(Established under Karnataka Act No. 16 of 2013)
100-ft Ring Road, Bengaluru – 560 085, Karnataka, India

Internship Report on

'Design, Development and Heat Transfer Analysis of Cryogenics Heat Exchanger'

at

Indian Institute of Science, Bangalore

Submitted by

TH Karthik (PES1UG20ME110)

Under the guidance of

Dr. Upendra Behera
Principal Research Scientist,
Centre for Cryogenic Technology,
Indian Institute of Science

and

Dr. Jyothi Prakash K H
Assistant Professor
Department of Mechanical Engineering
PES University
Bengaluru -560085

10th January 2024 – 30th June 2024

CERTIFICATE

CENTRE FOR CRYOGENIC TECHNOLOGY
Indian Institute of Science, Bangalore – 560012

Dr. Upendra Behera
Principal Research Scientist

Date: 29.04.2024

Provisional Certificate

This is to certify that Mr. T H Karthik bearing SRN – PES1UG20ME110 has undergone internship under my guidance at the Center for Cryogenic Technology, Indian Institute of Science, Bangalore during the period January 10, 2024 to till date. He is working on the project titled *'Design, Development and Heat Transfer Analysis of Cryogenics Heat Exchangers'* which is partially completed. He has carried out parametric studies on cryogenic heat exchangers through CFD analysis. His internship will continue till 30/06/2024.

Dr. Upendra Behera, Ph.D.
Principal Research Scientist
Centre for Cryogenic Technology
Indian Institute of Science
Bangalore - 560 012, India

91-80-2360 1612 / 2293 2339 / 2293 3081 91-80-2360 1612 behera@iisc.ac.in

PROOF OF COMMUNICATION

Gmail karthik t h <karthikth129@gmail.com>

Fwd: Feedback for TH Karthik internship

Jyothiprakash K H PESIT ME <Jprakash@pes.edu> Tue, Apr 30, 2024 at 5:46 PM
To: karthik t h <karthikth129@gmail.com>

---------- Forwarded message ---------
From: **Dr.Upendra Behera** <behera@iisc.ac.in>
Date: Tue, 30 Apr 2024, 5:32 pm
Subject: Re: Feedback for TH Karthik internship
To: Jyothiprakash K H PESIT ME <Jprakash@pes.edu>

Dear Dr. Jyothiprakash,

Thanks for your mail.

Mr. Karthik TH working as intern since January 10, 2024 till date. During this period, I found him sincere and hardworking. He is involved in design and analysis of cryogenic heat exchangers using Solidworks and Ansys Fluent softwares respectively. He is quite conversant with Solidworks and Ansys software. He also helped in department activities on the annual open day event IISc, during his internship period and in conducting cryogenic experiments in my group.

Regards,
Upendra Behera

From: Jyothiprakash K H PESIT ME <Jprakash@pes.edu>
Sent: Friday, April 12, 2024 1:15 PM
To: Dr.Upendra Behera <behera@iisc.ac.in>
Subject: Feedback for TH Karthik internship

External Email

Professor Upendra Behera,

I hope this email finds you well. My name is Dr. Jyothiprakash K H, and I am reaching out to you as the mentor for TH Karthik, who has been interning with your organization.

As TH Karthik's supervisor during the internship, your insights and feedback are very valuable to us. Could you please take some time to provide feedback on his performance during the internship? We are particularly interested in hearing about his strengths, areas for improvement, and any contributions he made during his time with your organization.

Thank you very much for your time and support in helping us ensure a meaningful and impactful internship experience for our students. We look forward to hearing from you soon.

Regards

--
Dr. JYOTHIPRAKASH K H
Assistant Professor,
Thermo-Fluids Domain,
Department of Mechanical Engineering,
PES University.

DECLARATION

I hereby declare that I have partially completed my six months of internship at *"Centre for Cryogenic Technology"*, Indian Institute of Science, Bangalore from 10/01/2024 to 30/06/2024 under the guidance of Dr. Upendra Behera, Principal Research Scientist, Centre for Cryogenic Technology, Indian Institute of Science, Bangalore and Dr. Jyothi Prakash K H, Assistant Professor, Department of Mechanical Engineering, PES University, Bangalore, submitted in fulfilment of the credits for the degree of Bachelor of Technology in Mechanical Engineering in PES University, Bangalore during the final semester. The matter embodied in this report has not been submitted to any other University or Institution for the award of any degree.

(TH Karthik)
PES1UG20ME110
Bangalore

ACKNOWLEGMENT

I am grateful to **Dr. Upendra Behera**, Principal Research Scientist, Centre for Cryogenic Technology, Indian Institute of Science, Bangalore for without him I would not have had the amazing opportunity to work in an institute of such prominence as IISc. I am also extremely grateful for all his insight and advice as it has given a new perspective.

