DEVELOPMENT OF CORRELATIONS FOR THERMOPHYSICAL PROPERTIES OF SUBCRITICAL NITROGEN (SCN_2) TO BE USED IN HIGH TEMPERATURE SUPERCONDUCTING (HTS) CABLES

DISSERTATION

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE

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MASTER OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

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CERTIFICATE

I hereby certify that the work which is being presented in the Dissertation entitled "**Development of Correlations for Thermophysical Properties of Subcritical Nitrogen (SCN$_2$) to be used in High Temperature Superconducting (HTS) Cables**" in partial fulfillment of the requirements for the award of degree of **Master of Technology** and submitted in the Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of our own work carried during period of dissertation under the supervision of **Mr. Raja Sekhar Dondapati, Asst. Professor**, Department of Mechanical Engineering, Lovely Professional University, Punjab.

The matter presented in this dissertation has not been submitted by me anywhere for the award of any other degree or to any other institute.

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This is to certify that the above statement mentioned by the candidate is correct to best of my knowledge.

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The M.Tech Dissertation examination of **Development of Correlation for Thermophysical Properties of Subcritical Nitrogen (SCN$_2$) to be used in High Temperature Superconducting (HTS) Cables** has been held on

Signature of the Examiner

DECLARATION

I, student of **Master of Technology (Thermal Engineering)** under Department of **Mechanical Engineering** of Lovely Professional University, Punjab, hereby declare that all the information furnished in this dissertation 1 report is based on my own intensive research and is genuine. This dissertation 1 does to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university without proper citation.

AJAY KUMAR RAMANI

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ABSTRACT

The storage and transmission of energy have been a major challenge and objective over a past decade. To accomplish such an objective of improving the effectiveness of power transmission system, superconductivity principle is introduced in 1978 which has become a revolutionary step towards the new era of sustainable energy. The present electrical transmission systems suffer 40-60% transmission losses such as AC losses, thermal losses due to the use of conventional conductors. Therefore, in order to reduce these losses to minimum extent, most of the power transmission systems are to be replaced by High Temperature Superconducting (HTS) cables in power applications. Since the losses are dissipated in the form of heat, the need arises to choose a suitable coolant (cryogen) which can accommodate the heating load in view of development of room temperature superconductor.

In present project work an attempt has been made to propose a novel cryogenic cooling concept with Subcritical Nitrogen (SCN_2) to maintain superconducting state over a wide range of applications and hence minimize the transmission load. As the nitrogen is the major constituent in the atmospheric air, the concern over its availability may not arise. Thereby, it can be separated from air and can be converted in to SCN_2 using various cryocoolers. This report discusses the thermo-physical properties such as **density, viscosity, thermal conductivity and specific heat** of SCN_2. The **supercritical temperature and pressure** of nitrogen is obtained from NIST web book **[10]** as 126.19K (-146.81 ^{0}C) and 3.3958MPa (33.958 bar) respectively, whereas **triple point** temp. is 63.15K (-209.85 ^{0}C) and **normal boiling point** temp. is 77.355K (-195.645 ^{0}C). It was found that near the critical point there is significant variation and superposition in the thermo-physical properties of SCN_2 with respect to temperature and pressure due to phase change and unit compressibility factor (Z ˜ 1) and hence almost ideal gas behaviour is shown by SCN_2 cryogenic fluid.

Further work of this dissertation is focussed towards the development of correlations for above thermo-physical properties, error analysis and compression of obtained

results, reason for drastic variations and superposition of properties and identify the suitable range of working temperatures, which can be beneficial for predicting performance of cryogenics and thermo-hydraulic modelling of HTS cables in future and hence time and money can be saved by this mathematical modelling and simulation without manufacturing the actual prototypes. In recent times, with the sophistication and advancement of computer technology, solving of various transport equations with temperature dependent thermo-physical properties became easy and simpler. Hence this dissertation thesis and developed correlations would benefit the technological community and upcoming generations to develop futuristic smart power grid with HTS cables, a move toward the green world by replacing Conventional Cables.

KEYWORDS: **Superconductivity, cryogenics, critical point, subcritical nitrogen, HTS.**

NOMENCLATURE

T_c	**Critical Temperature**

P_c	Critical Pressure
HTS	High Temperature Superconductor
LTS	Low Temperature Superconductor
H	Applied Magnetic Field
M	Intensity of Magnetic Field
LN_2	Liquid Nitrogen
SCN_2	Subcritical Nitrogen
SCN	Supercritical Nitrogen
Z	Compressibility factor
P	Density
μ	Viscosity
K	Thermal Conductivity
C_p	Specific Heat
AC	Alternating Current
ARE	Average Relative Error
SAR	Sum of Absolute of Residual
RE	Relative Error
AARE	Average of Absolute of Relative Error

DEVELOPMENT OF CORRELATIONS FOR THERMO-PHYSICAL PROPERTIES OF SUBCRITICAL NITROGEN (SCN_2) TO BE USED IN FUTURISTIC HTS CABLES FOR EFFICIENT POWER APPLICATIONS

CHAPTER 1

INTRODUCTION

1.1 RESEARCH NEEDS: PRESENT ENERGY SCENARIO

Energy is the driving source of all the phenomena of this physical world and it is the capacity of doing any work, so its proper management and utilization is a prime focus of study. Conservation of energy states that energy neither be created nor be destroyed, i.e. energy of the universe is conserved. As we in our daily life transforming the energy from one form to another form as per our requirements. So we need such an effective system to maximize the usage of energy to a greater extent. The total energy production of the world from all the sources is **13634 Million tonnes of oil equivalent (1Mtoe=11.63TWh)**, out of which **23132 TWh** is the share of electrical energy whereas the present electricity demand is too high as **29550 TWh** as per Enerdata 2014 **[48].** So to fulfil the required demand of electricity we need to optimize the whole systems/devices of energy generation, storage, transmission, distribution and utilization of conventional techniques which is only possible by replacing the normal conventional conductors and devices by High Temperature Super-conducting (HTS) cables and systems. Since the existing power transmission system encountered up to 60% losses of energy from the generation point to the utilization point due to various types of losses in between i.e. AC losses, Thermal losses, Hysteresis losses, Magnetic losses, etc. However, energy production is more at the generation point but we get less than the half of that energy at the utility point. As shown in the below clustered column bar diagram the demand is very high and production is low and hence the consumption is low as per production amount. Due to the urbanization, industrialization and higher living standard of people the consumption and demand of electricity is continuously increasing from the last decade and hence it is necessary to increase the production as well to fulfil the present need of electricity to the world.

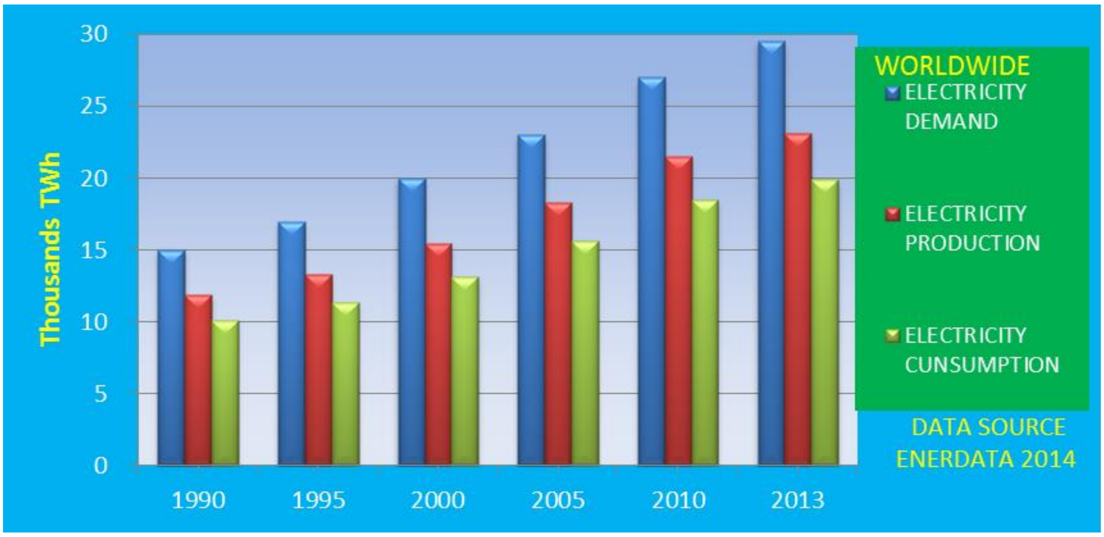
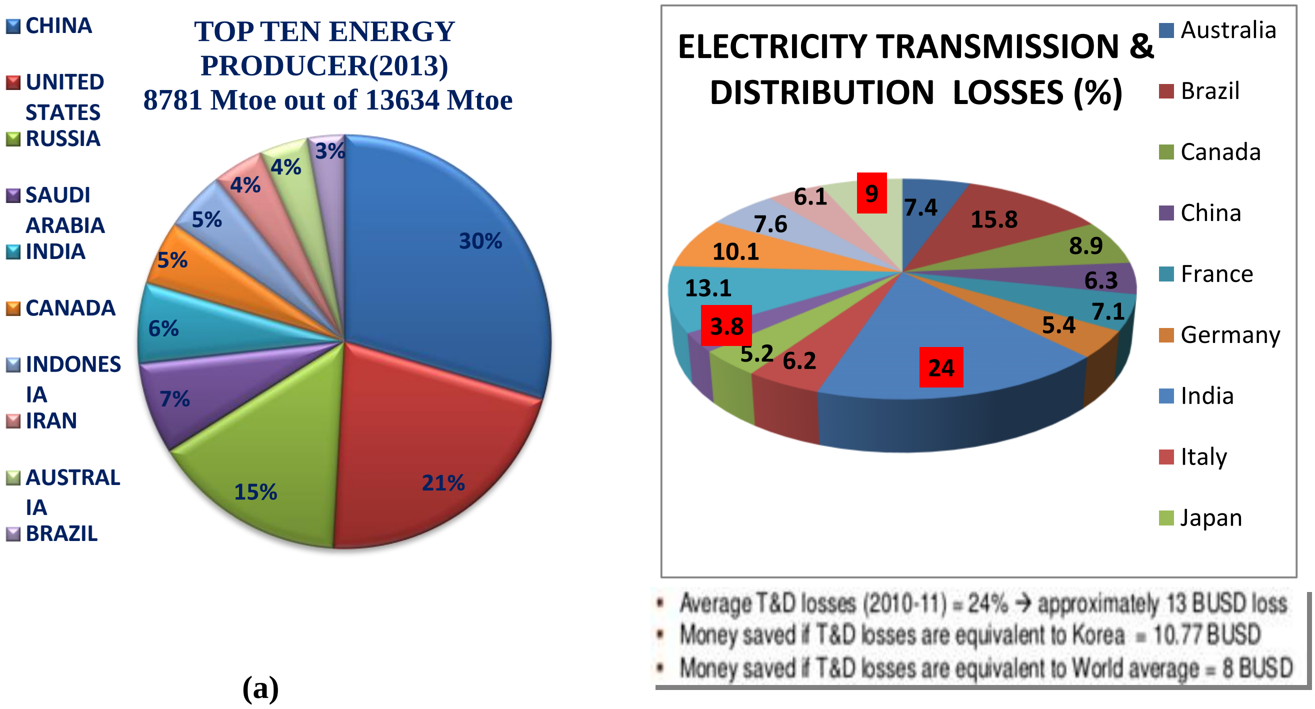


Figure 1 : Comparison of world's demand, production and consumption of electricity [48]

The top ten energy producer countries are shown in the below pie **chart (1)** in which China is the major producer contributes 30% of the total which India is in 5th rank shares 6% energy**.** These 10 countries share is 8781Mtoe to the total world energy production 13634Mtoe which is 64.4% **[50].** The transmission and distribution losses are shown in **figures 2 (a) and (b).**



- Average T&D losses (2010-11) = 24% → approximately 13 BUSD loss
- Money saved if T&D losses are equivalent to Korea = 10.77 BUSD
- Money saved if T&D losses are equivalent to World average = 8 BUSD

(a)

(b)

Figures 2:(a)Top ten energy producer of world (b)Percentage T&D Losses worldwide [50]

1.2 BACKGROUND CONCEPTS AND AREA OF STUDY

The study of superconductivity at cryogenic temperatures comes under the field of **condensed matter physics**, so the brief concept must be understood prior to the study of superconductivity and the role of cryogens. Condensed matter physics is a broad category of physics that deals with the physical properties of condensed phases (states) of matter. **Solid and liquid** are the most familiar condensed phases, while more unusual and exciting condensed phases are the **superconducting phase** exhibited by certain materials and fluids at low temperature, the ferromagnetic and anti-ferromagnetic phases are found in cold atomic systems as spins of atomic lattices[1].

In present era the study of **phase transitions** and **critical phenomena** is an focused and important part of modern science of condensed matter physics. Phase transition stands for the change of phase of a system and matter, which is brought about by change in an external parameter such as temperature, pressure etc. However quantum phase transitions refer to transitions of phase where the temperature is maintained at zero. The study of phase transitions and critical phenomena in correlated systems is an active area of research **[47].**

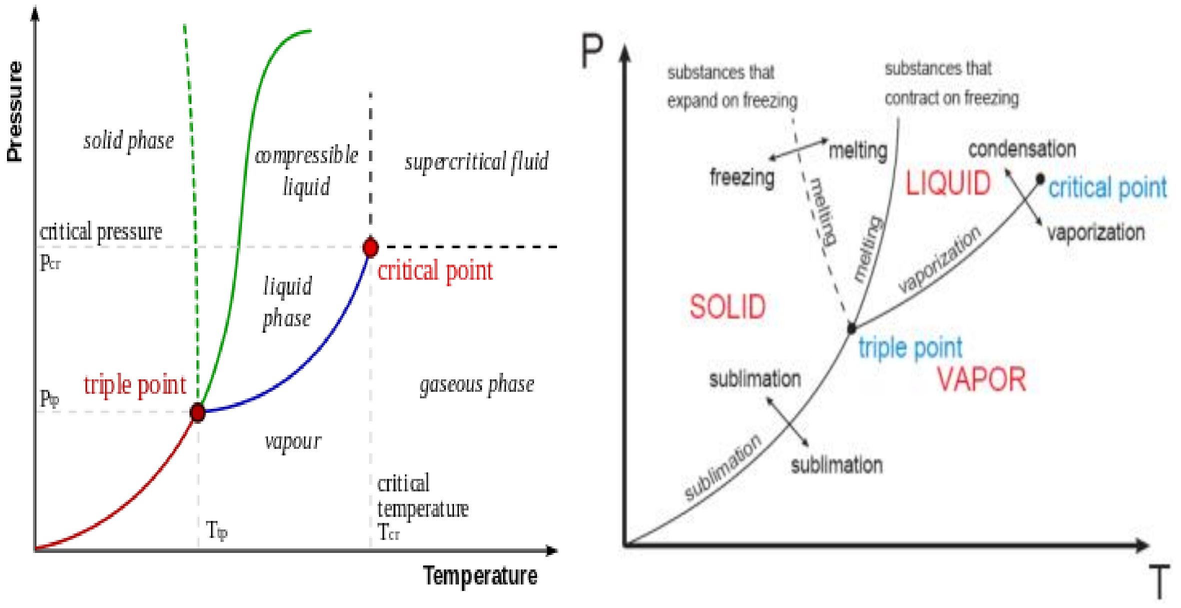


Figure 3: Illustration of different phases with phase diagrams [51]

When the temperature of substance approaches critical temperature, the properties of its gas and liquid phases converge, resulting into only one phase at and beyond the critical point. This homogeneous and non-distinguishable phase is of fluid is known as supercritical fluid. The **heat of vaporization is zero** at and beyond this critical point, and so no distinction exists between the two phases. On the P-T diagram, the point at which critical temperature and critical pressure meet is **called the critical point** and **critical phenomena** of the substance.

For pure substances, there is an inflection point in the critical isotherm (constant temperature line) on a PV diagram, Mathematically it means that at the critical point derivatives are zero.

$$\left(\frac{\partial P}{\partial V}\right)_T = \left(\frac{\partial^2 P}{\partial V^2}\right)_T = 0$$

Therefore the first and second partial derivatives of the pressure p with respect to the volume V at a constant temperature T are both zero at the critical point. It can be used for calculation of two parameters for an equation of state of substance in terms of the critical properties.

1.3 SUPERCONDUCTIVITY

Superconductivity refers to a phenomenon of exactly zero electrical resistance and exclusion or absence of magnetic fields occurring in certain materials and it alloys when cooled below a characteristic critical temperature (T_c). This phenomenon was discovered by **Dutch physicist Heike Kamerlingh Onnes on April 8, 1911** in Leiden for Solid Mercury (Hg) at **T_c of 4.2K** using liquid He. Superconductivity is a quantum mechanical phenomenon like Ferromagnetism.

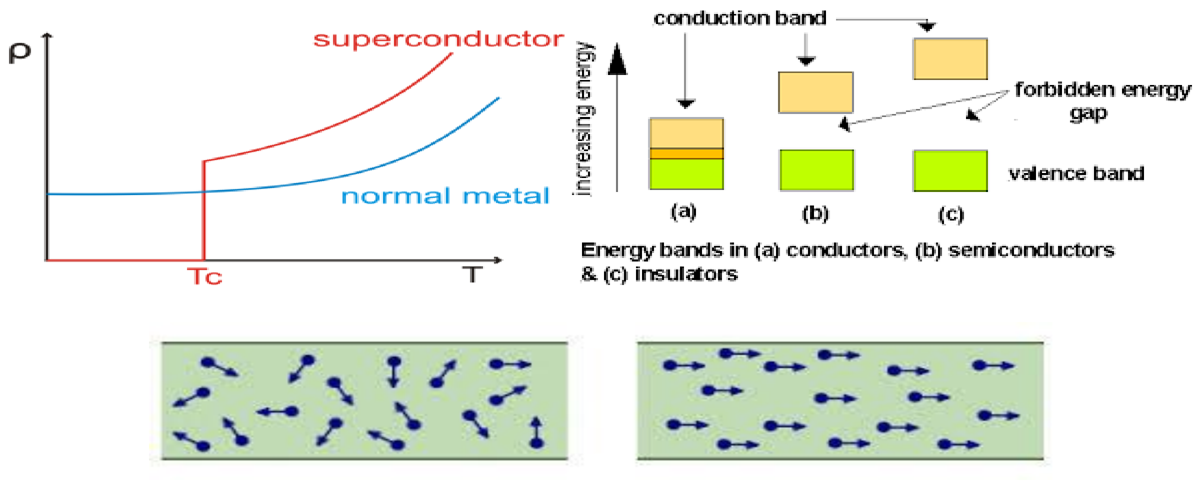


Figure 4: Comparison of decrease in resistivity for Normal and Superconductor [49, 55,56]

1.3.1 Meissner Effect and Magnetic Levitations

Superconductivity is characterized by the Meissner effect, the complete exclusion or ejection of magnetic field lines from the interior of the superconductor as it enters or transitions into the superconducting state. The Meissner effect and its occurrence indicate that superconductivity can levitate a magnet i.e. it describe the absence of magnetic field within the superconductor. The working of MagLev trans based on this principle due to the repulsion of magnetic field.

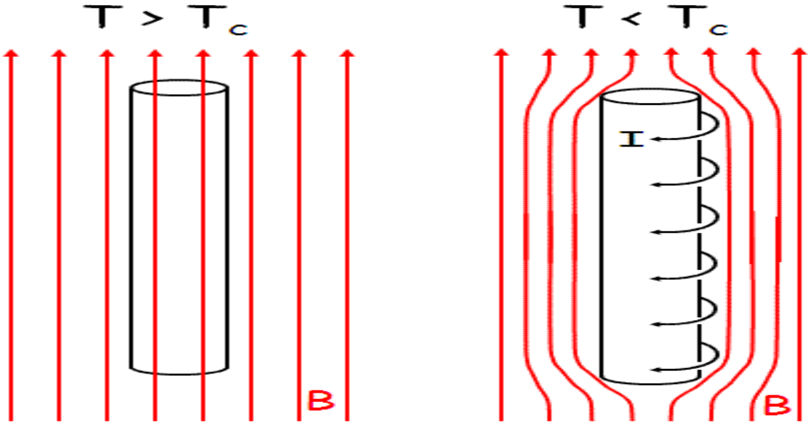


Figure 5: Meissner effect for Superconductor compared with normal conductors [53]

1.3.2 Cooper Pairs and BCS Theory

John Bardeen, Leon Cooper, and John Robert Schrieffer ("BCS") in 1957 first proposed the microscopic theory of superconductivity, which is based on the zero bnd gap and the Condensatoion of Cooper Pairs into a boson-like state without violating the **Pauli exclusion principle.** However the energy gap is highest at low temperatures but the band gap vanishes at the transition temperature when superconductivity exist at the critical temperature. When the Cooper pair is passing through a conductor, it attracts the lattice, causing distortion and a slight ripple toward its path which causes the electron to get attracted to that displacement. The coupling between electrons is depicted in a Feynman diagram as below:

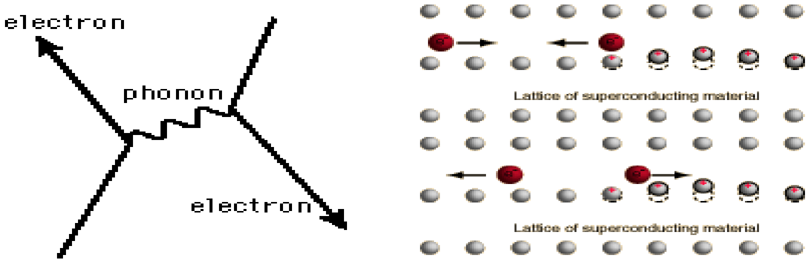


Figure 6: Illustration of cooper pairs and BCS theory [54]

1.4 MOTIVATION FOR THE REASEARCH

As the superconductivity is the phenomenon of zero resistivity of conductors at very low temperature i.e. at cryogenic temperature. So the application of superconductivity is impossible without cryogens such as Nitrogen, Hydrogen, Helium, Oxygen, Argon etc.. Thus the study of cryogenic is the prime field of research along with superconductivity and related applications such as HTS Cables, transformers, generators , SMES etc.

