Optimizing Heat Insulation of a Solar Oven

by

Mohd Ruzaini Bin Mohamad Noor

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JULY 2008

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Optimizing Heat Insulation of a Solar Oven

by

Mohd Ruzaini Bin Mohamad Noor

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____
(Mr. Azman Zainuddin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

MOHD RUZAINI BIN MOHAMAD NOOR

ABSTRACT

This is a dissertation report on optimizing heat insulation of a solar oven. Solar oven is a box that uses heat radiating from the sun to cook or heat the food. Solar oven not widely used because of the poor performance compared with conventional ovens. Solar oven performance is inconsistent; depend on the time of day, weather and geographic location. Temperature rise in solar oven is slow compared with conventional oven. Heat loss through the insulator is one of the disadvantages of a solar oven. The objective of this project is to investigate the suitability of insulation materials and thicknesses to use in a solar oven. This project will analyze different types of materials which are suitable as insulation from varies point of views and criteria. The existing solar oven model will be studied and the relevant journal will be as a base for my study. Testing and experiments will be made to evaluate the capability of the material in the system. The final result show that glass wool is the best insulation material compared with crumpled paper and cotton insulation. Glass wool is chosen base on the cost of material, availability in market and thermal conductivity. All relevant data, calculation, and discussion will be provided at the end of this report.

ACKNOWLEDGEMENTS

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَـٰنِ ٱلرَّحِيمِ

In the name of Allah, The Beneficent, The Merciful.

First of all, deepest gratitude to the Lord of the Universe, Allah S.W.T for His bless in various aspects to accomplish the final year project. Nothing will happen without His permission in accomplishing this final year project.

Secondly, thousands appreciation are dedicated to my beloved parents for their commitment and permission. They were big support behind all scenes, and the best source of inspiration ever had. All their support had firing up the spirit in finishing the entire job structured by my supervisor.

Appreciation is extended to my supervisor, Mr. Azman Zainuddin for the guidance and advice during the completion of this project. Without his comments and suggestions it could be difficult for me to finish this project. Acknowledgement is also given to my friends, technician, and others people who are involved directly and indirectly in completion of this project.

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLE

LIST OF GRAPH

CHAPTER 1

INTRODUCTION

1.1 Background of study

Home appliances are the world's fastest growing consumers of energy, second only to automobiles. Items such as stoves, ovens, and refrigerators account for 30 percent of electricity use in industrial countries and 12 percent of their greenhouse gas emissions. A portion of that energy expenditure could be eliminated by using solar ovens. Solar oven absorb the solar energy radiates from the sun to cook and heating the food. However not all of the heat energy trapped in the solar oven, some of them loss to the surrounding through conduction, convection and radiation. Insulated material is introduced to reduce the heat loss to surrounding and reduce the time taken to cook or heat the food. Insulator will reduce the rate of heat loss in the solar oven and increase the efficiency of the system. The insulator should have low thermal conductivity, low cost and chemical stability. This characteristic emphasizes the suitable material for the solar oven design insulation.

1.2 Problem statement

Solar oven is a device that uses solar energy as a heating component to cook food. As the cost of energy escalating in the previous year, heating cost using the solar seems more affordable compared with other non renewable energy sources. It does not consume fuel or oil to generate the heat and can operates with no cost. Energy gained from the sun light is absorbed and there is a reflector to bounce the light into the box. The problem occurs when there is a significant heat loss to surrounding through conduction, convection and radiation from the solar oven. Heat loss will reduce the efficiency of the system by taking long period of time to prepare a food. Furthermore, solar oven performance is inconsistent; depend on time of day, weather and geographic location. Temperature rise in solar oven is slow compared with conventional oven. This disadvantage aspect is a common reason why solar ovens are not widely used all over the world. Heat loss in the solar oven can be reduced by eliminating the possible ways of heat transferred out of the box. One of the ways is by adopting the insulation material at the wall of the solar oven. Therefore this project aims to choose the best insulation material for the solar oven.

1.3 Objective and scope of study

The objective of this project is to investigate the suitability of insulation materials and thickness to use in a solar oven. Different types of insulation material will be studied and the best will be chosen as a solar oven insulator. Material that can contained heat will be the best insulation material as long as the material does not react with temperature in the solar oven. Experimentation will be done to evaluate the efficiency and reliability of the material.

The scope of study for this project is to study relevant insulation material, investigate the thermal conductivity of the material and do the practical experiment to analyze the ability of some material to trap heat without reacting with the food and safety issue.

1.4 Significance of study

This project will be useful to designers of solar oven in specifying the suitable material for insulation. The material will be low cost, available in the market and posses low thermal conductivity. The disadvantage of the current solar oven system such as heat loss to surrounding will be reduced. Efficiency and effectiveness of the solar oven will be increase as the time taken to cook the food shorter. This study will give the information from different aspects and criteria evaluation which is suitable as insulation material.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to solar oven [1]

Cooking accounts for a major share of energy consumption in developing countries. Fifty per cent of the total energy consumed in India is for cooking. Most of the cooking energy requirement is met by non-commercial fuels such as firewood (75%), agricultural waste and cow dung cake (25%) in rural areas. The fuel wood requirement is 0.4 tons per person per year in India. In rural areas, firewood crisis is far graver than that caused by a rise in oil prices. Poor villagers have to forage 8–10 hours a day in search of firewood as compared to 1–2 hours 10 years ago. One third of India’s fertiliser consumption can be met if cow dung is not burnt for cooking and is used instead as manure. The cutting of firewood causes deforestation that leads to desertification. Fortunately, India is blessed with abundant solar radiation. The arid parts of India receive maximum radiation i.e., 7600–8000 MJ m^{-2} per annum, followed by semi arid parts, 7200–7600 MJ m^{-2} per annum with least amount on hilly areas where solar radiation is still appreciable i.e. 6000 MJ m^{-2} per annum. Therefore, solar cookers seem to be a good substitute for cooking with firewood. The first solar furnace was fabricated by naturalist Georges Louis Leclerc Buffon (1707–1788) but Horace-de-Saussure (1740–1799) was the first in the world to use the sun for cooking. Augustin Mouchot, a french physicist, described a solar cooker in his book “La Chaleur Solaire” published in Paris, in 1869. He also reported in the same book earlier work on solar cooking by English astronomer, Sir John Herschel, in South Africa, between 1834 and 1838. Since then different types of solar cookers have been developed all over the world. The solar cookers can be classified into three broad categories; reflector/focusing type, heat transfer type, and hot box type.

