PREDICTING THE EFFECT OF CARBON SOOT PARTICLES ON THE MELTING RATE OF ICE: THEORETICAL AND EXPERIMENTAL INVESTIGATIONS

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CERTIFICATE

I hereby declare that the dissertation entitled "**Predicting the Effect of Carbon Soot Particles on the Melting Rate of Ice: Theoretical and Experimental Investigations**" is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **Thermal Engineering** at **Thapar Institute of Engineering and Technology, Patiala** under the supervision of **Dr. Vikrant Khullar and (Assistant Professor, Mechanical Engineering Department) and Dr. Rohit Kumar Singla (Assistant Professor, Mechanical Engineering Department).** No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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ABSTRACT

Un-burnt carbon particles (soot particles) have been known to be highly absorbing in the solar irradiance wavelength band and thus have a significant impact on regional and global climate patterns. Furthermore, these particles when entrapped in the glacier ice, can affect the melting rate of the glaciers, which in turn can affect the global sea levels. The present work serves to understand and quantify the effect of soot particles on the melting rate of glaciers. A comprehensive mathematical model has been developed to simulate the melting process in glaciers. Interaction of sunlight with the glacier ice essentially being a volumetric phenomenon has been modeled as radiative heat transfer in participating media. Spectral radiant energy from the sun interacts with ice (and the entrapped soot particles) through absorption and scattering mechanisms. The magnitudes of the optical constants of the ice constituents dictate the amount of sunlight absorbed and hence the melting rate. Theoretical calculations show that even trace amounts of soot particles can significantly increase the melting rate under similar ambient conditions, 100 parts-per-million (ppm) concentration of carbon soot particles can increase the melting rate by approximately 4.65%. Furthermore, the soot particle size, and concentration have been identified as the key parameters that govern the melting process. Finally, laboratory scale proof of the concept experiments have been carried out to verify the theoretical hypothesis.

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NOMENCLATURE

English Symbols

A	Surface area of ice surface [m^2]
c_p	Specific heat [$kJkg^{-1}K^{-1}$]
d	Diameter of particle [m]
dy	Node thickness along the depth direction [m]
dt	Time to melt dy thickness of water [s]
f_v	Volume fraction of nanoparticles in water
g	Acceleration due to gravity [ms^{-2}]
h	Coefficient of convection [W/m^2K]
l	length of column [cm]
C	concentration of solution [ppm]
h_∞	Convective heat transfer coefficient [$Wm^{-2}K^{-1}$]
h_{fg}	Latent heat of fusion [$kJkg^{-1}$]
I_λ	Intensity of solar radiation [Wm^{-2}]
k	Thermal conductivity [$Wm^{-1}K^{-1}$]
K_λ	Spectral optical coefficient [m^{-1}]
L_c	Characteristic length [m]
m	Normalized refractive index of flu
N_o	Number density of particle
n	Index of refraction
P	Pressure [Nm^{-2}]
Q	Efficiency
s	Path length [m]
T	Temperature [°C]

Greek Letters

α	Size parameter
λ	Wavelength of solar radiation [μm]
κ	Index of absorption
ρ	Density [kgm^{-3}]

Subscripts

abs	Absorption
np	Nanoparticle
s	Surface
i	Ice
w	Water

Abbreviations

NIR	Near infrared
UV	Ultra violet
VIS	Visible

CHAPTER 1
INTRODUCTION

1.1 Introduction

Melting of glacier is a natural process by which fresh water is obtained; wherein after melting, the water is drained through rivers or streams into oceans or seas. There is a particular rate (governed by host of natural and anthropogenic factors) at which this melting occurs; an imbalance may result in flooding or drought like conditions in the flood plains. Due to industrial revolution lot of unburnt carbon and after burn of carbon gases such as CO_2, CO, NO_x etc. gets added to atmosphere, which leads to global warming which increased the average temperature of earth. But in this study we are going to study only the effect of un-burnt carbon on melting rate of glaciers. It is seen that experimentally sample of 100ppm takes 16% less time than pure ice and theoretically 9% lesser time is obtained.

1.2 Motivation

With increase in population, the need for energy is accelerating .In modern lifestyle comforts are increased in each field likewise energy demand requirement is reaching on its peak level. Burning of the non-renewable energy sources is increasing to pave way for energy utilization for vast population. With burning comes increased pollutants and main source that effects melting of glacier are un-burnt carbon. Half of world glacier has melted after industrial revolution, and other are about to get melted. Rivers get flooded during rainy season and winter season due to melting of ice but drought condition are observed in hot summer months. Overall effect on sea level also surprising with increase of water content in river more amount of water is dumped into sea which will result is increased sea level and world’s 10% population that lives at coastal areas will get submerged thus imbalance in nature is observed at one place there is drought other has excess of water.

1.3 Types of Glacier.

Category of glaciers can be separated by two modes

1. **Structure or Design**
2. **Location**

1.3.1 Structure or Design

- **Mountain Glacier**- Due to regular snow fall in the area it is seen that snow under the compressive force start becoming harder and solidifies into ice. This glacier is generally found in high mountain regions as snow is changed to ice at same place where it precipitated. Movement in this type of glacier is very limited.
- **Valley Glacier**- In this type of glacier contribution of movement of snow and ice is generally very important. Contribution to the amount of glacier ice is generally from upper part of mountain which flows downward across the mountain ground.
- **Tidewater Glacier-** These glacier are generally found floating on sea generally due to regular striking of tides on the edge of the glaciers there breakage of part of glacier from main structure which result in floating of these glaciers . These glaciers that interrupt the water transport.
- **Piedmont Glacier**- These glaciers are found generally on flat surfaces which generally below the hill mountainous areas. Ice generally moves downwards after moving steep mountains then gets collected over there to form massive structures.
- **Hanging Glacier**- When glacier are retreating then there is regular reduction in mass of ice most of part start moving downwards towards the plane areas, they keep on falling down from main part of the glacier.
- **Cirque Glacier**- This type of the glacier generally having more amounts of width rather than length and these are generally found in higher grounds and amount of glacier size is less than normal glacier.
- **Ice Apron**- Step inclination are found in his type of glacier like stairs, amount of ice is generally found on horizontal plane surfaces rather than the vertical surfaces

1.3.2 Types according to latitude scale (a) **Temperate Glacier, (b) Sub – polar Glacier and (c) Polar Glacier**

(a) Temperate glacier-According to latitude distribution it is seen that area that is covered between 0º to 23.5º N and 0º to 23.5º S is called tropics generally no glaciers are found in this area because direct sunlight comes to this area all over the year, so higher temperature prevents from depositing of ice in form of glacier. Then comes another category such as temperate area which is found in between 23.5º N to 66.5º N and 23.5º S to 66.5º S which covers Indian subcontinent and Australia & New Zealand areas. Mostly temperature of glacier remains at melting point throughout the year considering the peaks with having average heights height factor superimpose on latitude factor. So peaks due to more direct sunlight are more prone to melting then comparison to the polar glaciers.

(b) Sub polar glacier- According to latitude distribution it is seen that area that is seen between 66.5º N to 90º N and 66.5º S to 90º S is called sub polar areas. Areas have characteristics have cold weather in maximum period of year and summer is generally very rare in this area. Generally it is found that when there is winter generally day time is seen only for 4 to 5 hours and when there is summer night time is seen for only 4 to 5 hours but the sunlight is in form of diffused sunlight. In summer temperature may rise up to 30º C and in winter temperature may fall to about -40º C. Temperature is under freezing point for about 4 to 5 months. Average temperature of polar is below sub polar and average temperature of sub polar is below temperate glacier.

(c) Polar Glacier- According to latitude distribution it that area that is found beyond 90º N and 90º S are called polar glacier area. This is area which has maximum distance from sun; sunlight takes maximum time to reach this part of the world. This place has characteristic that it has six months of winter and six months of summer. Temperature may reach minimum of -89º C, average temperature remain about less than 10º C. So this type of ambience is ideal for ice to get accumulated, it is seen that ice is seen to be accumulated in polar areas over 10000 years and color of ice changes from white to whitish blue under years of compression. Characteristics of whitish blue ice are generally different from white ice and melting becomes further more difficult in this type of area and melting time required in the polar areas. On the scale of latitude it is seen that maximum melting occurs at temperate glaciers further which gets reduced at sub polar region and then at polar region.

1.4 Novel Design Idea

The present study introduces the idea of melting of glacier which can be different for different types of glaciers generally temperature seen in sub polar glacier is higher than the polar glaciers so time taken to melt the polar glacier is more than sub polar glacier. If we consider the ambient conditions, it is generally seen that ambient temperature of sub polar or temperate glacier is generally higher than polar glaciers. Temperate glacier and sub polar glacier which are close to equator are more prone to melting or retreating then polar glaciers. Temperate glacier such as Himalayan glacier and sub-polar glacier such as Alps. It is also observed in this study that amount of melting can also be judged from amount of carbon content in ice shelves. As pollution is main concern from industrial revolution as carbon content keeps on increasing results in percolation of un-burnt carbon to glacier shelves , more will be amount of carbon introduced into the glacier shelves more will the increase in melting rate and time taken to melt glacier ice simultaneously gets. With increased melting rate of glaciers rise in sea level, retreating of glaciers, formation of seasonal rivers are adverse effects observed. These all consequences motivates to have research in this field and to calculate effect of concentration of amorphous carbon on melting rate of glacier ice

1.5 Objectives

1. Find melting rate of pure glacier ice.
2. To evaluate the effect of amorphous carbon on melting of glacier ice.
3. To observe melting rate variation with different amount of amorphous carbon content in pure ice theoretically.
4. To justify the theoretical results with experimental data for different concentrated solution of amorphous carbon.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In starting of this chapter basic modeling of melting of ice is discussed how many operating parameters effect the melting of glacier and what factors enhance melting rate and which factor reduce the melting rate of glaciers. Critical factor that effects the melting rate of glaciers is temperature , more will be the temperature more will be melting rate and lesser will be the melting time for ice. Finally we introduce the effect of carbon soot particles on the melting rate of glaciers.

Ice structure is regular crystalline type of structure such that a lot of vacuum spaces are seen because ice is only solid which expands after the phase change from water to ice this expansion is volume is generally seen due to entrapment of water bubbles in whole structure. It is also observed that white color of the ice is due entrapment of air bubbles between water whereas when we go for freezing the boiled water which removes air dissolved in water ice formation seen to be transparent crystal clear ice is seen. While doing practical experiments also it was seen that 12 ml of water used to expand to 13.5 ml in setup after freezing .Thus 1.5 ml volume increase was seen in water to ice transformation. In practical experiments setup is made from injection’s cylindrical part which is cut down from whole structure, cylinder is then punched with holes to put thermocouples to observe temperature profile readings. This is then pasted with glass slid with suitable adhesives. Further freezing is done of carbonated and non-carbonated solution for about 18 hours and then melted using optical fiber with power of 18 suns. Generally the temperature of ice after freezing comes between 0.5-0.8^{o}C which is then melted with static setup which results in upper part melting first then middle part then goes further to lower most part and it is found that thinning of ice column is observed in every situation. Ice width keeps on decreasing and height also gets reduced and melted water starts to get accumulated on sides of this ice column and at last only thin cylinder of ice is seen which is reduced in height as well as width from earlier column of ice in setup. Ambient conditions affect the setup melting in large amount and results fluctuate when outside temperature is different whether outside weather is cloudy or clear also effects the reading of the system. It is observed that wind speed or fan also effect the melting of glaciers and thus this experiment is very sensitive of outside ambient. Thermal resistance is found in earlier stages of melting of ice but later on graph climbs instantaneously with upper thermocouple first followed by middle thermocouple then lower most thermocouple this graph has time/ observations on lower axis and vertical axis has temperature observed on thermocouples. The position of setup where optical fiber is put to input should be such that it does not change during the observation are made in whole time period of the experiment process and same position should also remain for rest of the repetitive experiments when done. After rigorous research paper observation it is seen that there is lot of factors that affect the mathematical model of melting phenomena where as it is observed that lot of factors that effect in actual practical experiments generally are never seen in mathematical model and difference in melting rate and melting time is observed which helps to validate mathematical model of phenomena and also confirms existence of unforeseen condition that effect the practical experiments that cannot be marked actually in MATLAB code they maybe error or process that is assumed not to exist in mathematical model.

2.2 Operating Parameters and Equations

Glacier Ice temperature (°C) and Ambient temperature (°C) -As temperature of the ice is main factor that effects the melting time or melting rate of glacier ice, more is the temperature of glacier ice more prone to melting down into water in simple way more will be temperature then temperature becomes more close the melting point of ice so latent heat is only heat that is required to phase change the ice to water but if there is lower temperature then sensible heat is also required to change phase thus lesser time is taken temperature is more close to the melting point of ice. In this research paper 22 glaciers are considered which are polar, sub-polar & temperate glacier and based completely on the temperature of glacier instead of the latitude. There is T_{min} which is base temperature found at upper part of ablation area and T_a which is used to get temperature of air annually. In rigorous research work it is found that Polar glacier on average have temperature lower then -10°C , whereas in case of Sub-polar glacier temperature remains between -1°C and -10°C and In case of temperate glacier temperature is above and further T_{min} remain at T_a in first case and rest two cases T_{min} certainly remains above T_a.. In detail when observation of polar glacier was done it is found that T_{min} is found lower then -12ºC, annual precipitation is observed to be 450mm and mean air temperature is seen to be -1ºC.Chongice Ice cap is observed to be of 18.1km^2 by investigation by Sino Japanese Joint expedition on West Kunlun mountains in 1987 temperature of -13.4ºC was observed there, Model of Zhou and Han was applied to it to draw temperature profile. Dunde Glacier and Laohugue glacier were also observed for research with -4.8ºC base temperature and -12.8ºC at top, in second peak -12.8ºC at top of the peak and -10.5ºC at 16m depth from top. Sub- polar glaciers were in form of Urunqui glacier at 0ºC at upper part and -0.1ºC at depth of 30 m.

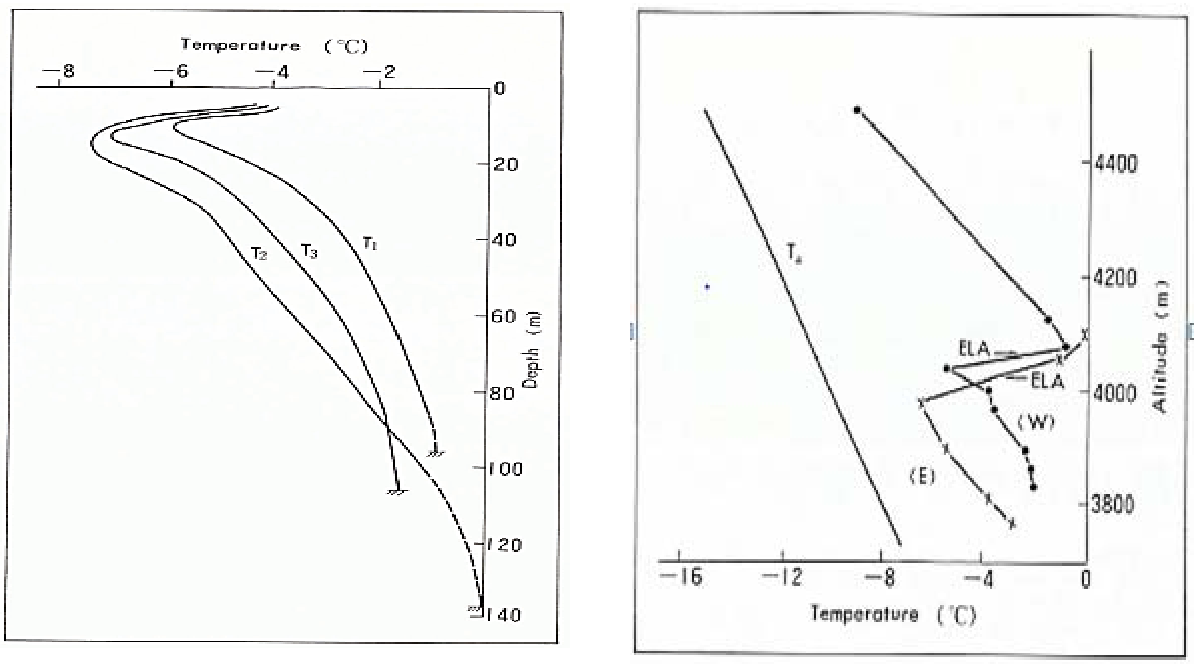


Fig 2.1 Temperature vs. Different parameters (Maohuan et al., 1990), (a) Depth (m), (b) Altitude (m).

Temperate glacier are one with maximum temperature in all section of glacier observed till now. Certainly temperature of temperate glacier is generally higher then -1ºC and they are very sensitive to even smallest change in temperature because it is at almost at melting point of ice. Glacier is so divided into zones accumulation zone and ablation zone. Accumulation zone is zone where ices gets accumulated and remain at temperature close to melting temperature. Ablation zone is the zone at which melting is done, where source of water from ice is obtained.

At ablation zone heat gets added to ice through convection and radiation medium which heats up the ice mass (Maohuan et al., 1990).

Reflectance of ice-Most of the work was done to transmittance beyond 2.5µm but less amount of research is done before 2.5 µm. Transmittance was generally measure to find the structure of ice crystals , design of crystals helps to find reflectance at different angles at which light hits the crystal surface. Spectral radiation short-ward of 2.5 µm is generally forgotten because complexity of spectral bands in this area is very large in amount. Different spectral bands formed help to get skeleton the ice crystals even at microscopic phase of the ice system, research paper also discusses the effect of the temperature and grain size on reflectance of ice. Researchers have traced path of the temperature variation on the reflectance of ice and tried to remove the effect and effect of the size of grain on reflectance of ice. Reflectance phenomena was also used to find amount of water and ice on other terrestrial planets by analyzing reflected rays coming back from the planets as response of direct rays that has been sent from source planet that is earth. In conclusion it is found that reflectance of ice and water frost depends on temperature and grain size in wavelength 0.65-2.5 µm specifically (Clark et al., 1981).

