



# Cryocooler Technology Development

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# Outline

- Cryocoolers – What ? Why ? Where ?
- Mixed Refrigerant Joule Thomson Cooler (MRJT)
- Pulse Tube Refrigerator – Various configurations
- Future Work



# What is a Cryocooler ?

- Generation of low temperature due to compression and expansion of gas
- Closed Cycle cooler
- Consists of compressor, Heat exchanger and Expander
- Can replace Cryogenics like Liq Nitrogen (77 K), and Helium (4.2K)



## 'Earth's Helium Reserves To Run Out By 2030'

Aug 23rd, 2010 | PTI



Tags: 2030 Earth Helium



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Earth's helium reserves will run out by 2030, a leading expert has claimed. According to Nobel laureate Prof. Robert Richardson of Cornell University, the US supplies 80 per cent of the helium used in the world at a very cheap rate and these supplies will run out in 25 to 30 years' time. And, once the helium reserves are gone, there will be no way of replacing it, the Professor of physics said. "There is no chemical means to make helium. The supplies we have on Earth come from radioactive alpha decay in rocks. Right now it's not commercially viable to recover helium from the air so we've to rely on extracting from rocks. "But if we do run out altogether, we will have to recover helium from the air and it will cost 10,000 times what it does today," Prof Richardson told the 'New Scientist'. A US law states that the biggest store of helium in the world — in a disused airfield in Texas — must be sold off by 2015 and is being sold at far too cheap a price. This means that the Earth's resources of helium are being depleted at an astonishing rate because it is too cheap to recycle. Helium is formed on Earth as rocks steadily decay and nearly all of our reserves have been formed as a by-product of the extraction of natural gas. The only way to obtain it will be to capture it from the decay of tritium — a radioactive hydrogen isotope, which the US stopped making in 1988. So what should the US do? "Get out of the business and let the free market prevail. The consequence will be a rise in prices. Party balloons will be US dollars 100 each but we'll have to live with that. We will have to live with those prices eventually anyway," he said.

**Asian Age,  
23 rd Aug 2010**



# Cryocoolers – Why ?

- No Cryogen requirement
- Reliable and Maintenance free operation
- Cost of Cryogen is going up
- Cost of Cryocoolers coming down
- Scope for new Technology
- Advances towards Invisible Cryogenics



# Cryocooler - Where ?

- Military – Night vision IR Camera
- Space and Satellite – I-R detector cooling
- Cryopumps
- Gas Cooling and Gas Liquefaction
- MRI and NMR SC Magnet cooling
- Cryogenic Catheter and Surgery
- MagLev Trains
- SC Transformer Motor and Generator



# Cryocoolers – Technical Parameters

- Cooling effect : --- W @ --- K
- Compressor power requirement - kW
- Cooling water requirement
- Service requirement of compressor
- Vibration level
- Cost



# Development of Mixed Refrigerant Joule Thomson Cooler

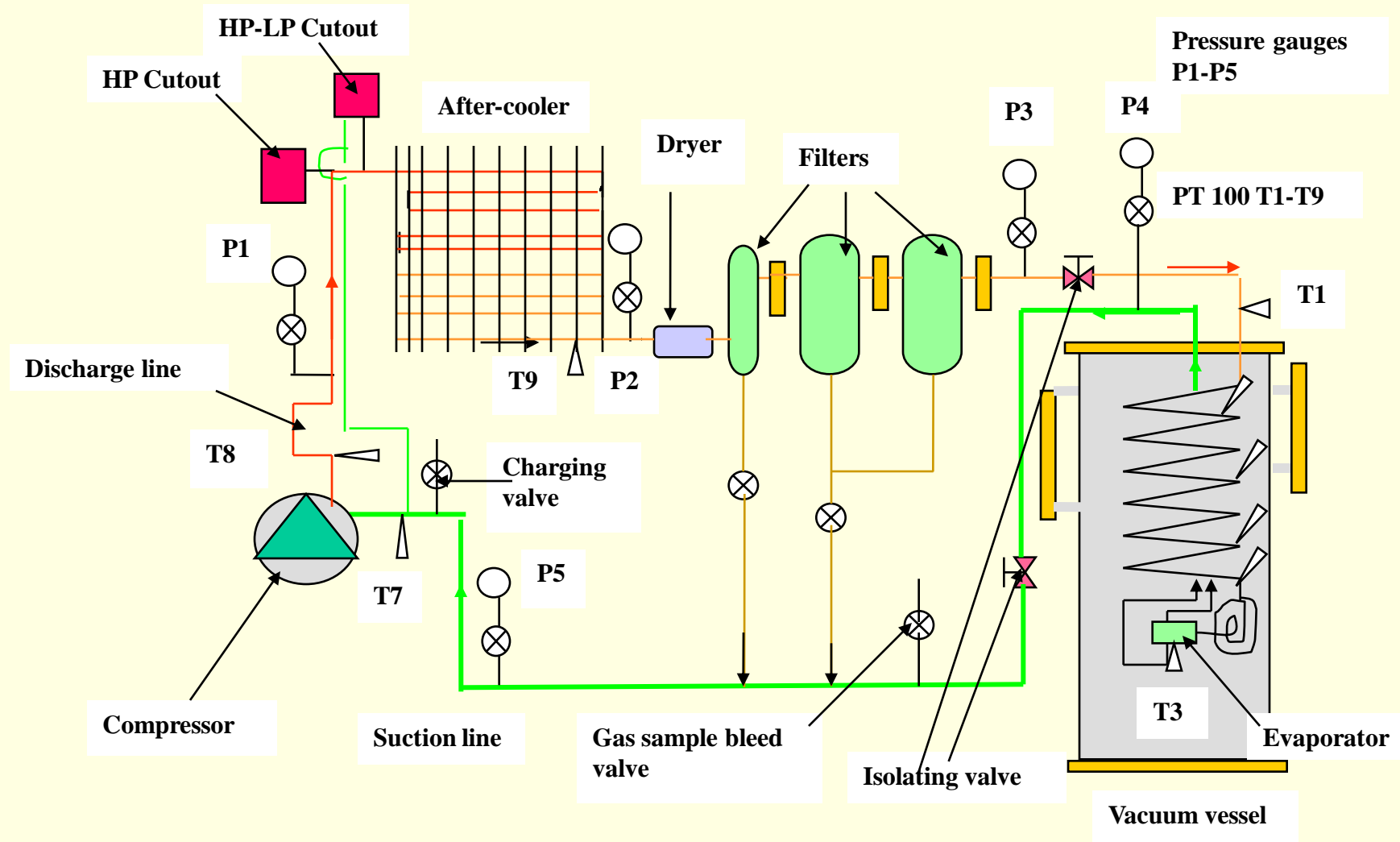
## Salient Features of this Project

- DST Sponsored Project 2007-2010
- Mixture of Refrigerants to reach down to low temperature using simple Air Conditioning compressor
- Understand the Thermodynamics of mixture, phase diagrams
- We used a mixture of 6 gases
- Heat Exchanger - Crucial component



