CFD Modeling Of A 4-He Evaporation Refrigerator For Polarized Target Experiments

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INTRODUCTION: Evaporation refrigerators are cryogenic equipment that can reach temperatures down to 1K and are used in nuclear physics experiments. These refrigerators have traditionally been designed using an approximate analytical treatment for the various individual components of the system, which is complex and results in difficulties when attempting to interconnect them and evaluate global behavior. In contrast, COMSOL Multiphysics® allowed us to model the system as a whole and obtain all relevant performance parameters.

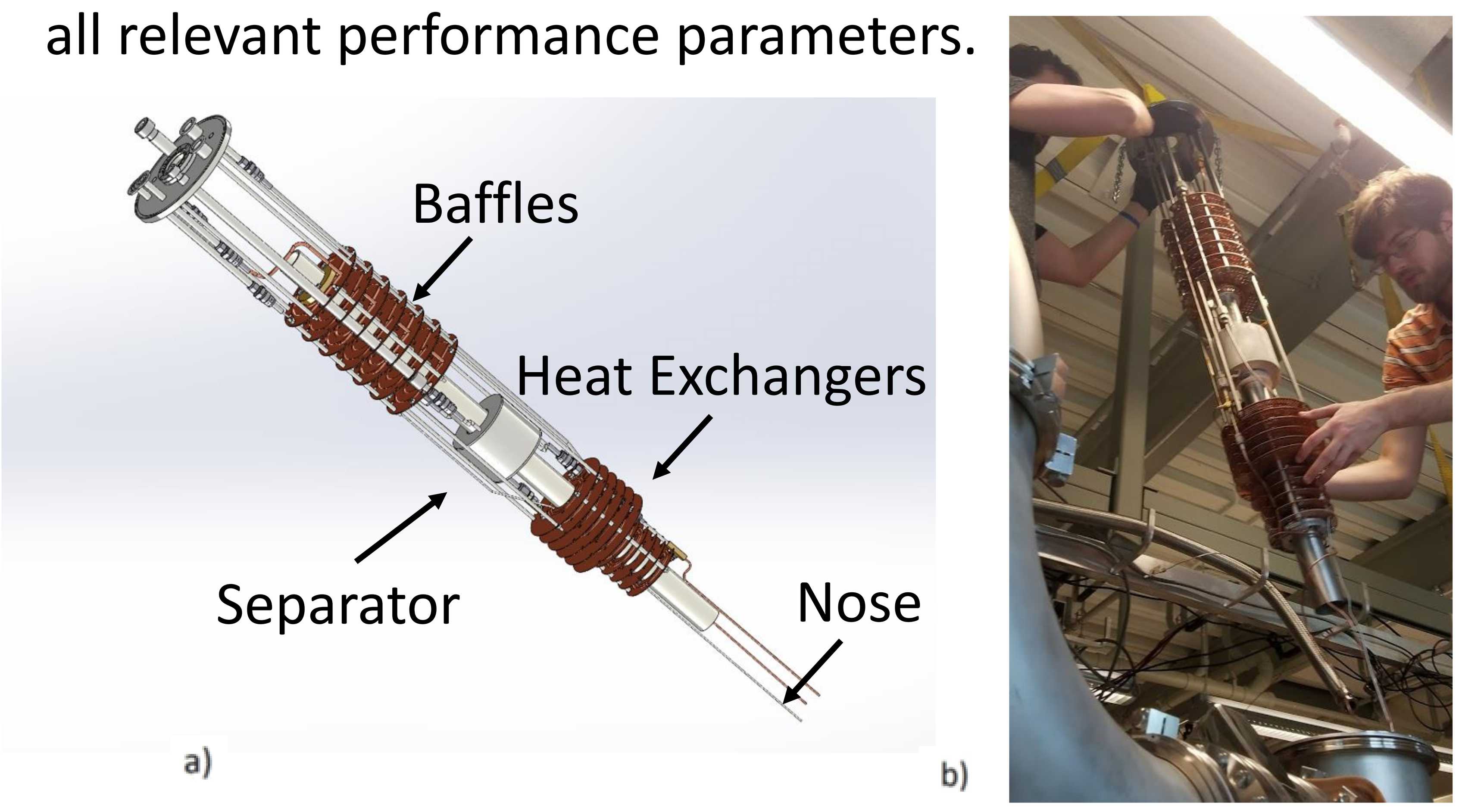

Figure 1. a) Main parts design. b) Mounting the refrigerator.

