Experimental Determination of Convective Heat Transfer Coefficient of Tissue Mimicking Gel

A thesis submitted in partial fulfillment of the requirement for a degree of

Bachelor of Technology

in

Biomedical Engineering

by

Seeta Hembram

Department of Biotechnology and Medical Engineering

National Institute of Technology

Rourkela

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Under the guidance of

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CERTIFICATE

This is to certify that the thesis entitled "*Experimental Determination of Convective Heat Transfer Coefficient of Tissue Mimicking Gel*" submitted by Ms. Seeta Hembram in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Biomedical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by her under my guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

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DECLARATION BY THE CANDIDATE

I **Seeta Hembram,** a student of Department of Biotechnology and Medical Engineering, National Institute of Technology Rourkela bearing Roll No: 109BM0006 hereby certify that my B.Tech Project Report entitled "*Experimental Determination of Convective Heat transfer Coefficient of Tissue Mimicking Gel",* under the guidance of Prof. Amitesh Kumar at National Institute of Technology Rourkela, Rourkela is being submitted in partial fulfilment of the requirements for the Degree of **Bachelor of Technology** in **Biomedical Engineering.** This is a record of bonafide work carried out by me and the results embodied in the Project Report have not been copied from any source. The results embodied in this Project Report have not been submitted to any other University or Institute for the Award of any other certificate or degree.

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Abstract

The present study deals with finding the convective heat transfer coefficient of agarose gel prepared at two different concentrations of 0.6 % w/v and 1.4% w/v. It is carried out with the help of very simple and easily available laboratory apparatus designed specifically for the determination of convective heat transfer coefficient of tissue mimicking gel. This paper demonstrates an experimental study on three reference temperatures corresponding to 60°C, 70°C and 80°C maintained in the water bath. The sample is designed in such a way that it behaves as a lumped parameter system characterized by a uniform temperature distribution within the system. The variation of temperature with time is recorded with the help of data acquisition system and LabView. The convective heat transfer coefficient of tissue mimicking gel is predicted by fitting the analytical result with the experimental result which ensures a goodness of fit in the range of 97% - 99%. The predicted value of convective heat transfer coefficient lies between 400-450 W/m^2 K.

Keywords: Convection, Lumped parameter Analysis, Agarose gel, Tissue-mimicking gel, Convective heat transfer coefficient.

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Agarose is one of the major components of polygalactoside agar, a neutral and non-toxic linear polysaccharide fraction extracted from marine red algae. Agarose is a linear copolymer composed of alternating 1,3-linked β-Dgalactopyranose and 1,4-linked 3,6-anhydro-α-L-galactopyranose. These units are joined by (α-1,3) glycosidic link to form a polymer of 600-700 residue long. Agarose has a remarkable gel forming property. When suspension of agarose in water is heated and cooled, the agarose forms a double helix: two molecules in parallel orientation twist together with a helix repeat of three residues; water molecules are trapped in the central cavity.

The setting and melting temperature for agarose gel is close to 40°C and 90°C respectively. Agarose gels have high elastic moduli at low concentrations and they are brittle and turbid [1]. The agarose at varying concentrations in the range of 0.5-1.0% w/w and at temperature of 30-40°C showed a characteristic values of space variable $h=6\times 10^{-5}$ $A^{\circ -1}$ for the light scattering system. Four different grades of agarose are available that is low Electro Endosmosis (EEO), intermediate EEO, high EEO and very high EEO. Low EEO agarose powder is the most common grade of purified agarose ideally used in routine electrophoresis of DNA and RNA due to its wider range of resolution and high gel strength.

The term 'gel' had originated from the Latin word "gelare" which means to cause creation of gel [2]. Gel refers to a semisolid condition of a precipitated or coagulated colloid. It may also be called as a jelly or a jelly-like colloid which contains a large amount of water. The term 'gel' should be able to define those systems which fulfill the following phenomenological characteristics that is they should consists of two or more components one of which is a liquid, present in substantial quantity and they need to be a soft, solid, or solid-like materials [3]. The process of a gel formation is known as gelation. Generally gels possess the following four properties: (1) Hydration (2) Swelling (3) Syneresis (4) Thixotropy. Due to these properties of gels it has found a widespread clinical application in medical and research industries such as saline gels are widely used for diagnostic images in ultrasound scanning (sonography).

Beside these, most recently many gelatin-based phantoms (also called tissue-mimicking phantom) have been investigated out that mimics specific tissue acoustical and optical properties for the purpose of photo acoustic and ultrasonic (PAUS) imaging studies that is finding importance in more clinically realistic imaging environment. The tissue-mimicking phantom is found to be similar to that of human soft tissue [4].

Agarose has widespread applications in separation of proteins ,enzymes and nucleic acid, immune diffusion technology, Gel and Affinity chromatography, crystallographic study, preparation of culture media, tissue typing, cell line verification, paternity determination, forensic testing, finger printing, immune electrophoresis and electro focusing. It is a powerful tool in Molecular Biology, Microbiology, Biochemistry, Cell and Structural Biology because of its high hysteresis greater than hydrocolloid. They are used in medicine and pharmacy, and they served as a thickening and gelling agent in food industry.

Convection is one of the distinct modes of heat transfer, it is a transfer of heat between a relatively hot and cold portion of the fluid by mixing. Convection is restricted to the flow of heat in fluids. If the fluid motion is caused by differences in density resulting from temperature difference in a fluid, the heat transfer is said to be natural convection. If the fluid is artificially fitted then the heat transfer is known as forced convection. The heat transfer coefficient can be defined as the quantity of heat transferred in unit time through unit area at a temperature difference of one degree between surface and surrounding. Heat transfer coefficient will increase with increase in heat transfer and decrease in temperature difference. It is a measuring parameter which indicates heat transfer will be larger with high heat transfer coefficient value. The study reveals that even small geometrical changes can result in distinct coefficients. Convective heat transfer rate is calculated from Newton's law of cooling. The natural convection of air has a value of convective heat transfer coefficient as 5 W/m^2 K and natural convection of water in a pipe is given as 570 W/m^2K. The phase change occurring at the surface during convection may also affect the value of convective heat transfer coefficient.

Thus it can be noted that it is important to calculate the various thermal properties of gels which mimic tissues. According to the author's best knowledge, no study has been conducted until now which deals with the convective heat transfer coefficient of agarose gel. Here we have investigated the thermal properties of gels mimicking tissues containing 0.6%

(w/v) and 1.4% (w/v) of agarose gel that possess similar thermal properties as that of human tissues. This study aims at calculating heat transfer coefficient for two different concentrations of agarose gel (0.6 and 1.4%).

1.2 LITERATURE REVIEW

1.2.1. LITERATURE REVIEW ON AGAROSE GEL PROPERTIES

Fernandez et al. [5] studied the rheological and thermal properties of agarose aqueous solution. The agarose (D-1-LE) solution of different concentrations (0.5, 1.5, 3, 4, 5, 6, 7 and 8%, g/mL) were prepared by mixing it in 20 mL of distilled water at 100°C and poured in cylindrical moulds (20 mm in diameter, 2 mm thickness). The viscosity curves of agarose solution of different concentrations obtained at 46°C, this experiment is done with the help of flow experiment (TA Instruments AR1000 Rheometer). The results were obtained as the viscosity get increase with the concentration of agarose solution at low concentrations up to (4% g/mL) there is no effect of viscosity with decreasing temperature for 38-40°C, beyond this temperature, the agarose solutions turns into gel and viscosity cannot be measured further. As the concentration has been increased to above 4%, the viscosity has more complex behavior with decreasing temperature but up to 60°C the viscosity does not change with temperature. As it reaches in between 60 and 50°C, the viscosity increases with decrease in temperature. The gelation temperature and time for the concentration of (3, 5, 6, 7 and 8%) is (34.3, 36.6, 37.0, 37.3 and 38.5°C) and (2742, 2600, 2600, 2560 and 2490 seconds) respectively.