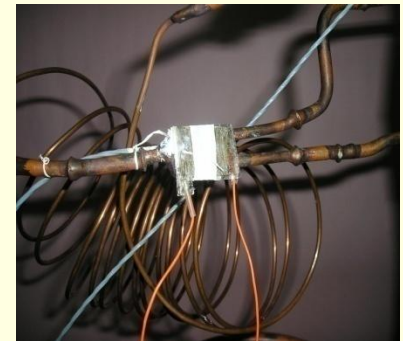


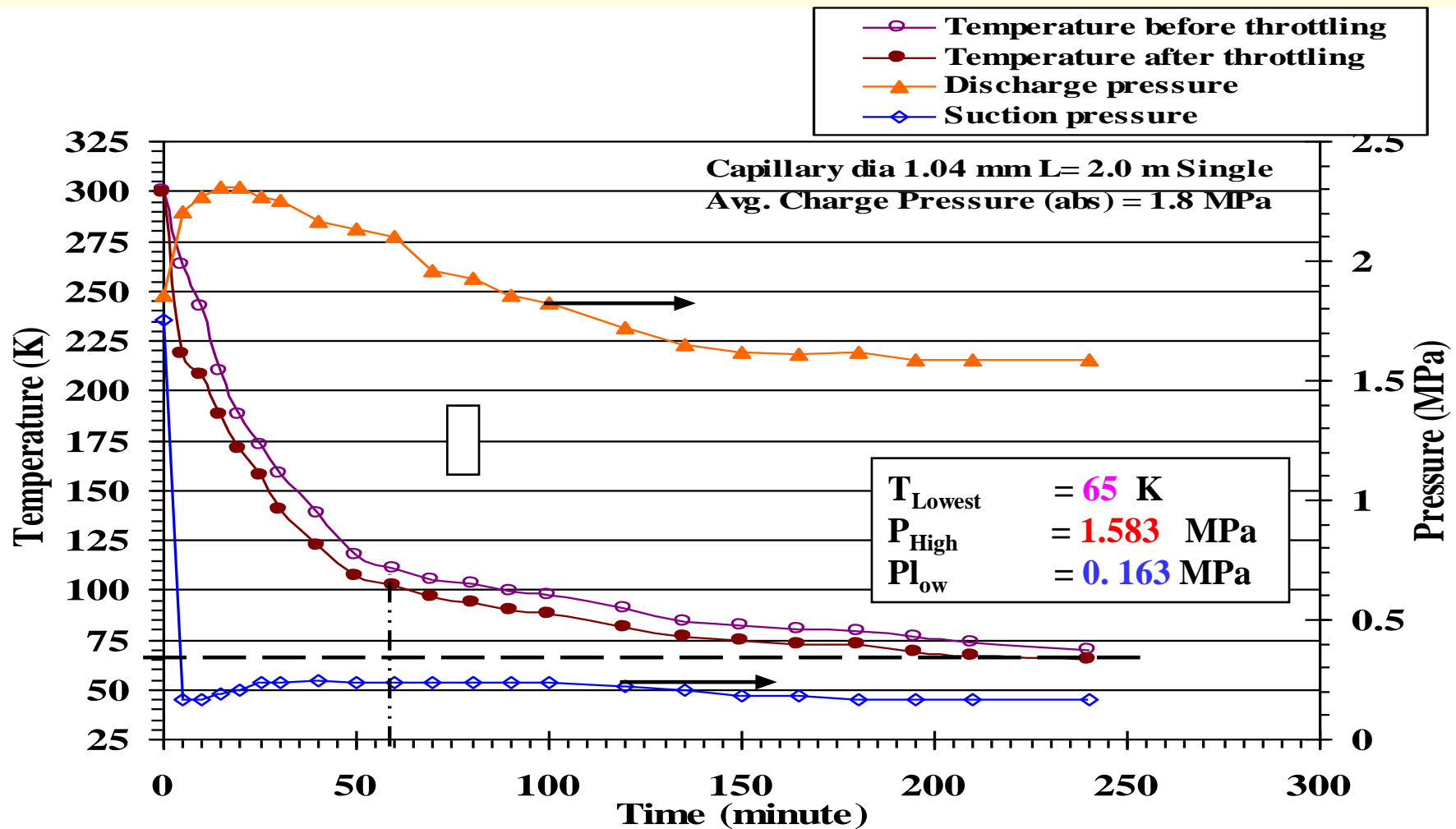
# Schematic of MRJT Cooler





# Fabricated Parts and Assembly

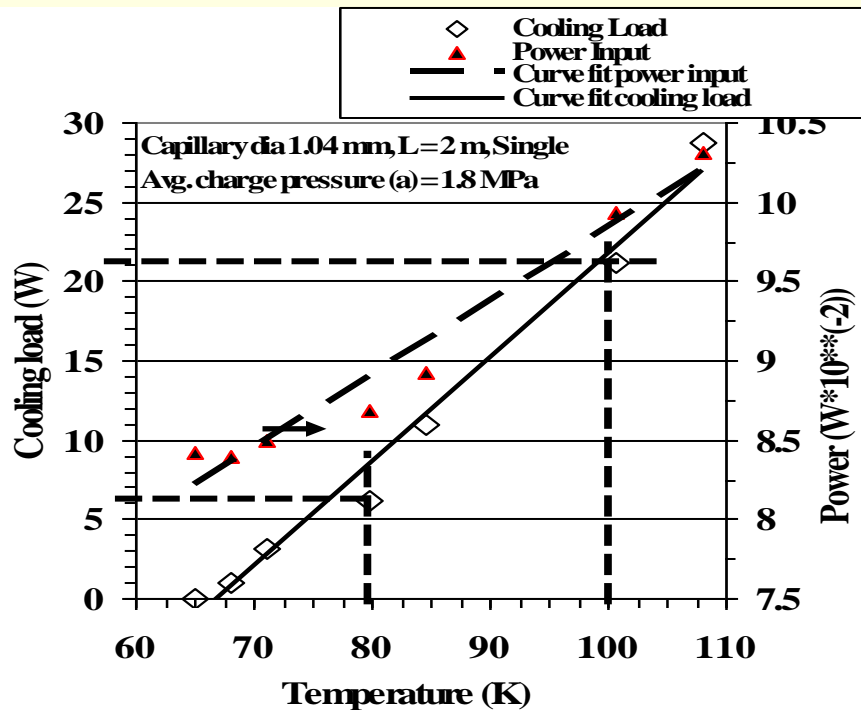




Cool down curve for Neon-11 Mixture



## Heat load performance for mixture Neon-11



**Lowest Temperature reported anywhere in the world using this technique of cooling**

**A simple Air Conditioning Compressor costs 5-6 thousand rupees – can take you down to 65 K ( -208 ° C )**

Cooling Capacity = **6.1 W at 80 K** / 21 W at 100 K

Compressor Power = 868 / 1031 W

COP = 0.00708 at 80 K / 0.0278 at 108 K

Lowest Temperature = 65 K



# Pulse Tube Cryocooler

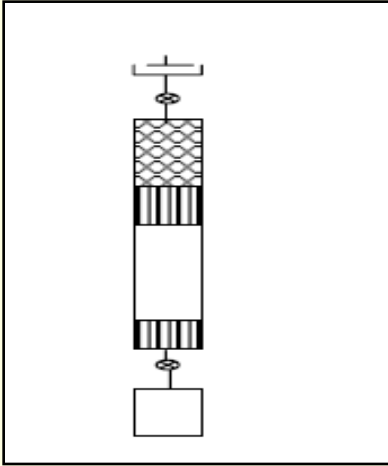
- Comprises of Compressor, Heat Exchanger (Regenerative type ) and Expander
- Absence of Mechanical displacer or piston as expander but instead a gas displacer
- Minimum vibration and high reliability



# Project Outline

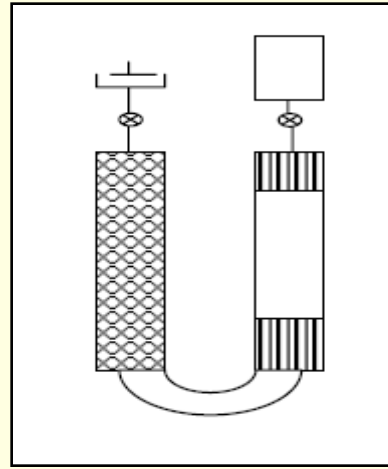
- BRNS Sponsored ( 2006-2009)
- Development of Two Stage Pulse Tube Cooler to reach below 25 K temperature for gas cooling
- Commercially, two stage Pulse Tube Cooler with Linear Compressor is not available
- Chinese, Americans, Germans and Japanese - race

## Configurations Based On Geometry



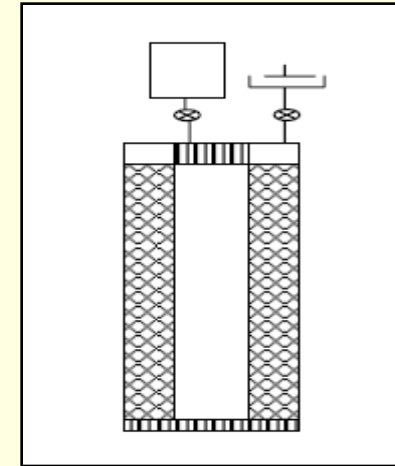
**A) Linear / In-Line**

- Reg and pulse tube are inline
- Thermodynamically, most efficient. Long vacuum jacket.
- Cold end – difficult to access



**B) U-Type**

- Reg and pulse tube are parallel in U shape
- Cold-End easily approachable.
- Performance reduces because of U-bend.



**C) Co – Axial / Annular**

- Reg and pulse tube are coaxial.
- Most Compact and easy access for cooling
- Viscous effects dominate

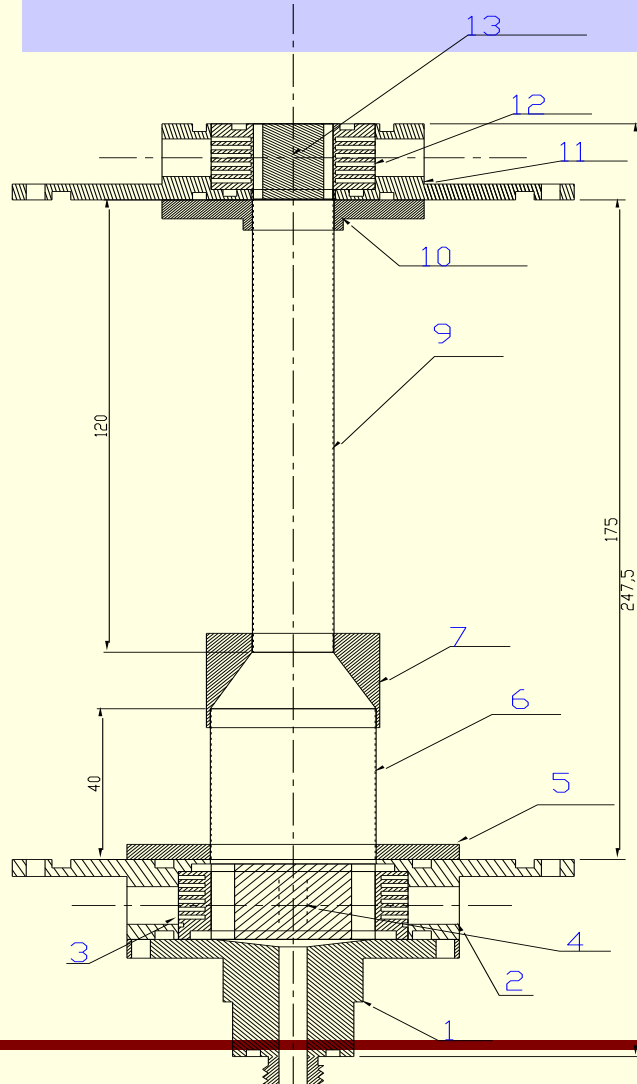




# Theoretical Studies

- Various Models have been developed in our laboratory to understand gas behavior
- Phasor analysis, Isothermal Model
- Numerical Model
- CFD Model
- The Models lead to finalization of Design and Operating parameters

