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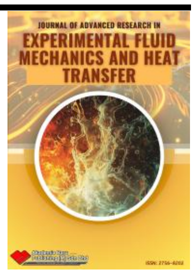

Experimental Study and Thermal Examination of a Practicable Helium Liquefaction Prearrangement using a Pervasive Gifford-McMahon Cryocooler

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ABSTRACT

Liquid helium has been attained by cooling helium gas to 4 K or -269^{0}C. Many laboratories around the globe compel liquid helium as a working medium for low temperature investigation. In current scenario, liquid helium generating systems are exclusive and momentously compatible. Helium recondensation or liquefaction system is the unsurpassed platform to liquefy or to condense the helium in many applications viz., Nuclear Magnetic Resonance (NMR), Magnetic Resonance Imaging (MRI) and Superconducting Quantum Interference Devices (SQUIDS). These applications make use of liquid helium as refrigerator. In this research, the experimental investigation of a small-scale liquefaction system for helium gas using two-stage GM cryocooler has been carried out. The experimentation using 100 cm^3 yielded a result of, initial collection of liquid in upright liquefaction system takes about 335 minutes and subsequent collection of liquid helium (batch liquefaction) takes place with the time interval of nearly 45 minutes at a pressure of approximate 1bar. In case of inverted system, the initial collection of liquid helium takes about 170 minutes and subsequent collection of liquid (batch liquefaction) takes place with the time interval of nearly 30 minutes at a pressure of approximate 1 bar. From the above result, it has been concluded that the liquefaction rate is a function of pressure exists inside collection vessel and the orientation in which it is operating. The study meticulously reviews the design, setup and experimentation stages, highlighting the thermal performance and efficiency of the cryocooler, with key insights into the cooling capacity, setup parameters and thermal measurements.

1. Introduction

Liquid helium, obtained by cooling helium gas to 4 K or -269^{0}C, is essential for low temperature experimentation in laboratories. However, current systems are expensive and require significant maintenance. Applications like NMR, MRI and SQUIDS require regular, medium amounts of liquid helium. A Gifford-McMahon (GM) based helium liquefaction system offers a viable substitute [1,2]. Gas liquefaction involves two thermodynamic processes: isothermal compression and adiabatic

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expansion. The first compresses the gas to high pressure, while the second allows it to expand in an adiabatic condition. The pressure is inversely proportional to temperature, causing a temperature drop. The process is repeated until gas liquefies, with isentropic or isenthalpic expansions. Conventional Linde and Claude's processes are used for helium gas liquefaction [3,4].

In 1872, Carl von Linde liquefied air by employing Joule-Thomson (JT) principle. Sir Louis Paul Cailletet, a French mining engineer produced oxygen fog in 1877 by compressing to 300 atmospheres. In the same year, a Swiss physicist produced liquid oxygen by using cascade system. In 1883, the two cryogenisists, Szygmunt Von Wroblewski and K. Olszewski first liquefied nitrogen and oxygen at a laboratory in Cracow University. They were successful in condensing gases; because of heat load coming from ambient condition, they were unable to store them in liquid form. Sir James Dewar of London at Royal Institution solved this problem. He discovered a vacuum environment (the environment which has least number of molecules) to store cryogen liquid.

McMahon and W.E. Gifford introduced a new system of refrigeration in 1959 for creating small cryogenic refrigerators. The thermodynamic cycle was referred to as Gifford-McMahon cycle. The main motivation for using this cycle is its ease of construction, practicality and dependability. The refrigerator system which operates on this cycle is known as Gifford-McMahon cryocooler. This refrigerator system is used for small scale liquefaction of Helium and Nitrogen gasses in MRI scanners for cooling of radiation shield and in superconducting magnetic systems. It is a smaller system and efficiently handles the heat load coming from atmospheric condition to liquid helium. Longsworth and Gifford introduced a pulse tube cryocooler in mid 1960s. Phenomenal growth has been achieved in past two decade by incorporating a buffer volume through an orifice volume at warm side of pulse tube resulting in enhanced cooling performance.

Chao Wang of Cryomech Inc. filed a patent on gas liquefaction in 2007 and was permitted in 2009 to use a pulse tube refrigerator by placing its cold head inside the neck of Dewar to liquefy the gases impending into Dewar. It was invented in order to support the laboratories working with liquid helium because most of helium liquefiers of larger size and not applicable to small laboratories [5,6].

In the present-day situation, scientists and researchers are engrossed in investigating innovative advancements related to liquefaction systems. Because of their excellent cryogenic qualities, they have conducted a great deal of study on various forms of cryogenic cooling. For the researchers, analysing the performance of liquefaction systems has been a challenging and tedious endeavour. More promising cryogenic systems are helium liquefaction systems and information about their cryogenic qualities has to be established. This feature has glimmered a great deal of interest in cryogenic liquefaction and refrigeration research. Therefore, research on cryogenic portrayal and exploration of liquefaction systems must be prioritized. This research work intends to enhance the comprehension of the cryogenic aspects of Helium liquefaction by using two-stage GM cryocooler, thus accentuating the scientific novelty and technological relevance.

