# ANNA UNIVERSITY OF TECHNOLOGY: TIRUNELVELI

## B.E. CRYOGENIC ENGINEERING

### R-2009

### SEMESTER I

| S.No | Sub Code | Title | L | T | P | C |
|---|---|---|---|---|---|---|
| 1 | MA 913 | APPLIED MATHEMATICS FOR THERMAL ENGINEERS | 3 | 1 | 0 | 4 |
| 2 | CR911 | ELEMENTS OF CRYOGENIC ENGINEERING | 3 | 0 | 0 | 3 |
| 3 | CR912 | ADVANCED HEAT & MASS TRANSFER | 3 | 1 | 0 | 4 |
| 4 | CR913 | VACUUM ENGINEERING | 3 | 0 | 0 | 3 |
| 5 | CR914 | ADVANCED REFRIGERATION | 3 | 1 | 0 | 4 |
| 6 | | ELECTIVE - I | 3 | 0 | 0 | 3 |
| LABORATORY | | | | | | |
| 7 | CR915 | CRYOGENIC ENGINEERING LABORATORY | 0 | 0 | 3 | 2 |

**LIST OF ELECTIVES**

| S.No | Sub Code | Title | L | T | P | C |
|---|---|---|---|---|---|---|
| 1 | CR951 | CRYOGENIC HEAT EXCHANGERS | 3 | 0 | 0 | 3 |
| 2 | CR952 | MATERIALS FOR LOW TEMPERATURE APPLICATIONS | 3 | 0 | 0 | 3 |
| 3 | CR953 | ADVANCED FLUID MECHANICS | 3 | 0 | 0 | 3 |
| 4 | CR954 | SUPER CONDUCTIVITY & LOW TEMPERATURE PHYSICS | 3 | 0 | 0 | 3 |
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**MA 913 APPLIED MATHEMATICS FOR THERMAL ENGINEERS** **L T P C**

**3 1 0 4**

**UNIT I APPLICATIONS OF FOURIER TRANSFORM** **9**

Fourier Transform methods – one-dimensional heat conduction problems in infinite and semi-infinite rod – Laplace Equation – Poisson Equation.

**UNIT II CALCULUS OF VARIATIONS** **9**

Concept of variation and its properties – Euler's equation – Functionals dependant on first and higher order derivatives – Functionals dependant on functions of several independent variables – Variational problems with moving boundaries – Direct methods – Ritz and Kantorovich methods.

**UNIT III CONFORMAL MAPPING AND APPLICATIONS** **9**

The Schwarz- Christoffel transformation – Transformation of boundaries in parametric form – Physical applications:Fluid flow and heat flow problems.

**UNIT IV FINITE DIFFERENCE METHODS FOR PARABOLIC EQUATIONS** **9**

One dimensional parabolic equation – Explicit and Crank-Nicolson Schemes – Thomas Algorithm – Weighted average approximation – Dirichlet and Neumann conditions – Two dimensional parabolic equations – ADI method.

**UNIT V FINITE DIFFERENCE METHODS FOR ELLIPTIC EQUATIONS** **9**

Solutions of Laplace and Poisson equations in a rectangular region – Finite difference in polar coordinates – Formulae for derivatives near a curved boundary while using a square mesh.

**L +T: 45+15 = 60PERIODS**

**REFERENCE BOOKS:**


1. Mitchell A.R. and Griffith D.F., The Finite difference method in partial differential equations, John Wiley and sons, New York (1980).

2. Sankara Rao, K., Introduction to Partial Differential Equations, Prentice Hall of India Pvt. Ltd., New Delhi (1997).

3. Gupta, A.S., Calculus of Variations with Applications, Prentice Hall of India Pvt. Ltd., New Delhi (1997).

4. Spiegel, M.R., Theory and Problems of Complex Variables and its Application (Schaum's Outline Series), McGraw Hill Book Co., Singapore (1981).

5. Andrews, L.C. and Shivamoggi, B.K., Integral Transforms for Engineers, Prentice Hall of India Pvt. Ltd., New Delhi (2003).

6. Elsgolts, L., Differential Equations and the Calculus of Variations, MIR Publishers, Moscow (1973).

7. Mathews, J.H. and Howell, R.W., Complex Analysis for Mathematics and Engineering, Narosa Publishing House, New Delhi (1997).

8. Morton, K.W. and Mayers, D.F. Numerical solution of partial differential equations, Cambridge University press, Cambridge (2002).