Presently there is a wide application of cryogens in liquid state and in subcritical regions due to the various benefits and suitability of these fluid rather than the supercritical fluids. Many of research groups and organizations are currently involved in the research of cryogenic fluid in supercritical region and subcritical region also but the study of fluids in subcritical region has following pros over supercritical fluids:

a. At a pressure and temperature below the critical point the handling of subcritical fluid is easy and safer than the supercritical fluid.

b. The latent heat of vaporization of the fluid is max at the boiling point.

c. The work required to pump and pressurized the subcritical fluid is lower.

d. Specific vol. is low so required smaller storage tank than supercritical fluid.

e. Subcritical fluid can be liquefied at high pressure whereas supercritical fluid can’t be liquefied at any pressure and hence possess very high specific volume.

There are many types of gasses used as cryogenic fluids according to their range of temperature and pressure, stability of their thermophysical properties, and ease of availability. Here this research is confined in only the study of thermophysical properties of Nitrogen in the subcritical region i.e. Subcritical Nitrogen (SCN_2) due to the following beneficial facts:

a) Nitrogen is the most abundant gas, 78% of the air, so better availability at low cost.

b) It is non-toxic, non-flammable, non-explosive, chemically stable and ease of handling.

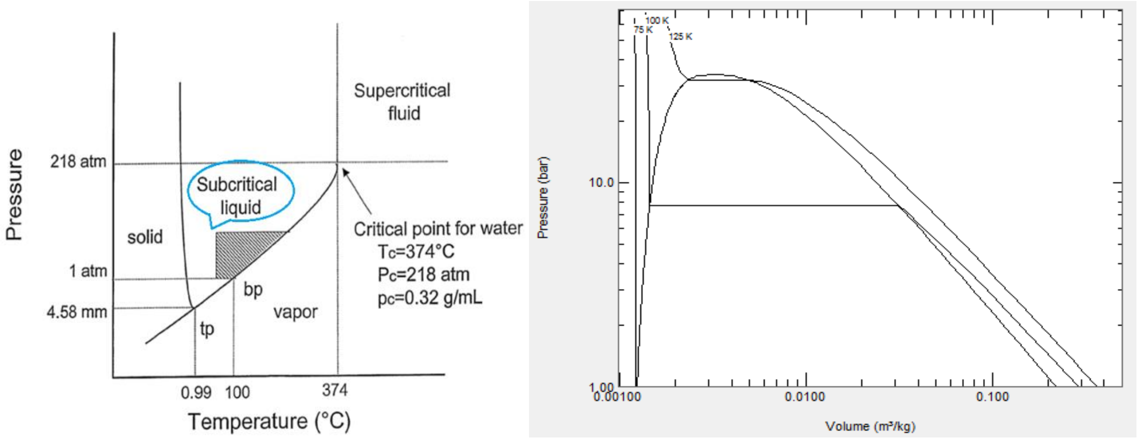
c) Large gap between saturation and critical temperature (50K), so more ref. effect (RE).

1.5 PROPOSED WORK AND ITS SIGNIFICANCE

The concept of superconductivity and the cryogenics (coolant) at supercritical and subcritical regions have been became more wide area of research application and thus gained much attention by researchers and engineers. As near critical point (sub critical region) and above critical point (supercritical region) at extreme pressure conditions the repulsive forces become important enough to overcome the surface tension and create almost single homogeneous phase which shares the properties of liquid and gases. At the critical point the isothermal compressibility of the one phase fluid becomes infinite **[4].** In the subcritical and transcritical regime, the thermophysical properties have non – linear relationship between the temperature and pressure. As the diffusivity and isobaric specific heat of cryogenics and supercritical fluid is high , it is considered as a proper solvent and coolant in many engineering applications**[2-3].**

As we increasing the temperature of any fluid from beyond its **triple point**(where all phase boundary exist) to its **critical point** (where no phase boundary exist) the transition of phase occurs and get converted into the supercritical fluid.

The below diagram shows the **subcritical region** for water, which can be defined for other fluids also such as Nitrogen, Argon, Hydrogen, Oxygen etc. between the normal boiling point to the characteristics critical point. For Nitrogen it lies from temperature range of 77.355 K to its Critical point 126.19 K



(a) **(b)**

Figure 7 (a), (b): Illustration of Subcritical and Subcritical region with phase diagrams [52, 10]

Critical phenomena and the formation of supercritical fluid of a substance is the result of dynamic phase equilibrium. When a material or fluid is heated until its specific critical temperature in a closed system (at constant pressure), a dynamic phase equilibrium is exist. This equilibrium state indicates that the same numbers of molecules coming out of the liquid phase to the gas by gaining energy and going into liquid phase from gas by losing energy. At this point, the phase curve between liquid and gas phases disappears and supercritical, a homogeneous phase appears. The **critical point** is **characteristic** of each material.

1.5.1 Application of Superconductivity and Function of Cryogens

Although the concept of superconductivity principle in engineering application is very useful in term of minimum energy losses and maximize the output in power generation, storage, transmission and distribution, but the major challenge is to achieve and maintain that extremely low temperature superconductivity phenomenon, which may exist within the temperature range of **-50 to -250 ^{0}C** for different fluids like Helium, Hydrogen, Oxygen, Nitrogen etc. So the need of proper coolant arises to dissipate the heat losses for efficient operation of HTS Systems.

The major function of any cryogen or coolant is to extract the heat from the superconducting device and maintain the cooling/refrigeration effect to achieve the desired temperature so that the operating condition can be kept stable and effective. Therefore the deep study and thermo-physical property analysis of cryogen with varying temperature and pressure is of major concern. Thus the development of correlations for major thermophysical and transport properties like thermal conductivity, specific heat, density, viscosity etc. would be very helpful for predicting the behaviour and performance of cryogen prior to actual application with the help of mathematical modelling and simulations. Liquid nitrogen cooling systems have been developed for HTS power devices over the past several years since liquid nitrogen is a cheap and excellent cooling medium and also a good electrical insulator. In recent research sub-cooled and subcritical Nitrogen are considered as important coolants. Compared to Supercritical and Saturated N_2, SCN_2 could obtain higher efficiency and performance.

CHAPTER 2

TERMINOLOGY

2.1 CONDUCTORS AND SUPERCONDUCTORS

Normal conductors are the material which having properties of transferring free electrons and having less energy gap and forbidden gap between conduction band and valance band, but due to the random motion and high entropy of the moving electron there is collision among the metal ions and electron which causes losses. However in Superconductors at very low or critical temperature there is very less entropy and therefore electron are aligned as a cooper pairs and moves freely without collision with positive ions and hence no resistance is offered by conductors resulting zero losses and heat generations.

Types of Superconductors: **(A)** Type I Superconductor and **(B)** Type II Superconductor

Type I Superconductor: It consist generally soft superconductors, in which magnetization loss occurs suddenly and exhibit Meissner effect. These are made of Pb, Hg, Sn etc.

Type II Superconductors: Hard superconductors with gradual magnetization losses and does not exhibit meissner effect. These types are made up of Nb-Ti, Nb-Sn and their alloys.

On the basis of Temperature Superconductors are further classified into two categories:

1. Low temperature superconductors (T_c <20K). [Here 77.35 K is the **Critical Point]**
2. High temperature superconductors (T_c >77K) [of N_2 which is taken as reference point]

2.2 CRYOGENICS AND CRYOGENIC FLUID

Cryogenic is the part of Physics and Engineering which deals with the production of very low temperature i.e. below -150^{0}C or 123K and the study of material behaviour at this temperature.

H.K. Onnes in 1911 identified the zero resistance/ superconductivity of solid mercury at cryogenic temperature using Liquid Helium as refrigerant at **4.2 K**. There are various fluids which are used as refrigerant like Nitrogen, Argon, Hydrogen, Oxygen etc. for cooling.

CHAPTER 3

LITERATURE REVIEW

3.1 PRESENT RESEARCHES

This chapter includes the studies of various scientist and research scholars in the field of cryogenics and its application in superconductivity especially in HTS power transmission cables. As the this thesis is focussed to study the major thermophysical properties of nitrogen is subcritical region near the critical point and hence develop the simpler correlations as a function of temperature and pressure to predict the behaviour, stability and performance of nitrogen as a suitable cryogenics, thus review of literature is also done with reference to properties of nitrogen in a wide range of temperature and pressure i.e. triple point to critical point including saturation or boiling point.

3.2 STUDIES BY RESEARCHERS AND CO-WORKERS

- **Richard T Jacobsen et al. (1973):** They studied and tabulated the thermodynamic properties of Nitrogen in wide range of temperature and pressure including liquid and vapour phases from 63K(freezing line) to 2000K with pressures 0 to 10,000 Bar. Their property table include values of density, internal energy, enthalpy, entropy, latent heat, isochoric specific heat(C_V), isobaric specific heat (C_P), velocity of sound, the isotherm derivative $\left(\partial P/\partial\rho\right)T$ and isochoric derivative $\left(\partial P/\partial T\right)\rho$.The thermodynamic tables which they presented are based of on an equation of state $P = P\left(\rho, T\right)$ which represent liquid and gaseous nitrogen in above mentioned temperatures and pressures. An extensive comparison is carried out for estimated data calculated from equation of states with reference to experimental thermodynamic data of each property. The coefficients of the equation of states were determined by a weighted least squares fit to selected $P-\rho-T$ and other property to illustrate the agreement between calculated and experimental data with an uncertainty of $\pm 1\%$ **[1].**

- **Azad Jarrahian et al. (2012):** They suggested a novel correlation approach to estimate the thermal conductivity of pure carbon dioxide in the supercritical region. Their work for development of correlation to predict the performance of SC-CO_2, created a curiosity to study the properties of cryogenic fluid below the critical point i.e. in subcritical region. Their study was mainly concerned about the correlation for thermal conductivity with the arithmetic average of the absolute value of relative errors(AARE) as 32.12% and sum of absolute of residual (SAR) as 5239 which is better than the prediction of ***Bahadori and Vuthaluru*** **[5].**
- **Ali Akbar Amooey (2014):** He also recently proposed a simple thermal conductivity correlation as a function of density and temperature for SC-CO_2 taking 600 data points. After statistical calculation, validation and comparison of results he concluded that the proposed correlation has better performance with lower AARE%(2.74) and SAR value(1044), hence having higher prediction abilities at a wider range of temperature from 290 K to 800 K and density from 1 to 1200 kg/m^3 with respect to **Jarrahian et al. and Bahadori et al**. Models **[6]**

3.3 STUDIES ON VARIOUS TYPES OF LOSSES

3.3.1 AC Losses in Conductors

When the AC current is varied the magnetic field would certainly leads to the movement of distraction which causes the induced e.m.f & current in the normal region as a result loss occurs due to this heat is being dissipated in the superconductor. This is known as AC losses in the HTS. AC losses in HTS conductors comprise of hysteresis losses due to self or external fields, eddy losses due to currents in sheath materials and coupling losses due to the presence of multiple filaments in HTS tape **[11].** So in order to dissipate heat loads SCN_2 may plays a vital role due to its unique thermophysical properties.

- **R.Wesche et al., [1999]** studied “Design of Superconducting cables” investigations shows [11]: Losses in superconducting cables are mainly due to AC losses, Thermal losses and dielectric losses. Cable geometry, operating conditions, transmitting power and resulting losses. According to Wesche, Bi-2223 cables with warm dielectric are operating well below 77 K. Temperature, 45-50 K, Bi-2212 super-conductors could be a best alternative instead Bi-2223. Properties of Superconductors for various cable applications.

- **J.A.Demko et al., [2001]** studied “Practical AC Loss and Thermal Considerations for HTS Power Transmission Cable Systems” investigations are as follows **[12]:** Counteracting ac losses and thermal losses by using parallel flow and counteracting flow arrangements, in both the arrangements, high temperatures are reached in the cable at lower flow rates (1000 g/s). In counter flow, the system temperature, at which the LN_2 is returned to refrigerator, is lower than the cable maximum. In parallel flow, it is quite opposite. Finally increasing the flow reduces the maximum temperature at the expenses of higher pressure drop.

- **H.Noji [2003]** studied “AC losses analysis of 114 MVA high-T_c superconducting model cable” investigation shows **[13]:** By using Electric circuit (EC) method the AC losses analysis for single phase HTS cable has been found out. Comparing axial field (B_{am}) and circumferential field (B_{cm}), B_{cm} values are dominant in the applied fields. Moreover, B_{cm} in the electrical shielding is low compared with B_{cm} in the conductor. This tendency strongly influences the distribution of the layer losses in the conductor. In the electrical shielding, the layer losses consist of W_{self} and W_{BC}

- **M.Yagi et al., [2003**] studied “Measurement of AC Losses of Superconducting Cable by Calorimetric Method and Development of HTS Conductor with Low AC Losses” investigations are as follows **[14]**: AC losses of 1 W/m level at 3 kA_{rms} obtained by enhancing winding pitches and twisted filaments in the tape. Accuracy of AC losses in a 3 m HTS conductor was 0.09 W/m with a measurement distance 2 m and flow rate of 0.5 kg/min. Placing insulation breaks between inner pipe and outer pipe eliminated the induced loss and the eddy current losses.

- **H.Noji et al., [2005**] studied “Numerical analysis of the AC loss in a high-T_C superconducting cable measured by calorimetric method”. His investigations shows [15]: Calculated AC losses on HTS cable manufactured by Furukawa Electric Industries Ltd (FEI) by using Electric Circuit method. Measured AC losses on HTS cable (FEI) by using Calorimetric method. The measured AC losses and Calculated AC losses show almost equal. Layer’s current are uniform on the low transport current. This indicates the drift-current phenomenon at higher transport current region.
- **K.Ryu et al., [2010]** studied “AC losses of the 5 m BSCCO cables with shield” investigations are as follows [16]: To measure the AC losses for multi-layered conductor and shield of HTS cable of 22.9KV/50MVA. Analysed results show that, AC loss measured from the lead attached to the shield (shield-lead) is constant irrespective of I_t. But the measured loss from the lead attached to the conductor is greatly dependent on transport period. Thick insulation around the conductor leads to exertion of heat transfer by the coolant around the conductor. As I_t high, the conductor temperature rises and thus the AC loss measured from the conductor-lead increases 1.5 times larger than that from the shield-lead.
- **Vysotsky et al.,[2011]** studied “AC losses and other researches with 5 m HTS model cable” investigations are as follows **[17]:** This test facility has taken place in Russian scientific R&D institute to perform extensive tests of heavily instrumented HTS cable model up to 5 m. Various test includes, critical current measurement, current distribution measurement among layers and joint resistance etc. For 5 m HTS cable models of 1G and 2G tapes, AC losses test has discussed.

3.3.2 Fluid and Pressure Losses

These losses are due to the variation in density and viscosity of the cryogenic fluid as the operating temperature and pressure of the cryogenic fluid rises therefore the intermolecular distance between the atoms will be less thereby the variation in transport properties leads to pressure drop and Heat transfer inside the HTS cable. So in order to overcome such challenges, SCN can be used due to viable transport properties at operating temperatures and pressures.

- **Posada. A et al., [2006]** studied "On conduction-cooling of a high-temperature superconducting cable" investigations are as follows **[21]:** Design of HTS cable with a copper layer incorporated in its thermal insulation, can achieve conduction cooling of HTS tape below its T_c. Various provisions considered for doing analysis, cable lengths, widths and insulation/copper thickness. Cable cost is minimised because there is no pumping requirement of cryogenic fluids.
- **J.A. Demko et al., [2009**] studied "Cooling configuration Design considerations for Long Length HTS Cables" His investigations are as includes **[20]**: HTS cable configurations were studied with a numerical model to asses thermal hydraulic performance with AC and thermal losses. Performance of long length cable systems for normal operating and fault conditions in a counter flow cooling geometry is perceived. Counter flow cooled, long length, HTS cables are technically feasible, energy saving and lower cost and it requires less cryostat. Analysed results, for 1000 meter HTS cable system it is feasible to build these lengths and stable recovery to full operating current can be achieved in reasonable.
- **Rajasekhar Dondapati and V.V. Rao [2013]** studied "Pressure drop and Heat transfer analysis of Long length internally cooled HTS cable". Their investigations show **[23]:** Analysis reveals, the phenomenon of turbulence preferment and heat transfer in HTS cables. At constant corrugation depth, pressure drop and Heat transfer increase with increase in corrugation pitch. To achieve efficient heat transfer, twisted tapes is inserted into the coolant path, elevating turbulence. Thermo physical properties of LN2are considered to be temperature dependent. Pressure drop and heat transfer carried out for different flow rates of LN2.At constant corrugation depth, the pressure drop increases with increases in corrugation pitch. In order to increase heat transfer twisted tapes are inserted by creating turbulence.

- **A.Sasaki et al., [2011]** studied “LN_2 circulation in cryopipes of superconducting power transmission line” His investigations includes **[22]:** Different kinds of losses in SC PT’s some are from coolant circulations others from radiation penetration into the cryopipe. Losses are directly proportional to the cable length, are large compared to the conduction loss through the current leads in the long distance systems.

3.3.3 Dielectric Losses in HTS Cable

Dielectric losses occur between the high temperature superconductor and shield material. In a cable with warm dielectric, each phase requires a separate high voltage cryostat enclosed in a conventional dielectric. The main disadvantage of this concept is the magnetic interaction of the different phases and eddy current losses. Whereas cold dielectric, it is immersed in $\mathbf{LN_2}$ and conductors are in direct contact with the coolant..

- **J.A.Demko et al., [2003]** studied “Cryostat Vacuum thermal considerations for HTS Power Transmission Cable Systems” investigation are as follows **[19].** Effects of degraded vacuum levels on the operation of HTS cables for different cryogenic thermal insulation systems have been studied. Two basic cable configurations being demonstrated are 1. Warm-dielectric (WD) 2. Cold dielectric (CD) and this study is based on single phase HTS cable for different lengths (100m and 1000m). CD cable shows, slightly higher temperature because there are ac losses in both the main and shield layers, which are at LN_2 temperatures. In both the cases, the pressure drops are not very high and do not change significantly due to extra heat loads caused by the degraded vacuum. Pressure drop over the 100m section is less than 0.9 bar for WD cable and less than 0.1 bar for CD cable.

- **J.A.Demko et al., [2005]** studied “Testing of the dependence of the number of layers on the performance of a one meter HTS Transmission Cable section” investigations are as follows [**20**]. Measurement of the dc V-I characteristics and the ac loss have been made on southwire company cable in the original four layer configuration and by varying with different layers (three, two and one layer cable). Different measurements used for finding ac loss measurements are calorimetric and electric method were used for one layer cable to within a factor of two. Electrical method, higher sensitivity at lower currents and the sample preparation is much simpler than the calorimetric method. The measured data for the four layer and one layer cable were compared against calculations using both the Monoblock model and Dresner model. When Ip/Ic <1 then ac loss is closer for four layer cable. For one layer cable both model is Ip/Ic <1. The HTS cable had a long response time for smaller current increase over some stable operating limit.

- **T. Nakatsuka[1] et al., (2014) [26]:** Research and develop the basic technology of HTS cable, fault current limiter, and transformer. Also study the 3 kA superconducting cable, cooling technology of HTS cable length 500m and power system analysis of cable and AC equipment's. The basic technologies have been started for the design of HTS cable by testing works. The feasibility studies for HTS cable also have been studied by power system analysis.
- **Dong Zhang[1] et al., (2012) [27]:**5 m/10 kA HTS DC power cable was developed which helps to investigate the design of a conductor, fabrication, current carrying capacity and stability of the 360 m/10 kA HTS power cable. A 5 m/10 kA HTS DC power cable has been designed, fabricated and tested to evaluate the performance of the 360 m/10 kA HTS DC power cable, which connect the rectifier output of a substation with the bus bar of an electrolytic aluminum cell in Henan Zhongfu Industrial.
- **Francesco Grilli [1] et al., (2012)** [**28**]**:** Evaluated the ac losses of HTS tapes and wires as well as of assemblies such as cables and coils. The formulation, used in the magnetic field components as state variables, had proved an efficient implementation to solve 2-D problems, which involves infinitely long or axially-symmetric geometries. Successfully implemented a 3-D model for time-dependent Simulations of high-

temperature superconductors using the H-formulation. The model has been validated by comparing the results with cases that can be solved in 2-D and has been used to show different examples of application on 3-D geometries.

- **Marijn Oomen[1] et al., (2012) [29]:** Investigate the use of 2nd-generation High-Temperature Superconductors (2G-HTSs) in the rotors of electrical motors and generators. It is operated in vacuum at temperatures around 30 K, in strong magnetic fields of about 2T.Impregnated Coils are desirable. Several of the coils show degradation of the superconducting properties. Three large impregnated 2G-HTS racetrack coils with kA current capacity were produced and successfully tested. Mechanical properties of 2G-HTS, their uniformity and fatigue behavior are studied.
- **Schmidt[1] et al.,(2009) [30]:** The integration of a high voltage cable in a networks always a particular case and in field of superconducting cables several designs are already available to fulfill the technical and environmental requirements. Superconducting cables have significant benefits for power transmission and distribution applications that provide new aspects and possibilities in network planning.
- **S.C. Kim[1] et al., (2007) [31]:** Two different Ag round wires are considered with different Ag ratio were fabricated by using powder in tube method and processing factor at each step was investigated. Microstructure after pre-annealing was investigated. Drawing stresses of two wires at first and second bundle wire are almost the same. In order to evaluate the uniformity of filaments, investigated COV of the wires.
- **Tosin Famakinwa[1] et al., (2007) [32]:** The eddy current losses in the matrix of two twisted filaments Bi-2223 HTS tapes in applied external AC magnetic field was calculated using 3D FEM software. Numerical calculation results shows that the Contribution of eddy current loss at commercial frequency is not minimum. The numerical results presented are for uncoupled filaments HTS tapes.