This section's goals are to provide a gestalt of previous studies on the characterization and examination of liquefaction systems using cryogenic processes. The practice of different cryogenic analysers, thermal behaviour of liquefaction systems, cryogenic methodologies and numerical thermal analysis has all been examined in this review of the literature. The evaluation of cryogenic and liquefaction systems' performance has been prioritized in the literature review. Additionally, finite element-based numerical analysis of cryogenic systems has been covered. Through a thorough literature assessment, the research difficulties and specific directions related to this topic have been determined. This section has covered the papers pertaining to cryogenic characterization and analysis of liquefaction systems.

After the overview of the pulse tube cooler by Gifford and Longsworth in the mid-1960s, numerous improvements of this refrigerator type have been achieved in the past decade by two types of modifications: adding a buffer volume via an orifice valve to the warm end of the pulse tube led to phase shift between pressure and velocity with resulting improvements in cooling performance.

In 1998, Thummes and his companions reported that the liquefaction rate of 127 ml/h obtained for a pulse tube cooler with 170 mW net cooling power at 4.2 K. A temperature of 3.6 K and a net cooling power of 30 mW at 4.2 K were first obtained with a three-stage pulse tube cooler by Matsubara. A regenerative tube at the warm end of the third stage pulse tube was used in their system. They obtained a lowest temperature of 2.75 K. Thummes achieved the lowest temperature of 2.75 K by using two-stage pulse tube cooler and the process and performance of two configurations of 4 K pulse tube coolers and GM cryocoolers by Wang [5]. Wang, Thummes and Heiden investigated a two-stage double-inlet pulse tube cooler in 1996 for cooling below 4 K is designed and constructed by numerical analysis.

Morie *et al.,* [7] have illustrated that, 4K GM cryocoolers are inevitably exposed to the magnetic field in MRI systems. The cooling capacity of a 4K GM cryocooler is strongly reliant on the heat capacity of the magnetic regenerator materials, such as $HoCu_2$, Er_3Ni and Gd_2O_2S(GOS). In order to clarify the effect of the magnetic field on a cryocooler's performance, it has been measured that the cooling capacity of Sumitomo Heavy Industries, Ltd. (SHI) 1W 4K GM cryocoolers in magnetic fields up to 2.0 T. It is found that the impact of a magnetic field on the cooling capacity with a $HoCu_2$/GOS hybrid regenerator is much smaller than that with a $HoCu_2$ regenerator.

Satoh *et al.,* [8] have explored a Gifford-McMahon cryocooler operating below 2K. According to the proposed theory, a Gifford-McMahon (GM) cycle cryocooler with ^{4}He cannot cool below 2 K because of the ^{4}He superfluid conversion near this temperature. However, replacing ^{4}He by ^{3}He removes this temperature limitation. The cooling performance of a GM cryocooler with a $HoCu_2$ magnetic regenerator material is investigated using ^{3}He. The minimum temperature of 2.3 K with ^{4}He goes down to 1.65 K when the ^{4}He working fluid is replaced by ^{3}He. The maximum cooling capacity at 2 K is 53.9 mW with a compressor power of about 2.5 kW and the cooling capacity at 4.2 K is enhanced by more than 20%.The effect of a new regenerator material ($NdInCu_2$) on the cooling performance was also investigated. The minimum temperature decreased to 1.64 K and the cooling capacity at 2 K improved to 57.1 mW with the use of this material in the bottom 40% of the regenerator.

Satoh *et al.,* [9] have developed 1.5 W 4 K GM cryocooler with a magnetic regenerator material. A two-stage 4 K Gifford-McMahon (GM) cycle cryocooler with magnetic regenerator material which has cooling capacity 1.5 W at 4.2 K has been developed. The hybrid structural second regenerator composed of lead and $ErNi_{0.9}Co_{0.1}$ was used in the cryocooler. $ErNi_{0.9}Co_{0.1}$ has a large specific heat peak at lower temperature than 10 K and lead has a larger specific heat in the high temperature region. The intake/exhaust valve timing was optimized to improve the cooling capacity not only of the second stage but also of the first stage. A larger size second cylinder in diameter than the former one was used to get a larger pressure-volume (PV) work.

Takashi *et al.,* [10] have developed a 2W class 4K Gifford-McMahon cycle cryocooler. This paper describes the principal design features and performance of the Gifford-McMahon cycle cryocooler by which they could obtain a cooling capacity of 2.2 W at 4.2 K. The main features of this machine are its large size expansion space, its use of rectifiable meshes which are packed in a regenerator at equal intervals and its use of the combination of Er_3Ni and $ErNi_{0.9}Co_{0.1}$ as regenerator materials.