9. Jain, M. K., Iyengar, S. R. K. and Jain, R. K. " Computational Methods for Partial Differential Equations", New Age International (P) Ltd., 2003.

**CR911 ELEMENTS OF CRYOGENIC ENGINEERING** **L T P C**
**3 0 0 3**

**1. Introduction:** Meaning & definition of cryogenics, Importance of cryogenics studies, properties of engineering materials at cryogenic temperatures, mechanical properties ,thermal properties, electric & magnetic properties, super conducting materials ,thermo electric materials, composite materials, properties of cryogenic fluids, super fluidity of He 3 &He4.

**2. Cryogenic Measurement systems:** Temperature measurements, pressure measurements, flow measurements, liquid level measurements, fluid quality measurements.

**3. Importance of Cryogenic insulations:** -Various factors for selection of insulations, various types such as expanded foams, gas filled& fibrous insulation, vacuum insulation, evacuated powder& fibrous insulation, opacified powder insulation, multi layer insulation, comparison of performance of various insulations.

**4. Salient Applications of cryogenic systems:** Super conductive devices such as bearings, motors, cryotrons, magnets, space technology, space simulation chamber, cryogenics in biology and medicine, food preservation and industrial applications, nuclear propulsions ,chemical propulsions.

**5. Hazards:**-Physical hazards, Chemical hazards, Physiological hazards, Combustion hazards, oxygen hazards, , accidents in cryogenic plants & Prevention Safety in handling of cryogens, care for storage of gaseous cylinders,familiarization with regulations of department of explosives. powder insulation by boil off calorimeter method.

## Reference Books:

1. Cryogenic systems-Baron, McGraw-Hill book
2. Cryogenic fundamentals-Haselden, Academic press New York
3. Cryogenic technology –Vance
4. Advance cryogenic –bailey, plenum press
5. Cryogenic engineering -Scott
6. Cryogenic Engineering & Gas Applications – By Dr. P.K.Bose.

**CR912 ADVANCED HEAT & MASS TRANSFER** **L T P C**
**3 1 0 4**

**1. Conduction:** Factors affecting thermal conductivity of solids, liquids & gases. General three dimensional heat conduction equation in Cartesian, cylindrical & spherical coordinates. Initial condition and various boundary conditions. Heat sources systems, Critical thickness of insulation. Different types of fins & their analysis. Two dimensional steady state conduction. Transient heat conduction.

**2. Convection:** Free & forced convection, Similarity & simulation of convection heat transfer, Boundary layer theory, Turbulent flow heat transfer. Analogy between momentum & heat transfer. Heat transfer with liquid metals. Recent developments in the theory of turbulent heat transfer. Natural convection under different situations. Empirical relations in convection heat transfer.

**3. Two phase flow & heat transfer:** Boiling- Introduction to boiling heat transfer, regimes of boiling heat transfer, pool boiling, flow boiling. Condensation- Heat transfer in condensation, Drop wise & film wise condensation. Empirical equations. Laws of thermal radiation. Shape factors. Radiation heat transfer between black, diffuse & gray surface.

**4. Design of Heat Exchanger:** LMTD Methods, importance of fouling factor, Overall heat transfer co-efficient, NTU- effectiveness method, Analysis of compact heat exchanger—plate-fin heat exchangers, regenerative type heat exchanger. Optimization & simulation of heat exchangers. 6. Basic aspects of heat transfer in porous media.

**5. Mass Transfer:** Modes of mass transfer, comparison between heat & mass transfer, Frick's law of diffusion, general mass diffusion equation, diffusion through stagnant gas, convective mass transfer, dimensionless parameters & dimensional analysis of convective mass transfer, Evaporation of water in air.

## Reference Books:


1. 1. J.P. Holman, “Heat Transfer”, McGraw Hill Book Co. 9th edition, 2008.
2. Roshenow, W. Hartnell, J. Ganic, “Hand Book of Heat Transfer”, Vol. 1 & 2, Mcgraw Hill, 2005.
3. Incropera & Hewitt, “Fundanentals of Heat & Mass Transfer”, John Willey, 2005.
4. Engineering heat & mass transfer by **Mahesh M. Rathore**.
5. S.P.Sukhatme “Heat Transfer “ University Press
6. Eckert and Drake. Heat and Mass transfer. McGraw Hill
7. Collier, J.B. and Thome, J.R., *Convective boiling and condensation*, Oxford Science Publications, 1994.
8. L S Tong and Y S Tang. *Boiling Heat Transfer and Two-Phase Flow*. Taylor and Francis, 1997.
9. P.B Whalley. *Boiling, Condensation and Gas-Liquid Flow.* Oxford University Press, 1987.
10. Louis C Burmeister, *Convective Heat Transfer*, John Wiley and Sons, 1993.
11. Adrian Bejan, *Convective Heat Transfer*, John Wiley and Sons, 1995.