2.2 Reflector/ Focusing type

The reflector type solar cooker was developed in the early 1950s [2] and was manufactured on a large scale in India [3] .However a reflector type solar cooker did not become popular due to its inherent defects such as it required tracking towards the sun every 10 min, cooking could be done only in the middle of the day and only in direct sunlight, its performance was greatly affected by dust and wind, there was a danger of the cook being burned as it was necessary to stand very close to the cooker when cooking and the design of the reflector type was complicated.

2.3 Heat transfer type

In the heat transfer type solar cooker, the collector is kept outside and the cooking chamber is kept inside the kitchen of the house [4-6]. But this type of solar cooker also did not become popular because of its high cost and only limited cooking can be performed.

2.4 Hot box type

The third type of cooker is known as a hot box in which most of the defects of the above two types of cookers have been removed. Different types of solar cookers have been tested and the solar oven has been found best. Although the performance of the solar oven is very good, it also requires tracking towards the sun every 30 min, it is too bulky and is costly. Therefore, the hot box solar cooker with a single reflector [7] has been promoted at subsidised cost by the Ministry of Non-Conventional Energy Sources, Government of India and the state nodal agencies in India since 1981–82, and 462,000 solar cookers were sold up to the 31 December 1998 [8] .From 1 April 1998 to December 1998 only 5000 solar cookers were sold. This shows that the popularity of solar cookers is declining due to its defects: it also requires tracking towards the sun every 60 min. Therefore, its operation also becomes cumbersome and the performance of the hot box solar cooker is very poor during winter when solar radiation and ambient temperatures are very low. Considering this, a two reflector hot box solar cooker was developed by Gupta and Purohit [9] so that tracking could be avoided for 3 h, but the problem of poor performance during winter still remains with this solar cooker. Therefore, attempts were also made by Nahar et al. [10] to improve performance of the hot box solar cooker during extreme cold weather by using Transparent Insulation Material (TIM) between two glazing, and a hot box solar cooker with a TIM was tested in an indoor solar simulator of the University of Wales, College of Cardiff. In this paper both defects of the hot box solar cooker have been removed by providing one more reflector, and convective heat losses have been suppressed by using TIM as suggested by Hollands [11], Goetzberger et al.[12-13], Hollands et al. [14] Nordgard and Beckman [15] Platzer [16-17] and Nahar et al [18]. The cooker is kept in such a way that one reflector is facing south and the other is facing east in the forenoon so that tracking is avoided for 180 min. In the afternoon, one reflector is facing south and other is facing west so that again tracking is avoided for 180 min. The maximum time taken for cooking a dish is less than 3 hours.

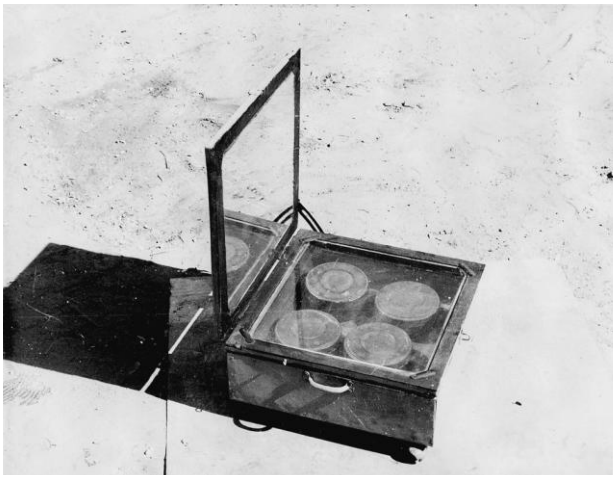


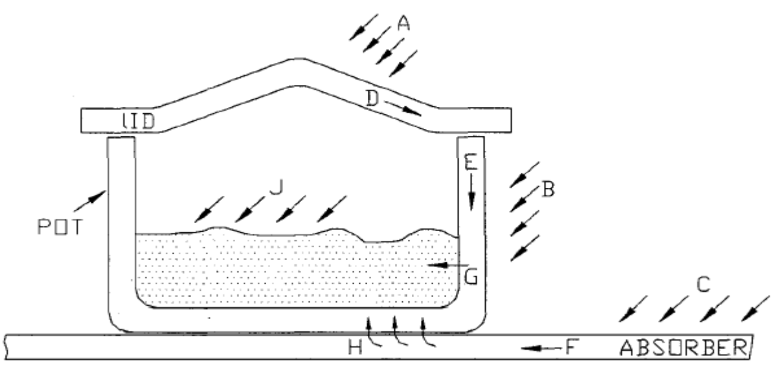
Figure 1.1: Hot box solar cooker.

2.5 Studies in insulation

The Pejack also has done the study on ranks bulk insulation materials from poor to best as crumpled Styrofoam cups, crumpled newspapers, straw, wool, rice hulls, and feathers. Field tests on this ranking unfortunately are not complete, however, Styrofoam in any form is not recommended because it is manufactured from chlorofluorocarbons (CFC) which destroy atmospheric ozone. The newer gases substituted in making Styrofoam are untested for use around food and should be avoided unless it is firmly established they are safe around food at solar oven temperatures. The gases could be hazardous and reacts with human health system. When Styrofoam was used prior to understanding its role in atmospheric ozone depletion, it was considered unreliable as an insulator as it sometimes melted within the solar oven wall resulting in a poorly functioning oven. Pressed fiberglass insulation has good insulation properties. As for example loose fiberglass batteries also insulate well but both present health hazards. Fibers are released while the material is being worked and penetrate the eyes, lungs. Foam insulation is made with toxic gases which continue to off gas for long periods. For these reasons both fiberglass insulation and foam insulation are not recommended [19].

2.6 Heat transfer in cook pot [19]

In a pot being heated over a fire or electric hot plate, heat enters the bottom of the pot and conducts to the bottom of the food inside the pot. The sides and lid of the pot do not have a major role in heat transfer. Since the heat transfer is primarily through the bottom, sometimes the pot bottom is constructed in a way to facilitate heat transfer, such as being plated with high conductivity copper, or having small grooves. In many solar cooking applications, the heat input is much different. A pot in a hypothetical solar heating environment is shown in the figure. Solar rays may be hitting the lid, becoming absorbed, and the heat then conducts along the lid at D, across the gap to the pot sides, then down the pot sides at E and to the food at G. In this mode, the thickness and conductivity of the pot material and the thermal resistance of the lid-pot gap govern the heat transfer.



A cook pot. Solar rays may be absorbed at the lid at A, on the side at B, at an absorber plate at C, or in the case of a transparent lid, directly at the food at J. Heat conducts along the lid at D, down the pot wall at E, along the absorber at F and into the food at G and H.