Xu *et al.,* [11] have developed a compressed 2 K GM cryocoolers. A compact 2K Gifford-McMahon (GM) cryocooler has been developed for cooling electronic devices, viz., Superconducting Single

Photo Detectors (SSPD). The heat exchangers, regenerators are optimized with the numerical simulation method developed for 4 K GM cryocoolers. After optimizing, the cylinder length has been reduced by 85 mm compared with a commercial 0.1 W 4 K GM cryocooler. With no load on the second stage, a temperature of about 2.1 K has been achieved. With 1 W and 20 mW heat load, the temperature is 44.4 K at the first stage and 2.23 K at the second stage with an input power of about 1.1 kW. And also, it is found that the temperature oscillation decreases as the average temperature decreases. A temperature oscillation of about ±20 mK has been achieved.

Xu *et al.,* [12] exhibited that 4.2 K could be used to re-liquefy evaporated helium gas of small sized and medium sized cryogenic devices. A sequence parallel path helium liquefier with a liquefaction rate of 83 litres per day (l/day) using five 4 K GM cryocoolers is developed and has been applied to Wuhan National High Magnetic Field Centre (WHMFC) in China. Kapitza [13] described an expansion engine which works without any lubrication at very low temperatures and accounting its use in liquefaction of helium. Only liquid nitrogen has been used to precool the liquefier and two stages involved in further cooling down to 10 K with the help of the expansion engine and finally achieving liquefaction by Joule-Thomson effect. Kneuer *et al.,* [14] explains about a multi-range helium liquefaction plant, designed for automatic constant state operation is described by them. During cooldown data are given for its operation, steady-state liquefaction and refrigeration takes place under certain conditions.

Nakano *et al.,* [15] manufactured a small-scale hydrogen liquefier with help of two-stage 10 K GM cycle refrigerator. It contains a hydrogen tank with the storage volume of 30 litres that was encapsulated by a shield of radiation. This liquefier continuously liquefies gaseous hydrogen with the volumetric flow rate 12.1 nanolitres/min. It accounts to the liquefaction rate of 19.9 l/day for liquid hydrogen. They also proposed a simple estimation method for the liquefaction rate and the estimation method well matches with the liquefaction rate of experimentation.

He *et al.,* [16] demonstrated Liquefaction of natural gas (LNG), which is usually a process of high energy consumption. Therefore, any performance advancement of the liquefaction process will result in reducing the energy consumption. Liquefaction process using nitrogen expansion is taken as a suitable process for small-scale LNG plant due to its quick startup, simplicity and easy maintenance. However, the demerit of this process is high-energy consumption. An efficient way to reduce its energy consumption is to include a precooling cycle. In this paper, they showed two different precooling cycles counting propane precooling cycle and R410a precooling cycle are recommended to the nitrogen expansion liquefaction process to upgrade the liquefaction process performance.

Schmidt-Wellenburg *et al.,* [17] have exemplified helium liquefaction by using a commercial cryocooler with 1.5 W cooling power at 4.2 K (Sumitomo model RDK415D with compressor CSW-71D, consuming 6.5 kW electrical power), equipped with heat exchangers for precooling the incoming gas. No additional cooling power of cryoliquids or additional Joule-Thomson stages was utilized. Measurements of the pressure dependence of the liquefaction rate were accomplished. A maximum value of 83.9 g/h was obtained for 2.25 bar stabilized input pressure. Including the time needed to cool the liquefied helium to 4.2 K at 1 bar after filling the bottle connected to the cold head and correcting for heat screen influences, this results in a net liquefaction rate of 67.7 g/h. Maintaining a pressure close to 1 bar above the bath during liquefaction, a rate of 55.7 g/h was obtained. The simple design enables many applications of the apparatus.

It is evident from the literature review that, the performance assessment of Gifford-McMahon cryocooler has been given greater emphasis. However, investigations concerning with the liquefaction of Helium by using 1.5 W cooling power at 4.2 K is meagre. Many experimental investigations have been conceded based on other liquefaction systems, but limited work has been accomplished pertaining to 1.5 W cooling power at 4.2 K. The literature review has indicated the need for further investigations on Helium liquefaction by using GM cryocooler. If these liquefaction systems are to be used for many engineering applications, the cryogenic aspects need to be given more emphasis. Hence it becomes important that the evaluation of cryogenic aspects and characteristics of liquefaction systems cannot be ignored in order to transform the material from design stage to manufacturing stage. This would provide the researchers a sense of continuity and help them pacing their research.

2. Experimentation for Liquid Helium Production

To produce liquid helium principally it is indispensable to separate helium from atmospheric air and cooling it down to 4 K for achieving condensation. The liquid helium at 4 K has been collected a Dewar flask. These collection vessels are vacuum jacketed to separate the vessel storing liquid helium from meteorological conditions. The space between the radiation shield and vacuum vessel is evacuated in order to reduce the convection thermal load and several layers of insulation has been used to bring down the radiation thermal load coming from vacuum jacket (at 300 K) to cryogen vessel (at 4 K).

