ANALYSIS OF CRYOSTAT FOR SMALL ANGLE NEUTRON SCATTERING AT SMALL RESEARCH TRIGA REACTOR BY USING COMPUTATIONAL FLUID DYNAMIC(CFD)

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ABSTRACT

The temperature profile of a cryogenic system for cooling of beryllium filter of a small-angle neutron scattering (SANS) instrument of TRIGA MARK II PUSPATI research reactor was investigated using computational fluid dynamics (CFD) modeling and simulation. The efficient cooling of beryllium filter is important for obtaining higher cold neutron transmission for the SANS instrument. This paper presents the transient CFD results of temperature distributions via the thermal link to the beryllium and simulation of heat flux. The temperature simulation data are also compared with the experimental results for the cooling time and distribution to the beryllium.

ABSTRAK

Sistem penyejukan kriogenik digunakan untuk menyejukkan berilium digunakan pada kemudahan penyerakan neutron bersudut kecil(SANS) yang terdapat di reaktor penyelidikan TRIGA MARK II PUSPATI. Penyejukkan berilium ini di simulasi dengan menggunakan Dinamik Perkomputeran Bendalir(CFD). Penyejukkan yang berkesan akan memberikan panjang gelombang yang lebih tinggi (cold neutron transmission) yang digunakan pada kemudahan SANS. Hasil simulasi ini dibandingkan dengan hasil ujikaji yang dijalankan terhadap masa penyejukan dan juga fluks haba pada berilium tersebut.

Keywords: Small Angle Neutron Scattering, Computational Fluid Dynamics (CFD)

INTRODUCTION

The use and application of cryogenic storage usually associates with the cooling system to cool samples. The cryogenic storage naturally the object of thermal contribution of the ambient conditions when the heat insulations is less efficient. In 1950, 25 liter cryogenic storage of liquid nitrogen lasted only 24 hours and in 1990 it became nearly a year. Few studies have considered in detail these problems and methods to reduce the heat leaks of cryogenic storage vessels. One of the applications is for neutron conditioning.

There are many methods to condition the neutrons. Nuclear Engineering Teaching Laboratory(NETL) in Texas University using a cryogenic cryostat cooling system to condition neutron to the required wavelength. The cryostat system consists of a heat pipe, a vacuum system and a helium cryorefrigerator. The system is designed to maintain the moderating material to 30K (Kenan Unlu et al.,1994).The Small Angle Neutron Scattering (SANS) instrument at Algerian nuclear research reactor, a liquid nitrogen cryostat is used to cool the bismuth and beryllium filter at 77K to improved its efficiency and also to suppress the gamma and fast neutron components(Allek et al.,2004).Liquid hydrogen as the cooling media for neutron filter such as beryllium filter to improved the cold neutron fraction used in the McClellan Nuclear radiation Center, University of California Davis. This cold neutron beam is being used for neutron radiography research. The lower the temperature the better the cold neutron transmission through the beryllium filters. Small change in the temperature will significantly reduced the transmission of the cold neutrons (Aswal and Goyal, 2000).

The main effort is maintaining the cryogenic media or liquid from rapid evaporation or heating. The interaction of neutron with the moderator induces heat generation within the moderator.From the heat transfer perspective, this heat generation can be considered as heat source (Quach et al., 2007). In this paper, the experimental results obtained on temperature profiling of beryllium concerning heat transfer will be presented and compared with simulated results using Fluent commercial code.

NEUTRON BEAM CONDITIONING

The Reaktor TRIGA PUSPATI at the Malaysian Nuclear Agency is a 1 MW research reactor. It has four neutron beam ports and one beam port is dedicated to a small-angle neutron scattering (SANS) instrument. The SANS instrument is of 8 meter long with a Q range of about 0.013-0.1 $Å^{-1}$. The thermal neutron from the beam port is first filtered using polycrystalline beryllium before monochromatic neutron of 5 Å reflected to the SANS setup using HOPG. The function of a beryllium filter is to transmit only cold neutron of wavelength higher than 4 Å. The filter diffracted most of the neutron wavelength that is lower than 2d with d the largest d-spacing that can scatter neutron for the material. In the case of beryllium, d is 3.96 Å.

The neutrons from the graphite reflector transmitted via this beam-tube (beam-tube #4) is conditioned for wavelength 4.5 Å or higher in order to be suited with the set up of the SANS instrument. One of the techniques used to filter neutrons to a desire wavelength is by cooling polycrystalline beryllium at liquid nitrogen temperature 77K to reduce the diffuse scattering due to phonon excitation and increase the transmission of 4.9 Å or higher wavelength (Chowdhuri,2000). On the other hand, the cooled beryllium also could improve the neutron fluxes of higher wavelength neutron. Ideally, the beryllium temperature should be constant during SANS experiment. It was reported that, beryllium filter suppresses thermal neutrons of wavelength less than 0.396 nm at 77K (Sufi et al., 1997).