Figure 2.1: Schematic diagram for heat transfer in solar oven

High thermal conductivity of the pot and lid material and thick pots and lids contribute to good heat conduction from D to E to G. If there is not good thermal contact between lid and pot, this may contribute to a thermal resistance and inhibit conduction from lid to pot. When rays hit the sides of the pot at B and are absorbed, heat is conducted down the pot wall at E and into the food at G. Again, a good conducting pot wall helps the heat transfer. The thermal path from E to G in the wall is shorter than the case from lid at D to food at G, so heat transfer from solar rays at B to the food may be more effective than from solar rays at A to the food. The relative area of the intercepted rays at A and at B must also be considered, since the lid and sides of pot may be intercepting different amounts of solar energy. A question may be posed about the optimum height of a pot, above the level of the food. If the pot is tall, the conduction path length from lid to food is increased, inhibiting heat transfer. However, a tall pot offers more area at the sides for increased absorption at B.

The optimum pot height would depend on the pot material, thickness, radiation flux, areas of lid and sides, and heat loss by air convection. In some cases the pot may be sitting on an absorber surface which is absorbing radiation. This is the case for example in a box cooker when the bottom of the box is an absorber surface. In the figure, rays at C are absorbed and conduct horizontally in the absorber to H, then conduct into the pot. The absorber material must have sufficient thermal conductivity with sufficient thickness so that there is not much temperature drop along the absorber. The gap between pot and absorber should have good thermal contact so that it does not offer a conduction resistance to the heat transfer. The underside of the absorber should be an insulating surface to prevent heat loss downward.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

In this chapter, a description of the methodology in conducting the project is given as below.

The project starts by defining the problem involving of a solar oven. This process is to analyze the root of causes why a solar oven not widely used until today. This task is done by consulting with the author's supervisor. The major problem related with solar oven is low performance compared with conventional gas kitchen and significant heat loss. The problem definition process gives the clear view about the paramount aspects in this study.

Then proceed with literature review process. Gather the information regarding the previous project available from the journals or books. This procedure is to ensure to analyze the pervious work that has done by the other people to accomplish the project. There a lot of journal related with solar oven design and insulation modification. Some of them use cheap material as an insulation and other uses different method to enhance the capability of the solar oven.

Next step is set the objective of this project to focus on the target that should be achieved. The objective of this project is to investigate suitability of insulation material that can prevent heat loss from solar oven to surrounding. The material will be chosen based on the criteria that been set by criteria evaluation

Then precede with establishment of the design criteria for insulation material. From discussion with the supervisor and previous journal as a benchmark, there are six criterias that should be followed. The criterias are cost of the material, availability in the market, insulation properties, reliability, and durability and risk of food contamination.

After decided the parameters used in the solar oven, process continues with generated possible list of material for insulation that qualifies for evaluation. There are about 8 materials which are suitable initially. The materials would be glass wool, fiber glass, aerogel, wood, crumpled paper, cotton, wool and straw. These materials will go through the evaluation rating method to decide which material is most preferably to used as insulation.

After list out the possible material, the author does the rating method to choose the suitable material. This material will be evaluated thoroughly based on the criterias that has been decided. The weight will be more on the first three criterias which are low cost, availability in the market and insulation properties. The shortlisted candidates for the experimentation stages would be glass wool, cotton, crumpled paper and wool.

The next stages would be preparation of the material and plan for the experiment setup. All the materials bought from the nearest shops and the author is using cardboard as a wall to put the insulation material. After preparing the material, setup the procedure for the experiment.

Then proceed with conducting the experiment at the Block 18. The solar meter use to measure the solar radiance from the sun. The experiment going on about 2 weeks with each material got two repeated process.

After finished the experiment stages, evaluation and interpretation of result is done. This to ensure the result of the experiment is valid and appropriate as in the journal and book.

Last but not least is specifying the best insulation materials. There are 3 materials which have been tested in the experiment. The materials are glass wool, crumpled paper and cotton insulation. The discussion and recommendation of the material will be done at the back of this report.

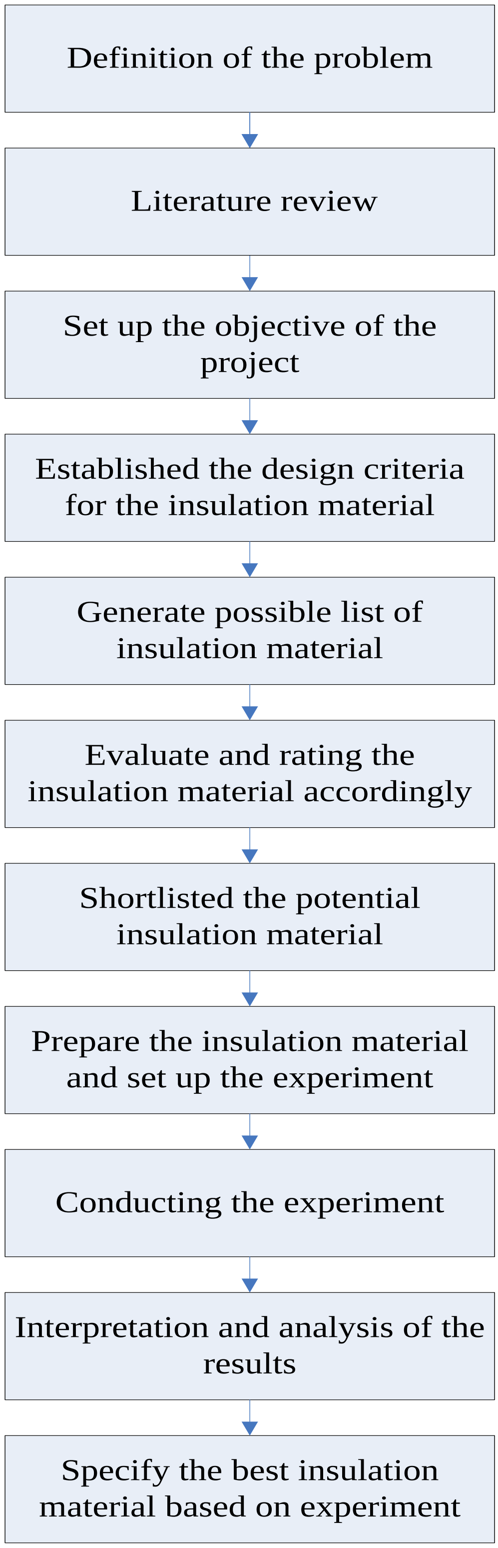


Figure 3.1: Methodology

3.1 Design specification

1. Cost of material.

   Financial planning plays important role in determine the achievement in the project. The author has a limited budget to spend which is RM 250 per semester and meticulous plans have to be prepared.

2. Availability.

   All the insulator material that is locally available is the second most important priority to the author. Local market’s price is cheaper compare to the outside market which is expensive and hard to get it.