The structure of the agarose solution and gels has been obtained with the help of small -angle X-ray scattering (SAXS). Time dependence of the optical rotation measured at wavelength of 436 nm for hot agarose solution initially at 90°C and cooled to temperatures of 38, 36 and 34 °C (agarose concentration 0.5%). There is no change occurred at 38°C at lower temperature the overall change is very small that is -0.4 to -0.5° as it reaches to lower temperature. The angular dependence of SAXS intensity from solution state at temperature 90°C and for gel states at temperature 25°C measured for same agarose concentration (2.4% w/w).The exposure time is 2 hour for solution and 1 hour for gel. There is a large scattering difference between solution and gel.

Chen [6] studied the dynamic mechanical properties of agarose gel. The functional derivative model used for characterization of elastic and viscous modulus with the function of frequency. The gel with agarose concentration (2, 3, 4 and 5% w/v). The sample of 5 mm in thickness is used for testing. The mechanical properties of gel were tested with dynamic mechanical analyzer (DMA 2980, TA instruments) over a frequency range of 1-20 Hz with constant amplitude of 2mm. It will help in measuring the complex modulus, elastic modulus and viscous modulus of gel and functional derivative model used to model the stress-strain relationship. The elastic modulus of agarose gel is usually 1-2 orders of magnitude larger than viscous modulus.

Thermal and physical properties of agarose of different composition resemble to the human tissue. Many experimental works has been conducted so far. Duck [7] had revealed that 0.2% concentration of agarose gel that has properties similar to that of human tissue. Cooper and Petrovic [8] investigate the distribution of temperature for the application of cryosurgery on a clear gel made of 1.5% gelatin and 98.5% water resembles the tissue phantom. Budman et al. [9] also used gel composition of 2% gelatin and 98% water as a tissue phantom. Rabin performed experiment with 2.5% gelatin and 97.5% water resembling prostate. Juan et al. [10] made the skin phantom preparation with highly purified agar powder dissolved in the mixture of deionized water (90%) and glycerol (10%) to achieve 1% concentration.

1.2.2 **LITERATURE REVIEW ON HEAT TRANSFER COEFFICIENT**

The Convective heat transfer Coefficient is an important physical parameter in heat transfer equations that is determined by experiments. Cancillo [11] had determined in his work about the heat transfer coefficient of solid copper bar in air at constant temperature by measuring the cooling curves with excesses of metal over the surrounding air in the range of 11-74°C and then comparison of the data to those calculated using a mathematical model to solve the equation for the heat flow in the bar. Gultekin and Gore [12] determine an experimental method to measure the heat transfer coefficient for fluid system by magnetic resonance imaging. This technique monitors the temporal variation of thermally induced nuclear shielding and measures the average heat transfer coefficient as a function of fluid velocity. Carson et al. [13] performed four different techniques to measure the apparent heat transfer coefficients within a typical domestic fan oven and commercial batch oven to reveal the time–variation in heat transfer coefficient.

Duangthongsuk and Wongwises [14] studied the convective heat transfer behaviors of nanofluids to predict the thermal and physical properties of nanofluids. Diller and Van den Berge [15] had designed a method to minimize experimental uncertainties and error due to heat losses in constant-wall-temperature convection measurement system.

Gracia et al. [16] provides an entirely new correlation to find out the heat transfer coefficient between an air flow and a plate made up of phage change material (PCM) to present a better stimulation of PCM heat storage systems. The application has also been extended to the field of food processing technology to ensure the safest modes of food preservation using mathematical models for heat transfer in food process designs. Augusto et al. [17] uses two methods that is conductive and convective heating inside packages to determine the convective heat transfer coefficient values for both heating and cooling using 2% agar (m/m) and pure water taken as medium respectively.

Adam et al. [18] had predicted and determined the heat transfer surface coefficient successfully using Computational Fluid Dynamics (CFD) for measurement of different geometry and flows with an accuracy of $\pm$0.5% in analytical values of convective heat transfer coefficient for laminar forced convection whereas the results shows good agreement with universal law-of-the-wall theory and correlations from literature for turbulent forced convection.

The reported value of heat transfer coefficient based on tissue phantom varies from 1600-60000 W/m^2 K [19]. Ruan et al. [20] studied the fluid particulate heat transfer coefficient for two sample system consisting of cylindrical heating device, cylindrical potato particle and a salt solution with sodium carboxy methyl solutes. The real time temperature maps were obtained for ohmically heated solution with the help of proton-resonance frequency shift method. The holding period, Magnetic Resonance Imaging (MRI) temperature map and numerical solution with the help of Fourier's Second Law can be used for determination of time-dependent interface heat transfer coefficient. The calculated value of fluid particulate heat transfer coefficient obtained in the range from 30-105 W/m^2 K.

Hossan et al. [21] analyze the effects of cylinder radius, heat transfer coefficient and incident frequency for the different length of cylindrical food stuffs in order to avoid the uneven heating in the food processed product. A closed form of analytical solution is used for the determination of temperature variation using energy equation and integral transform technique in the 3D cylindrical shape food. The radius of the food remains constant at 0.5 and 1.0 cm, but the length of the cylinder is varied from 1.25 to 5.0 cm for different study. In small cylinder, maximum electrical field strength is obtained at the middle of the cylinder but for longer cylinder, maximum field is obtained at the both ends of the food. Temperature variation is more like 1D as the cylindrical length decreases except near the top or bottom surface. The variation of radius has very small effect on temperature distribution. For higher heat transfer coefficients the temperature distribution becomes one dimensional while the temperature difference between maximum and minimum temperature decreases as the convective heat transfer coefficient increase from 1.5 to 50 W/m^{2}K.

Etheridge et al. [22] predict the temperature dependent thermal properties for ultrasound gel. These data will help in determination of Cryprobes behavior in phantoms. The experimental data were fit with finite element method and cosmol version 4a use for numerical modelling. Martin et al. provided analytical expression use for the prediction of convective heat transfer coefficient. The predicted value of heat transfer coefficient was in the order of 20kW/m^{2}K.

Christae et al. [23] determine the time- temperature profile which will help in determination of convective heat transfer coefficient at the fluid and solid particulate boundary for different flow condition. This will help in continuous sterilization of liquid foods containing solid particulate. Convective heat transfer coefficients were compared for two configuration of holding tubes, one is having circular cross section and other one is having noncircular cross section. A fluid that is water is inserted with immobilized sphere of vegetative cells of Bacillus stearothermophilus. The explicit difference scheme is used for the calculation of heat transfer equation, which will help in the determination of in activation of microorganism. Mean effective value for the circular cross section is 350 to 1700W/m^{2}K and for the non circular cross section is 400 to 2500 W/m^{2}K. With increase in flow rate and temperature for this two configuration, it will affect convective heat transfer coefficient. The presence of large number of solid particle will affect the convective heat transfer coefficient value.