Spectral albedo of ice-Snow is highly reflective in visible rays that is most of the rays gets reflected from the snow surface and very less amount of rays are absorbed. Snow basically earlier stage of ice, snow is form of precipitation that is generally found on mountain peaks and hill station as now takes time under effect of compressive force applied by new precipitated snow puts the crystal of snow to cling to each other and make it little hard and coarse grains of snow start to change into the fine smooth crystals of the ice. Ice properties are therefore different than that of snow. Upper part of glacier has snow at upper covering whereas with depth of glacier hardness of ice also increases and properties of the system also changes. Curve of spectral albedo vs. wavelength is studied both experimentally and theoretically. In albedo calculation it is found that when curve is drawn for albedo from 0.4-0.8 µm curve first increases to albedo to about 1 and then start decreasing and 0.8 comes to lowest position for this particular section. Next section is found between 0.8 to 1.2 µm where continuous decrease in albedo is seen which becomes local lowest at 1 µm then again increases in albedo from1 to 1.1 µm then peak is obtained.

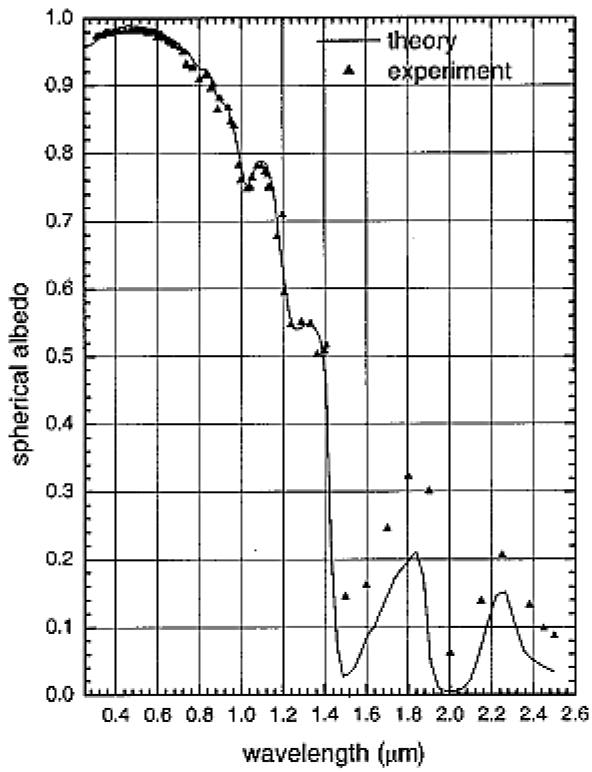


Fig 2.2 Curve between Spectral albedo and wavelength (µm) with theoretical and experimental investigation (Kokhanosky et al., 2004).

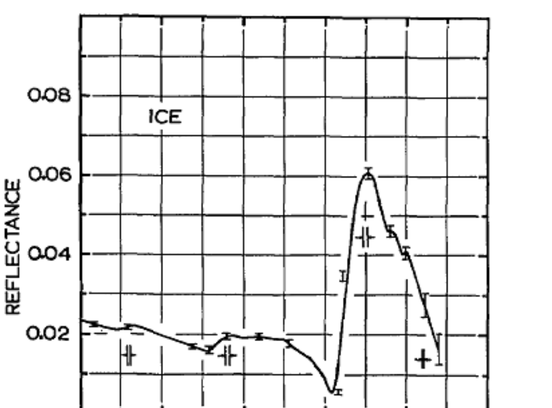
Another curve section is that 1.2 to1.4 µm where decrease in curve is seen rapidly then after stability in curve again sharp reduction in curve is seen till 1.4µm after 1.4µm to 1.8µm there is sharp rise and reduction in peak is seen at 2.0µm minima is found and again peak comes after it at 2.2µm and then again reduction in curve is seen at 2.4µm.Further whole data is validated with experimental results and it is found that curve follows mathematical model completely till 1.4µm after that little variation is seen between experimental and mathematical model results. In this research work it curve between reflection function and observation angle is also drawn , it is found that relation between reflection function and angle is very simple there are three types of observations done one is Hapke model second one is approximation model and last one is experimental readings. It observed as outcome from this paper that all three model correlate to each other till 40^{o} angle after that all three of readings separate out from each other. In general fashion it is seen that reflection decreases with increase in angle from 0 to 90 but most variable change is seen in experiment where it has least value at 80 degree (Kokhanosky et al., 2004).

Optical properties of ice (Warren et al., 1984) - research paper that discusses the important factors that are used to find the absorption coefficient of the ice, water and carbon soot particles. These factors are real part of complex index of refraction and imaginary part of complex index of refraction. The calculation formed from experimental results on ice sample and mathematical model of sample of the ice. After rigorous research on this type of the samples index of refraction of both type is obtained which is from 0.0443µm to 9.0µm which can be further into into a formula to get absorption coefficient of ice $K=4\pi\lambda/\kappa$ where λ is the wavelength , κ is the kappa which is the index of refraction. Thus the table that we obtain from Warren et al 1984 helps us to attain amount heat that will be captured inside the medium maybe ice, water or carbon soot particles, subtracting this data from overall direct rays helps to get energy generation that is attained in the system which can be inputted into the governing equations to get specific values for each node of the ice column.

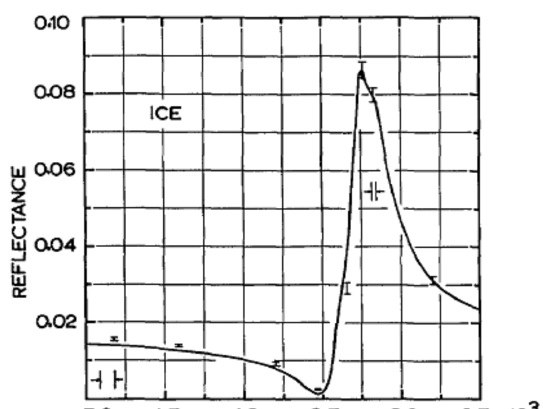
Optical properties of water- (Otanicar et al., 2008) gave important findings for optical properties of water and important property is transmittance , which means that amount of the transmitted rays upon the total direct rays that comes from the source maybe sun or source in form of optical fibre.When curve between the transmittance and wavelength for water is observed it is found that transmittance first increases sharply from 0.2 µm to 0.3 µm rising from 75% transmittance to 90% transmittance then becomes constant till 0.9 µm till sharp reduction in curve is seen which reduces to amount of 60% at 1 µm and then again the transmittance increases in amount to 82% at 1.1 µm then again from 82% transmittance the value reduces from 1.1 µm to 1.2 µm with sharp decreases in the curve and then there is increase in transmittance at 30% then at 1.3 µm there is further reduction in transmittance is seen which almost gets reduced to 0% at 1.4 to 1.5 µm so in other words we can say that at later stage of the curve transmittance becomes zero and total absorption and scattering is seen to occur in this system. Further in this research paper value curve of the ethylene glycol, propylene glycol, Therminol VP-1 is also analyzed here. In ethylene glycol it is found that in initial stage of the curve transmittance increases from 40% to 90% then remain constant value of 90%

transmittance till 0.9 µm then again after this peaks and lower curves are obtained in curve but local peaks in this curve are little higher in side then water. In case of the propylene glycol same curve as found in ethylene glycol. In case of the Therminol VP-1 curve is in initial stage of the curve reflectivity varies from lowest value of reflectivity to highest part of reflectivity to about 90 % reflectivity till 1.1 µm then instantaneous reduction in value of the transmittance at 1.15 µm then there is again increase in value of transmittance after 1.5 is again seen till 1.3 µm then the reduction in value of transmittance is seen further then again 1.4 µm there is increase in value to 80% of transmittance is seen.

Optical constant of ice infrared region -In this research work by Scaaf et al., 1973 focus is done to find out the reflectance and real imaginary index of refraction of ice to find absorption coefficient of the system. In this paper -7ºC ice is used in range of 300 to 5000cm^{-1} wavenumber. Kramer's Kronig phase shift analysis has approved the results to have real and imaginary parts of refractive index. Some of the optical constant that is arranged in such way that can be used planetary cloud analysis. In this work -7ºC ice is compared to various values of water at different temperatures. Experimental work was also done in this context such that measurement of the spectral reflectance of the ice in such a way that values of absolute reflectance of the mirror and nominal spectral reflectance is used. Formula used is $R=\mu R_n$ where R is the spectral reflectance of ice and µ is the absolute spectral reflectance of the mirror, R_n is the nominal spectral reflectance of ice.In experimental setup it is found that ice sample is put on aluminum receptacle to measure the changing phase change of the ice, to remain the ice away from the ambience effects. It is then surrounded by ice and salt mixture of prevent ambient temperature of change a lot , effect of the only neon light has to measured. Then further the system is surrounded by the polystyrene foam strength. The plane where ice is placed is remained in vertical position by screw tied on the lower part of the system. Auxiliary He-Ne laser beam is employed to measure the reflectance of the system with reflector mirror being placed on the top which measures the light intensity that comes back from the reflection from ice crystals. Temperature of ice crystals remain in-11 ± 4 Temp. Neon light after striking with ice keeps on striking back to the reflector mirror and analysis goes on. Results obtained in this system are in form of graphs. Reflectance vs. wavenumber it is found in the curve that reflectance first is at 0.022 at 2500cm^{-1} then after that value start decreasing reducing to amount of 0.015 at 1750 cm^{-1} after which slight increase in the value is seen then again value become constant to 0.02 e reflectance which start reducing in value at 1250 cm^{-1} reduce to minimum value of 0.01 reflectance then sudden rise in reflectance occurs becomes max amount of 0.06 at 750 cm^{-1} then curve again gets reduced in reflectance from 750 cm^{-1} to 500cm^{-1} data after this was not obtained .Trend of data obtained for 500 to 2500 cm^{-1} is also obtained in other graph trend, in this curve it is seen that reflectance at 0.022. Earlier gets reduced in the value smoothly to 0.05 reflectance at 3500 cm^{-1} then there is sharp increase in the value to 0.08 reflectance at 3250 cm^{-1} and then gets reduced simultaneously down at 2500 cm^{-1} wave number. Real part of refractive index is also calculated for ice which at value 1.2 at 250 cm^{-1}wavenumber from where value start increasing and becomes maximum at 750 cm^{-1} to value of 1.6 real value then gets reduced from there sharply comes to local minima at 1000cm^{-1}wavenumber again then peaks and valleys are formed again in the curve after that till 3000 cm^{-1}again value gets increased then again sharp reduction is seen at 3500 cm^{-1} and increase in value are seen which becomes constant later on. Another results were imaginary part of refractive index till also has one peak at 3250 cm^{-1} and where the imaginary part is at 0.6 value.



(a)



(b)

Fig 2.4 Variation of Reflectance with wavenumber for the ice for (a) 0 to 2.5cm^{-1} and (b) 2.5 to 5.0 cm^{-1} (Scaaf et al., 1973)

Infrared optical properties of water and ice spheres-Absorption coefficient, reflection like in previous papers have important contribution in finding the real and imaginary part of refractive index of ice and water. Value of refractive index is found for wavelength between $0.7\ \mu m<\lambda<200\ \mu m$. These values are beneficial in undergoing research in absorption coefficient of particular medium like ice or water. Mie theory is applied to observe scattering albedo, asymmetrical factor, extinction coefficient observed at different radii such as 0.3,1,3,10 microns is used. Now Irvine and Pollack(1973) made specification of the real and imaginary part of the refractions and tried to find the absorption coefficient curve according to the wavelength , Curve is divided into three section according to their importance and it is found that they are specified in such a manner that 0.2 to 1.6 µm is first section of the curve , 0 to 15 µm is second section that specifies more detail in case of the curves and last and third section is going from 10 to 200 µm which has larger variation and wider section are obtained in such case. Now when we explain each section of the absorption coefficient for each water and ice both. In beginning of the section 1 it is found that ice and water both overlapping at each other move around in same fashion at particular part means that from 0.2 to 0.8 µm there same fashion minima is found at 0.4 µm which is 0.0001 absorption means at lower wavelength minimum absorption coefficient is seen. After this at about 1.4 um constant absorption coefficients is seen which further again increases. Absorption coefficient is $k=4\pi\lambda/\kappa$ where λ is wavelength, κ is kappa imaginary part of refraction. When we come to second section it is seen that not much curve difference is seen between water and ice both overlap on each other 2 µm after which there is change trace of curve is seen. Ice prone to more absorption coefficient can be seen in the second section near 3 µm ice touches more than 1000 absorption coefficient but for water it remains lower than this after which depth is seen in the curve in which also ice is above water in absorption curve in every sense till 8 µm, after which there is change in the curve section is seen. After this water absorption coefficient keeps on increasing whereas in case of the ice curve keeps on moving downwards and end up at 1000 absorption coefficient whereas water at 5500 absorption coefficient. In third section where larger part of wavelength is considered from 10 to 200 µm. In this section simply we can see there is always higher absorption in water foe radiation then for ice, if we consider water curve it is seen that at starting of 10 to 15 µm there is increase in absorption coefficient then after 15 µm there is reduction in absorption coefficient till 50 µm, after some stability again the curve starts falling downwards. For the case of the Ice it is seen that regular peaks and valleys are observed continuously , at 50 µm wavelength absorption coefficient of the ice crosses the maximum value of water only for onetime, then at 150 µm reaches lowest position of 50absorption coefficient, whereas in case of water last value recorded in this section is 550 absorption coefficient. Real value of index of refraction versus wavelength curve is also made for both water and ice , curve can be explained in such a way that when we consider the broader section 10 to 200 µm it is seen that sharp slope rise is seen for ice in the curve then after rising a little bit it is seen that graph starts dropping downwards till 40 µm then again the curve starts to increase till it reaches 1.7 value at 150 µm , but in case of the water it is seen that there is gradual rise in the slope of the water curve which after some time at 20 µm reduces its value and later on the value is increased again but in each case there are values of water always higher than the ice. Single scattering albedo vs. wavelength for water is graph also considered from where it can be seen that smaller is particle size more spontaneously the curve falls down thus more will the size of the particle more it will be stable in case of the albedo calculation the slope of reduction is generally very stable in this case. Single scattering albedo vs. Wavelength for ice also has same fashion as seen in other sections. Symmetrical factor (CosΘ) vs. wavelength it is found that wavelength varies from 0 to 1000 µ and variation between the section can be seen as in first section factor comes to be 0.88 then local variations of peak and valley are obtained there with variation of factor from 0.9 to 0.8, after 10 µm reduction is factor is seen which falls and moves downward by sharp slope till 100 µm of wavelength and keeps on moving downward. Extinction coefficient is also important factor that can be observed from formula given by Tyagi et al 2009, this is important factor to find absorption coefficient for medium. Extinction coefficient is same as symmetrical factor varies from 2.0 to 2.4 till 10 µm till sharp reduction in the curve is seen at 10 then again increase in curve is seen till 50 µm then value of coefficient reduced from 3.6 to lower values and keep on reducing in the value to 0 at 100 µm.

Absorption Coefficient of Medium-In this research paper we get analytical solution of how to calculate absorption coefficient, scattering coefficient and extinction coefficient of particular medium maybe ice, water or impure solution. Absorption coefficient (K) can be expressed in form of relation between κ (imaginary index of refraction) and λ (wavelength).

$$K_{a\lambda} = \frac{4\pi\kappa}{\lambda} \qquad (1)$$

$$\alpha = \frac{\pi D}{\lambda} \tag{2}$$

$$m = n + i\kappa \tag{3}$$

$$m = \frac{m_{particle}}{n_{fluid}} \tag{4}$$

Equation 1 specifies the calculation of absorption coefficient of medium from imaginary index of refraction and wavelength, in equation 2 size parameter is calculated which can be calculated that is used in further analysis. Equation 3 specifies the normalized index of particle where n is real part of index of refraction and κ is the imaginary index of refraction, combined form normalized index of particle. Another way to find the normalized index of refraction of solution is normalized index of refraction of particle upon the real index of refraction of fluid. In physical terming Rayleigh scattering can be seen as the phenomena where particle size is less than incident direct radiations.

$$K_{e\lambda} = \frac{3 f_v Q_{ext}(\alpha, m)}{D} \tag{5}$$

where f_v is volume fraction, Q_{ext} is extinction efficiency and D is diameter of particle.

$$Q_{ext} = 4\alpha \operatorname{Im}\{\frac{m^2-1}{m^2+2}[1+\frac{\alpha^2}{15}(\frac{m^2-1}{m^2+2})\frac{m^4+27m^2+38}{2m^2+3}\} + \frac{8}{3}\alpha^4(\frac{m^2-4}{m^2+2}) \tag{6}$$

$$Q_{abs} = 4\alpha \operatorname{Im}\{\frac{m^2-1}{m^2+2}[1+\frac{\alpha^2}{15}(\frac{m^2-1}{m^2+2})\frac{m^4+27m^2+38}{2m^2+3}\} \tag{7}$$

Equation 6 and 7 specifies the efficiency of the extinction and absorption so that the values can be inputted into the equation 5 to get absorption coefficient for the medium that maybe ice or water.

$$K_{e\lambda} = \frac{12\pi f_v}{\lambda} \operatorname{Im}\{\frac{m^2-1}{m^2+2}[1+\frac{\pi^2 D^2}{15\lambda^2}(\frac{m^2-1}{m^2+2})\frac{m^4+27m^2+38}{2m^2+3}]\} + \frac{8\pi^4 D^3 f_v}{\lambda^4}|(\frac{m^2-1}{m^2+2})|^2 \tag{8}$$

$$K_{a\lambda} = \frac{12\pi f_v}{\lambda} \operatorname{Im}\{\frac{m^2-1}{m^2+2}[1+\frac{\pi^2 D^2}{15\lambda^2}(\frac{m^2-1}{m^2+2})\frac{m^4+27m^2+38}{2m^2+3}]\} \quad (9)$$

This is the final expression for finding the absorption coefficient of medium that maybe ice or water or impure medium and we can also find extinction coefficient by inputting values of extinction efficiency inside the extinction coefficient formula thus helping to amount of total energy that gets absorbed inside the medium, part of energy that gets extricated. To find amount of energy that gets scattered as part of the total energy that put into the system can be obtained from subtracting the absorbed energy and extricated energy from the total energy. Thus from this energy we can obtain the number of particle that are coinciding with direct light coming from any source.