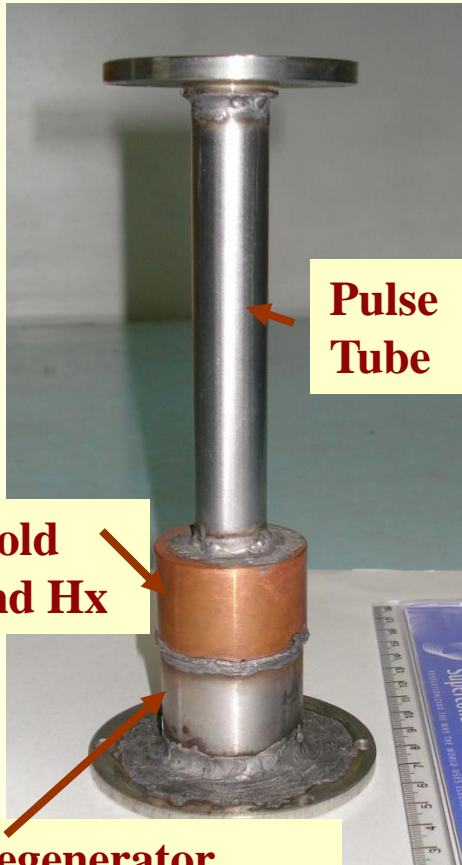
# In-Line PTR



	Name	Material
1	Compressor Flange	SS 304
2	After-cooler Flange ( Jacket flange)	SS 304
3	After-Cooler –Water flow path	Copper
4	After-Cooler Heat exchanger- Gas	Copper
5	Regenerator Flange	SS 304
6	Regenerator (Seam less tube)	SS 304
7	Cold end Heat exchanger-Connector	Copper
8	Cold end Heat Exchanger- Gas	Copper
9	Pulse Tube (Seam less tube)	SS 304
10	Pulse tube Flange	SS 304
11	Hot end Flange	SS 304
12	Hot end Heat exchanger -water	Copper
13	Hot end Heat exchanger - Gas	Copper



# Fabricated Components



Pulse  
Tube

Cold  
end Hx

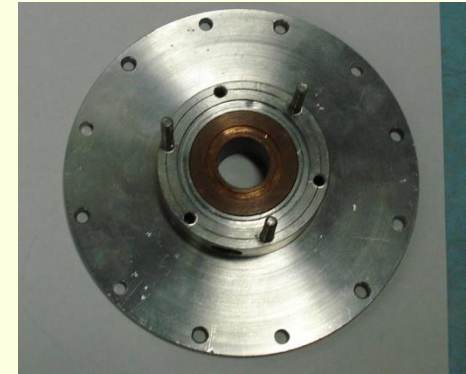
Regenerator



Heat exchanger, water flowing part



Regenerator tube



Flange to support vacuum jacket  
housing the heat exchanger

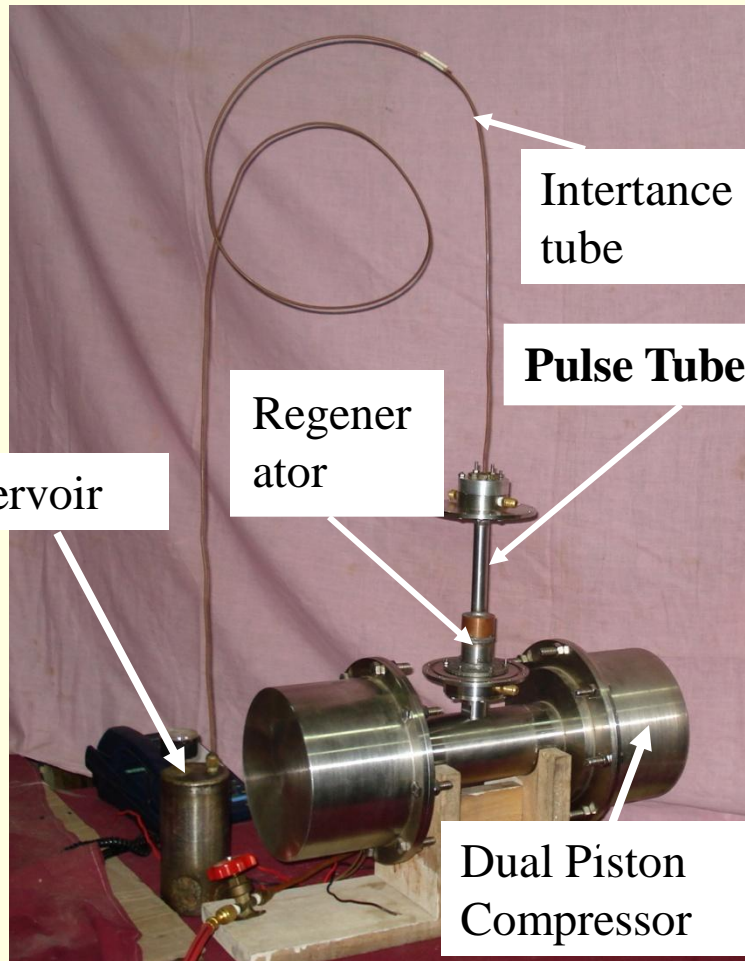


Vacuum jacket

# Instrumentation

## Instrumentation:

- Compressor: (Dual Piston)
  - Moving magnet type
  - Moving Coil type
- Temperature Sensor
  - PT 100 (RTD), Si Diode
- Pressure Sensor
  - ENDEVCO 8511A
- Vacuum System
  - Turbo-molecular pump (Adixen)
- Temperature Indicator - Lakeshore
- Oscilloscope: Yokogawa.

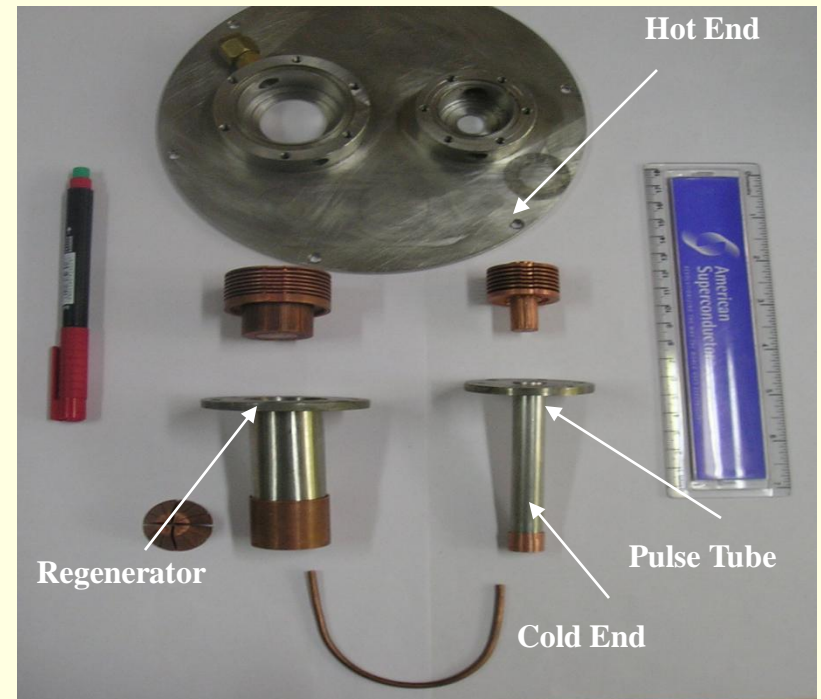
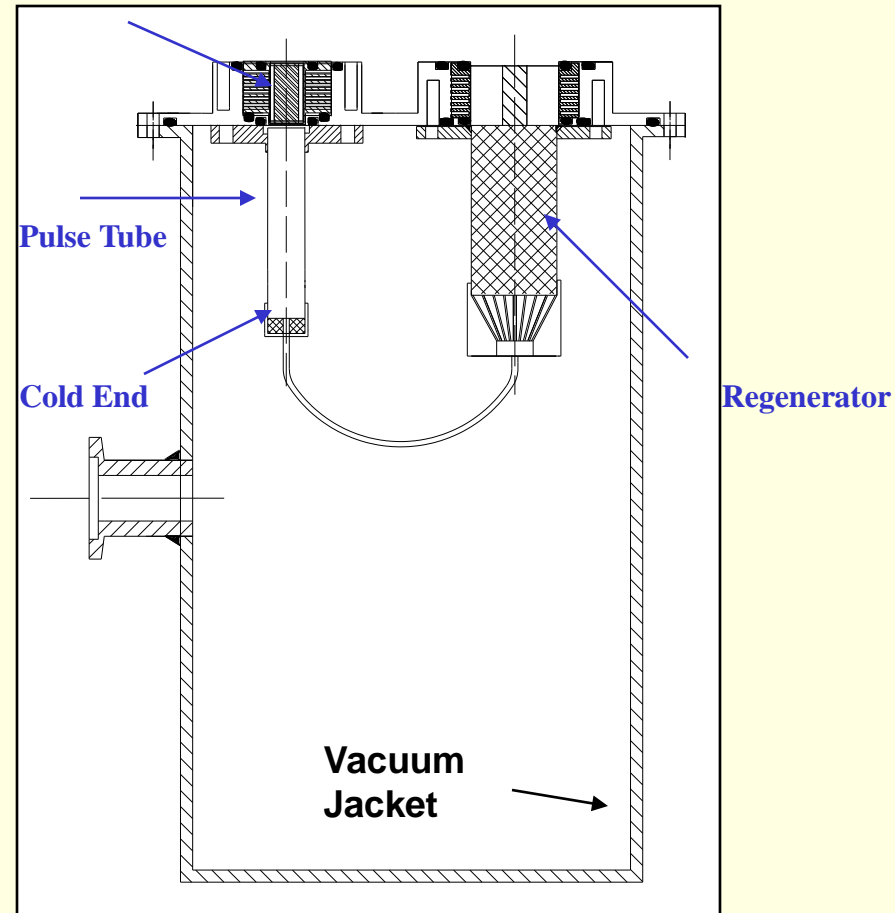


