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

M.Tech Dissertation

By

Ravula Jeswanth

(11306924)

DEPARTMENT OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY

PHAGWARA, PUNJAB (INDIA) -144402

2014 - 2015

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

DISSERTATION-II

Submitted in Partial Fulfillment of the

Requirement for Award of the Degree

Of

MASTER OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

RAVULA JESWANTH

(11306924)

Under the Guidance of

Mr. GURAV VYAS

DEPARTMENT OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY

PHAGWARA, PUNJAB (INDIA) -144402

2014 - 2015

Lovely Professional University Jalandhar, Punjab

CERTIFICATE

I hereby certify that the work which is being presented in the dissertation entitled **"Development of Correlations for Thermo-physical properties of Supercritical Nitrogen (SCN) to be used in High Temperature Superconducting Cables"** in partial fulfillment of the requirement for the award of degree of **Master of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried out during period of Dissertation under the supervision of **Mr. Gaurav Vyas**, **Assistant 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.

Date: **Jeswanth Ravula**

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

Date: **Mr. Gaurav Vyas**

Supervisor

The M- Tech Dissertation examination of Jeswanth Ravula, has been held on ______________

Signature of Examiner

TABLE of CONTENTS

List of FIGURES

List of TABLES

NOMENCLATURE

T_c	Critical Temperature
I_c	Critical Current
H_c	Critical Magnetic Field
HTS	High Temperature Superconductor
LTS	Low Temperature Superconductor
H	Applied Magnetic Field
M	Intensity of Magnetic Field
H_{c1}	Lower Critical Magnetic Field
H_{c2}	Higher Critical Magnetic Field
LN_2	Liquid Nitrogen
SCN	Supercritical Nitrogen
ρ	Density
μ	Viscosity
k	Thermal Conductivity
C_p	Specific Heat
AC	Alternating Current
EC	Electric Method
B_{am}	Axial Field
B_{cm}	Circumferential Field

CD	Cold Dielectric
WD	Warm Dielectric
AARE	Average Absolute Relative Error
SAR	Sum of Absolute of Residual
PRE	Percent Relative Error
NIST	National Institute of Standard and Technology
REFPROP	Refrigerant Properties software program
CFD	Computational Fluid Dynamics

ABSTRACT

Future power transmission applications demand higher energy efficiency. In order to conserve the transmission of electrical energy is a new challenge. At present, transmission of electrical energy with conventional electrical cables reported to have 40-60% losses. In order to overcome such critical challenges, a novel method of transmission is being developed using High Temperature Superconducting (HTS) cables. However, cooling of HTS cables need appropriate cryogenic coolant which can remove the deposited or infiltrated heat loads on the superconducting tapes. In the present work, Supercritical nitrogen (SCN) is proposed as one such cryogen which can be used in HTS cables due to its peculiar thermophysical properties such as density, viscosity, thermal conductivity and specific heat.

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 using various cryocoolers. In this proposed work, a conceptual application of SCN in HTS cables is introduced. Moreover various thermophysical (thermodynamic and transport) properties of SCN were studied in order to investigate the feasibility with HTS cables. In addition, the variation of thermophysical properties with respect to temperature (T_C + 50K) and pressure (P_C + 10bar) were analyzed. The analyzed results show that for every 0.1K rise in temperature, there is drastic variation in thermophysical properties. Moreover, correlations have been developed for different thermophysical properties at critical pressure (P_C=33.958bar) and for a temperature range (up to T_C+50K) of SCN. Further, in order to ensure the accuracy of the developed correlations, different statistical parameters such as Absolute Average of Relative Error (AARE), Average Relative Error (ARE) and Sum of Average Residues (SAR) have been calculated and which indicates an excellent pact between the data obtained from REFPROP-NIST software program and developed correlations property values. The development of correlations of SCN can be used for predicting thermohydraulic performance of futuristic HTS cables.

ACKNOWLEDGEMENT

First and the foremost I offer my sincerest gratitude to my supervisors, **Mr. Rajasekhar Dondapati**, Assistant Professor, School of Mechanical Engineering, Lovely Professional University, Punjab, **Mrs. Preeti Rao Usurumarti** who has supported me throughout my thesis with their patience, knowledge, valuable advice, uninterrupted active supervision and constant encouragement. I attribute the level of my Master's degree to their encouragement and effort without them this thesis, too, would not have been completed or written.

It has also been great opportunity for me to work under the guidance of **Mr. Gaurav Vyas**, Assistant Professor, School of Mechanical Engineering, Lovely Professional University, Punjab.

I am thankful to **Mr. Abhinav Kumar**, Assistant Professor, Mechanical Engineering, St. Soldier group of institutions, Punjab who continuously motivated, clearing concepts and encouraged me to do this research work.

I would like to thank the faculty of School of Mechanical Engineering, Lovely professional University for attending my presentations regarding my research work.

I also grateful and needful to my **research team members** Mr. Syed Mahaboob Idris, Mr. Mohit Kalsia, Mr. Mugilan S, Mr. Aal Arif Sarkar, Mr. Ajay Kumar Ramani, Mr. Shivam S Varma, etc.., for their encouragement and support in this research work.

I would like to thank lovely professional university for giving me opportunity to use their resource and work in such a challenging environment. I am grateful to the individuals whom contributed their valuable time towards my thesis.

Last but not the least, I express my sincere gratitude to my parents and family members who have always supported me throughout all my studies at university and encouraged me with their best wishes.

CHAPTER

1 INTRODUCTION

1.1 GLOBAL ENERGY SCENARIO AND RESOURCES

World's growth in financial, Technological, Environmental factors and civilization depends largely on effectiveness of energy utilization. In fact, Energy has been universally acknowledged as one of the most important inputs for economic growth and human development. There is a strong mutual relationship between economic development and energy consumption. On one hand, the economy growth, with its global competitiveness, hinges on the availability of cost effective and environmental friendly energy sources, and on the other hand, the level of economic development has been observed to be reliant on energy demand.

In coming decades, the energy needs of the country are expected to increase at a rapid rate. Therefore, it is imperative to take steps to increase the available energy resources so as to avoid excessive dependence on external sources. The options available in terms of nuclear and Hydel energy, as well as non-conventional sources of energy, also need to be seriously looked into. Non-conventional sources of energy may come to play an increasing role in meeting energy needs, particularly of the rural population, which depends mostly on non-commercial sources of energy. Access to affordable energy promotes growth in all sectors of the economy such as industry, services and transport, and is thus a key prerequisite for ensuring competitiveness.

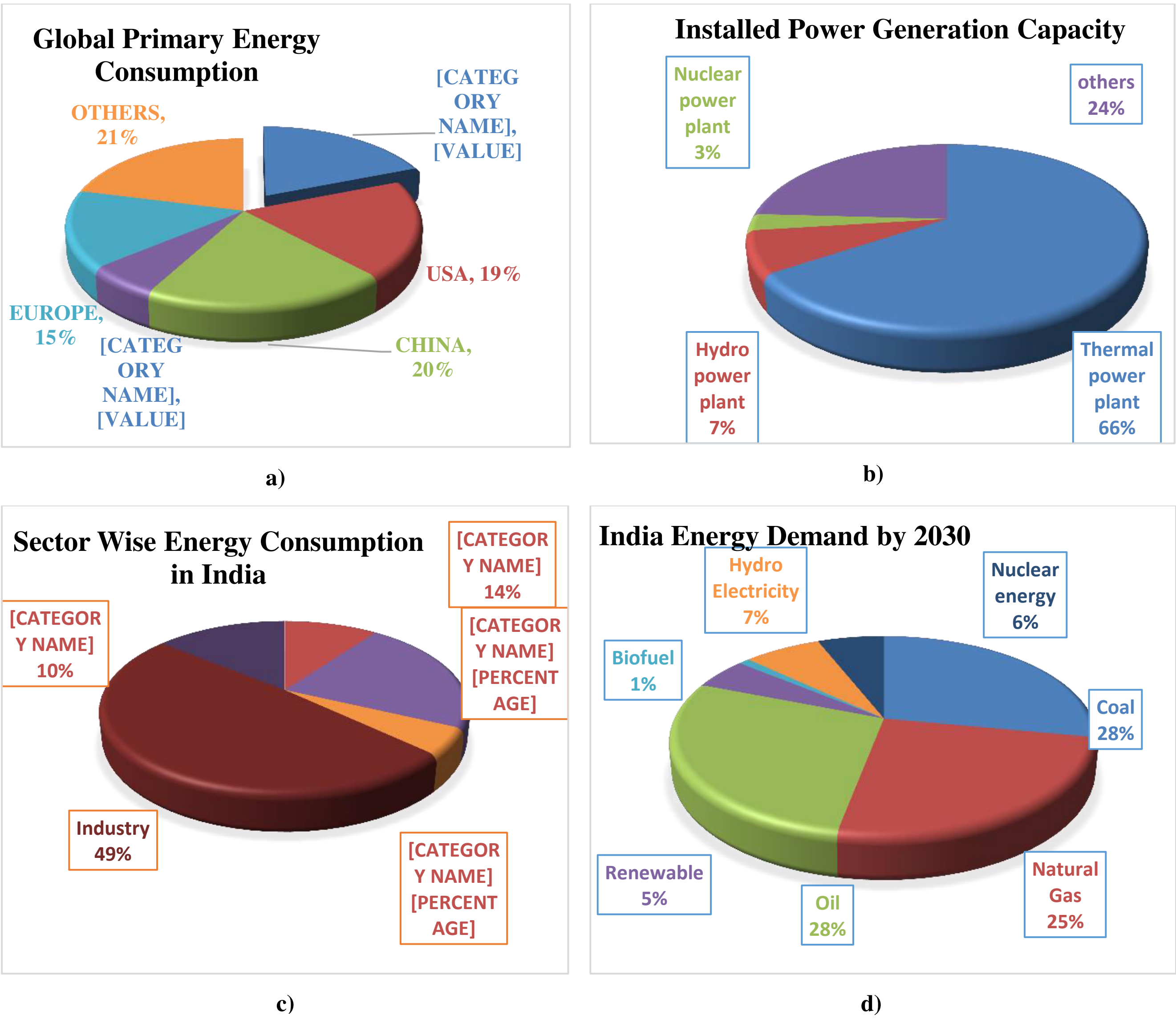


Figure 1-1 a) Global Primary Energy Consumption b) Installed Power generation capacity c)Sector wise Energy Consumption in India d) India Energy Demand by 2030 [1]-[2]-[3] -[4] -[5]

Moreover, above Figure 1-1 a) to d) describes the present global and national energy scenario. It can be observed from the above statistical data, India is the third largest energy consumption of global energy sources. Subsequently, in India, Thermal power plants are the largest contributors to the increase in electricity generation, with thermal energy accounting 66% of the total increment, hydro 7%, Nuclear 3% and other 24%. However, the consumption of generated power from various sources is consumed by different sectors among those industries and residential are the two largest consumables of electricity accounting 49% and 14%. On the other hand, consumption of oil and natural gas in the transport sector is the second largest consumption of the total, accounting 22%.

Future energy demands from fossil fuels will be comprehensively important. Oil, coal, and natural gas will all play a significant role in the industrial and power sector, each providing approximately a larger energy demands of the sector's accounting oil 28%, Natural gas 25% and Coal 28%, echoing the 2014 trend. Regardless though, coal continues to be the most important source of energy for power sector, still accounting for 28% of its total needs. Moreover, in transport sector, oil continues to be the main source of energy, accounting 90% of the sector's total energy consumption.

Electrical energy which is generated from the non-renewable energy sources should be transmitted and distributed to the utility/requirement. Therefore it is observed that, in conventional power transmission and distribution systems reported to have 40 to 60 % of losses due to large amount of heat dissipation [5]. In order to overcome such losses, there is one such solution which can justify 0% losses i.e. superconductivity these concepts are detailed discussed in the following sections.

CHAPTER

2 TERMINOLOGY

2.1 SUPERCONDUCTING MATERIALS

An elements, metals and compounds that will conduct electricity without resistance below a certain temperature. This phenomenon is known as superconductivity. Moreover, in this state the ion lattice have very low energy and valence electrons flow inside the conductor is persistent and lattice vibrations are minimum. Metals, alloys or metallic compounds etc. at cryogenic temperatures, characterized by the complete absence of electrical resistance and the damping of the interior magnetic field known as Meissner Effect [6] . Below Figure 2-1 predicts that, the effect of magnetic field into the normal conductor and superconductor with respect to the critical temperature.

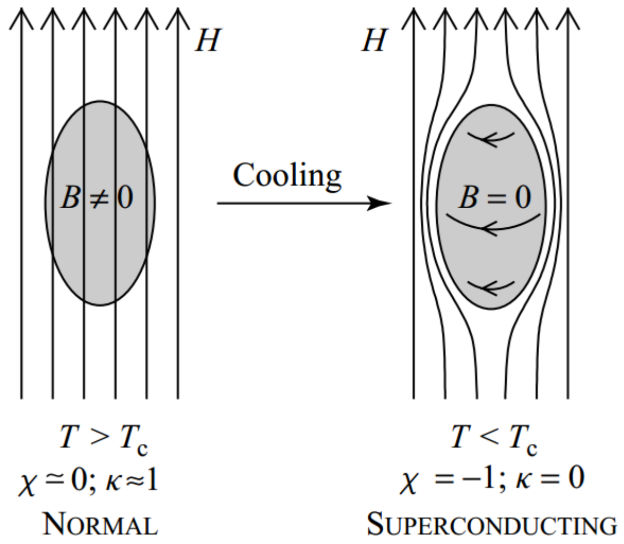


Figure 2-1Effect of magnetic field in normal conductor and superconductor [6]

As the electrons enters into the superconducting state the flow of electrons is constant throughout the superconductor thereby the circle formation of magnetic on the outer surface of the superconductor performs. This property of Superconductivity is fact quantum mechanics and it is highly pertinent for current and future power system applications. Few metals which does not show superconductivity are Copper, Iron, Gold and Aluminum. Below Figure 2-2 describes the critical surface phase diagram. In order to maintain superconducting state the materials have few constrictions those are as follows.

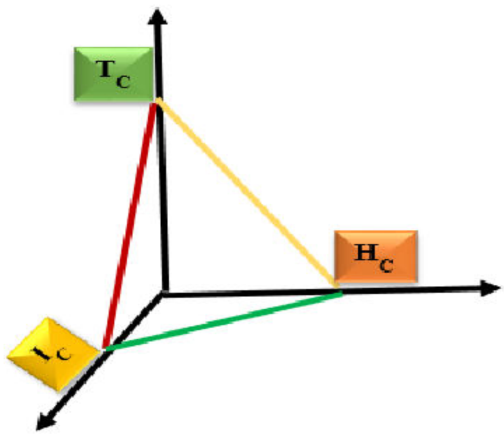


Figure 2-2 Critical Surface Phase Diagram

- **Critical temperature (T_c),** at this temperature the normal conductor losses its electric resistivity and becomes a superconductor this point is known as transition or critical point

[6]. Table 2-1 shows the critical temperatures of different superconductors and cryogenic coolants [7]

Table 2-1 Critical temperatures of different cryogens and superconductors [7]

Critical Temperature (K)	Cryogens and Superconductors	
5.1953K	Helium	
33.190K	Hydrogen	
126.19K	Nitrogen	
150.69K	Argon	
154.58K	Oxygen	
90K	YBCO	High Temperature Superconductors
110K	BaSrCaCuO	
118K	TiSrCaCuO	
134K	HgBaCaCuO	
3.72K	Sn	Low Temperature Superconductors
4.15K	Hg	
7.19K	Pb	
10K	Nb	

- **Critical current (I_c), i**t is the extreme value of current that can flow through the superconductor with zero electric resistance. Above this point the superconductor behaves as a normal conductor [6].
- **Critical magnetic field (H_c), i**t is the transition or critical point for the superconductor to behave as a normal conductor. If the magnetic field is large therefore the superconductor turns out to be a normal conductor [6]. The relation for the critical magnetic field and critical temperature [4] is expressed as

$$H_C = H_0 \left[1 - \left(\frac{T}{T_C} \right)^2 \right] \quad (1)$$

Where H_c = Critical Magnetic field, H_o = Critical field at 0K, T= Temperature below T_c and T_c = Critical temperature

Basically Superconductors are classified according to their critical temperatures they are as follows:

- High Temperature Superconductors (HTS)
- Low Temperature Superconductors (LTS)

2.2 HIGH TEMPERATURE SUPERCONDUCTORS

High Temperature superconductors (HTS) are the materials which is having critical temperature (T_c) >30 K [6]. In the year 1980-1990 first HTS material was found in LaBaCuO and its critical Temperature is 32 K. At present the development of HTS has enlarged its critical Temperature to 240 K [6].

- Advantages of HTS
    1. current carrying capacity is large
    2. Compact in Size
    3. Low losses etc.
- Applications of HTS
    1. Generators
    2. Superconducting Magnetic Energy Storage (SMES)
    3. HTS Power transmission Cables
    4. HTS Transformers
    5. HTS Motors

2.3 LOW TEMPERATURE SUPERCONDUCTORS

Low Temperature Superconductors (LTS) are the materials which is having critical temperature (T_c) <30K [6]. In the year 1911, H. Kammerlingh Onnes discovered that, superconductivity occurs in pure metals such as mercury and lead which are known as LTS.

- Applications of LTS
    1. Magnets

2.4 TYPE I SUPERCONDUCTORS

When a superconductor is placed in a magnetic field then its superconductivity losses very easily or abruptly at critical magnetic field (H_c) this is known as Type I superconductor. Moreover, it can be observed from the below figure that, after critical magnetic field (H_c) the superconductor behaves has a normal conductor. Type I superconductors are also known as soft conductors. Below Figure 2-3 describes the intensity of magnetic field (M) versus applied magnetic field (H). Type I superconductors (SC) obeys Meissner effect [6].

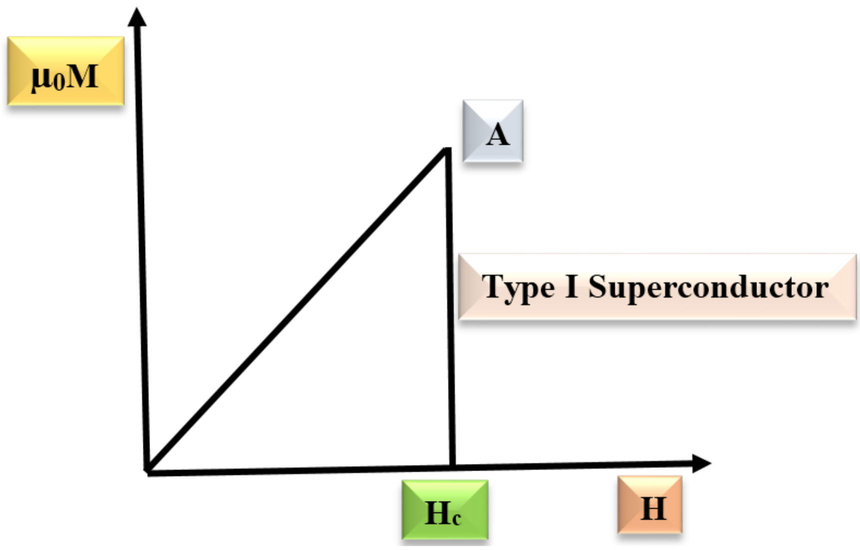


Figure 2-3 Intensity of magnetic field over applied magnetic field for Type I SC

2.5 TYPE II SUPERCONDUCTORS

When a superconductor is placed in a magnetic field then its superconductivity losses gradually or slowly this is known as Type II superconductor. Moreover, it can be observed from the below graph that, type II superconductors will start to loses its superconductivity at lower critical magnetic field (H_{c1}) and completely loose at higher critical magnetic field (H_{c2}). Type II superconductors are also known as hard superconductors. Below Figure 2-4 describes the intensity of magnetic field (M) versus applied magnetic field (H). Type II superconductors (SC) does not obey Meissner effect [6].

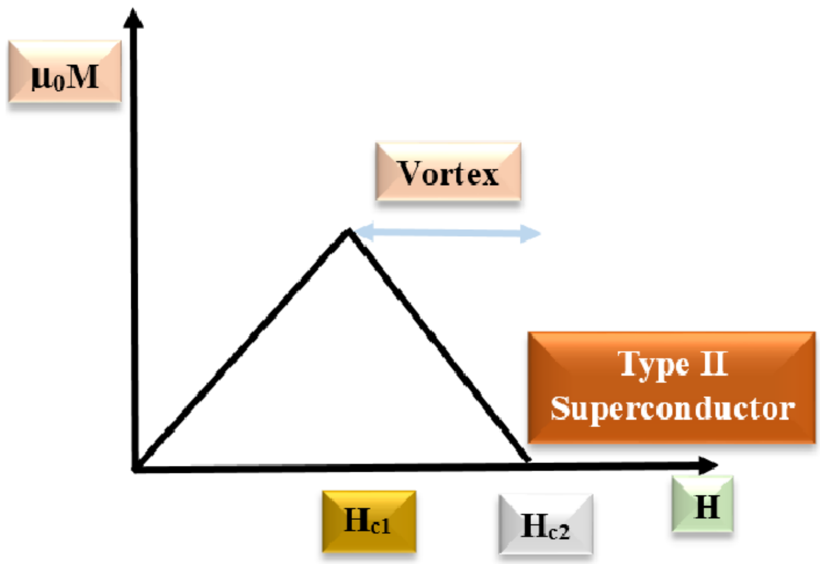


Figure 2-4 Intensity of magnetic field over applied magnetic field for Type II SC

2.6 ADVANTAGES AND USES OF HIGH TEMPERATURE SUPERCONDUCTING (HTS) CABLES IN POWER SYSTEMS

HTS cable is one of the promising applications of superconducting technology, which empowers in improving the capacity, efficiency and reliability of electrical systems. It can carry large amount of power to the destination or power grids and distributed to the utility. Various cryogenic coolants have to be used which are easily available in air such as Nitrogen, Oxygen, Hydrogen and Argon to maintain the HTS cable below its critical temperature. Moreover, the HTS does not emit electromagnetic radiation, increases reliability and security of power grid. HTS cables can carry power 10 times more than conventional cables. Thermal stresses in between the insulations layers are minimum which makes the HTS cable more stable [5]. Applications of HTS cables, at present in power transmission and distribution by conventional cables are report to have 40 to 60 % losses. In order to overcome such challenges conventional cables are replaced with HTS cables.

2.7 STRUCTURE OF HTS CABLE

Figure 2-5 construction of High Temperature superconducting (HTS) cable are discussed.