I would like to express my deep gratitude to **Dr. Debashish Panda**, Postdoctoral Fellow, Centre for Cryogenic Technology, Indian Institute of Science, for their unrelenting support and guidance without which any progress would have impossible.
I would also like to extend my gratitude to my guide, **Dr. Jyothi Prakash K H** Assistant Professor, Department of Mechanical Engineering, PES University, Bangalore, for his kind supervision and unrelenting support and encouragement during the entirety of the internship.

I also would like to thank **Dr. N Rajesh Mathivanan**, Chairperson, Dept. of Mechanical Engineering, PES University, Bangalore, for his kind support in helping me undertake this internship

I am extremely grateful to **Dr. Suryaprasad J**, Vice Chancellor, **Dr. K. S. Sridhar**, Registrar and **Dr. Keshavan B. K**, Dean Faculty of Engineering, PES University, Bangalore for all support extended.

(TH Karthik)
(PES1UG20ME110)

EXECUTIVE SUMMARY

The final year internship at the Centre for Cryogenic Technology, IISc Bangalore focused on designing and simulating a two-fluid heat exchanger for cryocooler systems. This involved studying existing research on plate heat exchangers used in similar setups and selecting a lead paper for reference. Parametric studies were conducted using helium and water, and oil and water, as working fluids to optimize heat transfer efficiency. Simulation was performed using Ansys Fluent for various configurations, yielding insights into thermal dynamics, flow rates, and pressure drops. The objective is to design a heat exchanger with effective heat transfer, suitable for cryocoolers. The project contributes to advancing two-fluid heat exchanger design, providing a foundation for future experimentation and development.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter-1
About Indian Institute of Science

1.1 History

Nusserwanji Jamsetji Tata, a successful industrialist, in the 1890s decided to use his personal wealth to establish a world-class university in India. He was a firm believer in the role of scientific research and higher education in bringing about social and economic change.

Tata's dream of establishing what has become known as the Indian Institute of Science (IISc), seen in Figure 1.1, became a reality thanks to the support of the rulers of Mysore State,who shared his commitment to education and research.

Moving into the twenty-first century, they set up an undergraduate programme, several new departments and centres in the areas of brain research, nanoscience and engineering,hypersonics and more, strengthened ties with several industries and have incubated severalstart-ups.

1.2 Achievements

Several eminent scientists have graduated from IISc, including Homi J Bhabha, the founder of India's nuclear program, Vikram Sarabhai, the founder of India's space programme, meteorologist Anna Mani, biochemist and nutrition expert Kamala Sohonie, and solid-state and materials scientist CNR Rao, to name a few. The Institute was also instrumental in the establishment of other academic organizations.

1.3 The Institute's Aim

IISc aims to be among the world's foremost academic institutions through the pursuit of excellence in research and promotion of innovation by offering world-class education to train future leaders in science and technology and by applying the same to achieve breakthroughs for India's wealth creation and social welfare. Conducting high-impact research, generating new knowledge, and disseminating this knowledge through publications in top journals and conferences. Applying faculty expertise towards the success of national science and technology initiatives.

1.4 Details of the Institute

There are 4000 students at the institute, including undergraduate, postgraduate, and postdoctoral students. It also has over 300 administrative task forces and over 500 faculty and researchers. For the fiscal year 2023-2024, the institute had a budget of 991 crore rupees, which was divided among six main divisions and more than 40 departments.

Figure 1.1 Main building at IISc

Chapter 2
About Centre for Cryogenic Technology

2.1 Centre for Cryogenic Technology, CCT Department

The department produces around 4,00,000 liters of liquid nitrogen and 30,000 liters of liquid helium per annum for the users in the institute and is the largest in producing cryogens among the academic sector institutions in the country. CCT also supplies cryogens to various R&D and medical doctors, and institutions in and around Bangalore.

Figure 2.1 Department members of Center of Cryogenic Technology

2.2 Current Research Projects

1. Cryogenic Transfer Lines (CTL)
2. Enhancement of vortex tube LOX separator technology for HTV
3. Pulse tube cryocoolers
4. Cryogenic heat pipes
5. Liquid helium FRP cryostat for operation of SQUIDs for NDT studies

Chapter 3
Tasks Performed

During the internship at the Indian Institute of Science's Centre of Cryogenic Technology, under the guidance of Dr. Upendra Behera, the task assigned was to design and simulate a two-fluid heat exchanger for cryocooler systems. This involved studying existing research on plate heat exchangers used in similar setups and selecting a lead paper for reference. Further task was to conduct parametric study for helium and water as working fluid and, Oil and water as working fluid. The objective is to design a heat exchanger with effective heat transfer, suitable for cryocoolers. All the task was performed using Solidworks for modelling and Ansys Fluent for numerical analysis

3.1 Validation

Kwon et al. [1] have conducted experiment on PHE using refrigerant R-1233zd(E) and water. In the experiment of single-phase water to water, HTC correlation was obtained using Wilson plot. This plate heat exchanger was modelled using SolidWorks and was used for further studies. Specifically, we compared the numerical analysis conducted in Ansys Fluent with the experimental findings of Kwon et al [1] for a PHE with grooves featuring Chevron angles on the plates. The validation focused on a scheme of a brazed PHE with corrugated characteristics, as depicted in Figure 3. The geometric attributes of the PHE from [1] are detailed in Table 1 for comparison, while Table 2 outlines the various cases examined for different mass flow rates and their corresponding temperatures for the hot and cold fluids. This validation process specifically targeted the single-phase water-to-water experiment.