Optical Properties of amorphous carbon-Imaginary and real part of index of refraction of amorphous carbon is important data to calculate the absorption coefficient of the impurities which is amorphous carbon. Tyagi et al., 2009 gave a formula to find efficiency of extinction, which was further introduced into absorption coefficient formula which tells us the absorption capacity of the nanoparticles. The normalized index of the refraction m is put in formula of extinction efficiency and value of m is combination of real and imaginary part of the index of refraction. The those real and imaginary part of index of refraction are obtained from this research paper by Maron et al., 1990.The real and imaginary part are estimated using absorption efficiencies , dispersion formula. Kramer's- Kronig relation from which we obtain that the analytical results start matching with the experimental results of the system of ice. Extinction efficiency can be found using Mie theory, but in case where the size parameter is lower than 1 we apply Rayleigh Jeans approximation (Bohlen et al., 1983).

$$Q_{abs} \cong Q_{ext} = 4xn_0 \operatorname{Im}\frac{(\varepsilon - \varepsilon_m)}{(\varepsilon + 2\varepsilon_m)} \quad (11)$$

Where ε specifies grain permittivity and ε_m specifies permittivity of surrounding medium.

$$\varepsilon_2 = \frac{3Q_{ext}}{8\pi n_0 a}\lambda$$

$$\varepsilon_1(\Omega) = 1 + (\frac{2}{\pi})p\int \frac{x\varepsilon_2(x)}{(x^2 - \Omega^2)}dx$$

From above equation s we can get values of the real and imaginary parts of the amorphous carbon so to obtain the values of n and kappa we again introduce two epsilon values which can be used to find values of real and imaginary part of index of refraction which can be specified in form of following form.

$$n = \{[(\varepsilon_2^2 + \varepsilon_2^2)^{1/2} + \varepsilon_1]/2\}^{1/2}$$

$$\kappa = \{[(\varepsilon_1^2 + \varepsilon_1^2)^{1/2} + \varepsilon_2]/2\}^{1/2}$$

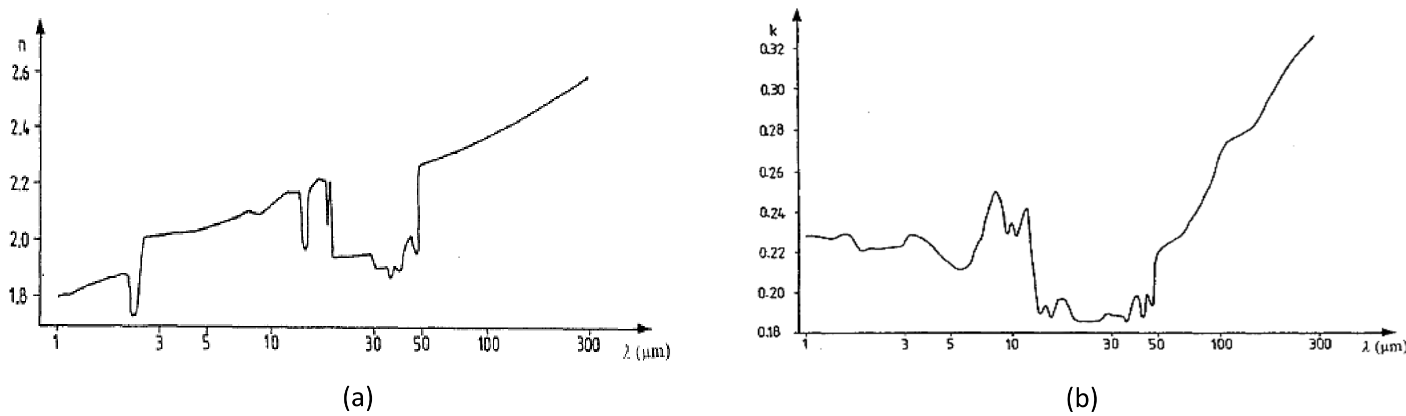


Fig 2.5 Variation of optical constants with wavelength (μm) (a) Real index of refraction vs. wavelength (μm) (b) Imaginary index of refraction vs. wavelength (μm) (Maron et al., 1990)

These formulation help to obtain both index of refraction of impurities which further is used to find absorption coefficient for amorphous carbon, which gets added to the absorption coefficient of medium which maybe ice or water, thus forms the overall absorption coefficient that is further used to find energy generation terms inside the ice or water or impure ice or impure water.

Thickness and optical constants measured using spectroscopic ellipsometry- Eypert et al., 2009 made important research on measuring the optical constants of the amorphous carbon maybe single layer or multilayer. Spectroscopic ellipsometry is optical technique to get the thickness and optical constants composed of single and multilayer. Measurement of polarized light with nondestructive no sample preparation is seen here. Oxidized layer is seen to occur at the middle of the substrate C-Si and a-C DLC film , DLC film is carbon single layer or multilayer that is observed to measure refraction index both real and imaginary part amorphous carbon. This is very accurate method compare to the other ellipsometer thus Jobin Yuon UVISEL Spectroscopic phase modulated ellipsometer is owing to phase modulation in such a manner that this type of ellipsometry is best and good performer then other ellipsometers. After this result in form of the graph that tells the result in form real and imaginary index of refraction of amorphous carbon. When we see results of imaginary index of refraction it is seen to be at 0.4 maximum at 200 nm then sharp reduction is value is seen after 250 nm slopes is negative and is very sharp such that it becomes 0 at 420 nm and remain 0 for all remaining wavelength from 400 to 2000 nm.

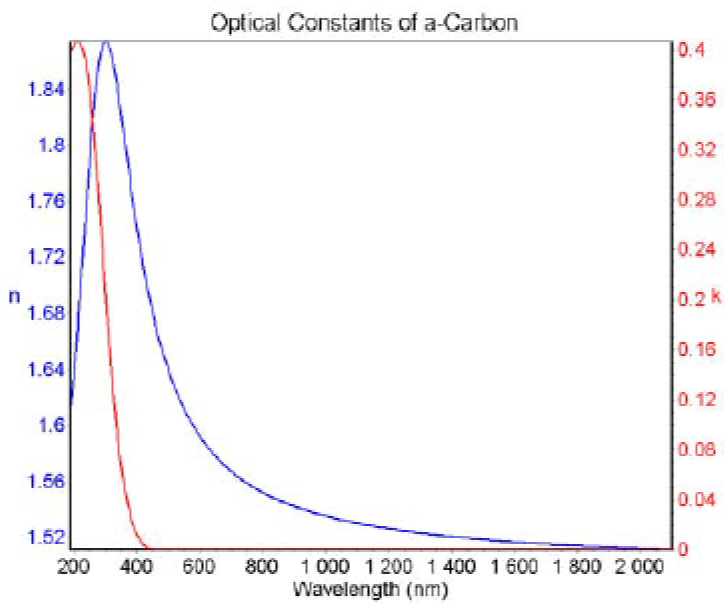


Fig 2.6 Optical constants of amorphous carbon vs. wavelength (nm) (Eypert et al., 2009)

When we see result of real part of the index of refraction it is seen that value of 1.64 is seen to occur at beginning at 200 nm then the n increases to maximum value of 1.86 at 400 nm after that there is sharp decrease in value after 400 nm till 600 nm after that also reduction in slope is seen but from 600 to 2000 nm there is continuous steady reduction in real index of refraction. There was one more technique to measure the optical constant two sample is considered one is carbon films on c- Si substrates with smooth surfaces and other sample is carbon films above c-Si substrates with rough surfaces on it. For graph of imaginary index of refraction for rough surface

0.85 is starting value then start increasing then reduces in slope with steady slope till gets reduced in amount till 0.4 in reduction amount. In graph of the smooth sample it is found that from 0.8 there is continuous reduction in slope and at 850 nm becomes zero. In case of real index of refraction it is found that when there is rough surface it is seen that value values increase from 2.1 then there is sharp increase in values from 2.1 to 2.46 till 500 nm then again the values start to become stable and slope keeps on decreasing till it ends at 2.65.For real index of refraction of the rough surface it is found that it starts from 0 at 200 nm then keeps on increasing in the value till it increases to 2.4 at 325 nm then it increases till the 2.75 at 800 nm but there is steady slope through which increase in real index of refraction occur. In sample 1 and sample 2 film thicknesses is 387 angstrom and roughness as 0, whereas in sample 2 it is found that film thickness is 379 angstrom and roughness is 44 angstrom.

Optical properties of amorphous carbon at different temperatures-Main motive of the work is to evaluate the effect of the temperature on the refractive index of soot, pyrolite graphite, amorphous carbon and flame soot at temperature range of 25 to 600ºC. Stagg et al., 1993 made important contribution in this research of optical properties of the amorphous carbon at different temperatures. Since ellipsometry is surface technique any modification of the surface such as oxidation will give great influence on the measured ellipsometric parameters and therefore there is interference in refractive index which is formed in form of very complex form. Oxidation is major problem to find refractive index that can be stopped by using inert gas in the system to stop it from getting oxidized .It has been seen that threshold temperature is 700ºC of carbonaceous samples, silicon wafer is seen to be at 800ºC, therefore maximum temperature utilized for study will be 600ºC. Table can be seen to find refractive index difference with each temperature difference.

Normal Reflectance and diffuse reflectance calculation-In this research paper we find there is needed to find the formula to fill gap in research of the melting of glacier ice. It is seen that that when direct sunlight falls on the ice layer part of the light gets reflected back , some part gets refracted which we have already discussed and remaining part gets absorbed. So to calculate the part that gets reflected we need specific formula that gets linked with wavelength to calculate the part of the energy that is getting lost from total direct sunlight. The normal reflectance can be calculated using formula

$$R_{norm} = \frac{1}{2}[(\frac{n_1 \cos\theta_2 - n_2 \cos\theta_1}{n_1 \cos\theta_2 + n_2 \cos\theta_1})^2 + (\frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2})^2] \tag{12}$$

Where n_1 and n_2 are the refractive indices of the liquid and air respectively. Taking $\theta_1 - \theta_2 \approx 0$, and let n_1 = n and let n_2=1 yields equation 12.

It is found that normal reflectance is only found when there is surface which is completely plain and reflection comes into action like it comes from mirror but in practical situation it is seen that upper part of the ice surface is generally very rough so according to the reflection principles this reflection is called diffuse reflection from the surface which forms different formula.

$$R_{diff} = 1 - \frac{1}{2}(\varepsilon_2 + \varepsilon_1) \tag{13}$$

Above is the formula that are used to find diffuse reflection of the ice surface which uses value of two epsilon to calculate the value of diffuse reflection of ice surface, epsilon depend upon the real and imaginary value of the index of refraction(Tetreault –Friend et al., 2017)

Governing equation and boundary conditions-

Problem is generally called Stefan problem or moving boundary problems. It is called Stefan problem because mainly analysis was done by Stefan in 1890 in connection to the melting of polar ice cap. The mathematical formulation of phase change problem is generally in form of the partial differential equation of parabolic type and location of the boundary keeps on increasing converting the ice into liquid continuously, phase change problem is generally is nonlinear and their analytic solution is very difficult. A very limited exact solution can be generated from this type of range of equations.

Rate of heat gained from ambience in positive x directions	=	Rate of heat that is supplies from liquid phase to the interface.	+	Rate of heat supplied from interface to solid

$$\frac{\partial^2 T}{\partial x^2} + \frac{e_g}{k_s} = \frac{1}{\alpha_S} \frac{\delta T}{\delta t} \tag{14}$$

$$\frac{\partial^2 \theta}{\partial x^2} + \frac{e_g}{kl} = \frac{1}{\alpha l} \frac{\delta \theta}{\delta t} \tag{15}$$

Boundary Conditions

$$-k_l \frac{\delta T}{\delta x} + hT = hT_\infty + e_g \Delta x^2 \tag{16}$$

$$[-r_{n,s} T_{i-1}^{n+1} + (1 + 2r_{n,s}) T_i^{n+1} - r_{n,s} T_{i+1}^{n+1} - \frac{r_{n,s} (\Delta x)^2 e_g}{k_s}] = T_i^n \tag{17}$$

Research Gaps

The aforesaid findings are very encouraging and point towards predicting the melting of glaciers. The proposed project is expected to decipher many interesting and tangible characteristics of glacier ice .In these works gaps are found as they don't tell about melting time of glacier and melting rate of glacier. Effect of concentration of impurities such as amorphous carbon on melting time is also missing. In the following work I will try to fill this gap and calculate time taken to melt particular volume of glacier, to fill the research gap between development of theoretical model for glacier ice we research on melting of glacier considering the problem as Stefan's problem, further effect of different concentration of amorphous carbon in pure ice on the melting rate and melting time of the glacier ice is also considered in theoretical model of melting of glacier ice. Further experimental work on melting of glacier ice with different concentration of amorphous carbon is also missing in research paper. Theoretical model of melting of glaciers is made in Chapter 3 and experimental investigation is done in Chapter 4.

CHAPTER 3

MATHEMATICAL MODELING OF MELTING OF GLACIAL ICE (PHASE CHANGE PHENOMENON)

3.1 Introduction

Natural melting of glaciers is beneficial, as it provides fresh water for animals and plants and is essential part of nature.

But when glacier is added with artificial elements due to natural or anthropogenic reasons; natural melting is disturbed and results in imbalance in nature. Natural melting of glaciers can be characterized into two groups: glacial ice temperatures at melting point and glacial ice temperature lower than melting point.

In the present work, comprehensive mathematical models have been developed for the two aforementioned glacial ice groups. Furthermore, for each of these, the effect of soot particles on the melting rate has been quantified.

The former i.e., the case in which glacial ice is considered to be at the melting temperature requires only latent heat to melt wheras in the latter case both latent heat and sensible heat gains are involved during the melting process.

Traditionally, the phase change phenomenon has been referred to as Stefan problem with moving boundary. Governing equations are developed for solid and liquid phases and for the interface. As a first step in the numerical modelling, the physical domain is discretized into finite number of nodes. The relevant governing equations and boundary equations are solved for each node which increase with each node, at one node different time interval data is obtained to get total time taken to melt particular node, which changes with each node. Spectral distribution helps us obtain energy generation term that gets added at each node as sunlight attenuates going further in deeper inside the ice block. This is physical explanation of pure ice melting.

Un-burnt carbon particles that make huge part in pollution assumed to interact with glaciers in homogenous way. Contribution of these particles can be seen as increase in overall conductivity of each node and effecting the albedo of the ice surface result in disturbance of natural melting. The effect on albedo is more important than insulation by the debris.

3.2 Theoretical Model

As we know Sun is prime source of energy on earth and melting and freezing of glacier completely depends upon incident energy that comes from sun. Incident light has direct relation with the melting of glaciers. As reflectivity of fresh snow ranges from 0.80-0.85 as it makes the top layer of glacier, most part of the light gets reflected from glacier and only 15-20% part goes to transmitted rays which enable regular cycle of melting of glaciers. But in this study it is assumed that whole energy is getting penetrated into the ice block. Due increased amount of impurities inside ice block absorptivity of ice goes on increasing and result in high melting rate. Main parts in which glacier are classified is:

a) A- Melted water layer1
b) B- Ice layer 2 (orange color shows rising temperature)
c) C- Ice layer 3 (lesser temp then layer 2)
d) D- Ice with layers that not effected by radiation till now

Part A keeps on increasing as boundary of ice and water moves downward following Stefan Problem and part B shows node besides to the melted water getting heated and temperature going high, part C is away from boundary has lower temperature then top layers.

D is specifically one of the areas where main chunk of ice is found and it represents remaining 6 nodes. D size found to be very in case of pure ice and size gets reduced as impurities are increased and more impurities are added to the system it is found that absorption coefficient in ice is seen to increase largely. Incident rays keeps on attenuate as they move further inside the ice block and last node obtain the minimum amount of radiation and maximum amount of radiation is found in top layer of the ice. Beer lambert's law is fundamental law that specifies magnitude of reduction of intensity.

It can be seen that melted water in ice is increased in large amount and incident rays are penetrating is larger amount then pure ice's absorption of radiation increased tremendously.

Heat obtained contributes to increased kinetic energy in molecules of ice, solid ice since had compact size and molecules together with each after obtain the kinetic energy increase the distance between each other and lead to formation of water from ice as seen in part A.

