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# Efficiency Enhancement of Cooling System for MRI

--By Raheem ABD Hamza

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**2013**

# Efficiency Enhancement of Cooling System for MRI

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2013

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# CERTIFICATE

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**VISHWAKARMA INSTITUTE OF TECHNOLOGY**

(An Autonomous Institute Affiliated to University of Pune)

This is to certify that I have completed the dissertation report on

**"EFFICIENCY ENHANCEMENT OF COOLING SYSTEMFOR MRI"**

In a satisfactory manner in a partial fulfillment for requirement of degree

M.E. HEAT POWER (MECHANICAL ENGINEERING)

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# Table of Content

## Abstract

This thesis presents the development of the cooling system of MRI (magnetic resonance imaging)compatible Cooling system. After comparing different types of MRI-compatible cooling system technologies, a modified cooling system is proposed. In this work, the unsteady state heat transfer from counter flow double pipe heat exchanger is analyzed. An implicit algorithm is developed to solve the unsteady heat transfer in countercurrent double pipe heat exchanger. The analysis is considering hot fluid flowing inside the tube and the cold fluid flows inside the outer annulus. Other advantages of the developed heat exchanger are low pressure loss, cheap materials and a simple construction. The experiment shows that the heat exchanger is capable of cooling at a minimal time, while also maintaining minimum pumping energy. The optimum mass flow rates of water and glycol have been determined. The optimum number of fins has also been determined.

**Acknowledgement**

The author is highly indebted to express our deep sense of gratitude towards our guide**Prof. (Dr.) V.S. Pavitran**, faculty of Mechanical Engineering, for his valuable suggestions and encouragement for this project. The author takes this opportunity to express his sincere gratitude to**Prof .(Dr) R . M. Jalnekar** , Director , Vishwakarma institute of Technology and the and the author also express his sincere thanks to the head of the Department (ME)Heartfelt gratitude is due to **Prof. (Dr) V.S. Pavitran** who gave permission to do the project work by vista many hospitals in India and Iraq .I would also like to extend our thanks to the Head of Mechanical Engineering Department, **Prof. (Dr.) V. S. Pavitran** and all the staff members of Mechanical Engineering department for their valuable guidance, encouragement and co-operation. I also express our thanks to all of them who directly or indirectly have helped me in preparing this project.

Finally author do thank all staff from VTI Pune, staff from ANAV Hospitals in Mumbai, And staff from Karbala hospital in Iraq and all friends and well-wishers who helped in making this project a big success .

M.E (Heat Power Dedication)

## Nomenclature

Cp specific heat (J\kg·K)

K thermal conductivity (W /m.K)

mass flow rate (kg/s)

P total pressure (Pa)

PrPrandtl number (μCp/k )

Q heat transfer rate (W)

Re Reynolds number ($VD_h$/ v)

T temperature (K)

V fluid velocity (m/s)

ΔP pressure drop across heat exchanger .

c cold fluid

i inlet

o outlet

t :Time (sec)

h:Heat transfer coefficient (W/m2.K)

*f*: friction coefficient

$\dot{m}$ mass flow rate (kg/s)

P total pressure (Pa)

i inlet.

o outlet

min minimum , max maximum value

f fluid

Nu Nestle number

MRI Magnetic Resonance Imaging

MR Magnetic Resonance

T Tesla

**Greek**

ρ Density (Kg/m3) Δ Change during element

μ Dynamic viscosity (Pa.Sec)

ν Kinematics viscosity (m2/Sec)

# Chapter 1

## 1.1 Introduction

Efficiency enhance of cooling system in MRI. It's includes a superconducting magnet that generates a static magnetic field and heat. All problem in MRI are starts from cooling system (heat exchanger).The MRI (Magnetic resonance imaging) is a very promising option for accurate guidance of complicated interventional procedures and provides high soft tissue contrast, but visualization of interventional devices is rather difficult. (MRI) has become an important diagnostic tool, because it is a noninvasive way to diagnose almost any person at any age. In 2003, 10,000 MRI units wherein existence worldwide. This number increased to 26,503 MRI units in 2008 (Honk, 2008).About 75 million MRI scans are performed every year. For these reasons should be carefully in this device especially in heat exchanger system because all problems start from it.

Heat exchangers, as the name implies, transfer heat from one substance to another. A heat exchanger is a heat transfer device that exchanges heat between two or more process fluids. Heat exchangers have widespread industrial and domestic applications and in the process industry for the recovery of the heat. They are an essential component in thermal power system, refrigeration system, and other cooling system. In all these systems, heat is transfer from one fluid to other. The counter flow heat exchanger is most favorite because it is gives maximum rate of heat transfer for a given surface areaIn many thermal equipment design are based on the steady state in calculation of the characteristic variable. Many applications require knowledge of the transient behavior of the thermal devices. In fact, it is necessary to explore the unsteady state of thermal properties when the real time control, state computation, optimization, and rational use of energy are investigated. In additional, the unsteady state gives more details and information than steady state and also gives indication to validity of the steady state assumption. The steady state heat exchanger is well defined and discussed in many literatures, The steady state solution are commonly divided in to two methods, the first method named "LogMean Temperature Difference (LMTD)", this method is applied when the inlet and outlet temperatures are knowing this method is used. Indicate anew steady state formulation for countercurrent double pipe heat exchanger with constant parameter experimentally. In our study, we analyzed countercurrent heat exchanger which used to cool a hot fluid (flow inside tube) by a cooled fluid (flow inside the annulus area). The finite difference techniques was used to solve the unsteady state countercurrent double pipe heat exchanger differential equations, The variable specific heat coefficient with mass flow and temperature was taken in account during the present analysis.

### 1.2 History

In the 1950s, Herman Carr reported on the creation of a one-dimensional MRI image. Paul Herman Carr expanded on Carr's technique and developed a way to generate the first MRI images, in 2D and 3D, using gradients. In 1973, Lautenberg published the first nuclear magnetic resonance image. and the first cross-sectional image of a living mouse was published in January 1974. Nuclear magnetic resonance imaging is a relatively new technology first developed at the University of Nottingham, England. Peter Mansfield, a physicist and professor at the university, then developed a mathematical technique that would allow scans to take seconds rather than hours and produce clearer images than Lautenberg had. In the Soviet Union, V.V filed (in 1960) a document with the USSR State Committee for Inventions and Discovery at Leningrad for a Magnetic Resonance Imaging device, although this was not approved until the 1970s.[19]

In a 1971 paper in the journal Science, Dr. Raymond Desmidian, an Armenian-Americanphysician, scientist, and professor at the Downstate Medical Center State University of New York (SUNY), reported that tumors and normal tissue can be distinguished in vivo by nuclear magnetic resonance ("NMR"). He suggested that these differences could be used to diagnose cancer, though later research would find that these differences, while real, are too variable for diagnostic purposes. Dalmatian's initial methods were flawed for practical use, relying on a point-by-point scan of the entire body and using relaxation rates, which turned out to not be an effective indicator of cancerous tissue. While researching the analytical properties of magnetic resonance, Dalmatian created the world's first magnetic resonance imaging machine in 1972. He filed the first patent for an MRI machine, U.S. patent3, 789,832 on March 17, 1972, which was later issued to him on February 5, 1974.As the National Science Foundation notes, "The patent included the idea of using NMR to scan' the Human body to locate cancerous tissue." However, it did not describe a method for generating pictures from such a scan or precisely how such a scan might be done. Dalmatian along with Larry Mink off and Michael Goldsmith, subsequently went on to perform the first MRI body scan of a human being on July 3, 1977 These studies performed on humans were published in .They ordered the biggest magnet available–a 1.5T, system–and built the first high-field whole-body MRI/MRS scanner, overcoming problems of coil design, RF penetration and signal-to-noise. The results translated into the highly-successful 1.5T MRI product-line of well over 20,000 systems today. Bottomed did the first localized MRS in human heart and brain. After starting collaboration on heart applications. Although MRI is most commonly performed at 1.5T, higher fields (such as 3T) are gaining more popularity due to the increased sensitivity and resolution. In research laboratories, human studies have been performed at up to 9.4Tand animal studies have been performed at up to 21.1T.

### 3.1 Basic Principle of MRI.

- The hydrogen (1^H) atom inside body possess “spin”
- In the absence of external magnetic field, the spin directions of all atoms are random and cancel each other.
- When placed in an external magnetic field, the spins align with the external field.
- By applying a rotating magnetic field in the direction orthogonal to the static field, the spins can be pulled away from the z-axis with an angle alpha. Be pulled away from the z-axis with an angle alpha.

This section will discuss some of the principles in magnetic resonance imaging (MRI).The focus of this section will be the magnetic fields and radiofrequency pulses which make the MRI environment a challenge for electronics design To understand the concepts behind the MRI, magnetic resonance (MR) first needs to be understood. MR is a concept based on the spin of an atom’s nucleus. This spin occurs naturally, and creates a magnetic field parallel to the axis of rotation. There are a select group of elements, which have a net spin and therefore can be detected in MRI. These elements include 1H, 2H, 31P,23Na, 14N, 13C, and 19F. Without the presence of a magnetic field, any volume of tissue contains collection of nuclei with random orientation.

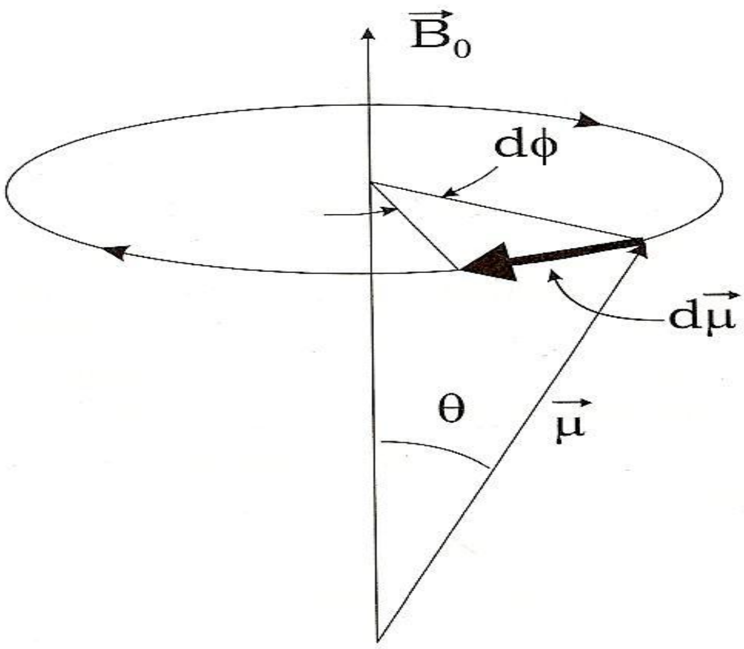



**Figure [1]: Nucleus Alignment in Magnetic Field (Haacke et al, 1999)[4].**

Magnetic resonance is a process of absorption and reemission of energy. Atoms will be subjected to a magnetic field, resulting in a fraction of the protons aligning with the magnetic field. At this point, the atoms will be in a low energy state. To get to a high energy state, the atoms will absorb photons. This energy is defined in eq. (1) (Hornak, 2008).

Table 1: Nuclei and Their Gyromagnetic Ratio (Hornak, 2008) .

| Nuclei | γ (MHz/T) |
|---|---|
| $^{1}H$ | 42.58 |
| $^{2}H$ | 6.54 |
| $^{31}P$ | 17.25 |
| $^{23}Na$ | 11.27 |
| $^{14}N$ | 3.08 |
| $^{13}C$ | 10.71 |
| $^{19}F$ | 40.08 |

**1.3 Objective of the Project:**

The primary objective of this study is to provide a cooling assembly for MRI, which provides excellent thermal efficiency and it is easy to manufacture and less expensive and less complicated from other cooling systems, there also exist a need for adapting an efficient cooling assembly to existing MRI without having to completely redesign the existing.

Specific objectives of project are

1. To get lower temperature around the superconducting leading to efficient thermal management and better utilization of MR project objective0.01. To get lower heat generates from all MRI and enhancement efficiency cooling system avoiding Evaporating helium from system.

2. High efficiency main good imaging.

3. The capability to handle higher peak power load for applications in computed medical imagining system.

**1.4 Background of Invention:**

The present invention relates general to (MRI) systems, and more particularly, to a system for generating a highly uniform static magnetic field. Both the cylindrical or open architecture configuration include as superconducting magnet that generates a temporally constant primary magnetic field. The superconducting magnet resides within a crystal, which cools the superconducting magnet and maintains the operating temperature there of the temperature of the superconductors is maintained at approximately 4 – 10 K for low temperature superconductors, and at approximately 20 – 80 K, for high temperature super conductors.

**1.5 Superconductor specification:**

A superconducting magnet is an electromagnet made from coils of superconducting wire. They must be cooled to cryogenic temperatures during operation. In its superconducting state the wire can conduct much larger electric currents than ordinary wire, creating intense magnetic fields. Superconducting magnets can produce greater magnetic fields than all but the strongest electromagnets and can be cheaper to operate because no energy is dissipated as heat in the windings. They are used in MRI machines in hospitals, and in scientific equipment such as mass spectrometers and particle**.**

Currently, all superconducting magnets use liquid helium to maintain the magnet coils at a temperature enabling superconductivity. The helium and magnet coils are maintained in a vacuum. The temperature of liquid helium is approximately -269 degrees C or 4.17degrees K. Liquid helium will boil at 4.22 degrees K. Any disruption to the temperature or loss of the vacuum will cause the liquid helium within the magnet to "boil off" causing an immediate and sudden loss of the magnetic field. This event is referred to as a "quench". When this occurs, the helium will expand at a rate of approximately 760 to 1.This means that for every liter of liquid helium, 760 liters of gas would be produced.

**Fig (1): Superconductor of MRI.**

**1.6 Development cooling of superconducting and materials.**

Conducts makes its superconducting components from a material called YBCO, mercifully short for yttrium barium copper oxide ($Y_1Ba_2Cu_3O_7$), which was the first superconductor discovered with a critical temperature above 77K--the boiling point of liquid nitrogen. Previous superconductors had required temperatures of a few degrees Kelvin, which could only be achieved with liquid helium--a more expensive fluid. Starting with a sapphire wafer as a substrate, Conducts technicians make the coils using the thin-film deposition and photolithographic processing techniques pioneered in the semiconductor industry. Sapphire is a good heat conductor and is structurally compatible with the YBCO, notes Mann."We operate the superconductors at the temperature of liquid nitrogen (77K) using a closed-cycle system," says Mann. "There's a working fluid--high-pressure helium--that goes through a compressor and is sent through heat exchangers to remove the heat from the wafer." This technique is more beneficial than an open-loop system from a user standpoint, according to Mann, because it's self-contained and the operator doesn't have to replace cryogenic fluid. Mann and Conducts are now working out the packaging issues. The subassembly has to be insulated from the patient, and needs to maintain a vacuum and a very low temperature. "Cry packaging is where the design challenges are," says Mann. "We want to make it easy to use, so all a radiology technician has to do is turn the MRI machine on."In the head and neck," continues Levin, "it's very difficult to position a needle, and it's difficult to see the detail you need on any other imaging modality."In addition to doing preclinical testing, Lewis's team is helping develop the superconducting coils in collaboration with Conducts. So far, they've been imaging phantoms--non-human objects such as fluid-filled beakers--to get the system calibrated to fully take advantage of the signal-to-noise capabilities of the coils.Because of the lack of resistance within the coil windings, you can theoretically have an SNR up to 10 times that of conventional copper coils, says Lewin. "In our setting, it's probably closer to two or three times copper," he notes. "But that still means you can cut your scan time in half or increase your resolution by a factor of two. A small SNR advantage can make a very big difference in imaging--especially in low-field machines."You don't want imaging to take a long time during an interventional procedure," stresses Lew in. "Conventional coil engineers are very happy if they can get a 10 to 15% increase in SNR by a major coil modification. Doubling it is really a huge step. Our hope is that the increased sensitivity will allow us to improve interventional procedures."We've improved the low-field systems almost to the point where the resolution is as good as that of a high-field system--and we should achieve that goal by the end of the year." Look for low-field MRI scanners with superconducting receivers to be available within a year.

An electromagnet whose coils are made of a type II superconductor wire with a high transition temperature and extremely high critical field, such as niobium tin, Nb3Sn; it is capable of generating magnetic fields of 100,000 roasted (8,000,000 amperes per meter) and more with no steady power dissipation. It must be cooled to cryogenic temperatures during operation. In its superconducting state the wire can conduct much larger electric currents than ordinary wire, creating intense magnetic fields. Superconducting magnets can produce greater magnetic fieldsthan all but the strongest electromagnets and can be cheaper to operate because no energy isdissipated as heat in the windings[18].

