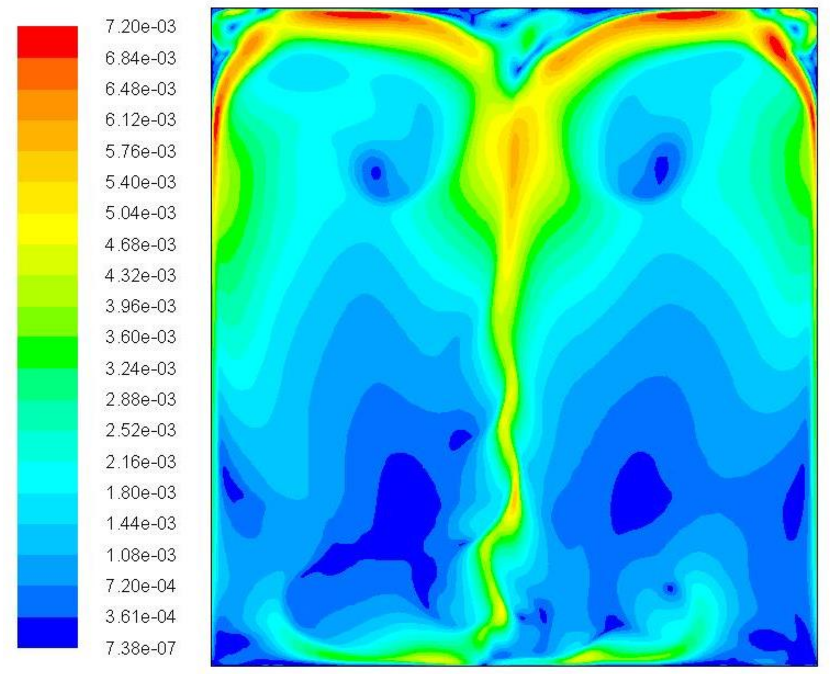
The Forward heat flux



The heat flux density of the thermal radiation is set at 31mW/m^2.

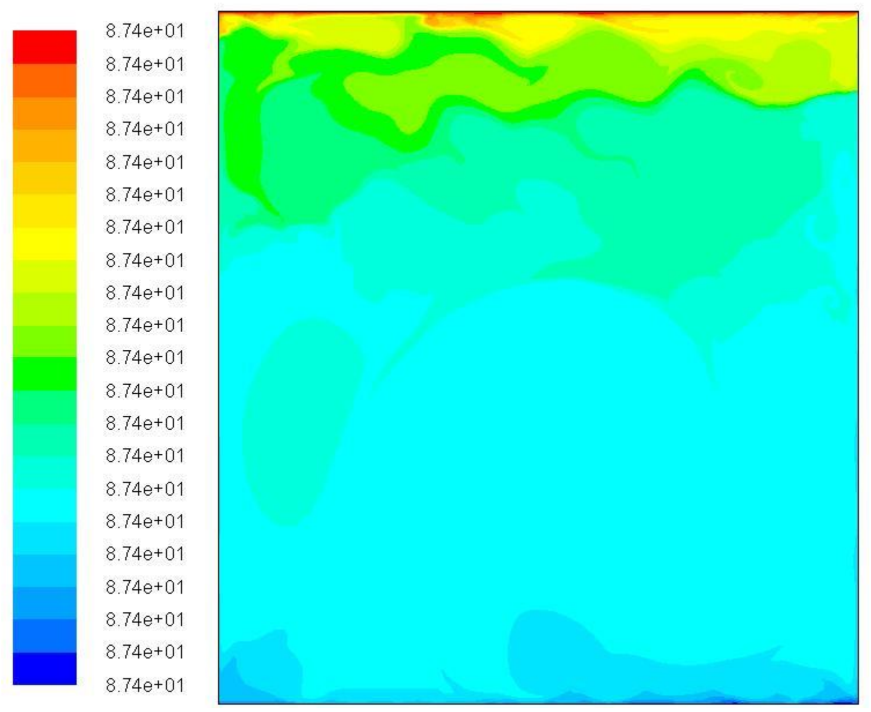
The temperature distribution in the LAr (left).
- the temperature difference is 6mK.
- the maximum temperature values is in the vicinity of the side wall and the bottom wall.

The flow of LAr in the thermostat (right).
- the fluid flows upward along the side wall driven by the density difference.
- then flows toward the bottom of the thermostat.