Table 3.1 Design Specification

Design Parameters	Dimensions
Chevron angle (degrees)	60
Enlargement factor	1.15
Hydraulic diameter [mm]	3.32
Wavelength [mm]	7.5
Length of flow [mm]	234
Thickness of the Plate [mm]	0.4
Width of plate [mm]	117
Pitch [mm]	1.94
Plate material	Stainless steel 316

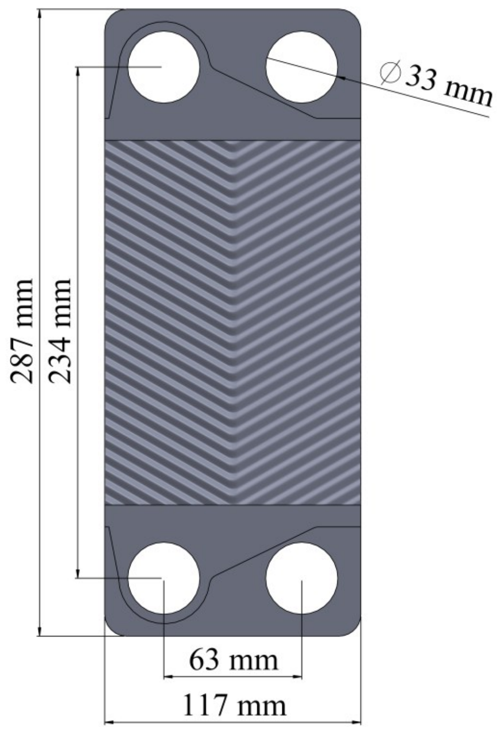


Figure 3.1 Illustration depicting the Plate Heat Exchange

Table 3.2 Boundary Conditions

Case:	fluid	Temperature (K)	mass flow rate (kg/s)
1	Hot	310.85	0.0412
	Cold	302.75	0.0788
2	Hot	317.85	0.0412
	Cold	310.15	0.0740
3	Hot	323.85	0.0412
	Cold	315.15	0.0675

3.1.1 Geometric Modelling

The heat exchanger consists of 6 plates as shown in Figure 4 which was designed using Solidworks. In this study water is used as working fluid. The hot fluid and flows through two channels in the PHE and cold fluid which flows through three channels in the PHE as shown in the Figure 4. The hot fluid flows in the Upward direction and cold fluid flows in the downward direction