COMPUTATIONAL METHODS: The 4-He gas is considered as an ideal gas and an isotropic Newtonian fluid. The incompressible form of the Reynolds Averaged Navier-Stokes equations are solved in COMSOL® CFD module. Turbulence effects are considered by using the eddy viscosity k-Omega model. To solve the temperature field we couple COMSOL® heat transfer module.

A 2D Computer-Aided Design model was build in COMSOL® Geometry Interface and boundary conditions for the modeling were set according to the measurements taken from the refrigerator constructed by University of New Hampshire (UNH) team. The meshing was done in the COMSOL® interface.

Boundary Element	Variable	Value [unit]
Inlet	Mass Flow: $\dot{m}$	1.67E-04 [kg/s
Outlet	Static Pressure: P	0 [Pa]
Inlet	Temperature: T1	1.11 [K]
Wall (Separator)	Temperature : T2	3.32 [K]
Wall (Separator)	Temperature :T3	4.16 [K]
Wall (Baffle)	Temperature : T4	3.39 [K]
Wall (Baffle)	Temperature :T5	82.05 [K]
Wall (Inner Shell)	Temperature : T6	103.60 [K]
Wall	No slip	
Wall	Adiabatic	
Wall (Outer Shell)	Radiation Heat Flux	

Table 1. Main boundary conditions.

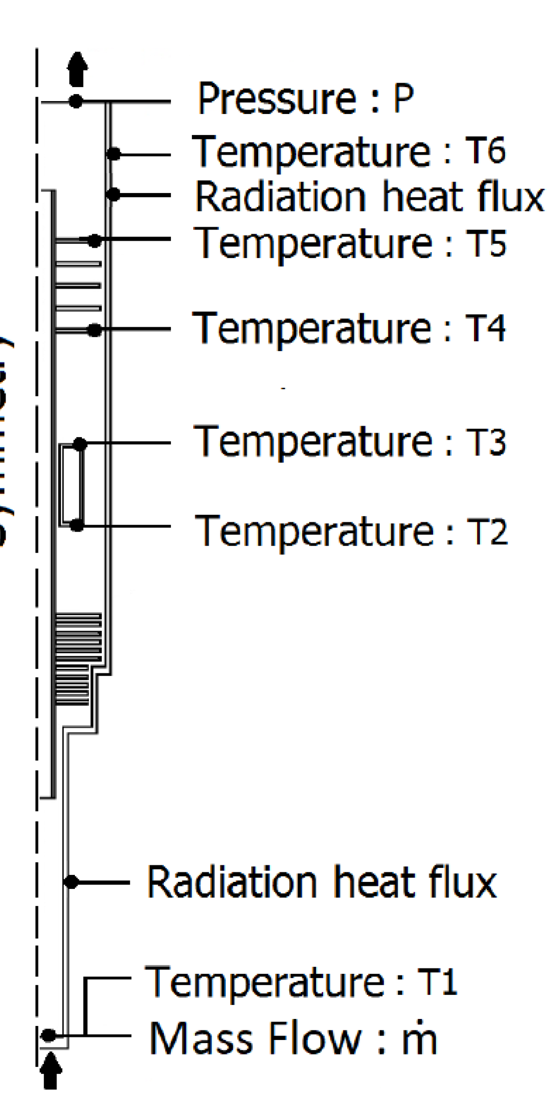

Figure 2. Geometry and main boundary conditions.

RESULTS: Fig 3a shows the zones of the refrigerator where the temperatures are T < 5K. There is a gradient in the refrigerator that separates the low temperature zone at near 1K from ambient temperature in the top flange which is 298 K. Fig 3b shows the velocity magnitude in the refrigerator. The flow accelerates in the high temperature zones. The density is shown in Fig 3c.