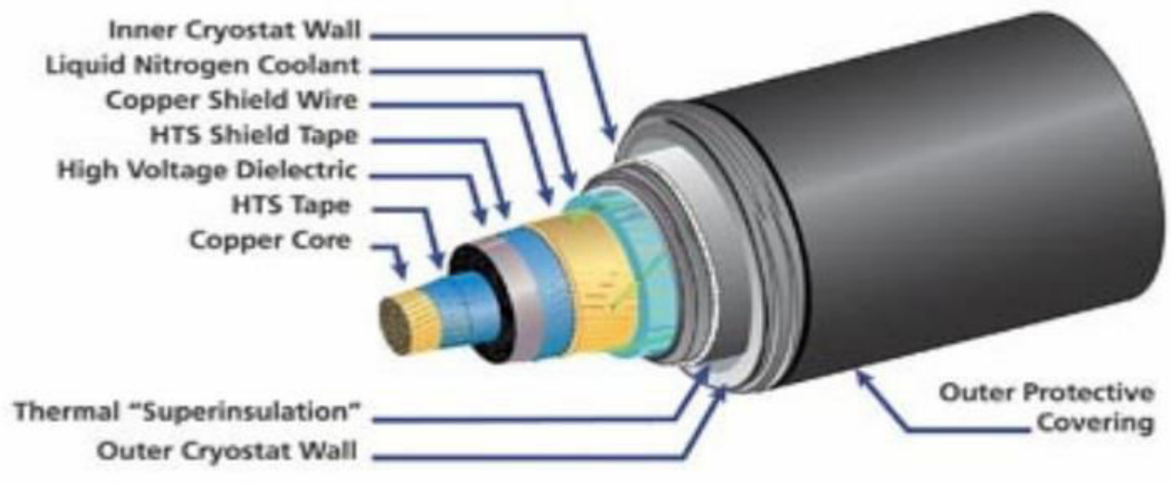


Figure 2-5 Schematic diagram of High Temperature superconducting (HTS) cable designed by NEXANS[8]

Basically, the construction of HTS cable consist of the following:

- Outer Protective Covering (CORE)
- Outer Cryostat Wall
- Inner Cryostat Wall
- Coolant (LN_2)
- High Temperature Superconducting (HTS) Tape
- Dielectric Material
- Thermal Insulation
- Copper core

2.7.1 Core

The main layer which gives the basic structure to the cable is the core. The material which is used to form this core is mainly copper or silver. In Nexan's designed HTS cable copper core is used. The purpose of using core in HTS cables are as follows

- Provides good strength, durability and flexibility to the cable.
- Reduction of Short circuit current as silver and copper are good conductors of electricity it can allow the excess current flowing through it.
- As silver and copper are also very good thermal conductors of heat they can remove the deposited or infiltrated heat loads on the superconductor.

- Due to some mishaps the cable may damage accidentally, at that time the expected power flow cannot be transmitted, auto recovery of silver or copper conductor can be taken place in the superconductor.

2.7.2 High Temperature Superconducting (HTS) Tape

In High Temperature Superconducting (HTS) cable it is the main part of the cable through which the flow of electrons (current) can be transmitted. Basically there are two different generations tapes which are Bismuth Strontium calcium copper oxide (BSSCO) which is first generations HTS tape whose critical temperature is 110K whereas the other one is Yttrium Barium Copper oxide (YBCO) which is second generation HTS tape whose critical Temperature is 90K. The above mentioned tapes are used to build or development of HTS cables. As per the requirement the no. of tapes can be installed over the copper former in order to transmit the transport current.

2.7.3 Dielectric Insulation

It deals with the electrical insulation to the cable. Within the HTS cable, in order to separate the phase of the HTS tapes and former electric insulation is used. Basically, in most common cases solid HTS tapes is used in most of the designs. Regularly used Dielectric materials are X linked poly ethylene, Polypropylene laminated paper are used. Moreover, Liquid Nitrogen (LN_2) coolant will be flown between the HTS tape and Dielectric material.

2.7.4 Shielding Layer

This layer offers an extra mechanical Strength and gives protection for any kind of stress developed from outside. It also make the cable more solid. Basically, in most common Poly vinyl Chloride (PVC) is used.

2.7.5 Coolant

It play a major role in HTS cables. Different types of coolants can be used but in most common Liquid Nitrogen (LN_2) is used as a coolant and it flows through the cable continuously in order to maintain the temperature of HTS tape. To maintain the flow of LN_2 and temperature of LN_2 at 77K intermediate cooling stations which is also known as terminations is used. At terminations the LN_2 is refrigerated by using cryocooler.

2.7.6 Cryostat Wall

Cryostat is used to carry the cryogenic coolant it consist of two sections i.e. inner cryostat wall and other one is outer cryostat wall. The outer cryostat wall is acting as a thermal insulator with the help of vacuum. Inner cryostat wall carry cryogenic fluid and is supported by the low conductivity wall. The intermediate shield between the two walls transfers the heat radiated from the outer layer and this heat is removed with the help of cryocooler.

2.7.7 Thermal Insulation

For cryogenic applications if the operating temperature is equal to or less than -101°C then thermal insulation is required. Under vacuum conditions, thermal insulation is formed by utilizing highly heat reflective things the material is used to form a heat barrier by positioning a plurality of spheres or fibers in a compact mass over a surface to be insulated. Various thermal insulating materials used here are Foam and sheet materials.

2.8 SUPERCRITICAL NITROGEN (SCN)

In order to cool the HTS cable, various cryogens are required to remove the deposited or infiltrated Heat loads. So liquid nitrogen (LN_2) can used in HTS cable as a cryogen. 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 LN_2 using various cryocoolers. Moreover, the difficulties in using Liquid cryogens are as follows.

- Pumping Power
- Change of phase

Electricity which is transmitting in the HTS cable will generate heat, in order to reduce those deposited or infiltrated heat, LN_2 is pumped at 77K in the form of liquid after prolonged usage of the cryogenic coolant rises its temperature starts evaporating therefore multiphase takes place [9].

The above difficulties are with respect to the length of the cable. To overcome such challenges, there is one such solution called **Supercritical fluid**. If the temperature and pressure of nitrogen is higher than critical temperature (T_c) and critical pressure (P_c) then it is said to be Supercritical Nitrogen (SCN). Below Figure 1-7 describes, Pressure and Temperature Phase diagram of Nitrogen.

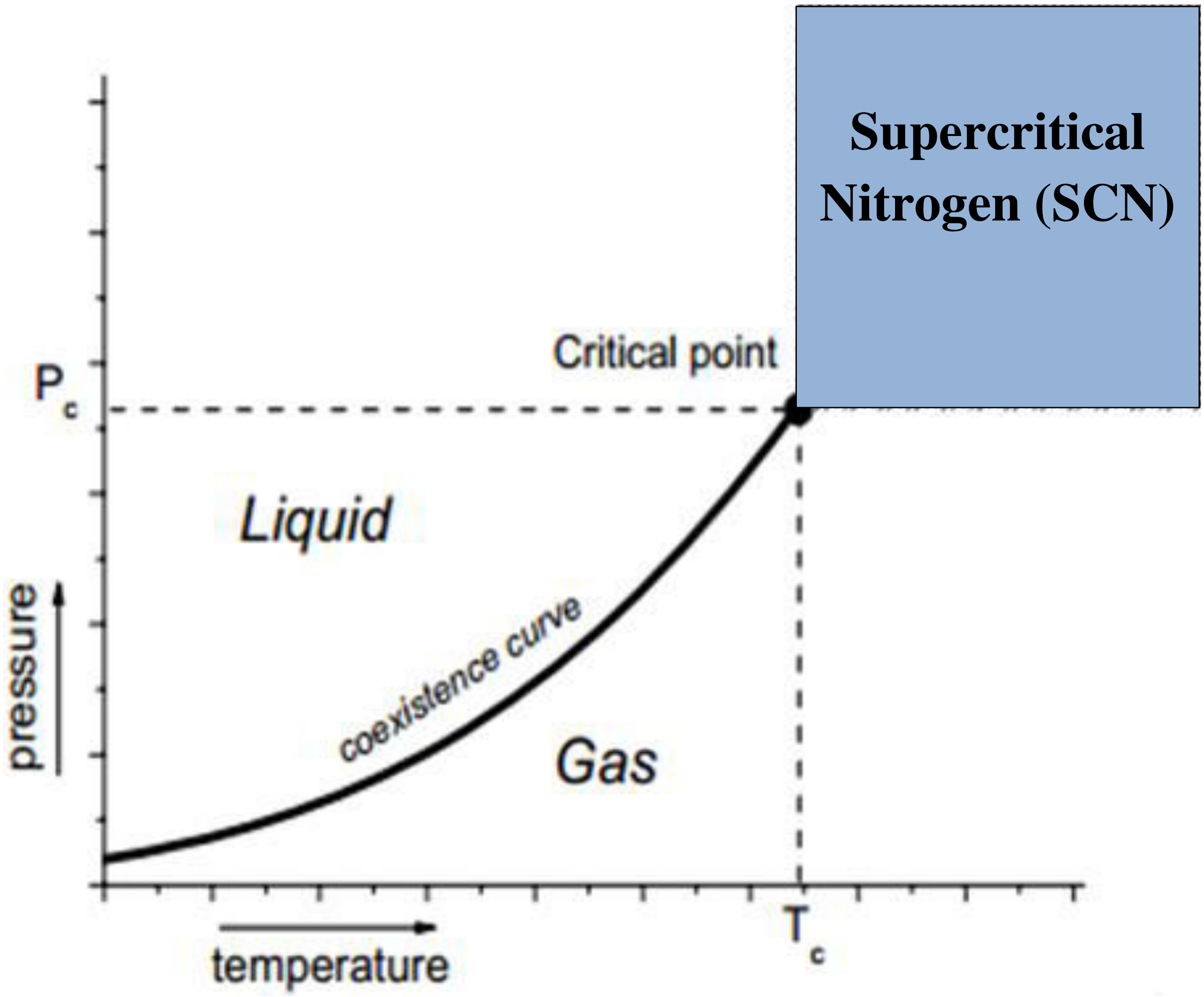


Figure 2-6 Phase diagram of Nitrogen [10]

In this region SCN behaves as a homogenous mixture and compressible. Moreover, density of the fluid in supercritical state is high. Hence we cannot define it as a gas or liquid. And also, diffusivity of SCN is much higher than LN_2 and it penetrates porous and fibrous solids [10]. There are drastic changes in some important thermophysical properties of SCN as its temperature and pressure are increased at and above the thermodynamic critical point. For example, under thermodynamic equilibrium conditions, the visual distinction between liquid and gas phases, as well as the difference between the liquid and gas densities, disappear at and above the critical point. Similar drastic changes exist in properties of a liquid mixture as it approaches the thermodynamic critical loci of the mixture [9]. Other properties of SCN that change widely near the critical region are thermal conductivity, Specific heat and viscosity. In comparing, liquid nitrogen (LN_2) with a supercritical nitrogen (SCN) both possessing the same density, thermal conductivity and diffusivity of a SCN are higher than the LN_2, while its viscosity and specific heat is much lower for LN_2. These drastic changes make a SCN appreciably preferred over that of a LN_2 with the same density. The critical temperature and pressure of SCN is found to be 126.19K and 33.958bar respectively [7]. Advantage of SCN, it can acts as good catalytic activity and non-toxic in nature. Below Table 2-2 and 2-3 describes the thermophysical properties of Liquid nitrogen and Supercritical Nitrogen [7].

Table 2-2 Thermophysical properties of LN2 at Boiling Temperature and P=1.01325 bar [7]

Boiling Temperature (K)	**Thermophysical Properties**			
	Density (kg/m^3)	**Viscosity (Pa-S)**	**Thermal Conductivity(W/m-K)**	**Specific Heat (kJ/kg-K)**
77.355	806.08	0.00016065	0.14581	2.0415

Table 2-3 Thermophysical properties of SCN at critical temperature and critical pressure (Pc=33.958bar) [7]

Critical Temperature (K)	**Thermophysical Properties**			
	Density (kg/m^3)	**Viscosity (Pa-S)**	**Thermal Conductivity(W/m-K)**	**Specific Heat (kJ/kg-K)**
126.19	342.67	2.0645E-5	0.13472	729.99

CHAPTER

3 LITERATURE REVIEW

3.1 INTRODUCTION

HTS cables experience technological challenges in efficient cooling. The cooling requirements need estimation of AC losses in the superconductors [11-12-13-14-15-16-17-18]. Pressure drop, parasitic heat loads, various cooling strategies and numerical investigation on flow behavior of LN2 were proposed in the past [19-20-21-22-23-24]. However, all the strategies discussed till date involve multiphase flows of which modelling and experimentation turned out to be a great challenge. So in order face such challenges a novel concept in cooling has been discussed in the present work, SCN is one such cryogen which can be used in HTS cable. Moreover, SCN involves in Single phase flows which can predict the thermohydraulic analysis for future power transmission applications. Below Figure 3-1 represents the construction of the Coaxial High Temperature Superconducting (HTS) Cable with different insulations modelled using ABAQUS.

Figure 3-1 Geometry of HTS coaxial cable with different insulations modelled using ABAQUS

3.2 A.C.LOSSES

By varying AC current or magnetic field would certainly leads to the movement of destruction which causes the induced emf & 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 [24]. So in order to dissipate heat loads SCN plays a vital role due to its unique thermophysical properties.

- ❖ R.Wesche [1999] studied "Design of Superconducting cables" investigations are as follows [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.
- Conceptual design of 112.5MW single phase transmission cable by optimizing various losses.

❖ J.A.Demko [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 are as follows [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 [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 reduced the eddy current loss.

- H.Noji [2005] studied "Numerical analysis of the AC loss in a high-T_C superconducting cable measured by calorimetric method" investigations are as follows [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.

- H.Noji [2007] studied "Numerical analysis of the AC losses of 500-m HTS power cable in Super-ACE project" investigations are as follows [16].
    - AC losses for 500-m HTS cable in Super-Ace project are calculated by using electric circuit model.
    - 69 percent of W_{tot} is dominated by W_{self}.
    - It was estimated that the W_{tot} of 1.29 W m^{-1} is obtained by a sum of 0.89 W m^{-1} as W_{self}, 0.32 W m^{-1} as W_{ext}, 0.06 W m^{-1} as W_{ohm} and 0.02 W m^{-1} as W_{eddy} at transport current, 1kA_{rms} to the HTS cable
    - Validation with, CRIEPI had estimated that the AC loss is obtained by a sum of 0.5 W m^{-1} consumed at the HTS conductor and HTS shield as the hysteresis loss, and 0.8W m^{-1} consumed at the former as the eddy-current loss.
    - It was considered that the difference is caused by an overestimation of the axial field at the former in CRI-EPI's loss calculation.

- FEI, designed 5-km HTS cable by using data of the field test of 500-m HTS cable of Ag/Bi-2223 tapes with $SrCO_3$ barriers are used for the 5 km HTS cable.
- The AC losses of the single type conductor and three-in-one type conductor are estimated at 0.4 W m^{-1} and 1.0 W m^{-1}.

❖ K.Ryu [2010] studied "AC losses of the 5 m BSCCO cables with shield" investigations are as follows [17].

- To measure the AC losses for multi-layered conductor and shield of HTS cable of 22.9KV/50MVA.
- Analyzed results shows 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 [2011] studied "AC losses and other researches with 5 m HTS model cable" investigations are as follows [18].

- 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 FLUID LOSSES

Basically these losses are incurred or leaked into former material from different layers in HTS cable. This losses is 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 [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 minimized because there is no pumping requirement of cryogenic fluids.

- ❖ J.A.Demko [2009] studied "Cooling configuration Design considerations for Long Length HTS Cables" investigations are as follows [22].
    - 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.
    - 2G HTS wire will be evaluated and compared to 1G HTS wire which typically consist of HTS filaments in a silver alloy matrix.
    - 2G HTS wire is expected to have lower ac loss and wire is being manufactured by using normal conductor stabilizer to accommodate fault currents.
    - Counterflow cooled, long length, HTS cables are technically feasible, energy saving and lower cost and it requires less cryostat.
    - Analyzed 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 times provided sufficient refrigeration is available.
- ❖ A.Sasaki [2011] studied "LN_2 circulation in cryopipes of superconducting power transmission line" investigations are as follows [23].
    - 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.
- Circulation losses and pump power are estimated in straight and bellows pipes forming circulation channels by both method (empirical formula and CFD).
- Sasaki studied the flow behavior in combined straight - corrugated pipe and estimated the pressure drop and the friction factor as a function of cable decentering by the CFD computation.
- Inserting small bellows into straight pipe, minimum coefficient hydraulic friction and mechanical stresses can be reduced.
- Results predict that, cable shift from center to cryopipe wall leads to further slight reductions in pressure drop. Therefore Sasaki suggested that there is no need to mount the cables at the center of the cryopipe.
- Friction factor of the bellow pipe and the pressure drop of the straight-bellow pipe are ~7 times and ~22 % higher than those of the straight pipe.
- If the cable is shifted and contacts the cryopipe surface, the change in viscous sublayer leads to ~70% reduction in pressure drop.
- For 10 km long length DC SC PT's for circulating LN_2, flow rate and pumping power are ~19L/min and 10W and the heat loss of 1.0W/m.

❖ Rajasekhar Dondapati [2013] studied "Pressure drop and Heat transfer analysis of Long length internally cooled HTS cable" investigations are as follows [24].

- 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.

3.4 DIELECTRIC LOSSES

Dielectric losses occurs 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 liquid nitrogen and conductors are in direct contact with the coolant. The main advantage of this concept is the magnetic interaction of the different phases can be ignored [9]. So in cold dielectric the SCN is used as a coolant instead of LN_2 because its critical temperature is 126.19K thereby the reliability of coolant increases compared with LN_2.

❖ J.A.Demko [2003] studied "Cryostat Vacuum thermal considerations for HTS Power Transmission Cable Systems" investigation are as follows [19].

- Effect 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) temperature are significantly higher in degraded vacuum case.
- 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 [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.

CHAPTER

4 SCOPE OF STUDY

The motivating idea behind the study of HTS cable that attracted me is enriched cooling properties of cryogenic fluids when passed into the HTS cable. At present, transmission of electrical energy with conventional electrical cables reported to have 40-60% losses. In order increase the efficiency of power transmission and distribution, High temperature superconducting (HTS) cables plays a vital role. However, cooling of HTS cables need appropriate cryogens which can remove the deposited or infiltrated heat loads on the superconducting tapes. Cryogenic coolant which are non-flammable and non-toxic such as nitrogen in order to maintain the temperature of HTS below its critical temperature.

- SCN is proposed as one such cryogen which can be used in HTS cables due to its peculiar thermophysical properties such as density (ρ), viscosity (μ), thermal conductivity (k) and specific heat (C_p).
- The complete study on thermophysical properties of supercritical nitrogen (SCN).
- The behavior of thermophysical properties above the critical temperature and critical pressure will be analyzed.
- The development of correlations for the thermophysical properties of SCN at critical pressure and varying temperature.

CHAPTER

5 OBJECTIVE OF STUDY

This chapter discusses about the objective of this study. Study of thermophysical properties such as Density, Viscosity, Thermal conductivity and Specific heat. Below are the objectives of this study

- Study of Thermophysical Properties such as Density, viscosity, Specific Heat and Thermal Conductivity of Supercritical Nitrogen.
- Characteristic behavior of Supercritical Nitrogen (SCN) at critical Point i.e. at Temperature (T_c=126.19K) and Pressure (P_c=33.958bar).
- Variation of thermophysical Properties of Supercritical Nitrogen (SCN) above the critical Point.
- Development of correlations for thermophysical properties of Supercritical Nitrogen (SCN).
- Developed correlations can be used to predict the thermohydraulic analysis on long length HTS cables.
- In future, there is a scope of developing a superconductor i.e. HgBaCaCuO (T_c=134K) in order to cool such superconductors, SCN (T_c=126.19K and P_c=33.958bar) is one such cryogen, which can be used in HTS cables to confiscate the heat loads which is intemperate from the superconductor.

CHAPTER

6 RESEARCH METHODOLOGY

This chapter discusses about the research method approach on cooling HTS cable that attracted me is enriched cooling properties of cryogenic fluids when passed into the HTS cable. In order to get the critical property data for SCN is done by using NIST software program REFPROP[7]. Then, in order to estimate the thermophysical properties such as density, specific heat, thermal conductivity and viscosity, further NIST software program REFPROP [7]have been used.

6.1 SELECTION OF CRITICAL PROPERTIES OF SUPERCRITICAL NITROGEN (SCN)

Temperature dependent properties of Supercritical Nitrogen (SCN) are prescribed in the literature shown in Table 6-1 Critical temperature and pressure data for Supercritical Nitrogen (SCN) is extracted from the NIST software program REFPROP[7].

Table 6-1 Critical property values of SCN at P_C=33.958 bar

Critical Temperature (K)	**Thermophysical Properties**			
	Density (kg/m^3)	**Viscosity (Pa-S)**	**Thermal Conductivity(W/m-K)**	**Specific Heat (kJ/kg-K)**
126.19	342.67	2.0645E-5	0.13472	729.99

6.2 STUDY OF THERMOPHYSICAL PROPERTIES OF SCN

Initially, thermophysical properties were observed at constant pressure and varying temperatures. Number of Data points (500 points) were obtained from NIST Software program REFPROP[7] within the pressure range of 33.958bar to 43.958 bar. Plots were drawn and discussed in the following sections. It has a reasonable good accuracy while estimating the thermodynamic properties.

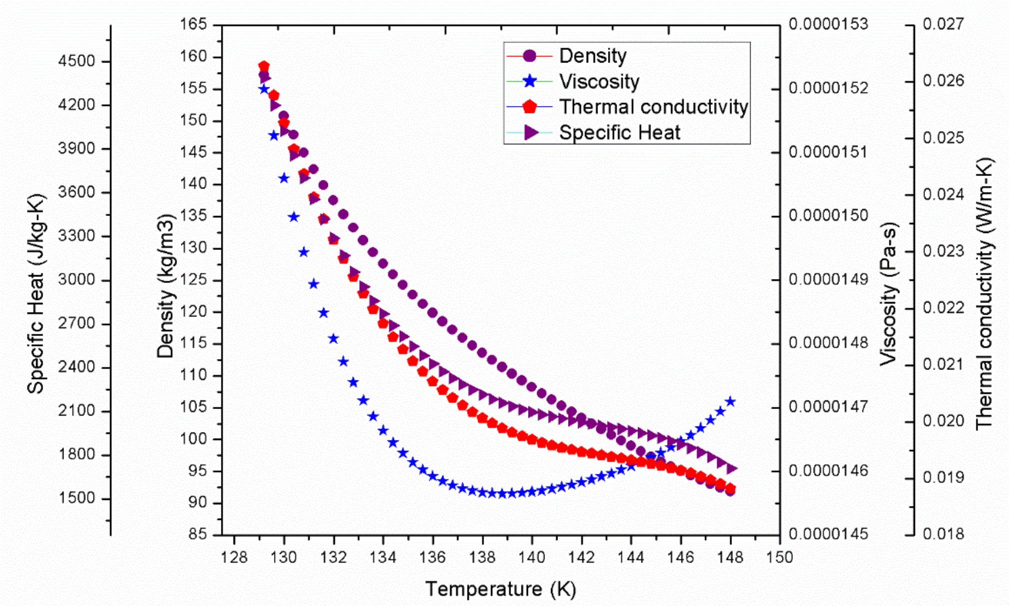


Figure 6-1 Temperature dependent properties of SCN at P_c=33.958bar

As described in the earlier section 3, the key focus of this study was to develop the correlations for the thermophysical properties such as Density, Viscosity, Thermal conductivity and Specific heat of SCN at critical pressure (P_c=33.958bar) and varying temperature (T_c+50K). Firstly, the behavior of thermophysical properties have been studied at varying pressure (P_c+10bar) and varying temperature (T_c+50K). Furthermore, the development of correlations for SCN to be analyzed by using various statistical methods. Finally, In order to ascertain the quality of the developed correlations, statistical parameters have to be used such as

- Average of the Absolute Values of the Relative Errors (AARE %)
- Sum of Absolute of Residual (SAR)
- Relative Error (RE %)

CHAPTER

7 RESULTS AND DISCUSSIONS

7.1 DEVELOPMENT OF CORRELATIONS

First of all, the plots, having variation of thermophysical properties with respect temperature (T_c+50K) and Pressure (P_c+10bar) have been plotted at and above the critical point. After analyzing the plots, a drastic variation in all the thermophysical properties such as density, heat capacity, thermal conductivity and viscosity has been observed in the supercritical region. So it becomes too difficult to fit the curve with a single correlation, therefore piecewise correlations are developed in order to estimate the properties with maximum accuracy and minimum standard errors. Below are the step followed in developing correlations for the thermophysical properties of SCN.