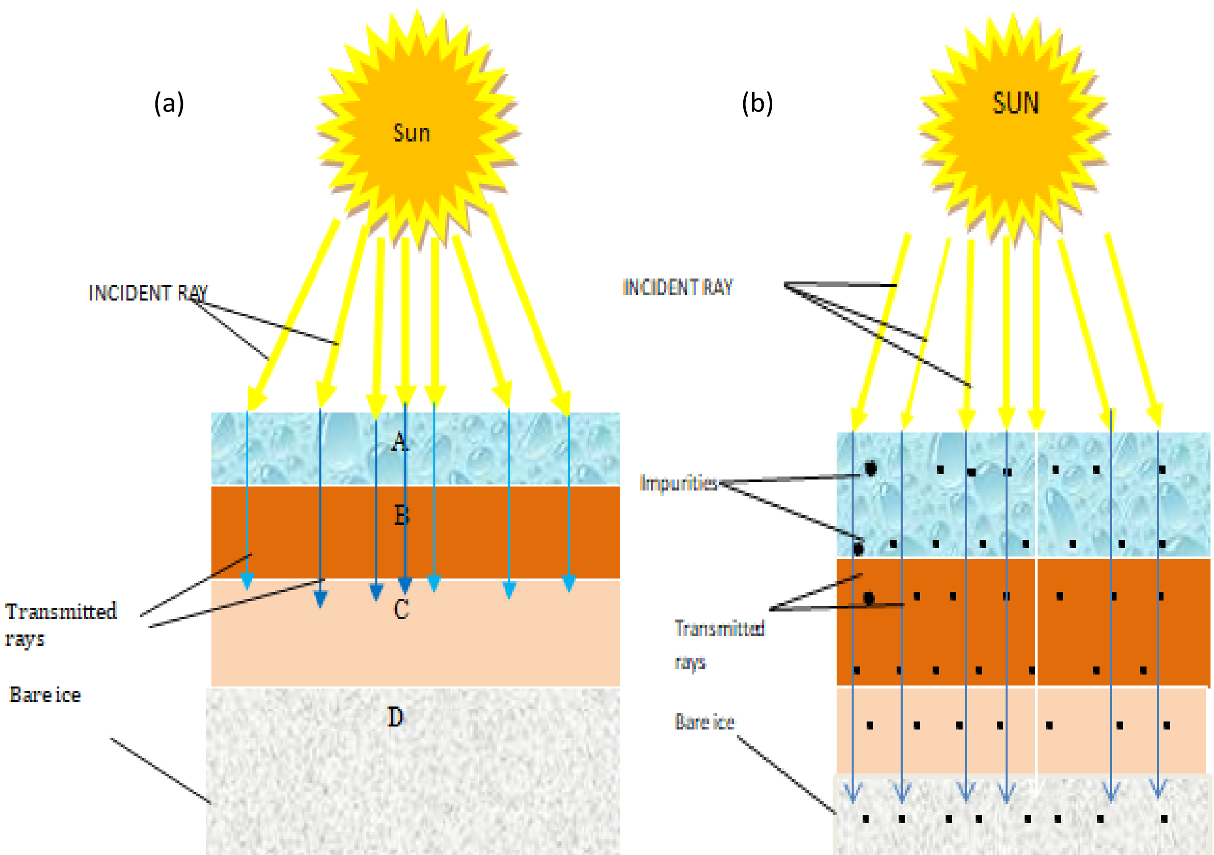


Fig 3.1 (a)Mathematical model of pure ice melting, (b) Mathematical model of impure ice melting.

3.3 Analysis

Melting process considering it as a Stefan's problem, governing equation and boundary condition are applied. As melting process goes on from left part to right part number of equations keeps on increasing thus matrix formed in MATLAB coding keeps on increasing continuously. At the boundary of the ice and water temperature is considered to be constant which equal to 1(considered as melting point in this case). Since we are considering two phase melting so temperature effect is seen both in ice and water. When considering single phase melting water part is considered to change but ice part and boundary part is considered to be at melting point. Further Eq 18 shows interface equation of the melting phenomena of ice into water, Eq 19 is a governing equation for solid and liquid which can be further discretized into Eq 21 and Eq 22.

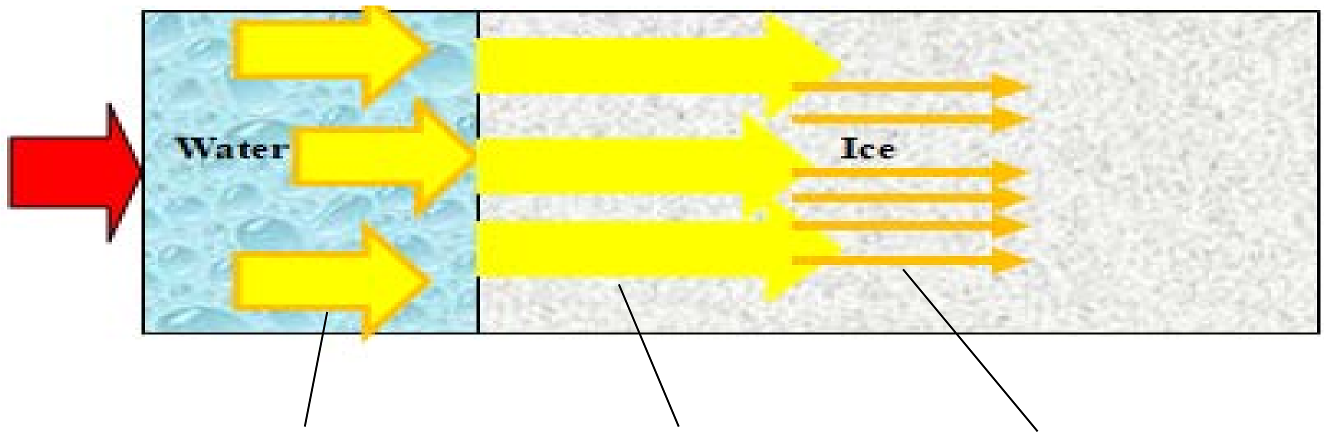


Fig 3.3 Theoretical model of melting of the ice under influence of sunlight.

$$k_s \frac{\delta T}{\delta x} - k_l \frac{\delta \theta}{\delta t} = \rho_s L \frac{dS(t)}{dt} \tag{18}$$

$$\frac{T_{i-1}^{n+1} - 2T_i^{n+1} + T_{i+1}^{n+1}}{(\triangle x)^2} + \frac{eg}{k_{(s/l)}} = \frac{1}{\alpha_s} \frac{T_i^{n+1} - T_i^n}{\Delta t_n} \tag{19}$$

$$T(x, t_n) = T(i\Delta x, t_n) \equiv T_i^n \tag{20}$$

Equation 20 can be further derived to get simplified

$$[-r_{n,s} T_{i-1}^{n+1} + (1 + 2r_{n,s}) T_i^{n+1} - r_{n,s} T_{i+1}^{n+1} - \frac{r_{n,s} (\Delta x)^2 e_g}{k_s}] = T_i^n \tag{21}$$

$$r_{n,s} = \frac{\alpha_s \Delta t_n}{(\Delta x)^2}$$

$$[-r_{n,l}\theta_{i-1}^{n+1} + (1+2r_{n,l})\theta_i^{n+1} - r_{n,l}\theta_{i+1}^{n+1} - \frac{r_{n,s}(\Delta x)^2 e_g}{k_l}] = \theta_i^n \tag{22}$$

$$r_{n,l} = \frac{\alpha_l \Delta t_n}{(\Delta x)^2}$$

$$[T_1^{n+1} - (1 + H \vartriangle x)T_0^{n+1}] = -H \vartriangle x T_\infty \tag{23}$$

Eq 22 represents governing equation for water, Eq 21 represents governing equation for ice to find temperatures for respective phase and Eq 23 represents boundary condition of the melting of ice phenomena.

3.4 Spectral Distribution of Energy for pure ice

a) For ice each wavelength we obtain spectral energy as energy for every wavelength is not same using Plank's law.

$$E_{b\lambda}(\lambda, T) = \frac{C1}{\lambda^5[\exp\frac{C2}{\lambda T} - 1]} \tag{24}$$

$$C1 = 2\pi h c_0^2 = 3.74177 \times 10^8$$

$$C2 = \frac{hc_0}{k} = 1.43878 \times 10^4$$

b) Total of each wavelength energy is found out which multiplied with multiplying factor in such a way that it is equal to 1000 watt energy to get the equilibrium in energy.

c) Multification factor obtained in the sum is then multiplied with each term to get the data out of 1000.

d) Energy is then inputted into Beer lambert's law get energy for each node.

$$E = E_b \exp(-K_{ai} s) \quad (25)$$

$Eg = E1 - E2$

Where E is energy at each node, E_b is spectral energy for each wavelength, K_{ac} is absorption coefficient of impurity, S is distance from top of surface, K_{ai} is impurities (carbon) .

For $K_{a\ value}$ of ice and water

$$K_{ai} = \frac{4\pi\lambda}{k} \quad (26)$$

Where λ is wavelength and k is imaginary part of refractive index.

e) After this total sum for all wavelengths for every node found for water and ice which is further put into matlab code.

3.5 Spectral Distribution of Energy for impure ice

f) For impurity each wavelength we obtain spectral energy as energy for every wavelength is not same using Plank's law.

$$E_{b\lambda}(\lambda, T) = \frac{C1}{\lambda^5[\exp\frac{C2}{\lambda T} - 1]} \quad (27)$$

g) Total of each wavelength energy is found out which multiplied with multification factor in such a way that it is equal to 1000 watt energy to get the equilibrium in energy.

h) Multification factor obtained in the sum is then multiplied with each term to get the data out of 1000.

Energy is then inputted into Beer lambert's law get energy for each node.

$$E = E_b \exp(-K_{ac} s) \quad (28)$$

3.6 Rayleigh Scattering

Rayleigh scattering can be understood as the regime in which the particle size is much smaller than the wavelength of the incident radiation. In general, the extinction coefficient can be given as:

$$K_{ab\lambda} = \frac{1.5 f Q_{e\lambda}(\alpha, m)}{D} \tag{29}$$

$$Q_{a\lambda} = 4\alpha im\{\frac{m^2-1}{m^2+2}[1+\frac{\alpha^2}{15}(\frac{m^2-1}{m^2+2})\frac{m^4+27m^2+38}{2m^2+3}]\} \tag{30}$$

$$Q_{s\lambda} = \frac{8}{3}\alpha^4[(\frac{m^2-1}{m^2+2})]^2 \tag{31}$$

$$\alpha = \frac{\pi D}{\lambda}$$

$$m = \frac{m_{particles}}{n_{fluid}}$$

$$Q_{e\lambda} = Q_{a\lambda} + Q_{s\lambda}$$

K_{ac} and K_{ai} is added are put into Beer Lambert's law to get the value

$$E = E_b \exp(-(K_{ac} + K_{ai})s) \tag{32}$$

When compare the data of pure ice and impure ice it is found that impure ice takes more time to melt then pure ice.

Table 3.1 Real and imaginary index of refraction for ice, water and amorphous carbon.

Wavelength(μm)	κ_{ice}	κ_{water}	κ_{cabon}	n_{ice}	n_{water}	n_{carbon}
0.1	0.999156	8.1692	1.636	1.424	1.4007	1.883
0.2	9.04896	1.50816	1.421	1.359	1.3339	2.029
0.3	0.085148	0.09426	1.206	1.343	1.3194	2.175

0.4	0.04801	0.020109	0.991	1.336	1.313	2.321
0.5	0.120024	0.146627	0.982	1.332	1.3094	2.343
0.6	0.520674	0.592491	1.005	1.33	1.3069	2.434
0.7	2.10514	2.10514	1.22	1.328	1.3049	2.58
0.8	5.865067	6.702933	1.435	1.328	1.3032	2.726
0.9	20.36016	35.44176	0.228	1.326	1.3015	1.799
1.0	19.42327	18.96625	0.225	1.324	1.2998	1.808
1.1	70.42327	102.0103	0.227	1.323	1.298	1.852
1.2	127.6135	1314.806	0.229	1.321	1.2961	2.075
1.3	177.7474	1299.89	0.227	1.32	1.2938	2.038
1.4	4942.575	1730.195	0.229	1.318	1.2915	1.856
1.5	2648.706	619.7595	0.226	1.316	1.2889	1.854
1.6	1227.228	515.288	0.228	1.315	1.2862	1.883
1.7	719.1689	800.1627	0.222	1.312	1.2826	1.857
1.8	3100.327	8050.135	0.221	1.309	1.2777	1.871
1.9	9978.992	6799.288	0.222	1.304	1.274	1.883
2.0	5035.579	2597.387	0.218	1.300	1.269	1.879
2.1	1639.553	1599.564	0.211	1.293	1.2628	1.743
2.2	2081.917	2300.49	0.21	1.286	1.2518	1.754
2.3	3822.767	4199.807	0.22	1.276	1.24	1.901
2.4	4650.16	8299.907	0.228	1.246	1.2258	2.004

Where κ is imaginary index of refraction, n is real index of refraction.

CHAPTER 4

EXPERIMENTAL INVESTIGATION

4.1 Introduction

Melting of the ice is natural phenomena in which continuous phase change occurs after absorbing latent heat of fusion by ice from ambience. There are two procedures seen in melting of ice, one is condition in which ice is at melting point of ice means at 0ºC in which only latent heat of fusion is required to change phase of ice from solid to liquid and second type of the ice is condition in which temperature is much below then the melting point of ice so there is requirement of both sensible heat and latent heat of fusion. So logically if we observe it is seen that melting time for second case is larger than the first case. Starting time taken by second case ice just to raise temperature is seen to result in phase change inside the first case ice, thus obviously at same ambient condition it is observed that polar glacier will take more time to melt then the temperate or sub polar glaciers because of added sensible heat factor that is required to melt the glacier ice. Further intensity of the direct rays effect the melting of glacier ice, when the weather is clear the melting rate gets enhanced, more heat is absorbed by the ice system, when there is cloudy weather it is seen that intensity of sunlight is reduced results in decreased melting rate and increased melting time for glacier ice. Further it is also observed that clear sky direct intensity also depends upon the season of the year, during summer season it is seen that sun is almost at top of the ice surface so the heat is more captured during this period, but instead during winter season sun farther more earth surface generally requires more time to strike the earth surface so number of photons striking earth surface are reduced so heating effect is very less in this case. Further coefficient of convection is also different for different wind flow conditions, during condition when there is static wind is seen then the h value lies between 30-50W/m^2 K, when speed of wind lies between 50 to 70km/hr then h values become 100 to 400W/m^2 K and whereas when speed of wind is more than 100km/hr which is mainly found in Mt.Everest is seen to increase the convection coefficient to more than 500W/m^2 K, which means that when speed of wind is high than heat removal rate also increases in large pace and whereas when there is no wind movement the pace of melting of ice is very slow. Humidity also plays important role in the melting of glaciers. More will be humidity in atmosphere more will the melting of glacier ice because the water particles in air keep on colliding with the ice surface releasing heat each time water particle hits the ice surface thus results in increased melting during high humid conditions. These all factors effect the melting of ice in experimental setup so experimental process in very sensitive and all the factors should be explored simultaneously so that effect of these factor should be ignored in each repetition of the experiments done till now.

4.2 Physical Phenomena

When ice setup is put under the source securely preventing the position change of the setup from earlier experiments. Intensity of the optical fiber is put on the maximum level. Ice from top position start to get effected by the heat from the source, some part from the upper part of ice is already melted due ambient condition before putting it under the source. When there was hotter environment it is seen that even lower thermocouple shows temperature above 0ºC ,because heat removed from ice setup is in such manner that upper part solidifies first then middle part and at last bottom part of the ice. So in hotter environment, it is seen that freezing time required in larger amount then with regular conditions. For 25% of starting time it is seen that only first node is getting melted lower nodes are not even getting affected by the source heat. It is seen that thinning of the ice is seen both in diameter and along the length of the ice. Though we ignore the ambient condition effect but setup is getting heated from sides as well as from bottom, from upper part it is getting heated by source in form of the optical fibre.So water that gets melted from top bottom and side is getting percolated from the sides of the ice column in such manner that cylinder of ice is keep on getting reduced in diameter and length, being cylinder bigger in diameter is getting reduced into shorter diameter with reduced length. If we talk about the temperature profile of the thermocouples , it is seen that temperature of first node keeps on increasing from steady position to increased temperature, whereas lower two thermocouple not being effected by the heat from the source. Changes in the thermocouple at lower position get effected after 40% of melting time, whereas 2 and 3 thermocouple keeps on increasing in the temperature but different characteristics are seen to occur for thermocouple1. Because ice is getting melted it starts floating on the top of the melted water, which results in reduced amount of temperature in case of the thermocouple 1.But temperature of other two thermocouple keeps on increasing as they are completely in water. Convection currents play important role in the melting of the ice.

Instruments Used

a. Digital Weighing Machine
b. Optical Fiber
c. Light Source
d. Thermal Imaging Camera
e. Wet and Dry Bulb Thermometer
f. Ultra Sonicator
g. Data Acquisition System

(a) Digital Weighing Machine – Weighing machine are instruments that help us to calculate the weight of the samples available during experimental process to form required sample concentration and weight. It is found that digital mechanisms are more reliable for correct information rather than the analog mechanisms, further then analog mechanisms have limited range and accuracy reduced decimal places up to which the data can be calculated. Digital weighing machine further has additional benefits such as body mass index, memory feature and auto shut on/off index.

Digital weighing machine used in our lab was METTLER TOLEDO ME104, which have specification of maximum capacity of weigh measurement is 120 gm, readability is 0.1 mg, repeatability (at normal load) is 0.1 mg, linearity deviation is 0.2 mg and sensitivity temp drift 2ppm/ºC. Linearity Deviation at typical values is 0.06mg, maximum sample weight is 0.24 gm, minimum sample weight as 0.016 gm .Setting time for machine is 2seconds with internal calculation as adjustment, interfaces as 1RS232. Balance dimension is 210*344*344 mm and weight of machine is 4.7 kg. Weighing panel of 90 mm is used on which the sample is placed to calculate any weight for experiments. Height up to which the samples can be measured is 235 mm from the panel from which the sample is placed.