3. Insulation properties.

   The third criteria the author looks for is the insulation properties. Low K value means low heat transfer and effectively can restore the heat for cooking purpose. Low K means the material is a good insulator and compatible as a component in the solar cooker.

4. Risk of food contamination

   Hazardous material might react at high temperature and contaminate the food and can cause poisoning to the user. Some material is chemically active and not suitable to use as an insulator.

5. Durability.

   The material should has a long life time because the ability to withstand the high temperature in the next experiment.

6. Reliability.

   Reliability means consistent performance of the material throughout the testing and experimentation. The stability performance is quite important as there are many experiments and testing will be done to evaluate the material.

These are the criteria and evaluation the author had decided when chooses the appropriate material for testing. There are three important criteria that the author specific for and the others three criteria just as a support and backup for the evaluation.

3.2 List of material

Below is a description of a relevant material to be used in a solar oven as insulation.

3.2.1 Glass wool

Glass wool is similar to steel wool. It is simply very thin strings of glass arranged into a spongy texture. Glass wool is used widely as an insulating material.

3.2.2 Fiber Glass

Glass fiber is formed when thin strands of silica-based or other formulation glass is extruded into many fibers with small diameters suitable for textile processing. Glass, even as a fiber, has little crystalline structure. The properties of the structure of glass in its softened stage are very much like its properties when spun into fiber. One definition of glass is "an inorganic substance in a condition which is continuous with, and analogous to the liquid state of that substance as a result of a reversible change in viscosity during cooling, has attained so high a degree of viscosity as to be for all practical purposes rigid.

3.2.3 Aerogel

Aerogel is a low-density solid-state material derived from gel in which the liquid component of the gel has been replaced with gas. The result is an extremely low density solid with several remarkable properties, most notably its effectiveness as a thermal insulator. It is nicknamed frozen smoke, solid smoke or blue smoke due to its semi-transparent nature and the way light scatters in the material; however, it feels like expanded Styrofoam to the touch.

3.2.4 Wood

Wood is hard, fibrous, lignified structural tissue produced as secondary xylem in the stems of woody plants, notably trees but also shrubs. This tissue conducts water to the leaves and other growing tissues and has a support function, enabling plants to reach large sizes. Wood may also refer to other plant materials and tissues with comparable properties. Wood is a heterogeneous, hygroscopic, cellular and anisotropic material. Wood is composed of fibers of cellulose (40% – 50%) and hemicellulose (15% – 25%) impregnated with lignin (15% – 30%).Wood has been used for millennia for many purposes. One of its primary uses is as fuel. It is also used as for making artworks, furniture, tools, and weapons, and as a construction material.

3.2.5 Cotton

Cotton is a soft, staple fiber that grows around the seeds of the cotton plant (*Gossypium*), a shrub native to tropical and subtropical regions around the world, including India and Africa. The fiber most often is spun into yarn or thread and used to make a soft, breathable textile, which is the widely used natural-fiber cloth in clothing today.

3.2.6 Wool

Wool is the fiber derived from the fur of animals of the Caprinae family, principally sheep, but the hair of certain species of other mammals such as goats, llamas and rabbits may also be called wool. Wool has two qualities that distinguish it from hair or fur: it has scales which overlap like shingles on a roof and it is crimped; in some fleeces the wool fibers have more than 20 bends per inch.

3.2.7 Straw

Straw is an agricultural byproduct, the dry stalk of a cereal plant, after the nutrient grain or seed has been removed. Straw makes up about half of the yield of a cereal crop such as barley, oats, rice, rye or wheat. In times gone by, it was regarded as a useful by-product of the harvest, but with the advent of the combine harvester, straw has become more of a burden, almost a nuisance to farm.

Material	**Cost of material (RM)**	**Availability**	**Thermal conductivity (K) at 25 °C**	**Durability**	**Hazardous**	**Remarks**
Wool	Unknown	Available	0.029 W/(m.K)	Depends on the testing	Non hazardous	Light and good insulator
Cotton	RM 2.00	Available	0.03 W/(m.K)	1 year	Non hazardous	Light and high resistance
Glass wool	RM 2.50	Available.	0.35 W/ (m.K)	6 months	Potentially Hazardous	Flexible and elasticity.
Fiber Glass	Unknown	Available in bulk.	0.04 W/ (m.K)	>1 year	Gives ill smelling gases as heat up. Health hazards	Higher resistance and stability.

Table 3.1: Comparison of the materials with the criteria

Material	Cost of material (RM)	Availability	Thermal conductivity (K) at 25 °C	Durability	Hazardous	Remarks
Wood	unknown	Available in store	0.12-0.04 W/(m.K)	1 year	Non hazardous	High resistance but heavy
Crumpled paper	RM 1.00	Available	0.05 W/(m.K)	1 weeks	Non hazardous	Light
Straw insulation	unknown	Available	0.09 W/(m.K)	Depend on the testing	Non Hazardous	Light
Aerogel	Expensive-use in spacecraft technology	Non available.	0.003 W/ (m.K)	Excellent	Non hazardous	Strong structurally.

Table 3.1: Comparison of the materials with the criteria

3.3 Material justification

From the Table 1, there are several materials which are suitable for the insulator. Wool, cotton, glass wool, fiber glass, wood, and crumpled paper are the materials that potentially suitable as an insulator for solar cooker. The materials has good characteristic to contain heat from loss to surrounding. They have low value of K which is referring to thermal conductivity. Thermal conductivity means the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area due to a unit temperature gradient under steady state conditions. Low value of K means the ability of the material to conduct heat is limited and can be a good insulator.

From the financial aspect cotton, glass wool, wood, and crumpled paper has a low market price compare to the materials. Its easily can be bought in the hardware store or shops. Crumpled paper has insulated hundreds of successful SBCs and is the preferred insulation in many areas. The entire items are available in local market except Aerogel which is a new technology and hardly found in Malaysia. This is a new material uses in spacecraft exploration has really low value of thermal conductivity. From the aspect quality and reliability all of the materials show their own advantages. As for example glass wool has flexibility and elasticity because its fabric is fine and suitable to use as a clothes. Same goes with the durability of the material. It seems all the material has their own life time. Glass wool has a problem with the environmental aspect. The study reviewed by Health Canada has shown that short time exposure to glass wool may cause minor irritation of skin, eyes, nose and throat. This claimed not affected the author study as this material is uses for short testing and experiment only.

Based on the explanation of the above criteria, the author finally decided to pick glass wool, cotton, wool, and crumpled paper for testing and experiment. From the testing and experiment we can know exactly which is the better insulator for solar cooker. The author chooses this material from three important aspects which are cost, market availability and low thermal conductivity. These three components play important roles in author evaluation.