In this research work, the commercially available GM cryocooler has been used and a heat exchanger wounded over the cryocooler stages to effectively produce liquid helium at 4 K. The estimated refrigeration capacity at 4.2 K is 1.5 W. The GM cryocooler system composed of Helium flex lines, compressor package and cold head. The collection vessel has been attached on the cold head (second stage) of the GM cryocooler. The helium gas when comes in contact with heat exchanger it begins to liquefy. The liquefied helium drops down from the heat exchanger into the collection vessel. The phase change would usually reduce the pressure inside the vessel, but the regulator flow allows more helium gas to come into the collection vessel to preserve the pressure at the predefined level. The rate of flow of helium gas into the vessel is monitored by the rate of liquefaction inside the collection vessel.

The helium liquefaction can be achieved by the evacuation of Dewar flask by employing a turbo molecular pump till required vacuum pressure has been achieved in vacuum pressure gauge. By switching on the GM cryocooler and note down the temperature reduction every 10 minutes till the cold head reaches a temperature of 2 K - 3 K. After achieving the required temperature, the inlet to gas from the helium cylinder has been opened the liquid helium starts collecting in the collection vessel. The thermoacoustic oscillations have been observed in pressure gauge when liquid helium comes in contact with the end of pressure gauge, this gives the indication that the collection vessel is filled with liquid helium.

Figure 1 illustrates the helium liquefaction experimentation setup. The helium gas which is at room temperature has been drawn from a standard helium gas cylinder through a pressure regulator. Rotameter type of flowmeter used to check the flow of helium gas. The shut off ball valve after the flowmeter used to regulate the flow of helium gas into the system.

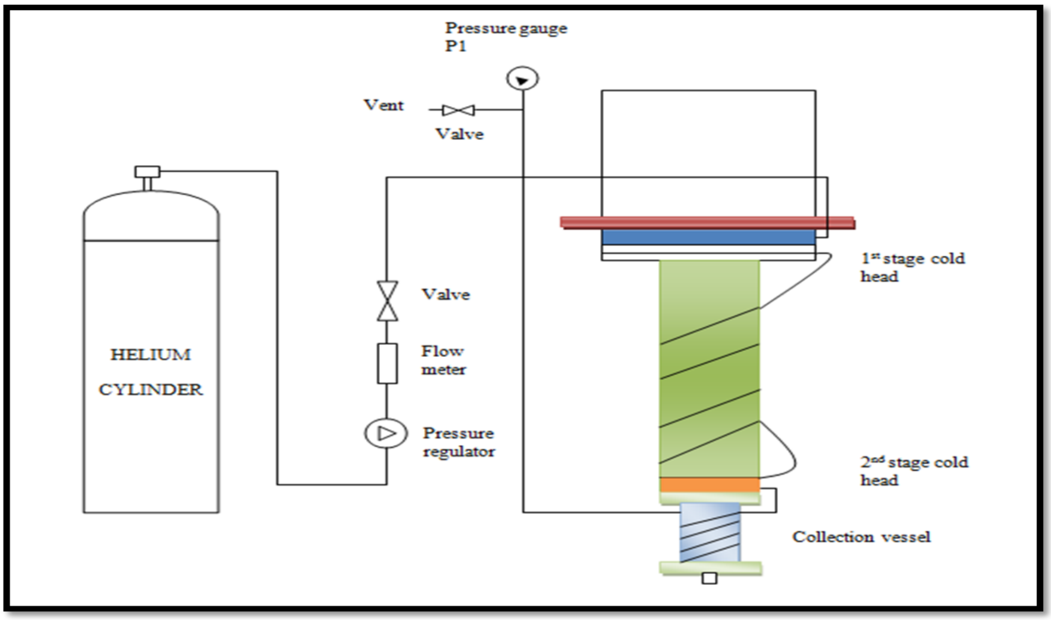

Fig. 1. Helium liquefaction setup

Small scale helium liquefaction system has been efficaciously developed by using GM cryocooler. This demonstrate the liquefaction with a commercial two-stage GM cryocooler, which delivers a cooling power of 1.5 W at 4.2 K at its second stage cold head and a cooling power of 30 W is available at 35 K in the first stage. The incoming helium gas is pre-cooled at the first stage cold head and subsequently is passed on to second stage cold head through specially designed heat exchanger. The collection of liquid helium has been monitored by thermo acoustic oscillation in the vapor pressure gauge connected outside. The setup comprises Gifford-McMahon cryocooler stages wounded with copper heat exchanger to increase the rate of heat transfer. The collection vessel has been employed for a known volume of 100 cm^3 collection vessel made of Copper. The collection vessel has two openings: one for the inlet of liquid helium and other for the connection of pressure gauge to monitor the thermoacoustic oscillations.

The precooling of incoming helium gas is very imperative in liquefaction process, this work is effectively accomplished by spirally wounded copper tube around cryocooler stages. At first helium gas passes through the spirally wounded heat exchanger around first stage cold head. The dimension as well as the number of turns of copper tube has to be optimized in order to achieve minimum pressure drop and also to ensure precooling of incoming helium gas to a temperature equivalent to temperature of first stage. It consists of a copper capillary with an outer diameter of 3 mm and a wall width measuring 0.25 mm, soft soldered to a thin copper sheet of thickness 0.2 mm and is fixed to first stage. The above-mentioned copper capillary is also used as heat exchangers, in order to ensure unstable flow of helium gas to achieve better radial heat transfer over the capillary wall.