Assembled PTR Unit without vacuum jacket



# Single – Stage Split U - Type Configuration

Hot End



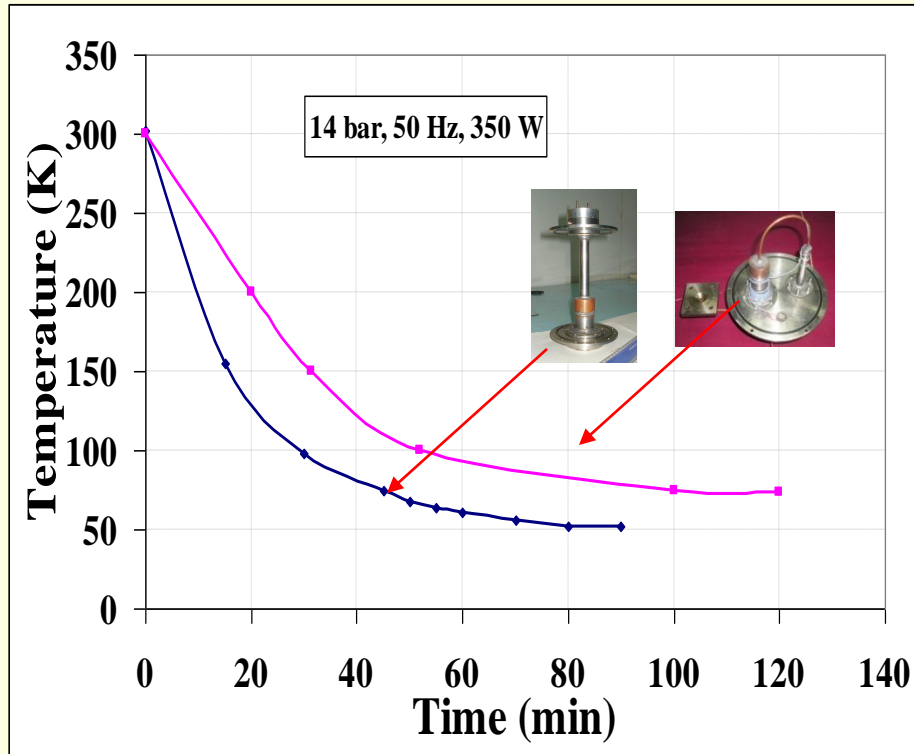




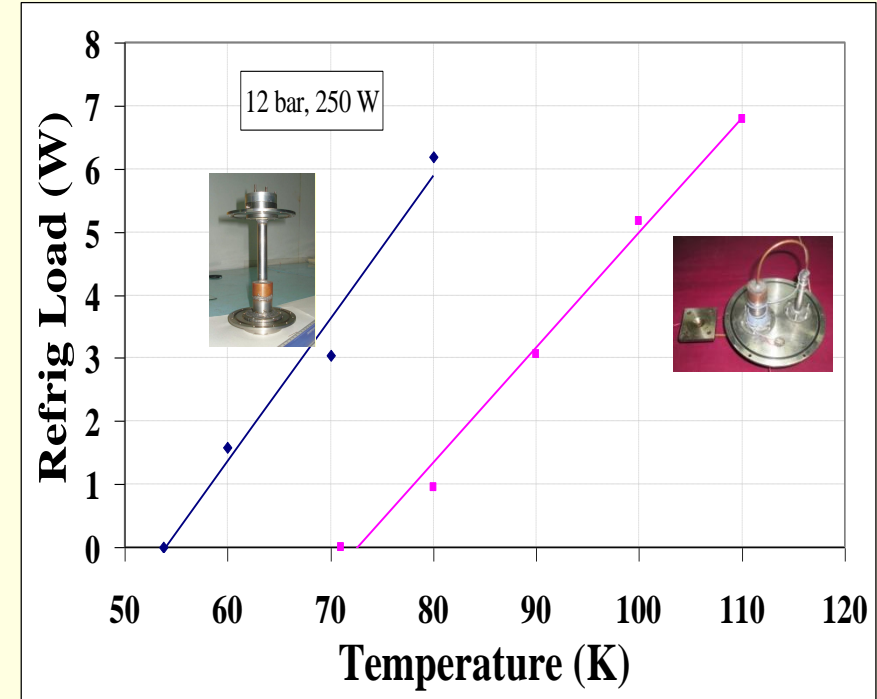
# Inline and ' U ' Configurations



# Comparison of Inline and U Pulse Tube Cooler



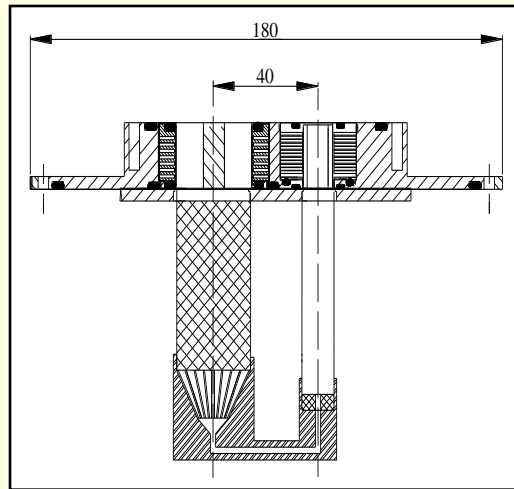
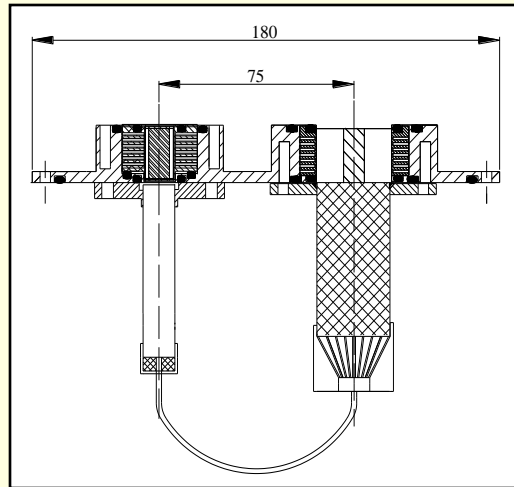
- Lowest temperature with Inline – 50 K
- Lowest temperature with U type – 70 K



- For 12 bar – cooling effect 80 K – 6 W - Inline
- For 12 bar – Cooling effect at 80 K – 1 W – U type



## Modifications of Single – Stage ‘U’ type PTR :



### Advantages :

1. The CD is reduced from 75 mm to 40 mm. This has reduced the dead volume.
2. The ‘U’ bend is made integral with Cold End. This has reduced the soldering problem.