3.4 Experiment setup

In this experiment the primary objective is to collect the temperature reading inside the solar oven and surrounding temperature. The author only interested in finding the temperature in order to calculate the rate of the heat loss from the solar oven to surrounding. The equipment used to collect the informational data is Digital Thermometer and Solar meter. This equipment is available at the energy lab Building 18. The experiment was done at the level 3 Building 18. This place was chosen because of the high stability in term of solar radiation. There was no building blocking the sun radiation towards the solar oven and free from congestion. The experiment was done from 8 am until to 5 pm in the evening. The reading was taken every hour until the author got ten reading for each experiment. However the experiment limited by the weather factors, if it is raining in the middle of the experiment the reading is just up to that hour and the temperature reading also change. Basically there are 4 experiments consists of without insulation panel, with glass wool insulation panel, cotton insulation panel and crumple paper insulation. The experiment is conducted during of working day due to availability of the apparatus and equipment used in the experiment.

3.5 Equipment used

There are several items used in the completion of the experiment such as Digital Thermometer and Solar meter. Digital thermometer is used to measure the amount of heat of the material and Solar meter used to measure the irradiance of the solar from the sun. The unit used to measure the irradiance is W/m^2. Below is the picture of the equipments used in the experiment.

Figure 3.2: Digital Thermometer.

Figure 3.3: Solar meter

3.6 Procedure

This experiment is conducted to collect the temperature reading for solar oven and surrounding temperature. The step for this experiment is stated as below:

I. Prepare the equipment need to be used in the experiment such as solar oven, Digital Thermometer, Solar meter and insulation material.
II. Put the solar oven at the free space below the radiation of the sun. Then leave for about one hour.
III. After one hour used the digital thermometer to take the reading inside of the solar oven and surrounding temperature. Make sure the temperature reading is in ^{o}C not K. The Digital Temperature takes about 5 minutes to get the stabilize reading for each place.
IV. Simply put the Digital Temperature inside the solar oven to get the value and hold the Digital thermometer if we want the surrounding temperature.
V. Take the reading and put back the equipment in the box.
VI. For using solar meter the step is same as using the Digital Thermometer but ensure the radiation part is facing upwards when to read the solar irradiance.

3.7 Calculation

In this experiment the author just considered the heat loss due to conduction. This loss principally due to conduction heat transfer through the wall of solar oven which is separates the inside solar panel and the surrounding air. It is possible to quantify heat transfer processes in terms of appropriate rate equations. In this case, the equation rate known as Fourier's Law. For the one dimensional plane wall, having a temperature distribution T(x), the rate heat flow is expressed as:

$$q_x'' = \frac{k\Delta T}{L}$$

q_x'' = rate of heat transfer through a section of unit area.(W/m^2)

k = Thermal conductivity (W/m.K)

Δ T = Temperature gradient (K)

L = Wall thickness (m)

There are three materials used in this experiment which are glass wool, cotton and crumpled paper. The value of k is difference for each material.

Glass wool thermal conductivity	= 0.038 W/m.K
Cotton insulation	= 0.06 W/m.K
Crumple paper	= 0.18 W/m.K

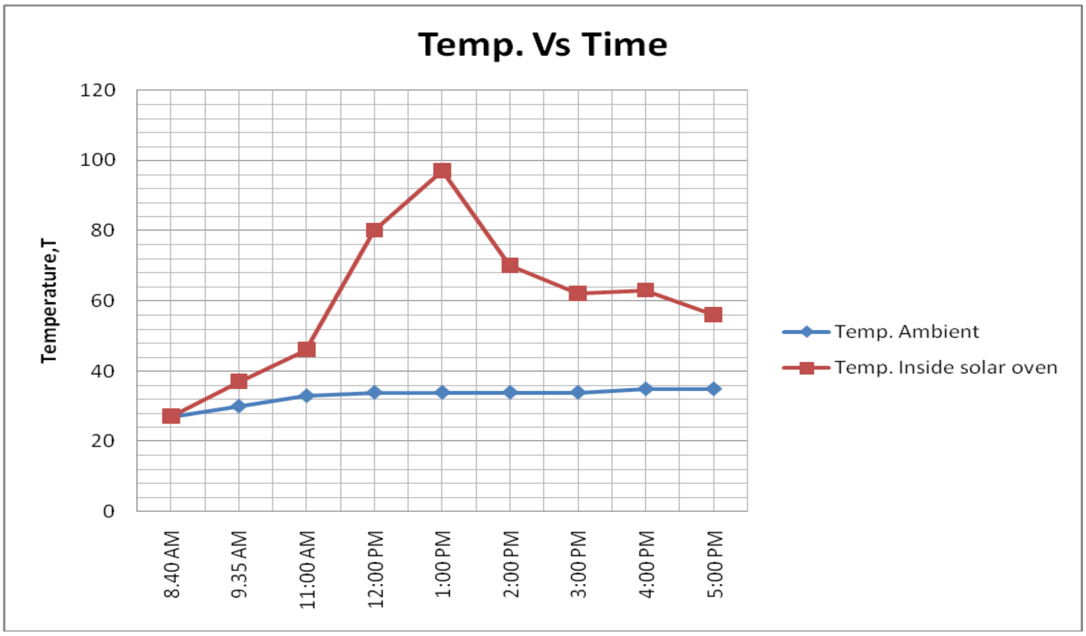
CHAPTER 4

RESULTS AND DISCUSSION

Several experiments have been conducted; there are solar oven:

- With no insulation.
- With Glass wool insulation.
- With Crumpled paper insulation.
- With Cotton insulation.