In order to estimate the thermophysical properties of SCN, Rational function fit (Eq.1) and Polynomial fit (Eq. 2) is used.

$$y = \frac{a + bx + cx^2}{1 + dx + ex^2}$$
$$y = \sum_{i=1}^{n+1} p_i x^{n+1-i} \qquad (2)\ \&\ (3)$$

Where x is the independent variable and y is the dependent variable and a, b, c, d, e are fitting parameters, n is the degree of the polynomial $1 \leq n \leq 9$, n+1 is the order of the polynomial. These models are employed in order to estimate the thermophysical properties of SCN and they show an excellent pact while estimating the property values. The property value changes drastically within a range of temperature variable.

7.2 SUPERCRITICAL NITROGEN (SCN)

The correlations have been developed for Supercritical Nitrogen (SCN) at critical pressure (33.958 bar) and for a temperature range of (129.19 – 179.19K). Total 500 data points are plotted for each thermophysical property such as density, specific heat, thermal conductivity and viscosity in order to fit the curve. Basically, the plots are drawn in between the temperature (along x-axis) and desired property (along y-axis) above the critical pressure in order to identify the variation in different thermophysical property values in the supercritical regime. Table 7-1 to Table 7-4 indicates the correlation coefficients for curve fits (Rational function fit and Polynomial fit) for all the four thermophysical Properties (density, viscosity, thermal conductivity and specific heat) of SCN.

Table 7-1 Correlation coefficients for density of SCN for Rational Curve fit [26].

Temperature Range	Correlation	Correlation Coefficients
126.29K≤T<127.99K	$\rho(T)=\dfrac{\rho_2+\rho_3*T}{1+\rho_1*T}$	$\rho_1=-0.00797, \rho_2=148.8154,$ $\rho_3=-1.19116$
128.09K<T<135.89K	$\rho(T)=\dfrac{\rho_5+\rho_6*T}{1+\rho_4*T}$	$\rho_4=-0.00829, \rho_5=74.63959,$ $\rho_6=-0.66828$
135.99K<T≤176.19K	$\rho(T)=\dfrac{\rho_8+\rho_9*T}{1+\rho_7*T}$	$\rho_7=-0.00962, \rho_8=2.99702,$ $\rho_9=-0.30743$

Table 7-2 Correlation coefficients for specific heat of SCN for Rational curve fit [26].

Temperature Range	Correlation	Correlation Coefficients
126.29K≤T<127.99K	$c_p(T)=\dfrac{c_{p2}+c_{p3}*T}{1+c_{p1}*T}$	$c_{p1}=-0.00793, c_{p2}=3.18982,$ $c_{p3}=-0.02567$
128.09K<T≤176.19K	$c_p(T)=\dfrac{c_{p5}+c_{p6}*T}{1+c_{p4}*T}$	$c_{p4}=-0.00799, c_{p5}=0.941,$ $c_{p6}=-0.00843$

Table 7-3 Correlation coefficients for thermal conductivity of SCN for Rational and polynomial cureve fit [26].

Temperature Range	Correlation	Correlation Coefficients
126.29K≤T<127.99K	$\kappa(T)=\dfrac{1+\kappa_3*T}{\kappa_1+\kappa_2*T}$	$\kappa_1=-0.00794, \kappa_2=0.02496,$ $\kappa_3=-1.99\mathrm{E}-04$

128.09K<T<145.99K	$\kappa(T)=\frac{\kappa_5+\kappa_6*T}{1+\kappa_4*T}$	κ_4 = -0.00803, κ_5 = 0.01626, κ_6 = −1.34E − 04
146.09K<T≤176.19K	$\kappa(T)=\kappa_7+\kappa_8*T^1+\kappa_9*T^2+\kappa_{10}*T^3$	κ_7 = 0.24416, κ_8 = −0.00402, κ_9 = 2.37E − 05, κ_{10} = −4.59E − 08

Table 7-4 Correlation coefficients for viscosity of SCN for Rational and Polynomial curve fit [26].

Temperature Range	Correlation	Correlation Coefficients
126.29K≤T<127.99K	$\mu(T)=\frac{\mu_2+\mu_3*T}{1+\mu_1*T}$	μ_1 = −0.00796, μ_2 = 1.19E − 05, μ_3 = −9.47E − 08
128.09K<T<135.89K	$\mu(T)=\frac{\mu_5+\mu_6*T}{1+\mu_4*T}$	μ_4 = −0.008, μ_5 = 1.12E − 05, μ_6 = −8.99E − 08
135.99K<T≤176.19K	$\mu(T)=\mu_7+\mu_8*T^1+\mu_9*T^2+\mu_{10}*T^3$	μ_7 = 8.38E − 05, μ_8 = −1.36E − 06, μ_9 = 8.40E − 09, μ_{10} = −1.67E − 11

7.3 VARIATION OF THERMOPHYSICAL PROPERTIES ABOVE CRITICAL POINT

The predictions of the thermophysical properties such as density, specific heat, thermal conductivity and viscosity above critical point for Supercritical Nitrogen (SCN) are plotted in **Error! Reference source not found.** to Figure 7-4. The plots consists the ariation of thermophysical properties for a pressure range of 33.958 bar above the critical pressure with an increment of 1 bar.

7.3.1 DENSITY

Error! Reference source not found. shows variation of density of SCN as a function of emperature at various pressures at and above critical point. It can be observed that, with an increase in temperature a drastic decrease in density of SCN. Moreover, with an increase in pressure, the density of SCN increases resulting in higher heat carrying capacities as shown in below Figure 7-1.

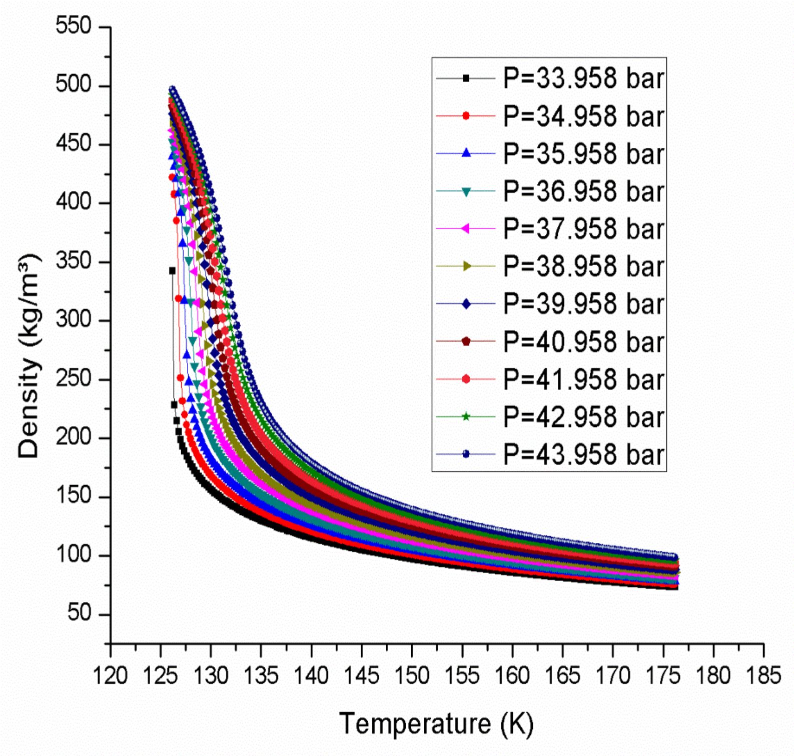


Figure 7-1Variation of density of SCN as a function of temperature at various pressures

7.3.2 SPECIFIC HEAT

Figure 7-2, shows variation of specific heat as a function of temperature at various pressures at and above critical point. It is also observed that, as the pressure increases the specific heat of SCN is increasing this indicates that heat carrying capacity of the SCN is increasing with varying pressures. Moreover, the curves become flatter at high pressures and there is not much variation in specific heat value with the increase in temperature.

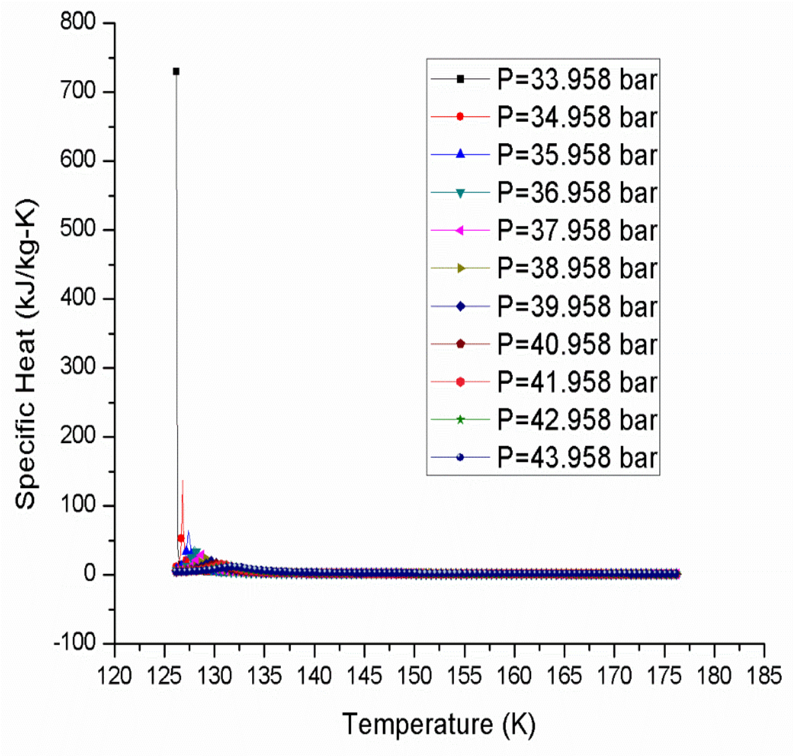
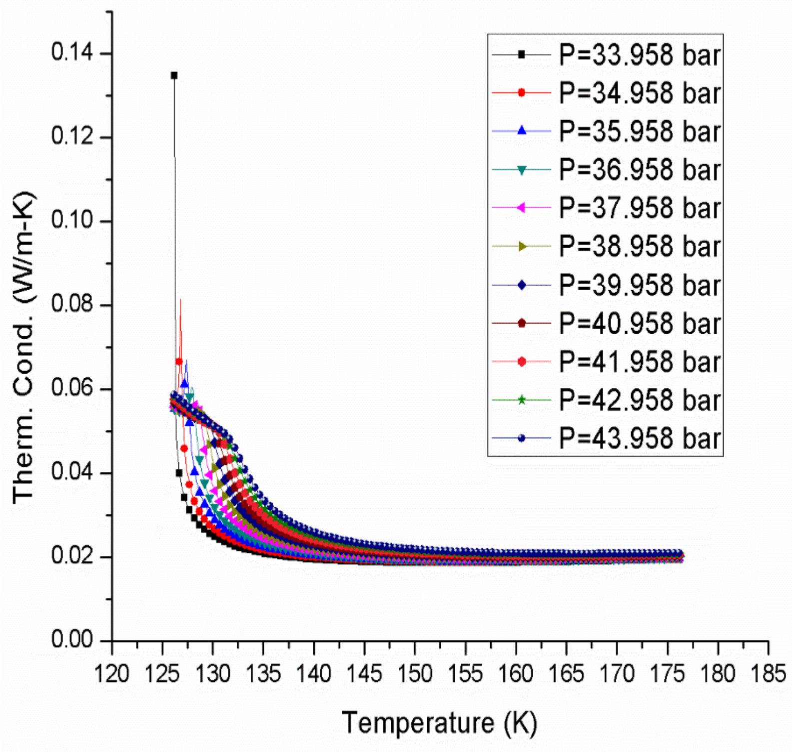


Figure 7-2 Variation of Specific Heat of SCN as a function of temperature at various pressures

7.3.3 THERMAL CONDUCTIVITY

Figure 7-3 shows the variation of thermal conductivity of SCN as a function of temperature at various pressures at and above critical point. It can be observed that the



thermal conductivity of the SCN decreases with respect to temperature under constant pressure. Moreover, it is observed that, thermal conductivity of SCN decreases drastically this indicates that, at (Tc+20K) the intermolecular forces and momentum between the molecules are large therefore drastic changes can be observed. Further, it is observed that the thermal conductivity of SCN is maintained constant trend this indicates that there is no much variation of thermal conductivity as the temperature and pressure varies.

Figure 7-3 Variation of thermal conducitvity as a function of temperature at various pressures

7.3.4 VISCOSITY

Figure 7-4 shows the viscosity variation of the SCN as a function of temperature at various pressures at and above critical point. It is observed that, the viscosity of SCN decreases drastically with the increase in temperature up to Tc+20K under varying pressures. Moreover, with an increase in pressure the viscosity of SCN increases resulting in higher frictional losses. Further, as the pressure and temperature increases viscosity of SCN increases (above 150K). Finally, it is recommended that, the viscosity of SCN is minimum at 135K-150K at this region lower frictional losses can be observed.

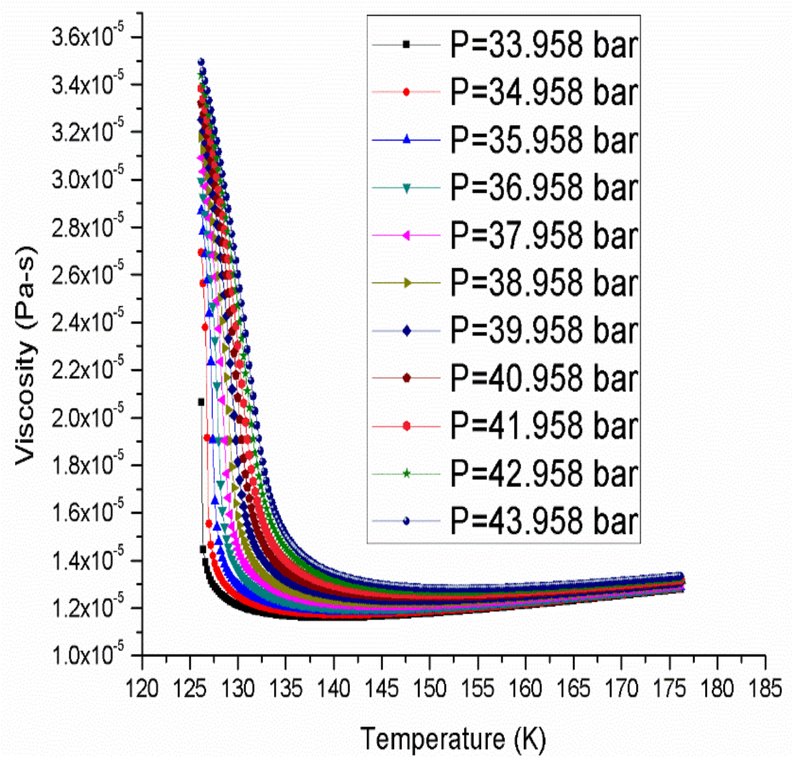


Figure 7-4 Variation of Viscosity of SCN as a function of temperature at various pressures

7.4 3-D SURFACE PLOTS

In order to envisage the variation of thermophysical properties of Supercritical Nitrogen (SCN) as a function of temperature and pressure 3-D plots has been developed by using MATLAB [25] tool.

7.4.1 3-D surface plot for SCN

Figure 7-5 shows the variation of density for SCN as a function of pressure and temperature in the supercritical region. The plot shows the variation in property over a wide range of temperature (126.19-176.19K) and pressure (33.958-43.958bar) in the supercritical region. Figure 7-5 shows that at critical pressure, the rate at which density drops with respect to temperature is found to be higher than that of elevated pressures. Also it can be noted that at temperatures higher than 140K, there is not much variation in the density for all pressure ranges. It can also to be noted that as pressure increases above critical value, the density of SCN also tend to increase and this increase is found to decrease as pressure increases for all temperature ranges.

Figure 7-6 shows the variation of specific heat for SCN as a function of pressure and temperature in the supercritical regime. The plot shows that the peak value is attained at P_C=33.958bar and temperature of about 126.19K in the supercritical region. Moreover, as the pressure increase i.e. above critical point it can be observed that drastic change in the specific heat of SCN has been observed. Figure 7-6 shows that, at higher temperatures 130K, there is not much variation in the specific heat values for all pressure ranges.

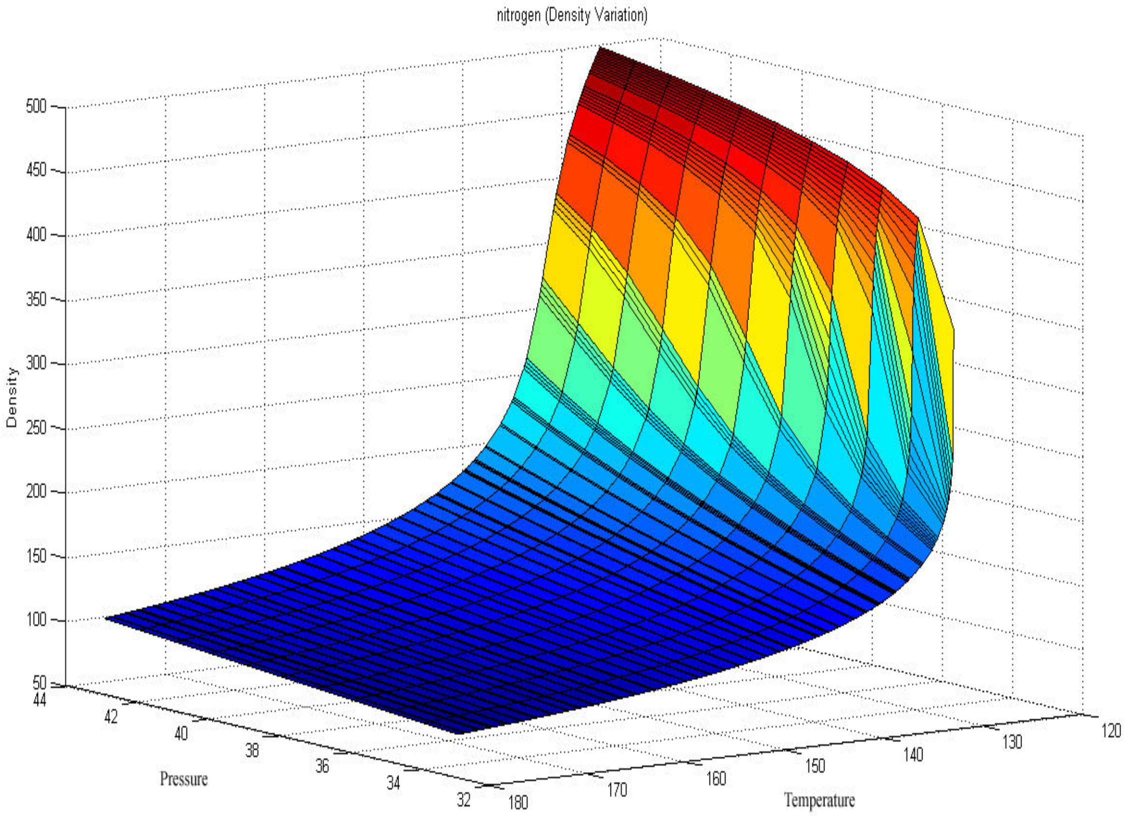


Figure 7-5 Density variation for SCN as a function of pressure and temperature.

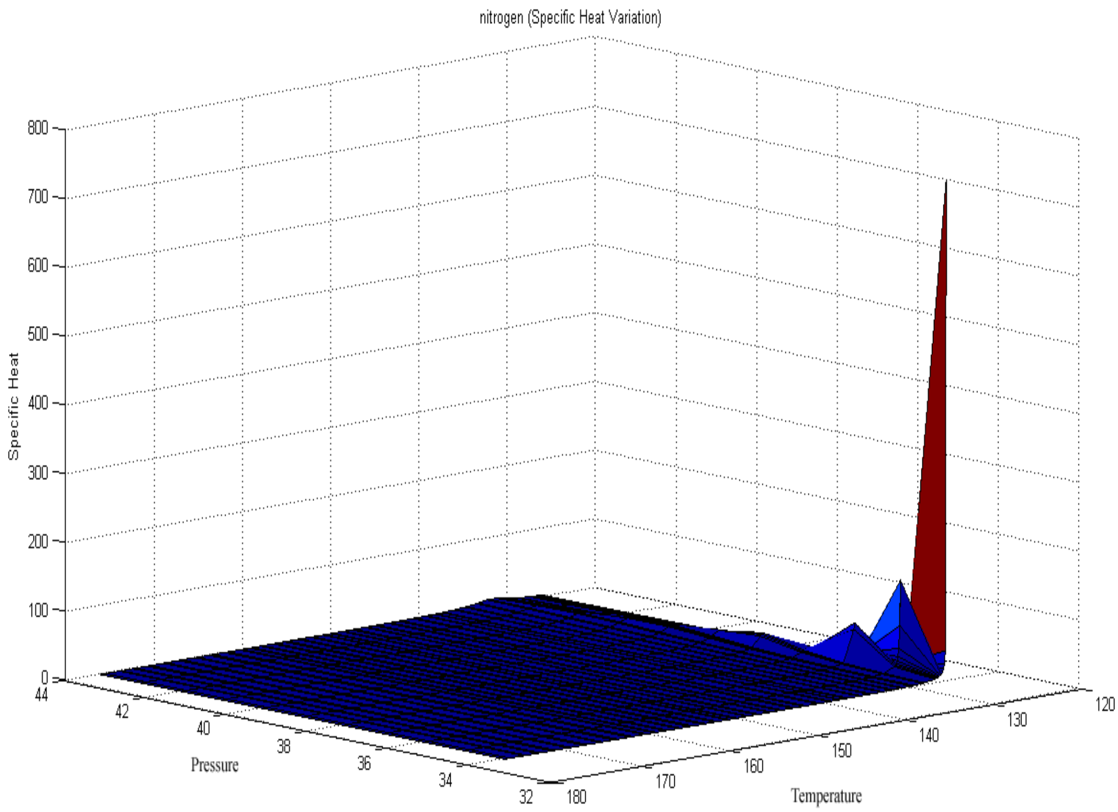


Figure 7-6 Specific heat variation for SCN as a function of pressure and temperature.

Figure 7-7 shows the variation of thermal conductivity of SCN as a function of pressure and temperature in the supercritical region. The plot shows that at Pc=33.958bar the rate at which thermal conductivity drops with respect to temperature is higher than that of higher pressure ranges. It can also to be noted that at temperatures greater than 130K, the thermal conductivity of SCN tends to increase again for all pressure ranges. It can also to be noted that as pressure increases above critical value, the thermal conductivity of SCN also tend to increase and this increase is found to decrease as pressure increases for all temperature ranges.