- **T. Hemmia[1] et al., (2006) [33]:** Study the current decay behaviors in HTS coils using Bi-2223/Ag tapes. Demonstrate that the resistance is enhanced due to the decay of the shielding current by the flux creep and flux flow. Results are compared with numerical analysis using a FEM. Current decay behavior is also discussed by choosing an overshooting excitation technique. The current decay behaviors are found to be affected by shielding currents. Improvement in decay behaviors is possible using appropriate excitation process like overshooting the initial current. It is determined by the joint resistance.
- **H.J.Kim[1] et al., (2004)** [**34**]**:** This paper is based on the study of electrical insulation properties of dielectric paper, such as breakdown voltage, partial discharge, which is one of the HTS cable structure elements. The PPLP had a high tensile stress in liquid nitrogen, but low tensile strain. As tensile stress increased the breakdown stress of PPLP was decreased because of micro crack occurrence.
- **Mitsuho Furuse[1]et al., (2003) [35]:** Establishment of long distance cooling techniques and design of a compact cross section are required for development of HTS cables. Temperature distributions of counter flow cooled HTS power cable and designed 3 different cable structures. These are effective from the view point of cooling design to produce compact cables**.**
- **ShinchiMukoyama[1] et al., (2003) [14]:** Reducing losses in large capacity cables and cooling cables. Obtain design data and improve the production technologies for the manufacture and installation of 500m cable.
- **Chikashi Suzuki[1] et al., (2003)** [**36**]**:** In this paper an investigation is done on the optimal design for the cabling parameters, Crossections of pitch length, dimensions of tape for YBCO and former diameter. Transverse bending strain can be calculated with the cabling parameters longitudinal bending strain can also be calculated.

- **Takato Masuda[1] et al., (2002)** [**37**]**:** Developed a 3-core 66 kV class HTSC cable and shield wound with Ag–Mn sheathed Bi-2223 tapes, insulation with polypropylene laminated paper impregnated with liquid nitrogen and thermal insulation with Co-axial corrugated pipes. The results of these tests clarifies good performance of the cable such as critical current value 2.4 kA, AC loss with 0.5 W/m/phase at 1 kA and AC 130 kV withstand voltage. It has the basic electric properties required to a 66 kV HTSC cable.
- **Yanhua Yang et al., [2009],** in their research paper "A new heat transfer correlation for supercritical fluids" **[45]** have indicated that: The heat transfer of supercritical fluids shows abnormal behavior as compared to that of conventional fluid. The new correlation can be applied to both normal and Heat Transfer Deterioration (HTD) conditions. New correlation shows better results as compared to the earlier developed correlations.
- **Z.Q. Long et al., [2013],** in their research "Natural convective heat transfer of supercritical helium in a closed vertical cylinder" **[46]** have indicated that The natural convective heat transfer of supercritical helium in a closed vertical cylinder gives excellent heat transfer performance as compared with that of conventional gases. Heat transfer can be enhanced by increasing the helium charging amount. In the Rayleigh number range (5 X 1010 to 2 X 1014), the Nusselt number increases almost exponentially with the Rayleigh number 9.
- **Raja Sekhar Dondapati and V.V. Rao [2014],** in their research paper "Entropy generation minimization (EGM) to optimise mass flow rate in dual channel cable-in-conduit conductors (CICCs) used in fusion grade magnets" **[24]** have indicated that: Factors that affect entropy generation in CICC include heat transfer, flow with friction and mixing of flow streams. Optimum mass flow rate was calculated at which heat transfer rate is highest. In dual channel CICC, entropy generation due to thermal

gradient dominates as compared to that of velocity gradient. In his work, optimum rate of entropy generation as found as a function of mass flow rate.

- **Anbin Chen et al., [2010],** in their paper “Design of the cryogenic system for a 400kW expertal HTS synchronous motor**”** **[38]** have indicated that the designed model has the heat load of 730.4 W. This heat load is the sum of heat leaks from the surroundings and internal heat generation in the device. By taking the basis of heat load, cryogenic system was designed.
- **S.K. Baik et al., [2006],** in their paper “Effect of synchronous reactance and power factor on HTS synchronous machine design and performance” and “Electrical Design of a 17MW Class HTS Motor for Ship Propulsion” **[43-44]** have concluded that as synchronous reactance becomes smaller, it is possible to get better design results and performance characteristics at steady state condition. Moreover, smaller synchronous reactance increases armature current at transient states such as fault condition and motor starting.
- **Minseok Joo et al., [2004],** in his paper “Dynamic control of large scale high temperatures uperconducting synchronous motor” **[41**] has indicated that the control strategy of starting the high temperature superconducting synchronous motor with constant field windings is to give gating signal commands during accelerating period.
- **Sang-Ho Lee et al., [2008],** in their paper “Study on homopolar superconductivity synchronous motors for ship propulsion applications” **[42]** have analysed for superconducting synchronous motors and their applications in ship propulsion application with effective cooling

CHAPTER 4

RATIONALE AND SCOPE OF STUDY

4.1 OBJECTIVES OF THE STUDY

As discussed and investigated in previous chapters and literature reviews it will be very helpful and beneficial to study the performance and behaviour of cryogenic fluids to be used in superconductivity applications. Thus the development of correlation for thermophysical properties of fluid will be an effective ways to predict the performance. Therefore the main objective of this research can be summarized as follows:

- To analyse and identify the major thermophysical properties of nitrogen which plays major role in its application as a cryogenic at very low temperature and high pressure.
- To study phase diagram of Nitrogen in subcritical region and draw the conclusion.
- To study the temperature dependent variation and the nature of trends of the two major thermophysical properties, i.e. thermal conductivity and isobaric specific heat and two major transport properties i.e. density and viscosity of Nitrogen in the subcritical region.
- To develop and proposed a novel temperature dependent correlation for a wide range of temperature, so that the study of its performance as a cryogenic will be easier in future.

4.2 SCOPE OF THE STUDY

The major role of cryogenic in superconductivity and HTS cables is to extract the heat, which is dissipated as a result various losses such as thermal losses, AC losses, etc. So it is necessary to analyse the heat transfer nature and thermophysical properties more precisely at a less interval of temperature. During its application in underground HTS cable the fluid has to be pumped and circulated within the steel corrugated pipe carrying the cable. So it is also necessary to study the flow behaviour and transport properties of Nitrogen in the subcritical region, which will be helpful in pressure drop analysis, frictional loss calculation and pumping power calculation for different length and current carrying load of HTS cable.

CHAPTER 5

RESEARCH METHODOLOGY

5.1 INTRODUCTION

Redman and Mory define research as a “systematized effort to gain new knowledge or in other words it is art of scientific investigation. To carry any research and study the research methodology is the heart of analysis and study. This is very crucial stage of study which requires lots of attention and investigation on the research problem. It includes the step by step progression of research toward the results. It is an iterative process in which lots of iteration is required to refine the results and reach to the expected outcomes. The research methodology will be shown as the below flowchart:

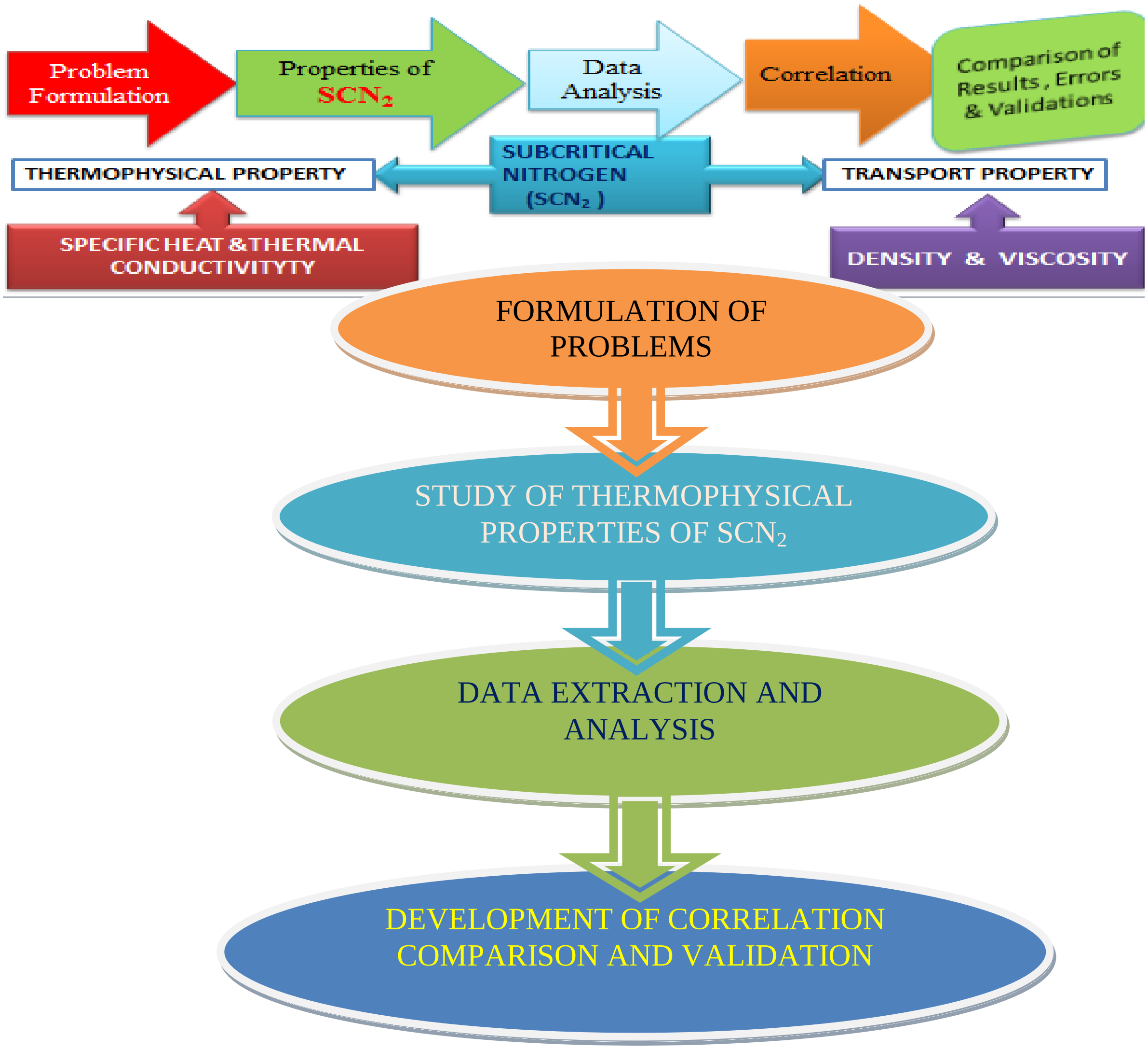
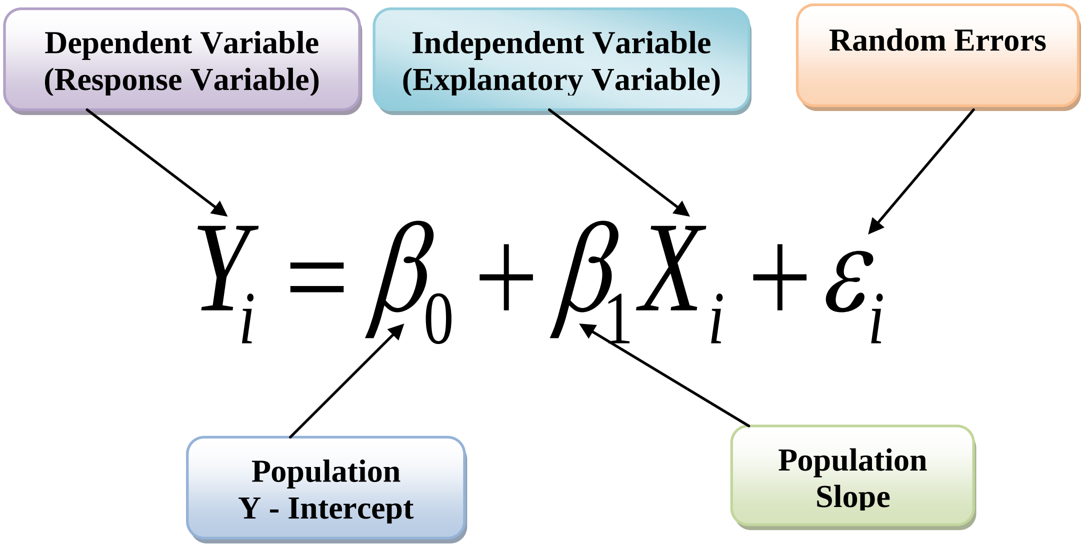


Figure 8: Flow chart for the research methodology

5.2 USE OF MATHEMATICAL TOOL

The present research is based on quantitative approach and data analysis to develop the temperature dependent correlation for each of the four major properties of Nitrogen. The formulation of research problem is to propose the correlation for thermophysical properties in the subcritical region. All the data are extracted from the **NIST web book** for the wide range of temperature and pressure in subcritical region of Nitrogen. After graphical investigation and data analysis it was found that there is drastic variation of property values in the specified sub critical region so it will be complicated to develop a single correlation for the whole data in subcritical region. Therefore multiple range of temperature was be taken and hence the multiple correlation will be develop as a piecewise continuity of polynomial functions. This required a number of iteration and investigation. The suitable range of temperature was identified for different pressures. After that **Linear Regression and Correlation Techniques** will be employed to develop the correlations and for minimizing the errors **Least Square Method** will be used. The linear regression model is defined as follow:



$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

In this research study the dependent variable are all of the four properties and temperature is the independent property, i.e. the resultant correlation will be temperature dependent.

5.3 STUDY OF MAJOR PROPERTIES OF NITROGEN

Table 1: Values of Major Thermophysical Properties of Nitrogen at Specific Points [25]

Temperatures (K) At P=1.03215 bar	**Thermal Cond.(W/m-K)**	**Specific Heat (KJ/kg-K)**	**Density (Kg/m3)**	**Viscosity (Pa-s)**
Near TP 63.251	**0.17726**	**1.9999**	**866.96**	**3.07E-04**
AT BP 77.355	**0.14581**	**2.0415**	**806.08**	**1.61E-04**
ATBP 77.355	**0.0075**	**1.1239**	**4.6121**	**0.0544E-04**
Near CP 126.15	**0.01241**	**1.0547**	**2.7334**	**0.0864E-04**

Table 2: Various Cryogenic Fluids and their normal characteristics points [25]

Cryogen	**Triple Point [K]**	**Boiling Point [K]**	**Critical Point [K]**
Methane	**90.7**	**111.6**	**190.6**
Oxygen	**54.4**	**90.2**	**154.6**
Argon	**83.8**	**87.3**	**150.9**
Nitrogen	**63.1**	**77.3**	**126.2**
Neon	**24.6**	**27.1**	**44.4**
Hydrogen	**13.8**	**20.4**	**33.2**
Helium	**2.2**	**4.2**	**5.2**

After going through the extensive literature review on various issues related to study of thermophyscal properties of cryogenic fluids and their application in cooling of HTS Cables, it is found that there is research gap i.e. no work is done for major properties of SCN_2 as cryogens. So major four properties i.e. Specific Heat, Thermal Conductivity, Density and Viscosity are chosen, which play vital role in heat transfer and flow circulation for cooling of HTS Cables. Here table (2) shows various cryogenic fluids out of which this dissertation describe only about Nitrogen in Subcritical region as a better cryogenic refrigerant for cooling of HTS cable at wide range of pressures and temperatures.

5.4 STUDY OF MAJOR THERMOPHYSISCAL PROPERTIES OF SCN$_2$

- **DENSITY:** It is defined as the mass of fluid per unit its volume, i.e. it specify that how closely the molecules are packed in the fluid, closer the packing means they are denser. The SI unit of density is kg/m^3 and denoted as ρ. The density of Nitrogen is high in liquid state in the temperature range between TP to BP. Whereas it drastically reduced after the boiling point as the phase changes from liquid to vapour phase. As shown in table at BP temperature density is 806.08 kg/m^3 in liquid state and 4.6121 kg/m^3 in vapour state. So it is preferable to in the temperature range above BP to Critical point. Lesser dense fluid will need lesser pumping power and hence circulation of cryogenic will be easier in the HTS cable.

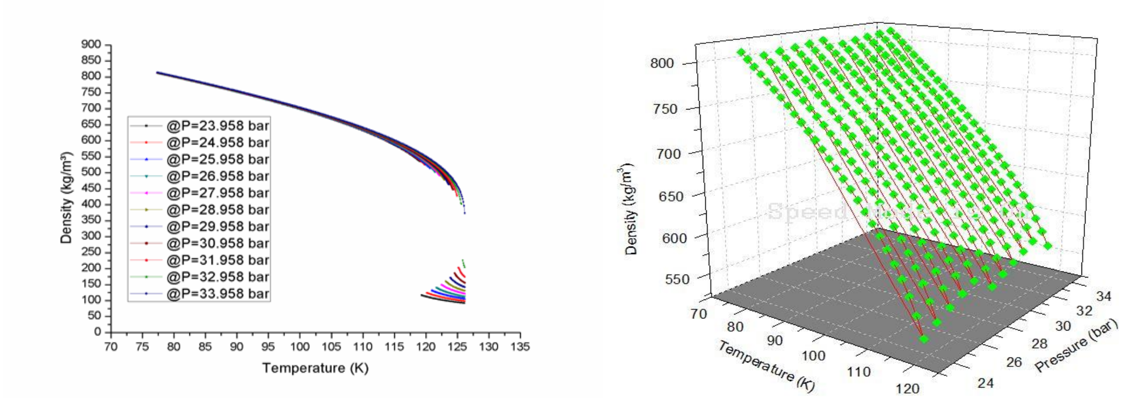


Figure 9: Density of Subcritical Nitrogen as function of temperature and pressure [10]

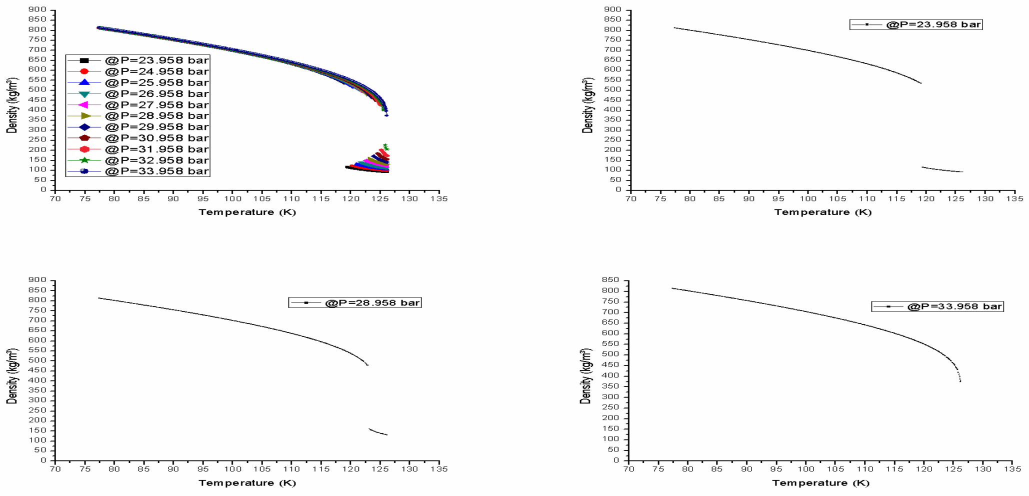


Figure 10: Density as a function of temperature at different pressures [10]

- **VSCOSITY:** It is the major factor responsible for flow behaviour and pressure drop of cryogenic fluid within the corrugated steel pipe carrying the HTS cable. It is defined as the resistance offer by any fluid during its flow due to shear stress between the different layers of fluid. Its SI unit is pa-s and denoted as μ and kinematic viscosity as ν. As shown in table the viscosity of Nitrogen is very less of the order 10^{-4} in liquid as well as in vapour state. It is also decreasing as the temperature rises due to increase in internal energy. At BP the values of viscosity is **1.61E-04 pa-s** and **0.0544E-04** pa-s respectively in liquid and vapour states, i.e. in vapour state viscosity is reduced by approximately by 30 times.