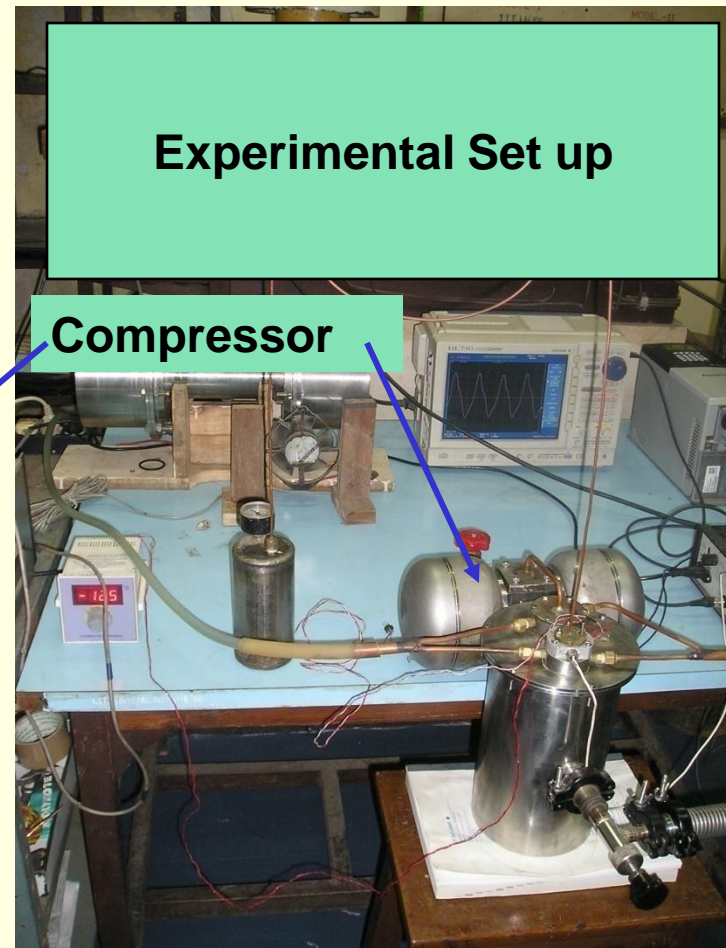




## Single – Stage Split U - Type Configuration

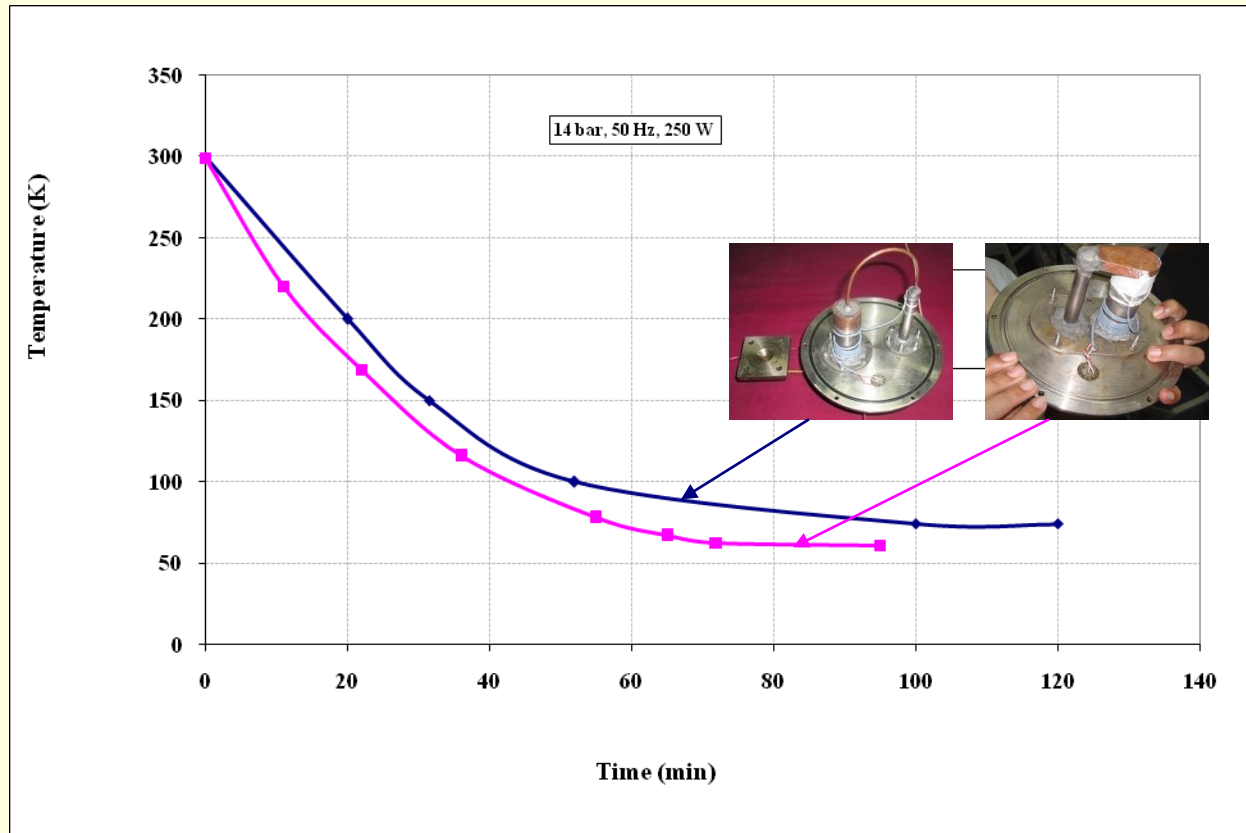


*Assembly*



*Experimental Setup*

## Modifications of Single – Stage ‘U’ type PTR

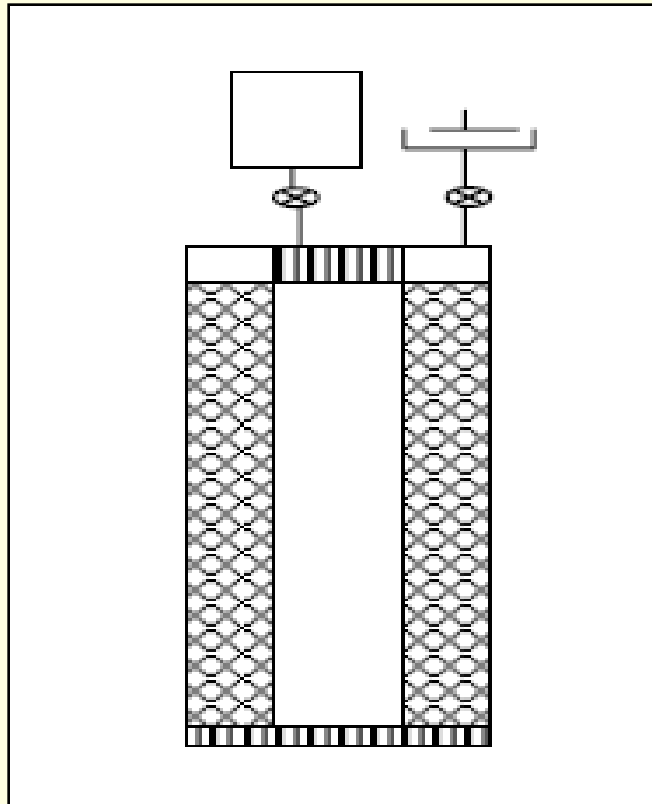


**Min. Temp : 68 K.....Original**

**Min. Temp : 54 K.....Modified**



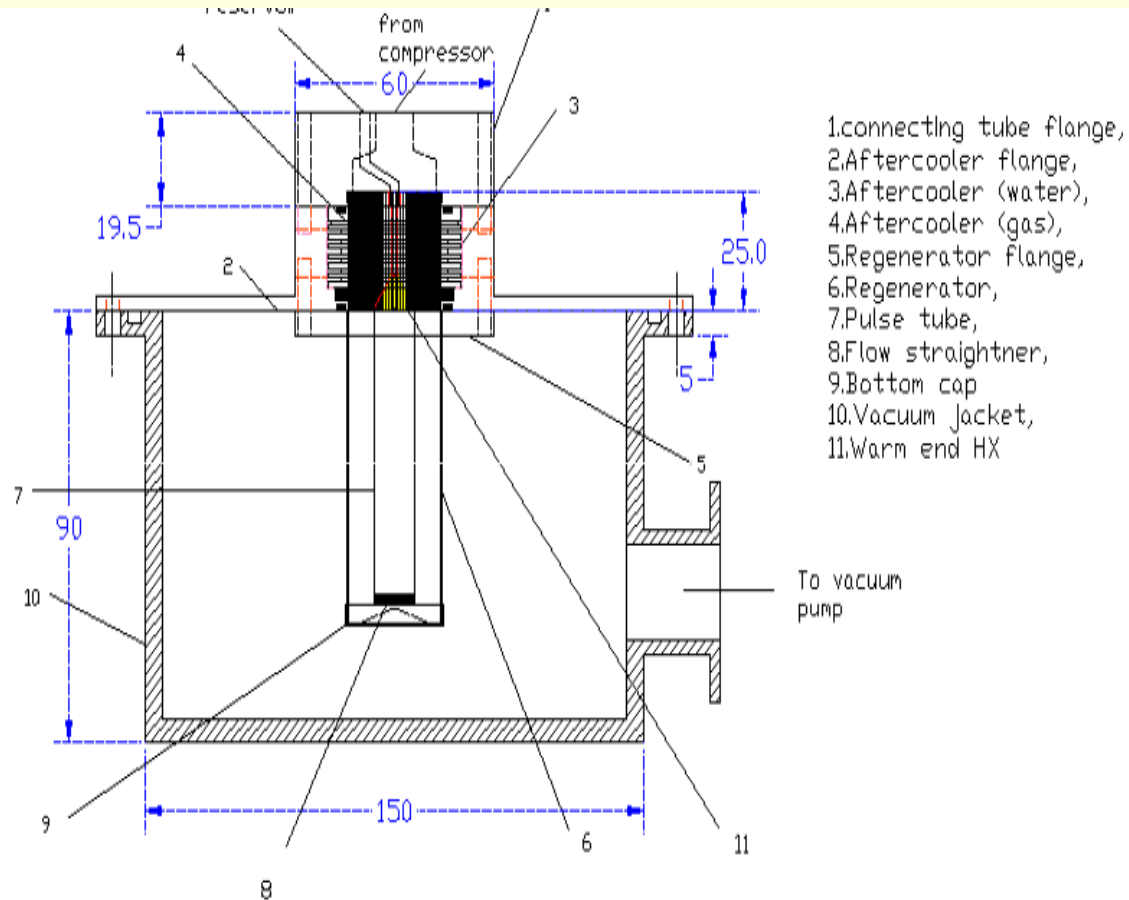
# Co-Axial PTR



- Regenerator is kept annular to the PT
- Most compact configuration
- The flow reversal not smooth
- Cold end heat exchanger configuration is important
- Heat transfer between PT and regenerator
- Fabrication of inertance tube and compressed gas inlet - critical