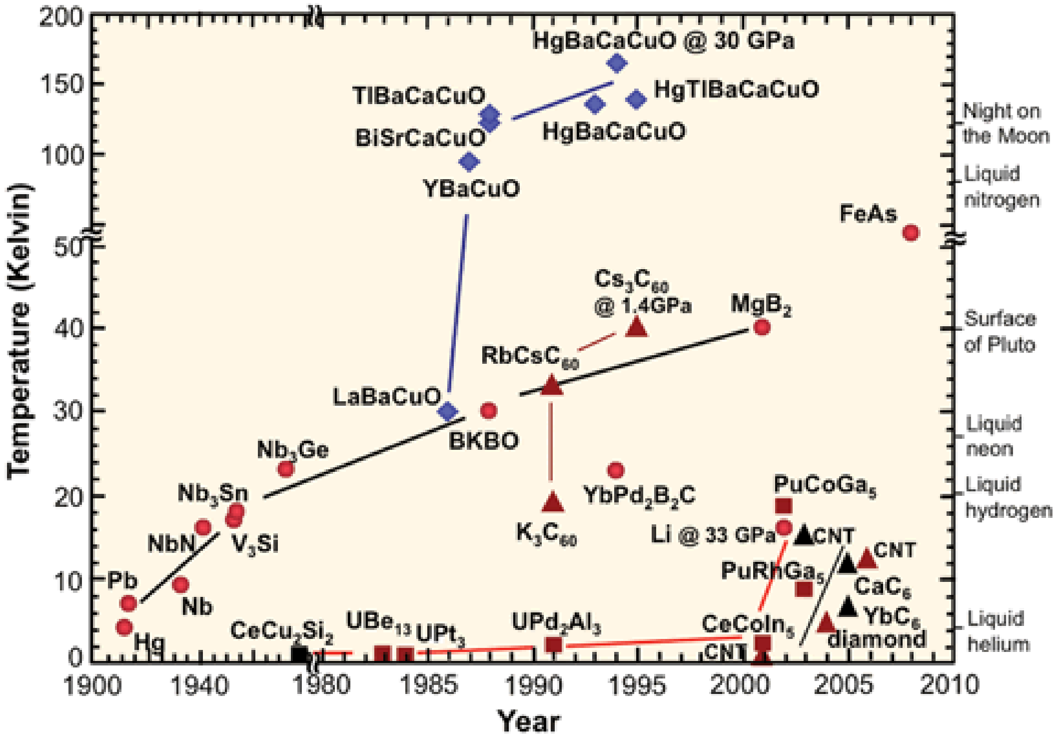



**Fig (2): the Superconductor Material work with Helium.**

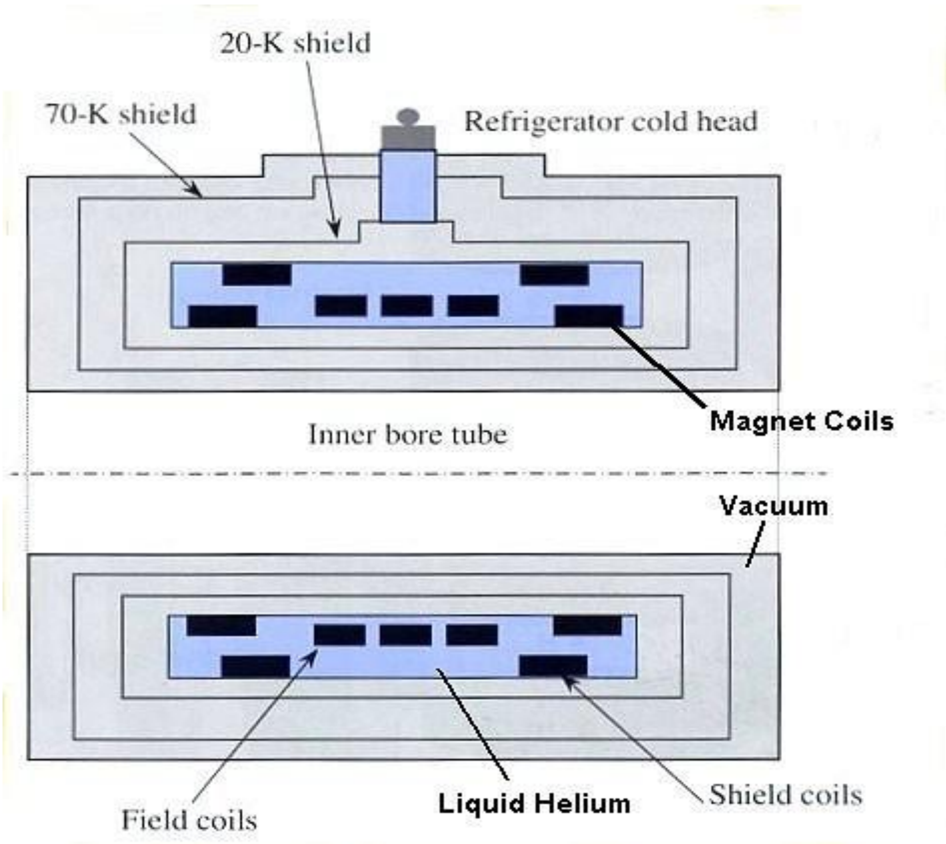



**Fig (3): Side view cross-section of superconductor cooling by liquid helium.**

**Fig (4): Helium working around superconductor when current passes.**

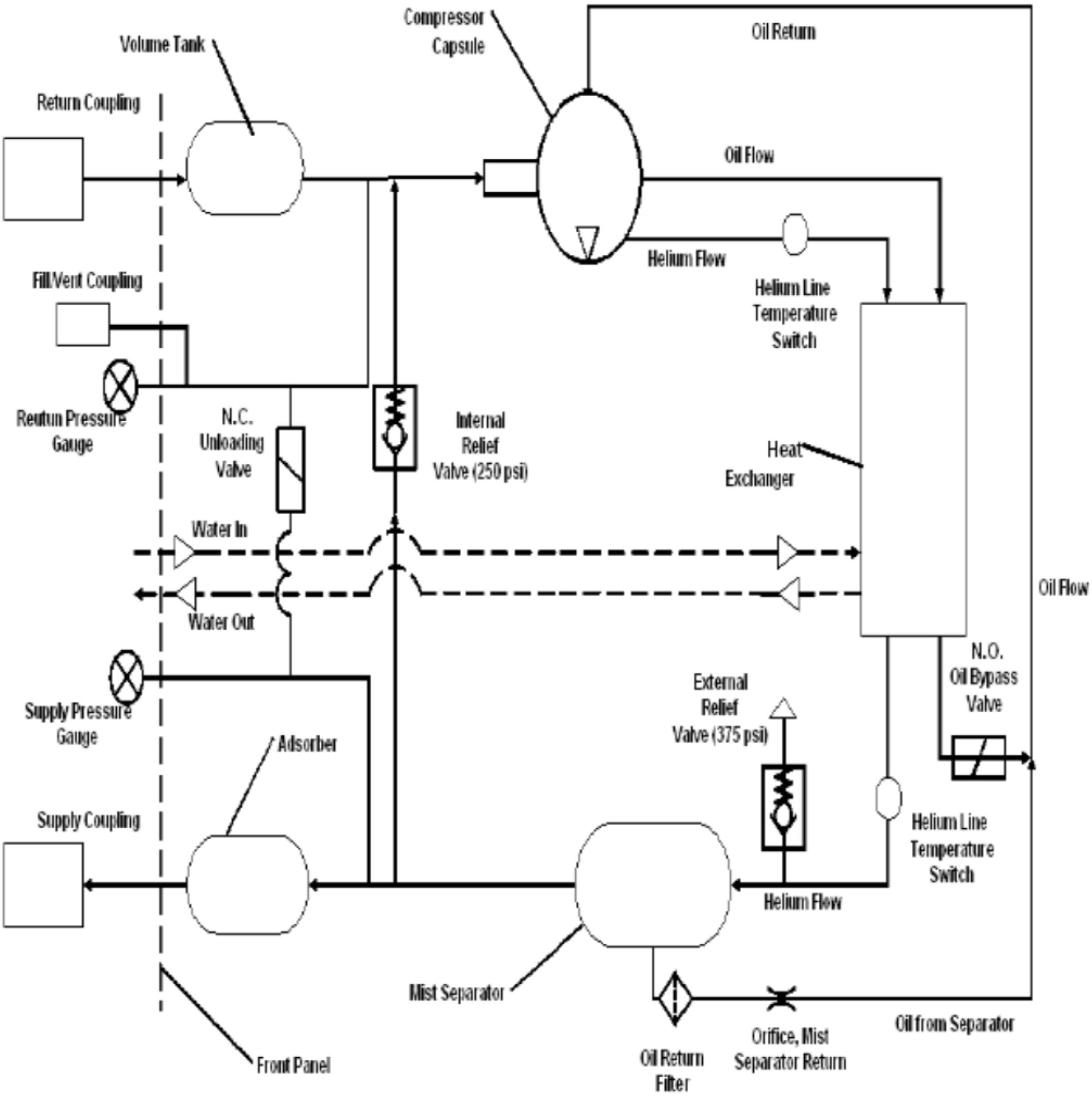



**Fig (5):Diagram of Cooling System in MRI (3T).**

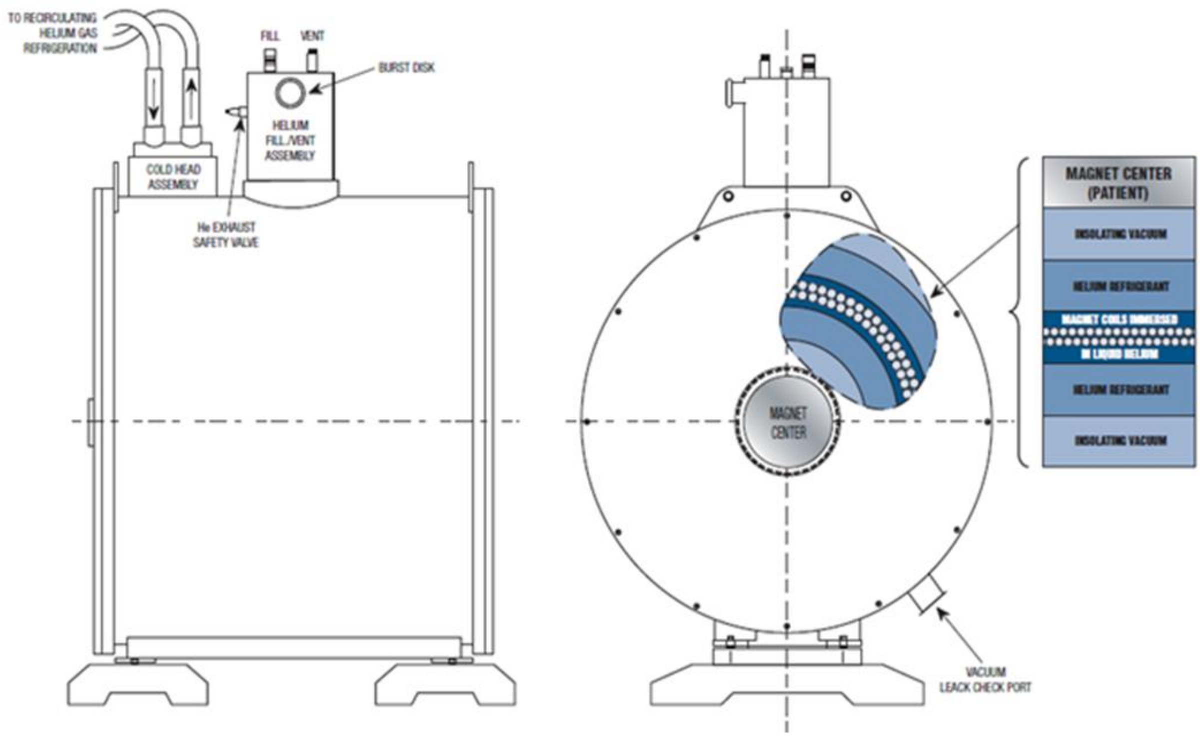



**Fig (6):Explain the Superconductor immerge in Helium Liquid .**

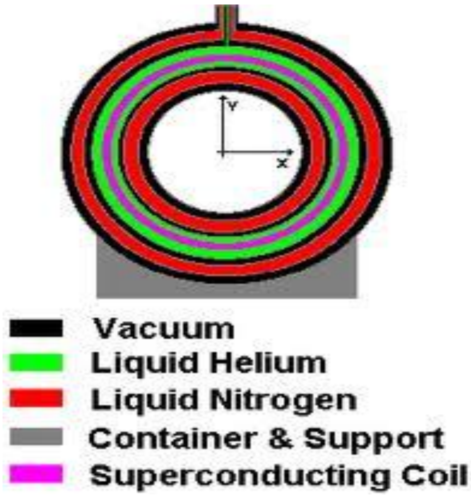



**Fig (7): Front Cross Section for MRI (5T).**

### 1.7Helium Compressor - M600.

High helium compressors are at the heart of the cryogenic pumping system, providing ultra-high purity helium to single or multiple pumps. Completing our offer of cryogenic systems, Austin Scientific offers industry proven compressors, also at highly competitive prices, and with flexible configurations. Based on proven scroll compressor technology, the Austin Scientific M600 air or water cooled helium compressors are highly versatile, with particular focus on ease of installation and maintenance.

**Table(1): Helium compressor technical specification:**

| | |
|---|---|
| **M600 Helium Compressor Technical Specifications** | |
| Helium Flow | 60 SCFM = 0.013Kg/s |
| Static Helium Charge | 240 psi (+/- 5 PSIG) = 1654.741KPa (+/- 34.47 KPaG) |
| Operating Voltage | Power Consumption |
| Recommended Breaker Rating - 30 Amp | 3 Phase 50Hz or 60Hz |
| Low Voltage - 190-260 Vac | 9 kw |
| High Voltage - 345 - 525 Vac | 9 kw |
| **M600W - Water Cooled Helium Compressor** | |
| Minimum required water flow | 1.5 gallons / min = 0.117 Kg/s. |
| Maximum Water Temperature | 297K. |
| Dimensions | H21"x W17.75"x D19.75" |
| Weight | 260 lbs |
| **M600A - Air Cooled Helium Compressor** | |
| Temperature Operating Range | 291K-308K |
| Dimensions | H26"x W17.75"x D32" |
| Weight | 300 lbs |

## 1.8 Chamber room of MRI.

**Fig (8): Camper room of MRI.**

Chamber MRI. For MRI magnets, the magnet room must be large and high enough to accommodate the helium cloud resulting from a quench (loss of superconducting field). During a quench, one half of the helium will boil off and be violently ejected from the helium vent on top of the magnet within one minute. This vapor cloud will seek the highest point in the room as it warms and expands up to 700 times in volume. During the next few minutes the remaining helium will boil off. Nothing can be done to stop a magnet quench once it begins. An MRI magnet room should always be sized so the space between the ceiling and the level of seven feet in the room is large enough to contain the initial volume of helium gas released from a quench. There must be adequate exhaust ventilation in the room of at least 10 air changes per hour.

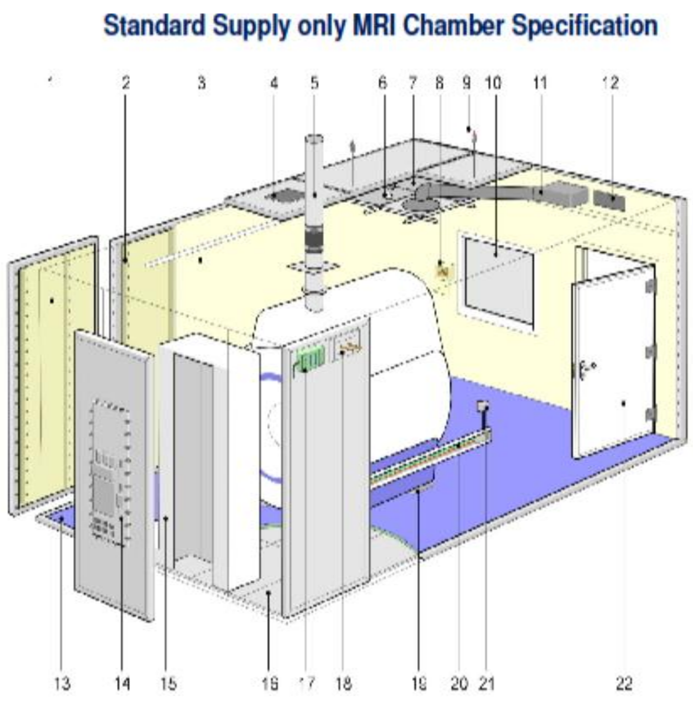



**Fig (9): Camper room technical specification:**

**Item No. Description.**

1. Internal Lining Board.

2..Lining Supports.

3. Decorative Plasterboard linings.

4.Air Vent.

5.RF Penetrations for Quench Pipe.

6. LED Lighting.

7. Suspended ceiling with mineral tiles and aluminum frame.

8. Medical Gases pipe penetrations.

9. Roof Panel supports.

10. RF Shield a window.

11. Plastic A/C Ducting.
12. Air Vent.
13. Vinyl floor finish
14. Blank MRI Filter Panel.
15 Filter Panel Cupboard.
16. RF Shielded Panel.
17. RF Power Filter.
19. Magnet Mounting points.
20 Surface Mounted Bus Bar Conduit.
21 Emergency power 'Off' button**2.**
22 RF Shielded Doors.
Additional Options & Turnkey systems

**1.9 The operation of cooling system:**

Compressor main components andOperation.Model 600 Helium Compressor water-cooled model is designed to run different cry pump or coldhead models from different manufacturers for compatibility information), for either high voltage or low-voltage and 60/50 Hz three-phase (OPs)The compressor itself consists of four main components:

• Compressor capsule.
• Heat exchanger.
• Oil mist (vapor) separator.
• Volume tank.
• Adsorbed.