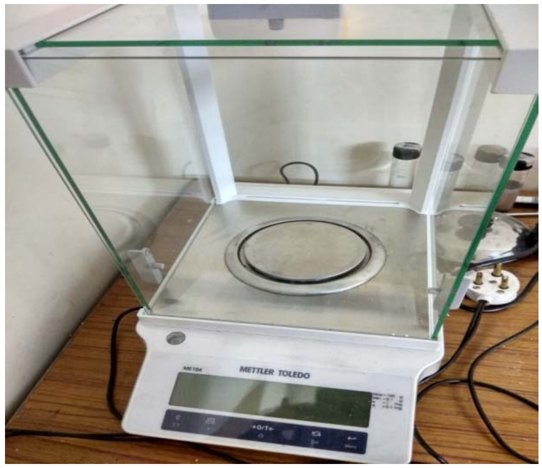


Fig 4.1 Image of Digital Weighing machine

(b) Optical Fiber- The communication system through which voice, data and images are communication from one place to another place through thin transparent fibers known as optical fibers, this technology is more promising than copper wire in long distance lines. Fiber optics is technology to examine internal parts of the body and structural products. Basic medium fiber optics hair thin fiber made up of plastic but often is called as glass, diameter is 125μm. This is actually diameter of the cladding or reflecting layer. Inner cylinder generally of 10μm.

Process followed is total internal reflection, light after total internal reflection does not gets attenuated from total amount and keeps on moving with same intensity, attenuation depends upon wavelength and depend upon the material of fiber. Optical fiber has three layers, plastic coating, cladding (which has plastic or glass covering) to enable total internal reflection in the system. Optical communication is generally in form of infrared light of wavelength 0.8-0.9 μm or 1.3-1.6 μm efficiently generated by LED or semiconductor lasers suffer least attenuation.

Fig 4.2 Image of optical fiber which is used as source

(c) Thermal Imaging Camera-Thermal Imaging is technique through which there is increased visibility of the objects even in dark environment the objects can be viewed and can be detected where they are present and find the temperature of the objects. IR camera present or infrared camera used by us in laboratory was used for the experimental validation. Thermal camera can capture details even after there is no ambient light present in the system. Function and working of camera is based upon the fact that the infrared rays are function of temperature, more will be the temperature, more will be the infrared rays that will hit the sensor of heat and thus this increased hitting of rays on the sensor will show that the temperature is high, when infrared rays are less than the temperature is low, generally white indicates higher temperature and black indicate low temperature, but gray shows the variation of radiation from high temperature to low temperature. In modern thermal imaging cameras it is found that many colors are found from blue, yellow, green, red and white, which is that ascending order of the increased temperature of the system from lower temperature to higher temperature which comes with increased radiation from low to high level of intensity. Model that we used was TrueIR U5850 Thermal imager. It has specification of detector pixel resolution 160 ×120 pixels, fine resolution of 320 ×240 pixels , thermal sensitivity of 0.07ºC at 30ºC and accuracy of 2ºC or 2%.Focus is mainly done at 10 cm away from the object. Monitor temperature changes through image logging and temperature trending capabilities.

Fig 4.3 Image of therml imaging camera

(d) Ultra-sonification-Sonication is technique in which sound energy is used to separate out the particles that accumulated together, helps to exact agitated particles from the whole group of masses of particles, ultra-sonification frequency is >20KHz. Electrical signal are converted into physical vibration to break substance apart. Sonication technique gives wave of high pressure and low pressure which breaks the particles into the smaller sub particles. Sonication is lab equipment which generator creates signal to power transducer, transducer convert by piezometer crystals into mechanical vibration which is response to the actual system. Sonicator passes has signal to pass from the generator to transducer then to amplifier, amplifier in this setup amplifies the signal that are seen to obtained from the transducer, which generally is only one probe that can bring the vibration in the system. Smaller the probe more will be the intensity of the vibrations obtained in the system. Solution is seen to vibrate more when probe is smaller in the size. Sonication is such technique that wave of high and low pressure is generated such that there is vacuum condition whenever it moves on. When the pressure wave goes through then the bubbles are formed that push the molecules of water in such force that all other layers of the water. So particles which were together earlier with this vacuum pressure wave separate out from each other sometimes positive and negative charge also comes into the particles. Power minimum required is 100 W (or higher) with frequency minimum of 30 kHz, there is temperature controller that is used to prevent overheating of specimen, probes used in this system are of different sizes according to sonication amount required, minimum volume is 50μm and maximum up to 250-500ml, cell is completely made of the stainless steel panels, power required is 220-240V AC, 50-60Hz.

Fig 4.4 Image of Ultra-sonicator which is used for sonication of different samples.

(e) Dry bulb and Wet bulb Thermometer- Dry bulb, Wet bulb and Dew point temperature which tell the state of humid air, the knowledge of this temperature help to determine the state of humid air, sensible heat and latent heat in the air. Dry bulb temperature is ambient temperature of the air; dry bulb temperature does not depend upon the moisture it is completely due to the ambient temperature without the radiation or moisture in the air. Setup in dry bulb temperature is seen to the bulb that is completely exposed into the ambient air; with mercury movement tells the temperature of the temperature of the ambient air .Wet bulb temperature is adiabatic saturation temperature. This is temperature measured by thermometer with bulb wrapped in wet muslin. Due to evaporation water vapor gets removed absorbing the heat from the system, which leads to decreased temperature due to which evaporative cooling is seen in the system.

Fig 4.5 Image of Dry bulb and wet bulb thermometer

(f) Data Acquisition System- This is the instrument that converts the information obtained from the thermocouple into electrical signals which further connected to the computer which tells the variation of the temperature on the desktop. In the laboratory we used National instrument DAC system which 17 thermocouple inputs, there is panel where positive and negative terminal is attached, with red wire in thermocouple being positive and colorless is negative. Further National instruments Lab view is software that is used to get the result from the thermocouple which is used to see temperature variation in the setup.

Fig 4.6 Image of DAC system

4.3 Making of the setup

Setup made for experiment was such that water can freeze easily inside the setup with opening of such form that the source can go inside the setup to melt the ice present inside the setup.

Material used- Three Injection of 10 ml, nine thermocouples, three glasses slits, Thermo Cole, Bond Tite solution. Procedure to make setup-In beginning of the setup formation suction rod and syringe are removed from the injection .Then injection is filled with bond tite solution in the lower position to prevent any leakage from the injection cylinder. Then three holes pierced to provide space to introduce knob of the thermocouple in to the setup. Thermocouple is already tested completely for the temperature measurement, which are introduced inside the injection cylinder to measure the temperature variation in whole experimental process. Thermocouple after introducing inside the setup is made leak proof by bond tite then cylinder is attached to the glass slit so that the setup can be positioned at flat surfaces.

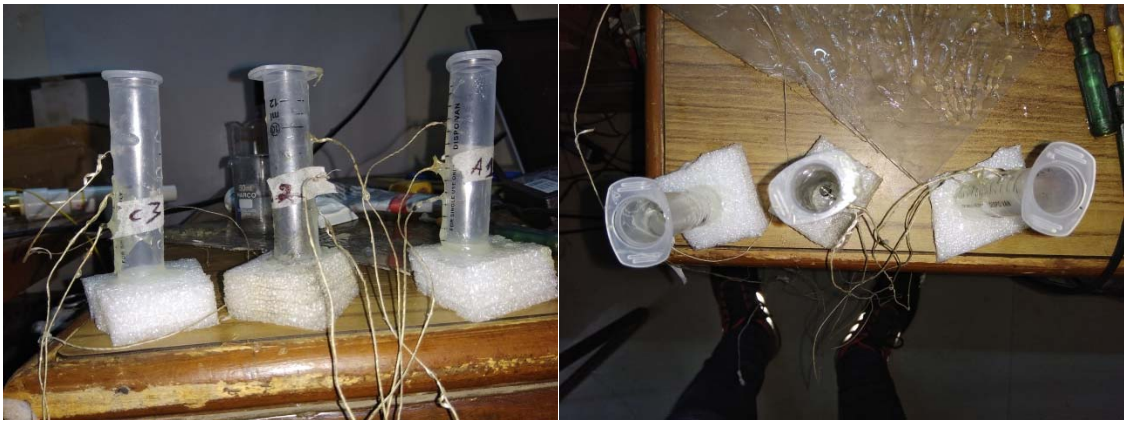


Fig 4.7 Ice melting setup for experimental investigation

In such way three setup are made to be used for the freezing of the solution and then melting it to get the melting time for the system.

4.4 Procedure of form solutions

1. Solution of different concentration are made using Sonicator in this case pure ice, 25 ppm, 50 ppm and 100 ppm are made by putting amorphous carbon of respective quantity.
2. By analyzing the formulation to make 100 ppm concentration carbon solution it is found that amount of 0.01 gms is put into 100 ml solution of the water, which quantity can be changed according to the concentration of the solution required.
3. Same way to make 50 ppm concentration solution we put 0.005 gms of the amorphous carbon into 100 ml of the water and to make 25 ppm concentration we put amorphous carbon quantity of 0.0025 gms of the amorphous carbon.
4. In continuation of step 2 beaker of 100 ml with 0.01 gms carbon is put on sonication for 30 mins till the carbon particles are found to be separated from each other or we put two drops of surfactant to reduce adhesion between the carbon particles.
5. Solution is then stored in beaker marking the concentration of the solution, 25 ppm and 50 ppm can also be made from this solution.
6. To make 25 ppm solution, solution of 100 ppm is put into separate beaker of 25 ml amount then 75 ml of the rest of the quantity is filled with the distilled water and then solution is sonicated for 30 mins so that homogenous solution is formed.

7. To make 50 ppm solution, solution of 100 ppm is put into separate beaker of 50 ml amount than 50 ml of the rest of the quantity is filled with the distilled water and then solution is sonicated for 30 mins so that homogenous solution is formed.

4.5 Experimental Procedures

1. Solution is put into the setup made earlier and put freezing it in deep freezer, sonication of the solution is must before freezing the solution.
2. Freezing of the mixture of three setups is done for 18hrs, I used to put mixture for freezing at 3 pm in afternoon and experiment was done at 9 am in morning next day.
3. Mixture is brought to laboratory from deep freezer in thermo Cole box to prevent the interaction of the ambient with the frozen mixture.
4. Lab view software is already setup for the experiments selecting 3 thermocouples in drive icon and storing the whole data with file location in file storage icon where storage is done in form of excel sheet.
5. Optical fiber being at fixed position to melt the ice in the setup and position of the setup is also made fixed position marked with marker at the particular position.
6. Setup is placed in particular marked position and thermocouple positive and negative terminals are attached to DAC system panel to observe the temperature profile in the lab view software.
7. Setup is removed from the thermo cole box and then put under the light source and tapping on the start option in software to calculate the temperature profile of the melting process.
8. Now while the temperature profile is being calculated in lab view software, we calculate surface temperature changes using thermal image camera.
9. Blue color shown in setup is seen to show cooler areas where ice crystals are found and as red and white colors are shown in the image it is seen that increase in the temperature is seen to occur that shows melting of the ice into liquid form which is water.
10. Experiment is terminated at position when visible flakes of ice are not seen in the setup.
11. Experiment is done with repetition of three for each type of the concentration of solution on which the experiment has to be done.

Fig 4.8 Image during experimental investigation

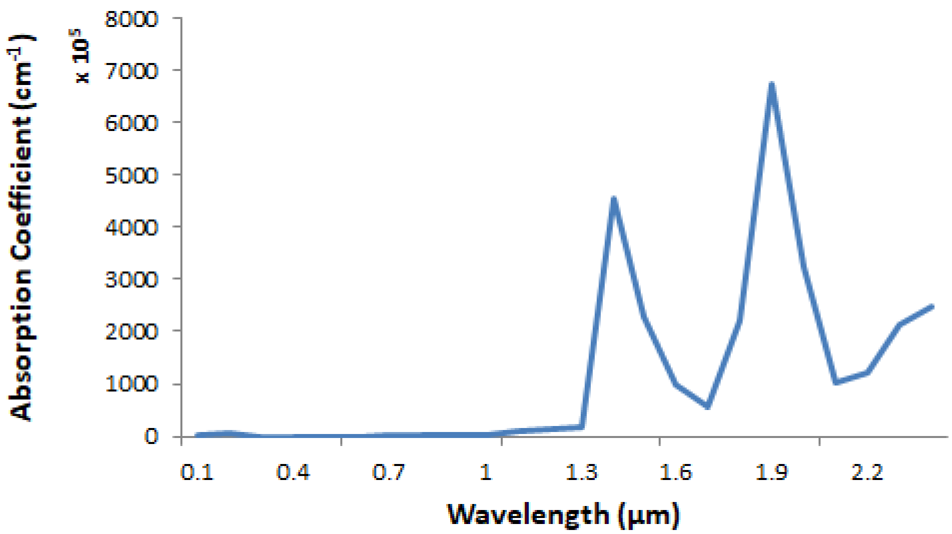
CHAPTER 5
RESULTS AND DISCUSSION

5.1 Introduction

In previous chapters we have studied about the mathematical model of melting of ice and experimental observations to validate whole the mathematical modeling results that came out from MATLAB (R 2017a) with computer configuration of 8GB RAM , Intel i7 processor and Radeon graphics card 4GB to implement the formulation. Solution in form of melting time required for melting of ice is seen to occur with different factors affecting the solution such as concentration of the solution, diameter of the nanoparticles, length of column etc. Different factors affect the melting time of the ice and changing the melting time of ice. In experimental results also it is found that ambient condition effect the melting time results such as humidity, temperature of atmosphere, amount of the freezing of the solution, time of total freezing. These all results tell us effect of each factor on the melting of the glacier ice. Further correction in the instruments used for measurement is also required. It is found that in hotter and humid conditions melting time required is very less whereas in cold and less humid conditions amount of time required is more.

5.2 Absorption Coefficient of Nanoparticles and Microparicles

Absorption as we already know is important factor to know amount of energy being captured by the medium either it may be pure medium like ice or water, or it may be impure due to addition of some of the impurities like amorphous carbon, it such case the absorption capacity of the medium increases because absorption coefficient of the carbon also gets added to the system so results in change in absorption coefficient of the overall system. Absorption coefficient vs. wavelength variation of pure ice and water is seen in fig 5.1. Pure ice is always impured by addition of some foreign impurities which change the overall characteristics of ice and water. Absorption vs. wavelength variation with different size parameters such as nanoparticles and micro particles is seen in fig 5.2.Major contribution to change is absorption coefficient of ice and water, there is addition to absorption of energy to ice and water. But variation of absorption of energy is obtained from size of nanoparticles and micro-particles and thus result is change is characteristics of ice and water. As in physical phenomena it is seen that different size of particles are obtained in nature with this absorption coefficient of particle also changes. In nanoparticles it is seen that as size of nanoparticles increases absorption coefficient increases, absorption coefficient change as size increases is seen to be a little but as more change in size is seen large change is absorption coefficient is seen which becomes steady after that .In micro-particles phenomena seen to be reverse then the nanoparticle case as size of micro-particles are increased absorption coefficient gets reduced.



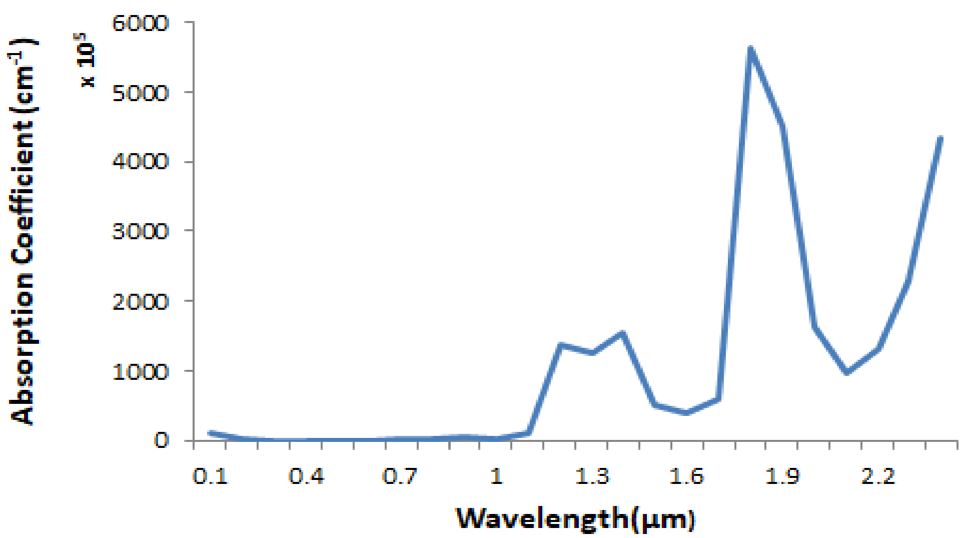
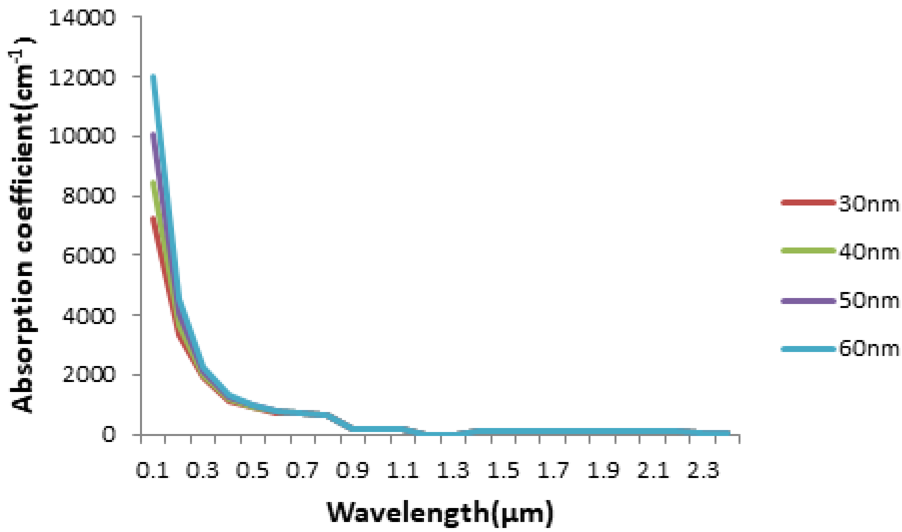


Fig 5.1 Absorption coefficient vs. Wavelength (μm), (a) Ice, (b) Water



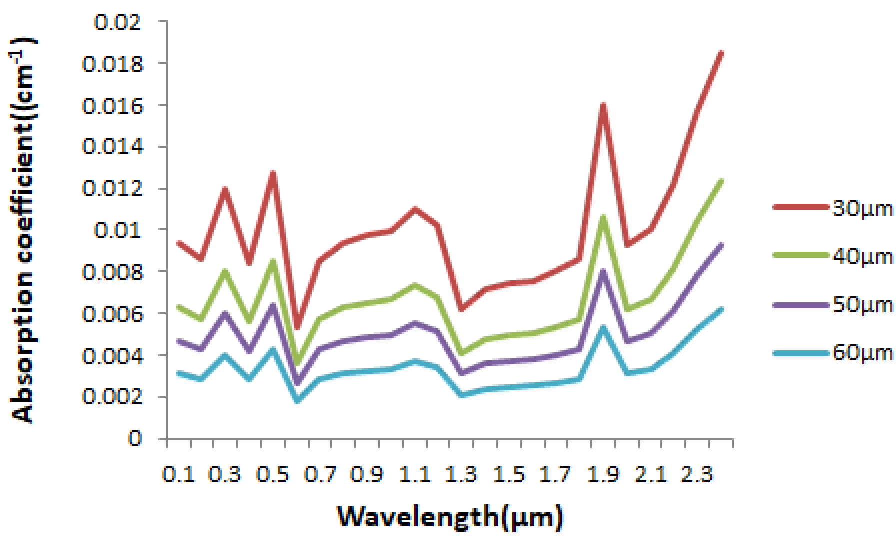


Fig. 5.2 Absorption coefficient vs. size parameter, (a) Nano-particles,(b) Micro-particles.