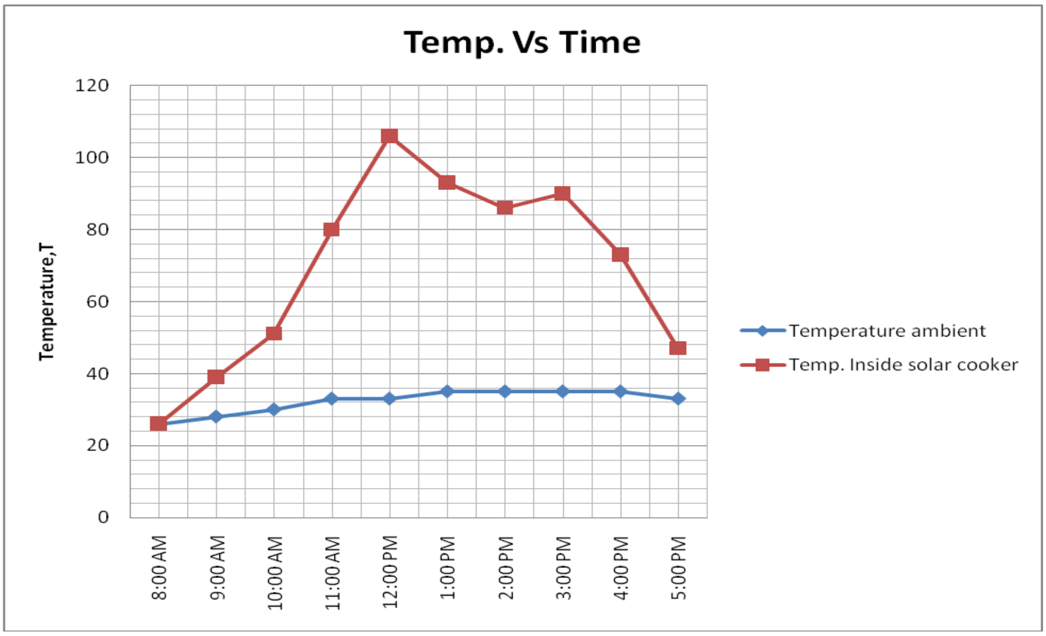
4.1 Solar oven with no insulation



Graph 4.1: Solar Oven with no insulation

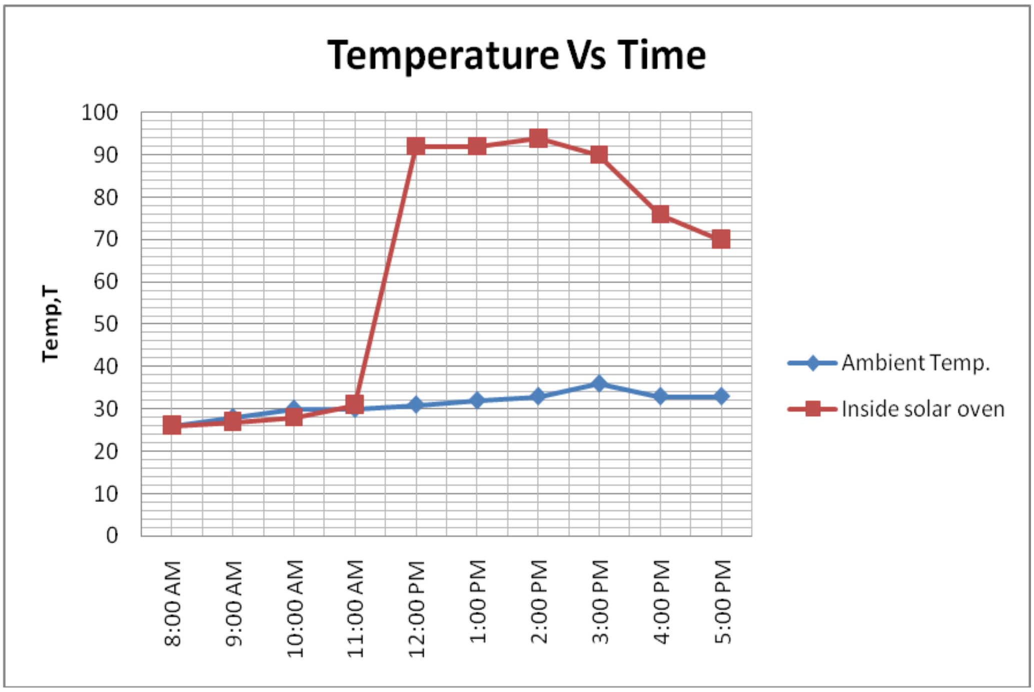
Graph 4.1 shows the result of temperature reading in a solar oven with no insulation material over period of time. The temperature reading started at 27 ºC in the morning and increasing after few hours. Ambient temperature in this graph refers to the surrounding temperature at the building. The ambient temperature is quite stabile for a period of time with no sudden increasing in temperature. Temperature reading in the solar oven started to increase after 3 hours. The highest temperature reading for the solar oven is 97ºC at 1 p.m, then after that the temperature started to decrease over time. At 1 p.m the sun is located at 90º above the head considering no cloud blocked the radiation. The weather is clear with no wind and cloud interrupts the experiment. The temperature started to decrease because of no insulation is introduced in this experiment. The insulation material supposedly to contain the heat from loss to surrounding. The temperature should be slightly higher when the insulation material is used in this experiment. The reading at 5 p.m is 56ºC after exposed to the sunlight for about 8 hours.

4.2 Solar oven with glass wool insulation



Graph 4.2: Solar Oven with Glass wool insulation (Day 1)

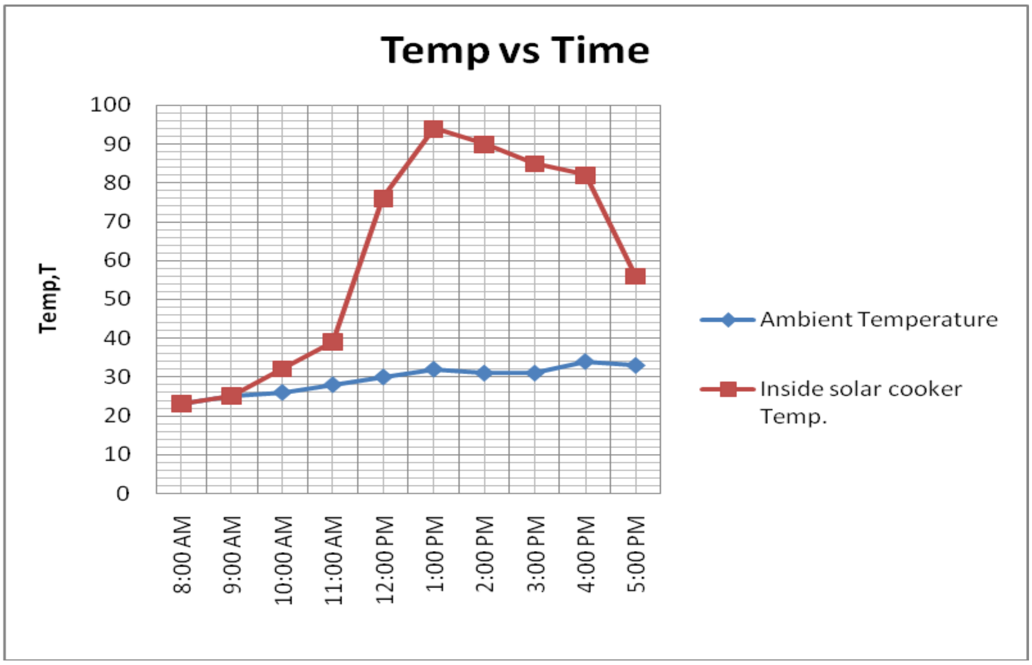
Graph 4.2 shows the result of temperature reading in a solar oven with glass wool insulation over period of time. The temperature reading started at 26 ºC in the morning and increase at every each hour. Ambient temperature in this graph refers to the surrounding temperature at the building. The ambient temperature is quite stabile for a period of time with no sudden increasing in temperature. The highest peak of temperature reading for the solar oven is 106 ºC at 12 p.m, then after that the temperature started to decrease over time. At 3 p.m the temperature in the solar oven increases again to 90ºC. This reading may due to the effect of the weather. The sun is radiates continuously with no cloud blocking the sun. After one hour the temperature started to decrease until reach 47 ºC at 5 p.m. The temperature reading in this experiment quite higher compare with no insulation material. The ability of the glass wool to trap and retain the heat cause the higher reading of temperature inside of the solar oven. This experiment is executed for about 8 hours with temperature reading is taken every each hour.