The compressor unit and the cold head are connected by way of helium gas flex lines. The compressor Unit, cold head and helium lines are fitted with self – sealing couplings, and are charged with ultra-high – purity (99.99%) helium gas. the heat exchanger removes the heat generated from the process. of compressing helium in the capsule. The heat generated by the capsule must be removed from the oil and the helium gas. To remove heat from the compressor capsule, oil is used as lubrication and cooling medium. The helium gas as well as oil, are then pumped by way of differential pressure, out of the capsule through the water-cooled or air-cooled heat exchanger. The cooled oil returns to the capsule to lubricate and cool the capsule. The volume tanks an holding tank that provides additional helium gas volume on the low pressure side of the compressor system. This prevents the low-side pressure from going too low when the compressor is running. The helium gas purifying occurs after the heat removal and cooling process. Helium gas purification must occur because the heat exchanger still has a small amount of oil vapor mixed with the gas. If this helium gas gets to the cry pump with oil vapor in it, the oil will freeze and foul the cry pump. The function of the oil mist (vapor) separatoris to rid the helium gas stream of this oilvapor. The condensate from the oil is then returned to the capsule. The helium gas still contains small quantity of oil vapor at this point. The absorberthen filters out the remaining oil vapor from the helium gas stream. Overtime, the absorber may become saturated from the oil vapor. Thus, it is important the absorber be replaced according to the recommended replacement interval.

Maximum helium flow and minimum water flow for 1.5T .

60.0 stander cubic feet per minute (scfm) = 0.0138 kg/s.

Where s =stander

Minimum required water flow.

1.5 gallons/ min = 0.117kg/s.

0.117kg/s at (291k – 293k) this perfect inlet

Low voltage input

190 - 260VAC _ 9 kw

High voltage input

345 – 525 VAC  _ 9 KW

Consumption

9 KW     3 phase 50 or 60 HZ

1 ton = 3.517 KW

1.055 KW = 1 BTU/S

1 gallon/m = 4.546 l/m

P1 = 50 ~ 60 psi = 344.74 ~ 413.67KPa .

P2 = 250 ~ 260Psi = 1723.79 ~ 1792.64KPa .

First, the liquidhelium needs to be refilled on a periodic basis (anywhere from every 2 to 4 months). This is avery sophisticated technique, and doing it wrong can result in allowing room-temperature air gointo the helium area, which will rapidly boil the liquid helium. This can build up enough pressure to initiate a quench. The second is the result of not maintaining the liquid nitrogen, which typically needs to be refilled every week [19].

In this model, blocks representing components of a MRI cooling system are implemented. A fixed displacement pump linked to a shaft drives coolant through the circuit. Heat from the engine, where pistons are cooled, is dissipated through the radiator. The system temperature is controlled by the thermostat-regulated path via the radiator. REFPROP from NIST was used to populate the fluid property data in the Fluid Properties block following figures are showing the different variations of controlled temperature for this system of MRI Above results shows, how the temperature of MRI based cooling system is controlled during the entire simulation time. Here three kinds of results we have measured for this temperature control. As we have presented cooling system in which the components such as Helium, nitrogen, with water chillier and high control system consisted of PC, custom servo board driver, piezoelectric valves, and sensors etc. are used to model the cooling system as showing in above The motives and goals for this thesis to develop and enhancement cooling system in MRI.

The specific goals of the current work are:

- Enhance efficiency cooling system in MRI.
- Suggesting the type of chiller compatible to the ambient temperature.
- Suggesting the pipe length suitable for ambient temperature.
- Analysis the effect of fins onheat transfer and pumping power and energy.

**Work scope:**

The organization of the work done in this project is follows:

Project literature is given under chapter 2, chapter 3 is devoted to computational method .Results and discussions are present in chapter 4. Finally some conclusions is presented in chapter 5.

# Chapter 2

## 2.1. Literature Review -Heat Exchanger:

Heat exchangers are equipment which transfers the heat from a fluid to another for thermal processes in which two fluids have different temperatures. The steady state heat exchanger is well defined and discussed in many literatures,NOOR.U.B [4,5,6,7,8]. The steady state solution are commonly divided in to two methods, the first method named “Log Mean Temperature Difference (LMTD)”, this method is applied when the inlet and outlet temperatures `know. These methods are widely discussed in many literature and textbooks.

If cold inlet air considerable below the freezing point is preheated using a heat exchanger, ice formation on the extracted airside will normally occur within a few hours, depending on the efficiency of the heat exchanger. The problem with ice formation in the heat exchanger for ventilation systems in cold climates is recognized, but only the preheating of the supply air is discussed as a possible solution, and rejected due to the findings that suggest that this solution significantly reduces the recovered energy. In new buildings, preheating the inlet air
Above 0 8C with heating panels often solves the ice and draft problem but, as mentioned earlier, this solution uses a lot of extra energy. The ice problem is not only seen in arctic climates, but also in places where the outside temperature for long periods stays a few degrees below the freezing point.

J. Kragh et al [9] are looked into the new heat exchanger’s efficiency theoretically and measured experimentally. The experiment shows that the heat exchanger is capable of continuously defrosting itself at outside air temperatures well below the freezing point while still maintaining a very high efficiency. They showed the construction and test of a efficient counter flow heat exchanger capable of continuously defrosting itself without using supplement heating.
The glycol–water blend will also contain inhibitors to protect the metals in the heat exchangers fromcorrosion.Inhibitors can be of many different forms including organic and inorganic chemicals, but they are designed to workin a water solution. Generally speaking, the addition of water activates the inhibitors, allowing them to protect the metals.One important function of the glycol–water blend is to protect the heat exchange system from freezing in coldweather. Pure propylene glycol does not freeze, but ratherexperiences a chemical phenomenon known as supercoolingMurthy SSN [10].The glycol–water blends are usually highly viscous at low temperatures. In thin walled concentric tube heat exchangersglycol–water blends flow through

the inner tube and are heated by warm water flowing in the annulus. In this case,for cold weather.Interior roughness increases heat transfer by perturbing the flow in layers adjacent to the inner tube wall. However, thisperturbation in the fluid flow would result in an increase of pressure drop which may be undesirable. Recently, heat transfer and pressure drop for flow of glycol–water blends in helically dimpled tubes were examined experimentally by Vicente et al [11].forced convection heat and mass transfer in a conduit with neglecting the effect ofaxial conduction is known. Dealing with multistream or multiphase problems coupling through conjugated conduction–convection conditions.. Applications of the recycle-effect concept in the design and operation of the equipment with external or internal refluxes can effectively enhance the effect on heat andmass transfer, leading to improved performance in separation processes andreactor designs. Heat transfer through double-pass concentric circular tubes with an impermeable sheet of negligible thermal resistance have been investigated and solved analytically by the use of the orthogonal expansion technique with the Eigen function expanding in terms of an extended power series. The method for improving the performance in a concentric circular double-pass heat exchanger is presented in this study. Application of the recycle-effect concept in designing a double-pass heat exchanger is technically and economically feasible. Moreover, further improvement in transfer efficiency may be obtained.

## 2.2. HeatExchangerCounter Flow

Heat exchangers are a device that exchanges the heat between two fluids of different temperatures that are separated by a solid wall. The temperature gradient, or the differences in temperature facilitate this transfer of heat. Transfer of heat happens by three principle means: radiation, conduction and convection. In the use of heat exchangers radiation does take place. However, in comparison to conduction and convection, radiation does not play a major role. Conduction occurs as the heat from the higher temperature fluid passes through the solid wall. To maximize the heat transfer, the wall should be thin and made of a very conductive material. The biggest contribution to heat transfer in a heat exchanger is made through convection.Heat exchangers, as the name implies, transfer heat from one substance to another. A heatexchanger is a heat transfer device that exchanges heat between two or more process fluids. Heat exchangers have widespread industrial and domestic applications and in the process industry for the recovery of the heat. They are an essential component in thermal power system, refrigeration system, and other cooling system. In all these systems, heat is transfer from one fluid to other. The countercurrent heat exchanger is most favorite because it is gives maximum rate of heat transfer for a given surface area In many thermal equipment's design are based on the steady state in calculation of the characteristic variable. Many applications require knowledge of the transient behavior of the thermal devices. In fact, it is necessary to explore the unsteady state of thermal properties whenthe real time control, state computation, optimization, and rational use of energy are investigated.In additional, the unsteady state gives more details and information than steady state & alsogives indication to validity of the steady state assumption. The steady state heat exchanger is well defined and discussed in many literatures, The steady state solution are commonly divided in to two methods, the first method named “LogMean Temperature Difference (LMTD)”, this method is applied when the inlet & outlettemperatures are knowing.this method is based on calculation of maximum heat transfer rate .indicate anew steady state formulation for countercurrent double pipe heat exchangerwith constant parameter experimentally.In our study , we analyzed countercurrent heat exchanger which used to cool a hot fluid (flowinside tube) by a cooled fluid (flow inside the annulus area). The finite difference techniques was used to solve the unsteady state countercurrent double pipe heat exchanger differential equations, The variable specific heat coefficient with temperature was taken in account during the present analysis.

**2.3.Analytical Analysis**

The assumptions that used in the theoretical analysis of countercurrent double pipe heat Exchanger is following:

1- There is no phase change for the hot and cold fluids during the heat exchanger pipes.
2- Hot and cold fluids are incompressible and turbulent in flow.

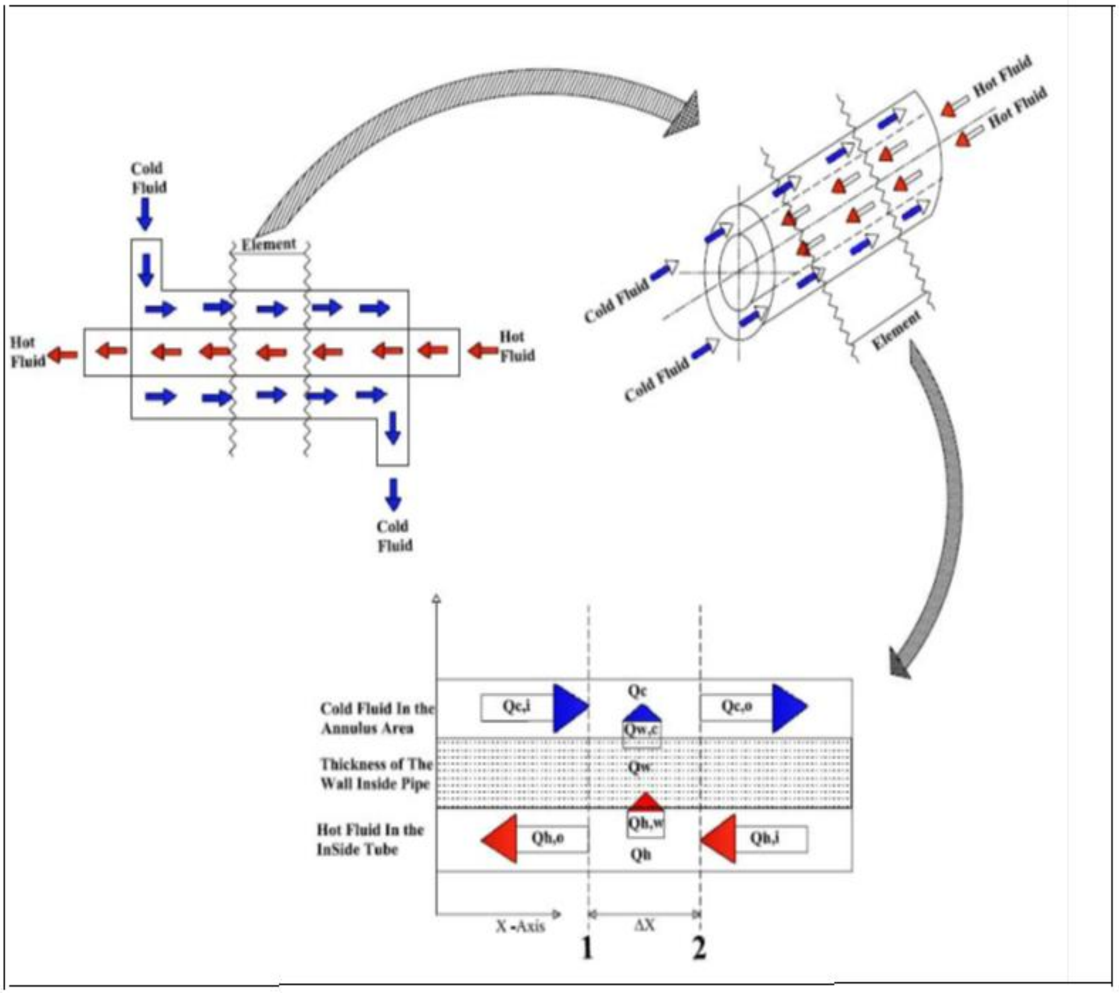
3- The axial heat conduction inside the tubes wall is negligible ( the convection resistance istoo high compared with conduction resistance).

4- The hot, cold fluids and the pipe wall temperature subject to unsteady state behavior.

5- The specific heat coefficient is variable with temperature.

6- The hot fluid flow inside the inner pipe and the cold fluid flow inoutlet firstpipes.

In order to derive the governor differential equations, the heat exchanger is subdivided in to manyelements volumes of length (Δx) as shown in fig (2). The hot fluid flows through the elementvolume transfer heat to the wall by convection, resulting in reduction in the outlet enthalpy and eternal stored thermal energy.Energy balance applied to the differential volume of the hot fluid leads to the first equation in thesystem. Similar energy balance is applied for the cold fluid and separation cylinder wall. The energy balance for the hot,cold fuel and for separation wall was done as following:




**Fig(10): Schematic of Double Pipe Heat Exchanger.**

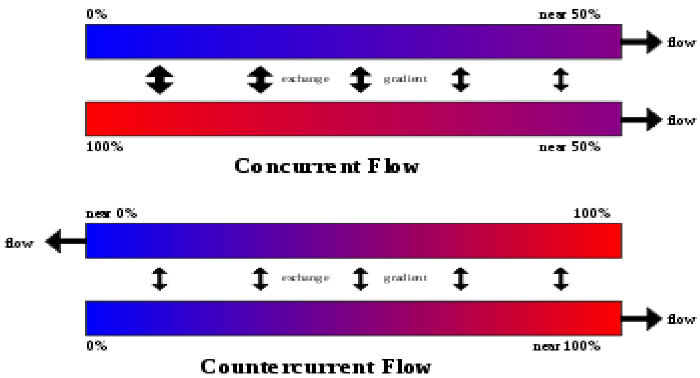
can be co-current or counter-current. There are two flow configurations: co-current is when the flow of the two streams is in the same direction, counter current is when the flow of the streams is in opposite directions.As conditions in the pipes change: inlet temperatures, flow rates, fluid properties, fluid composition, etc., the amount of heat transferred also changes. This transient behavior leads to 2 change in process temperatures, which will lead to a point where the temperature In a heat exchanger forced convection allows for the transfer of heat of one moving stream to another moving stream. With convection as heat is transferred through the pipe wall it is mixed into the stream and the flow of the stream removes the transferred heat. This maintains a temperature gradient between the two fluids.The double-pipe heat exchanger is one of the simplest types of heat exchangers. It is called a double-pipe exchanger because one fluid flows inside a pipe and the other fluid flows between that pipe and another pipe that surrounds the first. This is a concentric tube construction. Flow in a double-pipe heat exchanger.

## 2.4. Theory Double –Pipe Heat Exchanger.

The theory behind the operation of a double-pipe heat exchanger is covered in Incorporate and Dewitt (1996). Also in this same textbook is the derivation of how transient behavior is treated with respect to heat transfer. As with any process the analysis of a heat exchanger begins with an energy and material balance. Before doing a complete energy balance a few assumptions can be made. The first assumption is that the energy lost to the surroundings from the cooling water or from the U-bends in the inner pipe to the surroundings is negligible. We also assume negligible potential or kinetic energy changes and constant physical properties such as specific heats and density. These assumptions also simplify the basic heat-exchanger equations. Temperature can be defined as the amount of energy that a substance has. Heat exchangers are used to transfer that energy from one substance to another. In process units it is necessary to control the temperature of incoming and outgoing streams. These streams can either be gases or liquids. Heat exchangers raise or lower the temperature of these streams by transferring heat to or from the stream.

**Fig(11): Heat Exchanger Shall –Tube andDouble Pipe.**

**Flow arrangements**




**Fig(13) : Two types from heat exchanger.**

There are three main types of flows in a spiral heat exchanger:

## 2.5 Counter-Current Flow

Fluids flow in opposite directions. These are used for liquid-liquid, condensing and gas cooling applications. Units are usually mounted vertically when condensing vapor and mounted horizontally when handling high concentrations of solids.