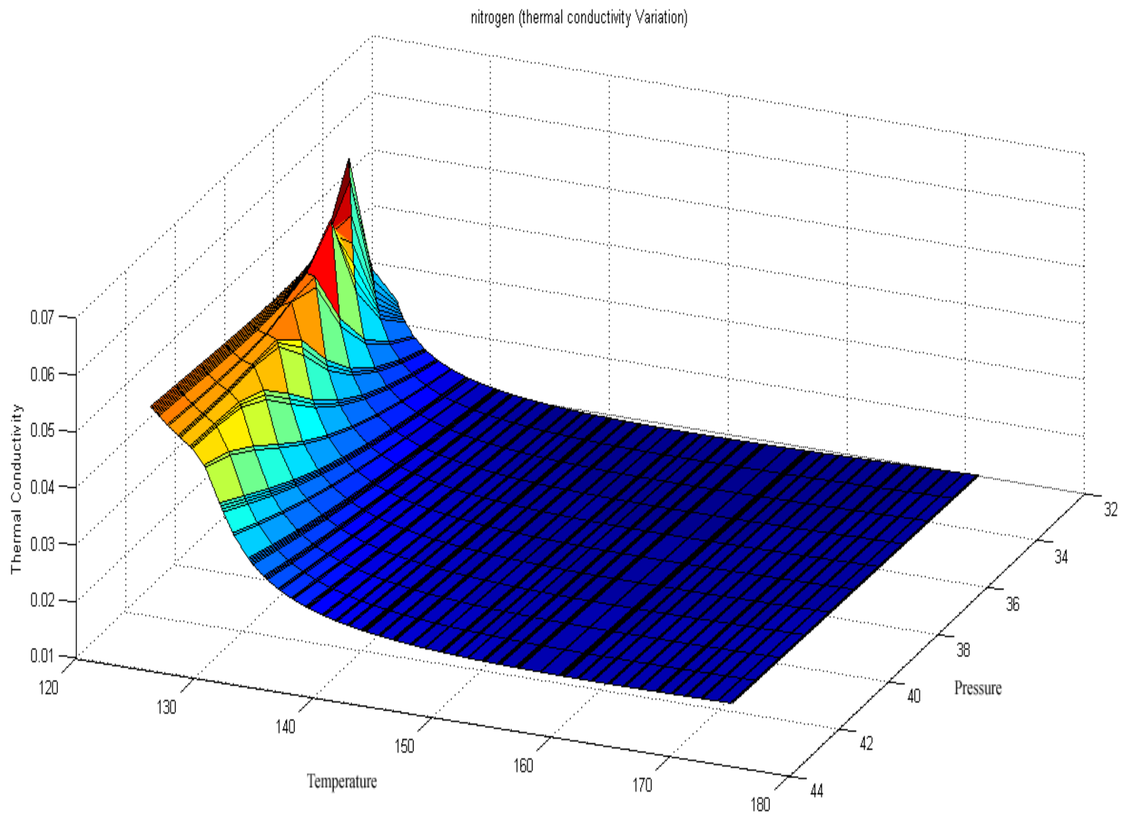


Figure 7-7 Thermal conductivity variation for n-heptane as a function of pressure and temperature.

Figure 7-8 shows the variation of viscosity of SCN as a function of pressure and temperature in the supercritical regime. The plot shows that at critical pressure, the rate at which viscosity drops with respect to temperature is higher than that of elevated pressure ranges. It can also to be noted that at temperatures greater than 135K, the viscosity of SCN is not much affected by pressure change for all pressure ranges. It can also to be noted that as pressure increases above critical value, the viscosity of SCN also tend to increase and this increase is found to decrease as pressure increases for all temperature ranges.

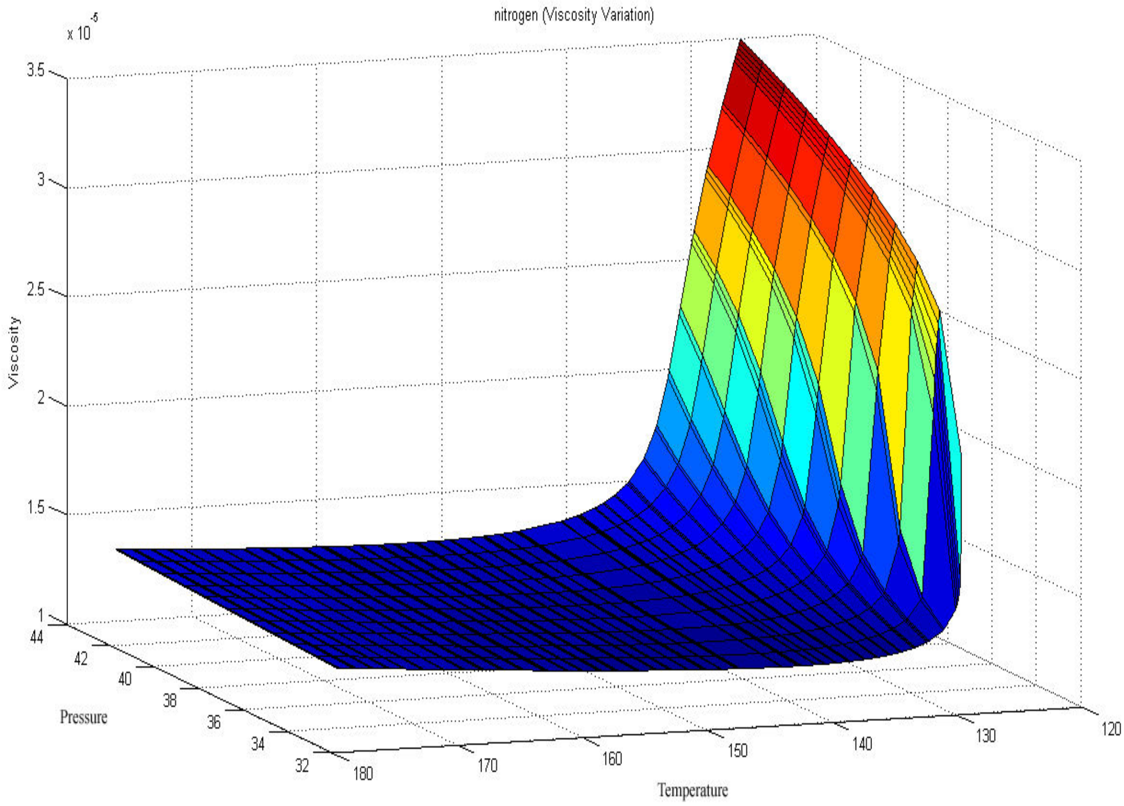


Figure 7-8 Viscosity variation for SCN as a function of pressure and temperature.

7.5 RESULTS

In this work, basically the reported data for thermophysical properties such as density, specific heat, thermal conductivity and viscosity has been extracted from the NIST software program REFPROP[7]. The predicted thermophysical properties of SCN at the respective critical point have been estimated by the correlations given in Eq. 3 and 4. In order to evaluate the proposed correlations, different statistical parameters are used.

7.5.1 Arithmetic Average of the Absolute Values of the Relative Errors (AARE %) and Sum of Absolute of Residual (SAR)

Arithmetic Average of the Absolute values of the relative errors (AARE %), which is defined in Eq. (3).

$$AARE\% = \frac{100}{N}\sum_{i=1}^{500}\left(\left|\frac{X^{act} - X^{cal}}{X^{act}}\right|\right) \quad (3)$$

This parameter indicates the accuracy of the correlations. The second parameter is defined as the Sum of Absolute of Residual (SAR) which shows the reliability of correlation for more dense data points and is given in Eq. (4).

$$SAR = \sum_{i=1}^{N} \left| X^{act} - X^{cal} \right| \quad (4)$$

Here 'X' denotes the thermophysical property of the SCN. Table 7-5 reports the average absolute relative error percentage AARE (%) and Sum of Absolute of Residual (SAR) of the developed correlations in compare with the actual data at critical point which is obtained from REFPROP[7].

Table 7-5 Average Absolute Relative Error Percentage (AARE %) for Rational Function fit

Thermophysical Property	Average Absolute Relative Error Percentage (AARE %)
Density	0.2820
Specific Heat	1.0673
Thermal Conductivity	0.5858
Viscosity	0.4330

7.5.2 Percent Relative Error

Percent Relative Error is a parameter that defines the relative error between the calculated properties by using Rational fit for SCN. Figure 7-9 to Figure 7-16 shows the variation of Percent Relative Error (RE %) of Rational Function fit and Polynomial curve fits of SCN as a function of temperature and thermophysical properties containing density, specific heat, thermal conductivity and viscosity which is defined in Eq. (5)

$$RE\% = \frac{X^{act} - X^{cal}}{X^{act}} \times 100 \quad (5)$$

Error! Reference source not found. shows the variation of percent relative error for the ational function and Polynomial function curve fits as a function of four thermophysical properties. From these plots some key observations made as

Table 7-6 Sum of Absolute of Residuals (SAR) for rational curve fits

Thermophysical Property	**Sum of Absolute Residual (SAR)**
Density	188.7149
Specific Heat	32.4109
Thermal Conductivity	0.07282
Viscosity	2.704E-05

Figure 7-9 shows that, at higher density values, error is approaching zero for both the fits and also to be noted that as the density decreases, fits shows the overlapped behavior for the entire range of density and also the error calculated is more in the range of 80-130kg/m^3. Figure 7-10 shows that, the random variation in errors at the higher values of specific heat. At the lower values of specific heat, the errors restrict within the range of $\pm$ 4%. Figure 7-11 shows that, the error limits to very small in the range of $\pm 2\%$ for low values of thermal conductivity. Figure 7-12 shows that, there is not much variation in percent relative error at low viscosity but error is found to be high at larger viscosity values for Rational Functional fits. As the viscosity decreases the error tends to reduce.

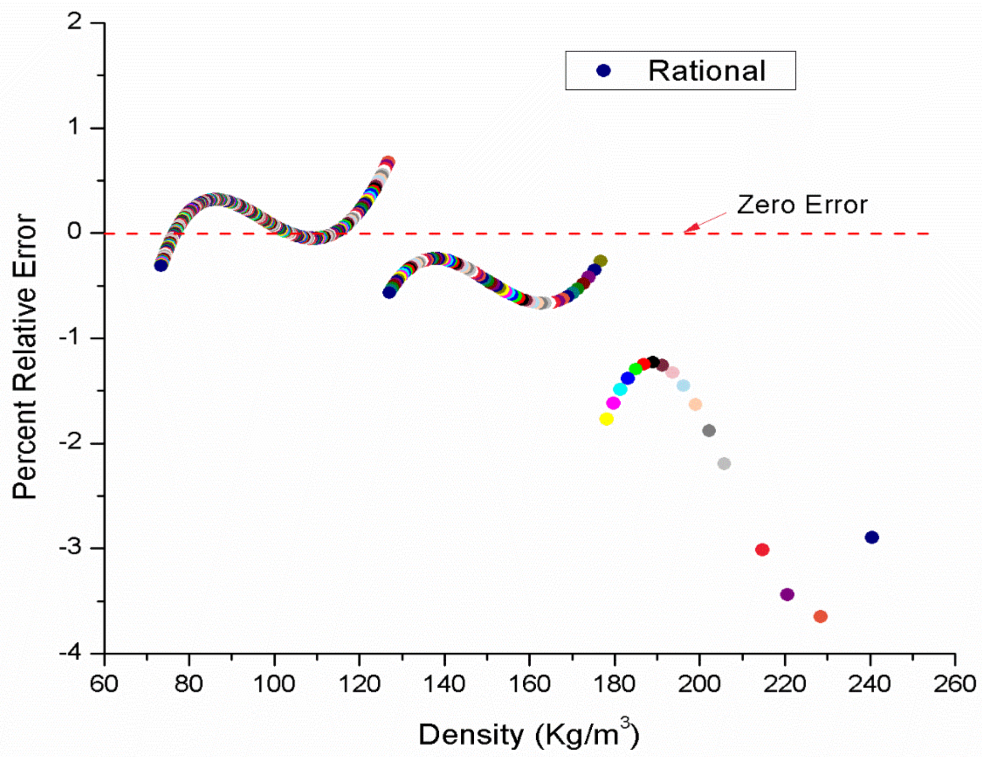


Figure 7-9 Percent Relative Error Variation with respect to Densityfor Rational Function fit

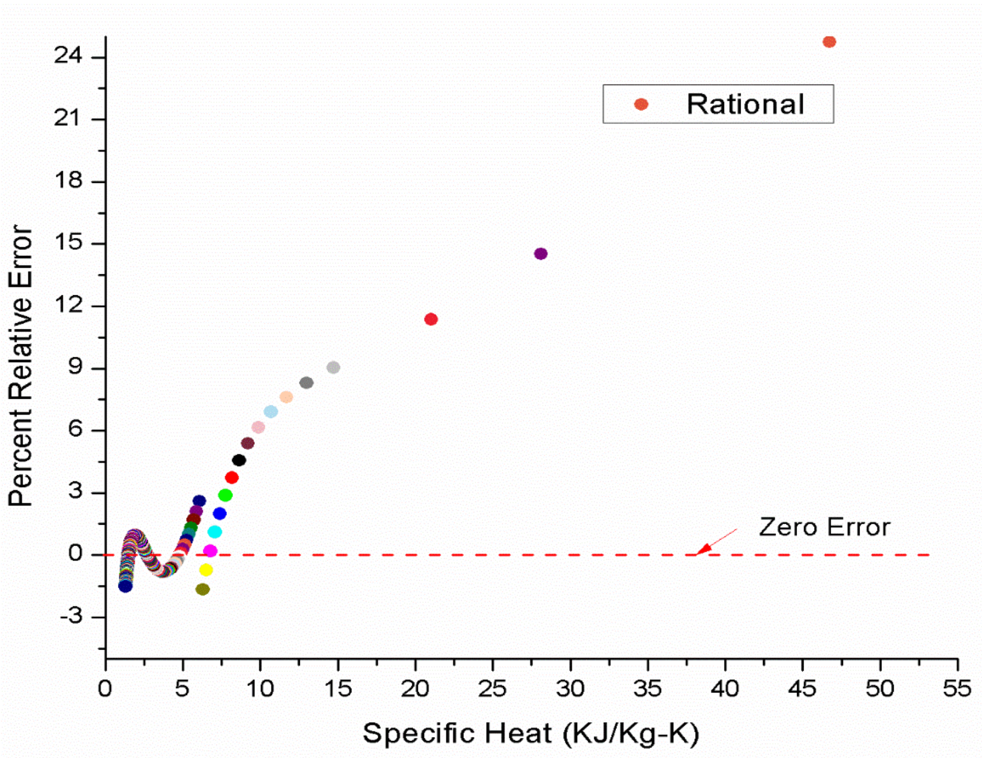


Figure 7-10 Percent Relative Error Variation with respect to Specific Heat for Rational Function fit

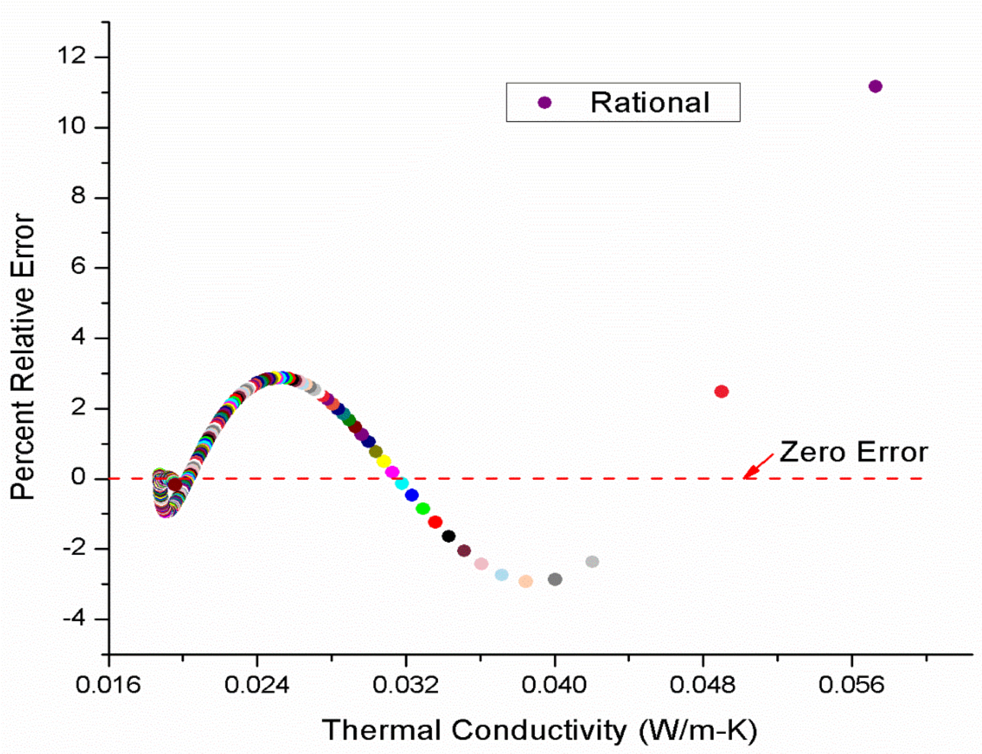


Figure 7-11 Percent Relative Error Variation with respect to Thermal Conductivity for Rational Function fit

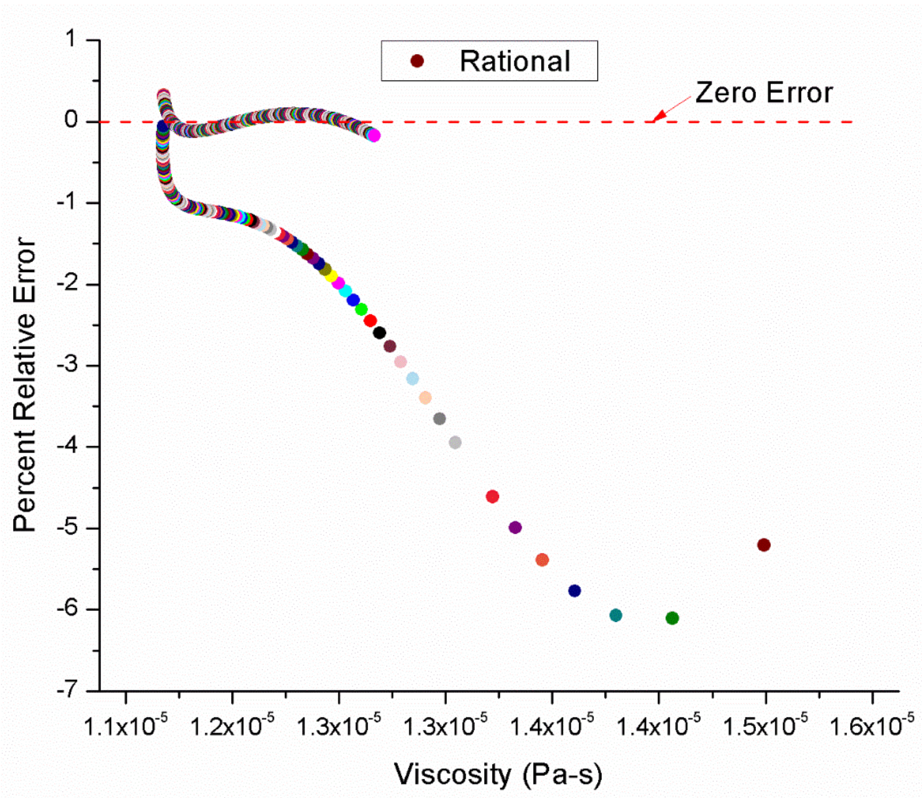


Figure 7-12 Percent Relative Error Variation with Respect to viscosity for Rational Functional fit

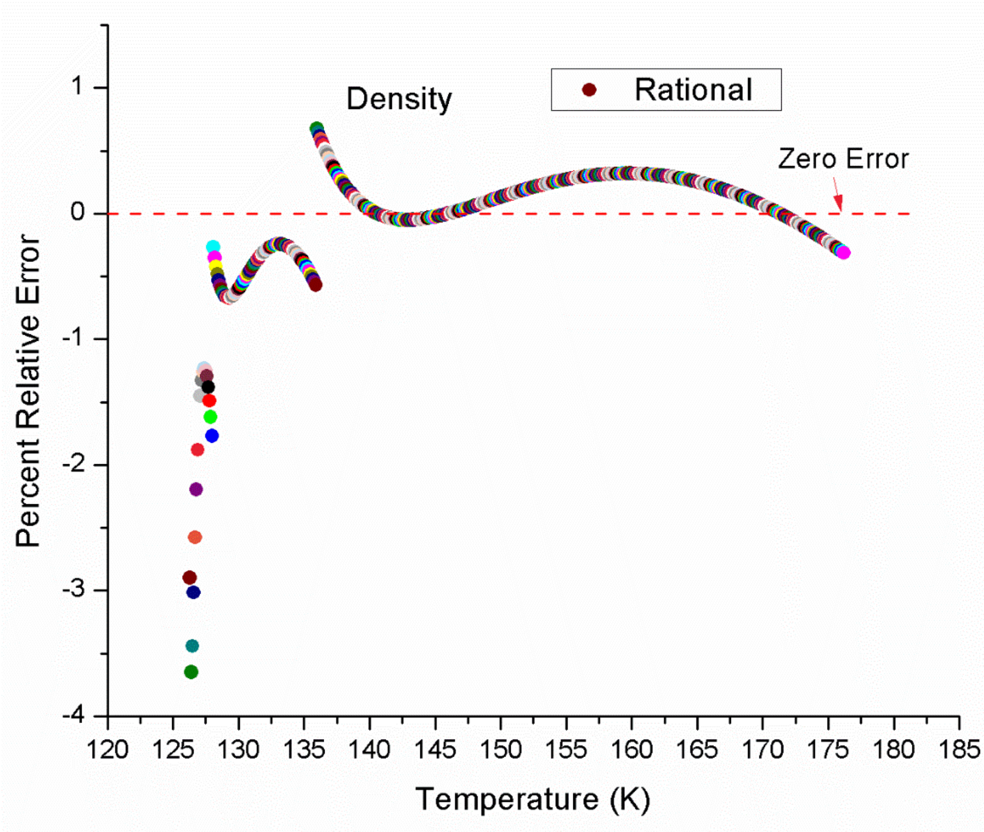


Figure 7-13 Percent Relative Error variation with respect to temperature for Rational Function fit

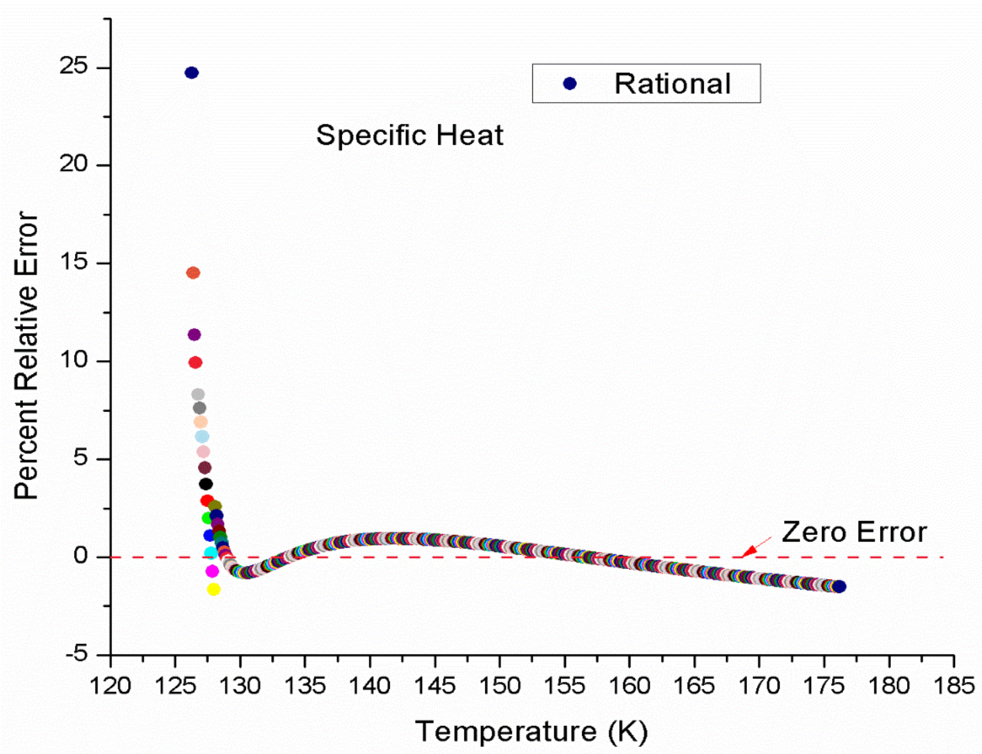


Figure 7-14 Percent Relative Error variation with respect to temperature for Rational Function fit