**CR913 VACUM ENGINEERING** **L T P C**

**3 0 0**

**1. Equation of state** for ideal gases ,real gases ,velocity and speed of gas molecules ,the mean free path ,volume occupied by gas molecules.

**2. Basic theory of pumping:** Basic definitions, resistance and conductance of arbitrary vacuum pipe work, fundamental equation of vacuum technique, regions of gas flow in pipes, calculation of pump down time. Interaction of gases with solid-taking up and evolution of gases by solids, adsorption and desorption of gases.

**3. Production of vacuum:** classification of vacuum pump-Calculation, operating limits of vacuum pump, their ranges, Types of vacuum pumps-oil sealed rotary, roots blower, ejector ,diffusion, turbo molecular ,sorption, getter pumps ,cold cathode &cryogenic pumps principles ,construction ,operation of pump and their salient features.

**4. Vacuum gauges**: classification –ranges of vacuum gauges, McLeod, mechanical, thermal conductivity gauges, hot cathode and cold cathode ionization gauges, ionization gauges with upper range-principle, construction and salient features. Metered leak measurement.
Leak hunting: Tightness of vacuum system, leak detection methods, halide leak detector, and mass spectrometer leak detector.

5. Vacuum system components: demountable vacuum joints, electrical lead ,introduction to vacuum valves, various types, their selection. Vacuum materials:-basic requirements, metals & their alloys, non metals, pump fluids. Selection of pumping facilities –determination of intrinsic speed-matching pumps operating in series and in parallel, calculation of fire vacuum cylinders. . Application of vacuum – vacuum systems for space simulation chamber,

Reference Books:

1. Fundamentals Of Vacuum Techniques-A Pipko
2. Vacuum technology: Andrew Gutheries.
3. Vacuum technology :A.roth
4. Hand book of high vacuum engg .:Steinherz.

**CR914 ADVANCED REFRIGERATION** **L T P C**

**3 0 0 3**

1. Balancing of vapor compression refrigeration system, Dual pressure vapor compression system and its analysis, Compound compression with flash cooler and flash intercooler, multiple expansions, parallel operation, sectionalizing, booster operations, various types of cascade systems analysis

2. Refrigerants: Ecofriendly refrigerants & their properties, secondary Refrigerants, mixture of refrigerants, azeotropics, salient characteristics of various refrigerants. Synthetic lubricating oil &their properties

3. Absorption refrigeration: H-x charts of LiBr-H2O and NH3-H2O solutions.,
analysis of vapor absorption refrigeration system on H-X charts, mass concentration &equilibrium charts , heat balance, COP comparison with vapor compression refrigeration systems, two stage vapor absorption refrigeration system ,balancing of vapor absorption refrigeration systems.

4. Air cycle refrigeration, Analysis of various cycles and their applications. Calculations of COP
Steam jet refrigeration - cycle analysis, analysis on H-O charts performance, control and various applications. Thermo-electric refrigeration: Thermo-electric effects, analysis of thermoelectric cooling, COP, FOM, thermoelectric, materials.

5. Heat pumps: Sources and sinks, refrigerant circuits, heating and cooling performance of heat pumps. Design of refrigeration systems for industrial &other application for transport refrigeration ,walk in coolers & cold storages for different applications. Preservation & processing of food by use of refrigeration.

## Reference Books:

1. Mechanical refrigeration, sparks and dilio
2. Refrigeration and air conditioning, stocker
3. Refrigeration and air conditioning, Jordan and priester
4. Refrigeration and air conditioning, C. P. Arora
5. Ashrae hand book, refrigeration 1998
6. 6.Thermal environmental engineering-threlked 1998
7. 7.Industrial refrigeration handbook ,stoecker,1998M.E. I(MECHANICAL)

## ELECTIVES – I SEMESTER

**CR951CRYOGENIC HEAT EXCHANGERS** **L T P C**
**3 0 0 3**

1. Advanced heat transfer: steady state conduction with two and three dimension with heat generation, solution of problem by numerical ,finite difference and graphical methods, matrix ,finite element methods, transient heat conduction and solution by analytical correlation for convective heat transfer for natural and forced convection ,transition flow, flow outside of duets, boiling heat transfer coefficients .pressure drop in two phase flow, frost formulation ,condensation ,heat transfer coefficient during condensation.