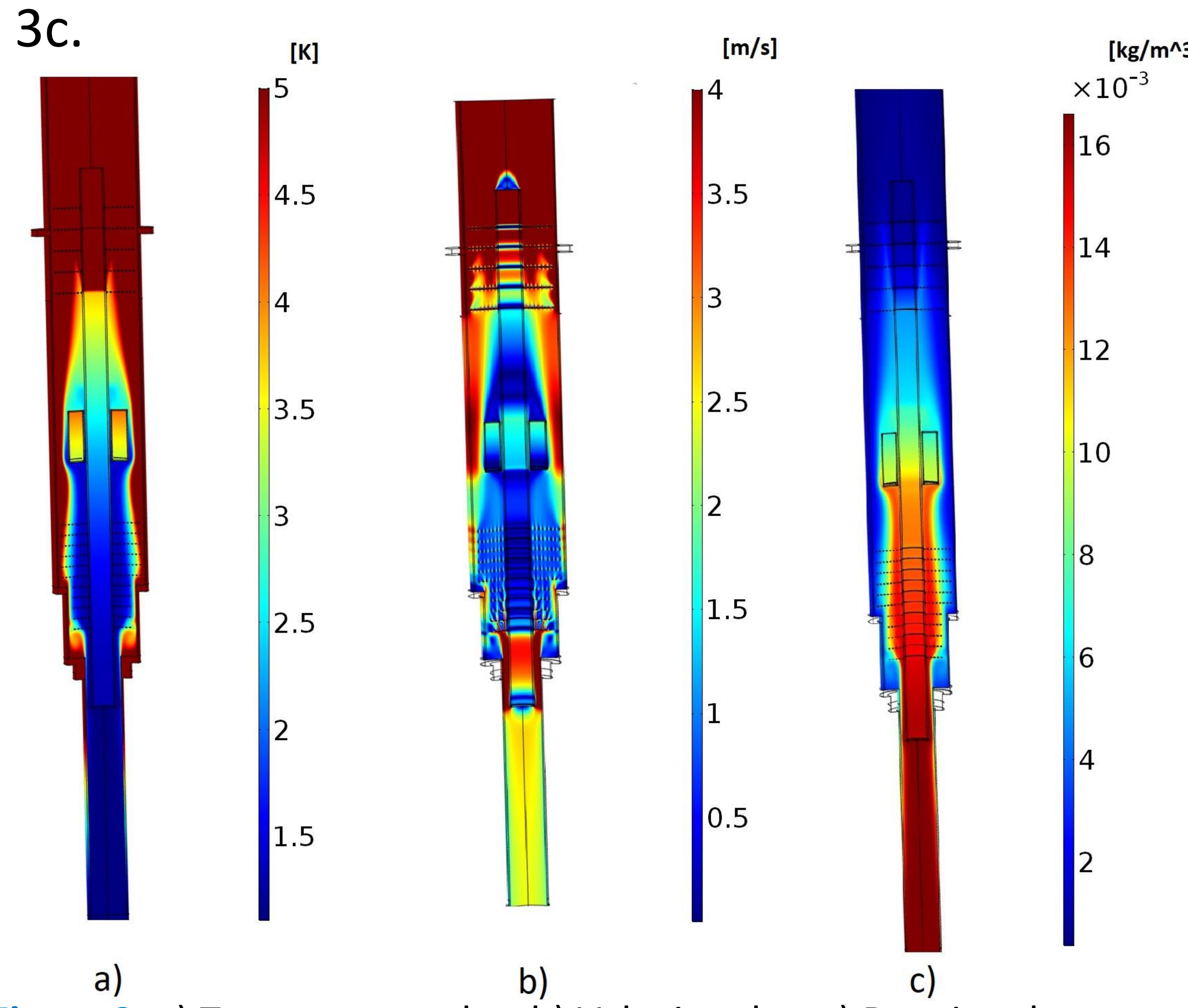

Figure 3. a) Temperature plot. b) Velocity plot. c) Density plot.

Fig. 4a shows that a turbulent flow develops in the "nose" and a laminar flow regime was obtained for the lower heat exchangers and radiation baffles. In Fig 4b an average value of 47 W/m^2K was obtained for the convection heat transfer coefficient obtained for the 4-He flow.