## 2.6 Construction features

- The counter flow double pipe design configuration allows heat pipe heat exchangers to recover more energy from hot to cold fluid under ideal conditions. However, the most economical heat exchanger system performance in installed double pipes.
- Performance Flexibility the large selection lengths and types can be design are available for required energy recovery performance.
- Quality Assurance subjected to a rigorous quality assurance process to ensure structural integrity and conformance with design requirements.
- Individual Heat Pipes this means greater reliability in performance, since failure of one heat pipe has little effect on the overall performance of the heat exchanger.

## 2.7 Transition temperatures

It was realized from the start that practical applications of superconductivity could become much more widespread if a high-temperature superconductor, that is, one with a high *Tc*, could be found. For instance, the only practical way to cool superconductors with transition temperatures below 20 K (−424°F) is to use liquid helium, which boils at a temperature of 4.2 K (−452°F) and which is rather expensive. On the other hand, a superconductor with a transition temperature of100 K (−280°F) could be cooled with liquid nitrogen, which boils at 77 K (−321°F) and which is roughly 500 times less expensive than liquid helium. Another advantage of a high-*Tc* material is that, since many of the other superconducting properties are proportional to *Tc*, such a material would have enhanced properties. In 1986 the discovery of transition temperatures possibly a sigh as 30 K (−406°F) was reported in a compound containing barium, lanthanum, copper, and oxygen. In 1987 a compound of yttrium, barium, copper, and oxygen was shown to be superconducting above 90 K (−298°F). In 1988 researchers showed that a bismuth, strontium, calcium, copper, and oxygen compound was superconducting below 110 K (−262°F), and transition temperatures as high as 135 K (−216°F) were found in a mercury, thallium, barium, calcium, copper, and oxygen compound.

### 2.8 Thermal properties

The appearance of the superconducting state is accompanied by rather drastic changes in both the thermodynamic equilibrium and thermal transport properties of a superconductor. The heat capacity of a superconducting material is quite different in the normal and superconducting states. In the normal state (produced at temperatures below the transition temperature by applying a magnetic field greater than the critical field), the heat capacity is determined primarily by the normal electrons (with a small contribution from the thermal vibrations of the crystal lattice) and is nearly proportional to the temperature. In zero applied magnetic fields, there appears a discontinuity in the heat capacity at the transition temperature Attemperatures just below the transition temperature; the heat capacity is larger than in the normal state. It decreases more rapidly with decreasing temperature, however, and at temperatures well below the transition temperature varies exponentially as $e{-}\Delta/kT$, where $\Delta$ is a constant and $k$ is Boltzmann's constant. Such exponential temperature dependence is a hallmark of a system with a gap $\Delta$ in the spectrum of allowed energy states. Heat capacity measurements provided the first indications of such a gap in superconductors, and one of the key features of the macro scope BCS theory is its prediction of just such a gap. Ordinarily a large electrical conductivity is accompanied by a large thermal conductivity, as in the case of copper, used in electrical wiring and cooking pans. However, the thermal conductivity of a pure superconductor is less in the superconducting state than in the normal state, and at very low temperatures approaches zero. Crudely speaking, the explanation for the association of infinite electrical conductivity with vanishing thermal conductivity is that the transport of heat requires the transport of disorder (entropy). The superconducting state is one of perfect order (zero entropy), and so there is no disorder to transport and therefore no thermal conductivity.

### 2.9 Occurrence

Some 29 metallic elements are known to be superconductors in their normal form and another17 become superconducting under pressure or when prepared in the form of thin films. The number of known superconducting compounds and alloys runs into the thousands.

Superconductivity is thus a rather common characteristic of metallic conductors. The phenomenon also spans an extremely large temperature range. Rhodium is the element with the lowest transition temperature (370 μK), while Hg0.2Tl0.8Ca2Ba2Cu3O is the compound with the highest (135 K or −216°F).Despite the existence of a successful microscopic theory of superconductivity, there are no completely reliable rules for predicting whether a metal will be a superconductor. Certain trends and correlations are apparent among the known superconductors, however—some with obviousbases in the theory—and these provide empirical guidelines in the search for newsuperconductors. Superconductors with relatively high transition temperatures tend to be rather poor conductors in the normal state.The ordered superconducting state appears to be incompatible with any long-range-ordered

.

**2.10 Two-fluid model**

C. J. Garter and H. B. G. Casmir introduced in 1934 [7] a phenomenological theory of superconductivity based on the assumption that in the superconducting state there are two components of the conduction electron "fluid" (hence the name given this theory, the two-fluid model). One, called the super fluid component, is an ordered condensed state with zero entropy; hence it is incapable of transporting heat. It does not interact with the background crystal lattice, its imperfections, or the other conduction electron component and exhibits no resistance to flow. The other component, the normal component, is composed of electrons which behave exactly as they do in the normal state. It is further assumed that the superconducting transition is are visible thermodynamic phase transition between two thermodynamically stable phases, the normal state and the superconducting state, similar to the transition between the liquid and vapor phases of any substance. The validity of this assumption is strongly supported by the existence of the Meissen-Cohen field effect and by other experimental evidence. This assumption permits the application of all the powerful and general machinery of the theory of equilibrium thermodynamics. The results tie together the observed thermodynamic properties of superconductors in a very satisfying way.

**2.11 Cooling properties.**

During operation, the magnet windings must be cooled below their critical temperature; the temperature at which the winding material changes from the normal resistive state and becomes a superconductor. Liquid helium is used as a coolant for most superconductive windings, even those with critical temperatures far above its boiling point of 4.2 K. This is because the lower the temperature, the better superconductive windings work—the higher the currents and magnetic fields they can stand without returning to their non upper conductive state. The magnet and coolant are contained in a thermally insulated container (Dewar) called a cryostat. To keep the helium from boiling away, the cryostat is usually constructed with an outer jacket containing (significantly cheaper) liquid nitrogen at 77 K. One of the goals of the search for high temperature superconductors is to build magnets that can be cooled by liquid nitrogen alone. At temperatures above about 20 K cooling can be achieved without boiling off cryogenic liquids. the maximum magnetic field achievable in a superconducting magnet is limited by the field at which the winding material ceases to be superconducting, its 'critical field', Hc, which for type-II superconductors is its upper critical field. Another limiting factor is the 'critical current'; I cat which the winding material also ceases to be superconducting. Advances in magnets have focused on creating better winding materials. The superconducting portions of most current magnets are composed of niobium-titanium.[9] This material has critical temperature of 10 K and can superconductor at up to about 15 Tesla. More expensive magnets can be made of niobium-tin (Nb3Sn). These have a Tcof 18 K. operating at 4.2 K they are able to withstand a much higher magnetic field intensity, up to 25 to30 Tesla. Unfortunately, it is far more difficult to make the required filaments from this material. This is why sometimes a combination of Nb3Sn for the high field sections and Nb3Ti for the lower field sections is used. Vanadium-gallium is another material used for the high field [9] inserts. High temperature superconductors (e.g. BSCCO or YBCO) may be used for high-field inserts when magnetic fields are required which are higher than Nb3Sncan managed. BSCCO, YBCO or magnesium debride may also be used for current leads, conducting high currents from room temperature into the cold magnet without an accompanying large heat leak from resistive leads. The coil windings of a superconducting magnet are made of wires or tapes of Type II superconductors (e.g. niobium-titanium or niobium-tin). The wire or tape itself may be made of tiny filaments (about 20 micrometers thick) of superconductor in a copper matrix. The copper isneeded to add mechanical stability, and to provide a low resistance path for the large currents incase the temperature rises above *T*c or the current rises above *I*c and superconductivity is lost. These filaments need to be this small because in this type of superconductor the current only flows skin-deep.The coil must be carefully designed to withstand (or counteract) magnetic pressure and Lorentz forces that could otherwise cause wire fracture or crushing of insulation between adjacent turns. magnetic field. The advantage of these persistent modes that stability of the magnetic field is better than is achievable with the best power supplies, and no energy is needed to power the windings. The short circuit is made by a 'persistent switch', a piece of superconductor inside the magnet connected across the winding ends, attached to a small heater. In normal mode, the switch wire is heated above its transition temperature, so it is resistive. Since the winding itself has no resistance, no current flows through the switch wire. To go to persistent mode, the current is adjusted until the desired magnetic field is obtained, then the heater is turned off. The persistent switch cools to its superconducting temperature, short circuiting the windings. The current and the magnetic field will not actually persist forever, but will decay slowly according to a normal L/R time constant:

where is a small residual resistance in the superconducting windings due to joints or a phenomenon called flux motion resistance. Nearly all commercial superconducting magnets are equipped with persistent switches. Although the idea of making electromagnets with superconducting wire was proposed by Heike Kimberling Ones shortly after he discovered superconductivity in 1911, a practical superconducting electromagnet had to await the discovery of type-II superconductors that could stand high magnetic fields. The first successful superconducting magnet was built by George Yenta in 1954 using niobium wire and achieved a field of 0.71 T at 4.2 K.[10] Widespread interest was sparked by Kunstler's 1961 discovery of the advantages of niobium-tin as a high *Hc*, high current winding material.[11]In 1986, the discovery of high temperature superconductors by Georg Bednorz and Karl Muller energized the field, raising the possibility of magnets that could be cooled by liquid nitrogen instead of the more difficult to work with helium. In 2007 a magnet with windings of YBCO achieved a world record field of 26.8 Tesla.[12] Thus National Research Council has a goal of creating a 30 tesla superconducting magnet.

Superconducting magnets have a number of advantages over resistive electromagnets. They can achieve an order of magnitude stronger field than ordinary ferromagnetic-core electromagnets, which are limited to fields of around 2 T. The field is generally more stable, resulting in less noisy measurements. They can be smaller, and the area at the center of the magnet where the field is created is empty rather than being occupied by an iron core. Most importantly, for large magnets they can consume much less power. In the persistent state (above), the only power the magnet consumes is that needed for any refrigeration equipment to preserve the cryogenic temperature. Higher fields however can be achieved with special cooled resistive electromagnets, as superconducting coils will enter the normal (non-superconducting) at high fields. Superconducting magnets are widely used in MRI machines, NMR equipment, mass spectrometers, magnetic separation processes, and particle accelerators. One of the most challenging use of SC magnets is in the LHC particle accelerator. [13] The niobium-titanium (Nb-Ti) magnets operate at 1.9 K to allow them to run safely at 8.3 T. Each magnet stores 7 MJ. In total the magnets store 10.4 GJ. Once or twice a day, as the protons are accelerated from 450 GeV to 7 TeV, the field of the superconducting bending magnets will be increased from 0.54 T to 8.3 T. The central solenoid and to radial field superconducting magnets designed for the ITER fusion reactor use niobium-tin (Nb3Sn) as a superconductor. The Central Solenoid coil will carry 46 kA and produce a field of 13.5 Tesla. The 18 To radial Field coils at max field of 11.8 T will store 41GJ. They have been tested at a record 80 kA. Other lower field ITER magnets (PF and CC) will use niobium-titanium. Most of the ITER magnets will have their field varied many times per hour. One high resolution mass spectrometer is planned to use a 21 Tesla SC magnet.[14]

A quench is an escalating reaction to heat. It causes the cryogens to boil off rapidly, which in turn causes the loss of the static magnetic field. This process takes approximately two minutes

[15].Once a superconducting magnet is ramped up and fully magnetized, it literally takes no additional current or power to keep the magnet going. There's zero resistance -- that's the “superconducting" part -- so the current flowing in the magnet coils will run forever. That is, forever if the liquid helium cooling the magnet is kept cold enough, which is quite close to absolute zero? If the cooling system goes on the fritz, the magnet starts to develop resistance, which causes heat, which causes more resistance, and more heat, and so on until all the liquid helium gets hot enough to become a gas, which then erupts in a jet-engine-sounding event known as a quench [16]

**2.12 Operation flow**

The work flow of helium gas within the compressor follows these steps:

1. High-pressure helium gas is delivered from the compressor to the cold head through the "Supply" helium flex line at 1723.79~1792.64KPa.
2. The helium gas is then compressed during the compression stroke of the cry pump.
3. The cry pump then expands the helium gas during its expansion stroke. During this cycle of compression and expansion of the cry pump, the helium gas is forced through regeneration materials to increase the thermodynamic efficiency of the cycle.
4. With each successive cycle, the regeneration material becomes colder and colder. Eventually, the cry pump temperatures come down to cryogenic range.
5. After expansion, the helium gas returns to the compressor through the "Return" helium flex line at 344.74~413.67KPa to begin the cycle again. The helium flow between the Model 600 compressor’s components is illustrated in for the water-cooled version of the Model 600 compressor [8]. During operation, the magnet windings must be cooled below their critical temperature, the temperature at which the winding material changes from the normal resistive state and becomes a superconductor. Liquid helium is used as a coolant for most superconductive windings, even those with critical temperatures far above its boiling point of 4.2 K. This is because the lower the temperature, the better superconductive windings work—the higher the currents and magnetic fields they can stand without returning to their non-superconductive state. The magnet and coolant are contained in a thermally insulated container (dewar) called a cryostat. To keep the helium from boiling away, the cryostat is usually constructed with an outer jacket containing (significantly cheaper)

Liquid nitrogen at 77K. One of the goals of the search for high temperature superconductors is to build magnets that can be cooled by liquid nitrogen alone. At temperatures above about 20 K cooling can be achieved without boiling off cryogenic liquids.[citation needed].[3]

Referring now to a second MRI system having a static magnet structure that incorporates use of the field-shaping coils and uses conduction or convection cooling in accordance with an embodiment of the present invention is shown. The field-shaping coils, instead of multiple cooling tubes. The cooling tubes are coupled to the cry cooler. coolant within the cooling tubes, circulates between the former and the cry cooler .Thermal energy within the field-shaping coils is transferred to the coolant .The cooling tubes may be formed of stainless steel, a composite material, or some other low conductive or eddy current free material. Referring now to a cross-sectional current area plot of a superconducting magnet structure and imaging volume for a typical 1.5 Tesla MRI system having a cylindrical architecture is shown. The vertical axis is theradius R in centimeters and the horizontal axis is Z also in centimeters .The size of the superconducting magnet structure is approximately 118,562 cubic centimeters, which provides the desired uniformity of static magnetic field. The positive areas correspond to positive current areas of the superconducting coils of the superconducting magnet structure. The negative areas correspond to negative current areas of the superconducting coils of the superconducting magnet structure. The positive areas and the negative areas are directly proportional to electromagnetic forces generated therein. The polygon ally shaped area represents the gradient coils. The amount of current passing through the superconducting coils, represented by areas and is Undesirable and the size of the superconducting magnet structure is infeasible to manufacture. a cross-sectional current area plot of the superconducting magnet structure and imaging volume of in accordance with an embodiment of the present invention is shown. In comparison to the superconducting magnet structure the field-shaping coils and the superconducting field coils of the superconducting magnet structure are significantly smaller. The positive areas correspond to positive current areas of the field-shaping coils and the superconducting coils, respectively. The negative areas correspond to the negative current areas of the field- shaping coils and the superconducting coils, respectively. The polytonally shaped area presents the gradient coils .Notice the reduced size in the positive areas and the negative areas and thus the reduced electromagnetic forces of the superconducting coils, as compared to the coils represented by areas. Also, the field- At least one gradient shield coil, and At least one static field-shaping coil residing between said at least one gradient shield coil and said patient bore enclosure and supplementing said static magnetic field. A system as in claim 1 wherein said at least one superconducting magnet resides within a cryostat having at least one thermal shield, said at least one static field-shaping coil resides between said at least one thermal shield and said patient bore enclosure.[8]

**2.13Properties of cryogenic fluids used of MRI cooling.**

Boiling temperatures at atmospheric pressure.

Nitrogen: 77.3 K.

Density: slightly less than water:

800 g/liter at 77 K .

Heat of evaporation:

1 watt evaporates 22,6 cm^3/hour liquid (Lvap=199 j/g).

Liquid Nitrogen.

Thermal conductivity issimilar to that of an insulator.

comparable to Teflon at 300 K , 1000 times less than Copper.

K = 1, 38 mW/cm.K.

Viscosity: small.

1500 micro poises.

7 times less than water.

Helium

4He = abundant.

- 2 stable isotopes :

3He = rare and expensive .

Helium 4 gas

World consumption = 35 millions of m 3/year.

Rate gas – price ~ 8 Euros/m.

One exception : helium

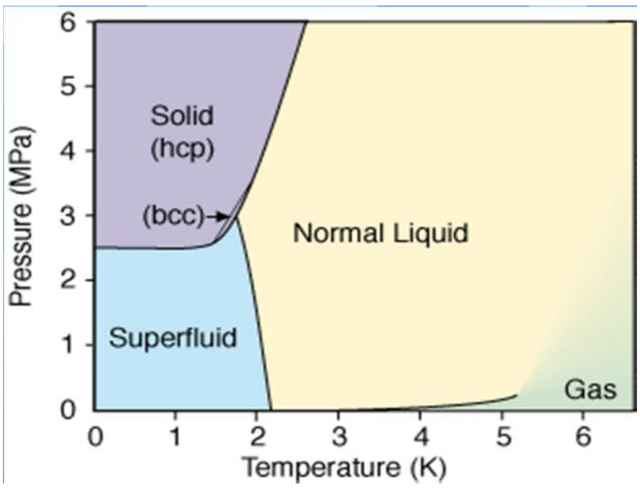



**Fig (16):Helium phases.**

Liquid4Helium:

Boiling temperature atmospheric pressure 4,2 K.