Miguel et al. [24] developed an instrument for the measurement of convective heat transfer coefficient in large blood vessels .This work developed a mechanical simulator and they validate an equation which analytically determines the value of h which was developed by

Consiglierli. The mechanical simulator that produces the flow conditions and geometry of large blood vessels in the liver, this will help in testing the instrument.

The average value of h using the instrument obtained as 2130($\pm$40) W/m^{2}K (mean $\pm$ sd). This instrument helps in measuring the value of convective heat transfer coefficient in vitro and the recurrence rate which is obtained in heptacellular carcinoma due to the high convective loss in the vessel, these data will help in prevention of carcinoma.

Sun [25] explained the experimental approach for the determination of the surface heat transfer coefficient of egg with the help of CFD. Empty egg shells were filled with convective heating materials, thermal processing carried out by immersing egg filled with agar gel in water bath. During this process temperature is recorded with the help of T-type needle thermocouple at three different locations. The eggs were fixed in a vertical position in a holder and the geometry of egg and accurate determination of Cartesian coordinates of the thermocouple hot junction was determined by CFD. The water circulation with rate of 50 L/min. and average velocity of 0.01m/s forced in a vertical direction of the egg. The initial temperature of processed egg is (19.4$\pm$0.2°C). Using the appropriate initial and boundary condition they predicted temperature distribution for three positions using different surface heat transfer coefficient. An average surface heat transfer coefficient obtained as 490$\pm$82 W/m^{2}K.

Chapter 2

MATERIALS AND METHODS

2.1. MATERIALS

- Agarose powder (HIMEDIA, Low EEO): Agarose gel is taken in different concentrations, which is used to resemble different tissue.

- Petri dish: Container used in biological laboratories to culture cells. It is used in those experiments where cross-contamination is a major problem.

- K-type thermocouple: It is the most common type of thermocouple with the most widely operating temperature range. Generally preferred for laboratory work mainly because its nickel based and corrosion resistance. Its thermal sensitivity is approximately 41µV/° C.

- Distilled water: To carry out different experimental works in physical and biological laboratories.

- Advantech portable data acquisition module (USB-4704): It is a 48kS/s, 14-bit, 8-channel multi-functional module with analog I/O, digital I/O and counter function specifically recommended for laboratory experiments. It measures the temperature recorded by transducer and converts it into corresponding voltage signal in mV.

- Water bath: Vessel containing water which can be kept at a desired temperature under constant monitoring of temperature.

- Analytical Laboratory Balance: Used for measuring the quantity of substance.

  Bread Board: Used in electronics laboratories to test circuits. A complete circuit consists of wires and components simply pushed into the holes which are freely movable to any position on bread board template.

- Lab View Software: It is a system design platform and development environment for a visual programming language from National Instruments. This software is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms.

2.2. METHODOLOGY

2.2.1. Gel Preparation:

For this experiment, different concentrations of agarose media with 0.6% w/v and 1.4% w/v respectively are used. Different concentrations of agarose gel are used to know the effect of convective heat transfer coefficient values with regard to analytical values. To study the variation of temperature with increasing time, even a small quantity of agarose powder is sufficient. So, it is customary to take about 0.3 and 0.7 gram of agarose powder (HIMEDIA) in 50 mL of distilled water respectively. For our requirement, 50-100 mL of beaker is used. Add powder slowly in the beaker whilst stirring to avoid clumping. The agarose powder is allowed to hydrate in solution for few minutes before heating to allow for quick and easier dissolution. The time and power settings are adjusted in accordance to microwave output strength. To prevent overheating of solution, the beaker is removed after one minute of interval from microwave oven and swirl gently and carefully to ensure uniform homogeneous mixing of all the particles. Precautions should be taken to avoid over boiling as it may cause agarose hydrolysis and lower gel strength. During heating process, sufficient care should to be taken to avoid any water loss due to evaporation, which may adversely affect the composition of concentration.

Also, it is advisory to continue heating with regular stirring at a regular time interval to ensure uniform heat distribution over the whole surface area and check uniform mixing of solution free from any suspended particle. The purpose of using the gel concentration of 0.6% m/v and 1.4%m/v respectively for our experimental work is to mimic different tissues in human body which is determined by different thermal conductivity of gel concentration as worked by Zhange et al**.** [26].

2.3. EXPERIMENTAL SETUP

2.3.1. Model Description

This experiment aims at measuring the convective heat transfer coefficient (h) for heating of different concentrations of agarose gel (0.6% & 1.4%) using water as surrounding media which is maintained at temperature of 60°C, 70°C and 80°C .

This experiment makes use of simple and convenient techniques of sample preparation and setup for experiment. The apparatus consists of a K-type thermocouple dipped in agarose gel to such a position that it just lies at the mid-point of designed geometry. We prefer here the cubical shape of gel having equal dimensions of 7 mm along all the dimensions (in length, breadth and height) as shown in Figure 1.1 so that it behaves as a lumped parameter system. For a system to be in lumped parameter its Biot Number must be less than one (Bi < 1).

The advantage of using such system being approximating the thermal conductivity to infinity as stated by Fourier's Law that assumes the temperature at the thermocouple tip to be equal to the temperature at the sample surface. It minimizes the temperature gradient within the system so that the temperature at every point inside the system is read out to be uniformly distributed. This implies the resistance to conduction within the system being apparently small compared to resistance to heat transfer at its interface.

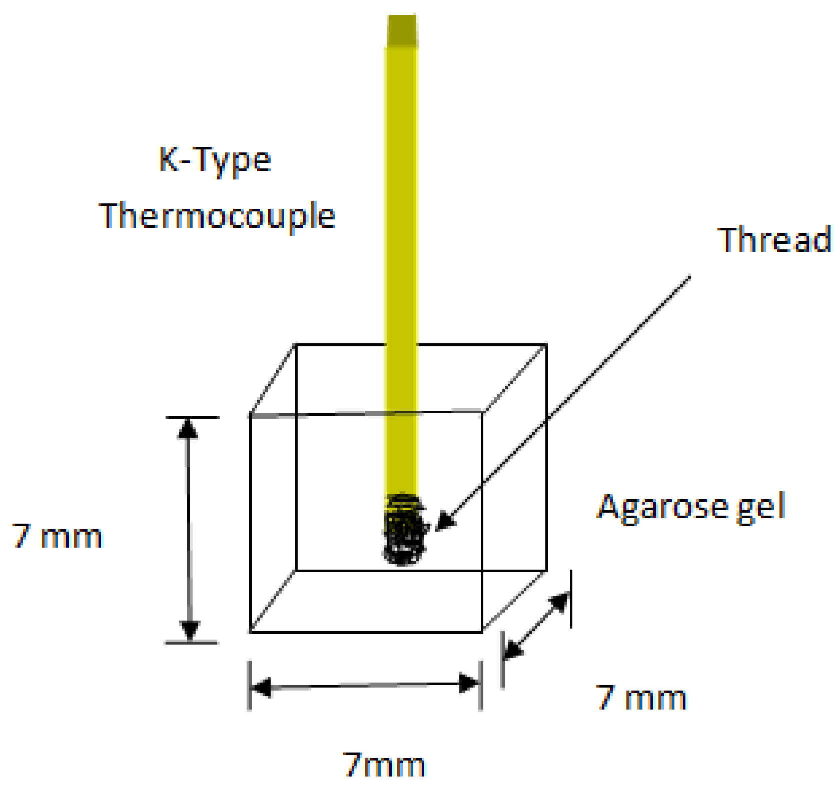

Figure:2.1. Schematic of K-type thermocouple wrapped with thread suspended in cubical shaped Agarose Gel