2. Shell & tube type heat exchangers-design, Fin effectiveness , surface effectiveness and overall coefficients of heat transfer. Overall pressure drop, effectiveness- NTU approach solution by equations and graphical methods,. Effect of heat-exchanger effect of various specific on exchanger performance.

3. Design of regenerative type heat exchanger for single and multi stage, Philips, Gifford single volume, double volume, Vuilleumier, magnetic cry refrigerators. Design of heat exchangers for liquefaction systems ,single tube ,double tube Linde heat exchangers three channel heat exchangers ,multiple tube type ,Giaque Hampton and Collins type heat exchangers.

4. Finned tube and plate type heat exchangers, different configuration heat transfer coefficients and friction coefficient for various configuration. Single tube Linde exchanger, double tube type, three channel heat exchanger. Linde multiple tube type , Giauque Hampson, Collin's,

5. Plate fin heat exchanger ,different fin configuration, heat transfer coefficients , and friction factors for various configurations. Testing of heat exchangers as per standards.

## Reference Books:

1. Saunders, E.A.D., ”Heat exchange – selection design and construction”, Longmann Scientific and Technical, N.Y.2001.
2. Kays, V.A and London,A.L., “Compact Heat Exchangers”, McGraw Hill, 2002
3. Holger Martin , “Heat Exchanger” Hemisphere Publ.Corp., Washington,2001
4. Kuppan,T., “Heat Exchangert Design Handbook”, Macel Dekker, Inc., N.Y.,2000
5. Seikan Ishigai, “Steam Power Engineering, Thermal and Hydraulic Design Principles”, Cambridge Univ. Press,2001

**CR952 MATERIALS FOR LOW TEMPERATURE APPLICATIONS L T P C**
**3 0 0 3**

**AIM:** To impart knowledge on material characterization at low temperature and selection for low temperature applications.

**OBJECTIVE:**

- To understand the behavioral changes in materials at low temperature.
- To understand the selection of material for low temperature applications.
- To understand the testing methods for low temperature behavior of materials.

**UNIT I MATERIAL BEHAVIOR 10**

Deformation process in pure , impure metals and alloys–effect of low temperature transformation , plastic deformation at constant stress-creep , Role of dislocations , Tensile , Shear strength of perfect and real crystals , Strengthening mechanisms , Work hardening , strain and strain rate on plastic behavior–super plasticity Ductile and Brittle Failure , Crack Propagation-Fracture , Toughness–fracture toughness , Griffith's theory , stress intensity factor and fracture toughness Toughening mechanisms–Ductile , brittle transition in steel

**UNIT II MATERIALS SELECTION 10**

Compatibility with liquid oxygen and other process fluids-external environment, Toughness-pressure vessel codes, Motivation for selection-cost basis and service requirements–Selection for surface durability, corrosion and wear resistance– Relationship between materials selection and processing–Case studies in materials selection.

**UNIT III NON METALLIC MATERIALS 7**

Polymeric materials for Cryogenic Application , Ceramics and Glasses , Cryogenic properties of Composites , Polymeric materials–Formation of polymer structure– Production techniques of fibres , foams , adhesives and coatings–Structure , properties and applications of engineering polymers–Advanced structural ceramics , WC , TiC , TaC , Al2O3 , Sic , Si3N4 , CBN and diamond–properties , processing and applications.

**UNIT IV TESTING METHODS AND TECHNIQUES 10**

Basic types of Cryostat and cooling system , Modification , Variations , and special purpose attachments–multiple specimen testing , compression testing , Flexural , torsional , fatigue and impact testing , Extensometry-Resistive strain gauges , Displacement Transducers , Capacitance gauges.

**UNIT V MODERN METALLIC MATERIALS 8**

Dual phase steels , micro alloyed , High strength low alloy (HSLA) steel , Transformation induced plasticity (TRIP) steel , Maraging steel-intermettallics , Ni and Ti aluminides–smart materials , shape memory alloys–Metallic glass–Quasi crystal and nano crystalline materials.