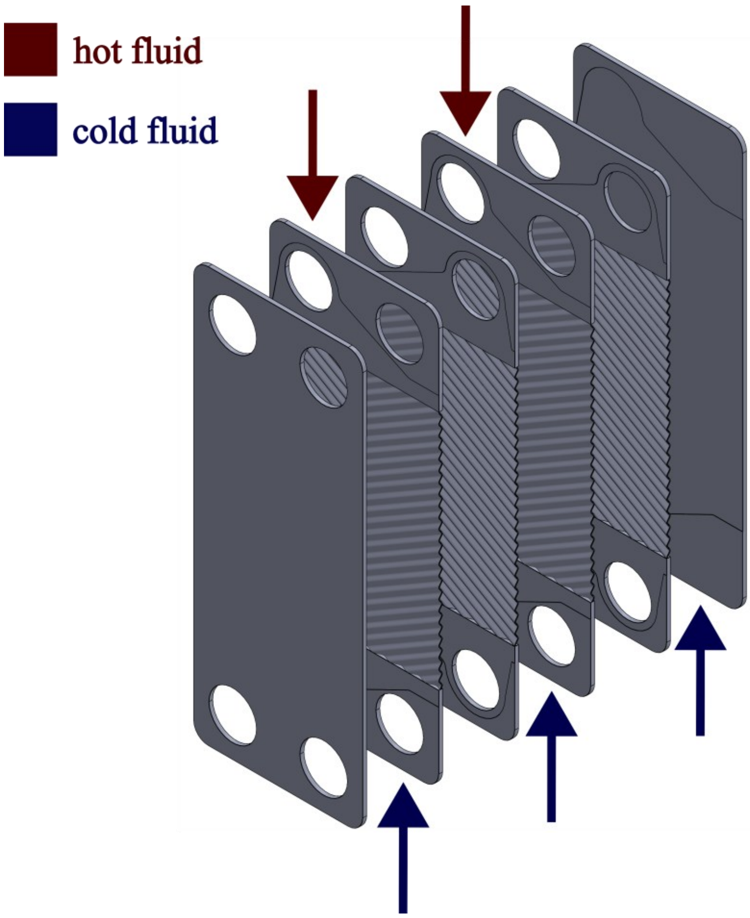
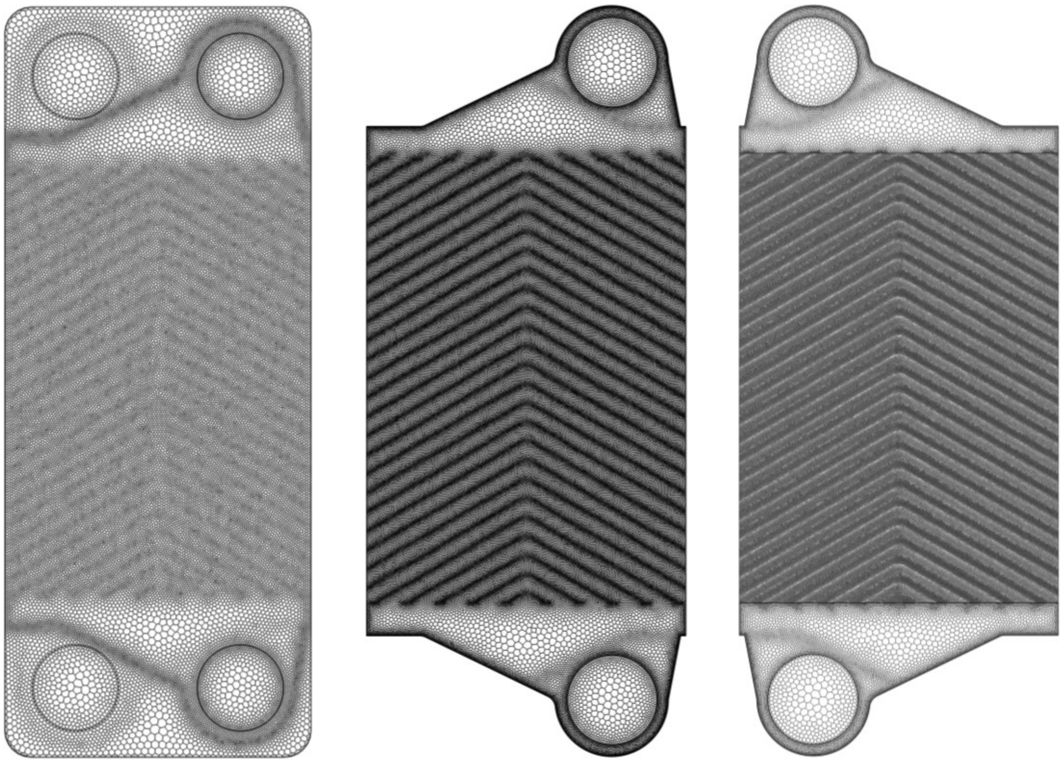


Figure 3.2 Stacked arrangement of PHE

3.1.2 Meshing

Meshing is a pivotal aspect of Computational Fluid Dynamics research, involving the division of the simulation domain into smaller elements. This process is essential for accurately modeling fluid flow, influencing the reliability and precision of research findings. The solid model is meshed with a Face sizing of 0.5mm using Ansys Fluent meshing and the type of element used for discretization is Polyhexcore. The meshing was refined around a corrugated pattern. Figure 5(a), 5(b) and 5(c) show the discretization of the plate using fluent meshing. The number of mesh elements formed using this value was 10,425,614.



(a) (b) (c)

Figure 3.3 (a) Discretization of PHE, (b) Discretization of cold fluid domain, (c) Discretization of hot fluid domain

3.1.3 Governing Equations

To determine the characteristics of the flow field, it's necessary to solve the conservation equations for energy, momentum and mass. Continuity equation ensures mass conservation which is given by Equation (1), the Navier-Stokes equation addresses momentum dynamics which is given by Equation (2), and the energy equation governs heat transfer rate which is given by Equation (3)

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho u_i\right)=0 \tag{1}$$

$$\frac{\partial\left(\rho u_i\right)}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho u_i u_j\right)=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i \tag{2}$$

$$\frac{\partial\left(\rho E\right)}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho E u_i\right)=\frac{\partial}{\partial x_i}\left(k\frac{\partial T}{\partial x_i}\right)+\rho u_i g_i+Q \tag{3}$$

For the analysis, Laminar model and second order upwind solution method are used. CFD Simulation was performed in Ansys Fluent, with water and helium as a working fluid. Table 3 provides details regarding the selected simulation model.

Table 3.3 Parameters Set for CFD Simulation

Solver Type	Pressure-based
Flow model	Laminar
Solver Method	Second Order method
Velocity-Pressure interaction	SIMPLE