Some authors have shown that, the transmission of cold neutron can be maximized up to 100% since under this temperature the scattering cross section falls to 0.05 barns. At this temperature, there will be no lost of cold neutrons during transmission through the beryllium bar as even as long as 75 cm path (Whittemore et al., 1989). A cryogenic cryostat is used to cool the beryllium filter. The cryostat is place in the biological shielding close to the beam tube #4. However, the cryostat needs to be analyzed to enhance the capability of the cryostat in reducing the heat leaks of cryogenics storage vessel or cryostat (Boukeffa et al., 2001). Figure 1 is the bird eye view perspective of the experimental set-up shows the cooled beryllium and the neutron optic of SANS instrument at beam tube #4 of TRIGA MARK II PUSPATI reactor.

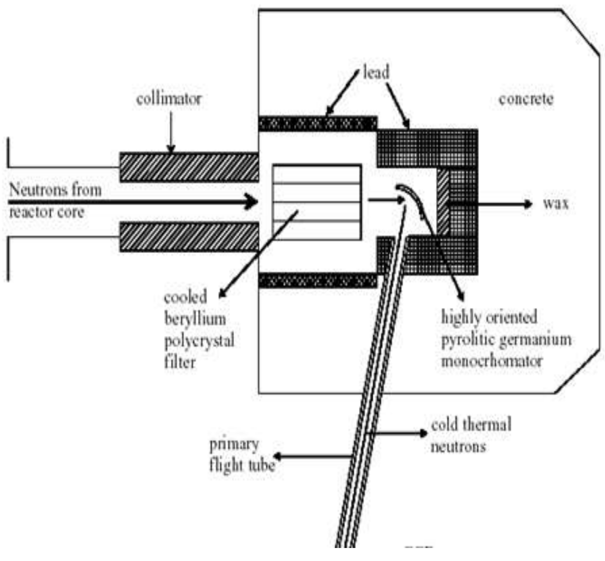


Figure 1. Top view of SANS collimation system

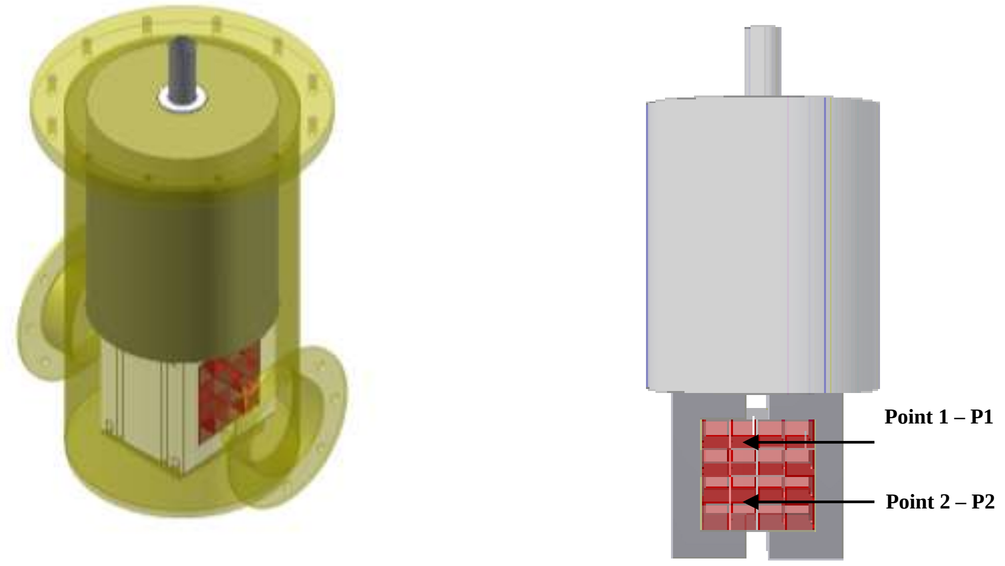
DESCRIPTION OF APPARATUS

The filter assembly is comprised of 4 x 4 rectangular bar polycrystalline beryllium with the dimension of 3 cm × 3 cm × 15 cm each, this made up a pigeonhole mesh with the gap 0.1 cm of cadmium sheet. The design ensures a small cross sectional area relative to the length of each bar, which makes it an effective neutron filter for the absorption of highly scattered neutrons, therefore results in a large surface area, sufficient to cover the entire neutron beam. It is cooled by a thermal link to a liquid nitrogen tank and is inserted in a cryostat chamber. However, according to (Khemis et al., 2004) to increase the insulation efficiency, cryostat chamber should be vacuum up to 10^{-8} torr. In this paper, the design of the cryogenic system and its performance for cooling the beryllium has been studied experimentally and compared with the numerical data. Figure 2 below is the geometrical model of the cryostat.