**TOTAL: 45 PERIODS**

**TEXT BOOKS:**

1. Wigley D.A., “Mechanical Properties of Materials at Low Temperatures”, Plenum Press, New York, 1972.

**REFERENCE BOOKS:**

1. Richard P. Reed, Alan F. Clark, Materials at low Temperature, ASME International, Dec 1983.
2. Thomas H.Courtney , “Mechanical Behavior of Materials”, (2nd Edition), McGraw-Hill , 2004.

**CR953 ADVANCED FLUID MECHANICS L T P C**
**3 0 0 3**

**AIM:**

To introduce the advanced concepts of fluid mechanics and aerodynamics with the emphasis on practical applications.

**OBJECTIVES:**

- To understand the laws of fluid flow for ideal and viscous fluids.
- To represent the real solid shapes by suitable flow patterns and to analyze the same for aerodynamics performances.
- To understand the changes in properties in compressible flow and shock expansion.

**UNIT I BASIC EQUATIONS OF FLOW 6**

Three dimensional continuity equation - differential and integral forms – equations of motion momentum and energy and their engineering applications.

**UNIT II POTENTIAL FLOW THEORY 12**

Rotational and irrorational flows - circulation – vorticity - stream and potential functions for standard flows and combined flows – representation of solid bodies by flow patters.Pressure distribution over stationery and rotating cylinders in a uniform flow - magnus effect - Kutta – Zhukovsky theorem.Complex potential functions.Conformal transformation to analyze the flow over flat plate, cylinder, oval body and airfoils.Thin airfoil theory – generalized airfoil theory for cambered and flapped airfoils.

**UNIT III VISCOUS FLOW THEORY 9**

Laminar and turbulent Flow - laminar flow between parallel plates - Poiseuille's equation for flow through circular pipes.Turbulent flow - Darcy Weisbach equation for flow through circular pipe - friction factor - smooth and rough Pipes - Moody diagram – losses during flow through pipes.Pipes in series and parallel – transmission of power through pipes.

**UNIT IV BOUNDARY LAYER CONCEPT 9**

Boundary Layer - displacement and momentum thickness - laminar and turbulent boundary layers in flat plates - velocity distribution in turbulent flows in smooth and rough boundaries - laminar sub layer.

**UNIT V COMPRESSIBLE FLUID FLOW 9**

One dimensional compressible fluid flow – flow through variable area passage – nozzles and diffusers – fundamentals of supersonics – normal and oblique shock waves and calculation of flow and fluid properties over solid bodies (like flat plate, wedge, diamond) using gas tables

**TOTAL: 45 PERIODS**

**TEXT BOOKS:**

1.Houghten, E.L. and Carruthers, N.B., Aerodynamics for Engineering Students, Arnold Publishers, 1993.

2. Anderson, J.D., Fundamentals of Aerodynamics, McGraw Hill, Boston, 2001.

**REFERENCES:**

1.Streeter, V.L., Wylie, E.B., and Bedford, K.W., Fluid Mechanics, WCB McGraw Hill, Boston, 1998.

2.Munson, B.R., Young, D.F. and Okiisi, T.H., Fundamentals of Fluid Mechanics, John Wiley and Sons Inc., NewYork, 1990

3.Kumar, K.L., Engineering Fluid Mechanics, Eurasia Publishing House, New Delhi, 2002

4.Bansal, R.K., Fluid Mechanics, Saurabh and Co., New Delhi, 1985.

**CR954 SUPER CONDUCTIVITY & LOW TEMPERATURE PHYSICS L T P C**
**3 0 0 3**

1. Properties Of Cryo Liquids, Liquid Air, Liquid Nitrogen, Liquid Oxygen, Liquid Hydrogen, Liquid Helium, General Properties, Phase Diagrams, Thermodynamic Properties

2. Super Fluid 4He – Helium II :Experimental Observations, Two – Fluid Model, Bose – Einstein Condensation, Macroscopic Quantum State, Excitation Spectrum of Helium Ii, Critical Phenomena Near The Lambda Point

3. Normal Fluid 3He :Ideal Fermi Gas –Comparison With 3He, The Landau Fermi Liquid Theory, Zero Sound

4. Super Fluid 3He -- Phase Diagrams , Specific Heat, Superfluidity, Nuclear Magnetic Resonance , Relevance Of Two Fluid Model, Quantum States Of Pairs Of Coupled Quasiparticles, Order Parameter Orientation – Textures, Leggett Equations Transverse Resonance, Longitudinal Resonance, Superflow, Macroscopic Quantum Interference – Josephson Effect, Normal Fluid Density – Quasiparticle Scattering , Collective Excitations, Sound Propagation

5. Mixtures Of 3He & 4He: Specific Heat, Phase Diagram And Solubility, Normal Fluid Component, Sound Propagation, Transport Properties, Search For a Superfluid Phase Of 3He In Mixtures.