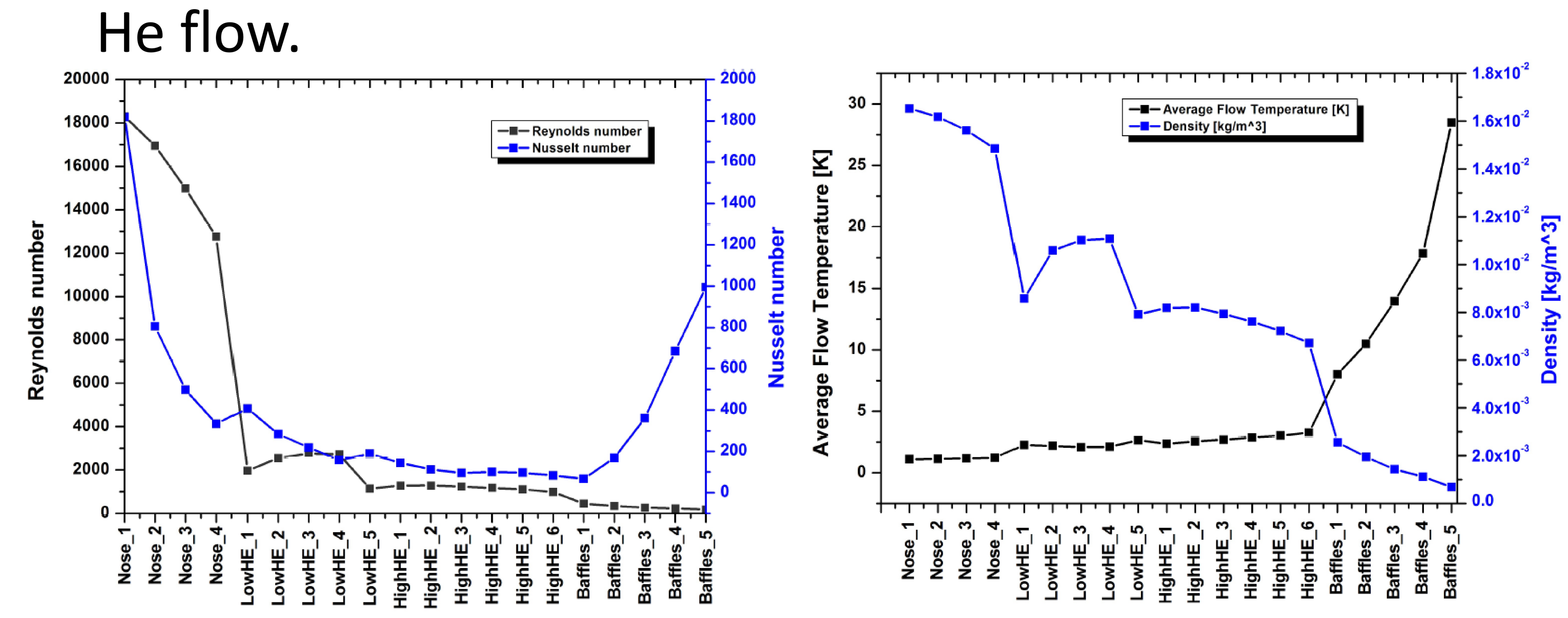

Figure 4. a) Reynolds and Nusselt number. b) Temperature and density.

CONCLUSIONS: In collaboration with members of the Department of Physics and Astronomy of UNH, we successfully develop a CFD simulation using COMSOL® Multiphysics for an 4-He evaporation refrigerator which predicts a cooling power of 2.68W for the superfluid helium bath at 1.11K. The difference between predicted and empirical cooling power was less than 7.5%. As this is the first time that this modern tool is used to study this type of refrigerators the results will be useful for design improvements, thermal studies and better understanding of its components.

REFERENCES:

1. Crabb, D. G., & Meyer, W. Solid polarized targets for nuclear and particle physics experiments. Annual Review of Nuclear and Particle Science, 47(1), 67-109(1997).
2. Pierce, J., et al. Dynamically polarized target for the gp2 and GpE experiments at Jefferson Lab. United States(2013).
3. Roubeau, P. Horizontal cryostat for polarized proton targets. Cryogenics, 6(4), 207-212 (1966).