The temperature difference between outlet and inlet of cold fluid is given by:

$$\Delta T_c = T_{co} - T_{ci} \tag{4}$$

The temperature difference between outlet and inlet of hot fluid is given by:

$$\Delta T_h = T_{hi} - T_{ho} \tag{5}$$

The heat transfer rate for cold fluid and hot fluid has been calculated using the temperature difference as follows:

$$Q_c = m_c c_p \Delta T_c \tag{6}$$

$$Q_h = m_h c_p \Delta T_h \tag{7}$$

The effectiveness of HX is given by:

$$\varepsilon = \frac{Q_{actual}}{Q_{\max}} \tag{8}$$

In order to obtain effectiveness, the maximum rate of heat transfer and actual rate of heat transfer is given by:

$$Q_{\max} = C_{\min} \Delta T \tag{9}$$

$$Q_{actual} = m_h c_p \Delta T_h = m_c c_p \Delta T_c \tag{10}$$

To find maximum rate of heat transfer, the temperature difference and minimum heat capacity is given by:

$$\Delta T = T_{hi} - T_{ci} \tag{11}$$

$$\begin{aligned} C_{\min} &= m_h c_h, if\ m_h c_h < m_c c_c \\ C_{\min} &= m_c c_c, if\ m_c c_c < m_h c_h \end{aligned} \tag{12}$$

3.1.4 Results

After performing CFD simulation, the obtained results are compared with experimental results [1] and shown in Table 4. The CFD simulation yielded results with a maximum error of 6.25%, indicating good numerical model accuracy. This suggests the model is suitable for further studies or analysis. Validation against real-world data and sensitivity analysis can enhance confidence in the model.

Table 3.4 Comparison of CFD and Experimental Results

Case:	T_{hi} (^{0}C)	T_{ci}(^{0}C)	$U_{experimental}$ (W/m^{2}K)	U_{cfd} (W/m^{2}K)	% error
Case 1	37.7	29.6	2673.916	2506.776	6.25
Case 2	44.7	37	2711.748	2824.218	4.147
Case 3	50.7	42	2716.468	2879.567	6.004

3.2 Parametric Analysis

Further CFD Simulation were performed for water and helium as working fluid. Here helium is considered as hot fluid and water as cold fluid. The water flows through three channels and helium flows through two channels as shown in Figure 5. The parametric analysis was performed for various flow rate and temperature. Table 5 outlines the operating conditions utilized for the present study.

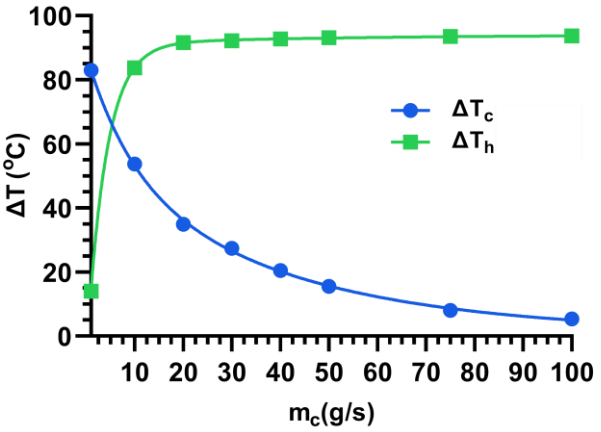
Table 3.5 Operating Condition

Fluid	Mass flow rate (kg/s)	T_i (^{0}C)
Hot	0.005	100
Cold	0.001-0.1	5-15

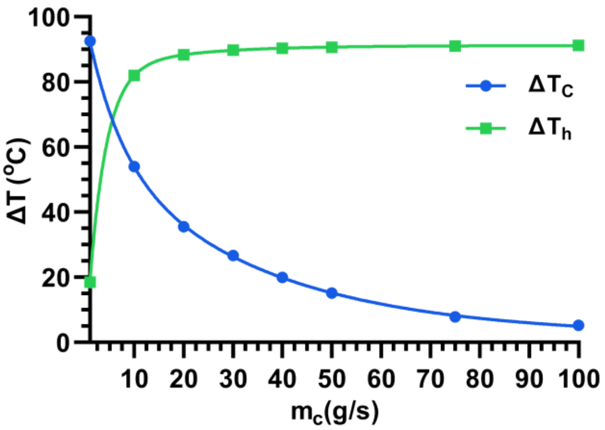
3.2.1 Effect of mass flow on ΔT

The mass flow rates of the cold are varied from 0.01 kg/s to 0.05 kg/s in 0.01 kg/s increments. The inlet temperatures are set at 5°C, 7.5°C, 10°C, 15°C for the cold fluid and 100°C for the hot fluid. ΔT_c and ΔT_h is calculated using Equation (4) and (5). Figure 6 illustrate the relationship between ΔT and the varying mass flow rate of the cold fluid. It is observed that ΔT_h increases as the mass flow rate of the cold fluid increases, indicating a transition to turbulent flow. This transition enhances the mixing of the cold fluid, resulting in a thinner thermal boundary layer and more efficient heat transfer to the hot fluid. On the other ΔT_c decreases as mass flow rate of cold fluid increases; this outcome is attributed to the reduced duration of fluid interaction for heat transfer at higher flow rates.