Density = 0.43 at 4,2 K.

Heat of evaporation :

Lvap = 20,9 J/g . very low.

1 watt evaporates 1400 cm^3/hour liquid (65 times more than nitrogen).

correspondence liquid/gas

1 L liquid – 750 L gas NTP triple.

3Helium  3,2K.

* Very expensive: Price ~ 3000 Euros (2011)/liter of gas NTP[7][8].

THE PROPERTIES OF GLYCOL C2H6O2**:**

Boiling temperature atmospheric pressure,in475 K.

Frees temperature atmospheric pressure, in -13K.

No effect on ozone layer.

No effect on health.

**2.14. Time perfect to work cooling system MRI.**

The typical switching time between magnetic field levels is 30-40 ms, which is significantly shorter than the $T_1$ relaxation times in most biological samples or in the human body.(MRI) systems, and more particularly, to a system for generating a highly uniform static magnetic field. Both the cylindrical or open architecture configuration include as superconducting magnet that generates a temporally constant primary magnetic field. The superconducting magnet resides within a crystal , which cools the superconducting magnet  and maintains the operating temperature thereof . the temperature of the superconductors is maintained at approximately 4–10Kforlowtemperaturesuperconductors, and at approximately20–80K.for high temperature superconductors. the cryostat is typically contained within several thermal shields.For high Tesla the superconducting coil workingbetween in low temperature (4k – 8k) and in high temperature (20K – 80K).below we will detailing explain the parts system in this case and how working also will interest  only in this typeof MRI because it complexand very important in more application not only in medical.

# Chapter 3

### 3.1. Computational Model.

A pipe with Helium flowing at a known mass flow rate, inlet temperature and wall temperature is considered for simulation.

#### 3.1.1. Finite Element Simulation

The Finite element analysis (FEA) is a computing technique that is used to obtain approximant solutions to the boundary value problem in engineering.In this problem it used to obtain temperature for fluid in side pipe as showed in fig (17).

Problem Description:

Ex:Given: Helium at 330K flowing in pipe $D_i$ = 0.0381m, $D_o$ = 0.04m,and length = 1m and mass flow 0.03kg/s ,$h_h$= 471 W/$m^2$.K.

Find change temperature relation to length of pipe and temperature ambientaround pipes using ANSYS and comparison with the standard results.

Mesh: SizeHex( 3*3*3)mm

Boundary Conditions:$T_{h,i}$=330K(inlet temperature) and $T_b$ = 288K (wall temperature).

Simulation Model

| Geometry | Properties Fluid.(helium) | Boundary Conditions |
|---|---|---|
| $D_i$ =0.0381m<br>$D_o$ = 0.0399m<br>L =1m<br>Mesh volumes<br>Shape Hex / wedge<br>3*3*3mm | ṁ= 0.03 kg/s<br>$C_p$ = 5193 KJ/ kg.K<br>h = 471 W/$m^2$.K | Tb =288K<br>Th,i=330K |

Heat Transfer Calculation by Semi-Analytical Method:

From the mass flow rate, the velocity is obtained as

$V = \dot{m} / \rho \times A_c$

V = 0.03*4/0.1615*π*0.038^2 = 163 m/s

This results in a Re given as

Re = VD / υ ……………………………………………………………………………..……..(1)

Using Dittus – Boelter equation:

Nu = 0.023 (Re)^0.8 (Pr)^0.4………………………………………………………….…………(2)

For gas

$Nu = 0.023 (Re)^{0.8} (Pr)^{0.33}$……………………………………………………………….……………(3)

Where :

$Re = VD/v$

$Re = 163 * 0.038 / 122*10^{-6} = 50749.6$

For gas

$Nu = 0.023 ( Re)^{0.8} ( Pr )^{0.33}$

$Nu = 0.023(50749.6)^{0.8} (0.68)^{0.33} = 117$

$h_i D_i/k = 117$

$h_i = 117 \times 15./0.038 = 471$ W/m^2.K

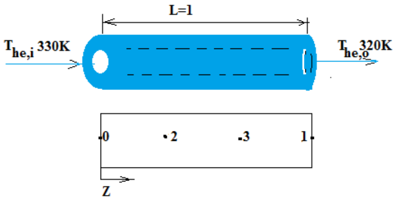
When use:

The inlet temperature of He is

$T_{h,i} = 330$ °C

The wall temperature is

$T_b = 15 + 273 = 288K$




The inner and outer diameter are given as .

$D_i$ = 0.0381 (m)

$D_o$ = 0.04(m).

A=area convection. $= \pi \times D_i \times L$ (m^2)

h = film specific coefficient = 471(W/m^2.c°)

ṁ = mass flow (kg/s) = 0.03(kg/s)

$C_p$ = constant pressure = 5.193 (kJ/kg)

Thus the bulk temperature as a function of axial distance(z) is given by

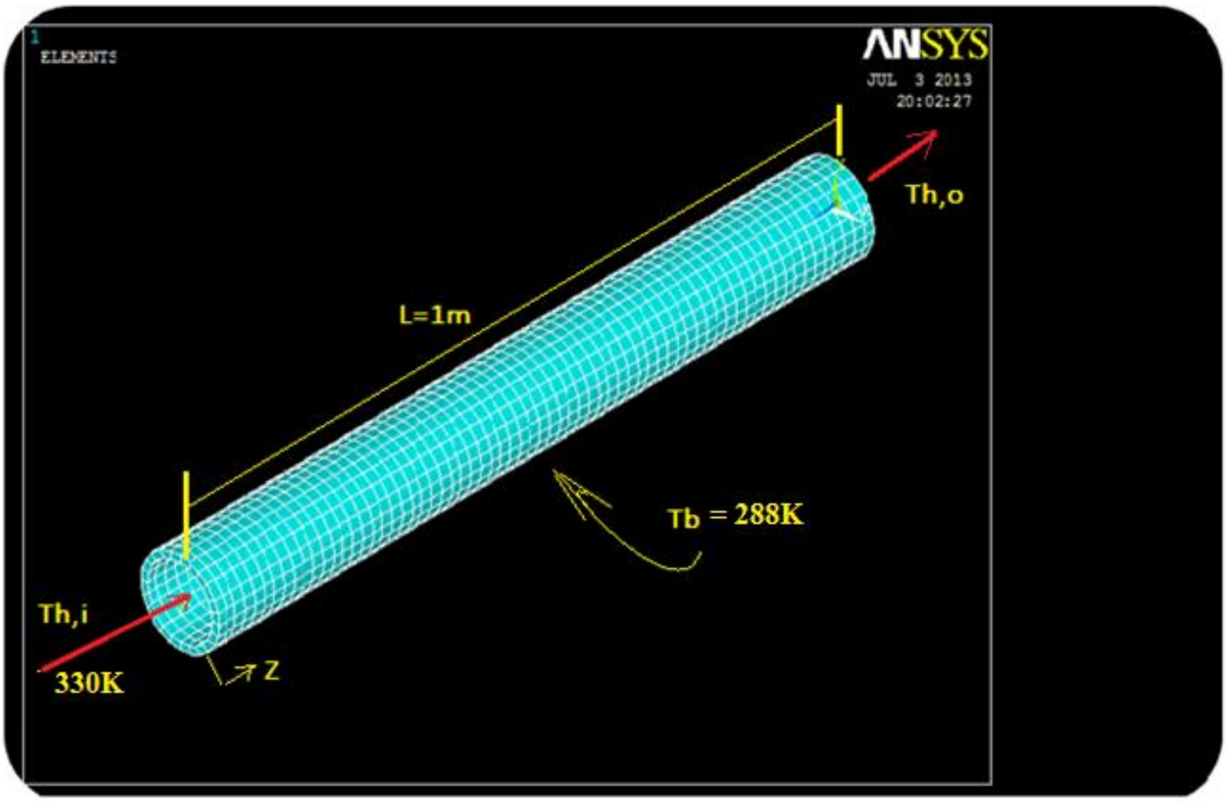
$[T_z = ( T_i - T_b)\exp(- hA / \dot{m} C_p \times Z/L) + T_b]$……………………………………………………………………….(4)

Solution:

At Z = 0

$T_z$ = (330 – 288) exp((-471×0.029/0.03×5193)×(0/1)) +288

$T_z$=(330-288)ex(0) +288 = 330K




**Fig(17): The effect Ambient temperature on the Cooling System .**

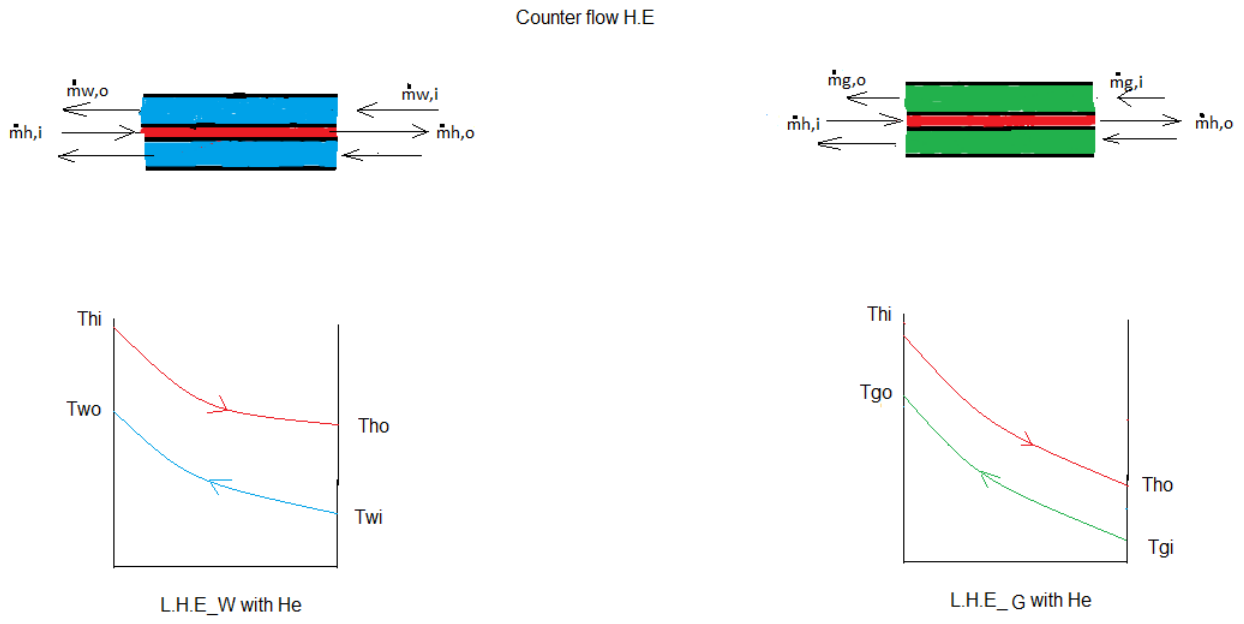
Solution by(ANSYS):

| Node | Location (z) | Analytical solution | ANSYS solution |
|---|---|---|---|
| 1 | 0.000 | 330330 | |
| 2 | 0.333 | 327327.01 | |
| 3 | 0.667 | 324.01 | 324.02 |
| 4 | 1.000 | 320.1 | 320.1 |

Thus, the solution from the simulation is matching well with the semi-analytical solution.

**3.1.2. Implicit Algorithm**:

In much thermal equipment, the design is based on the steady state. Many applications require knowledge of the transient behavior of the thermal devices. In fact, it is necessary to explore the unsteady state of thermal properties when the real time control, state computation, optimization, and rational use of energy are investigated.In additional, the unsteady state gives more details and information than steady state and also gives indication to validity of the steady state assumption.




**Fig(12):Heat Exchanger Counter Flow two Stage Lift Water with Helium and Right Glycol with Helium (3T)and(5T).**

Consider a water-Helium counter flow heat exchanger. Water is the cold fluid and He the hot one. The energy equations can be written as follows:

The energy equation for water is

$\partial/\partial t[m_w C_{p,w} T_w] = h_w A_w (T_{w-} T_t)$..............................................................(5)

The equation for He is

$\partial/\partial t[m_h C_{p,h} T_h] = - h_h A_h (T_{t-} T_h)$..............................................(6)

The equation for the tube is

$\partial/\partial t[m_t C_{p,t} T_{,t}] = h_w A_w (T_{w-} T_t) - h_h A_h ( T_{t-} T_h )$.......................................(7)

Using the Implicit method and taking:

$T_{w,a} = T_{w,I} - T_{w,o}/2.$

$T_{h,a} = T_{h,i} + T_{h,o}/2,$ one arrives at the discretized form of the energy equations as

$$\left(\frac{m_w C_{p,w}}{\Delta t}\right)[T_{w,a}^{n+1} - T_{w,a}^{n}] + (\dot{m}_w C_{p,w})[T_{w,o}^{n+1} - T_{w,i}] = (h_w A_w)[T_t^{n+1} - T_w^{n+1}] \text{.........(5)}$$

$$\left(\frac{m_t C_{p,t}}{\Delta t}\right)[T_{t,a}^{n+1} - T_{t,a}^{n}] = h_h A_h [T_h^{n+1} - T_t^{n+1}] - (h_w A_w)[T_{w,a}^{n+1} - T_t^{n+1}] \text{.........(6)}$$

$$\left(\frac{m_h C_{p,h}}{\Delta t}\right)[T_{h,a}^{n+1} - T_{h,a}^{n}] + (\dot{m}_h C_{p,h})[T_{h,o}^{n+1} - T_{h,i}] = -(h_h A_h)[T_{h,a}^{n+1} - T_{t,a}^{n+1}] \text{.........(7)}$$

# Chapter 4

## 4.1 Results and Discussions

After writing a computer program to solve the above differential equations. The results of the Algorithm are presented here. In figures from), we plotted the temperatures of the hot, cold fluids as a function of time. We can note the temperature of the cold fluid is increased with increase of the heat exchanger length and in the same time the temperature of the hot fluid is decreased because some energy is transfer from the hot fluid to the cold fluid (the thermal capacitance of the hot fluid decreased with time while the thermal capacitance of the cold energy increased with time) and this energy is transfer through the pipe wall, therefore we can notes the temperature of the pipe is increased along the heat exchanger length. The temperature of the hot fluid temperature is decreased with time (due to reduction of the hot fluid internal energy) and also we can note the effectiveness of the cold fluid will increase with time due to the temperature of the cold fluid is increased with time (due to increase of the hot fluid internal energy). We can also notes the instantaneous effectiveness decreased as time increase, because this effectiveness is depends on the temperature difference between the hot, cold fluid and this difference is reduced as the time increase, then the instantaneous effectiveness decreased as the time increased. The variation of temperature profile for the hot fluid against dimensionless heat exchanger length for different values of dimensionless time are plotted , as the time increase, the temperature of the hot fluid is decreased due to decreasing of the internal energy (increase the heat removed from the hot fluid). The difference between temperature profile lines will decreases the time increase due to decreasing of the heat removed (internal energy) from the hot fluid .as time increase.the efficiency of the hot fluid will increase (the thermal capacitance increase), then the energy transfer from the hot fluid to the cold fluid decreased (the cold fluid capacitance is small). At the time nearly zero, the effect of the hot energy is not noticeable and the increasing of the time will become the hot energy more effective due to the cold and hot fluids have initial values at time near zero.

<u>Outline of Calculations</u>

1. The temperature of Water perfect range for heat exchanger [trial and error method].
2. Mass flow and Time from equations [5,6,7].
3. Length and Diameter [trial and error method]
4. Helium Diameter Fixed. According to helium compressor.
5. No.fins require by [8,9,10,11,12].
6. Pumping power by [13].
7. Pressure drop by [14].

8. Pumping energy by [15].

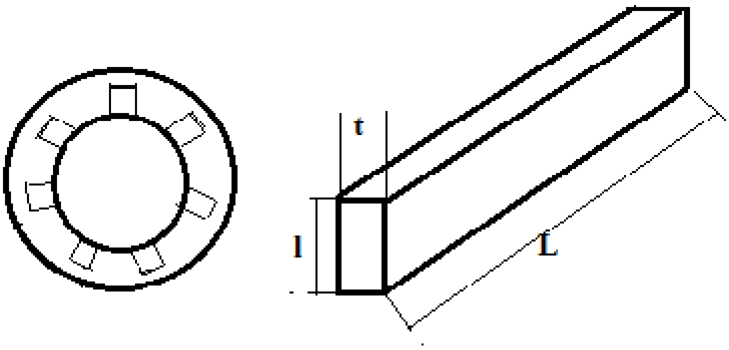
**Geometry and of fins details**

The heat transfer rate may be increased by increasing the surface area across which convection occurs. This my be done by using fins that extend from the wall into the surrounding fluid .