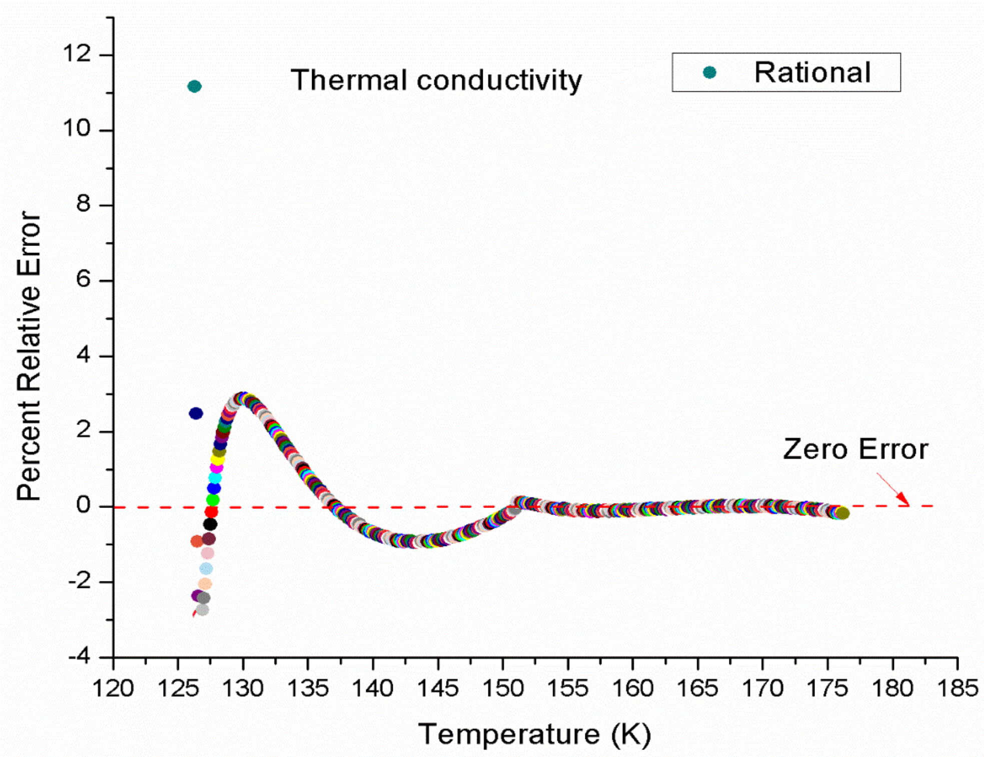


Figure 7-15 Percent Relative Error variation with respect to temperature for Rational Functional fit

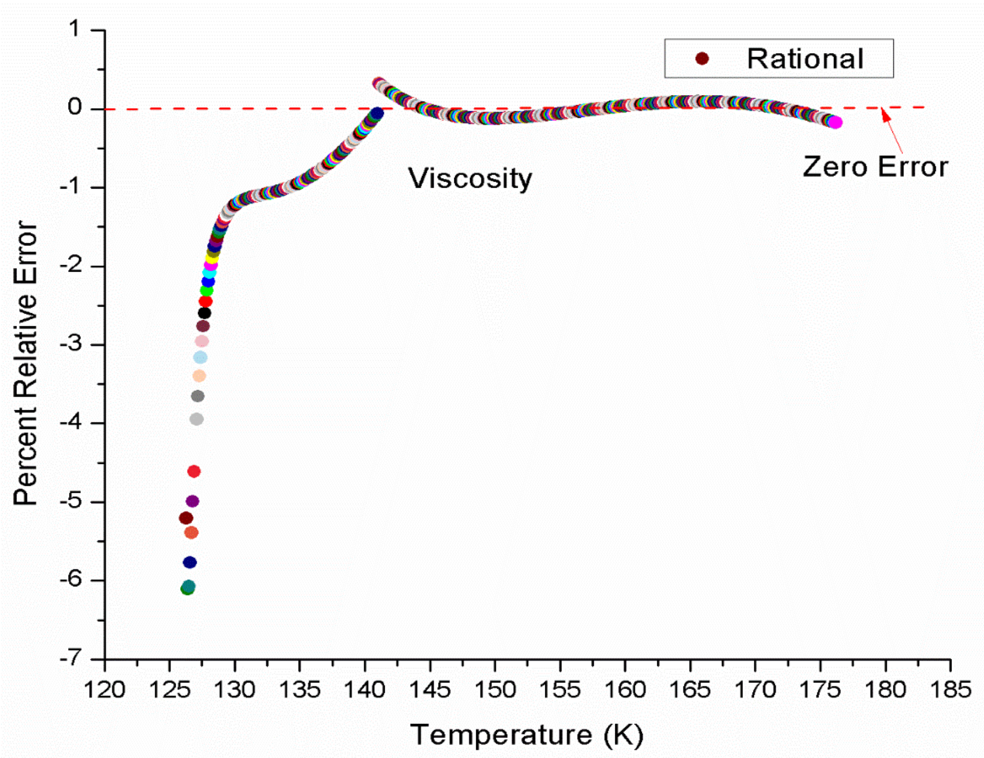


Figure 7-16 Percent Relative Error Variation with respect to temperature for Rational Function fit

Figure 7-13 shows that, the variation of Percent Relative error as a function of temperature above critical point for density. It is observed that, at temperature above 130K the error value ranges $\pm 3\%$ and at lower temperature ranges error is less. Figure 7-14 shows that, peak value of error has obtained at critical temperature (Tc=126.19K). Moreover, it is observed that, minimum Percent Relative Error can be obtained at higher temperatures. Figure 7-15 shows that, maximum error is obtained at temperature (136K) thereafter at higher temperatures minimum error can be obtained. Figure 7-16 shows that, maximum error is $\pm 1\%$. Moreover, it is observed that, minimum error can be obtained at higher temperatures in case of Rational Functional Fit.

7.5.3 Accuracy

In order to estimate the accuracy between the present work and actual values of the thermophysical properties extracted from NIST software program REFPROP[7] , the plots have been drawn between the calculated and actual property at the critical point of SCN used in this study. R^2 values indicate the level of accuracy between the two.

7.5.3.1 Density

Figure 7-17 shows, the comparison of accuracy between the actual and calculated density of SCN for the rational functional curve fit at temperature (126.29-127.99K). The accuracy level R^2-value of this fitting is 0.99789. Figure 7-18 illustrates the comparison of accuracy in thermodynamic property i.e. density for rational curve fits for the rational functional curve fit of SCN at temperature (128.09-135.89K). The accuracy level R^2-value of this fitting is 0.99984. Therefore, from Figure 7-19, it can be noted that polynomial fictional fit can estimate the thermodynamic property values with almost same accuracy level R^2-value of 0.99987 at temperature (135.99-176.19K).

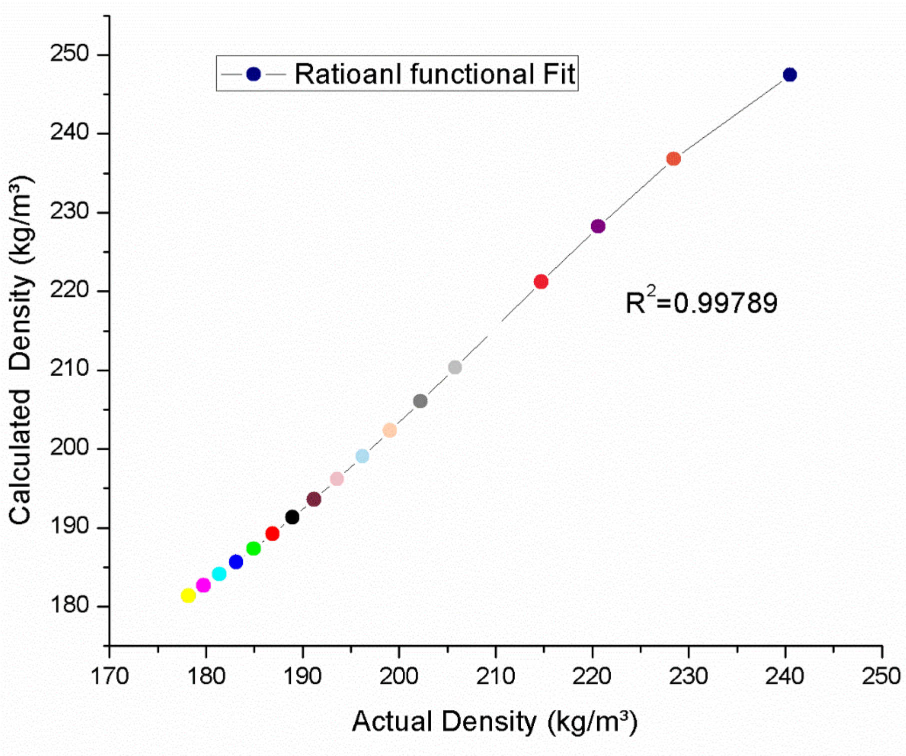


Figure 7-17 Comparison of accuracy between the actual and calculated density for rational functional fit1.

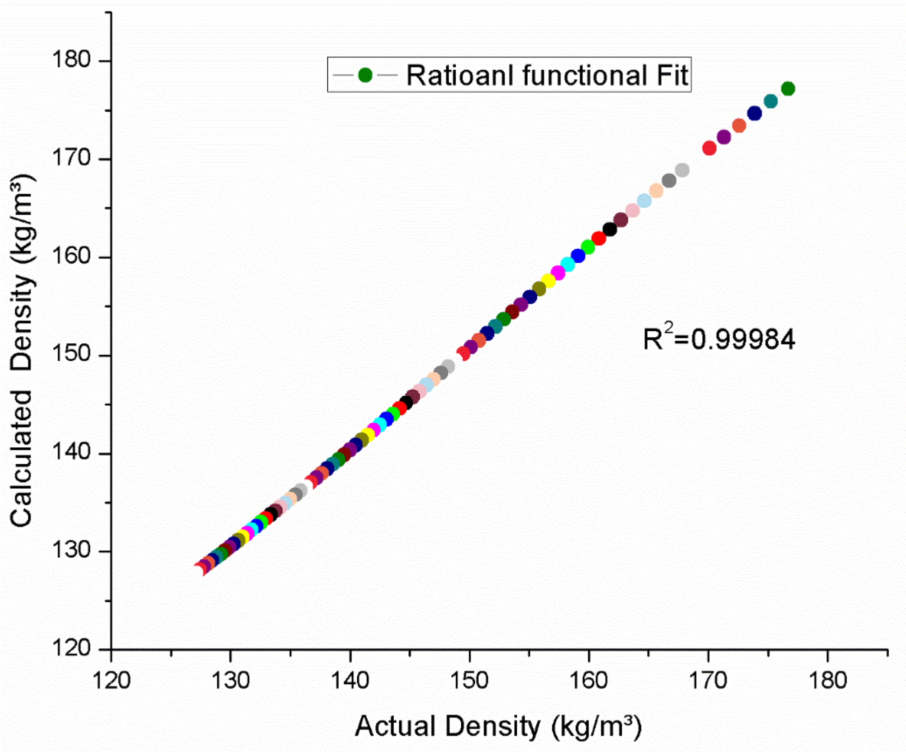


Figure 7-18 Comparison of accuracy between the actual and calculated density for rational functional fit2.

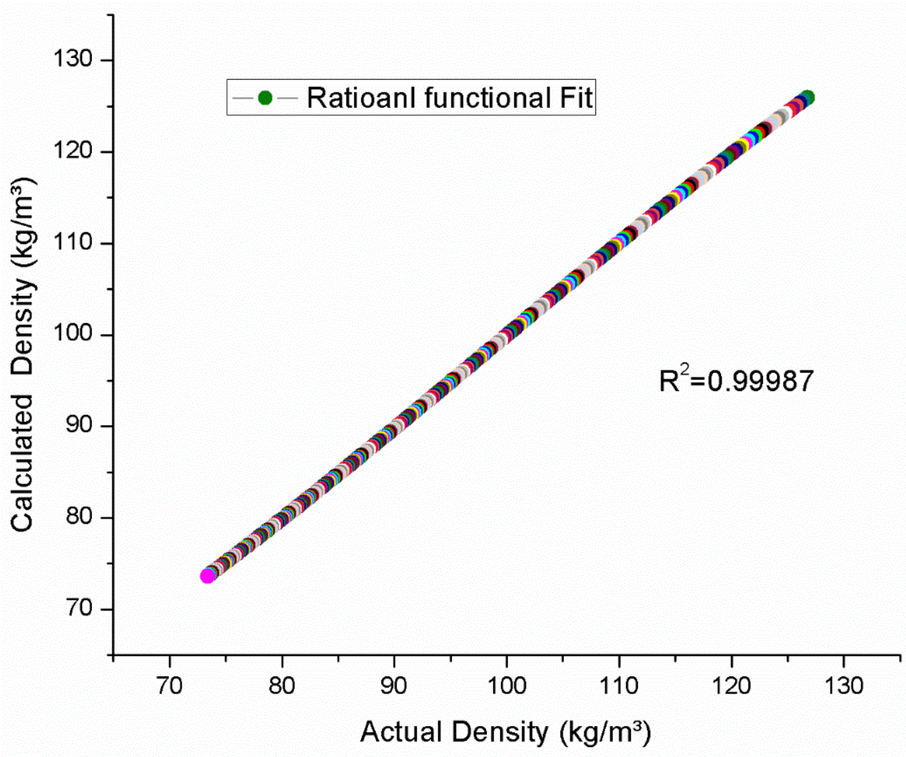


Figure 7-19 Comparison of accuracy between the actual and calculated density for polynomial functional fit.

7.5.3.2 Specific heat

Figure 7-20 shows, the comparison of accuracy between the actual and calculated Specific heat of SCN for the rational functional curve fit at temperature (126.29-127.99K). The accuracy level R^2-value of this fitting is 0.99956. Figure 7-21 illustrates the comparison of accuracy in thermodynamic property i.e. Specific heat for rational curve fits for the rational functional curve fit of SCN at temperature (128.09-176.19K). The accuracy level R^2-value of this fitting is 0.99958.

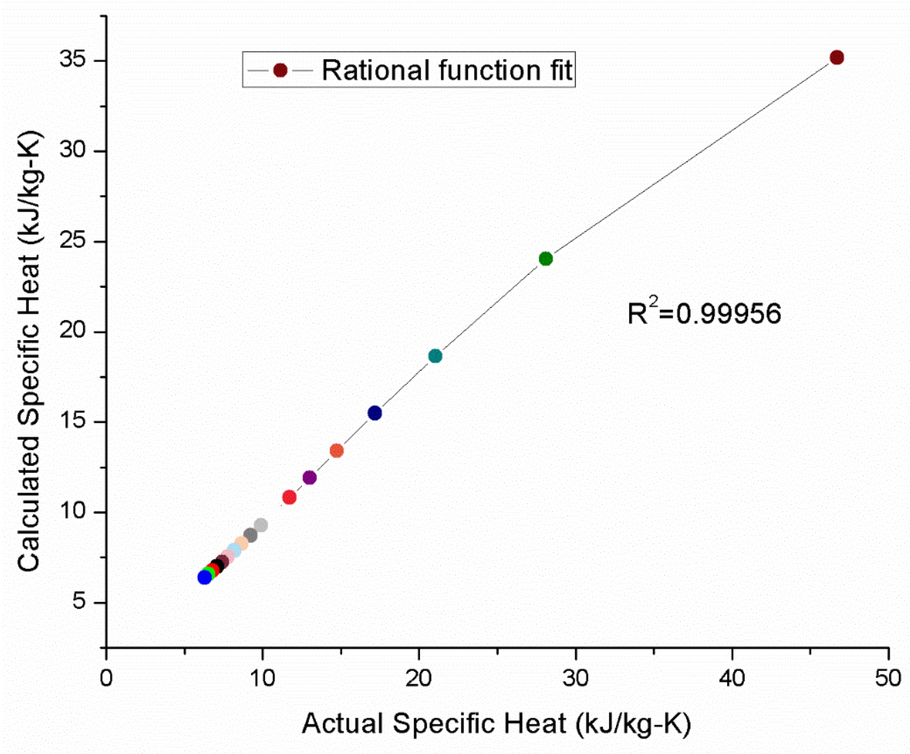


Figure 7-20 Comparison of accuracy between the actual and calculated specific heat for rational functional fit1.

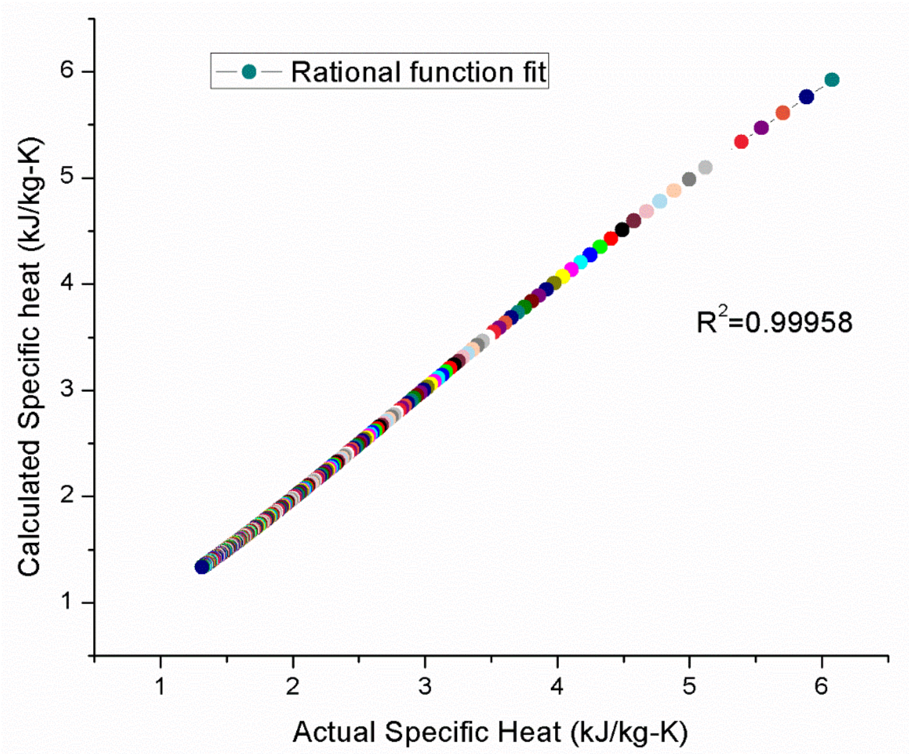


Figure 7-21 Comparison of accuracy between the actual and calculated specific heat for rational functional fit2.

7.5.3.3 Thermal Conductivity

Figure 7-22 shows, the comparison of accuracy between the actual and calculated thermal conductivity of SCN for the rational functional curve fit at temperature (126.29-127.99K). The accuracy level R^2-value of this fitting is 0.99708. Figure 7-23 illustrates the comparison of accuracy in thermodynamic property i.e. thermal conductivity for the rational functional curve fit of SCN at temperature (128.09-145.99K). The accuracy level R^2-value of this fitting is 0.99962. Therefore, from Figure 7-19, it can be noted that polynomial fictional fit can estimate the thermodynamic property values with almost same accuracy level R^2-value of 0.99957 at temperature (146.09-176.19K).

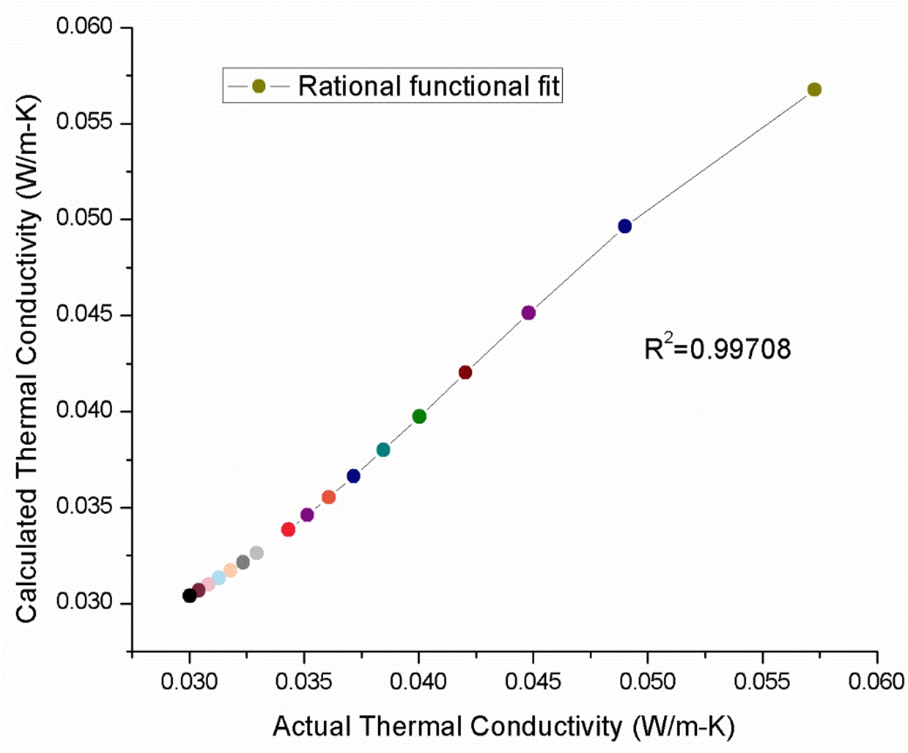


Figure 7-22 Comparison of accuracy between the actual and calculated thermal conductivity for rational functional fit1.

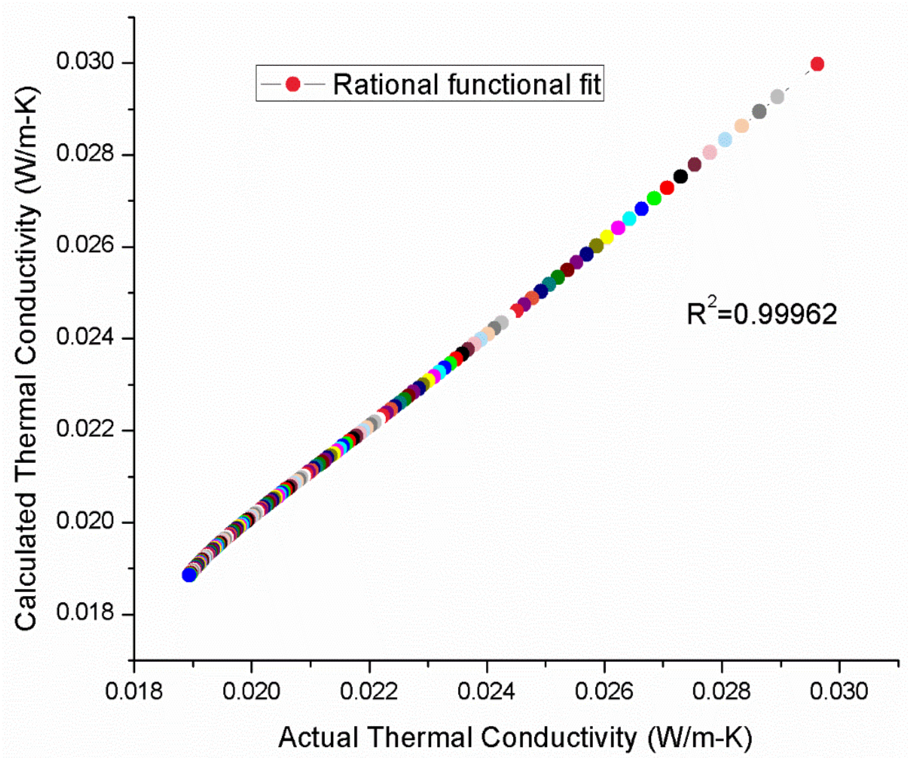


Figure 7-23 Comparison of accuracy between the actual and calculated thermal coductivity for rational functional fit2.