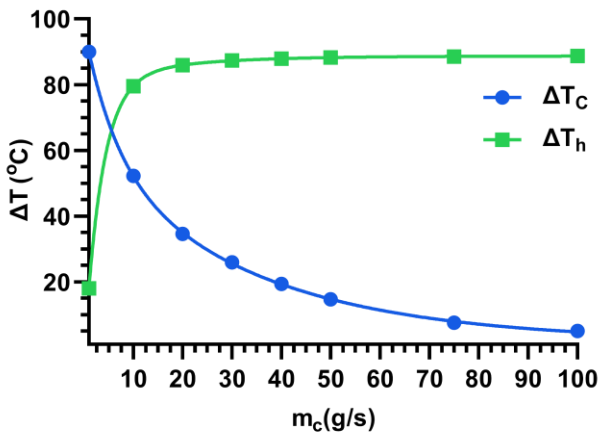
It is also observed that ΔT_h remains constant at high flow rates regardless of the inlet temperatures. Therefore, based on the results, it can be concluded that helium can be efficiently cooled at an optimal flow rate of 0.02 kg/s. Further increases in flow rate do not significantly affect the results within a broader range. In fact, higher flow rates lead to increased pressure drop, consequently resulting in higher pumping power requirements. On average, the ΔT_h value ranges from 85 to 87 °C.