NUMERICAL ANALYSIS

Fluent code description

A commercial package program, Fluent is used in this study. In this study, Fluent codes enables the simulation and calculation of fluid flows for dynamic and thermal regime. Finite volume method is used to discretize the Navier-Stokes equations. Therefore, mass balance and momentum equations are coupled through the SIMPLE (semi implicit method for pressure link equation) algorithm. The SIMPLE algorithm is based on the predictor-corrector steps.



(a) (b)

Figure 2. (a) Geometrical model of cryostat, (b) Location of thermocouple

Cryostat modelling

The two dimensional mesh model was prepared using Gambit software. In the case of cryostats design, simplying assumptions have to be accepted because many of the relevant physical parameters are not available (Hanzelka, 1993). It is a complete model which read into Fluent finite volume computer program. The Tet/hybrid mesh was used in this study. A refined mesh was utilized for the Be blocks and the aluminium brackets, this enabling more accurate temperature gradients to be determined within the liquid nitrogen tank and the aluminium brackets. The mesh size for each domain is shown as in Table 1.

The boundary and continuum zones are then specified as shown in Table 2 and Table 3. The k-ε turbulent model is selected for the liquid flow and the conjugate heat transfer mode is applied. The boundary conditions specified are inlet mass flow rate, pressure outlet, the couple interface between liquid and solid domain. The liquid nitrogen temperature was set to 77.36K and the solid domain was set at 303K. Simulation runs in an unsteady (transient) mode.

TABLE 1: MESHING DOMAINS FOR CRYOSTAT

Domains	Mesh size (mm)	Mesh	Map
Liquid	0.0025	*Quad*	*Submap*
Solid			
1. Tank Wall	0.0025	*Tri*	*Pave*
2. Aluminium bracket			
3. Beryllium	0.001	*Quad*	*Submap*
4. Cadmium	0.001	*Quad*	*Submap*
	0.001	*Quad*	*Map*

TABLE 2 : BOUNDARY CONDITION FOR CRYOSTAT

Boundary	Initial Temperature (K)	Initial Pressure (Pa)
Liquid Nitrogen	77	101325
Solid		
1. Tank Wall	300	101325
2. Aluminium bracket	300	101325
3. Beryllium	300	101325
4. Cadmium	300	101325

TABLE 3: CONTINUUM ZONE PARAMETER

Zone	Boundary Condition Parameter					
	Temperature (K)	Hydraulic Diameter (m)	Terbulance Intensity (%)	Boundary Condition	*Energy Source Terms (w/m^3)*	*Thermal Heat Flux (w/m^2)*
Outlet	300	0.007	10	*Pressure outlet*	-	-
Wall	-	-	-	*Wall*	-	0
Beryllium	-	-	-	-	412.9	-
Cadmium	-	-	-	-	35.12	-

EXPERIMENTAL SETUP

There are two thermocouple type-T used to measure the temperature, they were thermally attached to the beryllium bar as shown by the photograph in Figure 2. The distance between thermocouple P1x and P2x is about 6 cm. The aluminum bracket was used to couple the beryllium assembly to the bottom of cryogenic tank. A LabVIEW data logger was used to record the thermocouple data computationally under the windows 2000 operating system.

The cryostat chamber is then vacuumed using the turbo molecular pump at pressure magnitude about 10^{-3} torr. Attach to the cryostat is the incoming tube from the liquid nitrogen dewar filled with the liquid nitrogen. The liquid nitrogen is then pump into the cryogenic tank using the motorize pump. The flow of the liquid nitrogen from the dewar to the cryogenic tank is controlled manually using the ball valve. Mass flow rate of the liquid maintained at 0.036 kg/s. Figure 3 shows the layout of the experimental set-up.