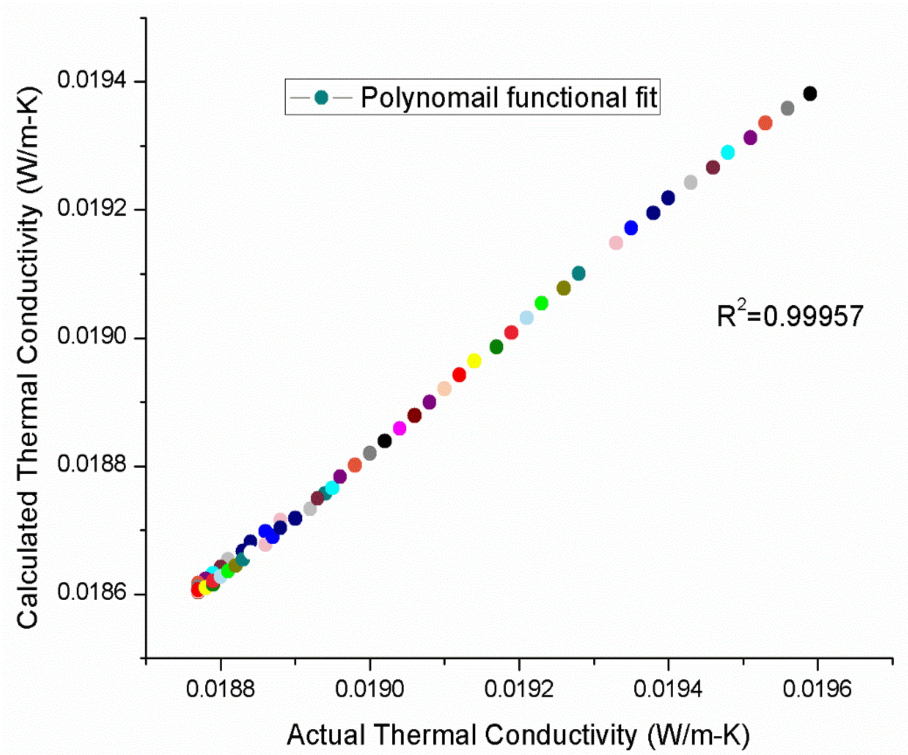


Figure 7-24 Comparison of accuracy between the actual and calculated thermal conductivity for polynomial functional fit.

7.5.3.4 Viscosity

Figure 7-25 shows, the comparison of accuracy between the actual and calculated viscosity of SCN for the rational functional curve fit at temperature (126.29-127.99K). The accuracy level R^2-value of this fitting is 0.99818. Figure 7-26 illustrates the comparison of accuracy in thermodynamic property i.e. viscosity for the rational functional curve fit of SCN at temperature (128.09-135.89K). The accuracy level R^2-value of this fitting is 0.99971. Therefore, from Figure 7-27, it can be noted that rational fictional fit can estimate the thermodynamic property values with almost same accuracy level R^2-value of 0.99969 at temperature (135.99-176.19K).

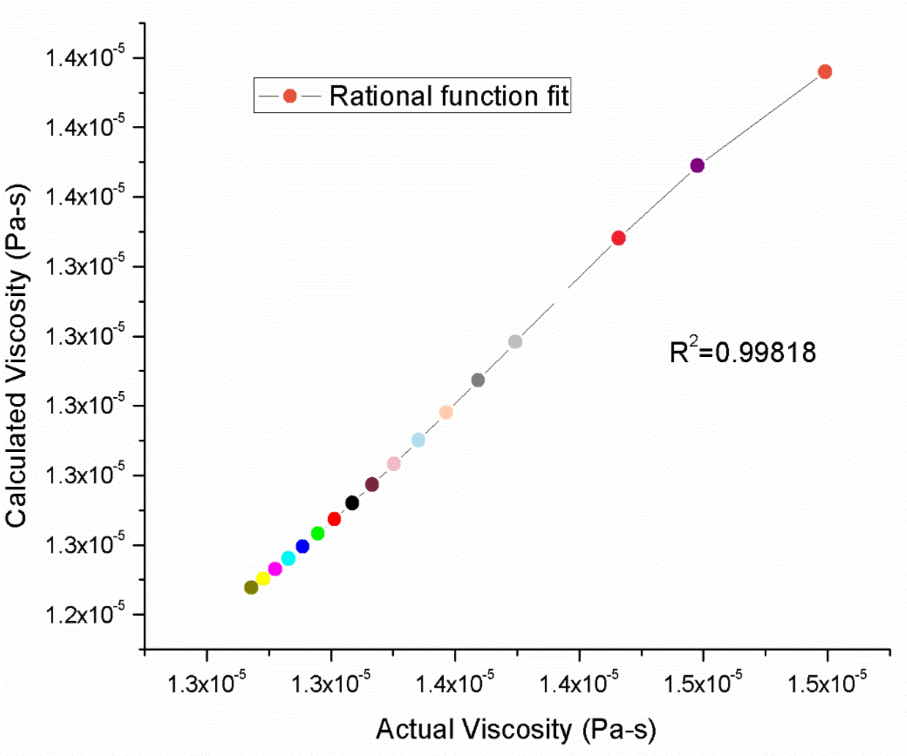


Figure 7-25 Comparison of accuracy between the actual and calculated viscosity for rational functional fit1.

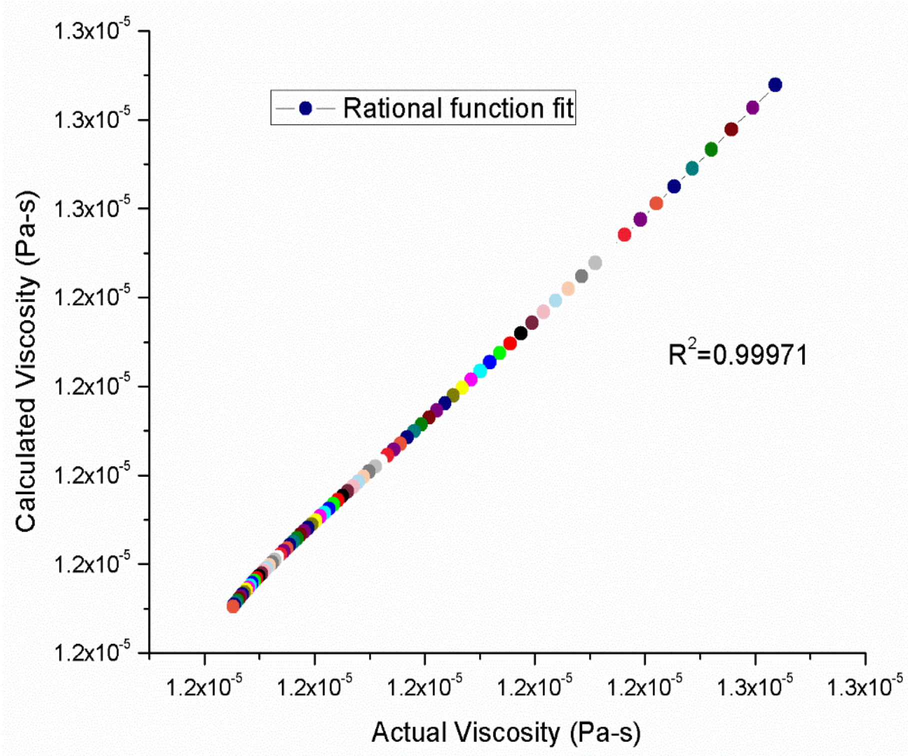


Figure 7-26 Comparison of accuracy between the actual and calculated viscosity for rational functional fit2.

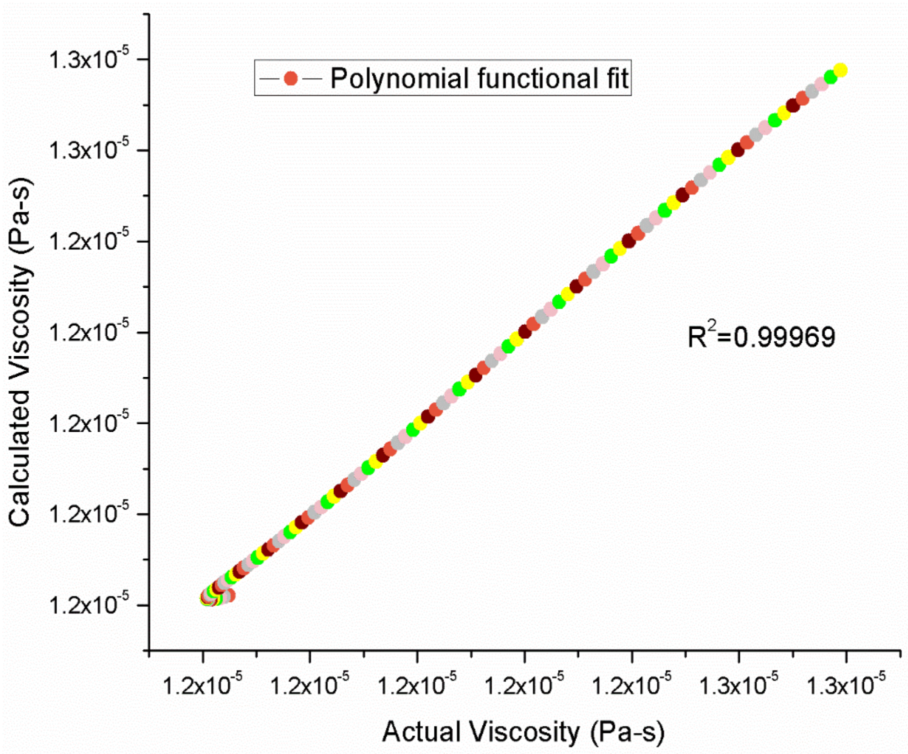


Figure 7-27 Comparison of accuracy between the actual and calculated viscosity for rational functional fit3.

CHAPTER

8 CONCLUSIONS AND FUTURE SCOPE

In the supercritical region, one cannot justify whether the fluid is gas or liquid, fluid behaves as a homogeneous mixture. Therefore, the results are concluded on the basis of thermophysical (thermodynamic and transport) properties such as density, specific heat, thermal conductivity and viscosity with respect to pressure and temperature. The results are found to be in good contract with NIST REFPROP data[7].

8.1 Density

From **Error! Reference source not found.**, it can be concluded that as temperature ncreases at any particular pressure, the density of SCN tends to decrease. As the pressure and temperature increases density is getting decreased due to the molecular kinetic energy between molecules are increasing which leads to severe reduction in the intermolecular forces of attraction at the critical point of SCN. Moreover, it can be concluded that, density at critical point i.e. at Pc=33.958bar and Tc=126.19K is found to be decreasing drastically.

8.2 Specific heat

From Figure 4-2, it can be concluded that, at critical temperature (Tc=126.19K) and critical pressure (Pc=33.958bar) specific heat is decreasing drastically. Moreover, it can be concluded from Figure 4-2 that, just above the 0.1K there is a drastic drop in specific heat of SCN this may be the reason that, the energy which stored in different forms in each and every molecule in all the directions which will results in increase in specific heat values which further increase in rate of heat transfer. And the sudden drop observed may be due to the thermal instability between the bonds.

8.3 Thermal conductivity

Figure 4-3, it can be concluded that, the variation of thermal conductivity is found to be similar as that of specific heat, at critical point (Pc=33.958bar and Tc=126.19K) it will tend to rise attain peak value and then experience a drastic drop. This may be due to the fact that in molecular level as the thermal excitation increases and various energy modes get activated, the molecular interactions found to be increased first and then because the thermal instability it will starts reducing.

8.4 Viscosity

From Figure 4-4, it can be concluded that, the variation in viscosity is found to be drastic and it will tend to decrease as the temperature increases. This may be due to the fact that as temperature increases, the kinetic energy of the molecules is getting increased and thus the viscosity will tend to decrease.

8.5 Future Scope

In near future, there is development of High Temperature Superconductor (HTS) at temperatures 130-140K. So in order to cool such superconductors Supercritical Nitrogen (SCN) plays a major role to maintain the critical temperature of that particular Superconductor.

Moreover, a single correlation applicable to large temperature ranges may be attempted in future so as to simplify and reduce the number of correlation coefficients.

In order to cool High Temperature Superconducting (HTS) cables a cryogenic coolant is required therefore it requires temperature dependent thermodynamic and transport properties, the present work may be beneficial in predicting thermohydraulic performance on High Temperature Superconducting (HTS) Cables by using Supercritical Nitrogen (SCN) as a coolant.

REFERENCES

[1] "BP Energy Outlook 2035," no. January, 2014.

[2] C. S. Office, M. O. F. Statistics, P. Implementation, and N. E. W. Delhi, "ENERGY," no. 21, p. 107, 2014.

[3] S. Gokarn, "Backgrounder Energy 2030," no. December, 2013.

[4] "Government Of India Ministry of Power Central Electricity Authority New Delhi Executive Summary Power Sector," 2014.

[5] I. E. Commission, "Efficient electrical energy transmission and distribution," p. 24.

[6] K. Fossheim and A. Sudbø, *Superconductivity Physics and Applications*. .

[7] H. E.W.Lemmon, M.O.Mclinden, *NIST standa rd reference database, physical and chemical properties division", version7.0,beta, USA.* 2002, p. 30.

[8] American Superconductor corporation, Nexans design of High Temperature Superconducting Cable.

[9] S. Erdogan Kiran, Pablo G.Debenedetti and Cor J. Peters, *Supercritical Fluids, Fundamentals and Applications*. .

[10] Y. T. Y.Arai, T.Sako, *Supercritical Fluids Molecular Interactions, Physcial Properties and New Application*. Springer.

[11] R. Wesche, a Anghel, B. Jakob, G. Pasztor, R. Schindler, and G. Vécsey, "Design of superconducting power cables," *Cryogenics (Guildf).*, vol. 39, no. 9, pp. 767–775, Sep. 1999.

[12] J. A. Demko, J. W. Lue, M. J. Gouge, J. P. Stovall, U. Sinha, and R. L. Hughey, "Practical AC Loss and Thermal Considerations for HTS Power Transmission Cable Systems," vol. I, no. 1, 2001.

[13] H. Noji, K. Haji, and T. Hamada, "AC loss analysis of 114 MVA high-Tc superconducting model cable," *Phys. C Supercond.*, vol. 392–396, pp. 1134–1139, Oct. 2003.

[14] M. Yagi, S. Tanaka, S. Mukoyama, M. Mimura, H. Kimura, S. Torii, S. Akita, and a. Kikuchi, "Measurement of ac losses of superconducting cable by calorimetric method and development of HTS conductor with low AC losses," *IEEE Trans. Appiled Supercond.*, vol. 13, no. 2, pp. 1902–1905, Jun. 2003.

[15] H. Noji, K. Ikeda, K. Uto, and T. Hamada, “Numerical analysis of the AC loss in a high-TC superconducting cable measured by calorimetric method,” *Phys. C Supercond.*, vol. 425, no. 3–4, pp. 97–100, Sep. 2005.

[16] H. Noji, “Numerical analysis of the AC losses of 500-m HTS power cable in Super-ACE project,” *Cryogenics (Guildf).*, vol. 47, no. 2, pp. 94–100, Feb. 2007.

[17] K. Ryu, Y. H. Ma, Z. Y. Li, S. D. Hwang, and H. J. Song, “AC losses of the 5m BSCCO cables with shield,” *Phys. C Supercond.*, vol. 470, no. 20, pp. 1606–1610, Nov. 2010.

[18] V. S. Vysotsky, A. a. Nosov, S. S. Fetisov, and K. a. Shutov, “AC Loss and Other Researches with 5 m HTS Model Cables,” *IEEE Trans. Appl. Supercond.*, vol. 21, no. 3, pp. 1001–1004, Jun. 2011.

[19] J. a. Demko, J. W. Lue, M. J. Gouge, D. Lindsay, M. Roden, D. Willen, M. Daumling, J. E. Fesmire, and S. D. Augustynowicz, “Cryostat vacuum thermal considerations for HTS power transmission cable systems,” *IEEE Trans. Appiled Supercond.*, vol. 13, no. 2, pp. 1930–1933, Jun. 2003.

[20] J. A. Demko, J. W. Lue, R. C. Duckworth, M. A. Young, M. J. Gouge, D. Lindsay, J. Tolbert, M. Roden, D. Willén, and C. Træholt, “Testing of a 1 . 5-m Single-Phase Short-Sample Cable Made With Copper Laminated HTS Tapes at ORNL,” vol. 15, no. 2, pp. 1755–1758, 2005.

[21] A. Posada, Y. I. Kim, and V. Manousiouthakis, “On conduction-cooling of a high-temperature superconducting cable,” *Cryogenics (Guildf).*, vol. 46, no. 6, pp. 458–467, Jun. 2006.

[22] L. H. T. S. Cables, J. A. Demko, and R. C. Duckworth, “Cooling Configuration Design Considerations for,” vol. 19, no. 3, pp. 1752–1755, 2009.

[23] a. Sasaki, Y. Ivanov, and S. Yamaguchi, “LN2 circulation in cryopipes of superconducting power transmission line,” *Cryogenics (Guildf).*, vol. 51, no. 9, pp. 471–476, Sep. 2011.

[24] R. S. Dondapati, G. S. Member, and V. V Rao, “Pressure Drop and Heat Transfer Analysis of Long Length Internally Cooled HTS Cables,” *IEEE Trans. Appiled Supercond.*, vol. 23, p. 5, 2013.

APPENDIX

Temperature (K)	Pressure (bar)	Density (kg/m^3)	Volume (m^3/kg)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Cp (kJ/kg-K)	Therm. (W/m-K)	Viscosity (Pa-s)
126.19	33.958	342.67	0.0029183	23.358	4.1683	729.99	0.13472	2.06E-05
126.29	33.958	240.49	0.0041581	47.257	4.3577	46.733	0.057277	1.50E-05
126.39	33.958	228.46	0.0043772	50.81	4.3858	28.11	0.049001	1.45E-05
126.49	33.958	220.64	0.0045322	53.225	4.4049	21.04	0.044802	1.42E-05
126.59	33.958	214.72	0.0046573	55.121	4.4199	17.19	0.042054	1.39E-05
126.69	33.958	209.9	0.0047643	56.709	4.4324	14.726	0.040038	1.37E-05
126.79	33.958	205.8	0.004859	58.09	4.4433	12.995	0.038459	1.36E-05
126.89	33.958	202.23	0.0049448	59.322	4.453	11.703	0.037167	1.35E-05
126.99	33.958	199.06	0.0050236	60.44	4.4618	10.696	0.036078	1.34E-05
127.09	33.958	196.2	0.0050968	61.468	4.4699	9.8851	0.03514	1.33E-05
127.19	33.958	193.59	0.0051655	62.422	4.4774	9.2166	0.034318	1.32E-05
127.29	33.958	191.19	0.0052304	63.315	4.4845	8.6543	0.033587	1.31E-05
127.39	33.958	188.97	0.0052919	64.156	4.4911	8.1737	0.032931	1.30E-05
127.49	33.958	186.89	0.0053507	64.952	4.4973	7.7575	0.032336	1.29E-05
127.59	33.958	184.95	0.005407	65.709	4.5032	7.3929	0.031793	1.29E-05
127.69	33.958	183.11	0.0054611	66.432	4.5089	7.0705	0.031294	1.28E-05
127.79	33.958	181.38	0.0055132	67.124	4.5143	6.783	0.030833	1.28E-05
127.89	33.958	179.74	0.0055635	67.789	4.5195	6.5248	0.030404	1.27E-05
127.99	33.958	178.18	0.0056122	68.43	4.5245	6.2914	0.030005	1.27E-05
128.09	33.958	176.69	0.0056595	69.048	4.5294	6.0793	0.029631	1.26E-05
128.19	33.958	175.27	0.0057055	69.646	4.534	5.8855	0.02928	1.26E-05
128.29	33.958	173.91	0.0057502	70.226	4.5386	5.7076	0.02895	1.26E-05
128.39	33.958	172.6	0.0057938	70.788	4.5429	5.5437	0.028638	1.25E-05
128.49	33.958	171.34	0.0058363	71.335	4.5472	5.3922	0.028342	1.25E-05
128.59	33.958	170.13	0.0058779	71.867	4.5513	5.2515	0.028062	1.25E-05
128.69	33.958	168.96	0.0059185	72.386	4.5554	5.1206	0.027796	1.24E-05
128.79	33.958	167.83	0.0059583	72.891	4.5593	4.9983	0.027542	1.24E-05
128.89	33.958	166.74	0.0059973	73.385	4.5631	4.8839	0.0273	1.24E-05
128.99	33.958	165.68	0.0060356	73.868	4.5669	4.7765	0.027069	1.23E-05
129.09	33.958	164.66	0.0060731	74.341	4.5705	4.6756	0.026848	1.23E-05
129.19	33.958	163.67	0.00611	74.804	4.5741	4.5804	0.026636	1.23E-05
129.29	33.958	162.7	0.0061462	75.257	4.5776	4.4906	0.026433	1.23E-05
129.39	33.958	161.76	0.0061819	75.702	4.5811	4.4056	0.026238	1.22E-05
129.49	33.958	160.85	0.0062169	76.139	4.5844	4.3251	0.026051	1.22E-05
129.59	33.958	159.96	0.0062514	76.567	4.5877	4.2486	0.02587	1.22E-05
129.69	33.958	159.1	0.0062854	76.988	4.591	4.176	0.025697	1.22E-05
129.79	33.958	158.25	0.006319	77.402	4.5942	4.1068	0.025529	1.22E-05
129.89	33.958	157.43	0.006352	77.81	4.5973	4.0409	0.025368	1.21E-05
129.99	33.958	156.63	0.0063846	78.211	4.6004	3.978	0.025212	1.21E-05
130.09	33.958	155.84	0.0064167	78.606	4.6034	3.9179	0.025061	1.21E-05
130.19	33.958	155.08	0.0064485	78.994	4.6064	3.8604	0.024915	1.21E-05
130.29	33.958	154.32	0.0064798	79.378	4.6094	3.8053	0.024775	1.21E-05