Graph 4.3: Solar Oven with Glass wool insulation (Day 2)

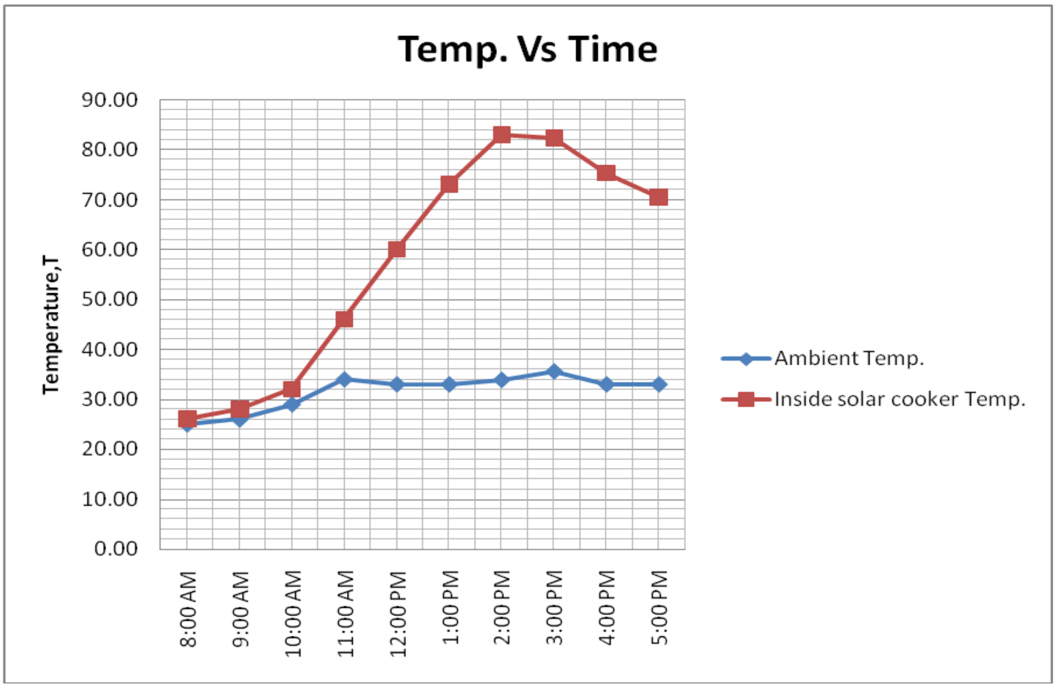
Graph 4.3 shows the graph of temperature reading in a solar oven with glass wool insulation over period of time. In this experiment cotton insulation is used to study the effect of the temperature inside of solar oven. The temperature reading started at 26 °C in the morning and no sudden increasing for 3 hours. At 12 p.m the temperature rises drastically to 92 °C. The sudden increment in temperature may due to sun radiation. The radiation that continuously absorb by the solar oven and no major heat loss to surrounding is the factor for the increment. After that the temperature is quite stabile for 4 hours before drop to76 °C at 4 p.m. The temperature reading at 5 p.m is 70°C and quite higher compare with the same material in day one. Ambient temperature in this graph refers to the surrounding temperature at the building. The ambient temperature is quite stabile for a period of time with no sudden increasing in temperature. The temperature reading in this experiment quite higher compare with no insulation material reading. The ability of the glass wool to trap and retain the heat cause the higher reading of temperature inside of the solar oven. This experiment is executed for about 8 hours with temperature reading is taken every each hour.

4.3 Solar oven with cotton insulation



Graph 4.4: Solar Oven with Cotton insulation (Day 1)

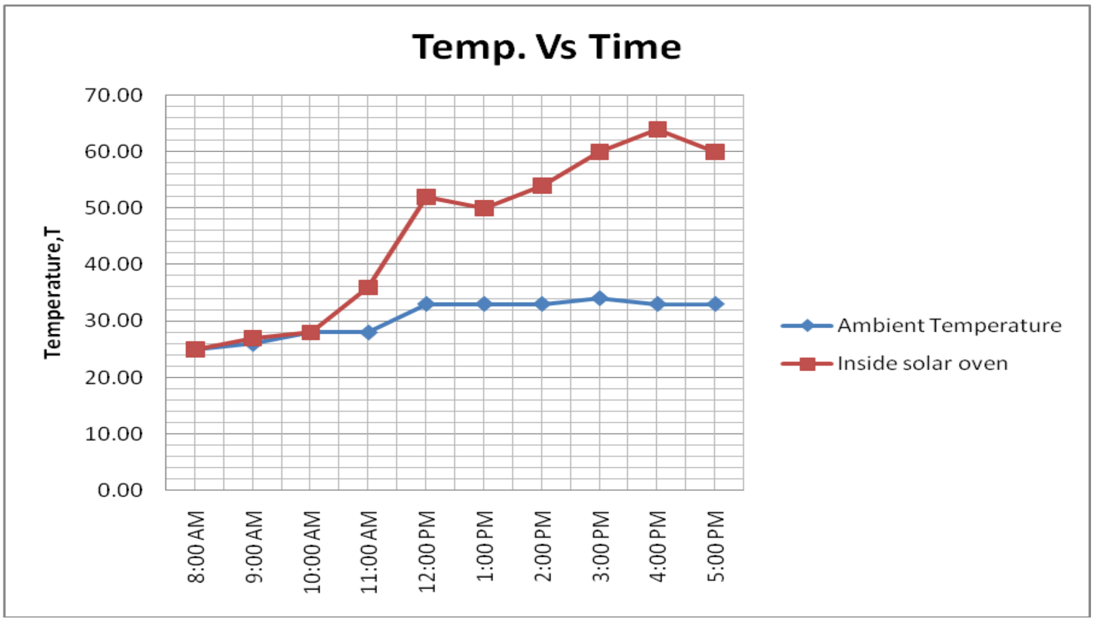
Graph 4.4 shows the graph of temperature reading in a solar oven with cotton insulation over period of time. In this experiment cotton insulation is used to study the effect of the temperature inside of solar oven. The temperature reading started at 23 °C in the 8 a.m and increase slowly hour by hour. At 1 p.m the temperature achieved the highest peak at 94 °C. The huge gap of temperature increment happens between 11 a.m to 12 p.m. The temperature increases about 37 °C in one hour. This happen either the effects of the weather or the sensitivity of the temperature equipment. After 12 p.m the temperature started to decrease gradually for the next 3 hours. The temperature reading at 5 p.m is about 56 °C and little bit low compare with glass wool insulation. Ambient temperature in this graph refers to the surrounding temperature at the building. The ambient temperature is quite stabile for a period of time with no sudden increasing in temperature. The temperature reading in this experiment is quite higher compare with no insulation material reading. The ability of the cotton to trap and retain the heat causes the higher reading of temperature inside of the solar oven. This experiment is executed for about 8 hours with temperature reading is taken every each hour.