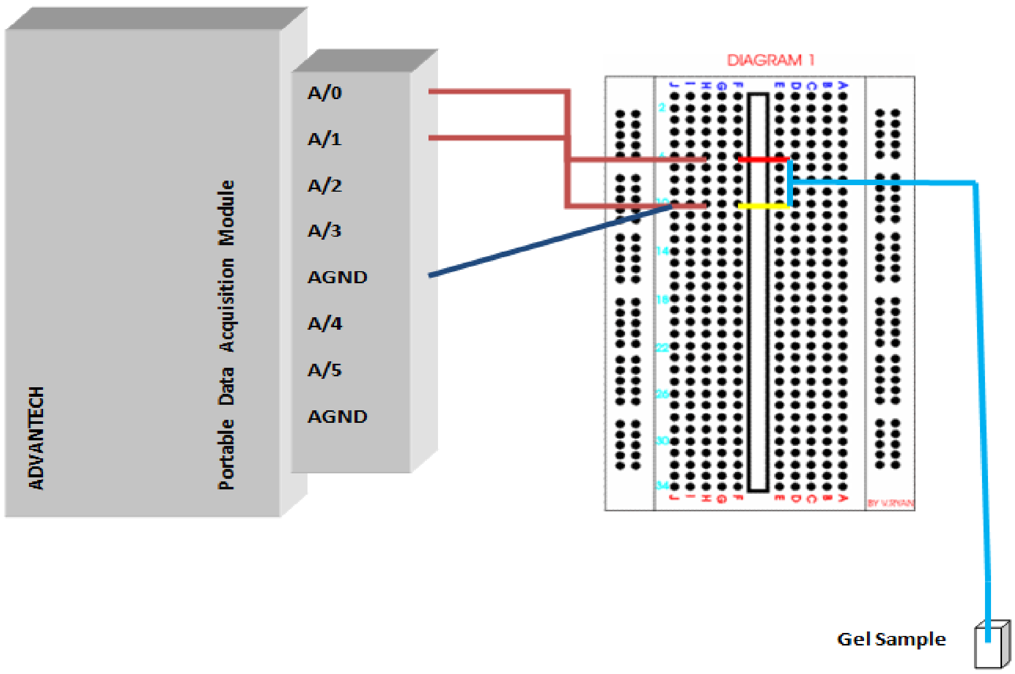

Figure2.2 Connection of Bread board circuit to Portable Data Acquisition Module (USB-4704)

In this figure 1.2, the positive leg (yellow) of thermocouple is grounded which on the other side is connected to the A/1 (odd) terminal of USB-4704 module. The negative leg of thermocouple on contrast is connected to A/0 (even) terminal of module. These terminals collect all the data acquired in temperature (°C) and DAQ module subsequently converts them into voltage readings (mV) which is monitored by Lab View Software.

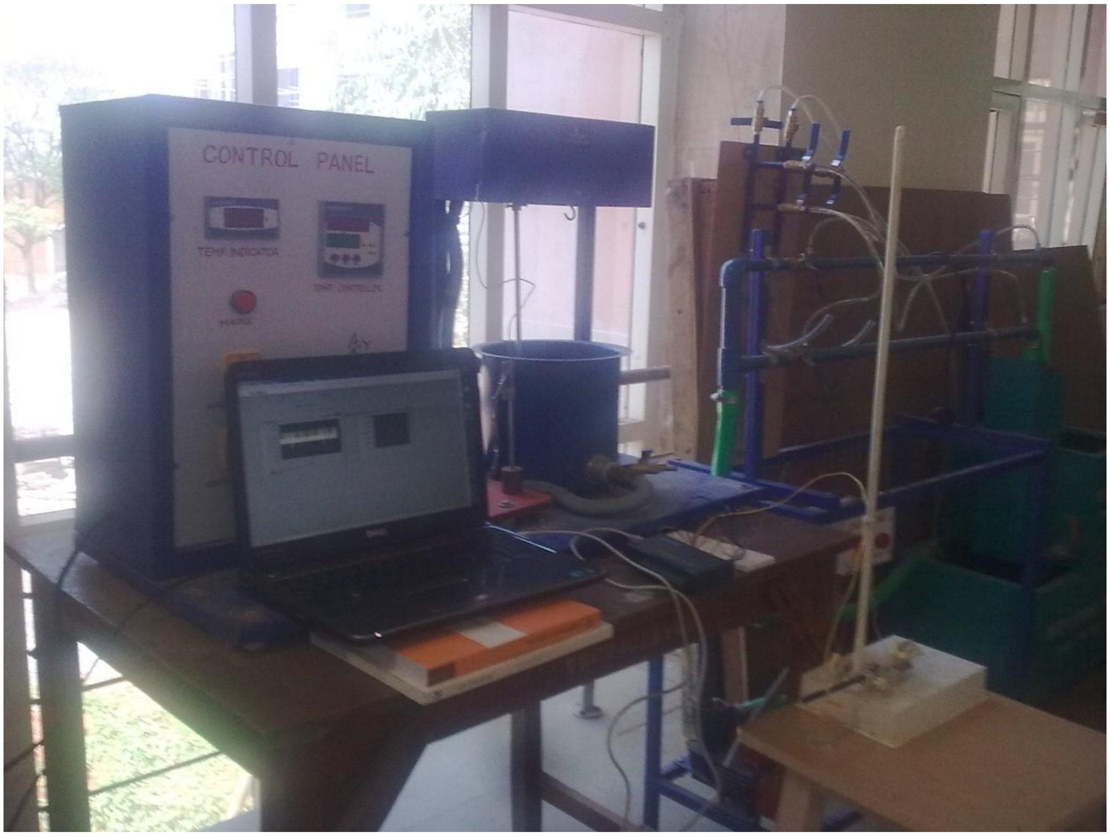

Figure 2.3. Experimental setup consisting of K-type thermocouple dipped in gel medium on one end and connected to DAQ module (USB-470) on other end.

2.3.2. **Temperature measurement using Advantech Portable Data Acquisition Module (USB-4704)**

K-type thermocouple acts as a transducer to convert the temperature variations to variations in the voltage. The variation in voltage is received via Advantech portable data acquisition module (USB-4704) mainly in the range of millivolt (mV).The data received in this process is highly susceptible to noise pollution.

Hence, the most easy, effective and accurate way to find the voltage value is by finding the Arithmetic mean by effectively calculating the mean of 1500 samples. For the purpose we sampled the data at the rate of 1500 samples/sec.

If N is the number of samples taken in one second, then the arithmetic mean is given by

$$\sum_{i=1}^{N} \frac{Vi}{N}$$

The precision of voltage value largely depends on the more number of samples. The voltage values are then stored by using write measurement files.

2.3.3. Calibration of Thermocouple

Calibration is the most important task in the whole procedure. The thermocouple is calibrated to avoid any temperature variations due to resistance of thermocouple wire showing the precise temperature with an error of ±5°C.

2.4. EXPERIMENTAL PROCEDURE

2.4.1. Analytical Analysis:

The gel sample is cut out with accurate precision in cubical shape as the value of h is largely dependent on surface area and volume of sample as governed by Equation 1.3.