The piping between the heat exchangers of the first and second stages are made up of narrow walled stainless-steel tubes having the same diameter as that of copper tube. Since the greater amount of enthalpy is removed at the first stage, helium gets liquefied in the heat exchanger that is mounted on the second stage due to passage of gas over cold surface area.

Figure 2 indicates heat exchanger of second stage cold head and mounted collection vessel on second stage. The liquid helium leaving the heat exchanger enters the collection vessel. The collection vessel is thermally connected to the second stage of the cryocooler.

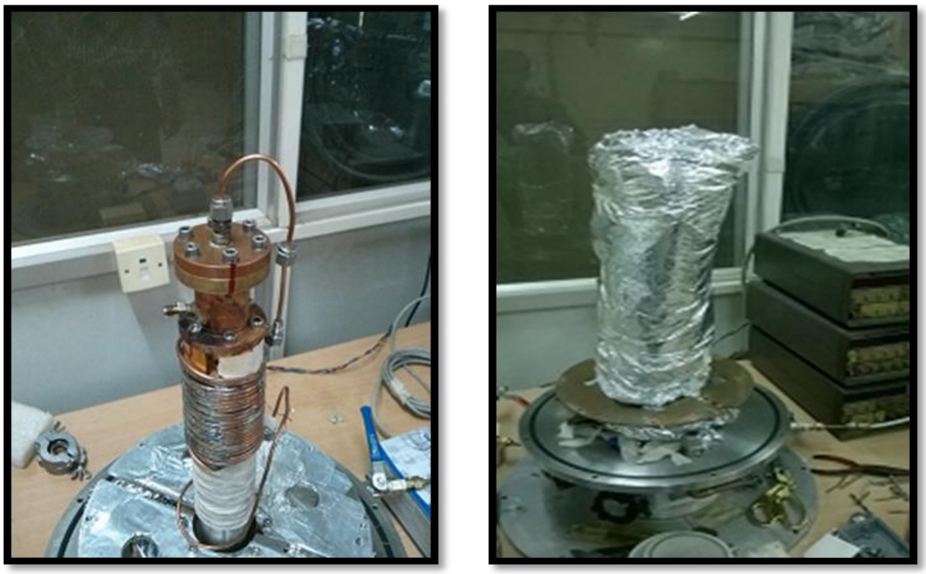

Fig. 2. Stages of cryocooler and radiation shielding

Figure 3 depicts the experimental setup of collection vessel on the cryocooler stages. These stages and collection vessel have been mounted with Silicon sensor to record the gradual temperature decrease in these stages and has been observed on a temperature controller. The whole setup is surrounded by a layer of radiation shielding and a vacuum environment in order to reduce the heat load coming from surrounding environment.

Fig. 3. Experimental setup

3. Monitoring Liquefaction using Vapor Pressure Gauge

Figure 4 depicts a pressure gauge arrangement to monitor the pressure inside collection vessel and also thermoacoustic oscillations.

Fig. 4. Pressure gauge arrangement

Figure 5 depicts the thermoacoustic oscillations that have been observed in a vapor pressure gauge. When liquid helium starts collecting in the collection vessel, thermoacoustic oscillations have been produced. The observed frequency is the low, when liquid helium touches the other end of the capillary tube. On the other side, when helium liquid is released to atmospheric conditions it gets condensed in the surrounding air. After emptying the collection vessel, the valve is closed completely. It results in high frequency of oscillation in the pressure gauge due to entry of warm helium gas into to the collection vessel due to high pressure variations.

Fig. 5. Vacuum pressure gauge

The following are the steps involved in experimentation:

i. Step 1: Switch on the chiller unit and turbo molecular pump for cooling of water and evacuation process inside Dewar. After some time, the temperature of chiller unit decreases to 11^{0}C from room temperature. The evacuation process results in the decrease in vacuum pressure from room pressure to a pressure of 10^{-3} mbar.
ii. Step 2: After achieving this temperature (chiller unit) and vacuum pressure, switch on the cryocooler device.
iii. Step 3: The liquid helium outlet is closed by using a suitable valve. The gas inlet of collection vessel is connected to an external helium gas cylinder fitted with pressure regulator through a flow meter. The inlet gas pressure is adjusted such that positive pressure head exist in the system.

iv. Step 4: By switching on the cryocooler device results in the gradual cooling of the first and second stages and vessel. This decrease in temperature readings have been noted by using a temperature controller device after every 10 minutes. During cooldown process, the system has to be ensured that the inlet pressure of helium gas from the cylinder through flow meter is always positive and exit to liquid helium is closed with suitable arrangement.

v. Step 5: After initial cool down (temperature of 4 K), which occurs after nearly 3 to 5 hours, liquid helium starts to collect in the collection vessel. When the liquid helium level touches the end of the capillary tube, low frequency thermoacoustic oscillations have been observed spontaneously.

vi. Step 6: The outlet vent valve is opened and then liquefied helium is now vented to recovery. Cold helium gas passes out through the stainless-steel tube and this in turn condenses with the ambient air on the outside of this pipe. After the release of cold helium, if the outlet vent is closed, it results in high frequency thermoacoustic oscillation. The experimentation is also carried out by inverting the Dewar flask on a suitable arrangement with similar procedure.