130.39	33.958	153.59	0.0065108	79.756	4.6123	3.7525	0.024638	1.21E-05
130.49	33.958	152.87	0.0065414	80.128	4.6151	3.7018	0.024506	1.20E-05
130.59	33.958	152.17	0.0065717	80.496	4.6179	3.6532	0.024378	1.20E-05
130.69	33.958	151.48	0.0066016	80.859	4.6207	3.6064	0.024253	1.20E-05
130.79	33.958	150.8	0.0066311	81.217	4.6235	3.5614	0.024133	1.20E-05
130.89	33.958	150.14	0.0066604	81.571	4.6262	3.518	0.024016	1.20E-05
130.99	33.958	149.49	0.0066894	81.921	4.6288	3.4762	0.023902	1.20E-05
131.09	33.958	148.85	0.006718	82.267	4.6315	3.4359	0.023792	1.20E-05
131.19	33.958	148.23	0.0067464	82.608	4.6341	3.397	0.023684	1.19E-05
131.29	33.958	147.61	0.0067745	82.946	4.6367	3.3594	0.02358	1.19E-05
131.39	33.958	147.01	0.0068024	83.28	4.6392	3.3231	0.023478	1.19E-05
131.49	33.958	146.41	0.00683	83.611	4.6417	3.288	0.023379	1.19E-05
131.59	33.958	145.83	0.0068573	83.938	4.6442	3.254	0.023283	1.19E-05
131.69	33.958	145.26	0.0068844	84.262	4.6467	3.2211	0.023189	1.19E-05
131.79	33.958	144.69	0.0069112	84.582	4.6491	3.1892	0.023098	1.19E-05
131.89	33.958	144.14	0.0069379	84.899	4.6515	3.1583	0.023009	1.19E-05
131.99	33.958	143.59	0.0069643	85.214	4.6539	3.1283	0.022922	1.19E-05
132.09	33.958	143.05	0.0069905	85.525	4.6562	3.0992	0.022837	1.19E-05
132.19	33.958	142.52	0.0070164	85.834	4.6586	3.071	0.022754	1.18E-05
132.29	33.958	142	0.0070422	86.139	4.6609	3.0435	0.022674	1.18E-05
132.39	33.958	141.49	0.0070678	86.442	4.6632	3.0169	0.022595	1.18E-05
132.49	33.958	140.98	0.0070932	86.743	4.6655	2.991	0.022518	1.18E-05
132.59	33.958	140.48	0.0071183	87.041	4.6677	2.9657	0.022443	1.18E-05
132.69	33.958	139.99	0.0071434	87.336	4.6699	2.9412	0.02237	1.18E-05
132.79	33.958	139.51	0.0071682	87.629	4.6721	2.9173	0.022298	1.18E-05
132.89	33.958	139.03	0.0071928	87.919	4.6743	2.894	0.022228	1.18E-05
132.99	33.958	138.56	0.0072173	88.208	4.6765	2.8714	0.02216	1.18E-05
133.09	33.958	138.09	0.0072416	88.494	4.6786	2.8493	0.022093	1.18E-05
133.19	33.958	137.63	0.0072658	88.778	4.6808	2.8277	0.022028	1.18E-05
133.29	33.958	137.18	0.0072898	89.059	4.6829	2.8067	0.021964	1.18E-05
133.39	33.958	136.73	0.0073136	89.339	4.685	2.7862	0.021901	1.18E-05
133.49	33.958	136.29	0.0073373	89.617	4.6871	2.7662	0.02184	1.18E-05
133.59	33.958	135.85	0.0073608	89.892	4.6891	2.7467	0.02178	1.17E-05
133.69	33.958	135.42	0.0073842	90.166	4.6912	2.7276	0.021721	1.17E-05
133.79	33.958	135	0.0074075	90.438	4.6932	2.7089	0.021664	1.17E-05
133.89	33.958	134.58	0.0074306	90.708	4.6952	2.6907	0.021608	1.17E-05
133.99	33.958	134.16	0.0074536	90.976	4.6972	2.6729	0.021553	1.17E-05
134.09	33.958	133.75	0.0074764	91.242	4.6992	2.6555	0.021499	1.17E-05
134.19	33.958	133.35	0.0074991	91.507	4.7012	2.6385	0.021446	1.17E-05
134.29	33.958	132.95	0.0075217	91.77	4.7031	2.6218	0.021395	1.17E-05
134.39	33.958	132.55	0.0075442	92.031	4.7051	2.6055	0.021344	1.17E-05
134.49	33.958	132.16	0.0075665	92.291	4.707	2.5895	0.021294	1.17E-05
134.59	33.958	131.77	0.0075887	92.549	4.7089	2.5739	0.021246	1.17E-05
134.69	33.958	131.39	0.0076108	92.806	4.7108	2.5586	0.021198	1.17E-05
134.79	33.958	131.01	0.0076328	93.061	4.7127	2.5436	0.021151	1.17E-05
134.89	33.958	130.64	0.0076547	93.315	4.7146	2.5289	0.021105	1.17E-05

134.99	33.958	130.27	0.0076764	93.567	4.7165	2.5145	0.02106	1.17E-05
135.09	33.958	129.9	0.0076981	93.818	4.7183	2.5004	0.021016	1.17E-05
135.19	33.958	129.54	0.0077196	94.067	4.7202	2.4866	0.020973	1.17E-05
135.29	33.958	129.18	0.0077411	94.315	4.722	2.473	0.020931	1.17E-05
135.39	33.958	128.83	0.0077624	94.561	4.7238	2.4597	0.020889	1.17E-05
135.49	33.958	128.47	0.0077836	94.807	4.7257	2.4466	0.020848	1.17E-05
135.59	33.958	128.13	0.0078048	95.051	4.7275	2.4338	0.020808	1.17E-05
135.69	33.958	127.78	0.0078258	95.294	4.7292	2.4212	0.020769	1.17E-05
135.79	33.958	127.44	0.0078467	95.535	4.731	2.4089	0.020731	1.17E-05
135.89	33.958	127.1	0.0078676	95.775	4.7328	2.3968	0.020693	1.17E-05
135.99	33.958	126.77	0.0078883	96.014	4.7346	2.3848	0.020656	1.16E-05
136.09	33.958	126.44	0.007909	96.252	4.7363	2.3731	0.020619	1.16E-05
136.19	33.958	126.11	0.0079296	96.489	4.738	2.3617	0.020584	1.16E-05
136.29	33.958	125.79	0.00795	96.725	4.7398	2.3504	0.020548	1.16E-05
136.39	33.958	125.46	0.0079704	96.959	4.7415	2.3393	0.020514	1.16E-05
136.49	33.958	125.15	0.0079907	97.193	4.7432	2.3284	0.02048	1.16E-05
136.59	33.958	124.83	0.0080109	97.425	4.7449	2.3176	0.020447	1.16E-05
136.69	33.958	124.52	0.0080311	97.656	4.7466	2.3071	0.020414	1.16E-05
136.79	33.958	124.21	0.0080511	97.886	4.7483	2.2967	0.020382	1.16E-05
136.89	33.958	123.9	0.0080711	98.115	4.75	2.2865	0.020351	1.16E-05
136.99	33.958	123.59	0.008091	98.344	4.7516	2.2765	0.02032	1.16E-05
137.09	33.958	123.29	0.0081108	98.571	4.7533	2.2666	0.02029	1.16E-05
137.19	33.958	122.99	0.0081306	98.797	4.7549	2.2569	0.02026	1.16E-05
137.29	33.958	122.7	0.0081502	99.022	4.7566	2.2474	0.020231	1.16E-05
137.39	33.958	122.4	0.0081698	99.246	4.7582	2.2379	0.020202	1.16E-05
137.49	33.958	122.11	0.0081893	99.47	4.7598	2.2287	0.020174	1.16E-05
137.59	33.958	121.82	0.0082088	99.692	4.7614	2.2196	0.020146	1.16E-05
137.69	33.958	121.53	0.0082282	99.914	4.7631	2.2106	0.020119	1.16E-05
137.79	33.958	121.25	0.0082475	100.13	4.7647	2.2017	0.020092	1.16E-05
137.89	33.958	120.97	0.0082667	100.35	4.7662	2.193	0.020066	1.16E-05
137.99	33.958	120.69	0.0082859	100.57	4.7678	2.1845	0.02004	1.16E-05
138.09	33.958	120.41	0.008305	100.79	4.7694	2.176	0.020014	1.16E-05
138.19	33.958	120.13	0.008324	101.01	4.771	2.1677	0.019989	1.16E-05
138.29	33.958	119.86	0.0083429	101.22	4.7726	2.1595	0.019965	1.16E-05
138.39	33.958	119.59	0.0083618	101.44	4.7741	2.1514	0.019941	1.16E-05
138.49	33.958	119.32	0.0083807	101.65	4.7757	2.1434	0.019917	1.16E-05
138.59	33.958	119.06	0.0083995	101.87	4.7772	2.1355	0.019894	1.16E-05
138.69	33.958	118.79	0.0084182	102.08	4.7787	2.1278	0.019871	1.16E-05
138.79	33.958	118.53	0.0084368	102.29	4.7803	2.1202	0.019849	1.16E-05
138.89	33.958	118.27	0.0084554	102.51	4.7818	2.1126	0.019827	1.16E-05
138.99	33.958	118.01	0.0084739	102.72	4.7833	2.1052	0.019805	1.16E-05
139.09	33.958	117.75	0.0084924	102.93	4.7848	2.0979	0.019783	1.16E-05
139.19	33.958	117.5	0.0085108	103.14	4.7863	2.0906	0.019763	1.16E-05
139.29	33.958	117.25	0.0085291	103.34	4.7878	2.0835	0.019742	1.16E-05
139.39	33.958	116.99	0.0085474	103.55	4.7893	2.0765	0.019722	1.16E-05
139.49	33.958	116.74	0.0085657	103.76	4.7908	2.0695	0.019702	1.16E-05

139.59	33.958	116.5	0.0085839	103.97	4.7923	2.0627	0.019682	1.16E-05
139.69	33.958	116.25	0.008602	104.17	4.7938	2.0559	0.019663	1.16E-05
139.79	33.958	116.01	0.0086201	104.38	4.7952	2.0492	0.019644	1.16E-05
139.89	33.958	115.77	0.0086381	104.58	4.7967	2.0426	0.019626	1.16E-05
139.99	33.958	115.53	0.008656	104.79	4.7982	2.0361	0.019607	1.16E-05
140.09	33.958	115.29	0.008674	104.99	4.7996	2.0297	0.019589	1.16E-05
140.19	33.958	115.05	0.0086918	105.19	4.8011	2.0234	0.019572	1.16E-05
140.29	33.958	114.82	0.0087096	105.39	4.8025	2.0171	0.019554	1.16E-05
140.39	33.958	114.58	0.0087274	105.6	4.8039	2.0109	0.019537	1.16E-05
140.49	33.958	114.35	0.0087451	105.8	4.8054	2.0048	0.019521	1.16E-05
140.59	33.958	114.12	0.0087628	106	4.8068	1.9988	0.019504	1.16E-05
140.69	33.958	113.89	0.0087804	106.2	4.8082	1.9928	0.019488	1.16E-05
140.79	33.958	113.66	0.0087979	106.4	4.8096	1.9869	0.019472	1.16E-05
140.89	33.958	113.44	0.0088155	106.59	4.811	1.9811	0.019457	1.16E-05
140.99	33.958	113.21	0.0088329	106.79	4.8124	1.9754	0.019441	1.16E-05
141.09	33.958	112.99	0.0088504	106.99	4.8138	1.9697	0.019426	1.16E-05
141.19	33.958	112.77	0.0088677	107.19	4.8152	1.9641	0.019411	1.16E-05
141.29	33.958	112.55	0.0088851	107.38	4.8166	1.9585	0.019397	1.16E-05
141.39	33.958	112.33	0.0089024	107.58	4.818	1.9531	0.019382	1.16E-05
141.49	33.958	112.11	0.0089196	107.77	4.8194	1.9476	0.019368	1.16E-05
141.59	33.958	111.9	0.0089368	107.97	4.8207	1.9423	0.019354	1.16E-05
141.69	33.958	111.68	0.0089539	108.16	4.8221	1.937	0.019341	1.16E-05
141.79	33.958	111.47	0.0089711	108.35	4.8235	1.9318	0.019328	1.16E-05
141.89	33.958	111.26	0.0089881	108.55	4.8248	1.9266	0.019314	1.16E-05
141.99	33.958	111.05	0.0090051	108.74	4.8262	1.9215	0.019302	1.16E-05
142.09	33.958	110.84	0.0090221	108.93	4.8275	1.9164	0.019289	1.16E-05
142.19	33.958	110.63	0.0090391	109.12	4.8289	1.9114	0.019276	1.16E-05
142.29	33.958	110.42	0.009056	109.31	4.8302	1.9064	0.019264	1.16E-05
142.39	33.958	110.22	0.0090728	109.5	4.8316	1.9015	0.019252	1.16E-05
142.49	33.958	110.02	0.0090897	109.69	4.8329	1.8967	0.01924	1.16E-05
142.59	33.958	109.81	0.0091064	109.88	4.8342	1.8919	0.019229	1.16E-05
142.69	33.958	109.61	0.0091232	110.07	4.8356	1.8872	0.019218	1.16E-05
142.79	33.958	109.41	0.0091399	110.26	4.8369	1.8825	0.019206	1.16E-05
142.89	33.958	109.21	0.0091565	110.45	4.8382	1.8778	0.019195	1.16E-05
142.99	33.958	109.01	0.0091732	110.64	4.8395	1.8733	0.019185	1.16E-05
143.09	33.958	108.82	0.0091897	110.82	4.8408	1.8687	0.019174	1.16E-05
143.19	33.958	108.62	0.0092063	111.01	4.8421	1.8642	0.019164	1.16E-05
143.29	33.958	108.43	0.0092228	111.2	4.8434	1.8598	0.019153	1.16E-05
143.39	33.958	108.23	0.0092393	111.38	4.8447	1.8554	0.019143	1.16E-05
143.49	33.958	108.04	0.0092557	111.57	4.846	1.851	0.019134	1.16E-05
143.59	33.958	107.85	0.0092721	111.75	4.8473	1.8467	0.019124	1.16E-05
143.69	33.958	107.66	0.0092885	111.94	4.8486	1.8424	0.019115	1.16E-05
143.79	33.958	107.47	0.0093048	112.12	4.8499	1.8382	0.019105	1.16E-05
143.89	33.958	107.28	0.0093211	112.3	4.8511	1.834	0.019096	1.16E-05
143.99	33.958	107.1	0.0093374	112.49	4.8524	1.8299	0.019087	1.16E-05
144.09	33.958	106.91	0.0093536	112.67	4.8537	1.8258	0.019078	1.16E-05

144.19	33.958	106.73	0.0093698	112.85	4.8549	1.8217	0.01907	1.17E-05
144.29	33.958	106.54	0.009386	113.03	4.8562	1.8177	0.019061	1.17E-05
144.39	33.958	106.36	0.0094021	113.22	4.8575	1.8137	0.019053	1.17E-05
144.49	33.958	106.18	0.0094182	113.4	4.8587	1.8098	0.019045	1.17E-05
144.59	33.958	106	0.0094342	113.58	4.86	1.8059	0.019037	1.17E-05
144.69	33.958	105.82	0.0094503	113.76	4.8612	1.802	0.019029	1.17E-05
144.79	33.958	105.64	0.0094663	113.94	4.8625	1.7982	0.019021	1.17E-05
144.89	33.958	105.46	0.0094822	114.12	4.8637	1.7944	0.019014	1.17E-05
144.99	33.958	105.28	0.0094982	114.3	4.8649	1.7906	0.019007	1.17E-05
145.09	33.958	105.11	0.009514	114.48	4.8662	1.7869	0.018999	1.17E-05
145.19	33.958	104.93	0.0095299	114.66	4.8674	1.7832	0.018992	1.17E-05
145.29	33.958	104.76	0.0095458	114.83	4.8686	1.7796	0.018985	1.17E-05
145.39	33.958	104.59	0.0095616	115.01	4.8698	1.7759	0.018979	1.17E-05
145.49	33.958	104.41	0.0095773	115.19	4.8711	1.7724	0.018972	1.17E-05
145.59	33.958	104.24	0.0095931	115.37	4.8723	1.7688	0.018965	1.17E-05
145.69	33.958	104.07	0.0096088	115.54	4.8735	1.7653	0.018959	1.17E-05
145.79	33.958	103.9	0.0096245	115.72	4.8747	1.7618	0.018953	1.17E-05
145.89	33.958	103.73	0.0096401	115.89	4.8759	1.7583	0.018947	1.17E-05
145.99	33.958	103.57	0.0096558	116.07	4.8771	1.7549	0.018941	1.17E-05
146.09	33.958	103.4	0.0096714	116.25	4.8783	1.7515	0.018935	1.17E-05
146.19	33.958	103.23	0.0096869	116.42	4.8795	1.7481	0.018929	1.17E-05
146.29	33.958	103.07	0.0097025	116.6	4.8807	1.7448	0.018923	1.17E-05
146.39	33.958	102.9	0.009718	116.77	4.8819	1.7415	0.018918	1.17E-05
146.49	33.958	102.74	0.0097335	116.94	4.8831	1.7382	0.018913	1.17E-05
146.59	33.958	102.58	0.0097489	117.12	4.8843	1.735	0.018907	1.17E-05
146.69	33.958	102.41	0.0097644	117.29	4.8855	1.7318	0.018902	1.17E-05
146.79	33.958	102.25	0.0097798	117.46	4.8866	1.7286	0.018897	1.17E-05
146.89	33.958	102.09	0.0097951	117.64	4.8878	1.7254	0.018892	1.17E-05
146.99	33.958	101.93	0.0098105	117.81	4.889	1.7223	0.018888	1.17E-05
147.09	33.958	101.77	0.0098258	117.98	4.8902	1.7192	0.018883	1.17E-05
147.19	33.958	101.61	0.0098411	118.15	4.8913	1.7161	0.018878	1.17E-05
147.29	33.958	101.46	0.0098564	118.32	4.8925	1.713	0.018874	1.17E-05
147.39	33.958	101.3	0.0098716	118.49	4.8937	1.71	0.01887	1.17E-05
147.49	33.958	101.14	0.0098868	118.67	4.8948	1.707	0.018865	1.17E-05
147.59	33.958	100.99	0.009902	118.84	4.896	1.704	0.018861	1.17E-05
147.69	33.958	100.83	0.0099172	119.01	4.8971	1.701	0.018857	1.17E-05
147.79	33.958	100.68	0.0099323	119.18	4.8983	1.6981	0.018853	1.17E-05
147.89	33.958	100.53	0.0099475	119.35	4.8994	1.6952	0.018849	1.17E-05
147.99	33.958	100.38	0.0099625	119.52	4.9006	1.6923	0.018846	1.17E-05
148.09	33.958	100.22	0.0099776	119.68	4.9017	1.6894	0.018842	1.17E-05
148.19	33.958	100.07	0.0099927	119.85	4.9028	1.6866	0.018839	1.17E-05
148.29	33.958	99.923	0.010008	120.02	4.904	1.6838	0.018835	1.17E-05
148.39	33.958	99.774	0.010023	120.19	4.9051	1.681	0.018832	1.17E-05
148.49	33.958	99.625	0.010038	120.36	4.9062	1.6782	0.018829	1.17E-05
148.59	33.958	99.477	0.010053	120.53	4.9074	1.6755	0.018825	1.17E-05
148.69	33.958	99.329	0.010068	120.69	4.9085	1.6728	0.018822	1.18E-05

148.79	33.958	99.183	0.010082	120.86	4.9096	1.6701	0.018819	1.18E-05
148.89	33.958	99.037	0.010097	121.03	4.9107	1.6674	0.018817	1.18E-05
148.99	33.958	98.891	0.010112	121.19	4.9119	1.6647	0.018814	1.18E-05
149.09	33.958	98.746	0.010127	121.36	4.913	1.6621	0.018811	1.18E-05
149.19	33.958	98.602	0.010142	121.53	4.9141	1.6594	0.018809	1.18E-05
149.29	33.958	98.459	0.010157	121.69	4.9152	1.6568	0.018806	1.18E-05
149.39	33.958	98.316	0.010171	121.86	4.9163	1.6543	0.018804	1.18E-05
149.49	33.958	98.173	0.010186	122.02	4.9174	1.6517	0.018801	1.18E-05
149.59	33.958	98.032	0.010201	122.19	4.9185	1.6492	0.018799	1.18E-05
149.69	33.958	97.891	0.010215	122.35	4.9196	1.6466	0.018797	1.18E-05
149.79	33.958	97.75	0.01023	122.52	4.9207	1.6441	0.018795	1.18E-05
149.89	33.958	97.61	0.010245	122.68	4.9218	1.6417	0.018793	1.18E-05
149.99	33.958	97.471	0.010259	122.85	4.9229	1.6392	0.018791	1.18E-05
150.09	33.958	97.333	0.010274	123.01	4.924	1.6367	0.018789	1.18E-05
150.19	33.958	97.195	0.010289	123.17	4.9251	1.6343	0.018787	1.18E-05
150.29	33.958	97.057	0.010303	123.34	4.9262	1.6319	0.018785	1.18E-05
150.39	33.958	96.92	0.010318	123.5	4.9273	1.6295	0.018784	1.18E-05
150.49	33.958	96.784	0.010332	123.66	4.9283	1.6271	0.018782	1.18E-05
150.59	33.958	96.648	0.010347	123.82	4.9294	1.6248	0.018781	1.18E-05
150.69	33.958	96.513	0.010361	123.99	4.9305	1.6224	0.018779	1.18E-05
150.79	33.958	96.379	0.010376	124.15	4.9316	1.6201	0.018778	1.18E-05
150.89	33.958	96.245	0.01039	124.31	4.9327	1.6178	0.018777	1.18E-05
150.99	33.958	96.111	0.010405	124.47	4.9337	1.6155	0.018776	1.18E-05
151.09	33.958	95.978	0.010419	124.63	4.9348	1.6133	0.018774	1.18E-05
151.19	33.958	95.846	0.010433	124.8	4.9359	1.611	0.018773	1.18E-05
151.29	33.958	95.714	0.010448	124.96	4.9369	1.6088	0.018772	1.18E-05
151.39	33.958	95.583	0.010462	125.12	4.938	1.6065	0.018771	1.18E-05
151.49	33.958	95.452	0.010476	125.28	4.939	1.6043	0.018771	1.18E-05
151.59	33.958	95.322	0.010491	125.44	4.9401	1.6021	0.01877	1.18E-05
151.69	33.958	95.193	0.010505	125.6	4.9412	1.6	0.018769	1.18E-05
151.79	33.958	95.063	0.010519	125.76	4.9422	1.5978	0.018768	1.18E-05
151.89	33.958	94.935	0.010534	125.92	4.9433	1.5957	0.018768	1.18E-05
151.99	33.958	94.807	0.010548	126.08	4.9443	1.5935	0.018767	1.18E-05
152.09	33.958	94.679	0.010562	126.24	4.9454	1.5914	0.018767	1.18E-05
152.19	33.958	94.552	0.010576	126.4	4.9464	1.5893	0.018766	1.19E-05
152.29	33.958	94.426	0.01059	126.55	4.9475	1.5872	0.018766	1.19E-05
152.39	33.958	94.299	0.010605	126.71	4.9485	1.5851	0.018766	1.19E-05
152.49	33.958	94.174	0.010619	126.87	4.9495	1.5831	0.018766	1.19E-05
152.59	33.958	94.049	0.010633	127.03	4.9506	1.581	0.018765	1.19E-05
152.69	33.958	93.924	0.010647	127.19	4.9516	1.579	0.018765	1.19E-05
152.79	33.958	93.8	0.010661	127.35	4.9526	1.577	0.018765	1.19E-05
152.89	33.958	93.677	0.010675	127.5	4.9537	1.575	0.018765	1.19E-05
152.99	33.958	93.553	0.010689	127.66	4.9547	1.573	0.018765	1.19E-05
153.09	33.958	93.431	0.010703	127.82	4.9557	1.571	0.018765	1.19E-05
153.19	33.958	93.309	0.010717	127.97	4.9568	1.5691	0.018766	1.19E-05
153.29	33.958	93.187	0.010731	128.13	4.9578	1.5671	0.018766	1.19E-05