During heating process, the loss is due to convection. As learnt from daily observation that any hot object when left by its own begins to cool or heated gradually until it attains the temperature of the surrounding. This phenomenon can be explained from Newton's Law of Cooling which states that the rate of cooling/heating of an object is approximately proportional to the temperature difference ΔT. This leads to the formulation of governing rate Equation 1.1 i.e.

$$Q = h\,A\,(T - T_{wb}) \qquad (1.1)$$

where Q is heat flow(in J/s = W) , A is heat transfer surface area (in m²) ,T is the temperature of system surface , T_{wb} is the temperature of fluid far from the surface maintained in water bath and h is the heat transfer coefficient (in W/(m²K)).

The water bath is first maintained at a temperature of T_{wb} = 60°C. The sample piece is initially at a uniformly temperature of T_i at (t<0) and then immersed into the water bath of temperature T_{wb} (>T_i).

The quenching is said to begin at time t=0, so the temperature of the system begins to rise for time t>0 exponentially as governed by Equation 1.9.

Every sample is kept for 2 minutes (120 seconds) in hot water until heat transfer takes place at the interface to balance the transient process. The sample is then carefully taken out and water droplets suspended on the surface is gently removed using tissue paper to avoid cooling effect.

2.4.2. Mathematical Modelling:

Once the temperature gradients within the system are neglected, there is no problem from within the framework of the heat equation. Therefore the transient temperature response is determined by formulating an overall energy balance which relates the rate of heat loss at the surface to rate of change of internal energy given in Equation 1.2.

$$-\quad h\,A\,(T - T_{wb}) = \rho\,V\,C\,\frac{\partial T}{\partial t} \qquad (1.2)$$

or

$$\frac{\partial T}{\partial t} = \frac{hA}{\rho VC}\,(T_{wb} - T) \qquad (1.3)$$

Introducing the temperature difference

$$\theta = T - T_{wb} \qquad (1.4)$$

and recognizing that $\frac{\partial \theta}{\partial t} = \frac{\partial T}{\partial t}$ follows that

or

$$\frac{\rho VC}{hA}\,\frac{\partial \theta}{\partial t} = -\,\theta \qquad (1.5)$$

Separating variables and integrating from the initial condition, for which t=0 and T (0)=T_i,

it follows that

$$\frac{\rho VC}{hA}\int \frac{\partial \theta}{\theta} = -\int \partial t \qquad (1.6)$$

where left hand side is integrated from θi to θ and right hand side from t=0 to t,

$$\theta_i = T_i - T_{wb} \qquad (1.7)$$

Evaluating the integrals it follows that

$$\frac{\rho VC}{hA} \ln \frac{\theta i}{\theta} = t \qquad (1.8)$$

or

$$\frac{\theta}{\theta i} = \frac{T - Twb}{Ti - Twb} = e^{-\left(\frac{hA}{\rho VC}\right)t} \qquad (1.9)$$

The forgoing results indicate that the difference between the system and fluid temperatures must decay exponentially to zero as time approaches infinity.

Chapter 3

RESULTS AND DISCUSSION

When the gel sample is exposed to different media, heat transfer takes place from the gel surface via convection. An inquiry is conducted to study the heat transfer coefficient of the gel sample. The gel sample is allowed to absorb heat at a temperature of 60°C, 70°C and 80°C sequentially from the room temperature of 37°C by immersing it in water bath containing water at respected temperature; the gel sample is then allowed to cool by its own in room air. The temperature response is recorded using data acquisition system and Lab View. Numerical modelling is done to study the heat transfer coefficient when the gel sample is immersed in hot water with respected temperature and then the numerical and experimental results are compared. The heat transfer coefficient numerically predicted to the temperature profile closely fits to the experimental observation taken for the heat transfer coefficient for the given system.

3.1. When 0.6% (w/v) of Agarose Gel is exposed to water maintained at temperature T_{wb}= 60°C, 70°C and 80°C respectively

Figure 3.1, Figure 3.2 and Figure 3.3 shows the temperature profile of gel sample when exposed to water at temperature T_{wb}=60°C, 70°C and 80°C respectively. The initial temperature of gel sample is at temperature T_i= 20°C with gel concentration of 0.6% (w/v). It is then immersed in hot water and is allowed to heat until it attends a steady-state condition. A steady-state condition in thermodynamics is when any property of the system is unchanging with time. The time taken to reach the steady state temperature is recorded and is given in Table 3.1 for different gel concentrations and temperature exposure.

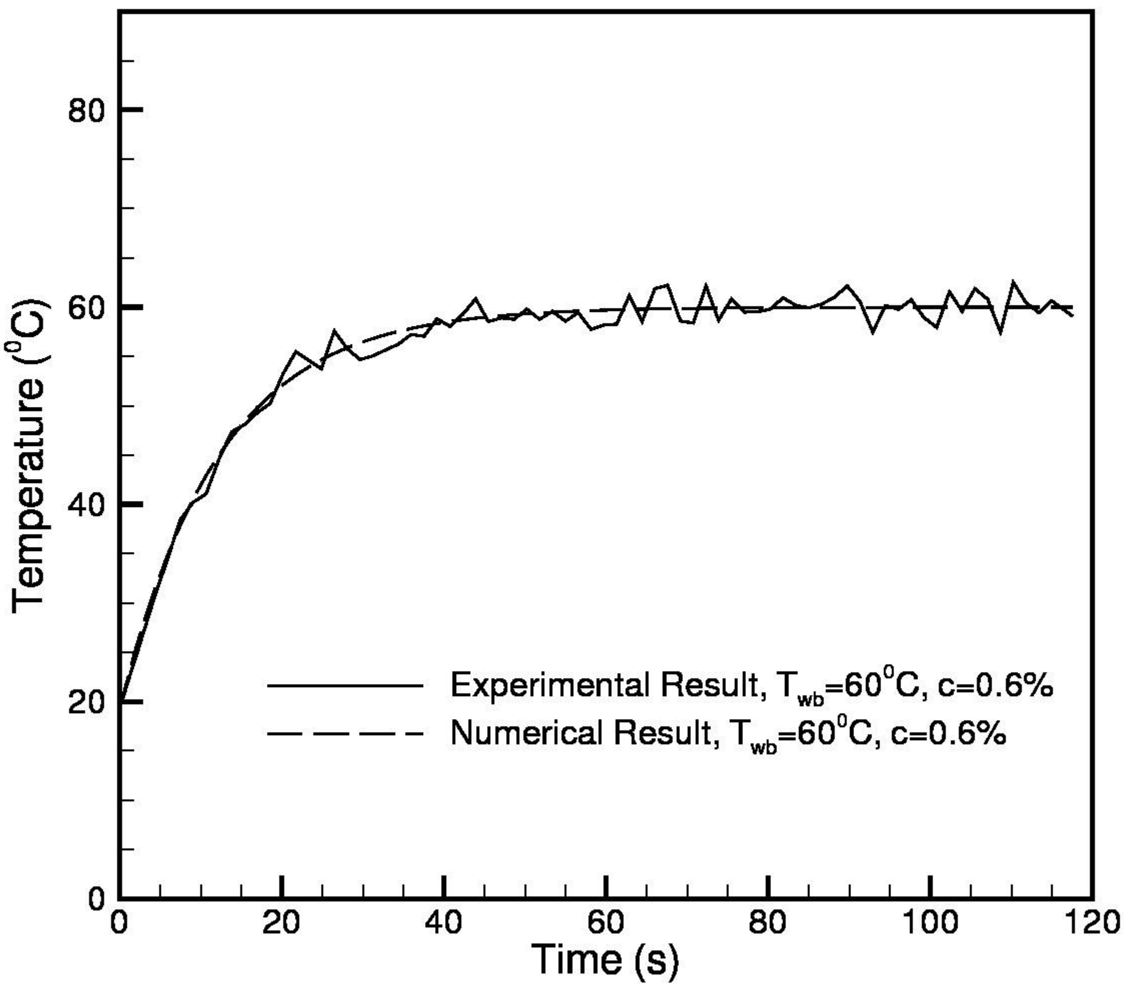

Figure 3.1. Temperature profile of agarose gel at concentration 0.6% (w/v) exposed to temperature at T_{wb} = 60°C