Ex:

The heat exchanger double pipes inure pipe flow hot helium at temperature inlet 330K and outer pipe flow cold water at temperature inlet at291K.

$D_i$ =0.038m,$D_o$=0.04m,length =2m, around inure pipe put fins, L = 2m, l =0.005m,Thickness =0.003m.




$A_t = \pi \times D_i \times L + N_f \times A_f$

$= \pi \times 0.0381 \times 2 \; + 7 \times [2 \times 2 \times 0.005 + 2 \times 0.005 \times 0.003] = 0.239m^2 + 0.1402 \; m^2 = 0.379m^2$

$$Q_0 = \sqrt{hpkA}\,,\theta_0 \frac{\tanh ml + \frac{h}{mk}}{1 + \frac{h}{mk}\tanh ml}$$ ..............................................................................................................................(8)

$$m = \sqrt{\frac{hp}{kA}}$$ ……………………………………………………………..(9)

$m = \sqrt{hp/kA}$

p = 2(L+t) = 4.003m

A = L× t = 2×0.003 = 6×10^-3m^2

$h_w$=1090 W/m^2.K

$k_s$=15.1W/m.K

m=√1090*4.003/15.1*6*10^-3=219.45m^-1

$\eta_f$ = tanh ml/ml…………………………………………………………………………(10)

ml =1.097

$\eta_f$=73%

To calculation number fins:

$\Theta_o$ = 330 – 291 =39k.

A = 2 * 0.003 = 6*10^-3m^2 ,

tanh ml = 0.997

P = 2[2+0.003]= 4.006m.

H = 1090.1 w/m^2.k

$Q_f$ = 2510 W

For study – state

Q = - ṁ

$_hC_{p,h}\Delta T_h$……………………………………………………………………………(11)

Q = -27948.7 W.

$N_f = Q_h/Q_f$= 11.13 =

12………………………………………………………………………………(12)

For unsteady- state

$Q_h$ = 16095W

$N_f$ =Q/Qf

$N_f$ = 6.4 = 7

Heat exchanger double pipe consists from double stage first water the outer pipe at 291K and exits from system at from 293K - 296K, relative of mass flow for both .The helium enters in opposite side at 330K and exit from anther at 310K with time relative to mass flow after exit helium from first stage enters the second stage here it enter at 301K and exit at300K,in stage two glycol enters at 260K

for water:

$Nu = h_o d_h / k$.

$D_h$ = 4A / p

$D_h = D_o – D_i$.

For helium:

$Nu = h_i d_i /k$.

If turbulent flow:

For liquid

Using Dittus – Boelterequation.

Nu = 0.023 (Re)^0.8(Pr)^0.4

For gas

$Nu = 0.023 (Re)^{0.8}(Pr)^{0.33}$

Where:

Reynolds number $Re = VD / \upsilon$……………………………………………………………...(3)

$V= \dot{m} / \rho A$.

Prenatal number = $Pr = \mu C_p / k$

For example:

Cooling system used water with helium:

Water :

$T_i$ =291K,

$\dot{m}$ =0.4 kg /s ,$C_p$ = 4200 kJ/kg .K , ρ = 1000 kg /m^3 , k =0.63 W/m.K, μ =855 ×10^-6 N.s/m^2 ,ν = 0.41 × 10^-6 m^2/s ,Pr = 3.6 ,

Helium:

$T_i$ =330K,

$\dot{m}$ =0.03 kg /s ,$C_p$ = 5193 kJ/Kg .K , ρ = 0.1615 kg /m^3 ,

μ =218×10^-7 N.s/m^2 ,ν = 122 × 10^-6 m^2/s , Pr = 0.672 ,k =160 (W/m.K)

Solution:

V =0.4 ×4 / 1000 ×π×4.35483×10^-3 = 0.1169 m/s

$Re = V \times (D_o – D_i) / \nu$.

Re = 0.1169 × (0.0762 – 0.0381) /0.4 × 10^-6 = 11139 >2000.

Nu = 0.023 (11139)^0.8(3.6)^0.4 = 66

$Nu = h_o d_h/k_w$ =66

$H_o$ =66 ×0.63/ 0.0381 =1091 W/m^2k.

for helium

V = 0.03 × 4/ 0.1615 ×π×0.0381^2 = 163 m/s.

$Re = VD_i/\nu$

Re = 977.6 × 0.0381/ 122×10^-6 =305299

Nu = 0.023 (305299)^0.8(0.672)^0.33 = 492. 65

$Nu = h_i\, d_i / k$ = 492 65 × 0.160 / 0.0381 = 2069

$1/U = 1/ h_i + x / k_c + 1/ h_o$

$x/ k_c$ it's very small

1/U = 1/ 1091 + 1/ 2069.

The overall coefficient heat transfer.

U = 714 .1 W/m^2.K

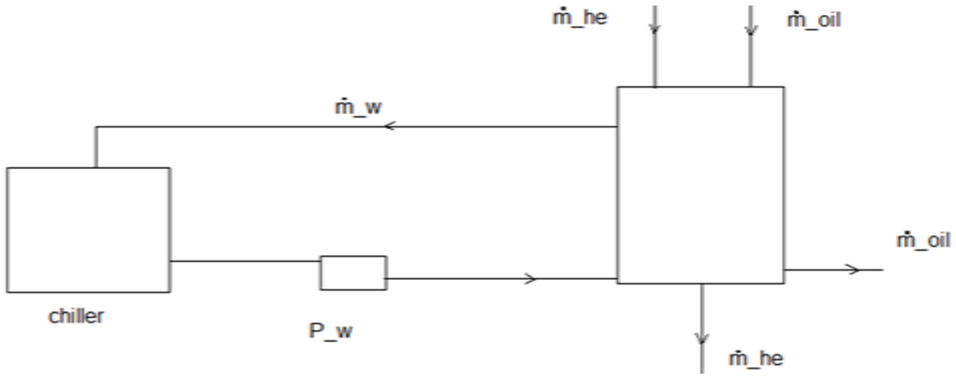



**Fig (18): Heat Exchanger Before Modification in MRI (3T)and(5T).**

In the counter flowheat exchanger system presented in Fig(18), water enters the system and cooling both helium and oil at the same time. The oil temperature exit form compressor is higher then helium temperature. Due to this,water gains more heat water from oil and less from helium. The efficiency of the heat exchanger between water and helium is low because ($c_{p,h}$) is higher than ($c_{p,oil}$). Due to this, helium may vapourise fast. When the temperature is higher than the superconducting one, the machine may stop.

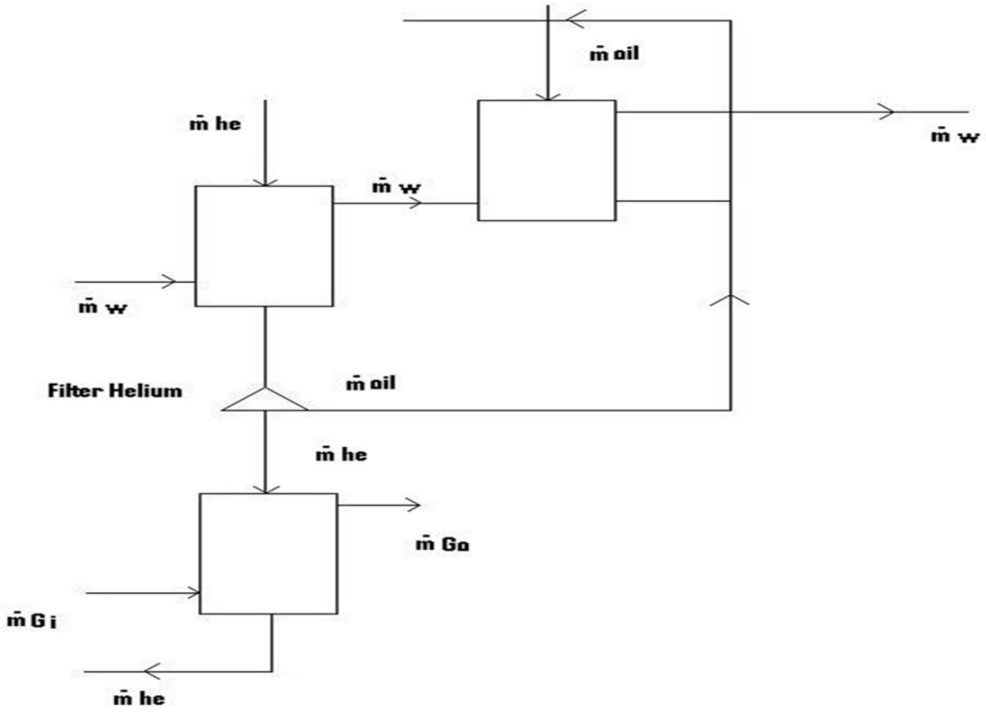
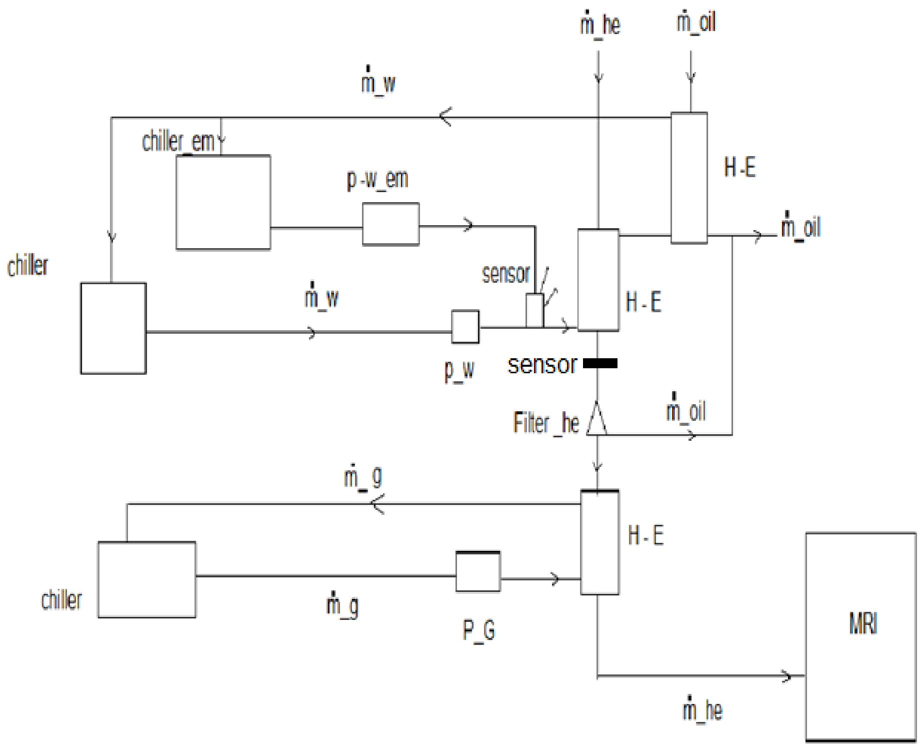



**Fig (19):DiagramCooling system after Modification(3T)and(5T).**

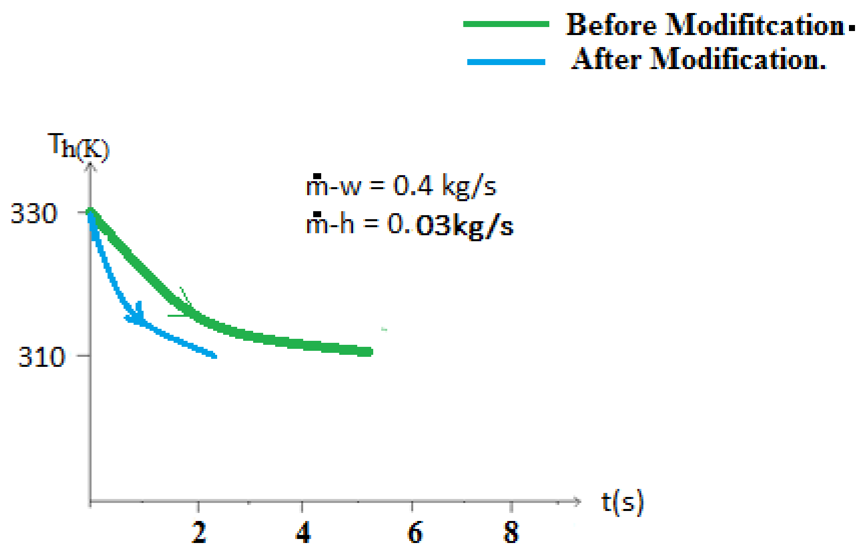
The system in Fig (19) heat exchanger in MRI (3T)and(5T) is a modification of the heat exchanger for helium and oil into two systems, one for helium and another for oil. In this case, water enters the first part of heat exchanger at a temperature of 291K and helium at 330K. After cooling, helium leaves at around 310K and water at 296K. Then, water enters the second exchanger for oil. In this case, the helium temperature is lower than the previous case, the one before modification. After exit from the first heat exchanger.Helium enters the distilling filter before entering the second heat exchanger where it is further cooled by glycol. Here, glycol enters at a temperature of 260K. This means that if helium is not pure, thenimpurities like grease or oil will freeze and create a problem in the cooling system. Helium enters stage two from the first stage at 310K and exits at300K. We got from this modification increased heat transfer(helium cooling) by about 33% compared to the first system. Thus, the machine may be able to operate for a longer time.




**Fig(20): Diagram Cooling System includesEmergencySystem**.

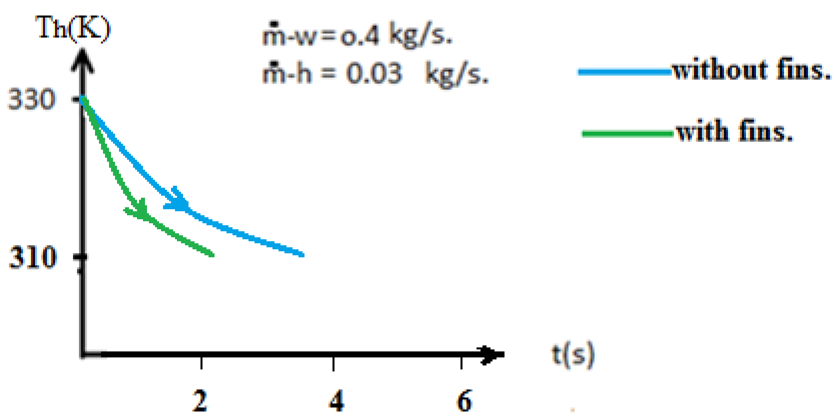
Sometimes, we need to have the machine for a longtime in an emergency situation. To have this feature, some parts can be added to the cooling system like a large compressor for water and two sensors and an actuator. When helium temperature increases above 310K the first sensor sends signal to another sensor to work the actuator of the large compressor to increase the mass flow of water in the heat exchanger.

The transient equations are solved for the outer and inner fluids as well as the tube. The heat transfer coefficients (h) are obtained from the standard correlations. It is assumed that the presence of fins does not change h. The fin increases the pressure drop by area increase factor.



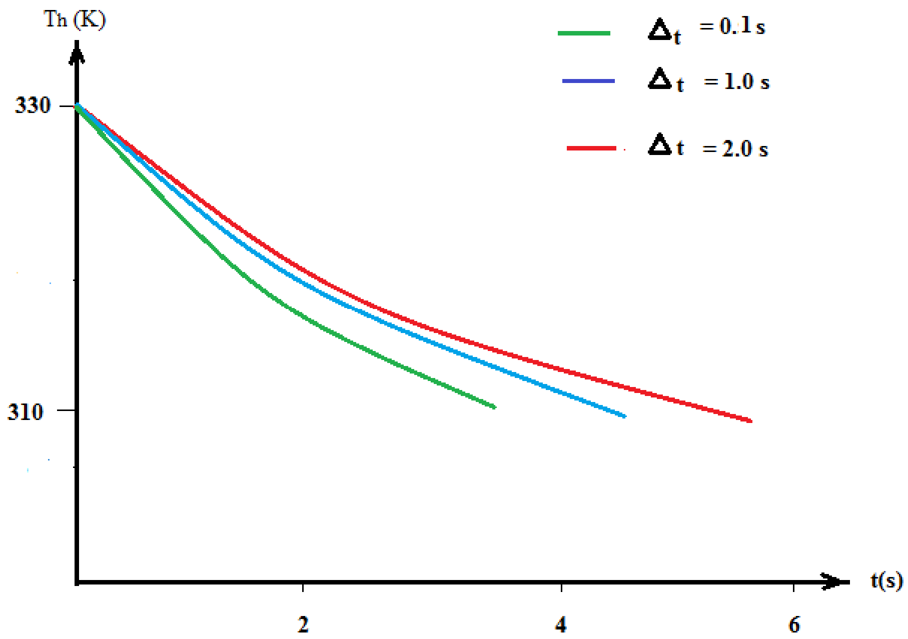

**Fig(21):Temperature Profiles of Helium with Water Before and After Modification Of Cooling System in (3T).**

The cooling time in MRI (3T) with mass flow of 0.4kg/s and mass flow of helium 0.03Kg/s. Fig (21) show the time cooling before modification and after modification with number fins equal 7.Cooling time equal 2.25s and before modification also without fins the cooling time equal 5.9s.Fig (21) Temperature profiles shown the different between two cases.