5.3 Effect of length of column on 100 ppm solution

Length of column is the total length of the setup up to which ice is observed to occur which is under the influence of the light source from above. Main factor that affects the melting rate is the more is the length of the setup longer it will take to melt down whole ice sample. Larger is length of the setup, lower most layer of ice remains at lower temperature for larger time, reason for all this is resistance that is offered by the medium to movement of light from top most position to lower position. Each time with increased length of column intensity of light from source keeps on getting reduced for lower most layers. It is seen in Table 5.1 that more is length of length of column more will be time taken to melt the ice sample, for same amount of intensity if more will be material for absorption lesser will be absorption of light by each subsequent layers. So we can conclude that slow absorption is seen when material for absorption is more

Table 5.1 Melting time values with respect to length of column.

Length of the column (m)	0.01	0.05	0.1
Melting time (hours)	3.4109	35.7250	114.0820

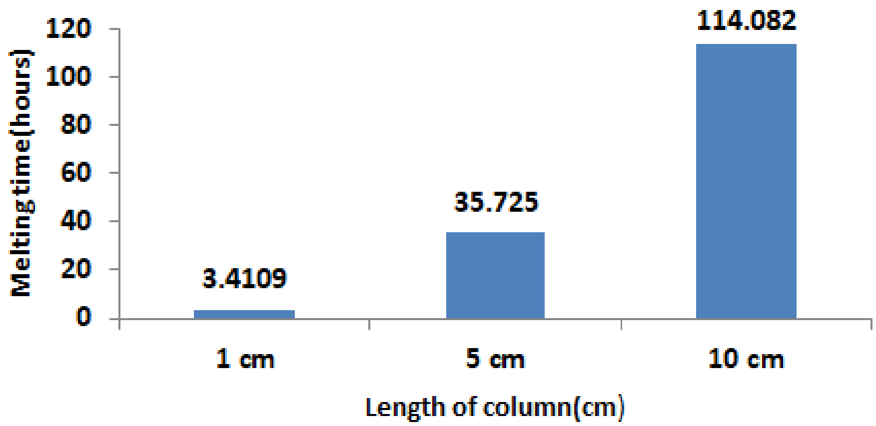


Fig 5.3 Concentration effect on melting time

It is seen in figure effect of the length of column on the temperature profile of the ice column under the sun which is source of rays in form of light and heat energy.In figure Fig 5.3(a) length of column considered as 0.01 m and temperature of lower most layer obtained is almost 0^{o} C. In Fig 5.3(b) length of column is considered as 0.05 m and temperature of lower most layer is about -1^{o}C. In Fig 5.3(c) length of column is considered as 0.1 m and temperature of lower most layer is about -2^{o}C. In this analysis it is found that more will be the height of the ice column lesser will be the temperature obtained at the lower most layer of ice column. Reason for such type of behavior is resistance offered by the layer of ice during transmittance of light from top to lower layer of the ice column, as the thickness of the ice is increased more amount of ice comes in contact with the light and volume of material for absorption is increased so most part of the light gets reduced while its movement in the layer as ice column height is increased. So there is inverse relation between the height of the ice column and lowest temperature obtained in ice column.

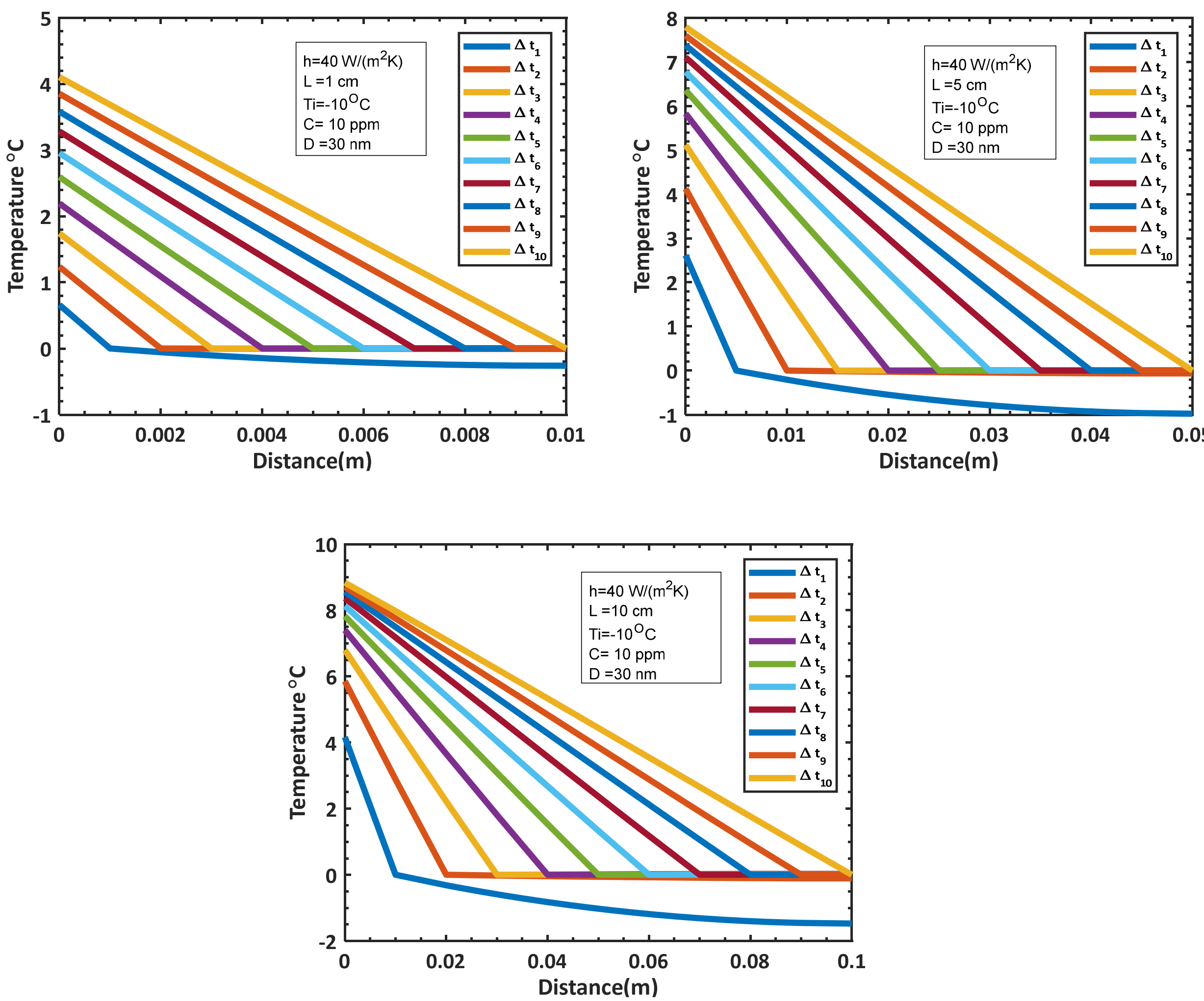


Fig 5.4 Temperature vs. Distance for different time intervals with length of column at 100 ppm, (a) 0.01m, (b) 0.05 m, (c) 0.1 m.

In Fig 5.4 we can observe relation of melting time required for each time interval for different length of column of ice. It is found that in first interval ice is under direct rays of sunlight, under no resistance direct sun rays leads to melting is lesser time. But when upper part of the ice gets melted then ice layer moves downward by one layer of water and water layer acts as conductor to direct sun rays and simultaneously it is seen that with each time interval layer of water on the ice layer keeps on increasing and result in increase of melting time with each time interval due to increased resistance of water layers so liner curve is obtained for the layers after the interval 2 as effect of increase in conductivity by water is overpowered by layer of water absorbing the rays. Fig 5.4(a), (b), (c) are curves for length column of 1 cm , 5 cm and 10 cm respectively. Effect of increased conductivity by water is seen to get reduced and effect of the increased resistance is seen to overpower when more height of ice column is used.

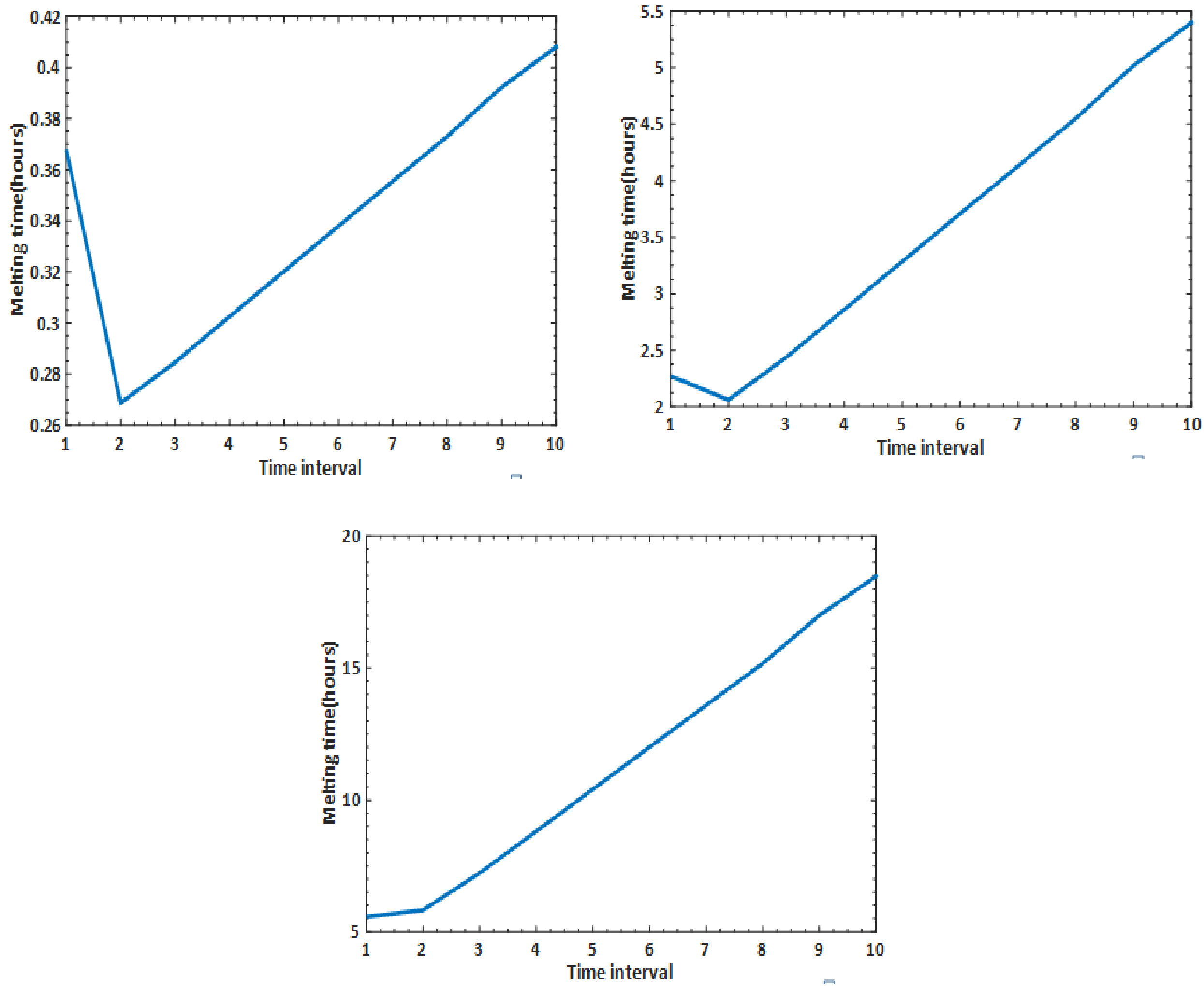


Fig 5.5 Melting time vs. Time interval, (a) 1 cm, (b) 5 cm, (c)10 cm.

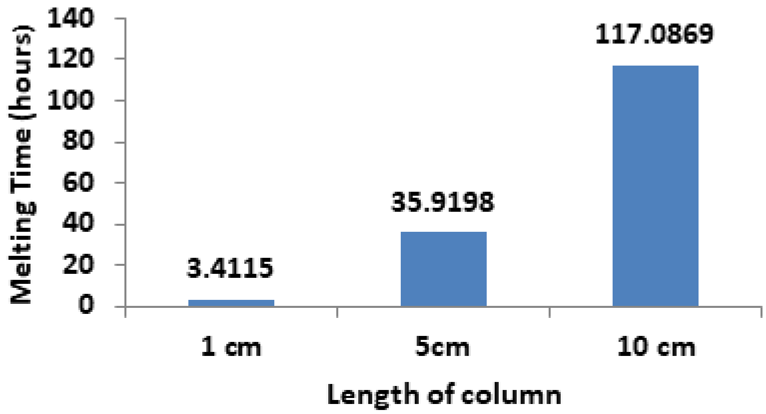


Fig 5.6 Comparison of melting time with different length columns at 0 ppm

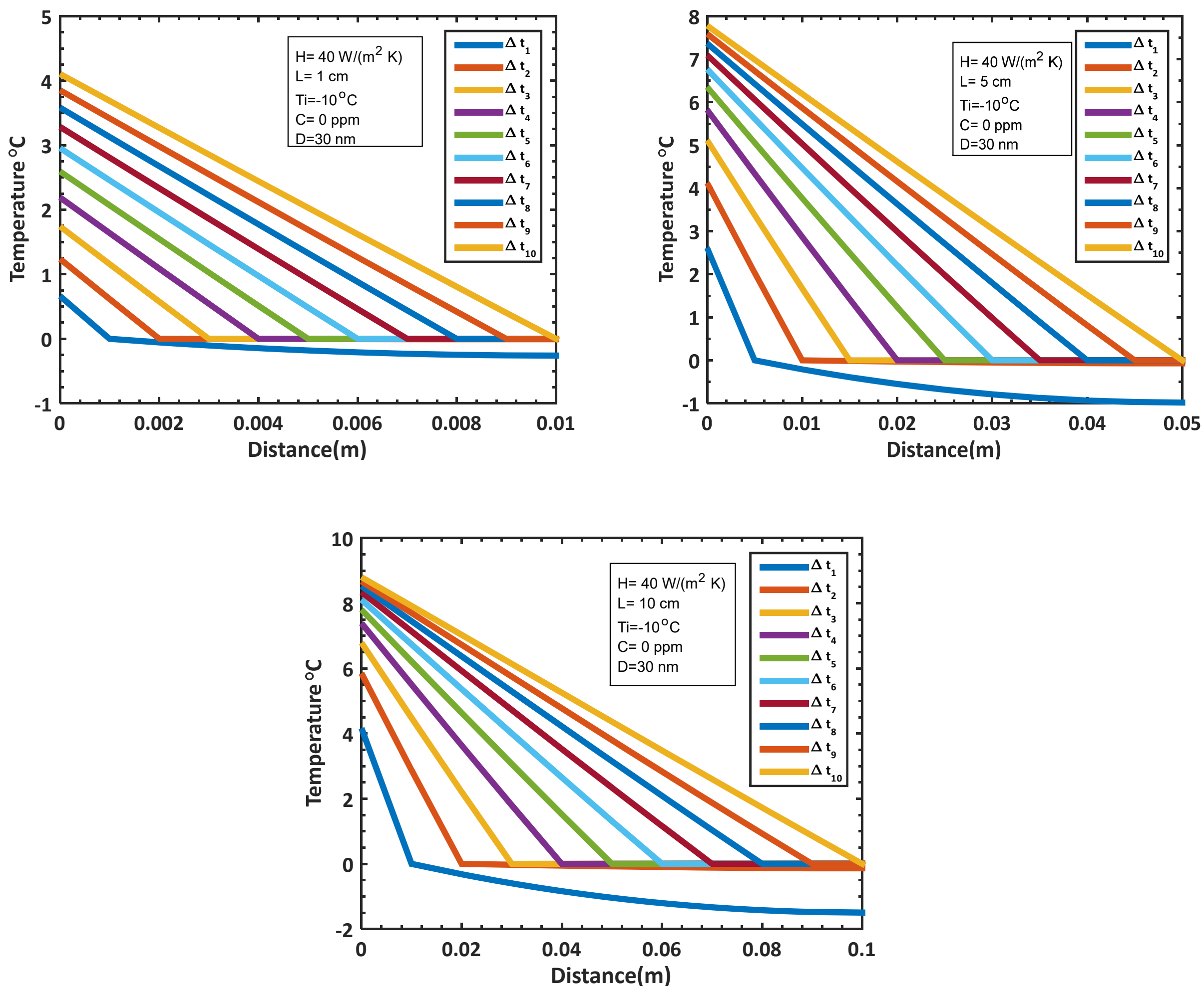


Fig 5.7 Temperature vs. Distance for different time intervals with length of column at 0 ppm, (a) 0.01m, (b) 0.05 m, (c) 0.1 m.