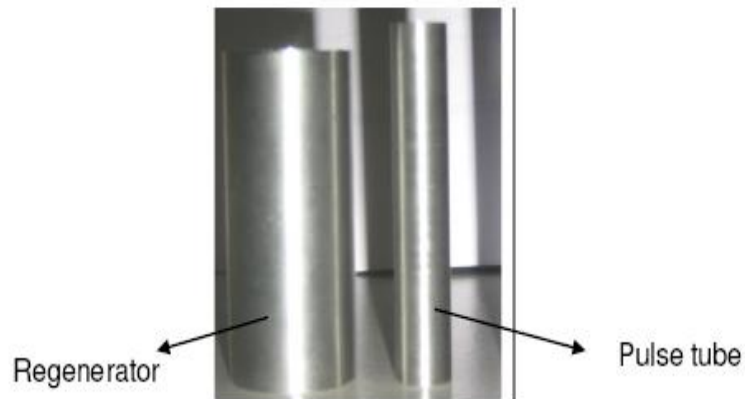
# Co-axial Pulse Tube Refrigerator – Assembly drawing



Assembly Drawing of Developed Coaxial Pulse Tube Refrigerator



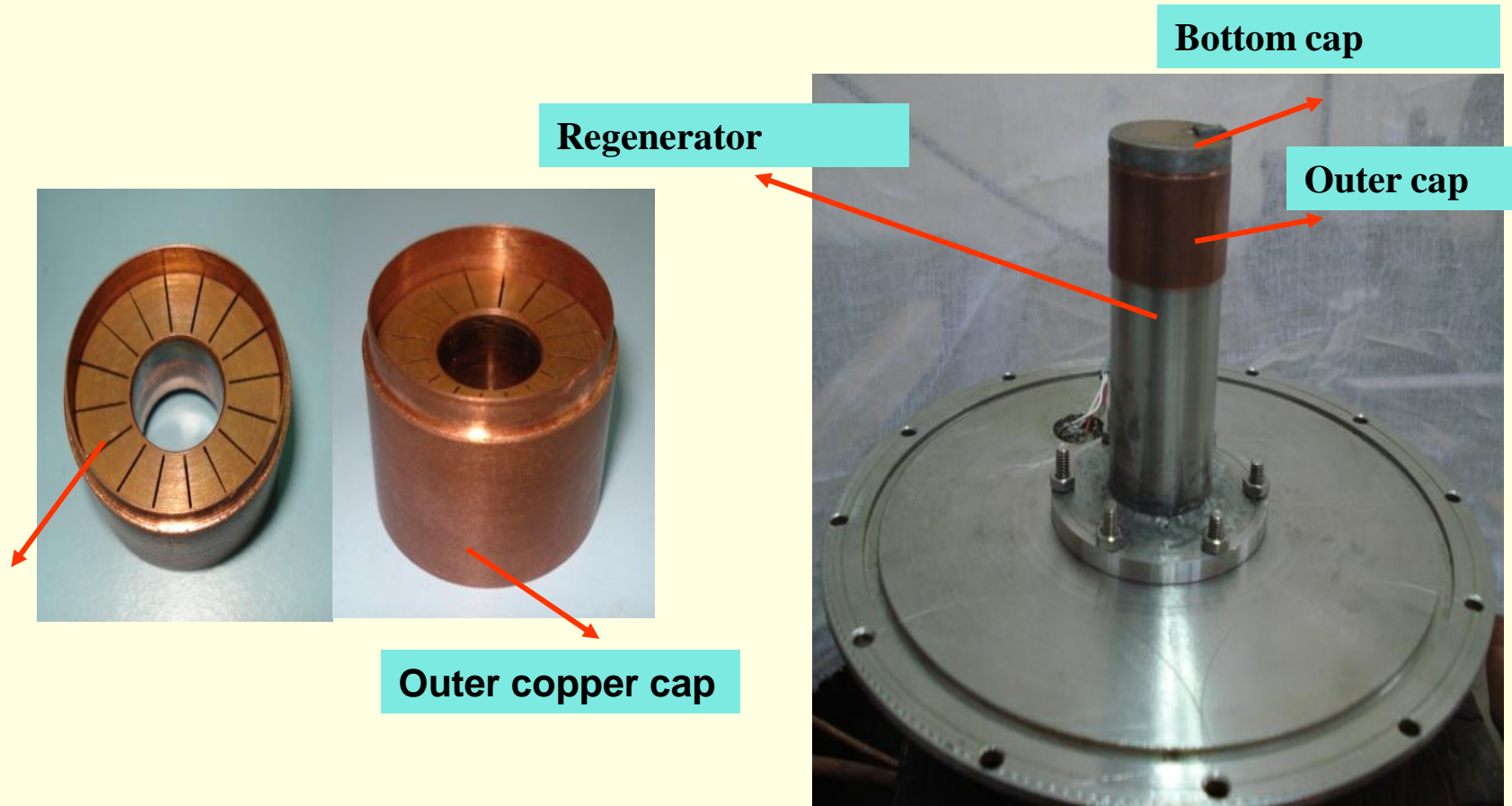
# Co-axial Pulse Tube Refrigerator – Fabricated parts





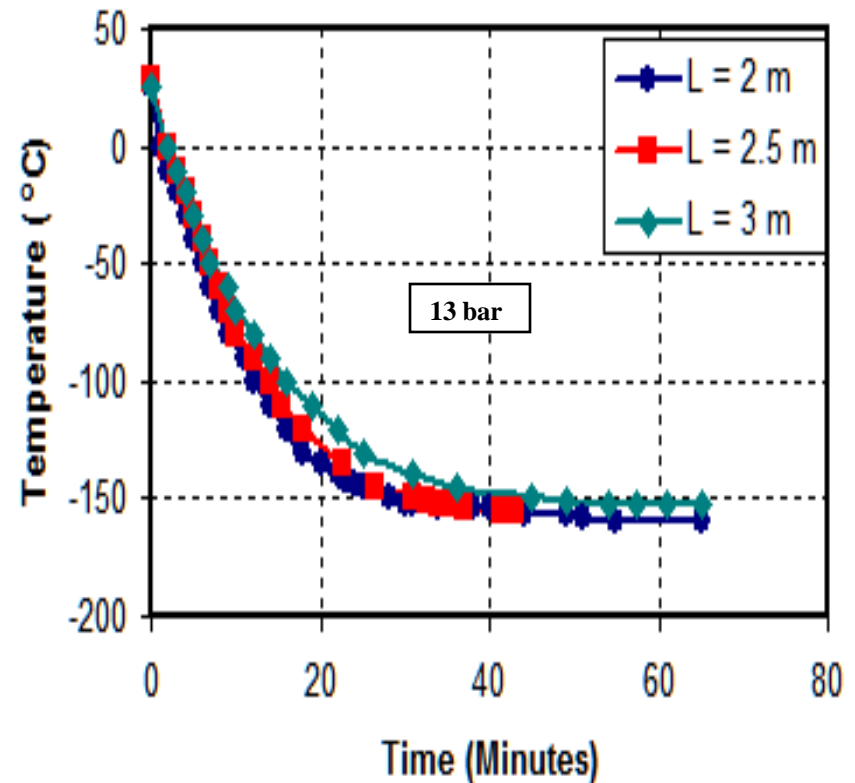
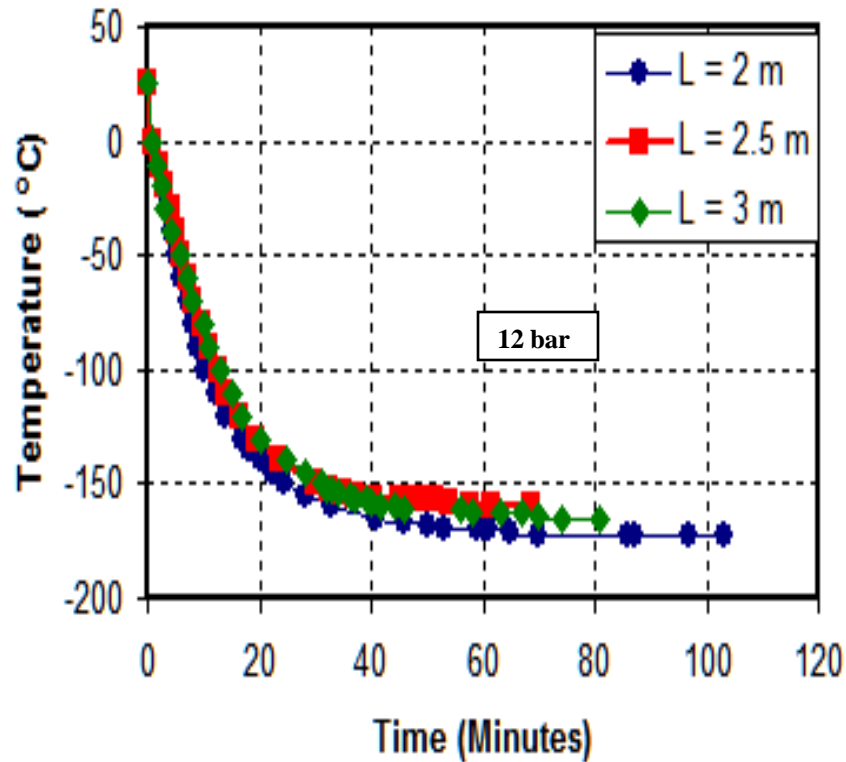