4. Experimental Results and Discussions

In the experimentation, helium liquefaction employs a 100 cm^3 collection vessel. Figure 6 is the temperature reduction with time concerning collection vessel. In this case, the gradual temperature decreases in first and second stages of cryocooler and vessel have been observed. The temperatures have been noted for a time interval of 10 minutes. Also, the time at which the thermoacoustic oscillations have been seen is also noted. After collecting the required liquid helium batch liquefaction is carried out. The liquefaction has been carried out by opening the outlet for liquid helium there by making the collection vessel empty. When collection vessel becomes empty the outlet valve is closed and simultaneously the inlet valve of collection vessel is opened for flow of helium gas, then the fresh liquid helium starts collecting in the collection vessel. During this process, the collection vessel is ensured to have a positive pressure inside.

In helium liquefaction, a cryocooler is essential for adequate refrigeration power at 4.2 K. Commercially, there are two types of cryocoolers viz., pulse tube and GM types. In this research work, the GM cryocooler (Janis Cryogenic systems, model RDK415D with the water-cooled helium compressor model F70) has been chosen. This system yields a refrigeration power of approximately 1.5 W at 4.2 K.

Figure 6 depicts the typical cooling down of the first and the second stages of GM cryocooler at no load condition. For no load condition, a bare cryocooler is installed inside the vacuum jacket and is wounded with several layers of insulation. With the help of assembled GM cryocooler unit, the experiment has been started. Using Silicon diode sensors placed on first and second stages of cryocooler, the temperatures at the first and second stages are monitored. From the Figure 6, it can be seen that the first stage attains the temperature of approximate 25.4 K at no load condition, while the temperature of second stage attains approximate 2.6 K. The temperature decrease of second stage is due to the continuous expansion of gas in second stage and the first stage temperature is because of the continuous compression of expanded gases. In about 110 minutes, the second stage reaches a steady state. The first stage of the cryocooler imparts a cooling power of approximate 30 W at 35 K. The second stage imparts a cooling power of approximate 1.5 W at 4.2 K.

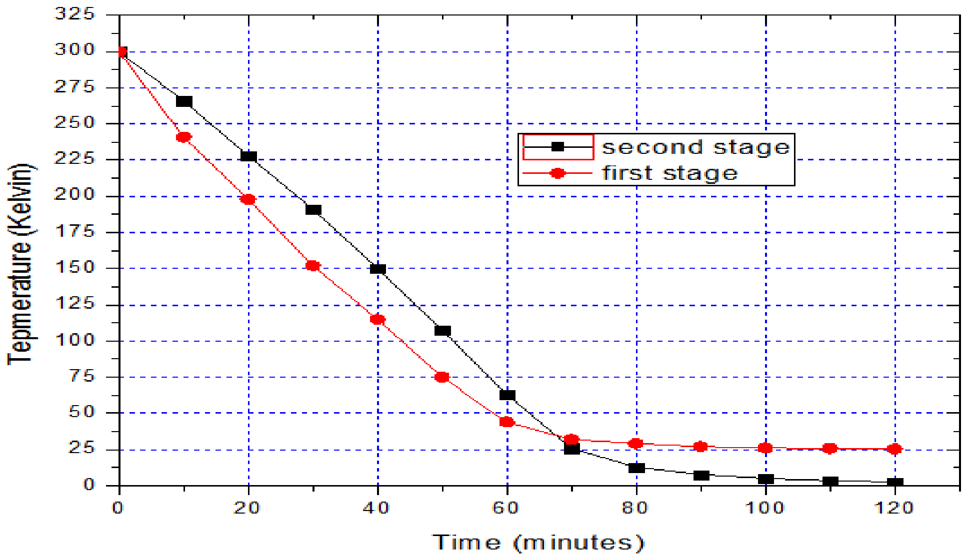

Fig. 6. Cooling down of first and second stages of GM cryocooler at no load state

The cooling power characteristics can be found out by mounting a heat source on second stage of the cryocooler. After achieving a temperature of about approximately 2.5 K, the heat load is supplied and the temperature increase caused by the heat source has been noted down. Figure 7 gives the cooling power characteristics of GM cryocooler. It can be noted that, the second stage imparts a cooling power of approximate 1.5 W at 4.35 K.