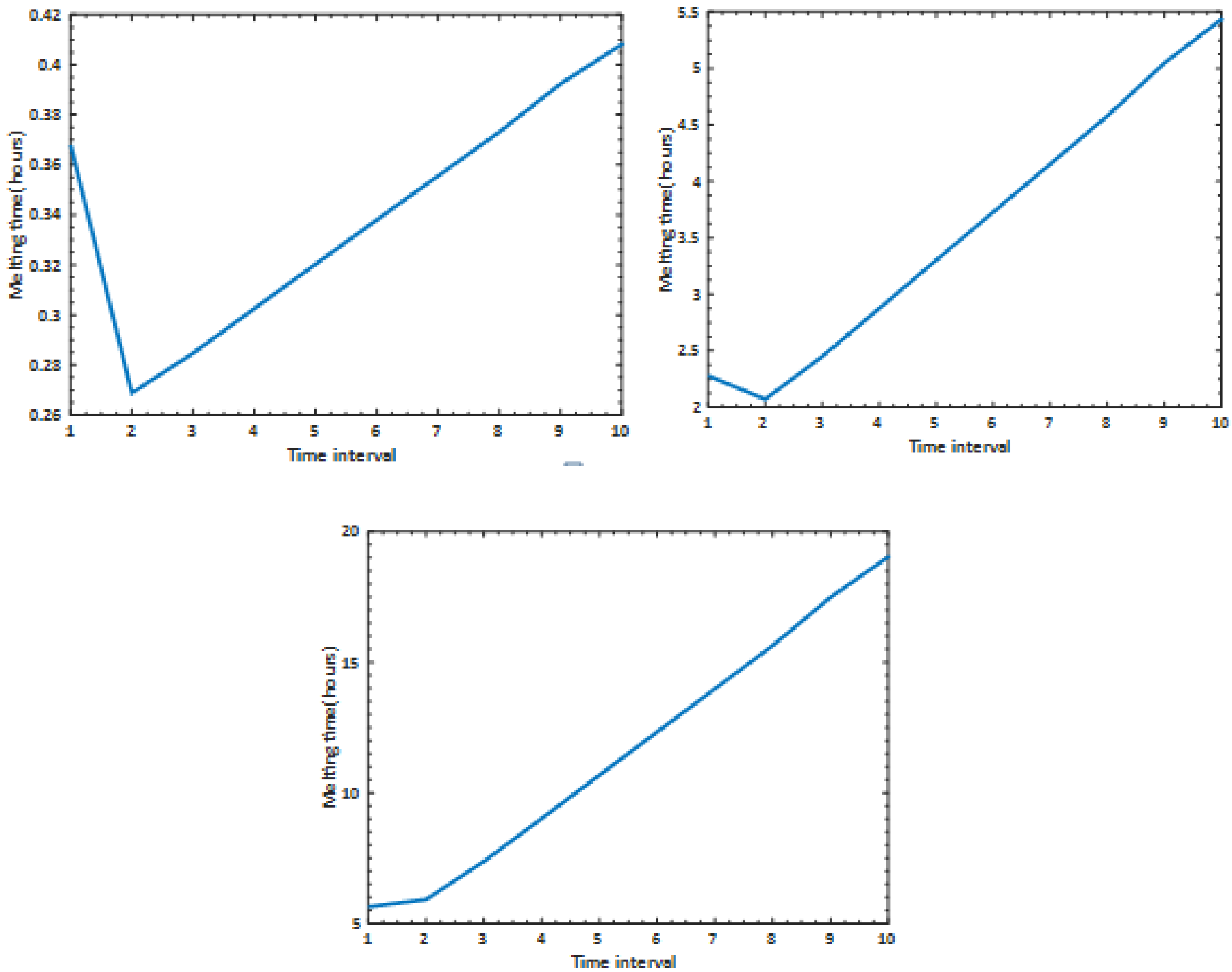


Fig 5.8 Melting time vs. Time interval for 0 ppm, (a) 1 cm, (b) 5 cm, (c)10 cm.

5.4 Effect of Diameter of Nanoparticles

Diameter of the nanoparticles play important role on the melting of ice, more is the diameter of the nanoparticles more will be absorption by the nanoparticles rather than the ice itself, with this phenomena nanoparticles create a melting points in whole volume of the ice. In this case two factors are seen to take part in phenomena due to large diameter of nanoparticles, one is factor is absorption coefficient of the impure ice gets increased and other is due larger diameter of the nano-particles amount of direct rays directly to the ice volume gets reduced but diffused and scattering radiation are increased by some amount in process. When absorption coefficient of the solution is increased melting rate gets increased and melting time gets reduced, in case of second factor because of scarcity of the direct radiation more of diffused and scattered radiation melting rate is reduced leading to increased melting time, so these both factors balance each other effect on the melting rate of ice. In table 4.2 it is seen that with increased diameter of nanoparticles time required to melt ice gets reduced.

Table 4.2 Melting time values with respect to diameter of nanoparticles

Diameter of nanoparticles (nanometers)	30	40	50	60
Melting time(hours)	114.0837	114.0820	114.0797	114.0766

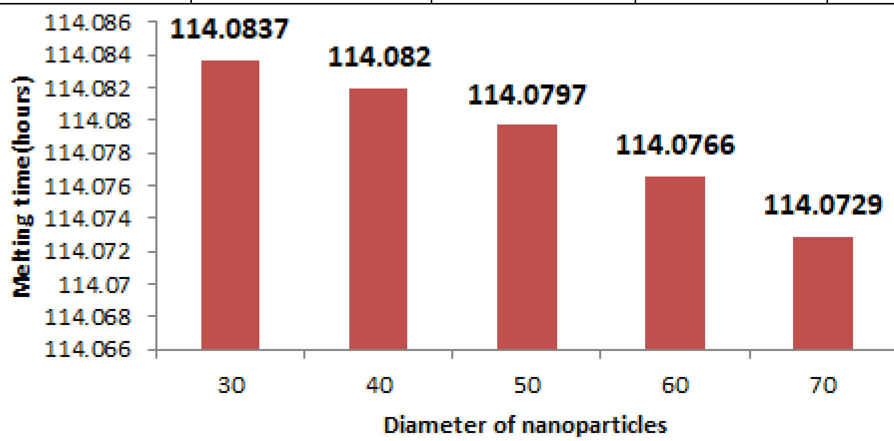


Fig 5.9 Diameter of nanoparticles effect on melting time

In case of the change in diameter of nanoparticles it is seen in Fig 5.6 (a), (b), (c) and (d) represent temperature vs. distance curve for 30 nm, 40 nm, 50 nm and 60 nm diameter of nanoparticles, and it is seen that as diameter of nanoparticles is increased lowest temperature possible in lower most layer is decreasing but temperature reduction is very less amount. So factor of reduction of the direct intensity and increase in diffuse light is overpowering the increased absorption coefficient by addition of nanoparticles into the ice.

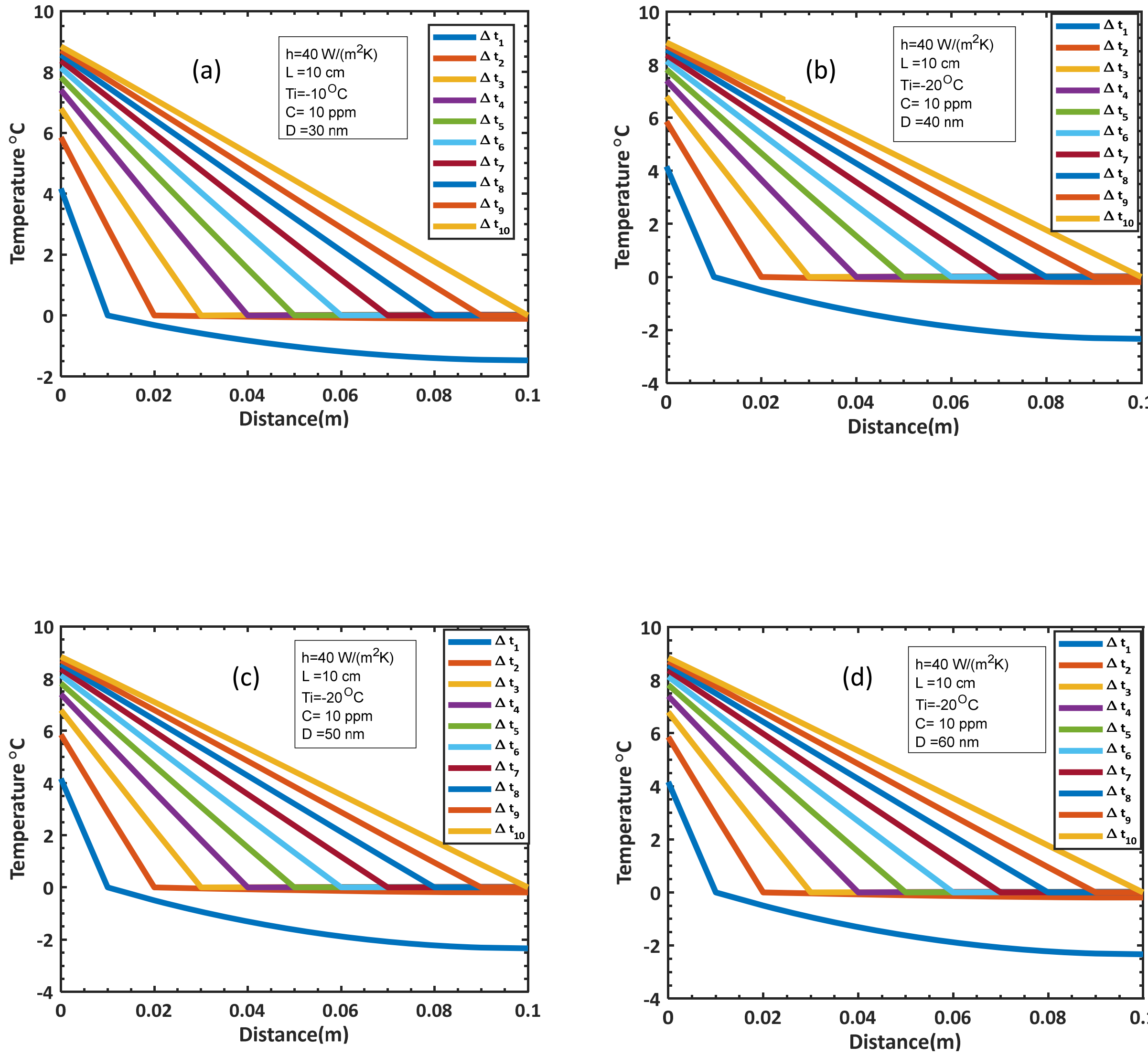


Fig 5.10 Temperature vs. Distance for different time intervals for diameter of Nano-particles as, (a) 30 nm,(b) 40 nm, (c) 50 nm,(d) 60 nm

Fig 5.7 is melting time vs. time interval for different diameter of nanoparticles such as 30 nm, 40 nm, 50 nm, 60 nm, it is seen that effect of increased melting with one layer of water and then increased resistance by other water layers after time interval 2 as seen in length of column parameter but in this after 30 nm diameter effect of conductivity increase in compare to increased resistance is seen to get reduced and curve is seen to increase low slope to interval 2 and then after it sharp increase in slope is seen after it.

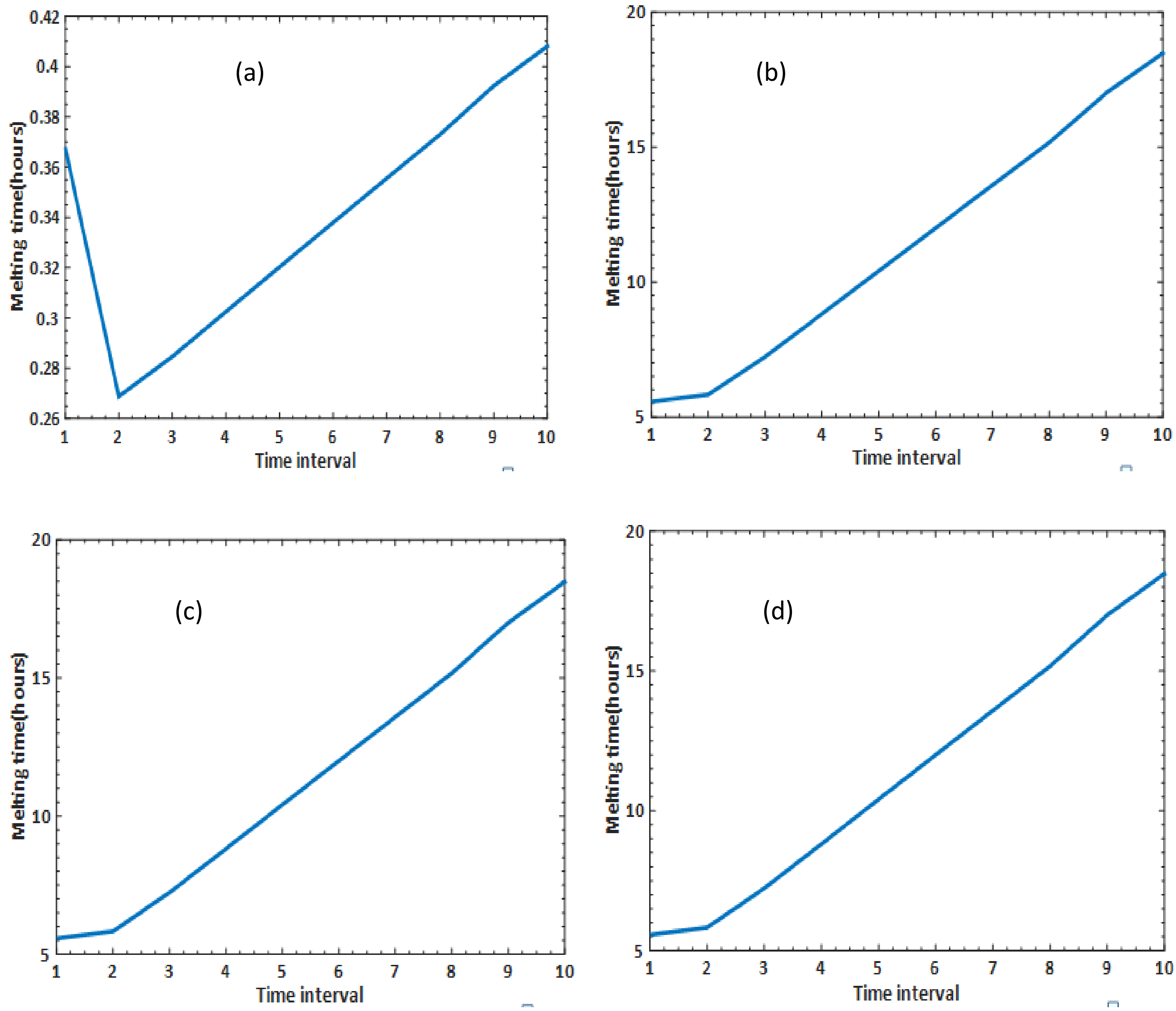


Fig 5.11 Melting time vs. Time interval on basis of different diameter of nano-particles, (a) 30 nm,(b) 40 nm, (c) 50 nm,(d) 60 nm.

5.5 **Effect of Volume fraction**

Volume fraction in this context means amount of amorphous carbon in the water medium. In mathematical modeling we have considered four types of concentration one is 0 ppm, 10 ppm , 50 ppm and 100 ppm. Increased amount of amorphous carbon in the solution results in increased overall absorption coefficient of the solution. Only factor that influences the melting rate is increased overall absorption coefficient. More will amount of nanoparticles lesser will be time taken to melt the sample. Amount of the amorphous carbon in the solution can be calculated as

0.1 gm for 100ppm, 0.01 gm for 10 ppm and 0.001 gm for 1 ppm. At 0 ppm pure ice is seen to occur where absorption coefficient of ice is only considered as amount of amorphous carbon increases from 10 ppm , 50 ppm to 100 ppm massive increase in absorption coefficient results in in increased melting rate and reduced melting time simultaneously.