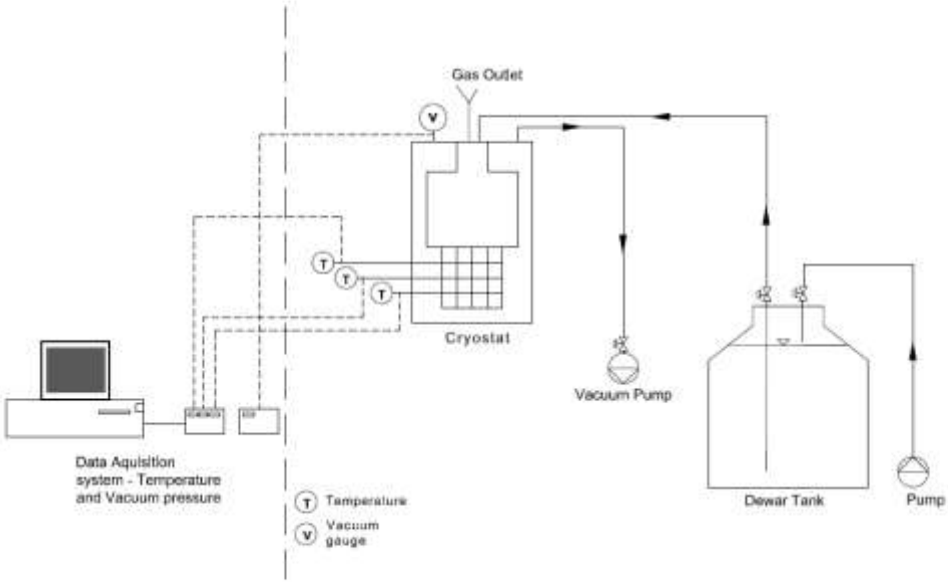


Figure 3. Schematic layout of experimental set-up

The temperatures from thermocouples have been recorded in-situ with the presence of neutrons from the reactor. The neutron beam at 750 KW reactor thermal power at the beam tube #4 of TRIGA MARK II PUSPATI research reactor was utilized. Before experiment, the cryogenic tank was placed in the biological shielding enclosure with the front surface of the beryllium bars assembly facing the beam tube and the back surface looking at the highly oriented pyrolitic germanium (HOPG) monochromator.

DISCUSSION

The simulation iteration converges and the iteration stops after 14400 time steps. The temperature profiles were obtained along the beryllium blocks. Experimental data were collected for 240 minutes and the results were compared with simulation. Figure 4 below shows the temperature profile for beryllium blocks.

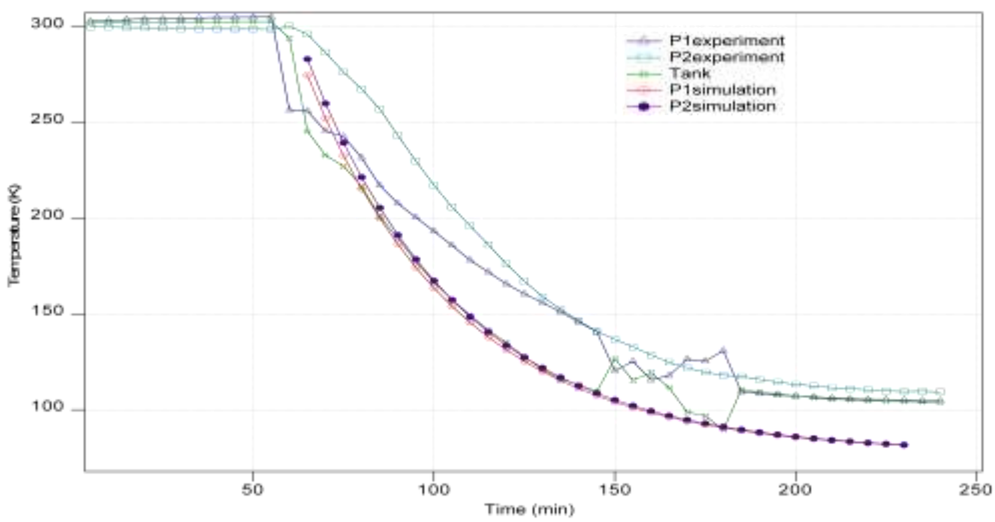


Figure 4. Temperature profile for beryllium

Figure 4 shows that the decrease of temperature at beryllium during the cooling process. However, the difference is 21% between simulation and experimental data. The achievable temperature after 240 minutes is 77.36K and 105K for simulation and experiment respectively. In Figure 5 shows the cooling profile of beryllium during the simulation process. There were significance changes of temperature from 30 minute to 60 minutes. It shows that the cooling process conducted heat vertically due to single plane cooling effect. However, there are instability of the temperature from 140 minutes to 180 minutes due to decrease of the liquid nitrogen tank and it stabilize after the liquid nitrogen is top-up or fill.