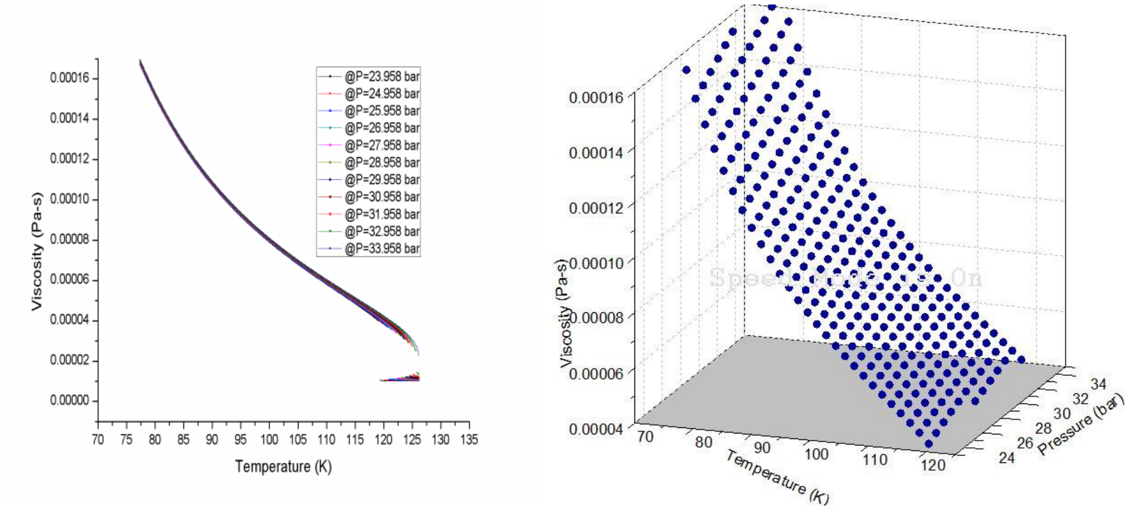


Figure 11: Viscosity of subcritical Nitrogen as function of temperature and pressure [10]

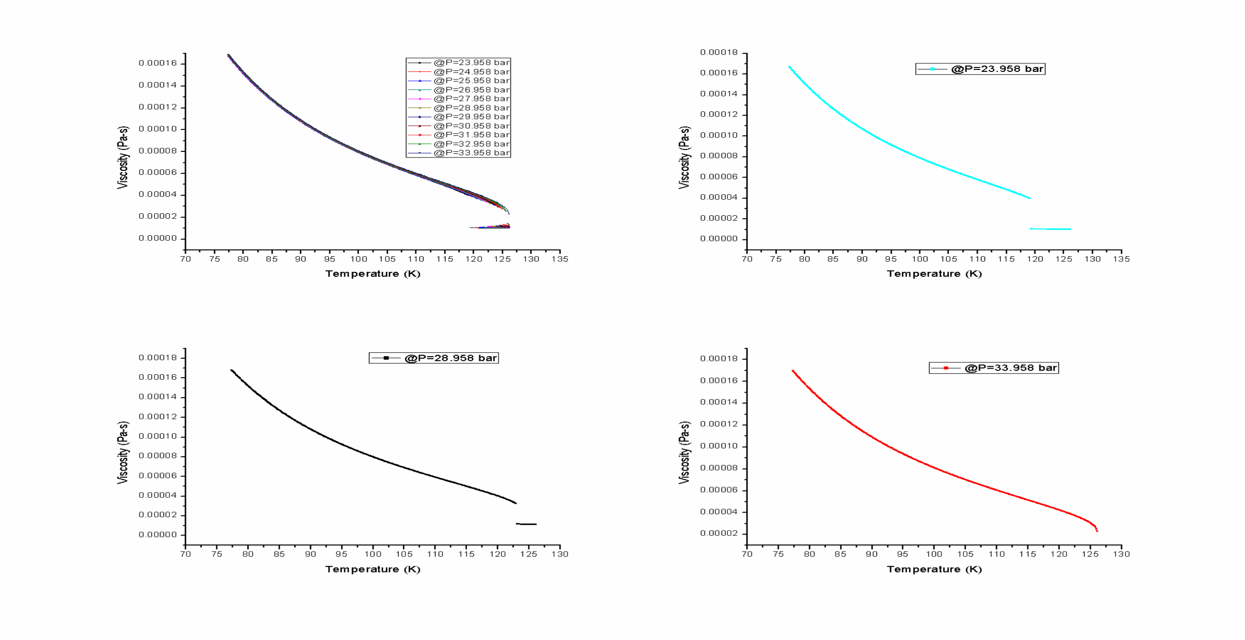


Figure 12: Viscosity as a function of temperature at different pressures [10]

- **<u>THERMAL CONDUCTIVITY</u>:** It is major thermophysical property of cryogenic fluid in the heat transfer point of view, as it shows the property of material to conduct the heat and it is evaluated by using Fourier's law of heat conduction. It is often denoted as k, λ, or κ and its SI unit is W/mK. High thermal conductivity materials are used in heat sink or cooling application and low thermal conductivity material are used in thermal insulation application. At boiling point due to the phase change from liquid to vapour all the properties have two different values, one for liquid phase and other for vapour phase. The K values at boiling point are 0.14581 and 0.0075 respectively. It can be seen that as the temperature approaches to critical point K value decreases.

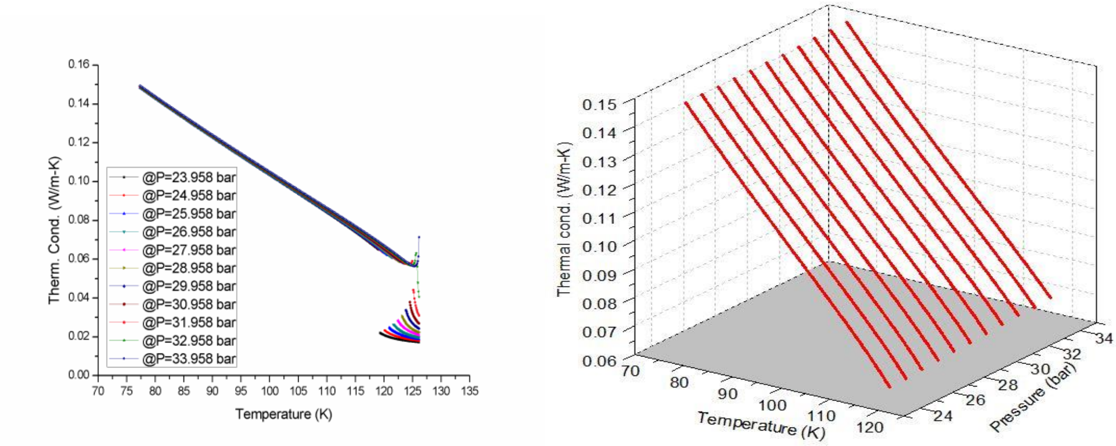


Figure 13: Thermal Conductivity of SCN$_2$ as function of temperature and pressure [10]

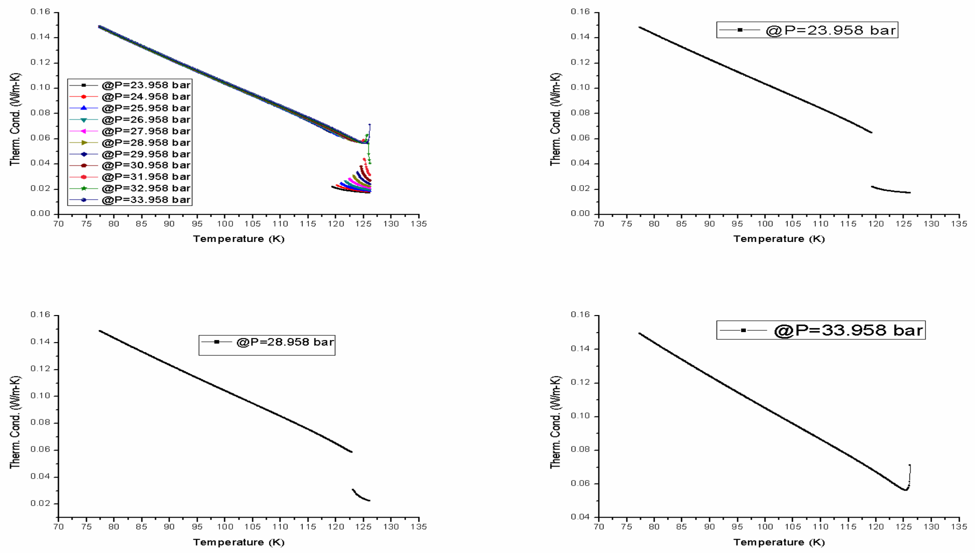


Figure 14: Thermal Conductivity as a function of temperature at different pressures [10]

- **ISOBARIC SPECIFIC HEAT:** It is defined as the amount of heat required for the temperature of unit mass of fluid by 1 ^{0}C at constant pressure. Its SI unit is KJ/kg-K and denoted as C_P. Since it signifies the required heat energy, so for ideal refrigerant low specific heat is desirable. As shown is table the specific heat of Nitrogen is less and continuously decreasing after BP and near critical point, it is minimized (1.054KJ/kg-K

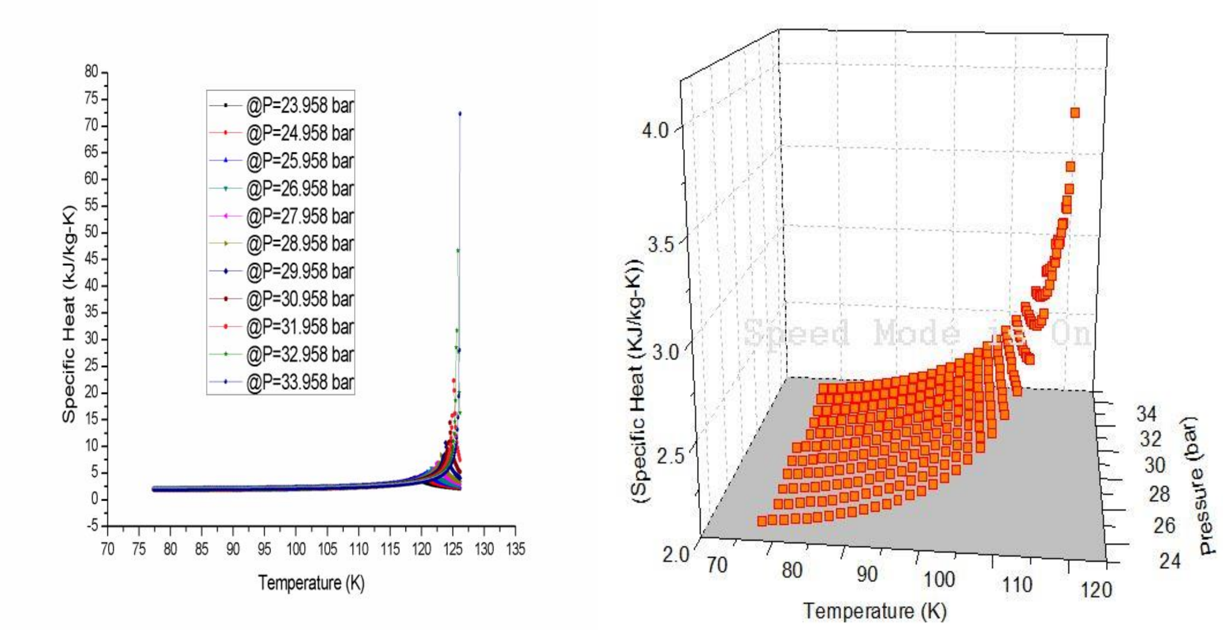


Figure 15: Specific Heat of SCN_2 as function of temperature and pressure [10]

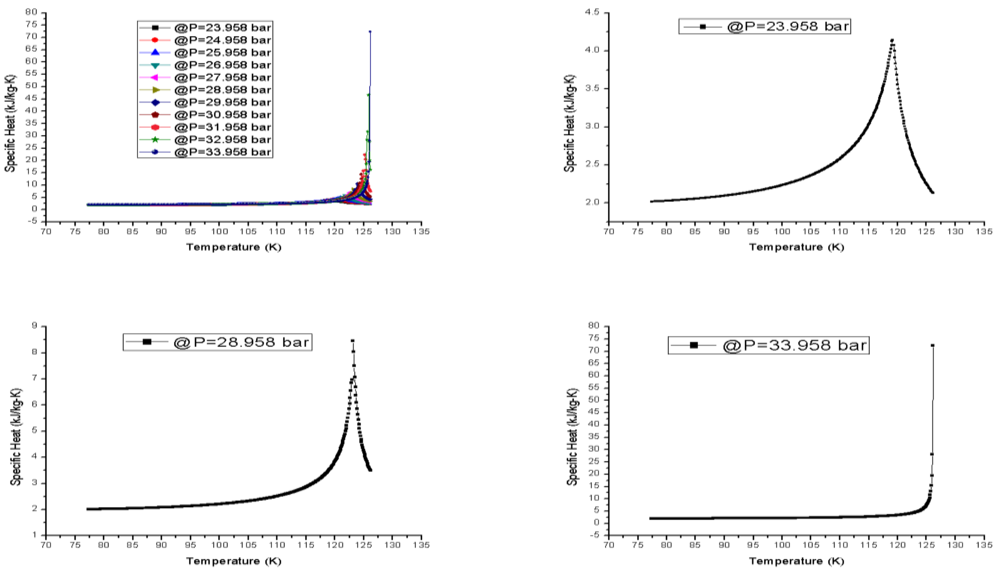


Figure 16: Specific Heat as a function of temperature at different pressures [10]

5.4.1 Conclusion for Thermophysical Properties

Thus after analysing all the above major properties of Nitrogen it can be concluded that it is suitable for cryogenic cooling of HTS cables and can minimize all losses during its application.

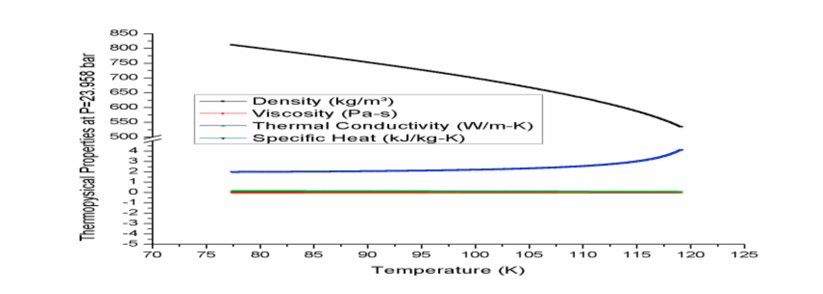


Figure 17: All the prop. as a function of temperature at a pressure 23.958bar [10]

Here in the above figure (17), variations of all the four properties are well compared within the range 77.355K – 126.15K. There is increase in thermal conductivity whereas specific heat and viscosity are almost constant with temperature. The increase in thermal conductivity and decrease in density value are desirable for cryogenic refrigerant point of view, as less dense fluid will need lesser pumping power and higher thermal conductivity will favour the rapid heat transfer rates, whereas constant viscosity may offer less viscous loss and pressure drop.

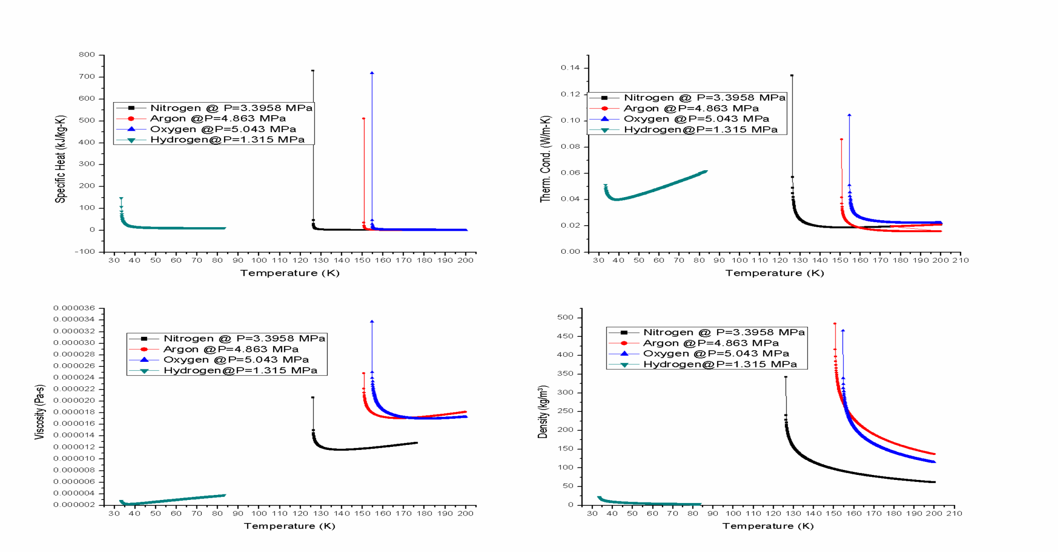


Figure 18: Properties of N_2 compared with other cryogens at their Critical Pressure [10]

Here Nitrogen is compared with Oxygen, Argon and Hydrogen at their critical pressure as shown **figure (18).** The higher values of thermal conductivity and specific heat whereas lower values of density and viscosity shows dominating applicability of Nitrogen over other cryogens

CHAPTER 6

RESULTS AND DISCUSSION

6.1 STUDY OF PHASE DIAGRAM AND PHASE CHANGE

The trends of extracted data from the NIST web book for thermophysical property of Nitrogen in subcritical region shows the drastic variation and with rise in temperature at a particular pressure. So after data analysis it is found that at a pressure of 23.958 bar the thermophysical properties shows continuous variation within he temperature range 77.355 K to 119.00 K and then from 119.15 K to 126.15 K. This breakage of range is due to the fact that 119.07 K is the boiling point of Nitrogen at a pressure of 23.958 bar and hence phase change occurs. Thus at that particular point of temperature all the properties have two different values, one for liquid phase and another vapour phase. For example it can be seen for density of Nitrogen as below:

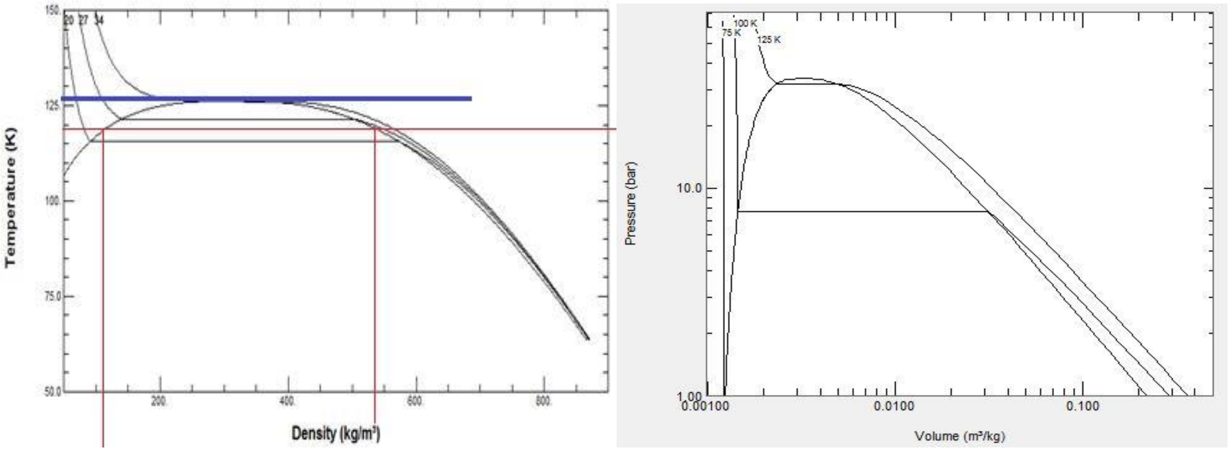
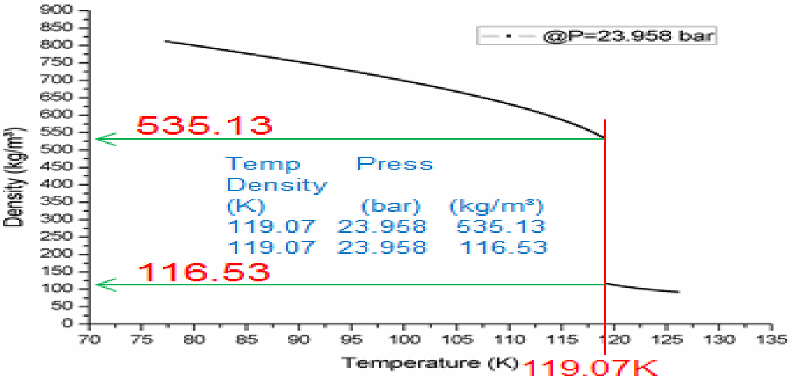


Figure 19: Temperature- density and P-V diagram of Subcritical Nitrogen [25]



Temp (K)	Press (bar)	Density (kg/m³)
119.07	23.958	535.13
119.07	23.958	116.53

Figure 20: Breakage of density value at the boiling point due to phase change [10]

6.2 POLYNOMIAL CURVE FITTING AND DEVELOPMENT OF CORRELATIONS

The outcome of this research is the temperature dependent correlations for thermophysical properties of Nitrogen in the subcritical region for different suitable range of temperature. The correlation are obtained by using the mathematical curve fitting technique using **Linear Regression Model** and **Least Square Method**. The curve fitting is polynomial as per trends of variation of data and extent of errors with respect to exact fit. Since exact fit is very rare due presence of residual errors so best fit is desirable to obtain the simple correlation. In exact curve fitting the curve passes through each data points whereas the best fitted curve only concern those major points which follow a particular trend and variation.