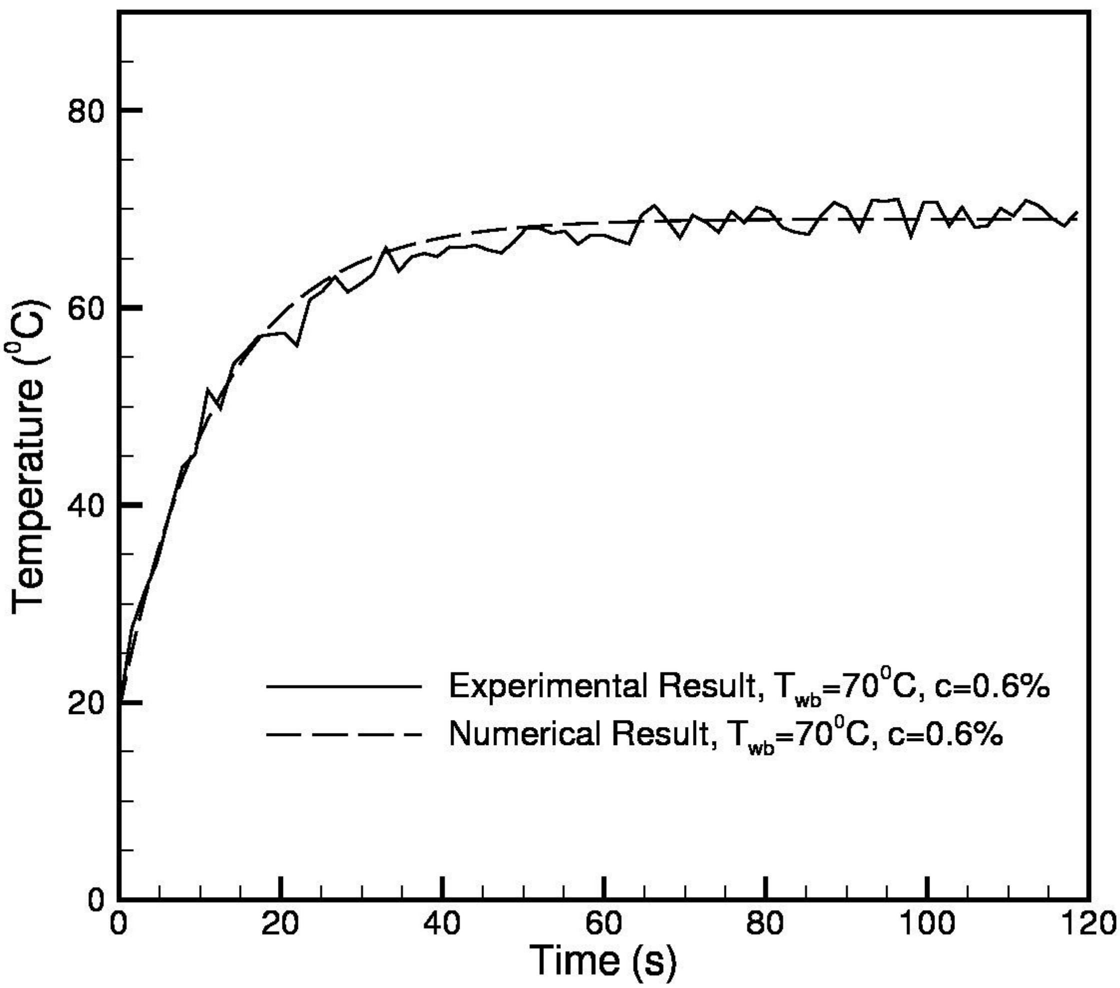

Figure:3.2. Temperature profile of Agarose gel at concentration 0.6% (w/v) exposed to temperature at T_{wb} = 70°C

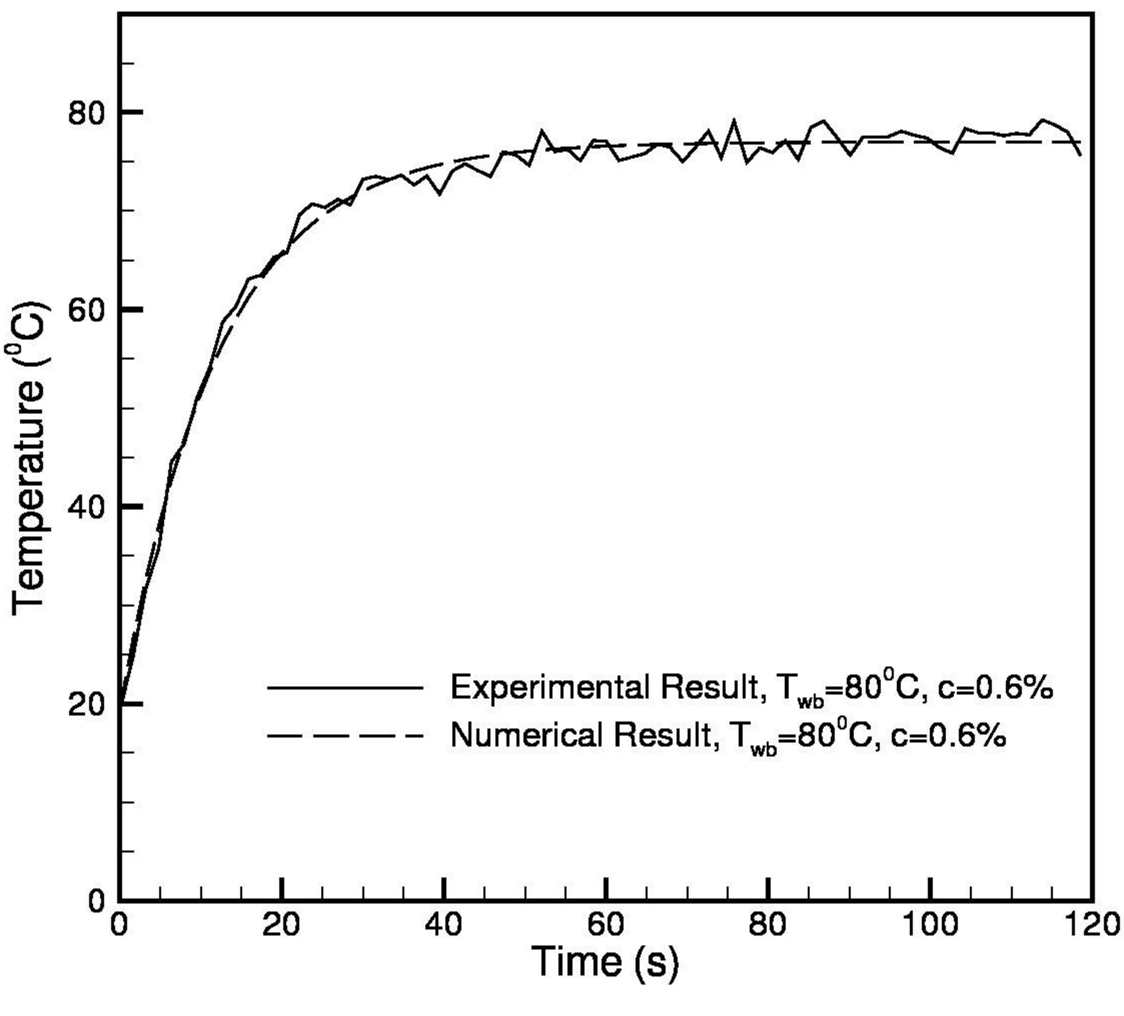

Figure:3.3. Temperature profile of Agarose gel at concentration 0.6% (w/v) exposed to temperature at T_{wb} = 80°C