## Reference Books:

1. Low Temperature Superconductivity & Superconductivity By Christian Enss & Siegfried Hunklinger
2. Matter & Methods At Low Temperature By F.Pobell.
Experimental low temperature physics by Anthony Kent

**CR954** **ADVANCED CRYO COOLERS** **L T P C**

**3 0 0 3**

**1. Cryocoolers:**

Classification of cryocoolers, Working of cryocoolers, Selection of cryocooler and comparison of different types of cryocoolers, Ideal working Cycles, Important parameters –mass, volume, vibration, acoustic noise, electromagnetic interface, operating life, Technical parameters - cooling effect, compressor power requirement, cooling water requirement, service requirement of compressor ,Vibration control, Steady flow and oscillating flow cryocoolers, Different types of at exchangers, Applications of cryocoolers –military, environmental , commercial, medical, transportation, energy, police and security.

**2. Gifford Mcmahon Cryocooler:**

Advantages and disadvantages of G-M cryocooler, Design of two stage G-M cryocooler , Efficiency of pressure oscillators, 4K operation, improved valve timing, Application of GM Cooler, Monolithic regenerator technology for low temperature cryocoolers, Progress of multilayered regenerators.

**3. Stirling Cryocooler:**

Ideal Stirling cycle, Concept of practical Stirling cycle, First order analysis Stirling cycle, Second order analysis, Third order analysis , Loss analysis, Comparison of Stirling and Carnot cycle, Design and optimization of Stirling Cryocoolers, Performance and reliability improvement of low cost Stirling cooler, Development of long life stirling cooler, Analysis of Stirling Cycle, Multi stage Cryocooler, hybrid cooler , Long life tactical and commercial Stirling cooler, Miniature stirling cryocooler, Linear compressor design.

**4. Pulse tube Cryocoolers:**

Advantages and disadvantages of pulse tube cryocooler, History of pulse tube Cryocooler, Comparison of stirling and orifice pulse tube cryocoolers, Double inlet pulse tube refrigerator, Geometry of pulse tube –U-tube, co-axial, in-line, Two stage pulse tube refrigerator design , Thermoacoustically driven pulse tube refrigerator, Different methods of analysis, Phasor

analysis , Oscillating flow behavior of PTR, Valve timing effect on performance of 4K pulse tube cryocooler. Design of Dual use PTR, Low vibration flexure bearing compressor, Miniature 50 k to 80 K space application of PTR, Experimental characteristics of PTR, Effect of D.C. flow, Active phase control of stirling type PTR, Expansion efficiency considering shuttle heat transfer, Co-axial PTR for high Tc- SQUID, Characteristics of Double inlet PTR, Experimental study and analysis of components of orifice pulse tube refrigerator. Theoretical model of G-M type pulse tube refrigerator, High frequency pulse tube cryocooler with base temperature below 20 K, Novel regenerator material Er3 Ni Hx-He-H2 mixture, Numerical and experimental study of Rotary valve for pulse tube, . Valve timing effect on cooling performance of pulsetube cryocooler, V-M type PTR, Variable resistance orifice, Effect of valve timing on PTR, Performance of single stage pulse tube, Some of the phase shifting types of two stage G-M type pulse tube refrigerator, Small He3 PTR Multi stage pulse tube cooler 4 K technology - new material

**5. Space pulse tube Cryocooler development :**

Miniature pulse tube cryocooler for space, High frequency pulse tube cooler, High performance cryocooler compressor, Vibration reduction in balanced linear compressor, G-M type pulse tube cryocooler . Regenerator material analysis and material development Ductile, High heat capacity magnetic regenerator alloy material, Manufacturing considerations of rare earth powder used in cryocooler

**6.Magnetic refrigerator:**

Magnetic refrigerator –Its development and its utility in magnetic hydrogen liquefier. Government Cryocooler development program Military space cryogenic cooling requirement, Linear drive Cryocooler for weapon system, Cryocooler reliability

**Reference Books:**

1. Cryocoolers by G. Walker

2. Cryocoolers Volumes ( Proceedings of International Cryocooler conference) Journal 'Cryogenics' published by Elsevier available at www.sciencedirect.com

3. Advances in Cryogenic Engineering. (Proceedings of International Cryogenic Engineering Conference )