Results

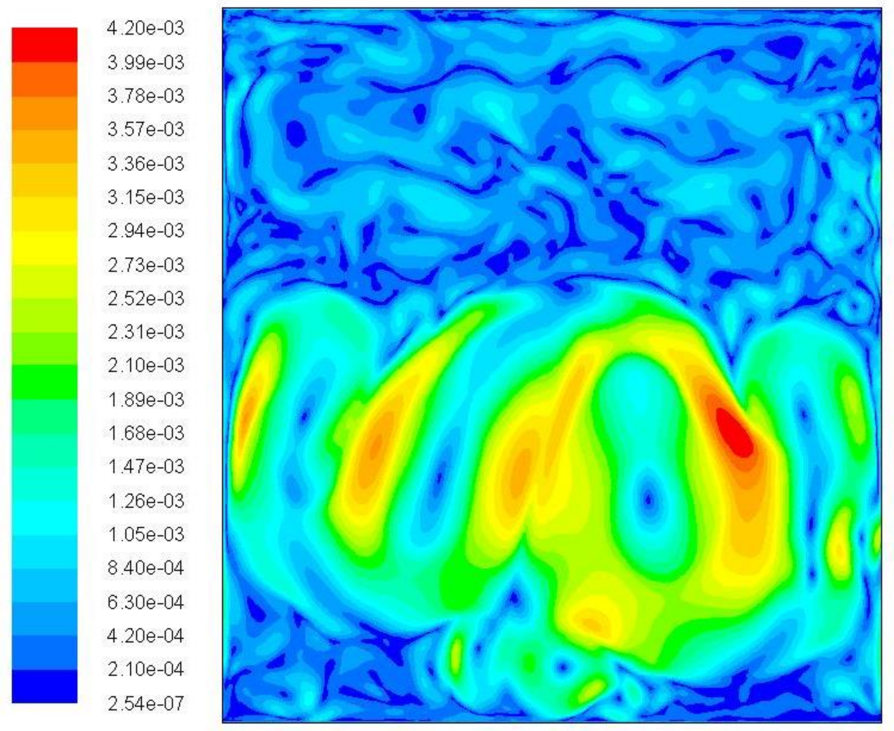
The Reverse Heat Flux



The heat flux density of the thermal radiation is set at 31mW/m^2, with the direction of the heat flux is the same as the outer-pointing normal of the walls.

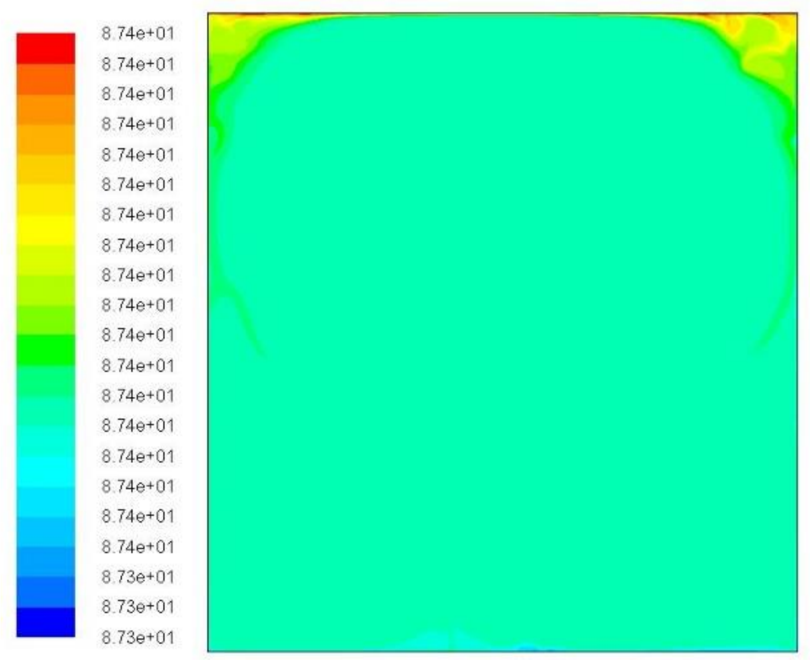
The temperature distribution in the LAr (left).
- the LAr temperature is lower than the saturation temperature at the surface, 87.38K.
- the maximum temperature appears near the surface.

The flow of LAr in the thermostat (right).
- the density of the fluid at the bottom is higher than that near the surface.
- the LAr in the thermostat gradually tends to stabilize under the action of gravity.
- the flow state will become relatively static due to viscous dissipation of the fluid.



Results

The Reverse Heat Flux



The heat flux density of the thermal radiation is set at 310mW/m^2.

The temperature distribution in the LAr (left).
- the LAr temperature distribution below the surface becomes more uniform.

The flow of LAr in the thermostat (right).
- The flow will also eventually tend to stabilize under the effect of gravity and viscous dissipation,
- the fluid speed will reach the order of 10-2m/s or even 10-1m/s,
- the disturbance to which the entire fluid region is enhanced.