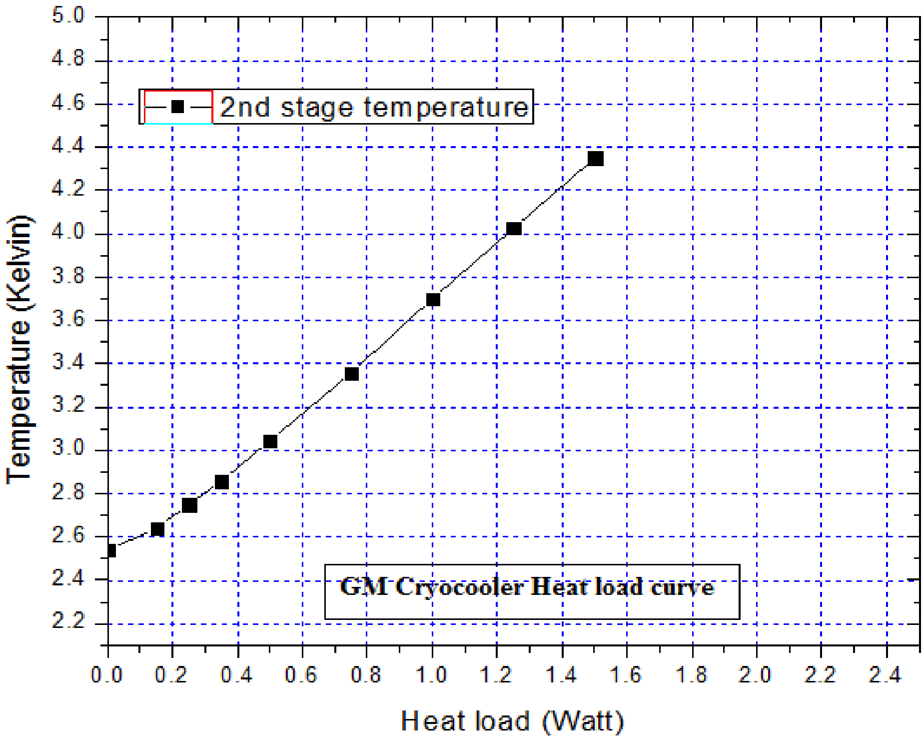

Fig. 7. GM cryocooler cooling power characteristics

Experimental conditions: Supply pressure= 14 bar
Running pressure= 22 bar
Chiller temperature= 11^0C
Vacuum pressure level= 8.3×10^{-3} mbar

From Figure 8, it is clear that, it takes about 5 h for the collection of liquid helium and has been indicated by oscillation point. Figure 8 indicates cooldown temperatures of first stage, second stage, vessel and the point of thermoacoustic oscillation. The continuous decrease of temperature in the second stage to a value of 2.84 K is because of continuous expansion of high-pressure gas in the second stage of cryocooler in every cycle and the first stage attains a temperature of 32.025 K is due to gas from continuous compression process of expanded gas from previous cycle. The vessel temperature is almost similar to the second stage temperature because of material contact with each other as it has been mounted on the second stage.

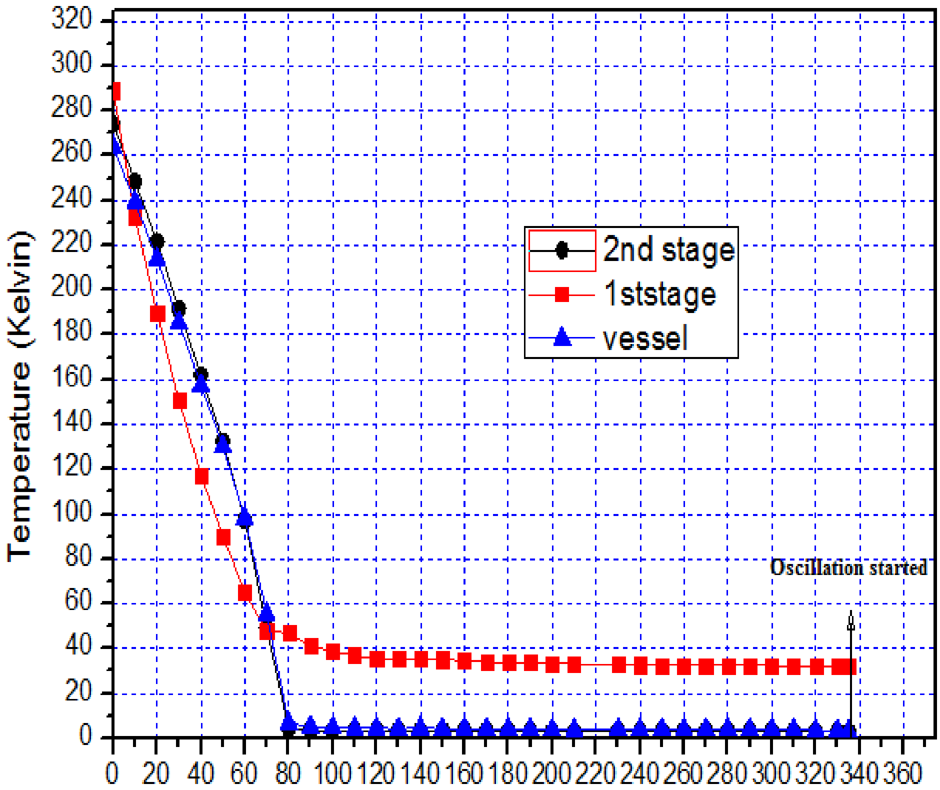

Fig. 8. Cool down temperatures of cryocooler stages and vessel

The experimentation has been repeated by inverting the liquid helium Dewar on a suitable arrangement.