# Co-Axial PTR





## Co-Axial PTR – test results

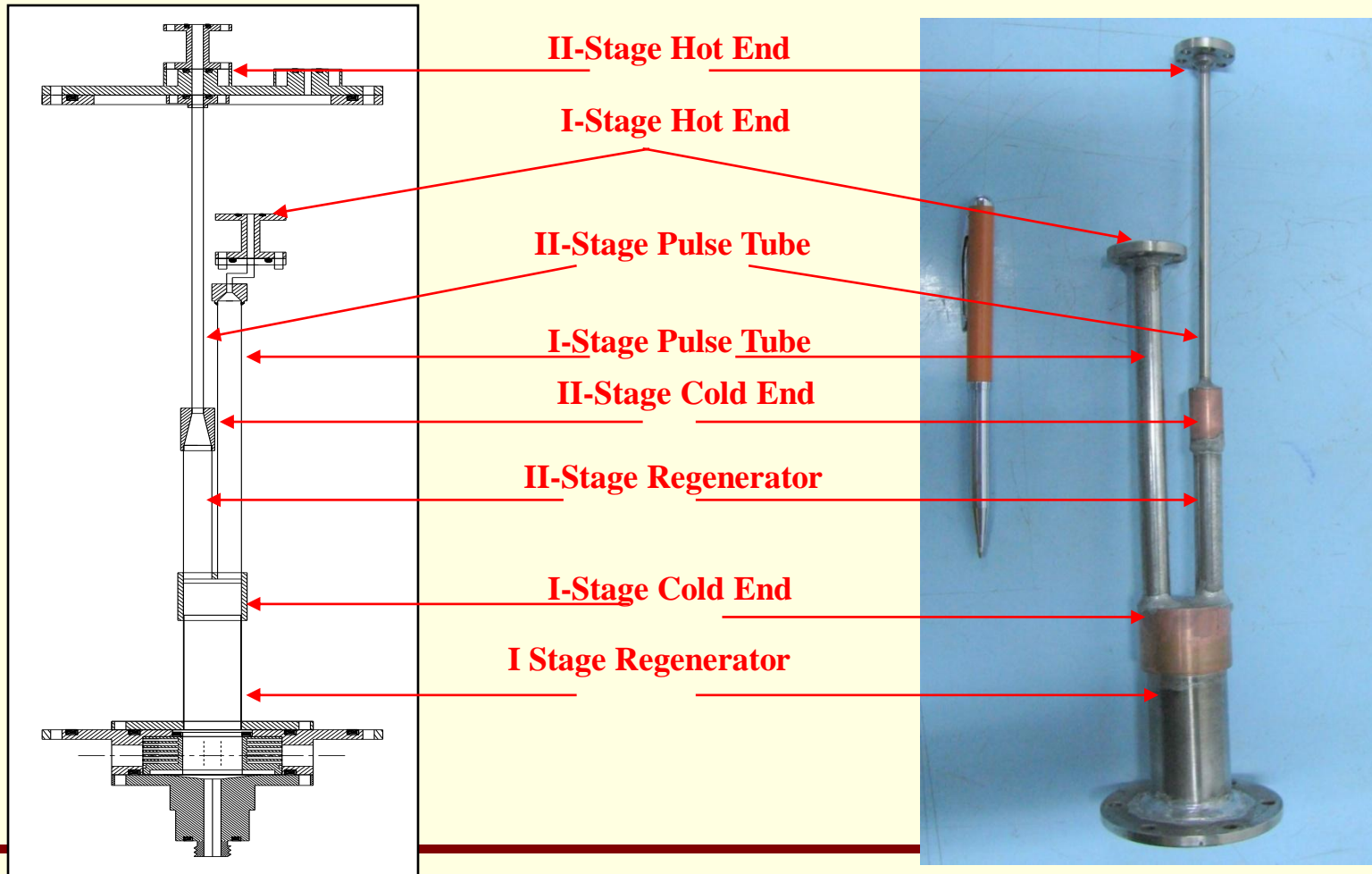


Lowest temperature reached – 89 K



# Two Stage Inline PTR

## Two – Stage Inline Configuration :





# Fabrication

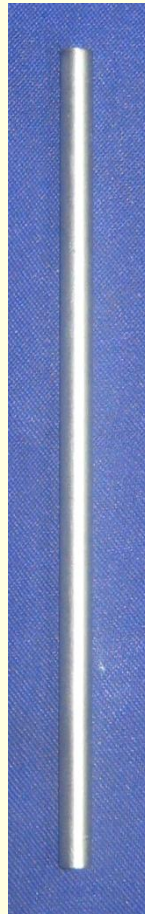
## Two – Stage Inline Configuration :