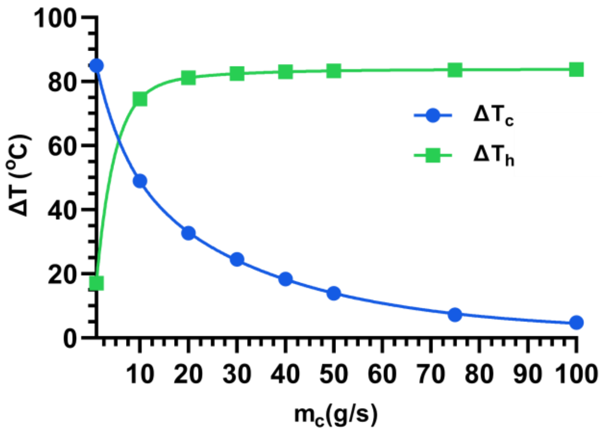
(a) T_{ci} = 5 ºC



(b) T_{ci} = 7.5 ºC



(c) T_{ci} = 10 ºC

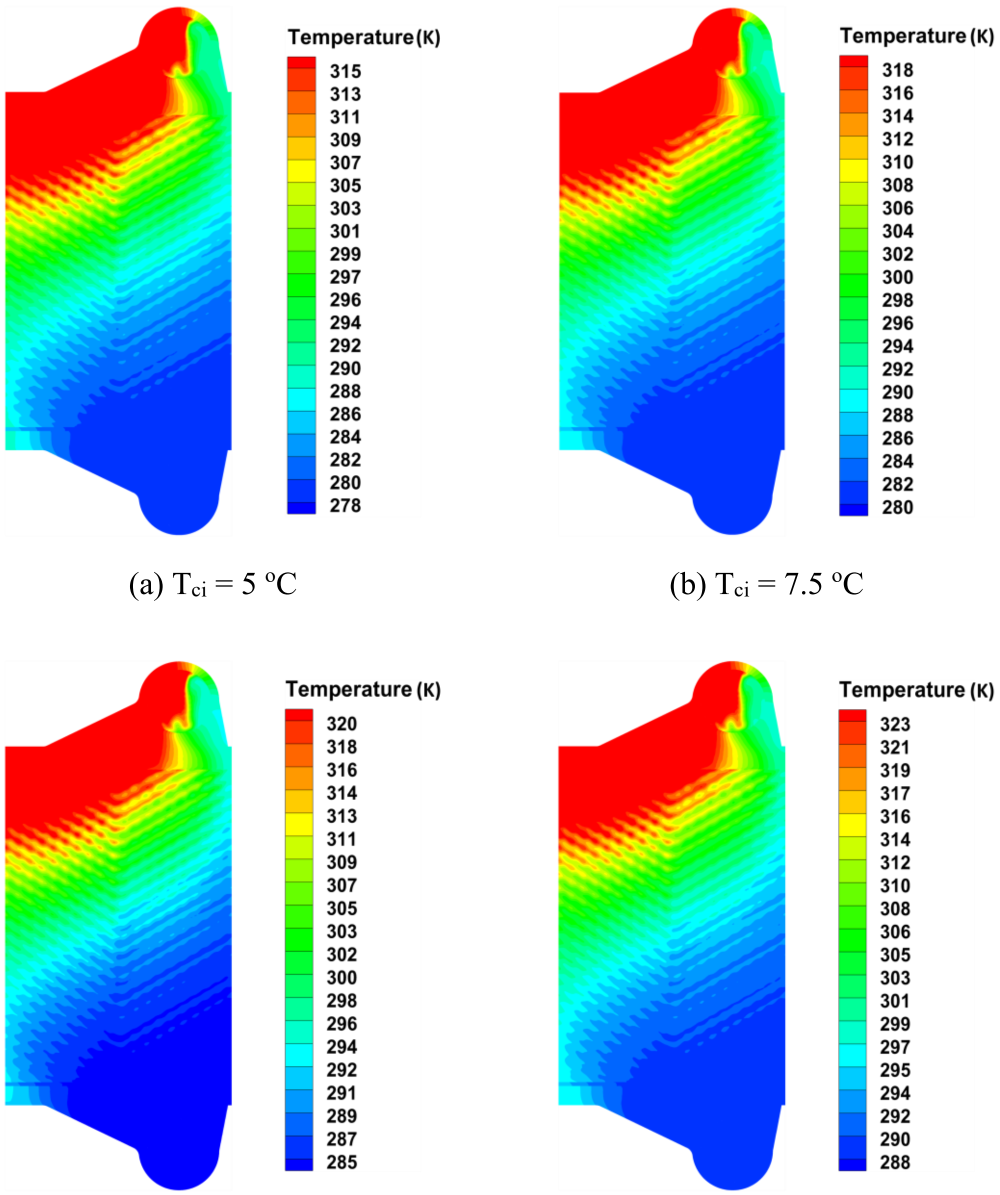


(d) T_{ci} = 15 °C

Figure 3.4 Plot of ΔT vs mass flow rate for various cold fluid inlet temperature

3.2.2 Cold Fluid Temperature Contours

Figure 7 displays temperature contours of the cold fluid for various cold fluid temperatures. These temperature contours correspond to a cold fluid mass flow rate of 20 g/s. It is evident from the contours that the majority of heat transfer occurs at the outlet side. This phenomenon is attributed to the incoming hot fluid on the opposite side of the plate. Given the contour flow, most of the heat transfer happens at the outlet of the cold fluid for the colder side.



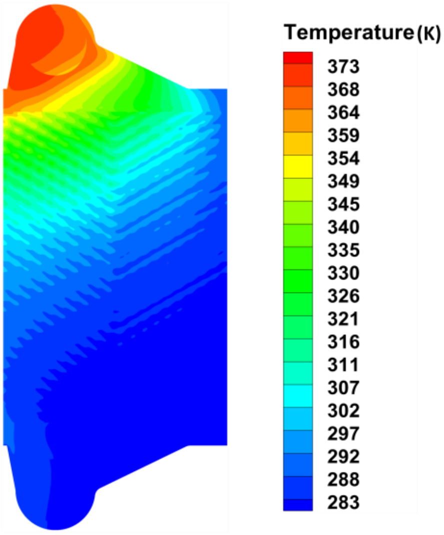
(a) T_{ci} = 5 ºC (b) T_{ci} = 7.5 ºC

(c) T_{ci} = 10 ºC (d) T_{ci} = 15 ºC

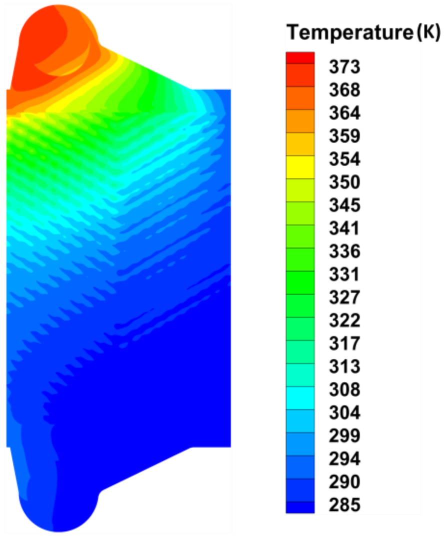
Figure 3.5 Temperature Contours of cold fluid at different cold fluid temperatures

3.2.3 Hot Fluid Temperature Contours

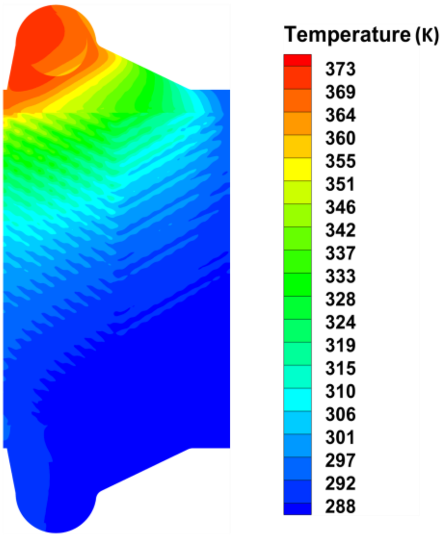
Figure 8 illustrates temperature contours of the hot fluid for different cold fluid temperatures. These contours are associated with a cold fluid mass flow rate of 20 g/s and a hot fluid mass flow rate of 5 g/s. Observing the contours, it becomes apparent that the hot fluid undergoes cooling before reaching the outlet. This contrasts with the behaviour of the cold fluid. The reason behind this deviation lies in the low mass flow rate of the hot fluid, granting it more time for heat transfer.