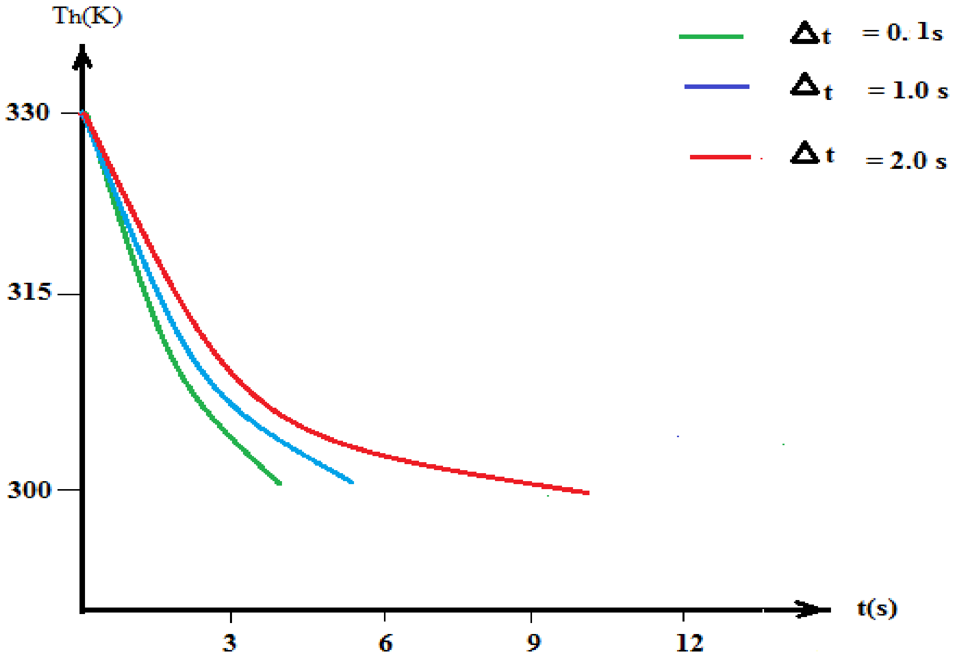

**Fig(22):Temperature Profiles ofHelium with Water with fins and without Fins (3T).**

The cooling time in MRI (3T) with mass flow of 0.4kg/s and mass flow of helium 0.03Kg/s .With 7fins, the Cooling timeis 2.25s and without fins it is 3.5s Thus, the fins help us cool much faster. In Fig. 22 the temperature profiles shown to highlight the effect of fins in the performance of the heat exchanger system.




**Fig(23):Temperature Profiles of Helium withchange time and without Fin (3T).**

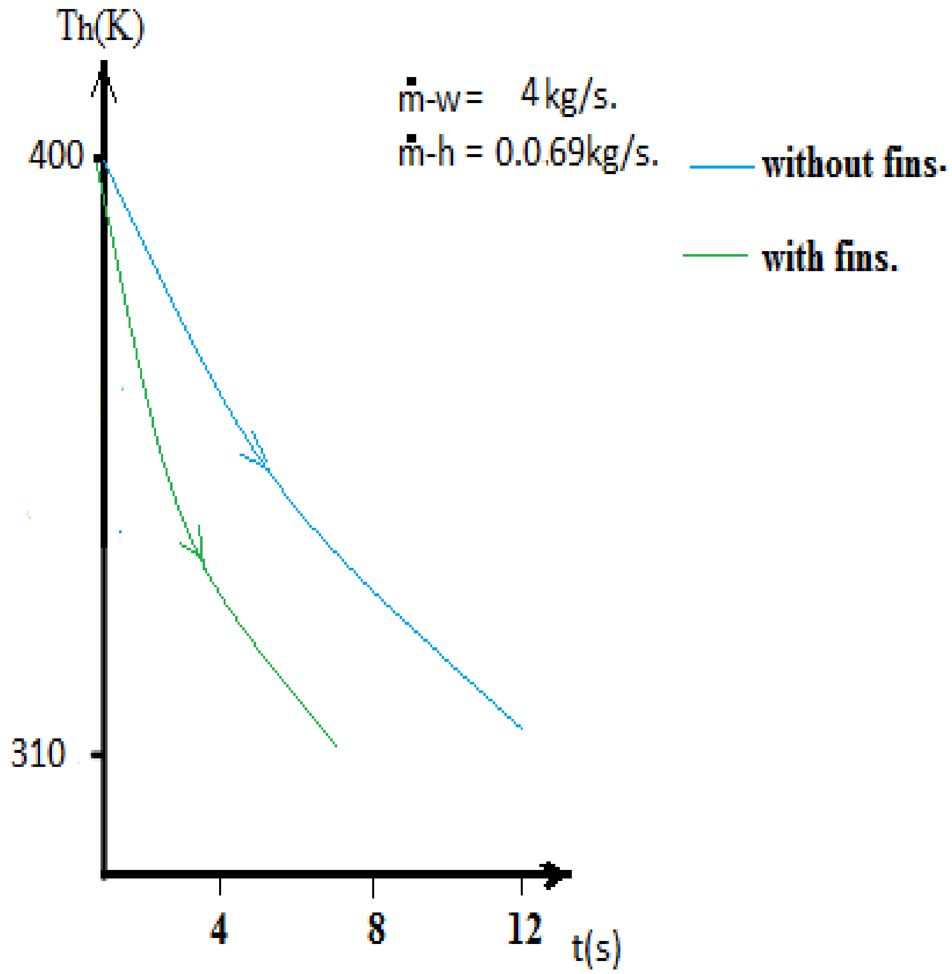
When Δt = 2s we observe the time cooling in (3T) is equal 5.8s and lower from cooling time at Δt=1s is equal 4.5and when Δt = 1 the cooling time lower than cooling time at Δt =0.1 s is equal 3.8s .The effect of step size in the case without fins is presented in Fig. 23.




**Fig(24):Temperature Profiles of Helium with change time and with 7 Fins(3T).**

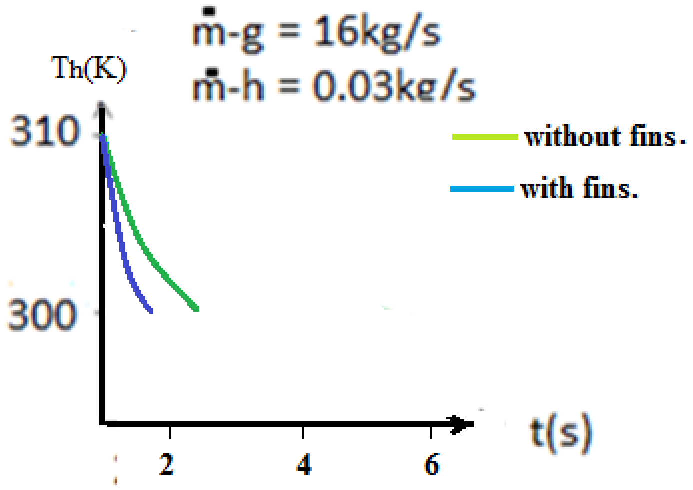
When Δt = 2s we observe the time cooling in (3T) is 11s and lower from cooling time at Δt=1s and when

Δt = 1 the cooling time equal 5.9s and lower than cooling time at Δt = 0.1s equal 3.75s. The effect of step size in the case with 7 fins is presented in Fig. 24.




**Fig(25):Temperature Profiles in a Counter Flow without Fins (5T).**

The cooling time in MRI (5T) with mass flow of water 4kg/s and mass flow of helium 0.069Kg/s .In number fins 7 Cooling time 7.8s and without fins 10.9s. The effect of step size in the case without fins is presented in Fig. 26. The effect of step size in the case with 7 fins is presented in Fig. 25.




**Fig(26): Temperature Profiles in Counter Flow With number Fins 7. (3T).**

The cooling time in MRI (3T) with mass flow of glycol 16 kg/s and mass flow of helium 0.03Kg/s. The number of fins is 7 and the Cooling time is 1.5s, while without fins it is2.2s. This is presented in Fig. 26.

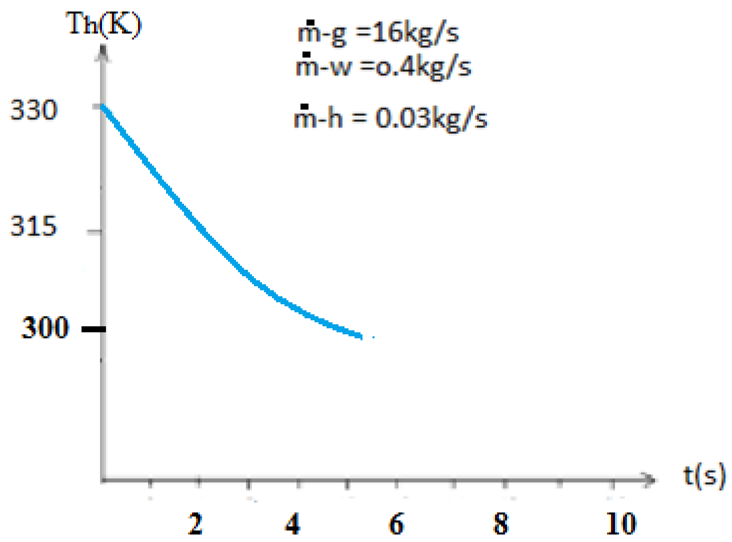



**Fig (28): Temperature profiles explain effect Modification in Heat ExchangerHelium with WaterandGlycol two Stage (3T).**

The temperature profiles are shown in fig (28) to present and explain the cooling for helium in MRI (3T)..In this case, the time in stage one 3.5s( heat exchanger between helium and water)and the time in stage two (heat exchanger between helium and glycol) is 2.2s. Thus, the cooling time with 7fins is5.7s.

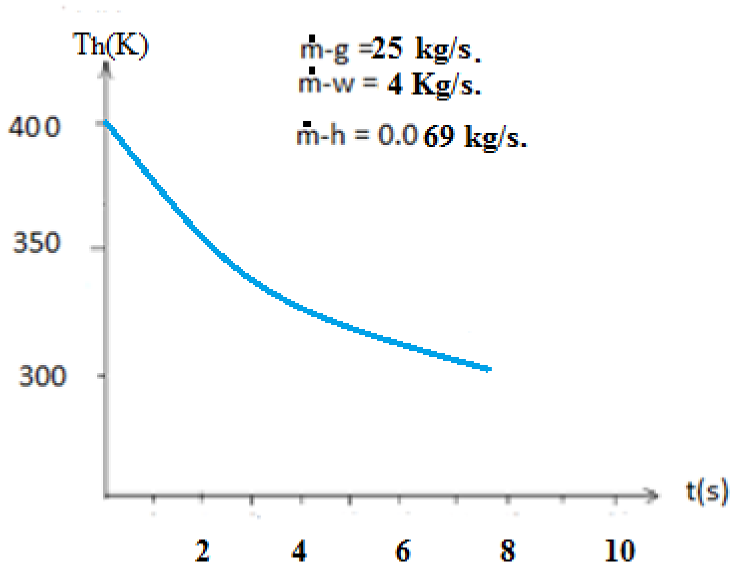



**Fig (29): Temperature Profiles explain Effect Modify in H.E between Helium with Water and GlycoltwoStage (5T).**

The temperature profiles for cooling of Helium is shown in fig 29, for helium mass flow rate of 0.069kg/s, mass flow water rate at 4kg/s and mass flow of glycol at 25kg/s in MRI (5T).The cooling time is 6.2s in stage one(heat exchanger between helium and water) and in stage two 1.68s (heat exchanger between helium and glycol). Thus, the total cooling time is7.7s with 7 fins.

PROPERTIES AND INLET-OUTLET CONDITIONS

The fluid properties, inlet and outlet conditions are given below:

Re = V Dh / ν .

V = m / s

Dh = 4A / P

in double pipe ( Do – Di ).

Pr= Prenatal number

Pr = μ $C_p$ /k.

If Re > 2000 the flow is turbulent can use this equation .

Nu = 0.023 ( Re)^ 0.8 ( Pr ) ^ 0.4

Or

Nu = 0.023 ( Re)^ 0.8 ( Pr ) ^ 0.33

When use :

Thermo physical properties of water at291K are:

ṁ = 0.4 kg /s , ν = 0.53 × 10 ^ -4 (m^2/s) , $C_p$ = 4.2 (KJ/kg.K) , $T_i$= 291K ,$T_o$ = 302K.

Thermo physical properties of heliumat330K are:

ṁ = 0.03 kg /s , ν = 1.22 × 10 ^ -4 (m^2/s) , $C_p$ = 5.19 (KJ/kg.k) , $T_i$ = 330 k ,$T_o$ = 310 k.

Thermo physical properties of Ethylene [ C2H6O2] at 260K are:

ṁ = 0.4 kg /s , ν = 0.576 × 10 ^ -4 (m^2/s) , $C_p$ = 2.21 (KJ/kg.K) , $T_i$ = 263 K , $T_o$ = 303 K.

Counter flow heat exchanger and design pipe length and type material compatible to ambienttemperature.This equation explain effect length, material for pipe also it using to test inTemperature calculation :

The increase in heat transfer from the tube per unit length due to addition of fins..

Where :

Thickness = t =0.003m.

Length = L =2 m.

Width = l =0.005m.

Circumference = P = 2[L+t].

Area =[L×t].

Compressor and PumpingPower ?

Suitable power of Helium , Water and Ethylene (C2H6O2) .

P = ṁ×Δp / ρ

We are choose material for design in 1.5 Tesla fore helium pipe Commercial steel and for water , Glycol plastic .

For 3Tasle and 5Tasle used all for helium,water and glycol pipes Riveted steel.

Choose Pump required

1. Pump meets required performance and is operating smoothly and quietly

2. There are no leaks. Particularly at the shaft seal.

3. The motor is not overheating.

4. Remove and clean all strainers or filters in the system.

5. Verify the tripping of the motor overload protection.

6. Check the operation of all controls. Check unit control cycling twice and adjust,if necessary.

7. If the pump is not operated for unusually long periods. The unit should be maintained in accordance with these instructions. In additions, if the pump is not drained. The pump shaft should be manually rotated or run for short periods of time at monthly intervals.

8. To extend the pump life in severe duty applications, consider performing one of the following actionsPreventative maintenance

Power calculation:

The Pumping power is calculated as

$P = \dot{m} \times \Delta p$…………………………………………………………………………………(13)

The ΔP is calculated as

$\Delta p = f \times L \times \rho \times V^2 / 2D$……………………………………………………………(14)

From Moody chart be Re and ε/D can get $f$.

.When MRI (5T) mass flow for water 4kg/s, $D_o$ =0.11m, $D_i$=0.076m find pumping power.

Solution:

$\dot{m}$ = 4 kg /s.

$D_h = D_o - D_i$

$D_{w,h}$ =[0.11- 0.07] = 0.034m.

$V = \dot{m} / \rho A_c$

V = 4×4 / 1000×π×[0.11^2 – 0.07^2] = 0.88 m/s .

$Re = VD_{h} / \nu$

Re =0.88 × [0.11 -0.076] / 0.4 × 10^-6 =74800

ε/D =0.9 /60 = 0.015

From mood's diagram: Reynolds number with (ε/D) surface roughness'sgetfriction factor.

Ƒ = 0.042. The ΔP is calculated as

$\Delta p = f \times L \times \rho \times V^2 / 2D$

$\Delta P = 0.042 \times 2 \times 1000 \times (0.88)^2 / 2 \times 0.034 = 777$ pa

The pumping power is calculated as

$P = \dot{m} \times \Delta P / \rho$

$p = 4 \times 777 / 1000 = 3.5$ W.