**Regen-I**



**PT-I**



**PT-II**



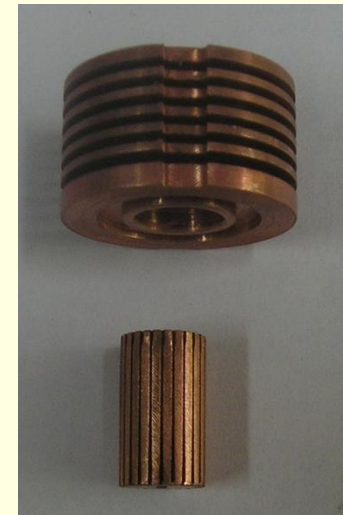
**Cold End I**



**Aftercooler**



**Cold End II**

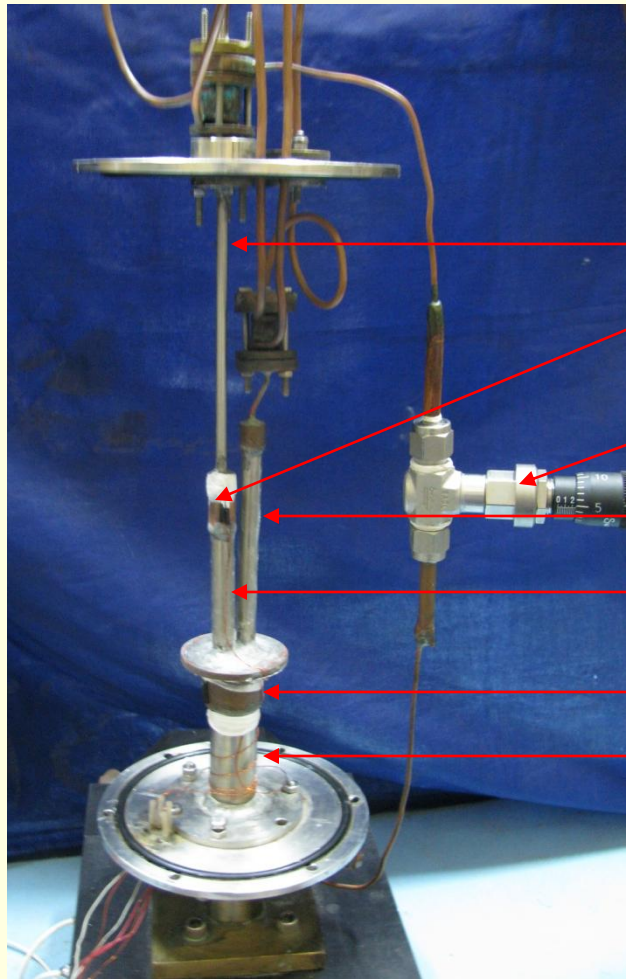


**Hot End HX**



**Regen-II**

# Assembly



II-Stg Pulse Tube

II-Stg Cold End HX

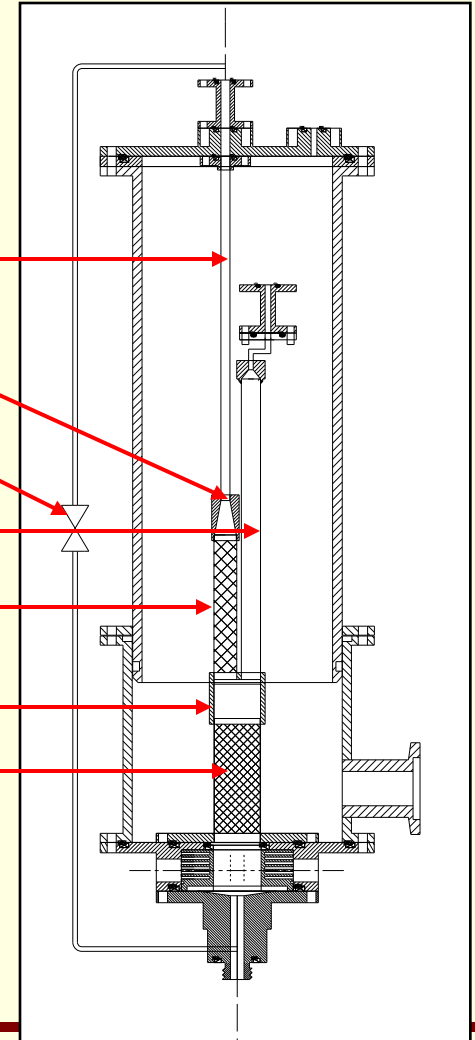
II-Stg Double Inlet Valve

I-Stg Pulse Tube

II-Stg  
Regenerator

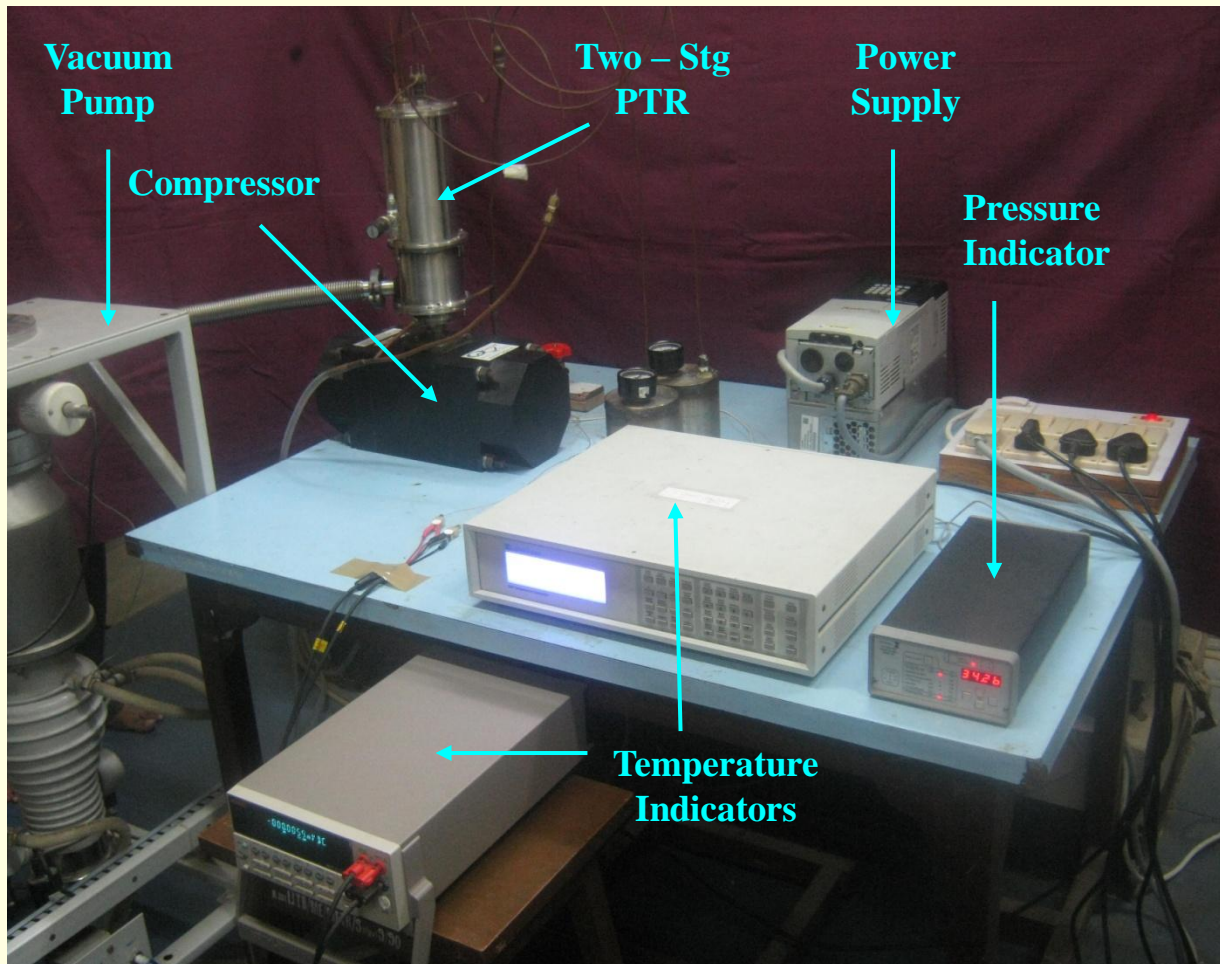
I-Stg Cold End HX

I-Stg Regenerator





# Experimental Setup



**Linear Compressor :**  
CFIC, Model 2S132W  
Max. Power 350 W

**DI Valve :**  
Swagelok  
Model SS-4MG-MH

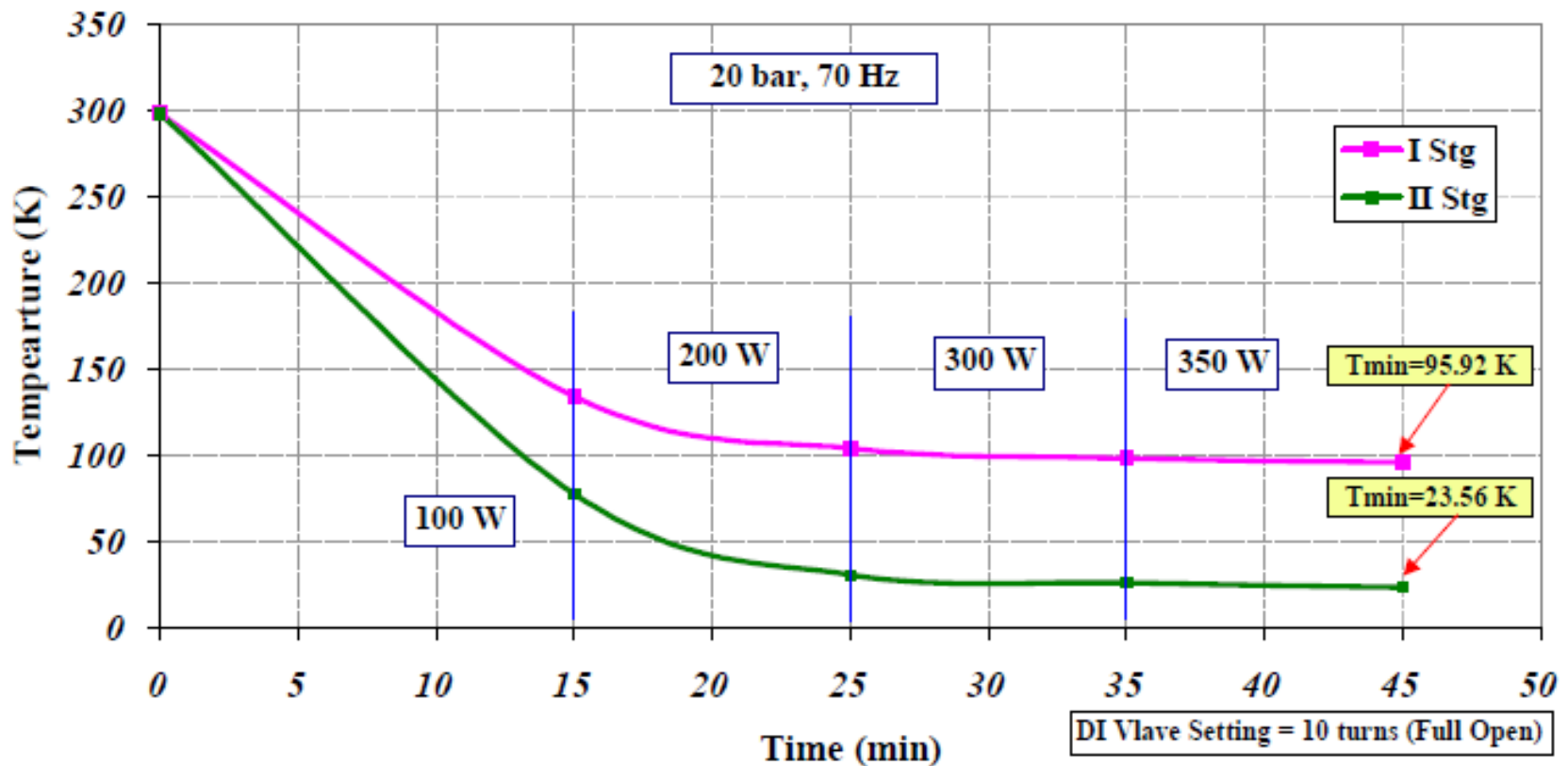
**Pr. Measurement :**  
ENDEVCO  
Piezo-resistive sensors

**Temp. Measurement :**  
Silicon Diodes  
DT-670-CU





# Final Results after Optimisation



Major Temperature Drop → 25 min.

Stability → 45 min.



# Workforce – Refrigeration and Cryogenics Laboratory

- **MRJT Cooler** – Dr Nihar Walimbe, Rohit Mehta and P Ardhapurkar ( ongoing )
- **Single Stage Pulse Tube Coolers**  
Tapan Totla, Chandrajeet Thaokar, Lokanath Mohanta, Mridul Sarkar, Rajeev Hatwar, Hemant Kumar, Prashant Patunkar, Amrish Badgukar, Mandar Tendolkar
- **Two Stage Pulse Tube Cooler**  
Mandar Tendolkar, Lokanath Mohanta, Amrish Badgukar ( ongoing )
- **Moving Magnet Compressor** - Shreesh Mishra, Jagan Mohan
- **Thermoacoustic Refrigerator** – Ram Dhuley
- **Technicians** – Vasudev Khandare, Pandurang Bhandare



# Thank you !