153.39	33.958	93.066	0.010745	128.29	4.9588	1.5652	0.018766	1.19E-05
153.49	33.958	92.945	0.010759	128.44	4.9598	1.5633	0.018767	1.19E-05
153.59	33.958	92.824	0.010773	128.6	4.9608	1.5613	0.018767	1.19E-05
153.69	33.958	92.705	0.010787	128.76	4.9618	1.5594	0.018767	1.19E-05
153.79	33.958	92.585	0.010801	128.91	4.9629	1.5576	0.018768	1.19E-05
153.89	33.958	92.466	0.010815	129.07	4.9639	1.5557	0.018768	1.19E-05
153.99	33.958	92.348	0.010829	129.22	4.9649	1.5538	0.018769	1.19E-05
154.09	33.958	92.23	0.010843	129.38	4.9659	1.552	0.01877	1.19E-05
154.19	33.958	92.112	0.010856	129.53	4.9669	1.5501	0.01877	1.19E-05
154.29	33.958	91.995	0.01087	129.69	4.9679	1.5483	0.018771	1.19E-05
154.39	33.958	91.878	0.010884	129.84	4.9689	1.5465	0.018772	1.19E-05
154.49	33.958	91.762	0.010898	130	4.9699	1.5447	0.018773	1.19E-05
154.59	33.958	91.646	0.010912	130.15	4.9709	1.5429	0.018774	1.19E-05
154.69	33.958	91.53	0.010925	130.31	4.9719	1.5411	0.018775	1.19E-05
154.79	33.958	91.415	0.010939	130.46	4.9729	1.5394	0.018776	1.19E-05
154.89	33.958	91.301	0.010953	130.61	4.9739	1.5376	0.018777	1.19E-05
154.99	33.958	91.186	0.010967	130.77	4.9749	1.5359	0.018778	1.19E-05
155.09	33.958	91.073	0.01098	130.92	4.9759	1.5341	0.018779	1.19E-05
155.19	33.958	90.959	0.010994	131.08	4.9769	1.5324	0.01878	1.20E-05
155.29	33.958	90.846	0.011008	131.23	4.9778	1.5307	0.018781	1.20E-05
155.39	33.958	90.734	0.011021	131.38	4.9788	1.529	0.018782	1.20E-05
155.49	33.958	90.621	0.011035	131.53	4.9798	1.5273	0.018784	1.20E-05
155.59	33.958	90.51	0.011049	131.69	4.9808	1.5256	0.018785	1.20E-05
155.69	33.958	90.398	0.011062	131.84	4.9818	1.5239	0.018787	1.20E-05
155.79	33.958	90.287	0.011076	131.99	4.9828	1.5223	0.018788	1.20E-05
155.89	33.958	90.177	0.011089	132.14	4.9837	1.5206	0.018789	1.20E-05
155.99	33.958	90.066	0.011103	132.3	4.9847	1.519	0.018791	1.20E-05
156.09	33.958	89.957	0.011116	132.45	4.9857	1.5174	0.018793	1.20E-05
156.19	33.958	89.847	0.01113	132.6	4.9867	1.5157	0.018794	1.20E-05
156.29	33.958	89.738	0.011144	132.75	4.9876	1.5141	0.018796	1.20E-05
156.39	33.958	89.629	0.011157	132.9	4.9886	1.5125	0.018797	1.20E-05
156.49	33.958	89.521	0.011171	133.05	4.9896	1.5109	0.018799	1.20E-05
156.59	33.958	89.413	0.011184	133.2	4.9905	1.5093	0.018801	1.20E-05
156.69	33.958	89.306	0.011198	133.36	4.9915	1.5078	0.018803	1.20E-05
156.79	33.958	89.198	0.011211	133.51	4.9924	1.5062	0.018805	1.20E-05
156.89	33.958	89.092	0.011224	133.66	4.9934	1.5047	0.018806	1.20E-05
156.99	33.958	88.985	0.011238	133.81	4.9944	1.5031	0.018808	1.20E-05
157.09	33.958	88.879	0.011251	133.96	4.9953	1.5016	0.01881	1.20E-05
157.19	33.958	88.773	0.011265	134.11	4.9963	1.5	0.018812	1.20E-05
157.29	33.958	88.668	0.011278	134.26	4.9972	1.4985	0.018814	1.20E-05
157.39	33.958	88.563	0.011291	134.41	4.9982	1.497	0.018816	1.20E-05
157.49	33.958	88.458	0.011305	134.56	4.9991	1.4955	0.018818	1.20E-05
157.59	33.958	88.354	0.011318	134.71	5.0001	1.494	0.018821	1.20E-05
157.69	33.958	88.25	0.011331	134.86	5.001	1.4926	0.018823	1.20E-05
157.79	33.958	88.146	0.011345	135	5.002	1.4911	0.018825	1.20E-05
157.89	33.958	88.043	0.011358	135.15	5.0029	1.4896	0.018827	1.20E-05

157.99	33.958	87.94	0.011371	135.3	5.0039	1.4882	0.018829	1.20E-05
158.09	33.958	87.838	0.011385	135.45	5.0048	1.4867	0.018832	1.21E-05
158.19	33.958	87.736	0.011398	135.6	5.0057	1.4853	0.018834	1.21E-05
158.29	33.958	87.634	0.011411	135.75	5.0067	1.4838	0.018836	1.21E-05
158.39	33.958	87.532	0.011424	135.9	5.0076	1.4824	0.018839	1.21E-05
158.49	33.958	87.431	0.011438	136.04	5.0085	1.481	0.018841	1.21E-05
158.59	33.958	87.33	0.011451	136.19	5.0095	1.4796	0.018844	1.21E-05
158.69	33.958	87.229	0.011464	136.34	5.0104	1.4782	0.018846	1.21E-05
158.79	33.958	87.129	0.011477	136.49	5.0113	1.4768	0.018849	1.21E-05
158.89	33.958	87.029	0.01149	136.64	5.0123	1.4754	0.018851	1.21E-05
158.99	33.958	86.93	0.011504	136.78	5.0132	1.474	0.018854	1.21E-05
159.09	33.958	86.83	0.011517	136.93	5.0141	1.4727	0.018856	1.21E-05
159.19	33.958	86.731	0.01153	137.08	5.0151	1.4713	0.018859	1.21E-05
159.29	33.958	86.633	0.011543	137.22	5.016	1.47	0.018862	1.21E-05
159.39	33.958	86.534	0.011556	137.37	5.0169	1.4686	0.018865	1.21E-05
159.49	33.958	86.436	0.011569	137.52	5.0178	1.4673	0.018867	1.21E-05
159.59	33.958	86.339	0.011582	137.67	5.0187	1.4659	0.01887	1.21E-05
159.69	33.958	86.241	0.011595	137.81	5.0197	1.4646	0.018873	1.21E-05
159.79	33.958	86.144	0.011608	137.96	5.0206	1.4633	0.018876	1.21E-05
159.89	33.958	86.048	0.011621	138.1	5.0215	1.462	0.018878	1.21E-05
159.99	33.958	85.951	0.011635	138.25	5.0224	1.4607	0.018881	1.21E-05
160.09	33.958	85.855	0.011648	138.4	5.0233	1.4594	0.018884	1.21E-05
160.19	33.958	85.759	0.011661	138.54	5.0242	1.4581	0.018887	1.21E-05
160.29	33.958	85.663	0.011674	138.69	5.0251	1.4568	0.01889	1.21E-05
160.39	33.958	85.568	0.011687	138.83	5.026	1.4555	0.018893	1.21E-05
160.49	33.958	85.473	0.0117	138.98	5.027	1.4543	0.018896	1.21E-05
160.59	33.958	85.379	0.011713	139.12	5.0279	1.453	0.018899	1.21E-05
160.69	33.958	85.284	0.011725	139.27	5.0288	1.4518	0.018902	1.22E-05
160.79	33.958	85.19	0.011738	139.42	5.0297	1.4505	0.018905	1.22E-05
160.89	33.958	85.096	0.011751	139.56	5.0306	1.4493	0.018909	1.22E-05
160.99	33.958	85.003	0.011764	139.7	5.0315	1.448	0.018912	1.22E-05
161.09	33.958	84.91	0.011777	139.85	5.0324	1.4468	0.018915	1.22E-05
161.19	33.958	84.817	0.01179	139.99	5.0333	1.4456	0.018918	1.22E-05
161.29	33.958	84.724	0.011803	140.14	5.0342	1.4444	0.018921	1.22E-05
161.39	33.958	84.632	0.011816	140.28	5.0351	1.4432	0.018925	1.22E-05
161.49	33.958	84.54	0.011829	140.43	5.0359	1.442	0.018928	1.22E-05
161.59	33.958	84.448	0.011842	140.57	5.0368	1.4408	0.018931	1.22E-05
161.69	33.958	84.356	0.011854	140.72	5.0377	1.4396	0.018934	1.22E-05
161.79	33.958	84.265	0.011867	140.86	5.0386	1.4384	0.018938	1.22E-05
161.89	33.958	84.174	0.01188	141	5.0395	1.4372	0.018941	1.22E-05
161.99	33.958	84.083	0.011893	141.15	5.0404	1.4361	0.018945	1.22E-05
162.09	33.958	83.993	0.011906	141.29	5.0413	1.4349	0.018948	1.22E-05
162.19	33.958	83.903	0.011919	141.43	5.0422	1.4337	0.018951	1.22E-05
162.29	33.958	83.813	0.011931	141.58	5.043	1.4326	0.018955	1.22E-05
162.39	33.958	83.723	0.011944	141.72	5.0439	1.4314	0.018958	1.22E-05
162.49	33.958	83.634	0.011957	141.86	5.0448	1.4303	0.018962	1.22E-05

162.59	33.958	83.545	0.01197	142.01	5.0457	1.4292	0.018965	1.22E-05
162.69	33.958	83.456	0.011982	142.15	5.0466	1.428	0.018969	1.22E-05
162.79	33.958	83.367	0.011995	142.29	5.0474	1.4269	0.018973	1.22E-05
162.89	33.958	83.279	0.012008	142.43	5.0483	1.4258	0.018976	1.22E-05
162.99	33.958	83.191	0.012021	142.58	5.0492	1.4247	0.01898	1.22E-05
163.09	33.958	83.103	0.012033	142.72	5.0501	1.4236	0.018983	1.22E-05
163.19	33.958	83.015	0.012046	142.86	5.0509	1.4225	0.018987	1.22E-05
163.29	33.958	82.928	0.012059	143	5.0518	1.4214	0.018991	1.23E-05
163.39	33.958	82.841	0.012071	143.15	5.0527	1.4203	0.018994	1.23E-05
163.49	33.958	82.754	0.012084	143.29	5.0536	1.4192	0.018998	1.23E-05
163.59	33.958	82.668	0.012097	143.43	5.0544	1.4181	0.019002	1.23E-05
163.69	33.958	82.581	0.012109	143.57	5.0553	1.417	0.019006	1.23E-05
163.79	33.958	82.495	0.012122	143.71	5.0562	1.416	0.019009	1.23E-05
163.89	33.958	82.41	0.012135	143.86	5.057	1.4149	0.019013	1.23E-05
163.99	33.958	82.324	0.012147	144	5.0579	1.4138	0.019017	1.23E-05
164.09	33.958	82.239	0.01216	144.14	5.0587	1.4128	0.019021	1.23E-05
164.19	33.958	82.154	0.012172	144.28	5.0596	1.4117	0.019025	1.23E-05
164.29	33.958	82.069	0.012185	144.42	5.0605	1.4107	0.019029	1.23E-05
164.39	33.958	81.984	0.012197	144.56	5.0613	1.4097	0.019033	1.23E-05
164.49	33.958	81.9	0.01221	144.7	5.0622	1.4086	0.019036	1.23E-05
164.59	33.958	81.816	0.012223	144.84	5.063	1.4076	0.01904	1.23E-05
164.69	33.958	81.732	0.012235	144.98	5.0639	1.4066	0.019044	1.23E-05
164.79	33.958	81.648	0.012248	145.12	5.0647	1.4056	0.019048	1.23E-05
164.89	33.958	81.565	0.01226	145.26	5.0656	1.4045	0.019052	1.23E-05
164.99	33.958	81.481	0.012273	145.41	5.0664	1.4035	0.019056	1.23E-05
165.09	33.958	81.399	0.012285	145.55	5.0673	1.4025	0.01906	1.23E-05
165.19	33.958	81.316	0.012298	145.69	5.0681	1.4015	0.019064	1.23E-05
165.29	33.958	81.233	0.01231	145.83	5.069	1.4005	0.019069	1.23E-05
165.39	33.958	81.151	0.012323	145.97	5.0698	1.3995	0.019073	1.23E-05
165.49	33.958	81.069	0.012335	146.11	5.0707	1.3986	0.019077	1.23E-05
165.59	33.958	80.987	0.012348	146.25	5.0715	1.3976	0.019081	1.23E-05
165.69	33.958	80.906	0.01236	146.39	5.0724	1.3966	0.019085	1.24E-05
165.79	33.958	80.824	0.012373	146.52	5.0732	1.3956	0.019089	1.24E-05
165.89	33.958	80.743	0.012385	146.66	5.0741	1.3947	0.019093	1.24E-05
165.99	33.958	80.662	0.012397	146.8	5.0749	1.3937	0.019097	1.24E-05
166.09	33.958	80.581	0.01241	146.94	5.0757	1.3928	0.019102	1.24E-05
166.19	33.958	80.501	0.012422	147.08	5.0766	1.3918	0.019106	1.24E-05
166.29	33.958	80.421	0.012435	147.22	5.0774	1.3909	0.01911	1.24E-05
166.39	33.958	80.341	0.012447	147.36	5.0782	1.3899	0.019114	1.24E-05
166.49	33.958	80.261	0.012459	147.5	5.0791	1.389	0.019119	1.24E-05
166.59	33.958	80.181	0.012472	147.64	5.0799	1.388	0.019123	1.24E-05
166.69	33.958	80.102	0.012484	147.78	5.0807	1.3871	0.019127	1.24E-05
166.79	33.958	80.023	0.012496	147.92	5.0816	1.3862	0.019131	1.24E-05
166.89	33.958	79.944	0.012509	148.05	5.0824	1.3853	0.019136	1.24E-05
166.99	33.958	79.865	0.012521	148.19	5.0832	1.3843	0.01914	1.24E-05
167.09	33.958	79.786	0.012533	148.33	5.0841	1.3834	0.019145	1.24E-05

167.19	33.958	79.708	0.012546	148.47	5.0849	1.3825	0.019149	1.24E-05
167.29	33.958	79.63	0.012558	148.61	5.0857	1.3816	0.019153	1.24E-05
167.39	33.958	79.552	0.01257	148.75	5.0865	1.3807	0.019158	1.24E-05
167.49	33.958	79.474	0.012583	148.88	5.0874	1.3798	0.019162	1.24E-05
167.59	33.958	79.397	0.012595	149.02	5.0882	1.3789	0.019167	1.24E-05
167.69	33.958	79.319	0.012607	149.16	5.089	1.378	0.019171	1.24E-05
167.79	33.958	79.242	0.01262	149.3	5.0898	1.3772	0.019175	1.24E-05
167.89	33.958	79.165	0.012632	149.43	5.0907	1.3763	0.01918	1.24E-05
167.99	33.958	79.088	0.012644	149.57	5.0915	1.3754	0.019184	1.24E-05
168.09	33.958	79.012	0.012656	149.71	5.0923	1.3745	0.019189	1.24E-05
168.19	33.958	78.936	0.012669	149.85	5.0931	1.3737	0.019193	1.25E-05
168.29	33.958	78.859	0.012681	149.98	5.0939	1.3728	0.019198	1.25E-05
168.39	33.958	78.784	0.012693	150.12	5.0947	1.3719	0.019202	1.25E-05
168.49	33.958	78.708	0.012705	150.26	5.0956	1.3711	0.019207	1.25E-05
168.59	33.958	78.632	0.012717	150.4	5.0964	1.3702	0.019212	1.25E-05
168.69	33.958	78.557	0.01273	150.53	5.0972	1.3694	0.019216	1.25E-05
168.79	33.958	78.482	0.012742	150.67	5.098	1.3685	0.019221	1.25E-05
168.89	33.958	78.407	0.012754	150.81	5.0988	1.3677	0.019225	1.25E-05
168.99	33.958	78.332	0.012766	150.94	5.0996	1.3668	0.01923	1.25E-05
169.09	33.958	78.257	0.012778	151.08	5.1004	1.366	0.019235	1.25E-05
169.19	33.958	78.183	0.01279	151.22	5.1012	1.3652	0.019239	1.25E-05
169.29	33.958	78.109	0.012803	151.35	5.102	1.3643	0.019244	1.25E-05
169.39	33.958	78.035	0.012815	151.49	5.1028	1.3635	0.019249	1.25E-05
169.49	33.958	77.961	0.012827	151.63	5.1036	1.3627	0.019253	1.25E-05
169.59	33.958	77.887	0.012839	151.76	5.1044	1.3619	0.019258	1.25E-05
169.69	33.958	77.814	0.012851	151.9	5.1052	1.3611	0.019263	1.25E-05
169.79	33.958	77.741	0.012863	152.03	5.1061	1.3603	0.019267	1.25E-05
169.89	33.958	77.668	0.012875	152.17	5.1069	1.3595	0.019272	1.25E-05
169.99	33.958	77.595	0.012887	152.31	5.1077	1.3586	0.019277	1.25E-05
170.09	33.958	77.522	0.0129	152.44	5.1084	1.3579	0.019282	1.25E-05
170.19	33.958	77.449	0.012912	152.58	5.1092	1.3571	0.019286	1.25E-05
170.29	33.958	77.377	0.012924	152.71	5.11	1.3563	0.019291	1.25E-05
170.39	33.958	77.305	0.012936	152.85	5.1108	1.3555	0.019296	1.25E-05
170.49	33.958	77.233	0.012948	152.98	5.1116	1.3547	0.019301	1.26E-05
170.59	33.958	77.161	0.01296	153.12	5.1124	1.3539	0.019306	1.26E-05
170.69	33.958	77.089	0.012972	153.26	5.1132	1.3531	0.01931	1.26E-05
170.79	33.958	77.018	0.012984	153.39	5.114	1.3523	0.019315	1.26E-05
170.89	33.958	76.947	0.012996	153.53	5.1148	1.3516	0.01932	1.26E-05
170.99	33.958	76.876	0.013008	153.66	5.1156	1.3508	0.019325	1.26E-05
171.09	33.958	76.805	0.01302	153.8	5.1164	1.35	0.01933	1.26E-05
171.19	33.958	76.734	0.013032	153.93	5.1172	1.3493	0.019335	1.26E-05
171.29	33.958	76.663	0.013044	154.07	5.118	1.3485	0.01934	1.26E-05
171.39	33.958	76.593	0.013056	154.2	5.1187	1.3478	0.019345	1.26E-05
171.49	33.958	76.523	0.013068	154.34	5.1195	1.347	0.019349	1.26E-05
171.59	33.958	76.453	0.01308	154.47	5.1203	1.3463	0.019354	1.26E-05
171.69	33.958	76.383	0.013092	154.6	5.1211	1.3455	0.019359	1.26E-05

171.79	33.958	76.313	0.013104	154.74	5.1219	1.3448	0.019364	1.26E-05
171.89	33.958	76.243	0.013116	154.87	5.1227	1.344	0.019369	1.26E-05
171.99	33.958	76.174	0.013128	155.01	5.1235	1.3433	0.019374	1.26E-05
172.09	33.958	76.105	0.01314	155.14	5.1242	1.3426	0.019379	1.26E-05
172.19	33.958	76.036	0.013152	155.28	5.125	1.3418	0.019384	1.26E-05
172.29	33.958	75.967	0.013164	155.41	5.1258	1.3411	0.019389	1.26E-05
172.39	33.958	75.898	0.013176	155.54	5.1266	1.3404	0.019394	1.26E-05
172.49	33.958	75.829	0.013188	155.68	5.1273	1.3396	0.019399	1.26E-05
172.59	33.958	75.761	0.013199	155.81	5.1281	1.3389	0.019404	1.26E-05
172.69	33.958	75.693	0.013211	155.95	5.1289	1.3382	0.019409	1.26E-05
172.79	33.958	75.625	0.013223	156.08	5.1297	1.3375	0.019414	1.26E-05
172.89	33.958	75.557	0.013235	156.21	5.1304	1.3368	0.019419	1.27E-05
172.99	33.958	75.489	0.013247	156.35	5.1312	1.3361	0.019424	1.27E-05
173.09	33.958	75.421	0.013259	156.48	5.132	1.3354	0.019429	1.27E-05
173.19	33.958	75.354	0.013271	156.61	5.1328	1.3347	0.019434	1.27E-05
173.29	33.958	75.286	0.013283	156.75	5.1335	1.334	0.01944	1.27E-05
173.39	33.958	75.219	0.013294	156.88	5.1343	1.3333	0.019445	1.27E-05
173.49	33.958	75.152	0.013306	157.01	5.1351	1.3326	0.01945	1.27E-05
173.59	33.958	75.086	0.013318	157.15	5.1358	1.3319	0.019455	1.27E-05
173.69	33.958	75.019	0.01333	157.28	5.1366	1.3312	0.01946	1.27E-05
173.79	33.958	74.952	0.013342	157.41	5.1374	1.3305	0.019465	1.27E-05
173.89	33.958	74.886	0.013354	157.55	5.1381	1.3298	0.01947	1.27E-05
173.99	33.958	74.82	0.013365	157.68	5.1389	1.3292	0.019475	1.27E-05
174.09	33.958	74.754	0.013377	157.81	5.1397	1.3285	0.019481	1.27E-05
174.19	33.958	74.688	0.013389	157.95	5.1404	1.3278	0.019486	1.27E-05
174.29	33.958	74.622	0.013401	158.08	5.1412	1.3271	0.019491	1.27E-05
174.39	33.958	74.556	0.013413	158.21	5.1419	1.3265	0.019496	1.27E-05
174.49	33.958	74.491	0.013424	158.34	5.1427	1.3258	0.019501	1.27E-05
174.59	33.958	74.426	0.013436	158.48	5.1435	1.3251	0.019507	1.27E-05
174.69	33.958	74.361	0.013448	158.61	5.1442	1.3245	0.019512	1.27E-05
174.79	33.958	74.296	0.01346	158.74	5.145	1.3238	0.019517	1.27E-05
174.89	33.958	74.231	0.013472	158.87	5.1457	1.3232	0.019522	1.27E-05
174.99	33.958	74.166	0.013483	159.01	5.1465	1.3225	0.019527	1.27E-05
175.09	33.958	74.101	0.013495	159.14	5.1473	1.3219	0.019533	1.27E-05
175.19	33.958	74.037	0.013507	159.27	5.148	1.3212	0.019538	1.28E-05
175.29	33.958	73.973	0.013518	159.4	5.1488	1.3206	0.019543	1.28E-05
175.39	33.958	73.909	0.01353	159.53	5.1495	1.3199	0.019548	1.28E-05
175.49	33.958	73.845	0.013542	159.67	5.1503	1.3193	0.019554	1.28E-05
175.59	33.958	73.781	0.013554	159.8	5.151	1.3186	0.019559	1.28E-05
175.69	33.958	73.717	0.013565	159.93	5.1518	1.318	0.019564	1.28E-05
175.79	33.958	73.654	0.013577	160.06	5.1525	1.3174	0.01957	1.28E-05
175.89	33.958	73.59	0.013589	160.19	5.1533	1.3167	0.019575	1.28E-05
175.99	33.958	73.527	0.0136	160.33	5.154	1.3161	0.01958	1.28E-05

CONTENTS