Table 4.3 Melting time values with respect to volume fraction

Concentration of the solution(ppm)	1 ppm	10 ppm	100 ppm
Melting time (hours)	116.6730	114.0820	111.6374

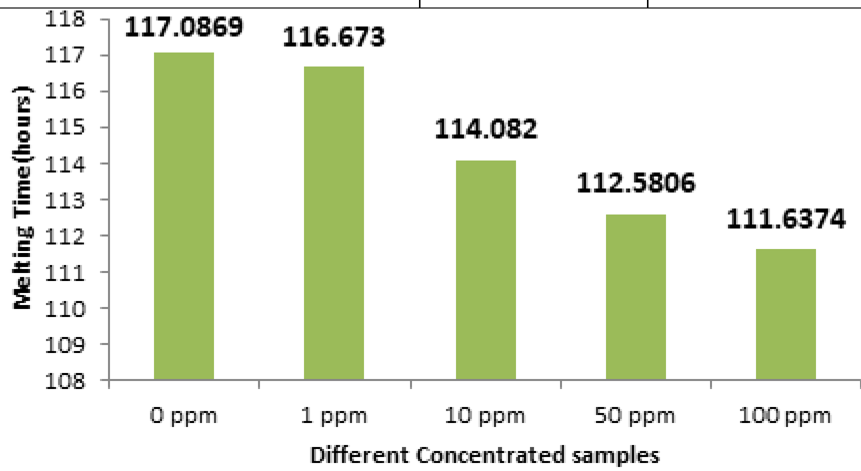


Fig 5.12 Different length of concentration effect on melting time

In Fig 5.8 Temp vs. distance curve can be seen for different concentration and Fig 5.8 Melting time vs. time interval, temperature profile and melting time curve does not change that much but

Specific time required for melting of each interval is seen to be different which can be seen in table.

Table 4.4 Melting time (hours) for different concentration solutions

S no.	0ppm	10 ppm	50 ppm	100 ppm
1	5.632778	5.568611	5.504167	5.503611
2	5.916111	5.824167	5.753333	5.774167
3	7.373611	7.228611	7.094444	7.084444
4	9.015833	8.812778	8.625556	8.611944
5	10.67556	10.40972	10.16472	10.14806
6	12.33167	12.00056	11.69306	11.67194
7	13.985	13.58722	13.21083	13.1825
8	15.63667	15.17194	15.83333	14.68
9	17.48361	17.00111	16.42083	16.32722
10	19.03611	18.47722	18.39444	18.65306
Total Melting time	117.0869	114.0819	112.6947	111.6369

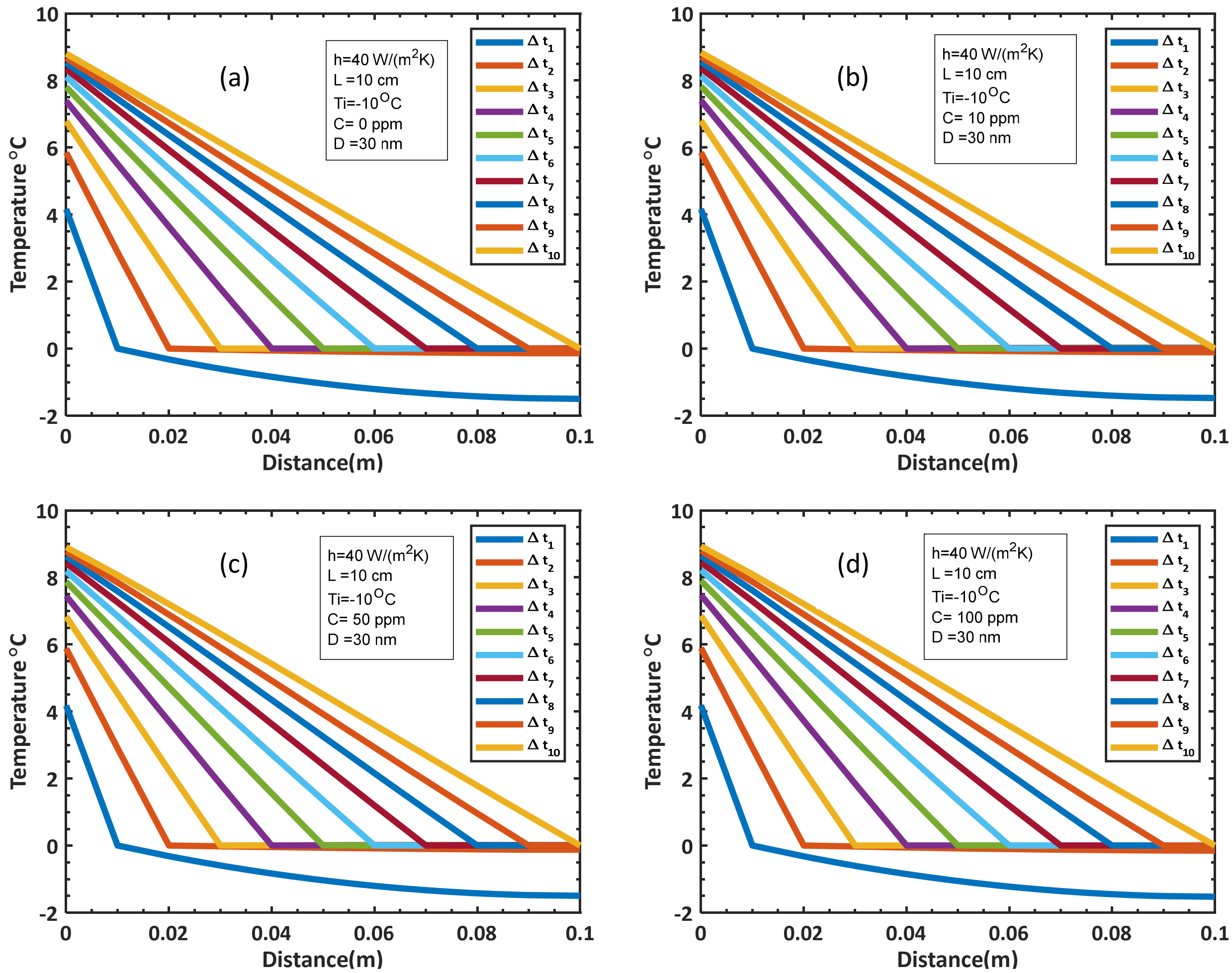


Fig 5.13 Temperature vs. Distance for different time intervals on basis of variation of concentration of Nano-particles, (a) 0 ppm, (b)10 ppm, (c) 50 ppm, (d)100 ppm

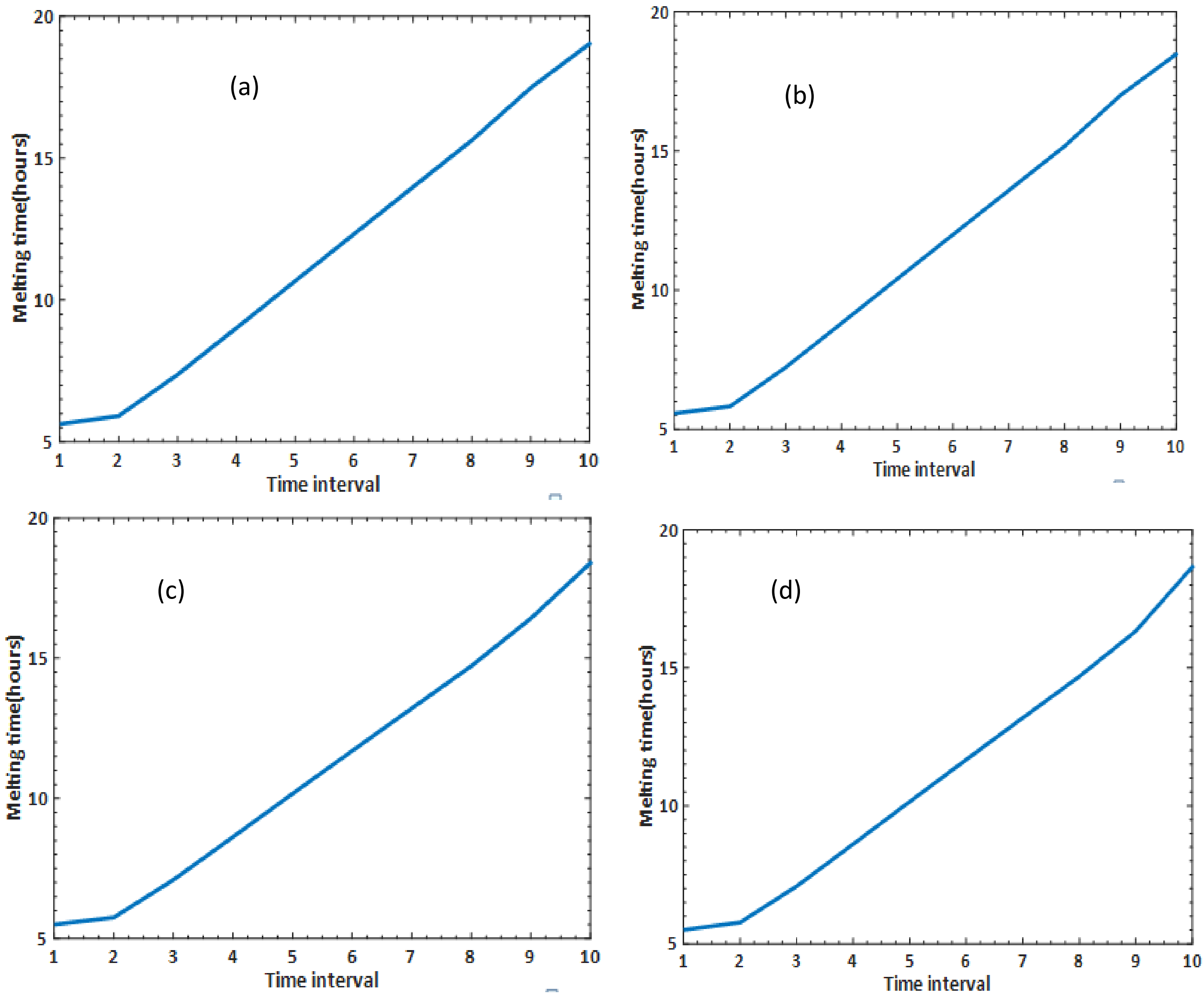


Fig 5.14 Melting time vs. Time interval for different concentration of Nano-particles, (a) 0 ppm, (b) 10 ppm , (c) 50 ppm, (d) 100 ppm.

5.6 Experimental investigation results

Setup specified earlier is used to take melting time experimental data replacing sun by optical light source after freezing the sample of each particular concentration, three readings are performed. Concentration of samples used is 0 ppm, 50 ppm and 100ppm of amorphous carbon in distilled water. Each concentration solution is made by mixing particular amount of amorphous carbon in distilled water and then ultra-sonication of the sample for about 30 mins before going for freezing.

Table 5.4 Melting time results in each reading of different concentrations.

Conc. of solution	1st reading	2nd reading	3rd reading
0 ppm	19 min 27 sec	16 min 16 sec	16 min 6 sec
50 ppm	13 min	13 min 2 sec	13 min 48 sec
100 ppm	11 min 49 sec	12 min 59 sec	13 min

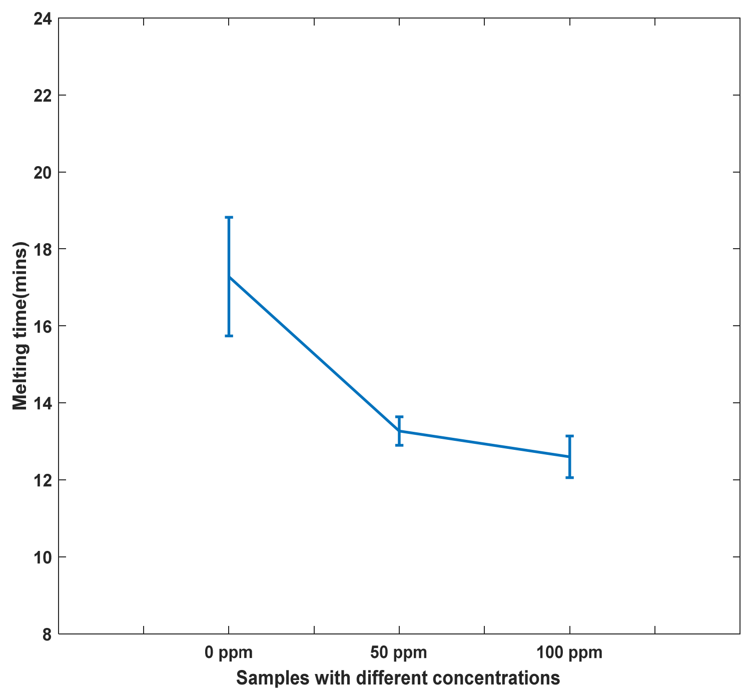


Fig 5.15 Error bar for 0 ppm, 50 ppm and 100 ppm concentration of amorphous carbon in pure ice on basis of experimental investigation.

CHAPTER 6
VALIDATION OF DEVELOPED THEOREICAL MODEL

6.1 Validation of the developed theoretic model

In order to validate the developed theoretical model for predicting the melting rate during volumetric melting, I have compared the results of the present work with that of theoretical work recently reported by Ozisik et al., 1984.
In order to aid validation, we have tried to keep all the operating parameter in our theoretical model similar to those in Ozasik et al.,1984.

Table 7 details these parameters and provides a comparison of the input parameters in the two works

Parameter	**Ozisik model**	**Present model**
Phenomenon	Solidificaton	Solidificaton
No of phase	Single	Single
Melting temperature	1	1
Convective cooling location	At x=0	At x=0
Insulated	At x=1	At x=1
H=h/k	10	10
Ambient temp	0	0
ρL/K	1	1
No of iteration	4	4

Aforementioned parameters have been employed in the developed theoretical model to predict melting time and temperature for volumetric solidification. Furthermore it has been compared with that of Ozisik et al., 1984.

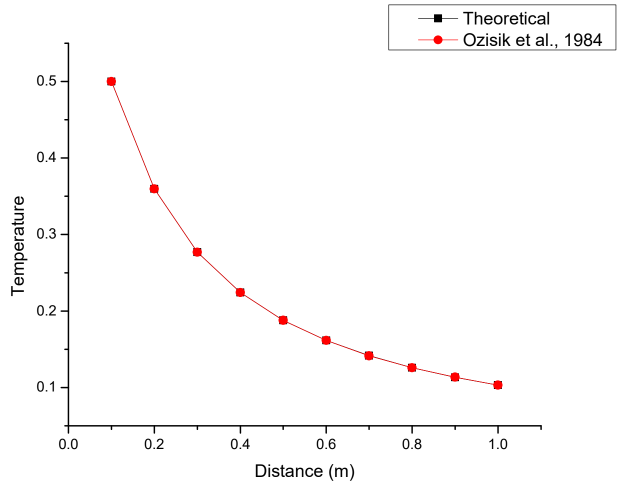


Fig. 6.1 Comparing the temperature profile as predicted by the present theoretical model (PTM) with that of Ozisik et al., 1984.

Comparison of above work reveals that the pratical theoretical model coincides with the readings of the ozasik model readings for the temperature. However effect of the nanoparticles on the temperature profile of the graphs cannot be studied because ozasik model never discussed the temperature profile change due to introduction of impurities into the pure medium. However but the with nanoparticles slope of the temperature profile increases in comparison to the pure ice temperature profile.

It is found that temperature profile of theoretical and actual curve completely coincides with each other , governing equation and boundary condition obtained from ozasik et al., 1984 is used to write MATLAB code from which values of melting time for each time interval can be obtained.

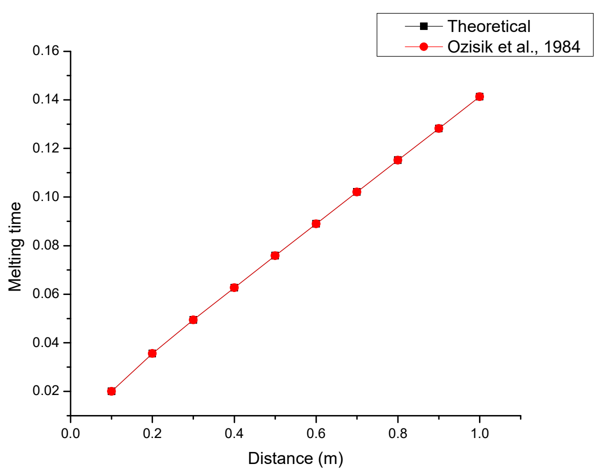


Fig.6.2 Comparing the melting rate as predicted by the present theoretical model (PTM) with that of Ozisik et al., 1984.

CHAPTER 7

CONCLUSIONS

Glacier are natural source of fresh water and continous melting of glacier ice results in addition of the natural water into the rivers and stream. Amount of water inputed into the rivers get trigggered when amount of carbon gets added into the glacier ice which increases the overall absorption coefficient of the glacier ice and results in increased melting rate and reduced melting time. So accordingly to this situation effect of different factors on the melting rate of the glaciers can be understood and how much is increase in melting time.

- Effect of volume fraction of amorphous carbon on solution can be observed during theoretical and experimental study, in theoretical study 0 ppm, 1 ppm, 10 ppm, 50 ppm and 100 ppm are considered and in experimental 0 ppm, 50 ppm and 100 ppm are considered. It is found that in theoretical model from 0 ppm to 10 ppm there is 2.56% decrease in time required to melt the solution and from 0 ppm to 100 ppm 4.65% decrease in melting time of the solution, further there is 2.142% decrease in melting time when concentration change from 10 ppm to 100 ppm. Experimentally it is found that when the concentration varies from 0 to 50 ppm decrease in time by 2.32% and when concentration goes from 0 ppm to 100ppm decrease in melting rate is about 2.70%.
- Effect of length of column of the setup seen to effect the melting rate and melting time of glaciers, this result was only found in theoretical model, 1 cm, 5 cm and 10 cm ice models were considered, 1 cm took 3.41 hours to melt whereas in case of 5 cm ice model increased hours of melting are seen which is about 35.72 hours are taken to melt whole setup and for setup of the length 10 cm will take 114.0820 hours to melt.
- Effect of diameter of nanoparticles also has crucial role in melting rate of the glaciers it is found that with increased diameter of nanoparticles as overall absorption coefficient is increased amount of time to melt the ice sample for 30 nm of diameter of nanoparticles melting time is 114.0837 hours, 40 nm it is 114.0820, 50 nm it is 114.0797, 60 nm it is 114.0766 and 70 nm it is 114.0729. Between 30 nm to 70 nm there is reduction in time by 0.00946%.

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