6.2.1 Curve Fitting for Density Data

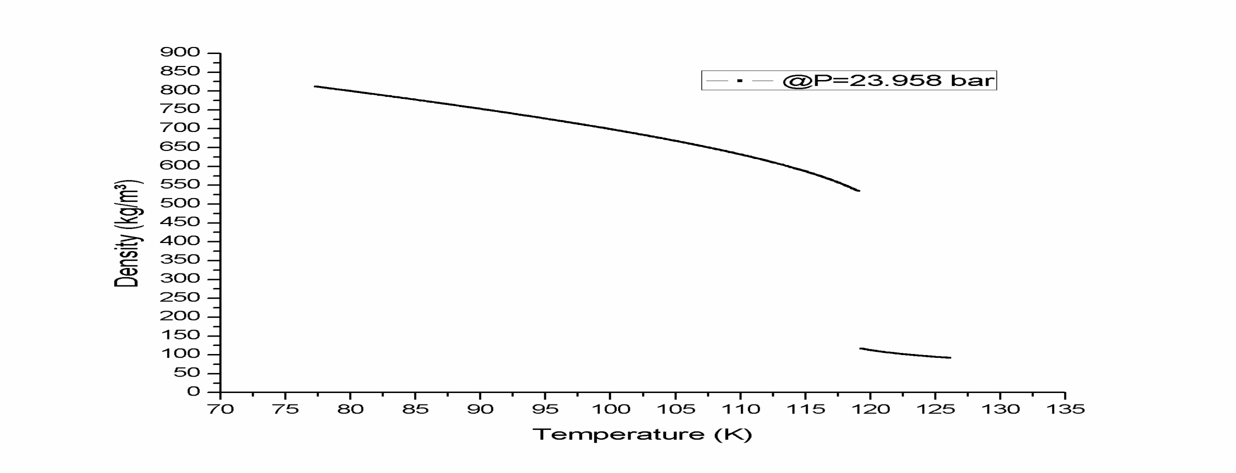
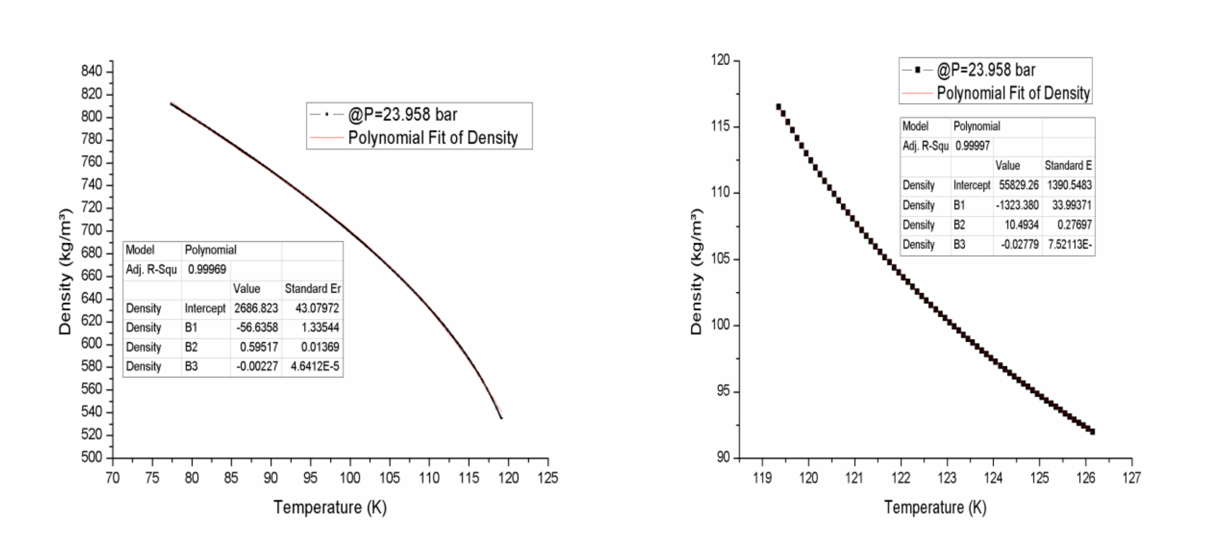


Figure 21: Density as a function of temperature at a pressure 23.958bar [10]



Model	Polynomial		
Adj. R-Squ	0.99969		
		Value	Standard Er
Density	Intercept	2686.823	43.07972
Density	B1	-56.6358	1.33544
Density	B2	0.59517	0.01369
Density	B3	-0.00227	4.6412E-5

Model	Polynomial		
Adj. R-Squ	0.99997		
		Value	Standard E
Density	Intercept	55829.26	1390.5483
Density	B1	-1323.380	33.99371
Density	B2	10.4934	0.27697
Density	B3	-0.02779	7.52113E-

Figure 22: Polynomial curve fitting of Density data at a pressure 23.958bar [10]

6.2.2 Curve Fitting for Viscosity Data

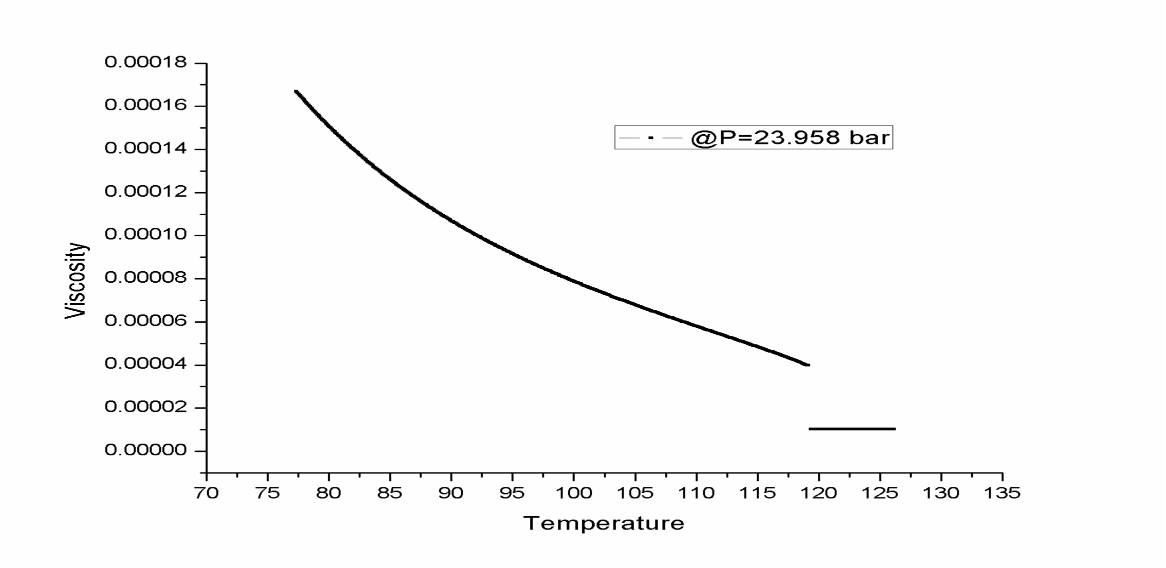
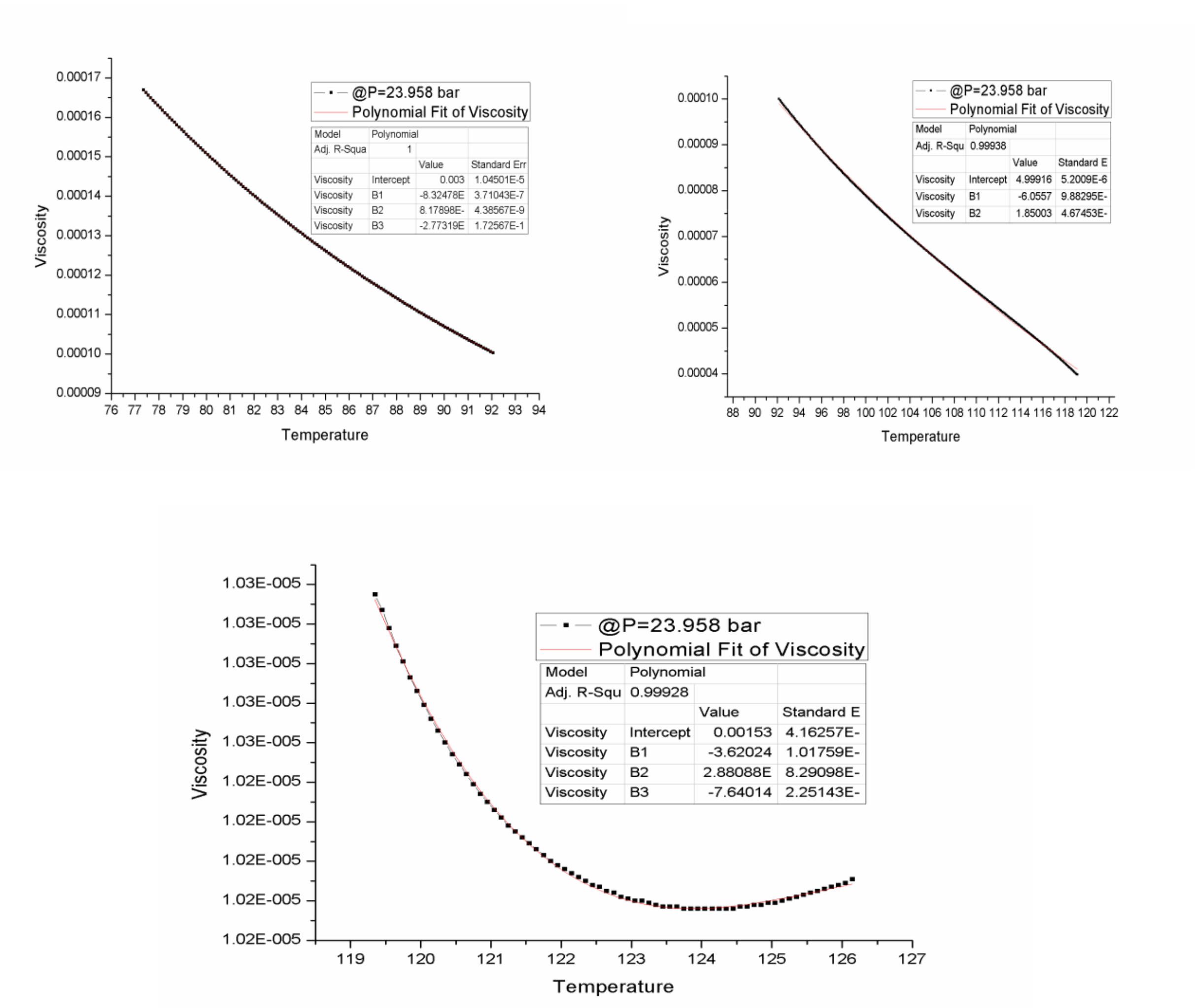


Figure 23: Viscosity as a function of temperature at a pressure 23.958bar [10]



Model	Polynomial		
Adj. R-Squa	1		
		Value	Standard Err
Viscosity	Intercept	0.003	1.04501E-5
Viscosity	B1	-8.32478E	3.71043E-7
Viscosity	B2	8.17898E-	4.38567E-9
Viscosity	B3	-2.77319E	1.72567E-1

Model	Polynomial		
Adj. R-Squ	0.99938		
		Value	Standard E
Viscosity	Intercept	4.99916	5.2009E-6
Viscosity	B1	-6.0557	9.88295E-
Viscosity	B2	1.85003	4.67453E-

Model	Polynomial		
Adj. R-Squ	0.99928		
		Value	Standard E
Viscosity	Intercept	0.00153	4.16257E-
Viscosity	B1	-3.62024	1.01759E-
Viscosity	B2	2.88088E	8.29098E-
Viscosity	B3	-7.64014	2.25143E-

Figure 24: Polynomial curve fitting of Viscosity data at a pressure 23.958bar [10]

6.2.3 Curve Fitting for Thermal Conductivity Data

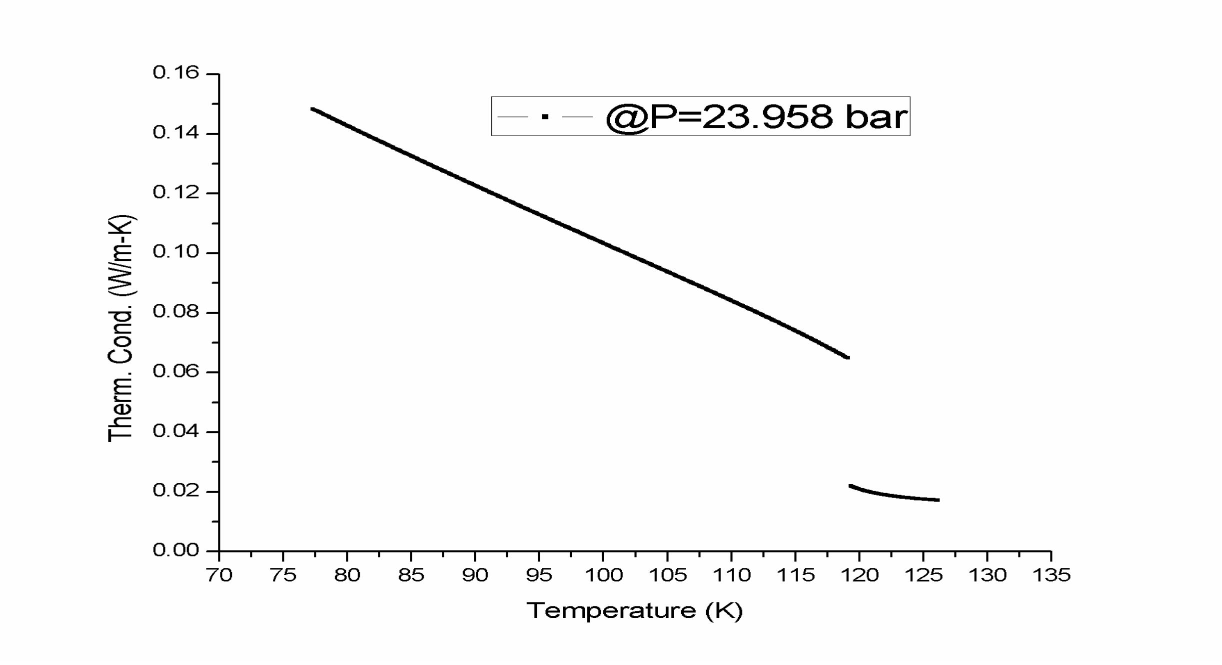


Figure 25: Thermal Cond. as a function of temperature at a pressure 23.958bar [10]

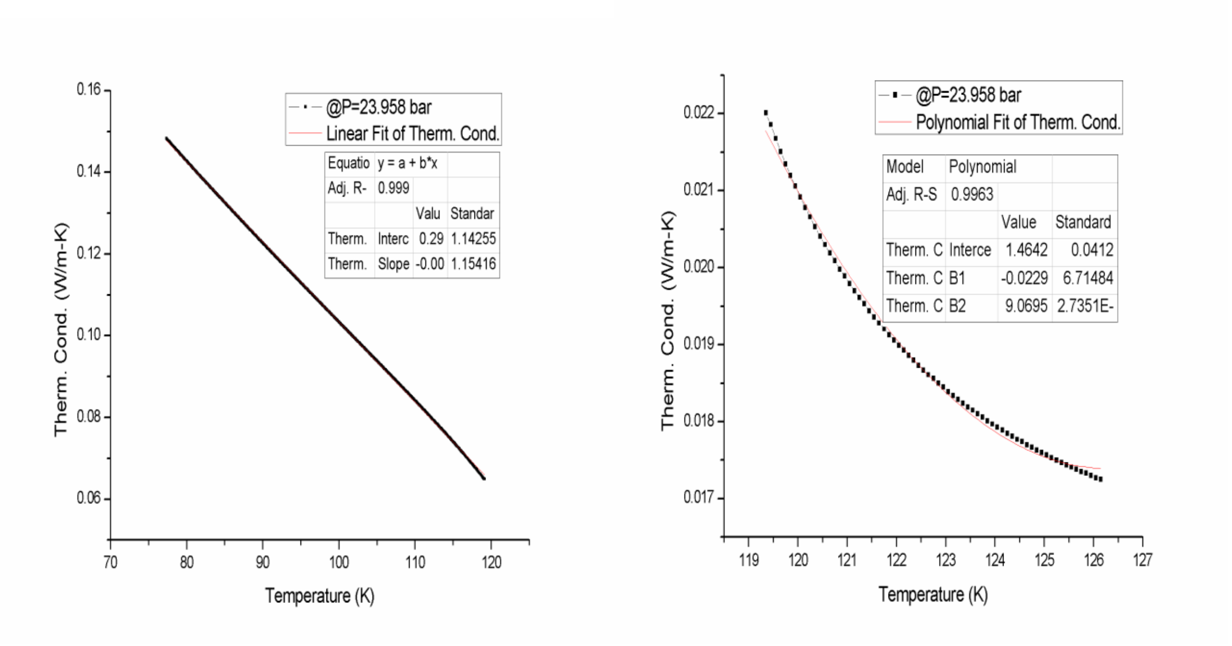


Figure 26: Polynomial curve fitting of Viscosity data at a pressure 23.958bar [10]

Here the figure () shows almost linear variation of thermal conductivity with respect to temperature (77.355K-119.15K) which follows first order linear equation **y = mx + c,** whose slope (m) is **– 0.00196** with positive X-axis and intercept on Y-axis (c) is **0.29929.**

6.2.4 Curve Fitting of Isobaric Specific Heat Data

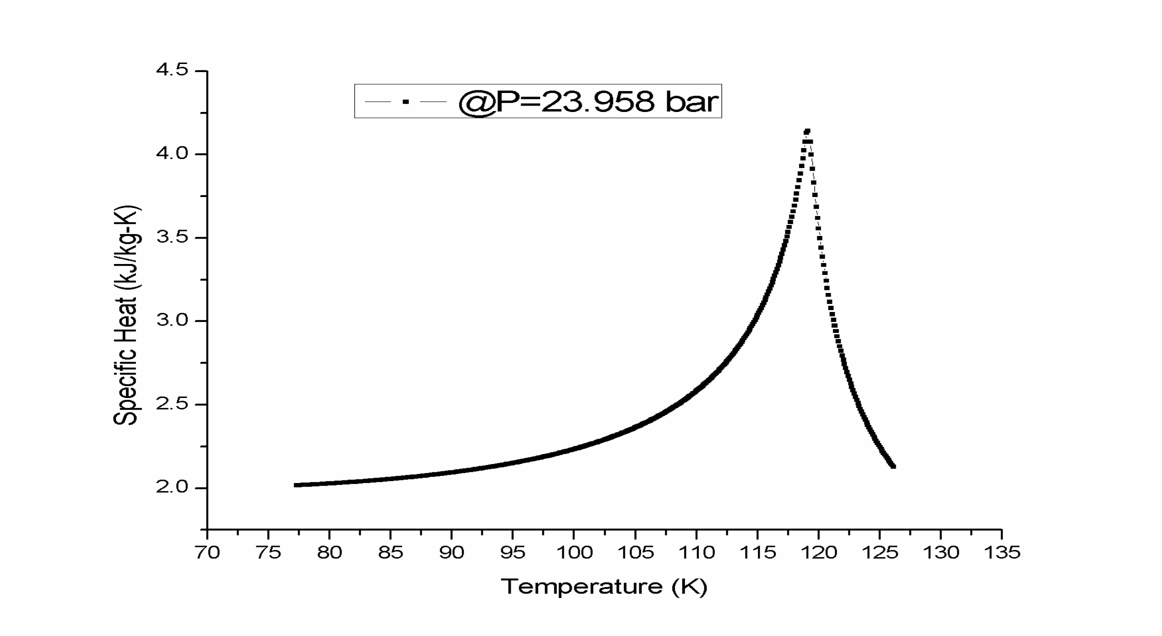
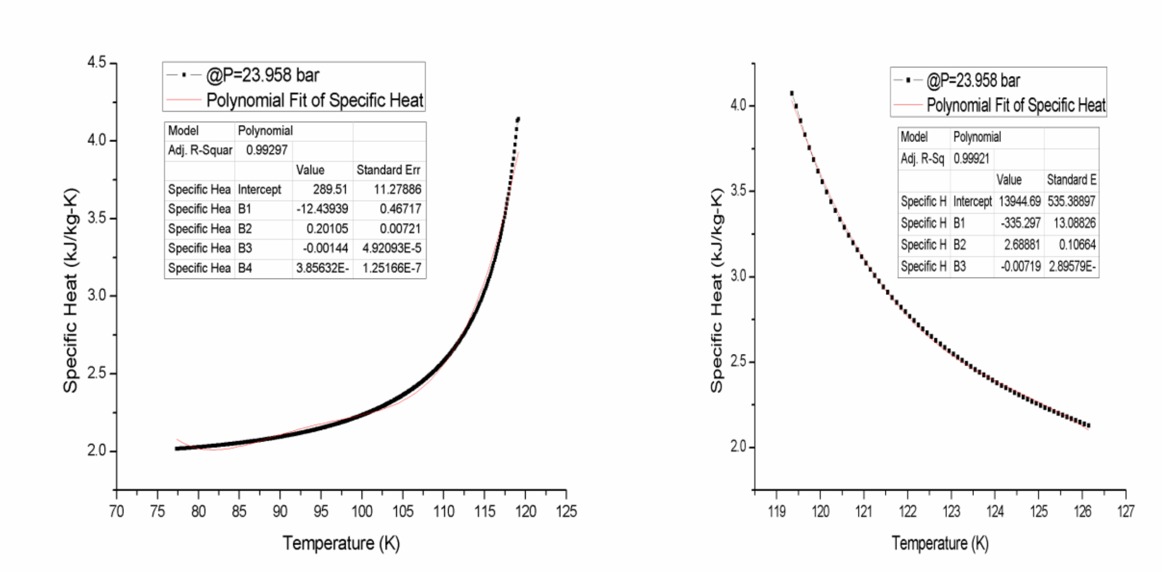


Figure 27: Specific Heat as a function of temperature at a pressure 23.958bar [10]



Model	Polynomial		
Adj. R-Squar	0.99297		
		Value	Standard Err
Specific Hea	Intercept	289.51	11.27886
Specific Hea	B1	-12.43939	0.46717
Specific Hea	B2	0.20105	0.00721
Specific Hea	B3	-0.00144	4.92093E-5
Specific Hea	B4	3.85632E-	1.25166E-7

Model	Polynomial		
Adj. R-Sq	0.99921		
		Value	Standard E
Specific H	Intercept	13944.69	535.38897
Specific H	B1	-335.297	13.08826
Specific H	B2	2.68881	0.10664
Specific H	B3	-0.00719	2.89579E-

Figure 28: Polynomial curve fitting of Specific Heat data at a pressure 23.958bar [10]

After the best curve fitting of all the data for Density, Dynamic Viscosity, Thermal Conductivity and Isobaric Specific Heat for suitable temperature ranges got the simple polynomial temperature dependent correlations which is well tabulated and described in section - 6.2.5 with their polynomial coefficients and correlation coefficients.