The pumping energy is calculated as

Pumping energy(J) = pumping power(J/s) × time (s)…..…………………………(15)

Table(2) Results explain the relation between mass flow, time cooling, power pump, and pumping energy in (3T)Tesla (5T) Tesla of MRI at mass flow for helium 0.03kg/s of (3T) and 0.069 kg/s of (5T).

| M.f(kg/s) | Time(s) | Pumping power(W) | Pumping energy(J) | No.fin |
|---|---|---|---|---|
| 0.4 | 3.5 | 5.0 | 17.5 | 0 |
| 0.4 | 2.8 | 6.1 | 17.3 | 3 |
| 0.4 | 2.55 | 6.27 | 15.9 | 5 |
| 0.4 | 2.25 | 6.97 | 15.7 | 7 |
| 0.4 | 2.21 | 7.2 | 16.2 | 10 |
| 0.6 | 3.2 | 6.6 | 21.1 | 0 |
| 0.6 | 2.8 | 7.47 | 20.9 | 3 |
| 0.6 | 2.5 | 7.99 | 19.9 | 5 |
| 0.6 | 2.3 | 8.3 | 19.1 | 7 |
| 0.6 | 2.05 | 9.36 | 19.1 | 10 |
| 0.8 | 3.15 | 11.28 | 35.5 | 0 |
| 0.8 | 2.75 | 11.7 | 32.1 | 3 |
| 0.8 | 2.4 | 12.0 | 28.8 | 5 |
| 0.8 | 2.18 | 13.3 | 29.0 | 7 |
| 0.8 | 2.0 | 15.42 | 30.8 | 10 |
| 1.0 | 2.5 | 17.6 | 44.0 | 0 |
| 1.0 | 2.3 | 18.47 | 42.5 | 3 |
| 1.0 | 2.1 | 19.5 | 41.0 | 5 |
| 1.0 | 2.04 | 19.7 | 40.2 | 7 |
| 1.0 | 2.01 | 23.6 | 41.5 | 10 |
| 1.5 | 2.5 | 37.2 | 93.0 | 0 |
| 1.5 | 2.1 | 41.9 | 87.96 | 3 |
| 1.5 | 2.06 | 42.3 | 87.13 | 5 |
| 1.5 | 2.01 | 43.0 | 86.43 | 7 |
| 1.5 | 1.95 | 44.7 | 87.2 | 10 |

The overall heat transfer coefficient with fins is calculated as:

The increased area is

$A_f$= n[2×L×W+ t×L +2×W× t]

As = [π×2.5×0.07] +7 [2×0.005×2.5 + 2×0.005×.003]

As = 0.8 m^2

$1/UA_o = 1/h_i A_i + 1/h_i A_o$

$1/UA_o$ = 1/ (0.55×1605)+ 1/ (0.25×1029)

0.799U = 428.6

Thus, the overall heat transfer coefficient is given by

U = 536.5 W/m^2.k

Pumping energy.calculation:

The pumping energy is calculated as

Pumping energy = pumping power * cooling time

Thus, it is important to decrease the cooling time. This can be achieved by employing fins.

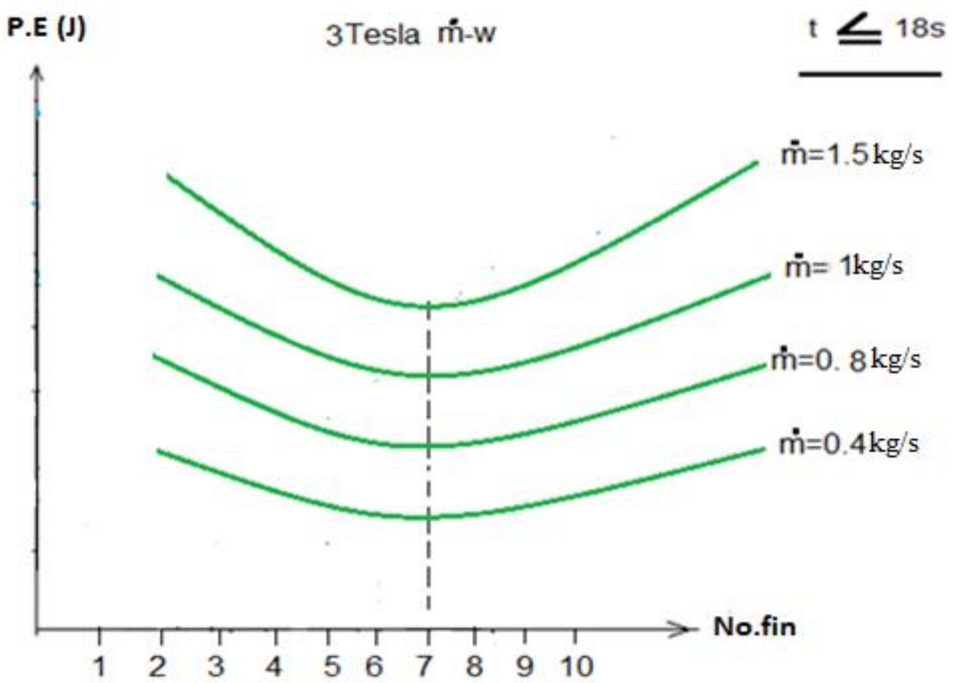



**Fig (30): Effect of number Fins onPumping Energy (3T)**

From fig (30), the lowest pumping energy is obtained at mass flow of water =0.4kg/s when no.of fins =7. The corresponding  cooling time is2.25seconds, pumping energy is 15.7 J. At mass flow 1.5 kg/s,  the cooling time is2.01s and pumping energy is86.43 J for MRI (3T). Thus, we can choose 0.4 kg/s as the one with the least pumping energy.

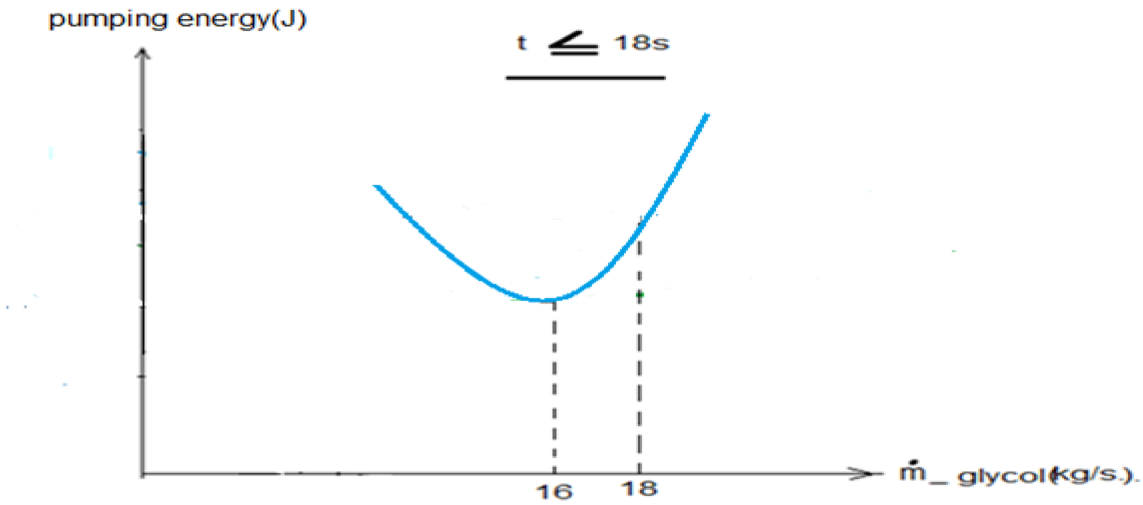



**Fig (32): pumping energy at number fin 7 for (3T).**

We observe from Fig (32) that relation between pumping energy with mass flow rate of glycol. We get the lowest pumping energy at8.7J. The corresponding cooling time is 1.5 seconds at mass flow of glycol = 16 kg/s.When mass flow equals to 18Kg/s the pumping energy equals to 13.23Joules and thecooling time is 1.8 seconds and number of fins =7 for MRI (5T). With the minimum pumping energy we can get thebest performance for the cooling system for (5T).

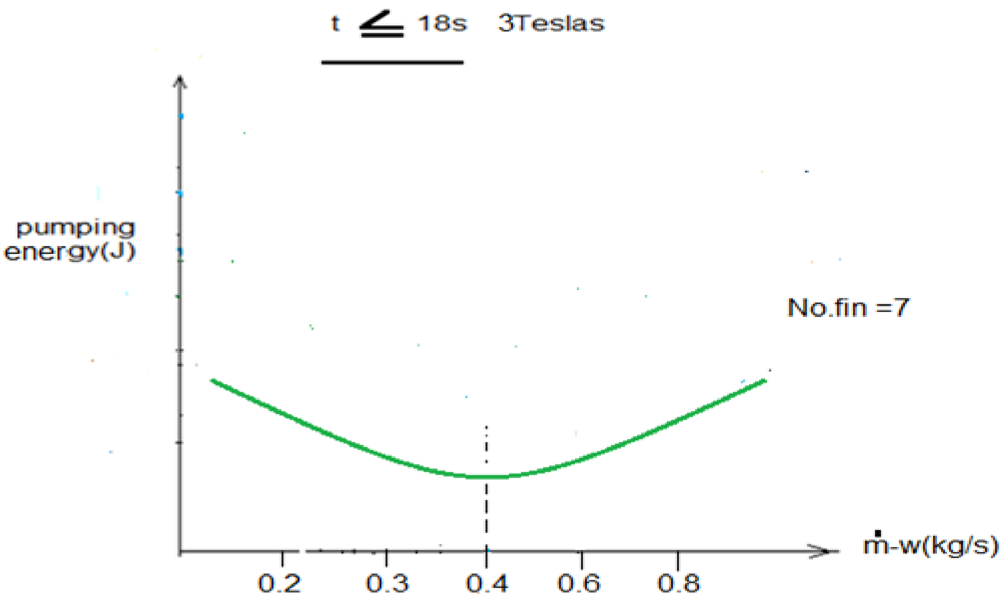



**Fig (33):relation between mass flow and pumping energy with number fins =7 for (3T).**

We observe from Fig (33) the relation between pumping energy with mass flow of water also got low pumping energy equals to 15.7J and time equals to 2.25s at number fins = 7.

**Cooling optimization of MRI (3T)and(5T).**

Using heat exchanger counter flow double pipe.

Using two stage heat exchanger stage one water, stage two glycol.

Mass flow water and glycol,0.4kg/s, 14 kg/s respective. For 3T.

Mass flow water and glycol,4kg/s , 25kg/s respective for 5T.

Put 7 fins around helium pipe.

Length heat exchanger = 2m.

Pumping energy 24.4J for one patient at 3.75s.(3T)

Pumping energy 57J for one patient at 7.8s.(5T)

Put helium filter before stage two.

Put emergency system for emergency state need long time.

**The relative efficiency is defined as**

$$\eta_{relative} = \text{Pumping energy}_{\text{best case}} / \text{Pumping energy}_{\text{actual case}}$$

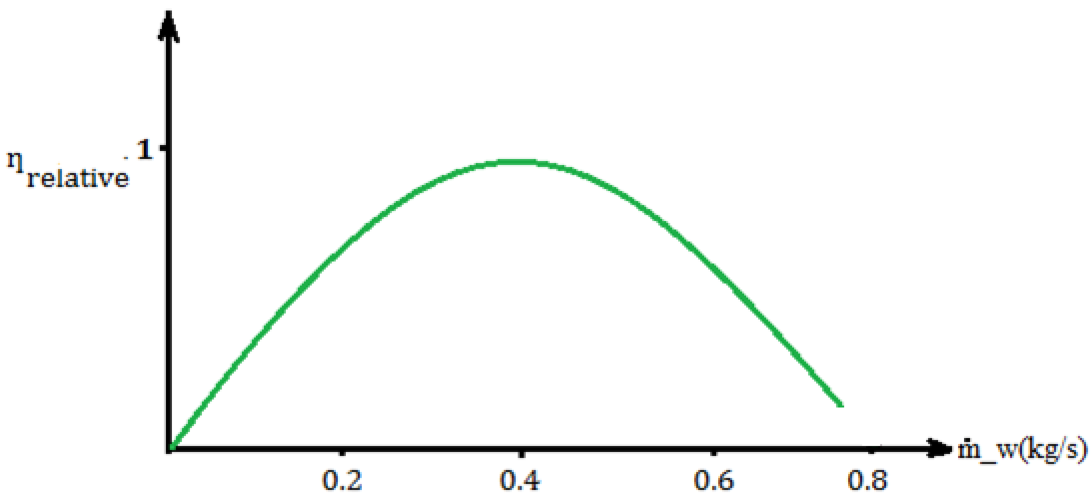



**Fig (36): The relation between efficiency with mass flow of water at number fins =7 and MRI (3T).**

Fig (36) shows the relation between efficiency with mass flow from water in cooling system of (3T). We observe that the maxmum relative efficiency at 0.4 kg/s.

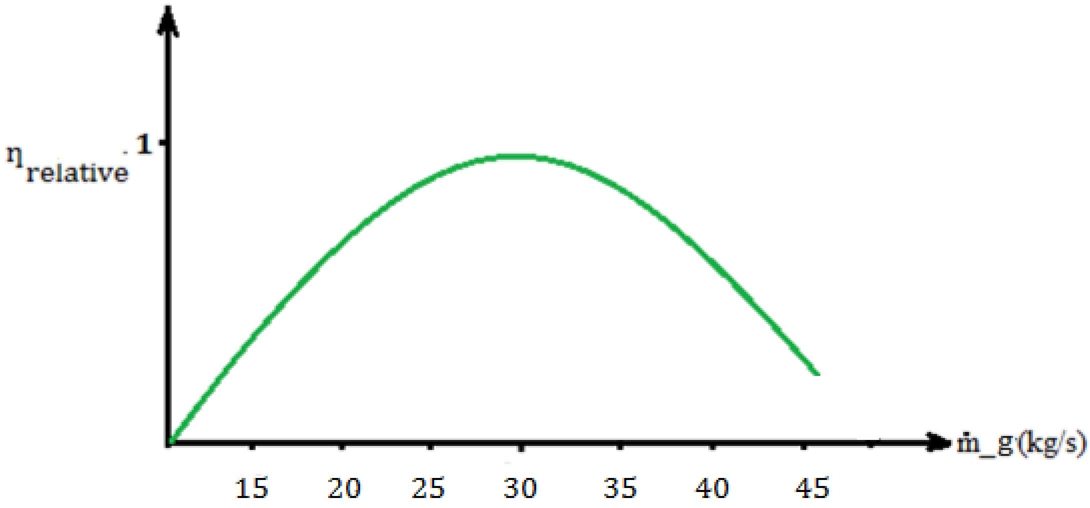



**Fig (39): The relation between efficiancy cooling with mass flow of glycol at number fins =7 and MRI (5T).**

Fig (39) shows the relation between efficiency cooling with mass flow from glycol in cooling system of (5T) We observe that the maxmum efficiency at mass flow 30kg/s.

$\eta$relative

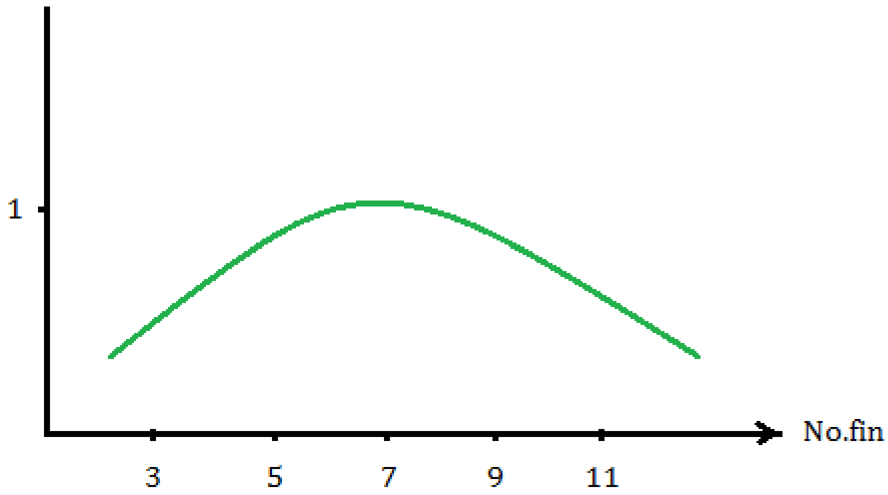



**Fig (40): The relation between efficiency cooling with number fins in MRI .**

Fig (40) shows the relation between relative cooling efficiency with number of fins We observe that the maxmum efficiency at number fins =7.

For a counter flow heat :

Effectiveness = ε

$\varepsilon = Q_{act} / Q_{max}$

$Q_{max} = (\dot{m}c)_s (T_{h,i} - T_{c,i})$

If $\dot{m}_h c_h < \dot{m}_c c_c$ or $T_{h,i} - T_{h,o} < T_{c,o} - T_{c,i}$

Effectiveness =ε

$\varepsilon = T_{h,I} - T_{h,o} / T_{h,I} - T_{c,i}$

In case one (before modification )

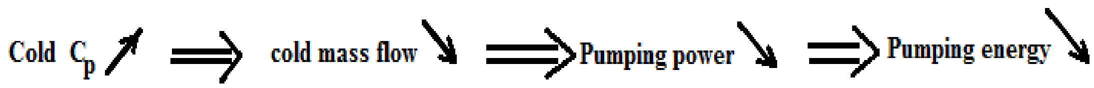
ε = 330 – 310 / 330-291 = 0.51

In case two (after modification)

ε = 330 -300 /330 -291 = 0.77

**Future scopes of development the cooling system.**

- Decreases pumping energy.by use cold fluid has high $C_p$and high density also it has same properties for $C_2H_6O_2$.



# Chapter 5

## 5.1Conclusions.

The unsteady state counter flow double pipe heat exchanger differential equations is solved numerically by using finite difference technique with variable temperature for hot,cold fluid and tube wall. The effect of the time,mass flow and heat specific coefficient (h).

Our analysis is considering hot fluid (that we need to cool it) flowing side the tube and the cold fluid flows inside the annulus area.

The effect of Reynolds number on the individual heat transfer coefficients.

Performance of the counter flow heat exchanger vs. the counter flow heatexchanger.Possible causes of deviations, if any, between the results of heat exchanger obtained bythe two different calculation procedures, (steady and unsteady) for the same run.

Make recommendations to increase the heat transfer rate to the cold stream, and forthe better control of variables to obtain more accurate experiment results.

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