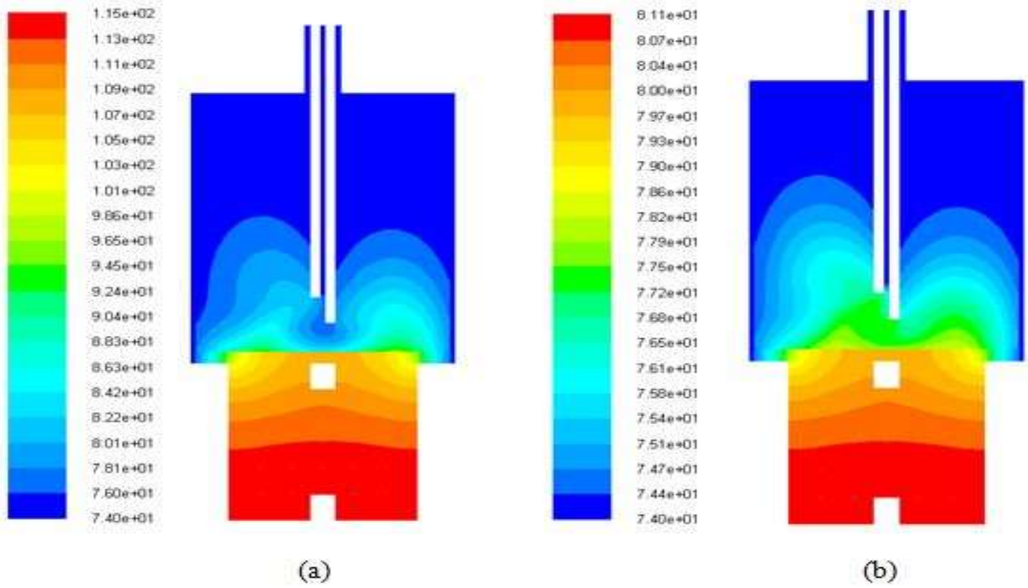


Figure 5. 2D Temperature profile at: (a) 30 min; (b) 60 min

Figure 6 shows that during the cooling process, the heat flux and gas mass of the liquid nitrogen exponentially decrease. Therefore, the liquid volume fraction content increase.The increase in liquid fraction will sustain the cooling of the beryllium in the cryostat.

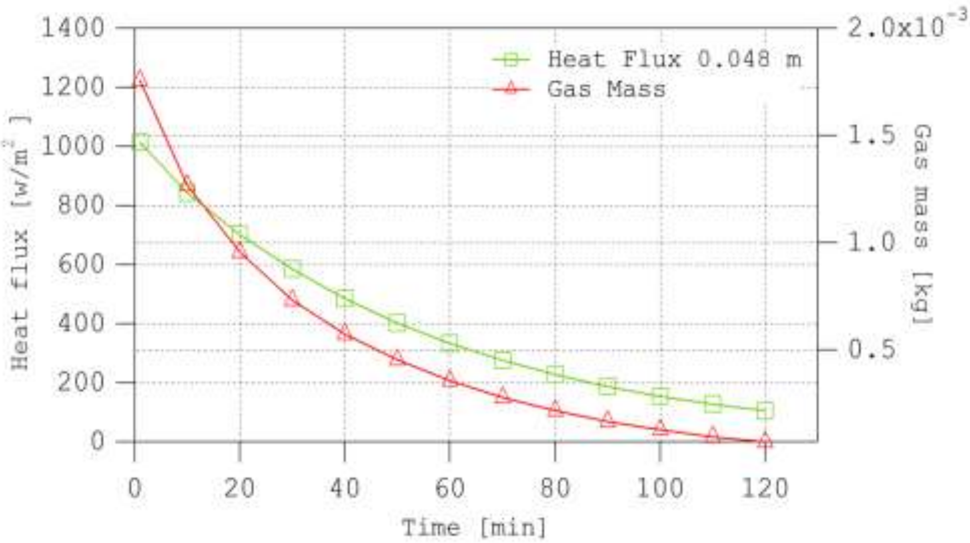


Figure 6. Simulated data for heat flux and gas mass

CONCLUSION

The simulation and experimental studies on the cryostat performance were carried out. The numerical results are obtained from simulation with an industrial code, Fluent, for a nitrogen cryostat. Experimental and simulated results concerning the temperature profile, heat flux and gas mass have been presented. This study shows that the agreement between the experimental and simulated results for the temperature profile. There is a decrease of temperature profile for beryllium during the cooling process from the simulation result. From observation the heat flux and gas mass is in good agreement, it shows that the gas mass decrease over time when the heat flux is decreased. These results demonstrate the good choice of the code and a correct modeling. The cryostat needs further upgrading in order to improve the heat transfer to the beryllium filters.

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