6.2.5 FINALLY DEVELOPED TEMPERATURE DEPENDENT CORRELATIONS

Table 3: Correlation Table for all the properties of SCN_2 for different T ranges

PROPERTIES	Temperature Range	Correlations	Correlation Coefficients
DENSITY **Correlation Coeff.** **R^2 = 0.9996**	77.355K ≤T ≤119.15K	$\rho(T)=\sum_{i=0}^{3}\rho_i T^i$	ρ_0 = 2686.823 ρ_1 = -56.6358 ρ_2 = 0.59517 ρ_3 = -0.00227
	119.35K ≤ T ≤126.15K	$\rho(T)=\sum_{i=0}^{3}\rho_i T^i$	ρ_0 = 55829.26 ρ_1 = -1323.38 ρ_2 = 10.4934 ρ_3 = -0.02779
VICOSITY **Correlation Coeff.** **R^2 = 0.9993**	77.355K≤ T ≤ 92.055K	$\mu(T)=\sum_{i=0}^{3}\mu_i T^i$	μ_0 = 0.003 μ_1= -8.324 x10^{-5} μ_2 = 8.1789x10^{-5} μ_3 = -27731x10^{-9}
	92.15K ≤ T ≤ 119.15K	$\mu(T)=\sum_{i=0}^{2}\mu_i T^i$	μ_0 = 4.999x10^{-4} μ_1= -6.055x10^{-6} μ_2 = 1.850x10^{-5}
	119.35K ≤ T ≤ 126.15K	$\mu(T)=\sum_{i=0}^{3}\mu_i T^i$	μ_0 = 0.00153 μ_1= -3.620 x10^{-5} μ_2 = 2.8808x10^{-7} μ_3 = -7.64x10^{-11}
THERMAL CONDUCTIVITY **Correlation Coeff.** **R^2 = 0.9998**	77.355K ≤ T ≤ 119.15K	$\kappa(T)=\kappa_0+\kappa_1 T$	k_0 = 0.229929 k_1 = -0.00196
	119.35K ≤ T ≤ 126.15K	$\kappa(T)=\sum_{i=0}^{2}\kappa_i T^i$	k_0 = 1.46421 k_1 = -0.02291 k_2 = 9.069x10^{-5}
ISOBARIC SPECIFIC HEAT **Correlation Coeff.** **R^2 = 0.99929**	77.355K ≤ T ≤ 119.15K	$C(T)=\sum_{i=0}^{4}C_i T^i$	c_0 = 289.51 c_1 = -12.43939 c_2 = 0.20105 c_3 = -0.00144 c_4 = 3.8563x10^{-5}
	119.35K ≤ T ≤126.15K	$C(T)=\sum_{i=0}^{3}C_i T^i$	c_0 = 1.3944x10^{4} c_1 = -335.2974 c_2 = 2.6881 c_3 = -0.00719

6.3 STATISTICAL PARAMETERS FOR VALIDATION OF CORRELATIONS

There are various statistical parameters for the validation and error analysis of obtained results. All those parameters will be employed at the final stage of research to assure the accuracy and suitability of research results. In order to ascertain the quality of the proposed fitted model and correlations, statistical following parameters will be used. Small values of parameters refer to dependable correlation.

- The Arithmetic Average of the Absolute Values of the Relative Errors **(AARE%)** is defined as

$$AARE\% = \frac{100}{N}\sum_{i=1}^{N}\left(\left|\frac{X_i^{\exp} - X_i^{cal}}{X_i^{\exp}}\right|\right) \quad \textbf{……… \{1\}}$$

- It is an indication of the accuracy of the correlation. Another parameter is defined as Sum of Absolute of Residual (SAR) which is defined below shows the reliability of correlation for more dense data points.

$$SAR = \sum_{i=1}^{N}\left|X_i^{\exp} - X_i^{cal}\right| \quad \textbf{………… \{2\}}$$

- The Average Percent Relative Error (ARE%), which is defined in Eq. (3) gives a measure of the bias of the correlation, a value of zero indicates a random of the measured values around the correlation.

$$ARE\% = \frac{100}{N}\sum_{i=1}^{N}\left(\frac{X_i^{\exp} - X_i^{cal}}{X_i^{\exp}}\right) \quad \textbf{…………. \{3\}}$$

- The **Percent Relative Error (RE%)** which is defined in Eq. (4) Measures the calculated values w.r.to experimental values. for each thermophysical properties correlation as a function of temperature.

$$RE\% = 100 \times \left(\frac{X_i^{\exp} - X_i^{cal}}{X_i^{\exp}} \right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\{4\}$$

- The **Adj. R-Square Value(Curve Fitting Coeff.),** which is defined in Eq.(5) gives the degree of approximation of curve fitted w.r.to exact curve fitting for equations.

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (X_i^{\exp} - X_i^{cal})^2}{\sum_{i=1}^{N} (X^{mean} - X_i^{cal})^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\{5\}$$

Table 4: Values of Statistical Parameters for fitted curves and correlations

PROPERTIES	TEMP.	AARE%	ARE%	SAR	R^2
DENSITY	TR1 TR2	0.688326	6.88E-01	1912.7869	0.9996
		4.719823	4.71E+00	325.39993	0.9999
VISCOSITY	TR1 TR2 TR3	3.152771	3.15772	59.13E-05	1.0000
		0.574809	1.00E-02	9.600E-05	0.9993
		3.601E+01	3.61E+01	25.429E-05	0.9992
SPECIFIC HEAT	TR1 TR2	2.161E+01	2.16E+01	221.4477	0.9929
		1.599942	9.96E-02	3.157411	0.9992
THERMAL COND.	TR1 TR2	0.2679530	0.1285998	0.104779	0.9998
		1.1797511	1.18E+00	15.635E-03	0.9963

6.4 ERROR ANALYSIS OF DEVELOPED CORRELATIONS

As discussed in above **section 6.3**, these parameters are very helpful to justify the fitted values of correlations with the experimental NIST values. Here all the four temperature dependent properties are plotted taking into account their relative errors with respect to the values of NIST web book. Minimum error shows correlations are not much biased.

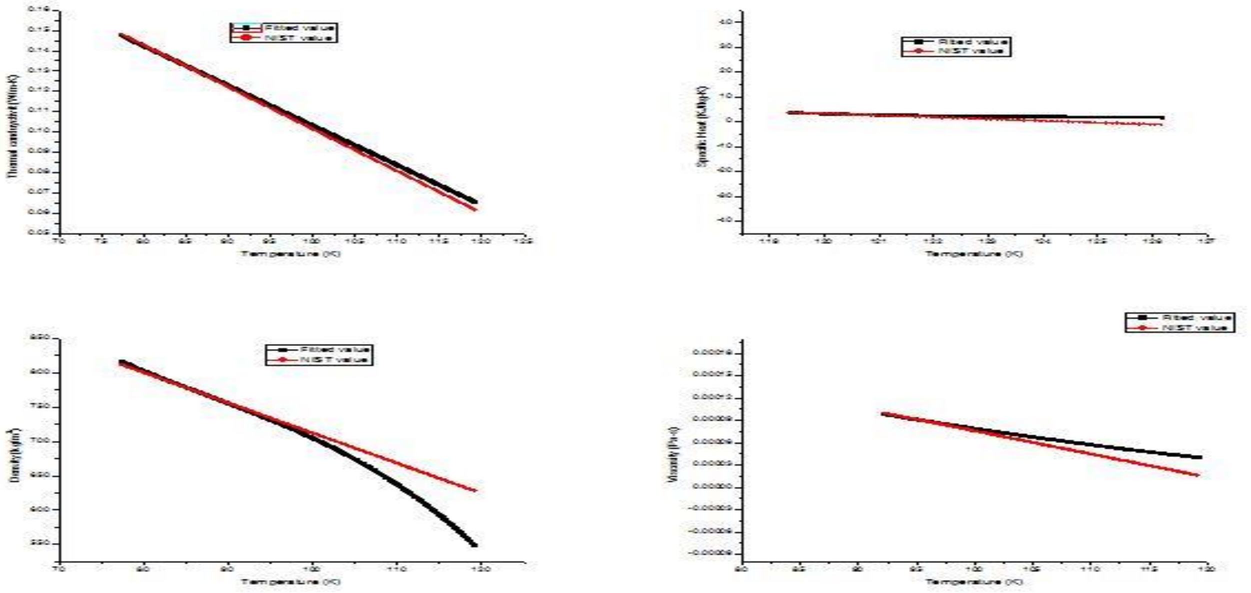


Figure 29: Comparison of Correlation Fitted v/s NIST values with Temperature [10]

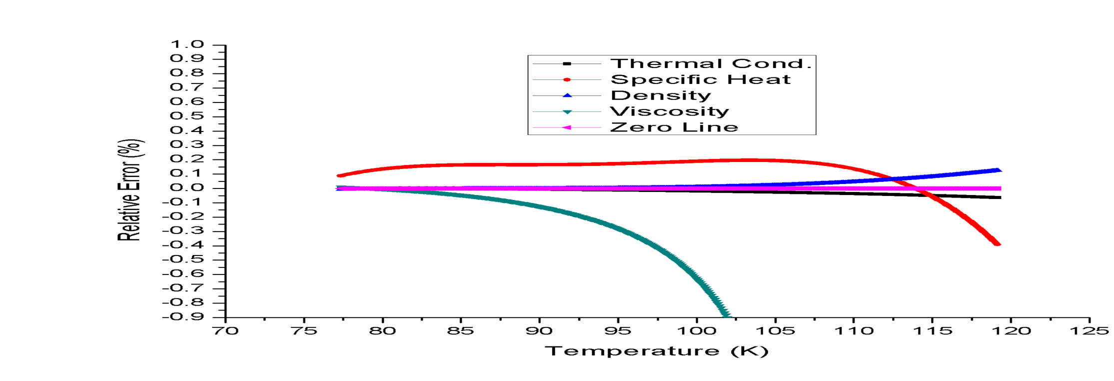


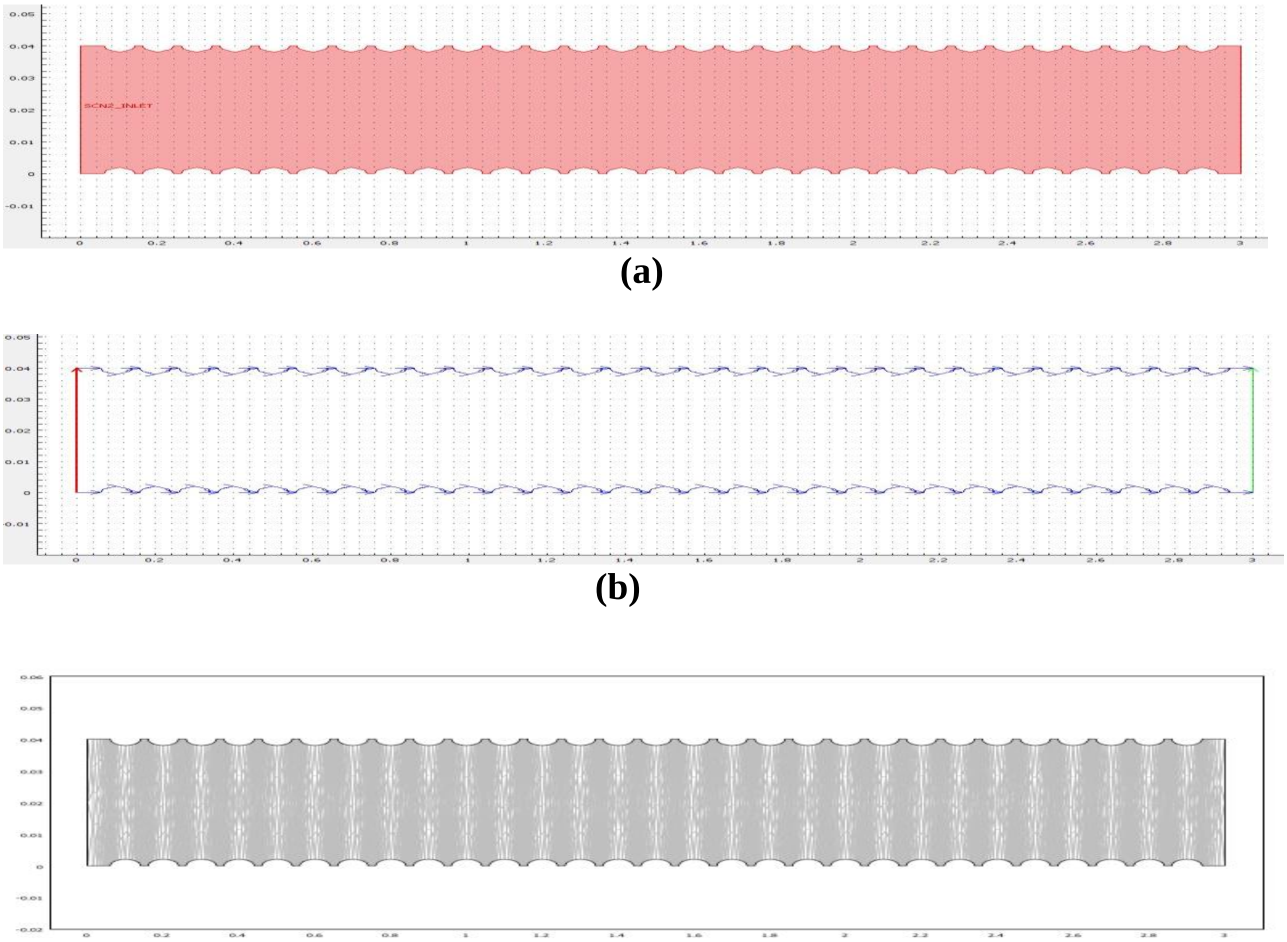
Figure 30: Relative errors of Correlation Fitted values with Temperature [10]

As shown in **figure 30** the relative errors are much lesser and closer to zero line. The errors lie within a narrow range of +0.3 to -0.9, which indicates the dependency and reliability of the developed correlation. The errors may be due to the less precision in taking the interval of analysis. Moreover these errors can minimized to greater extent by taking fine temperature intervals and more number of iterations during the data analysis and interpolation of values.

6.5 EXTENDED FUTURE WORK

This research work can be further extended for Design and Simulation work using the developed correlation function for various major properties of Subcritical Nitrogen (SCN_2). Heat transfer and Flow analysis are of major concern to judge the better suitability and applicability of Nitrogen cryogenic fluid as a refrigerant for better cooling of HTS cables. Therefore a prototype of corrugated steel pipe **(CSP)** of internal **diameter 40mm and 3m of length [23]** is taken for simulation in **COMSOL** Multiphysics Software. For heat transfer analysis 2D **convection and conduction mode** and for flow velocity analysis the **incompressible Navier-Stokes equation** mode is applied. The results are shown below:

6.5.1 Heat Transfer and Flow Velocity Analysis



(a)

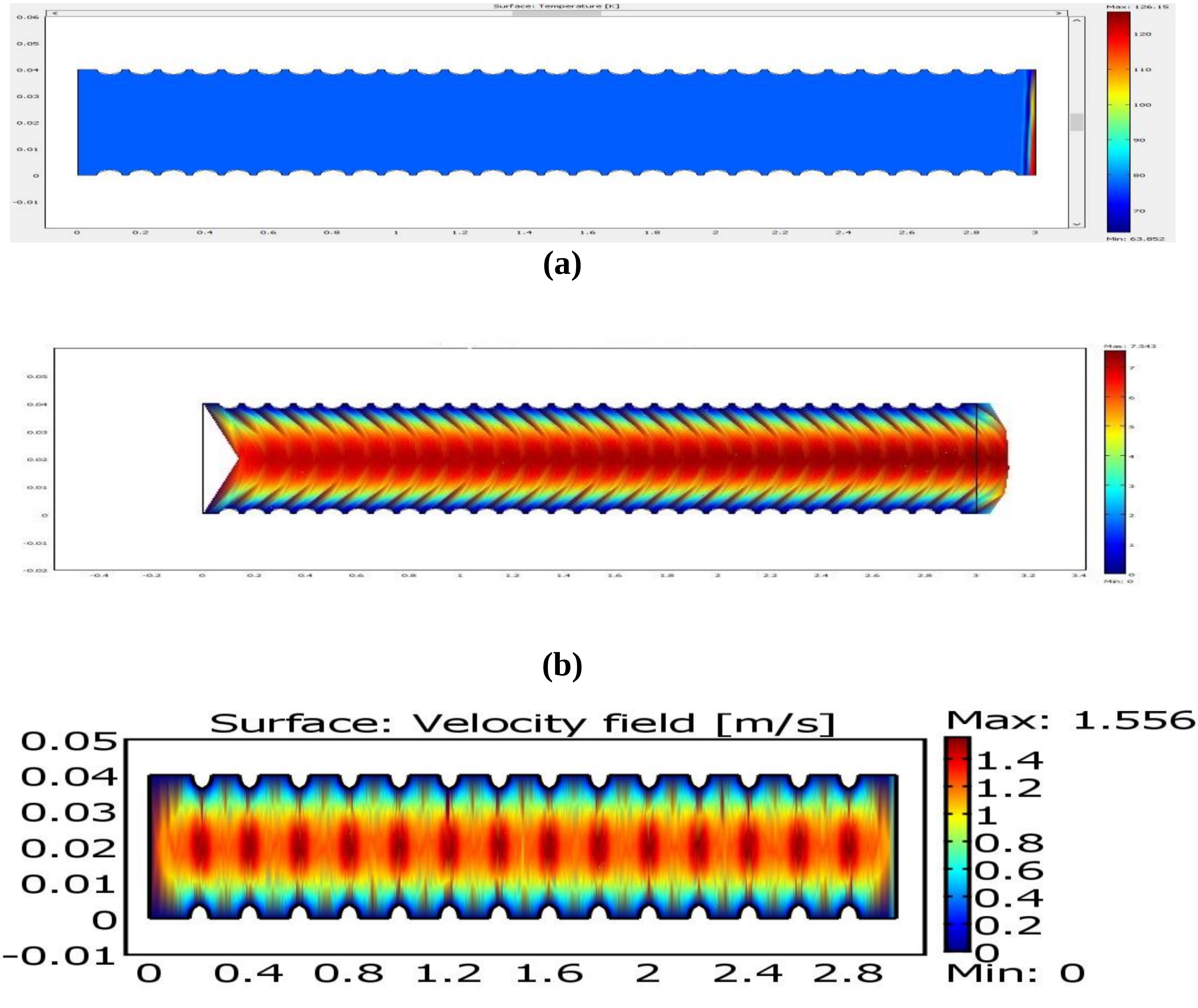
(b)

(c)

Figure 31: (a) Geometry of CSP (b) Boundary Conditions (c) Meshed Structure [57]

After solving the simulation problem with applied boundary conditions and subdomain settings, following results are observed:

- There is a uniform and minimum temperature distribution on the surface of former.
- The inlet temperature is 63K and rises to 126K when exiting out by absorbing heat.
- Heat transfer rate and temperature rise is more along the center of the corrugated pipe.
- Heat absorbed by subcritical Nitrogen circulating along center is around 7.543KW.
- There is minimum velocity and better circulation of Nitrogen cryogen near the wall.
- Corrugated geometry of wall surface provides better turbulence of fluid and flexibility.
- Flow velocity is maximum about 1.55 m/s along the center of the corrugated steel pipe.



(a)

(b)

(c)

Figure 32: (a) Temp. Distribution (b) Heat Transfer (c) Flow Velocity Analysis [57]

6.5.2 Cooling Capacity for Different Volume Flow Rates

The main purpose of cryogenic fluid is to cool the HTS cables by dissipating the heat and maintaining the superconducting state during the entire application of transmission. Therefore analysis and study of cooling capacities for different flow rates are of prime concern for better heat dissipation and effective transmission of current in HTS cable. Here cooling capacities at different flow rates and fluid temperatures are analyzed at **23.958bar** and a fixed wall temperature of **164K**. It can be seen from the **figures 33 (a) and (b)** that as the temperature difference and volume flow rates increase form **5L/min to 10L/min** the cooling capacity get increased accordingly from 14.44KW to 28.95KW. Although the increased flow rates may cause more pressure drop within the pipe and also require more pumping power to circulate it continuously, however it will be more effective and preferable for stationary cooling application such as for transformer etc.

$$Cooling\_Capacity = \rho * V * C_p * (T_w - T_f) \text{..............................} \quad \textbf{(6)}$$

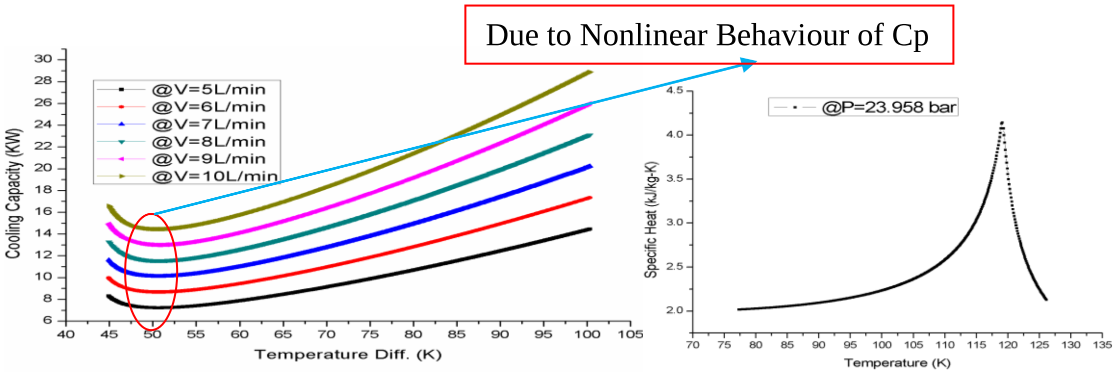


Figure 33(a): Cooling capacity v/s temp. difference for various flow rates[10]

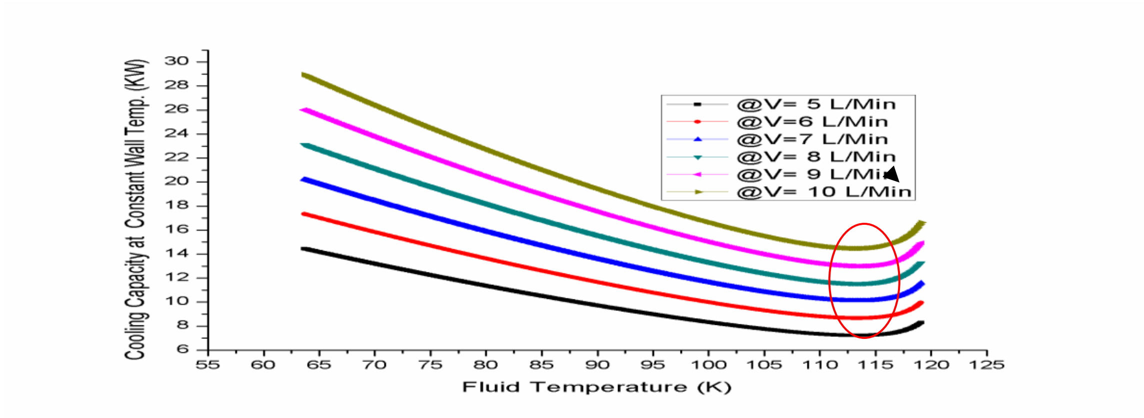


Figure 33(b): Cooling capacity with varying fluid temperature and flow rates[10]

CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE

After proper analysis of all the major thermophysical properties of Nitrogen in the subcritical region from triple point to critical point it is found that subcritical fluid has better performance as a cryogenic. At a pressure and temperature below the critical point, the handling of subcritical fluid is easy and safer than the supercritical fluid. The latent heat of vaporization of the fluid is maximum at the boiling point. The work required to pumping the subcritical fluid is lower. Specific vol. is low so required smaller storage tank than supercritical fluid. Subcritical fluid can be liquefied at high pressure whereas supercritical fluid can't be liquefied at any pressure and hence there may be storage problem due to very high specific volume.