The numerical analysis is also plotted, shown by broken lines. The graphs obtained by numerical analysis indicate that the results obtained by Mathematical Modelling have a closer fit to maximum accuracy with the values obtained by experimental results. The heat transfer coefficient was thus found out to be 400 (W/m^2 K).

3.2. Comparison of Temperature profile of 0.6% agarose gel when exposed to different Temperature

Table 3.1. Variation of time to attend steady-state temperature with increasing temperature at concentration 0.6%

Concentration of Agarose-Gel (w/v in %)	Temperature maintained in Water Bath, T_{wb} (°C)	Time to attend steady-state temperature (t in sec.)
0.6 %	60°C	50 sec.
0.6 %	70°C	55 sec.
0.6 %	80°C	60 sec.

3.3. When 1.4% (w/v) of agarose gel is exposed to water maintained at temperature T_{wb}= 60°C, 70°C and 80°C respectively

Figure 3.4, Figure 3.5 and Figure 3.6 show the temperature profile of gel sample when exposed to water at temperature T_{wb}=60°C, 70°C and 80°C respectively. The initial temperature of gel sample is at temperature T_i= 25°C with gel concentration of 1.4% (w/v). It is then immersed in hot water and is allowed to heat until it attends a steady-state condition. The time taken to reach the steady state temperature is given in Table 3.2 for different gel concentrations and temperature exposure.

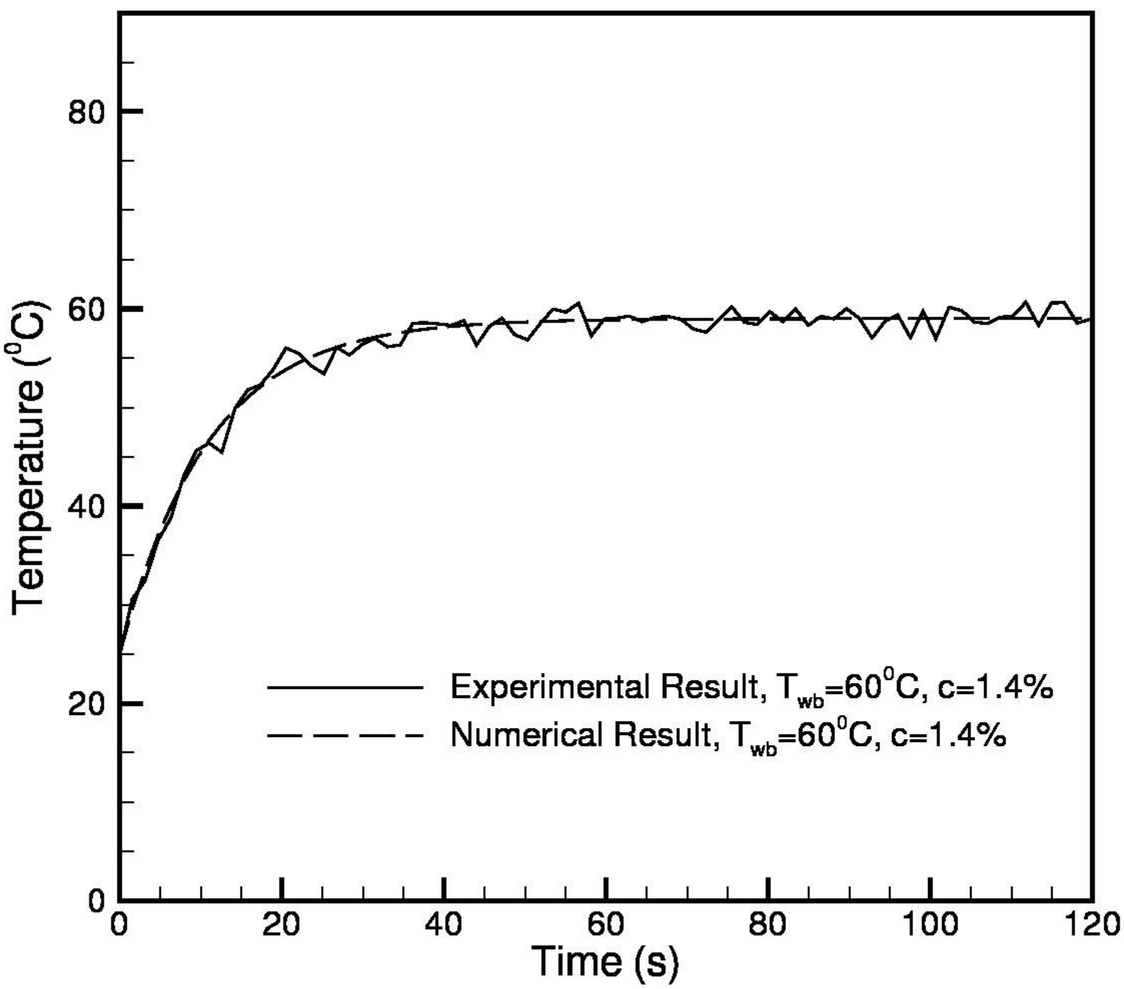

Figure:3.4.. Temperature profile of agarose gel at concentration 1.4% (w/v) exposed to temperature at T_{wb} = 60°C