Supply pressure= 14 bar
Running pressure= 22 bar
Chiller temperature= 11^{0}C
Vacuum pressure level= 7.3×10^{-3} mbar

Figure 9 indicates cooldown temperatures of first stage, second stage, vessel and the point of thermoacoustic oscillation. The continuous decrease of temperature in the second stage to a value of 3.224 K is because of continuous expansion of high-pressure gas in the second stage of cryocooler in every cycle and the first stage attains a temperature of 35.524 K is due to gas from continuous compression process of expanded gas from previous cycle. The vessel temperature is almost similar to second stage temperature because of material contact with each other as it was mounted on second stage. Uncertainty of temperatures, especially cool down temperatures of cryocooler stages have been estimated independently.

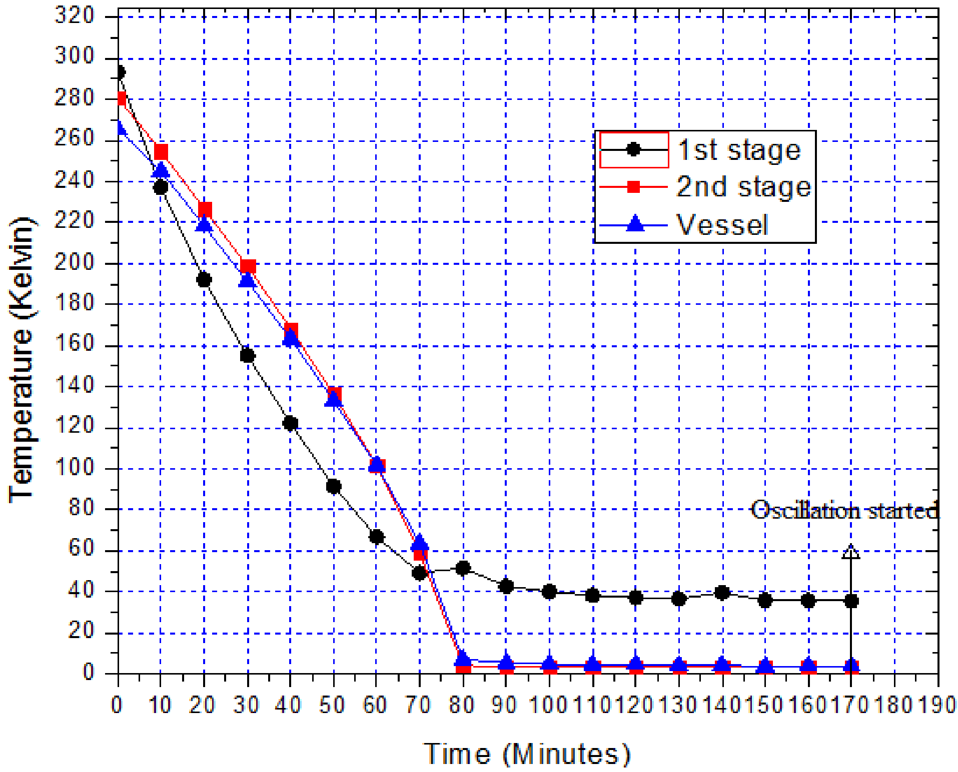

Fig. 9. Temperature variation at first, second and vessel stage with time of inverted Dewar

5. Conclusions

In this research, the experimental investigation of a small-scale liquefaction system for helium gas using two-stage GM cryocooler has been carried out. The experimentation using 100 cm^3 yields a result of, initial collection of liquid in upright liquefaction system takes about 335 minutes and subsequent collection of liquid helium (batch liquefaction) takes place with the time interval of nearly 45 minutes at a pressure of approximate 1bar. In case of inverted system, the initial collection of liquid helium takes about 170 minutes and subsequent collection of liquid (batch liquefaction) takes place with the time interval of nearly 30 minutes at a pressure of approximate 1 bar. From the above result, it has been concluded that the liquefaction rate is a function of pressure exists inside collection vessel and the orientation in which it is operating. The performance of inverted system is better due to reduced load on the second stage cold head. With suitable modifications this system can be employed to above mentioned applications. Thus, small scale helium liquefaction by using two-stage GM cryocooler with special type heat exchangers is absolutely thriving.

6. Scope for Future Work

i. The temperature of 4 K may be achieved faster by incorporating a Joule-Thomson (JT) valve in series with GM cryocooler stages.
ii. By introducing a heat exchanger above the second stage cold head along with the heat exchanger around the cryocooler stages allows faster rate of liquid helium production.
iii. The collection vessel can be incorporated with a series of resistors to know the level of liquid helium collected. The liquid level corresponds to change in resistance.

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