The developed Correlations will not need big computations & large number of parameters. Lower AARE%, ARE% and SAR and Adj. R-Square values very close to 1 identify will give a better and dependable approach for prior analysis of Subcritical Nitrogen in the application for cooling of HTS Systems & Cables. A Convenient and Suitable subcritical temperature regime (77.355K-119.15K) of SCN_2 has been identified which can be used in Futuristic HTS Cables and their cooling applications for efficient power transmission. Therefore the above correlations tabulated at table (3) may be beneficial and convenient for the prior analysis and simulations of Subcritical Nitrogen before using it as a cryogenic fluid.

The further study of this research is can be extended to develop more realistic and accurate correlations with minimum errors or without errors.The development of futuristic HTS cable with better utility and practical applications by employing new cooling concepts. Subcritical fluids have better scope in cryogenics so similar investigation can be done for other fluids like Helium, Argon Oxygen etc. Moreover this work can also play a crucial and major role for designing; modelling and simulation of various HTS analysis as a reference such as Flow Velocity, Pressure drop and Heat transfer Analysis etc. using developed correlations.

CHAPTER 8

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APPENDIX

THERMOPHYSICAL PROPERTIES OF SUBCRITICAL NITROGEN

Temperatue	Pressure	Density	Specific Heat	Thermal Cond.	Viscosity	Cooling Capacity
(K)	(bar)	(kg/m³)	(kJ/kg-K)	(W/m-K)	(Pa-s)	
77.355	23.958	811.86	2.0174	0.14832	1.67E-04	13.23947139
77.455	23.958	811.42	2.0178	0.14811	1.66E-04	13.22016472
77.555	23.958	810.98	2.0181	0.1479	1.66E-04	13.20102441
77.655	23.958	810.54	2.0185	0.1477	1.65E-04	13.18173729
77.755	23.958	810.1	2.0189	0.14749	1.64E-04	13.16246004
77.855	23.958	809.66	2.0193	0.14728	1.64E-04	13.14269095
77.955	23.958	809.22	2.0196	0.14707	1.63E-04	13.1234343
78.055	23.958	808.78	2.02	0.14686	1.62E-04	13.10418753
78.155	23.958	808.34	2.0204	0.14665	1.62E-04	13.08495063
78.255	23.958	807.89	2.0208	0.14644	1.61E-04	13.06572361
78.355	23.958	807.45	2.0212	0.14623	1.61E-04	13.0473144
78.455	23.958	807.01	2.0216	0.14602	1.60E-04	13.02810598
78.555	23.958	806.56	2.022	0.14581	1.59E-04	13.00890744
78.655	23.958	806.12	2.0224	0.1456	1.59E-04	12.98971881
78.755	23.958	805.68	2.0228	0.1454	1.58E-04	12.97054008
78.855	23.958	805.23	2.0232	0.14519	1.57E-04	12.95137125
78.955	23.958	804.79	2.0236	0.14498	1.57E-04	12.93221233
79.055	23.958	804.34	2.024	0.14477	1.56E-04	12.91306333
79.155	23.958	803.9	2.0244	0.14456	1.56E-04	12.89456868
79.255	23.958	803.45	2.0248	0.14435	1.55E-04	12.8754385
79.355	23.958	803	2.0252	0.14415	1.55E-04	12.85616444
79.455	23.958	802.56	2.0257	0.14394	1.54E-04	12.83705427
79.555	23.958	802.11	2.0261	0.14373	1.53E-04	12.81859438
79.655	23.958	801.66	2.0265	0.14352	1.53E-04	12.79950307
79.755	23.958	801.21	2.027	0.14332	1.52E-04	12.7804217
79.855	23.958	800.76	2.0274	0.14311	1.52E-04	12.76119722
79.955	23.958	800.32	2.0278	0.1429	1.51E-04	12.74277219
80.055	23.958	799.87	2.0283	0.1427	1.51E-04	12.72371982
80.155	23.958	799.42	2.0287	0.14249	1.50E-04	12.70515904
80.255	23.958	798.97	2.0292	0.14228	1.49E-04	12.68612574
80.355	23.958	798.52	2.0296	0.14207	1.49E-04	12.6675823
80.455	23.958	798.07	2.0301	0.14187	1.48E-04	12.64856808
80.555	23.958	797.61	2.0305	0.14166	1.48E-04	12.62941183
80.655	23.958	797.16	2.031	0.14146	1.47E-04	12.6110469
80.755	23.958	796.71	2.0315	0.14125	1.47E-04	12.59253821
80.855	23.958	796.26	2.032	0.14104	1.46E-04	12.57356223
80.955	23.958	795.81	2.0324	0.14084	1.46E-04	12.55507094

81.055	23.958	795.35	2.0329	0.14063	1.45E-04	12.53611411
81.155	23.958	794.9	2.0334	0.14042	1.45E-04	12.51764025
81.255	23.958	794.45	2.0339	0.14022	1.44E-04	12.49917469
81.355	23.958	793.99	2.0344	0.14001	1.43E-04	12.48009534
81.455	23.958	793.54	2.0349	0.13981	1.43E-04	12.46179808
81.555	23.958	793.08	2.0354	0.1396	1.42E-04	12.44335829
81.655	23.958	792.63	2.0359	0.1394	1.42E-04	12.42430776
81.755	23.958	792.17	2.0364	0.13919	1.41E-04	12.40588561
81.855	23.958	791.71	2.0369	0.139	1.41E-04	12.38747179
81.955	23.958	791.26	2.0374	0.1388	1.40E-04	12.3690663
82.055	23.958	790.8	2.0379	0.1386	1.40E-04	12.35066915
82.155	23.958	790.34	2.0384	0.1384	1.39E-04	12.33166634
82.255	23.958	789.88	2.0389	0.13819	1.39E-04	12.31328689
82.355	23.958	789.42	2.0395	0.13799	1.38E-04	12.2949158
82.455	23.958	788.96	2.04	0.13779	1.38E-04	12.27655308
82.555	23.958	788.5	2.0405	0.13759	1.37E-04	12.25819873
82.655	23.958	788.04	2.0411	0.13739	1.37E-04	12.23985275
82.755	23.958	787.58	2.0416	0.13719	1.36E-04	12.22151515
82.855	23.958	787.12	2.0422	0.13698	1.36E-04	12.20318595
82.955	23.958	786.66	2.0427	0.13678	1.35E-04	12.18471664
83.055	23.958	786.2	2.0433	0.13658	1.35E-04	12.16640438
83.155	23.958	785.74	2.0438	0.13638	1.35E-04	12.14810053
83.255	23.958	785.28	2.0444	0.13618	1.34E-04	12.12980509
83.355	23.958	784.81	2.045	0.13597	1.34E-04	12.11197211
83.455	23.958	784.35	2.0456	0.13577	1.33E-04	12.09369268
83.555	23.958	783.88	2.0461	0.13557	1.33E-04	12.07527404
83.655	23.958	783.42	2.0467	0.13537	1.32E-04	12.05701162
83.755	23.958	782.96	2.0473	0.13517	1.32E-04	12.03920827
83.855	23.958	782.49	2.0479	0.13497	1.31E-04	12.02096191
83.955	23.958	782.02	2.0485	0.13476	1.31E-04	12.00257695
84.055	23.958	781.56	2.0491	0.13456	1.30E-04	11.98434767
84.155	23.958	781.09	2.0497	0.13436	1.30E-04	11.96657405
84.255	23.958	780.62	2.0503	0.13416	1.29E-04	11.94821425
84.355	23.958	780.16	2.0509	0.13396	1.29E-04	11.93060169
84.455	23.958	779.69	2.0515	0.13376	1.29E-04	11.91225831
84.555	23.958	779.22	2.0521	0.13356	1.28E-04	11.89451371
84.655	23.958	778.75	2.0528	0.13336	1.28E-04	11.87618693
84.755	23.958	778.28	2.0534	0.13316	1.27E-04	11.85845695
84.855	23.958	777.81	2.054	0.13296	1.27E-04	11.8401468
84.955	23.958	777.34	2.0547	0.13275	1.26E-04	11.8225771
85.055	23.958	776.87	2.0553	0.13255	1.26E-04	11.80486848
85.155	23.958	776.4	2.056	0.13235	1.26E-04	11.78658269
85.255	23.958	775.92	2.0566	0.13215	1.25E-04	11.76888876
85.355	23.958	775.45	2.0573	0.13195	1.25E-04	11.7512017
85.455	23.958	774.98	2.058	0.13175	1.24E-04	11.73279556
85.555	23.958	774.5	2.0586	0.13155	1.24E-04	11.71512339

85.655	23.958	774.03	2.0593	0.13135	1.23E-04	11.69745812
85.755	23.958	773.56	2.06	0.13115	1.23E-04	11.67979975
85.855	23.958	773.08	2.0607	0.13095	1.23E-04	11.66214829
85.955	23.958	772.61	2.0614	0.13075	1.22E-04	11.64378344
86.055	23.958	772.13	2.062	0.13055	1.22E-04	11.62614696
86.155	23.958	771.65	2.0627	0.13035	1.21E-04	11.60851741
86.255	23.958	771.17	2.0634	0.13015	1.21E-04	11.59075101
86.355	23.958	770.7	2.0642	0.12996	1.21E-04	11.57313551
86.455	23.958	770.22	2.0649	0.12976	1.20E-04	11.55538344
86.555	23.958	769.74	2.0656	0.12956	1.20E-04	11.53835217
86.655	23.958	769.26	2.0663	0.12936	1.19E-04	11.5206135
86.755	23.958	768.78	2.067	0.12916	1.19E-04	11.5030252
86.855	23.958	768.3	2.0678	0.12896	1.19E-04	11.48530093
86.955	23.958	767.82	2.0685	0.12876	1.18E-04	11.46772678
87.055	23.958	767.34	2.0693	0.12856	1.18E-04	11.45001695
87.155	23.958	766.86	2.07	0.12836	1.17E-04	11.43287869
87.255	23.958	766.37	2.0708	0.12816	1.17E-04	11.41518251
87.355	23.958	765.89	2.0715	0.12797	1.17E-04	11.39749366
87.455	23.958	765.41	2.0723	0.12777	1.16E-04	11.38051557
87.555	23.958	764.92	2.0731	0.12757	1.16E-04	11.36284027
87.655	23.958	764.44	2.0739	0.12737	1.15E-04	11.34573167
87.755	23.958	763.95	2.0747	0.12717	1.15E-04	11.32807011
87.855	23.958	763.47	2.0754	0.12697	1.15E-04	11.3109733
87.955	23.958	762.98	2.0762	0.12678	1.14E-04	11.29332551
88.055	23.958	762.49	2.077	0.12658	1.14E-04	11.27624053
88.155	23.958	762.01	2.0779	0.12638	1.14E-04	11.25860655
88.255	23.958	761.52	2.0787	0.12618	1.13E-04	11.24139242
88.355	23.958	761.03	2.0795	0.12599	1.13E-04	11.22432493
88.455	23.958	760.54	2.0803	0.12579	1.12E-04	11.2067114
88.555	23.958	760.05	2.0811	0.12559	1.12E-04	11.18965584
88.655	23.958	759.56	2.082	0.12539	1.12E-04	11.1724653
88.755	23.958	759.07	2.0828	0.1252	1.11E-04	11.15542089
88.855	23.958	758.58	2.0837	0.125	1.11E-04	11.138382
88.955	23.958	758.08	2.0845	0.1248	1.11E-04	11.12120856
89.055	23.958	757.59	2.0854	0.1246	1.10E-04	11.10418089
89.155	23.958	757.1	2.0863	0.12441	1.10E-04	11.08701895
89.255	23.958	756.6	2.0872	0.12421	1.10E-04	11.07000254
89.355	23.958	756.11	2.088	0.12401	1.09E-04	11.05285215
89.455	23.958	755.61	2.0889	0.12382	1.09E-04	11.03570763
89.555	23.958	755.12	2.0898	0.12362	1.09E-04	11.01870826
89.655	23.958	754.62	2.0907	0.12342	1.08E-04	11.00157535
89.755	23.958	754.12	2.0916	0.12323	1.08E-04	10.98444835
89.855	23.958	753.63	2.0925	0.12303	1.08E-04	10.96786513
89.955	23.958	753.13	2.0935	0.12283	1.07E-04	10.95074897
90.055	23.958	752.63	2.0944	0.12264	1.07E-04	10.93363875
90.155	23.958	752.13	2.0953	0.12244	1.06E-04	10.91706944

90.255	23.958	751.63	2.0963	0.12224	1.06E-04	10.89997014
90.355	23.958	751.13	2.0972	0.12205	1.06E-04	10.88287681
90.455	23.958	750.63	2.0982	0.12185	1.05E-04	10.86632152
90.555	23.958	750.12	2.0992	0.12166	1.05E-04	10.84923919
90.655	23.958	749.62	2.1001	0.12146	1.05E-04	10.83269299
90.755	23.958	749.12	2.1011	0.12127	1.04E-04	10.81615087
90.855	23.958	748.61	2.1021	0.12107	1.04E-04	10.79894711
90.955	23.958	748.11	2.1031	0.12087	1.04E-04	10.78241429
91.055	23.958	747.6	2.1041	0.12068	1.03E-04	10.7658856
91.155	23.958	747.1	2.1051	0.12048	1.03E-04	10.74869859
91.255	23.958	746.59	2.1061	0.12029	1.03E-04	10.73217928
91.355	23.958	746.08	2.1071	0.12009	1.03E-04	10.71552725
91.455	23.958	745.57	2.1082	0.1199	1.02E-04	10.6990164
91.555	23.958	745.06	2.1092	0.1197	1.02E-04	10.68237314
91.655	23.958	744.55	2.1102	0.11951	1.02E-04	10.66587082
91.755	23.958	744.04	2.1113	0.11931	1.01E-04	10.64923637
91.855	23.958	743.53	2.1124	0.11912	1.01E-04	10.63260641
91.955	23.958	743.02	2.1134	0.11892	1.01E-04	10.61598097
92.055	23.958	742.51	2.1145	0.11873	1.00E-04	10.60001265
92.155	23.958	742	2.1156	0.11853	1.00E-04	10.58339517
92.255	23.958	741.48	2.1167	0.11834	9.97E-05	10.56678224
92.355	23.958	740.97	2.1178	0.11814	9.94E-05	10.55017388
92.455	23.958	740.45	2.1189	0.11795	9.91E-05	10.53408291
92.555	23.958	739.94	2.12	0.11775	9.88E-05	10.51748277
92.655	23.958	739.42	2.1211	0.11756	9.85E-05	10.50126293
92.755	23.958	738.9	2.1223	0.11736	9.82E-05	10.4846712
92.855	23.958	738.38	2.1234	0.11717	9.78E-05	10.46859308
92.955	23.958	737.86	2.1246	0.11698	9.75E-05	10.45200968
93.055	23.958	737.34	2.1257	0.11678	9.72E-05	10.43593801
93.155	23.958	736.82	2.1269	0.11659	9.69E-05	10.41973457
93.255	23.958	736.3	2.1281	0.11639	9.66E-05	10.40316345
93.355	23.958	735.78	2.1293	0.1162	9.64E-05	10.38696694
93.455	23.958	735.26	2.1305	0.11601	9.61E-05	10.37090768
93.555	23.958	734.73	2.1317	0.11581	9.58E-05	10.35471722
93.655	23.958	734.21	2.1329	0.11562	9.55E-05	10.33866379
93.755	23.958	733.68	2.1341	0.11542	9.52E-05	10.32247944
93.855	23.958	733.16	2.1354	0.11523	9.49E-05	10.30629823
93.955	23.958	732.63	2.1366	0.11504	9.46E-05	10.29012018
94.055	23.958	732.1	2.1379	0.11484	9.43E-05	10.27394532
94.155	23.958	731.57	2.1391	0.11465	9.40E-05	10.25790692
94.255	23.958	731.05	2.1404	0.11446	9.37E-05	10.24223396
94.355	23.958	730.52	2.1417	0.11426	9.34E-05	10.22606765
94.455	23.958	729.98	2.143	0.11407	9.32E-05	10.20990458
94.555	23.958	729.45	2.1443	0.11388	9.29E-05	10.19410477
94.655	23.958	728.92	2.1456	0.11368	9.26E-05	10.17794742
94.755	23.958	728.39	2.1469	0.11349	9.23E-05	10.16228426

94.855	23.958	727.85	2.1482	0.1133	9.20E-05	10.14613257
94.955	23.958	727.32	2.1496	0.1131	9.18E-05	10.13047321
95.055	23.958	726.78	2.1509	0.11291	9.15E-05	10.11468314
95.155	23.958	726.24	2.1523	0.11272	9.12E-05	10.09853974
95.255	23.958	725.71	2.1537	0.11253	9.09E-05	10.08275396
95.355	23.958	725.17	2.155	0.11233	9.07E-05	10.06710174
95.455	23.958	724.63	2.1564	0.11214	9.04E-05	10.05131938
95.555	23.958	724.09	2.1579	0.11195	9.01E-05	10.03553882
95.655	23.958	723.55	2.1593	0.11176	8.98E-05	10.0198915
95.755	23.958	723.01	2.1607	0.11156	8.96E-05	10.00411448
95.855	23.958	722.46	2.1621	0.11137	8.93E-05	9.988339307
95.955	23.958	721.92	2.1636	0.11118	8.90E-05	9.973045558
96.055	23.958	721.37	2.1651	0.11099	8.88E-05	9.95727322
96.155	23.958	720.83	2.1665	0.11079	8.85E-05	9.9415028
96.255	23.958	720.28	2.168	0.1106	8.82E-05	9.926211034
96.355	23.958	719.73	2.1695	0.11041	8.80E-05	9.910443568
96.455	23.958	719.19	2.171	0.11022	8.77E-05	9.895152916
96.555	23.958	718.64	2.1725	0.11002	8.74E-05	9.879388484
96.655	23.958	718.09	2.1741	0.10983	8.72E-05	9.863968812
96.755	23.958	717.54	2.1756	0.10964	8.69E-05	9.84820762
96.855	23.958	716.98	2.1772	0.10945	8.67E-05	9.832919569
96.955	23.958	716.43	2.1788	0.10926	8.64E-05	9.817501865
97.055	23.958	715.88	2.1803	0.10906	8.61E-05	9.802214366
97.155	23.958	715.32	2.1819	0.10887	8.59E-05	9.786797496
97.255	23.958	714.76	2.1835	0.10868	8.56E-05	9.771381134
97.355	23.958	714.21	2.1852	0.10849	8.54E-05	9.756094691
97.455	23.958	713.65	2.1868	0.1083	8.51E-05	9.740679297
97.555	23.958	713.09	2.1885	0.1081	8.49E-05	9.725729004
97.655	23.958	712.53	2.1901	0.10791	8.46E-05	9.710313851
97.755	23.958	711.97	2.1918	0.10772	8.43E-05	9.694899321
97.855	23.958	711.41	2.1935	0.10753	8.41E-05	9.679947155
97.955	23.958	710.84	2.1952	0.10734	8.38E-05	9.664533005
98.055	23.958	710.28	2.1969	0.10715	8.36E-05	9.6495794
98.155	23.958	709.71	2.1986	0.10695	8.33E-05	9.634037272
98.255	23.958	709.15	2.2004	0.10676	8.31E-05	9.619082437
98.355	23.958	708.58	2.2021	0.10657	8.29E-05	9.604126503
98.455	23.958	708.01	2.2039	0.10638	8.26E-05	9.589041385
98.555	23.958	707.44	2.2057	0.10619	8.24E-05	9.574083441
98.655	23.958	706.87	2.2075	0.106	8.21E-05	9.558996591
98.755	23.958	706.3	2.2093	0.10581	8.19E-05	9.544036737
98.855	23.958	705.73	2.2112	0.10562	8.16E-05	9.528948258
98.955	23.958	705.15	2.213	0.10542	8.14E-05	9.513859059
99.055	23.958	704.58	2.2149	0.10523	8.11E-05	9.499219707
99.155	23.958	704	2.2168	0.10504	8.09E-05	9.484128217
99.255	23.958	703.42	2.2187	0.10485	8.07E-05	9.469484769
99.355	23.958	702.85	2.2206	0.10466	8.04E-05	9.454391092