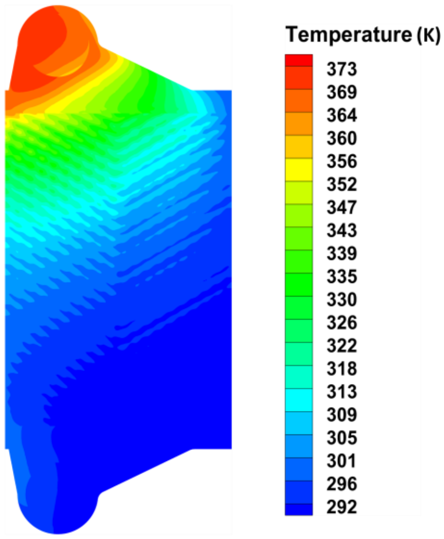
(a) T_{ci} = 5 °C



(b) T_{ci} = 7.5 °C



(c) T_{ci} = 10 °C



(d) T_{ci} = 15 °C

Figure 3.6 Temperature Contours of hot fluid at different cold fluid temperatures

3.2.4 Effect of mass flow on rate of heat transfer

The mass flow rate ranges from 1 g/s to 100 g/s for the cold fluid, with inlet temperatures of 100°C for the hot fluid and 50°C, 7.5°C, 100°C, and 150°C for the cold fluid. Figure 9 illustrates the heat transfer rate plotted against the mass flow rate of the cold fluid. Initially, it's observed that the rate of heat transfer increases with the mass flow rate up to 30 g/s. However, beyond this point, increasing the mass flow rate of the cold fluid leads to a decrease in the rate of heat transfer. This could be attributed to the possibility that at higher flow rates, there may be instances where the fluid does not make contact with the plate, consequently reducing the heat transfer efficiency.

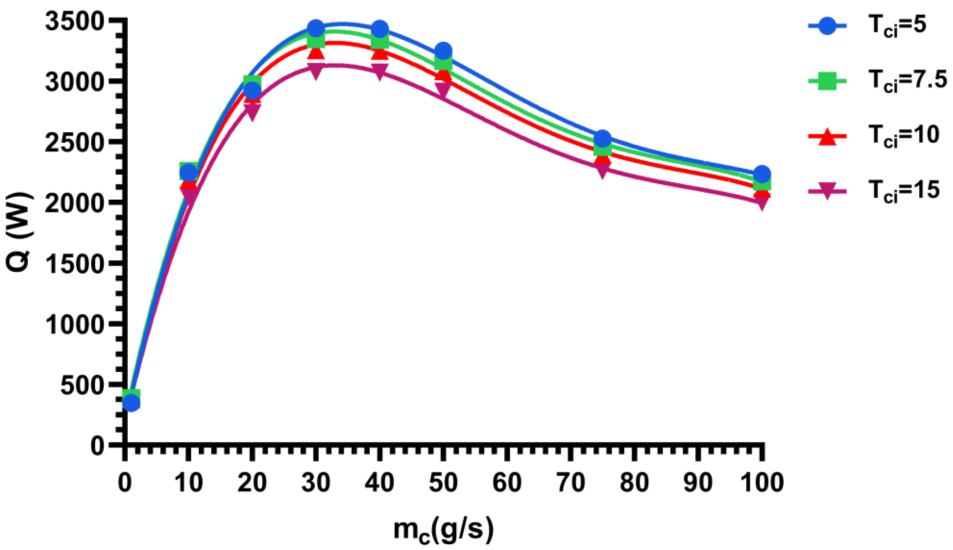


Figure 3.7 Plot of rate of heat transfer vs mass flow rate for various cold fluid inlet temperature

3.2 Non-Technical Tasks

The internship mainly focused on technical tasks, but some non-technical duties were also part of the experience. Firstly, assistance was provided in relocating lab components to a new facility and setting up workstations. Secondly, an experiment demonstrating Boyle's Law was conducted and showcased during the IISC Open Day 2024.

Chapter 4
Reflection Notes

IISc is a dream institute to work at for many students like me. Having worked there as an intern makes me feel privileged and blessed. The meticulousness in research and humbleness of faculty and students are things to learn from. Working at IISc has made me realize that learning has no limits and that there is a need to strengthen my fundamental understanding of things. Interacting with may brilliant students has been an added benefit of the internship.

4.1 Technical Outcomes

During the internship, I focused on designing and analysing heat exchangers used in cryocoolers. I learned about various types of cryogenic heat exchangers and gained experience in conducting numerical analysis using ANSYS Fluent. Additionally, I enhanced my skills in post-processing by utilizing Tecplot software to generate high-quality contours for better representation of results. Moreover, I improved my ability to create high-quality diagrams using Inkscape software and performed graph plotting using GraphPad Prism software.

4.2 Non-Technical Outcomes

Meeting deadlines regularly has developed vital skills like time management, working under pressure, and discipline. Presenting work progress to our supervisor improved my presentation and public speaking skills. Coordinating with a team during lab relocation enhanced teamwork abilities. Participating in the IISc open day program highlighted the importance of communication, patience, and crowd management.

Reference

[1] Oh Jin Kwon, Byung Hoon Shon, Yong Tae Kang. Experimental investigation on condensation heat transfer and pressure drop of a low GWP refrigerant R-1233zd(E) in a plate heat exchanger. *Int. J. Heat Mass Transf.* **131** 1009-1021.