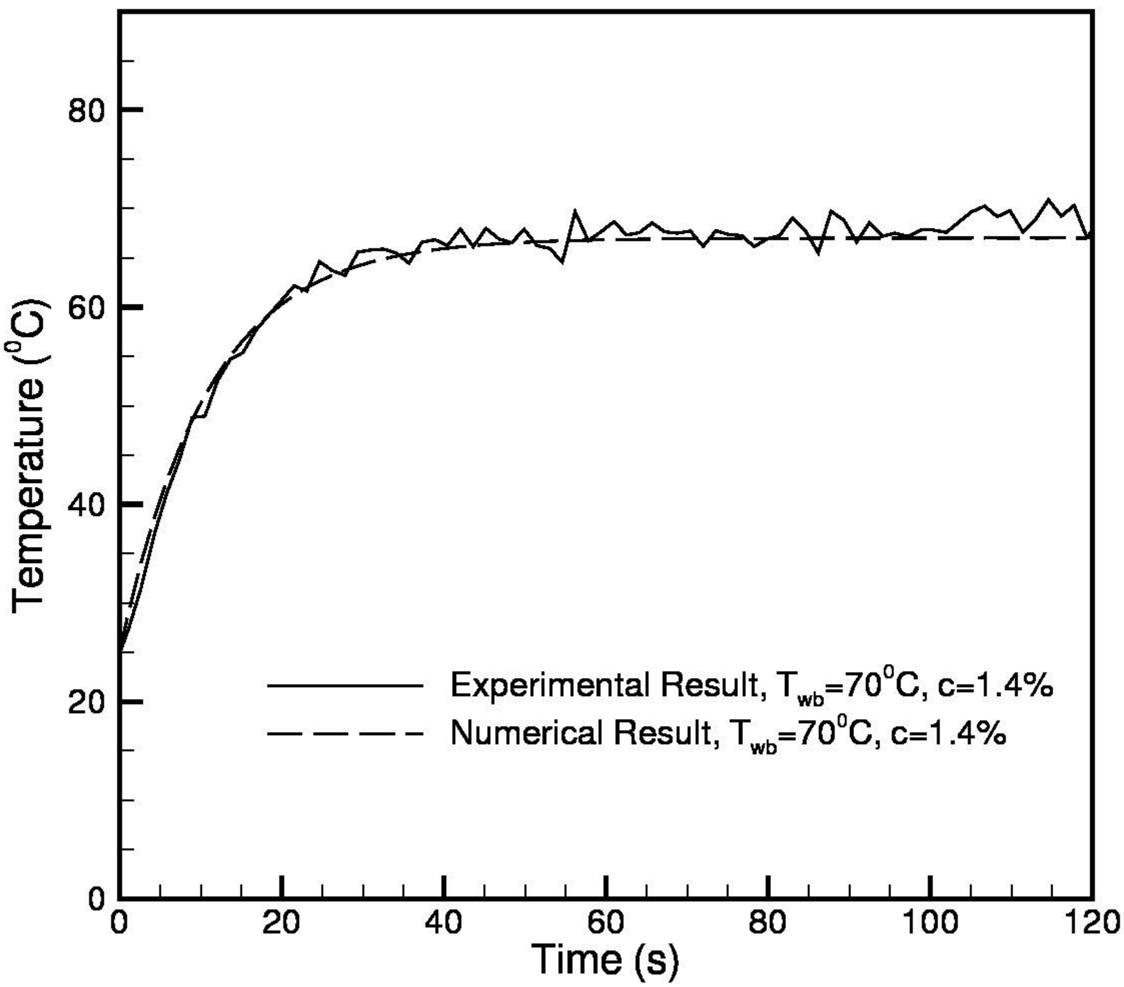

Figure:3.5. Temperature profile of agarose gel at concentration 1.4% (w/v) exposed to temperature at T_{wb} = 70°C

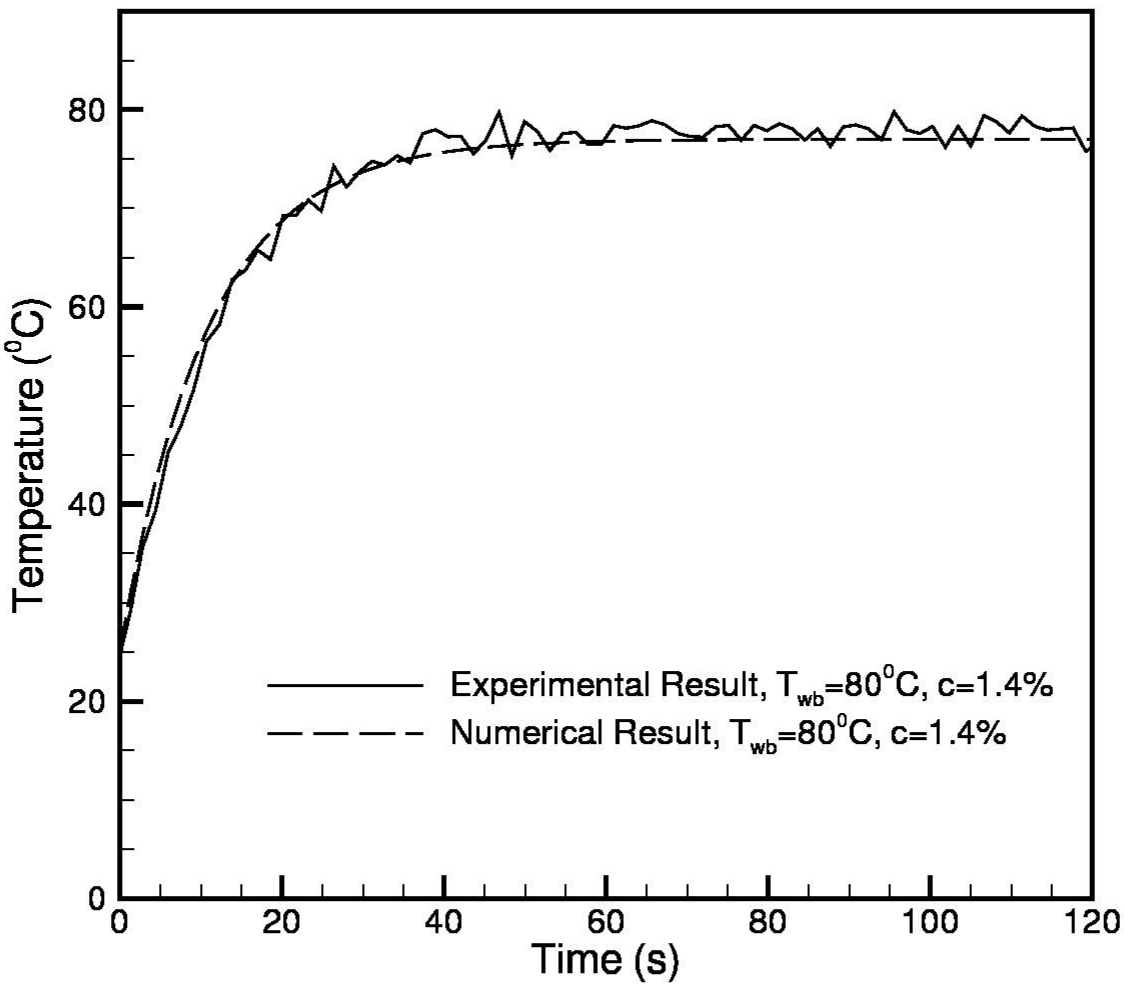

Figure:3.6. Temperature profile of agarose gel at concentration 1.4% (w/v) exposed to temperature at T_{wb} = 80°C

3.4. Comparison of Temperature profile of 1.4% agarose gel when exposed to different Temperature

Table 3.2. Variation of time to attend steady-state temperature with increasing temperature at Concentration 1.4%

Concentration of Agarose-Gel (w/v in %)	Temperature maintained in Water Bath T_{wb} (°C)	Time to attend steady-state temperature (t in sec.)
1.4%	60 °C	42 sec.
1.4%	70 °C	46 sec.
1.4%	80 °C	50 sec.

CONCLUSION

The initial temperature of agarose gel at 0.6% w/v was 20°C, which increased gradually due to heating. It was observed that the time taken to reach higher temperature i.e. 80°C was more than the time taken to reach 60°C. When the concentration of agarose was kept 1.4% w/v, then the initial temperature of the gel was observed to be 25°C. Therefore, it could be said that at higher concentrations of agarose, the initial temperature of the gel also increased. This variation in temperature is a result of the internal properties of the gel itself. The convective heat transfer coefficient of tissue mimicking gel is predicted by fitting the analytical result with the experimental result which ensures a goodness of fit in the range of 97% - 99%. The predicted value of convective heat transfer coefficient lies between 400-450 W/m^2 K.

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