99.455	23.958	702.27	2.2225	0.10447	8.02E-05	9.439743655
99.555	23.958	701.69	2.2245	0.10428	7.99E-05	9.424647898
99.655	23.958	701.1	2.2264	0.10409	7.97E-05	9.409996582
99.755	23.958	700.52	2.2284	0.10389	7.95E-05	9.395216266
99.855	23.958	699.94	2.2304	0.1037	7.92E-05	9.380560367
99.955	23.958	699.35	2.2324	0.10351	7.90E-05	9.365902163
100.05	23.958	698.76	2.2344	0.10332	7.88E-05	9.351115376
100.15	23.958	698.17	2.2365	0.10313	7.85E-05	9.336326563
100.25	23.958	697.59	2.2386	0.10294	7.83E-05	9.322101268
100.35	23.958	697	2.2406	0.10275	7.81E-05	9.307307452
100.45	23.958	696.4	2.2427	0.10256	7.78E-05	9.292949279
100.55	23.958	695.81	2.2449	0.10237	7.76E-05	9.278150689
100.65	23.958	695.22	2.247	0.10218	7.74E-05	9.263785955
100.75	23.958	694.62	2.2492	0.10199	7.71E-05	9.248982709
100.85	23.958	694.02	2.2514	0.10179	7.69E-05	9.234611535
100.95	23.958	693.43	2.2535	0.1016	7.67E-05	9.220236727
101.05	23.958	692.83	2.2558	0.10141	7.65E-05	9.205733094
101.15	23.958	692.23	2.258	0.10122	7.62E-05	9.191351219
101.25	23.958	691.62	2.2603	0.10103	7.60E-05	9.176840795
101.35	23.958	691.02	2.2625	0.10084	7.58E-05	9.162881273
101.45	23.958	690.42	2.2648	0.10065	7.56E-05	9.148363265
101.55	23.958	689.81	2.2672	0.10046	7.53E-05	9.133966717
101.65	23.958	689.2	2.2695	0.10027	7.51E-05	9.119868713
101.75	23.958	688.59	2.2719	0.10008	7.49E-05	9.105765706
101.85	23.958	687.98	2.2742	0.09989	7.47E-05	9.091233025
101.95	23.958	687.37	2.2766	0.0997	7.44E-05	9.077121032
102.05	23.958	686.76	2.2791	0.0995	7.42E-05	9.063004138
102.15	23.958	686.14	2.2815	0.09931	7.40E-05	9.048882378
102.25	23.958	685.53	2.284	0.09912	7.38E-05	9.034631822
102.35	23.958	684.91	2.2865	0.09893	7.36E-05	9.020920661
102.45	23.958	684.29	2.289	0.09874	7.33E-05	9.006783701
102.55	23.958	683.67	2.2916	0.09855	7.31E-05	8.992518355
102.65	23.958	683.05	2.2941	0.09836	7.29E-05	8.978665905
102.75	23.958	682.42	2.2967	0.09817	7.27E-05	8.964930636
102.85	23.958	681.8	2.2993	0.09798	7.25E-05	8.95065001
102.95	23.958	681.17	2.302	0.09779	7.23E-05	8.936779649
103.05	23.958	680.55	2.3046	0.0976	7.20E-05	8.922903122
103.15	23.958	679.92	2.3073	0.09741	7.18E-05	8.909020465
103.25	23.958	679.28	2.31	0.09721	7.16E-05	8.895543623
103.35	23.958	678.65	2.3128	0.09702	7.14E-05	8.881647911
103.45	23.958	678.02	2.3155	0.09683	7.12E-05	8.867623423
103.55	23.958	677.38	2.3183	0.09664	7.10E-05	8.854124994
103.65	23.958	676.74	2.3212	0.09645	7.08E-05	8.840210544
103.75	23.958	676.1	2.324	0.09626	7.05E-05	8.826575086
103.85	23.958	675.46	2.3269	0.09607	7.03E-05	8.812932146
103.95	23.958	674.82	2.3298	0.09588	7.01E-05	8.799404043

104.05	23.958	674.18	2.3327	0.09569	6.99E-05	8.785746168
104.15	23.958	673.53	2.3357	0.0955	6.97E-05	8.772080934
104.25	23.958	672.88	2.3387	0.09531	6.95E-05	8.758811199
104.35	23.958	672.23	2.3417	0.09511	6.93E-05	8.745130466
104.45	23.958	671.58	2.3448	0.09492	6.91E-05	8.7317217
104.55	23.958	670.93	2.3479	0.09473	6.89E-05	8.718425828
104.65	23.958	670.27	2.351	0.09454	6.87E-05	8.705120999
104.75	23.958	669.62	2.3541	0.09435	6.84E-05	8.691685731
104.85	23.958	668.96	2.3573	0.09416	6.82E-05	8.678241779
104.95	23.958	668.3	2.3605	0.09397	6.80E-05	8.664910529
105.05	23.958	667.64	2.3638	0.09378	6.78E-05	8.651449252
105.15	23.958	666.97	2.367	0.09358	6.76E-05	8.638374088
105.25	23.958	666.31	2.3704	0.09339	6.74E-05	8.624894853
105.35	23.958	665.64	2.3737	0.0932	6.72E-05	8.611800016
105.45	23.958	664.97	2.3771	0.09301	6.70E-05	8.598574075
105.55	23.958	664.3	2.3805	0.09282	6.68E-05	8.58545894
105.65	23.958	663.62	2.384	0.09263	6.66E-05	8.572333683
105.75	23.958	662.95	2.3875	0.09244	6.64E-05	8.559466977
105.85	23.958	662.27	2.391	0.09224	6.62E-05	8.546200277
105.95	23.958	661.59	2.3946	0.09205	6.60E-05	8.533431667
106.05	23.958	660.91	2.3982	0.09186	6.58E-05	8.520530971
106.15	23.958	660.23	2.4018	0.09167	6.56E-05	8.507618773
106.25	23.958	659.54	2.4055	0.09148	6.54E-05	8.494695127
106.35	23.958	658.85	2.4092	0.09128	6.52E-05	8.481760082
106.45	23.958	658.16	2.413	0.09109	6.50E-05	8.46869367
106.55	23.958	657.47	2.4168	0.0909	6.48E-05	8.456118111
106.65	23.958	656.77	2.4207	0.09071	6.46E-05	8.44340966
106.75	23.958	656.08	2.4246	0.09051	6.44E-05	8.430427919
106.85	23.958	655.38	2.4285	0.09032	6.42E-05	8.417694705
106.95	23.958	654.68	2.4325	0.09013	6.40E-05	8.405327229
107.05	23.958	653.97	2.4365	0.08994	6.38E-05	8.392567754
107.15	23.958	653.27	2.4406	0.08974	6.36E-05	8.379795681
107.25	23.958	652.56	2.4447	0.08955	6.34E-05	8.367386824
107.35	23.958	651.85	2.4489	0.08936	6.32E-05	8.354844403
107.45	23.958	651.14	2.4531	0.08917	6.30E-05	8.342407129
107.55	23.958	650.42	2.4574	0.08897	6.28E-05	8.329836567
107.65	23.958	649.7	2.4617	0.08878	6.26E-05	8.317743285
107.75	23.958	648.98	2.4661	0.08859	6.24E-05	8.305143919
107.85	23.958	648.26	2.4705	0.08839	6.22E-05	8.292901112
107.95	23.958	647.53	2.475	0.0882	6.20E-05	8.280642751
108.05	23.958	646.81	2.4795	0.08801	6.18E-05	8.26825015
108.15	23.958	646.07	2.4841	0.08781	6.16E-05	8.255960944
108.25	23.958	645.34	2.4887	0.08762	6.14E-05	8.24365637
108.35	23.958	644.61	2.4934	0.08743	6.12E-05	8.231583884
108.45	23.958	643.87	2.4982	0.08723	6.10E-05	8.219494519
108.55	23.958	643.13	2.503	0.08704	6.08E-05	8.207506723

108.65	23.958	642.38	2.5079	0.08684	6.06E-05	8.195383727
108.75	23.958	641.64	2.5128	0.08665	6.05E-05	8.183606397
108.85	23.958	640.89	2.5178	0.08646	6.03E-05	8.171331047
108.95	23.958	640.13	2.5229	0.08626	6.01E-05	8.159517952
109.05	23.958	639.38	2.528	0.08607	5.99E-05	8.147568569
109.15	23.958	638.62	2.5332	0.08587	5.97E-05	8.135719096
109.25	23.958	637.86	2.5385	0.08568	5.95E-05	8.124091501
109.35	23.958	637.09	2.5438	0.08548	5.93E-05	8.112087215
109.45	23.958	636.33	2.5492	0.08529	5.91E-05	8.100421198
109.55	23.958	635.56	2.5547	0.08509	5.89E-05	8.088735634
109.65	23.958	634.78	2.5602	0.08489	5.87E-05	8.077267295
109.75	23.958	634.01	2.5659	0.0847	5.85E-05	8.065542037
109.85	23.958	633.23	2.5715	0.0845	5.83E-05	8.054032502
109.95	23.958	632.44	2.5773	0.08431	5.81E-05	8.042619516
110.05	23.958	631.66	2.5832	0.08411	5.80E-05	8.031068201
110.15	23.958	630.87	2.5891	0.08392	5.78E-05	8.019846034
110.25	23.958	630.08	2.5951	0.08372	5.76E-05	8.008135161
110.35	23.958	629.28	2.6012	0.08352	5.74E-05	7.996869142
110.45	23.958	628.48	2.6074	0.08333	5.72E-05	7.9854637
110.55	23.958	627.68	2.6137	0.08313	5.70E-05	7.974499607
110.65	23.958	626.87	2.6201	0.08293	5.68E-05	7.963394597
110.75	23.958	626.06	2.6266	0.08273	5.66E-05	7.952265901
110.85	23.958	625.24	2.6331	0.08254	5.64E-05	7.941113602
110.95	23.958	624.43	2.6398	0.08234	5.62E-05	7.929820919
111.05	23.958	623.6	2.6465	0.08214	5.60E-05	7.918963639
111.15	23.958	622.78	2.6534	0.08194	5.59E-05	7.907964483
111.25	23.958	621.95	2.6603	0.08174	5.57E-05	7.897057124
111.35	23.958	621.12	2.6674	0.08155	5.55E-05	7.886347428
111.45	23.958	620.28	2.6746	0.08135	5.53E-05	7.875611225
111.55	23.958	619.44	2.6819	0.08115	5.51E-05	7.864732041
111.65	23.958	618.59	2.6892	0.08095	5.49E-05	7.853943154
111.75	23.958	617.74	2.6968	0.08075	5.47E-05	7.843347287
111.85	23.958	616.89	2.7044	0.08055	5.45E-05	7.832723617
111.95	23.958	616.03	2.7122	0.08035	5.43E-05	7.822072242
112.05	23.958	615.17	2.72	0.08015	5.41E-05	7.811726324
112.15	23.958	614.3	2.7281	0.07995	5.40E-05	7.801351133
112.25	23.958	613.43	2.7362	0.07975	5.38E-05	7.790830513
112.35	23.958	612.55	2.7445	0.07955	5.36E-05	7.78072754
112.45	23.958	611.67	2.7529	0.07935	5.34E-05	7.770148123
112.55	23.958	610.78	2.7615	0.07914	5.32E-05	7.760197235
112.65	23.958	609.89	2.7702	0.07894	5.30E-05	7.74977027
112.75	23.958	609	2.779	0.07874	5.28E-05	7.739756001
112.85	23.958	608.09	2.7881	0.07854	5.26E-05	7.729593718
112.95	23.958	607.19	2.7972	0.07834	5.24E-05	7.719840753
113.05	23.958	606.28	2.8066	0.07813	5.22E-05	7.709938302
113.15	23.958	605.36	2.8161	0.07793	5.21E-05	7.699886575

113.25	23.958	604.44	2.8258	0.07773	5.19E-05	7.69024007
113.35	23.958	603.51	2.8356	0.07752	5.17E-05	7.680442818
113.45	23.958	602.58	2.8457	0.07732	5.15E-05	7.670610872
113.55	23.958	601.64	2.8559	0.07711	5.13E-05	7.66106419
113.65	23.958	600.7	2.8663	0.07691	5.11E-05	7.651481293
113.75	23.958	599.75	2.877	0.0767	5.09E-05	7.642180384
113.85	23.958	598.79	2.8878	0.07649	5.07E-05	7.6324088
113.95	23.958	597.83	2.8989	0.07629	5.05E-05	7.62323406
114.05	23.958	596.86	2.9102	0.07608	5.03E-05	7.614020134
114.15	23.958	595.88	2.9217	0.07588	5.01E-05	7.604767155
114.25	23.958	594.9	2.9334	0.07567	4.99E-05	7.59535958
114.35	23.958	593.91	2.9454	0.07546	4.98E-05	7.586341706
114.45	23.958	592.92	2.9576	0.07525	4.96E-05	7.577479702
114.55	23.958	591.91	2.9701	0.07504	4.94E-05	7.568575699
114.65	23.958	590.9	2.9829	0.07483	4.92E-05	7.559514218
114.75	23.958	589.89	2.9959	0.07463	4.90E-05	7.550835934
114.85	23.958	588.86	3.0093	0.07442	4.88E-05	7.542307124
114.95	23.958	587.83	3.0229	0.0742	4.86E-05	7.533425867
115.05	23.958	586.79	3.0369	0.07399	4.84E-05	7.524999294
115.15	23.958	585.74	3.0511	0.07378	4.82E-05	7.516336172
115.25	23.958	584.69	3.0658	0.07357	4.80E-05	7.50812277
115.35	23.958	583.62	3.0807	0.07336	4.78E-05	7.499861546
115.45	23.958	582.55	3.096	0.07315	4.76E-05	7.491437068
115.55	23.958	581.47	3.1117	0.07293	4.74E-05	7.483382923
115.65	23.958	580.38	3.1278	0.07272	4.72E-05	7.475164085
115.75	23.958	579.28	3.1443	0.0725	4.70E-05	7.467196797
115.85	23.958	578.17	3.1612	0.07229	4.68E-05	7.459362978
115.95	23.958	577.05	3.1785	0.07207	4.66E-05	7.451592649
116.05	23.958	575.93	3.1964	0.07186	4.64E-05	7.443654742
116.15	23.958	574.79	3.2146	0.07164	4.62E-05	7.436258998
116.25	23.958	573.64	3.2334	0.07142	4.60E-05	7.428692461
116.35	23.958	572.48	3.2528	0.07121	4.58E-05	7.421186637
116.45	23.958	571.31	3.2726	0.07099	4.56E-05	7.41380469
116.55	23.958	570.13	3.2931	0.07077	4.54E-05	7.406544111
116.65	23.958	568.93	3.3141	0.07055	4.52E-05	7.399341311
116.75	23.958	567.73	3.3358	0.07033	4.50E-05	7.392548398
116.85	23.958	566.51	3.3582	0.07011	4.48E-05	7.38540356
116.95	23.958	565.28	3.3812	0.06988	4.46E-05	7.378663619
117.05	23.958	564.03	3.405	0.06966	4.44E-05	7.371861157
117.15	23.958	562.77	3.4296	0.06944	4.42E-05	7.365284563
117.25	23.958	561.5	3.455	0.06921	4.40E-05	7.358644108
117.35	23.958	560.21	3.4812	0.06899	4.37E-05	7.352396858
117.45	23.958	558.91	3.5084	0.06876	4.35E-05	7.346082583
117.55	23.958	557.59	3.5365	0.06853	4.33E-05	7.339986165
117.65	23.958	556.26	3.5656	0.06831	4.31E-05	7.33398906
117.75	23.958	554.91	3.5959	0.06808	4.29E-05	7.327921995

117.85	23.958	553.54	3.6273	0.06785	4.27E-05	7.322349242
117.95	23.958	552.15	3.6599	0.06762	4.24E-05	7.316587184
118.05	23.958	550.74	3.6939	0.06739	4.22E-05	7.311032506
118.15	23.958	549.32	3.7292	0.06716	4.20E-05	7.305566392
118.25	23.958	547.87	3.7661	0.06693	4.18E-05	7.300419232
118.35	23.958	546.4	3.8046	0.06669	4.16E-05	7.295355728
118.45	23.958	544.91	3.8448	0.06646	4.13E-05	7.290096564
118.55	23.958	543.4	3.8868	0.06622	4.11E-05	7.285310182
118.65	23.958	541.86	3.9309	0.06599	4.09E-05	7.280716595
118.75	23.958	540.3	3.9772	0.06575	4.06E-05	7.27619657
118.85	23.958	538.7	4.0258	0.06551	4.04E-05	7.271591249
118.95	23.958	537.08	4.0771	0.06527	4.02E-05	7.26744554
119.05	23.958	535.43	4.1311	0.06503	3.99E-05	7.263365885
119.07	23.958	535.13	4.1414	0.06499	3.99E-05	7.259466878
119.07	23.958	116.53	4.0758	0.02201	1.03E-05	7.252235355
119.15	23.958	116	4.0002	0.02186	1.03E-05	7.248745632
119.25	23.958	115.37	3.9135	0.02168	1.03E-05	7.245576363
119.35	23.958	114.76	3.8327	0.02151	1.03E-05	7.242456114
119.45	23.958	114.16	3.7571	0.02135	1.03E-05	7.239765319
119.55	23.958	113.59	3.6862	0.0212	1.03E-05	7.23697033
119.65	23.958	113.02	3.6195	0.02106	1.03E-05	7.234743707
119.75	23.958	112.48	3.5567	0.02092	1.03E-05	7.232408028
119.85	23.958	111.94	3.4973	0.02078	1.03E-05	7.23036859
119.95	23.958	111.42	3.4412	0.02066	1.03E-05	7.228477796
120.05	23.958	110.91	3.3879	0.02053	1.03E-05	7.226993255
120.15	23.958	110.41	3.3374	0.02041	1.03E-05	7.225672312
120.25	23.958	109.93	3.2893	0.0203	1.02E-05	7.224608042
120.35	23.958	109.45	3.2434	0.02019	1.02E-05	7.223698333
120.45	23.958	108.98	3.1997	0.02009	1.02E-05	7.223039001
120.55	23.958	108.53	3.1579	0.01998	1.02E-05	7.22252516
120.65	23.958	108.08	3.118	0.01989	1.02E-05	7.222509956
120.75	23.958	107.64	3.0797	0.01979	1.02E-05	7.222629343
120.85	23.958	107.21	3.043	0.0197	1.02E-05	7.223117461
120.95	23.958	106.78	3.0077	0.01961	1.02E-05	7.223969413
121.05	23.958	106.37	2.9739	0.01953	1.02E-05	7.224688371
121.15	23.958	105.96	2.9413	0.01944	1.02E-05	7.226133116
121.25	23.958	105.56	2.91	0.01936	1.02E-05	7.227684777
121.35	23.958	105.17	2.8797	0.01928	1.02E-05	7.229579478
121.45	23.958	104.78	2.8506	0.01921	1.02E-05	7.232059691
121.55	23.958	104.4	2.8225	0.01913	1.02E-05	7.234628139
121.65	23.958	104.02	2.7953	0.01906	1.02E-05	7.237522302
121.75	23.958	103.65	2.769	0.01899	1.02E-05	7.240981963
121.85	23.958	103.29	2.7436	0.01893	1.02E-05	7.244754727
121.95	23.958	102.93	2.719	0.01886	1.02E-05	7.248834044
122.05	23.958	102.58	2.6952	0.0188	1.02E-05	7.253334003

122.15	23.958	102.23	2.6721	0.01873	1.02E-05	7.258369514
122.25	23.958	101.89	2.6497	0.01867	1.02E-05	7.263685854
122.35	23.958	101.55	2.628	0.01861	1.02E-05	7.269521508
122.45	23.958	101.22	2.6069	0.01856	1.02E-05	7.27574472
122.55	23.958	100.89	2.5864	0.0185	1.02E-05	7.28270893
122.65	23.958	100.57	2.5665	0.01845	1.02E-05	7.289917624
122.75	23.958	100.25	2.5471	0.01839	1.02E-05	7.297847317
122.85	23.958	99.93	2.5283	0.01834	1.02E-05	7.306236412
122.95	23.958	99.619	2.51	0.01829	1.02E-05	7.315324573
123.05	23.958	99.312	2.4921	0.01824	1.02E-05	7.324742398
123.15	23.958	99.008	2.4747	0.01819	1.02E-05	7.334944821
123.25	23.958	98.708	2.4578	0.01815	1.02E-05	7.345917611
123.35	23.958	98.412	2.4412	0.0181	1.02E-05	7.35741657
123.45	23.958	98.12	2.4251	0.01806	1.02E-05	7.369659164
123.55	23.958	97.831	2.4094	0.01801	1.02E-05	7.382631029
123.65	23.958	97.545	2.394	0.01797	1.02E-05	7.396317759
123.75	23.958	97.263	2.379	0.01793	1.02E-05	7.410801307
123.85	23.958	96.984	2.3644	0.01789	1.02E-05	7.426098131
123.95	23.958	96.708	2.3501	0.01785	1.02E-05	7.442382139
124.05	23.958	96.435	2.3361	0.01781	1.02E-05	7.459539451
124.15	23.958	96.166	2.3225	0.01777	1.02E-05	7.477774914
124.25	23.958	95.899	2.3091	0.01774	1.02E-05	7.497068095
124.35	23.958	95.635	2.296	0.0177	1.02E-05	7.517485624
124.45	23.958	95.374	2.2832	0.01767	1.02E-05	7.538916558
124.55	23.958	95.115	2.2707	0.01763	1.02E-05	7.561424032
124.65	23.958	94.86	2.2585	0.0176	1.02E-05	7.585552813
124.75	23.958	94.607	2.2465	0.01757	1.02E-05	7.610840134
124.85	23.958	94.356	2.2347	0.01753	1.02E-05	7.637556373
124.95	23.958	94.108	2.2232	0.0175	1.02E-05	7.665883934
125.05	23.958	93.863	2.2119	0.01747	1.02E-05	7.695787352
125.15	23.958	93.62	2.2008	0.01744	1.02E-05	7.727370529
125.25	23.958	93.379	2.19	0.01741	1.02E-05	7.760882964
125.35	23.958	93.141	2.1793	0.01738	1.02E-05	7.796282419
125.45	23.958	92.905	2.1689	0.01735	1.02E-05	7.833945624
125.55	23.958	92.671	2.1586	0.01733	1.02E-05	7.873614937
125.65	23.958	92.439	2.1486	0.0173	1.02E-05	7.915866918
125.75	23.958	92.21	2.1387	0.01727	1.02E-05	7.960706121
125.85	23.958	91.982	2.129	0.01725	1.02E-05	8.008422324
125.95	23.958	91.757	2.1195	0.01722	1.02E-05	8.059156911
126.05	23.958	91.534	2.1102	0.0172	1.02E-05	8.113099887
126.15	23.958	91.313	2.101	0.01717	1.02E-05	8.170780556