Graph 4.5: Solar Oven with Cotton insulation (Day 2)

Graph 4.5 shows the graph of temperature reading in a solar oven with cotton insulation over period of time. In this experiment cotton insulation is used to study the effect of the temperature inside of solar oven. The temperature reading started at 26 ᵒC in the 8 a.m and increase slowly hour by hour. At 2 p.m the temperature achieved the highest peak at 83 ᵒC. The temperature is increase evenly for this experiment as we can see the curve until its reach the top. This happen either the effects of the weather which is no cloud and wind situation occurred. After 2 p.m the temperature started to decrease gradually for the next 3 hours. The temperature reading at 5 p.m is about 70 ᵒC and quite higher compare with the same experiment last day. This result could be related with the sunlight which sometimes the sun radiates vibrantly until 6 p.m.Ambient temperatures in this graph refers to the surrounding temperature at the building. The ambient temperature is fluctuated for a period of time but still in control. The temperature reading in this experiment is quite higher compare with no insulation material reading. The ability of the cotton to trap and retain the heat causes the higher reading of temperature inside of the solar oven. This experiment is going on for about 8 hours with temperature reading is taken every each hour.

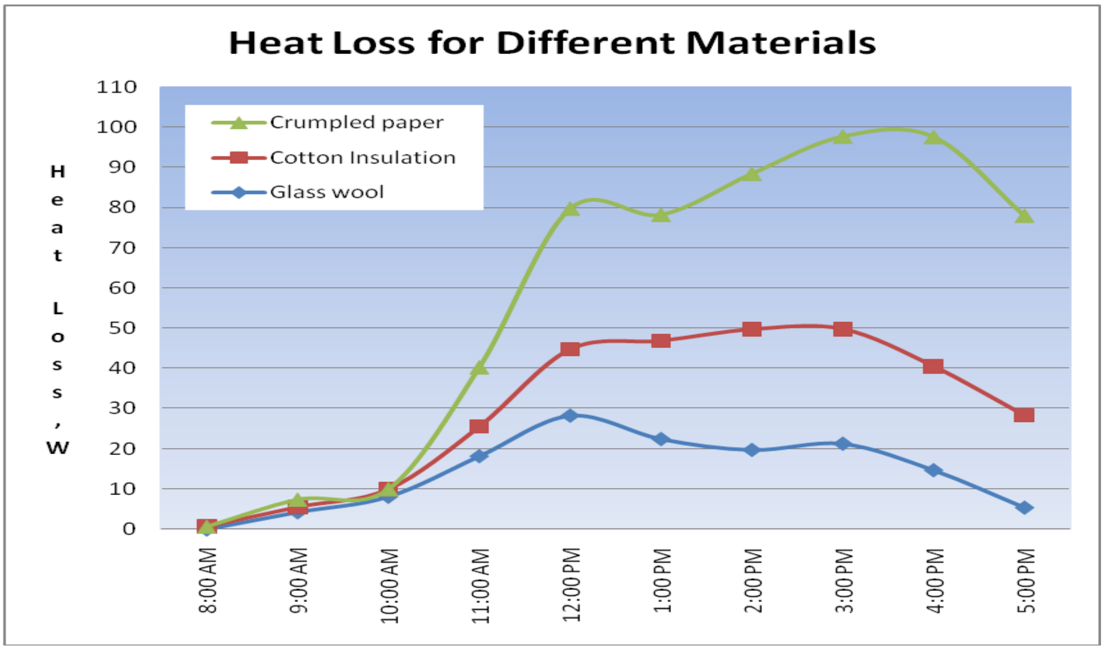
4.4 Solar oven with crumpled paper insulation



Graph 4.6: Solar Oven with Crumpled paper insulation

Graph 4.6 shows the graph of temperature reading in a solar oven with crumpled paper insulation over period of time. In this experiment crumpled paper insulation is used to study the effect of the temperature inside of solar oven. The temperature reading started at 25 ᵒC in the 8 a.m and relatively maintain at the ambient temperature. The temperature starts to increase and reached the first peak at 12 p.m with 52 ᵒC and then drop a little bit to 50 ᵒC at 1 p.m. Then temperature increase again until reached the second peak at 4 p.m with 64 ᵒC. The strange temperature gradient with two peaks occurred maybe because of the setup of the experiment is not appropriate. The error in the equipment used also maybe a cause for this result. Furthermore more experiment needs to be done to ensure the reliability of the result. An ambient temperature in this graph refers to the surrounding temperature at the building. The ambient temperature is quite stabile for a period of time but there is increment at 12 p.m in the noon. The temperature reading in this experiment is quite lower compare with previous experiment which has been used glass wool and cotton insulation.

4.5 Comparison of heat loss between three materials



Graph 4.7: Heat Loss for different materials.

Graph 4.7 shows three different materials which consist of glass wool, cotton and crumpled paper with corresponding of the heat loss. It is clearly shown that crumple paper had a tremendous amount of heat loss compared with other two materials. The amount of heat loss for crumpled paper at 333 K is 48 W. The cotton insulation at 333 K is about 17 W and glass wool insulation at 333 K is 8 W. The huge amount of heat loss from the crumple paper told us that this material is not capable acted as an insulator in the solar oven. Supposedly crumpled paper is a good insulation material as it has air gap in the material. Air is such a good insulator because the low thermal conductivity. Furthermore, a better explanation could be done to reveal what are the causes for this result. Cotton insulation shows a smooth and nice curve with the corresponding heat loss. The amount of heat loss is moderate and more reliable compared with the crumple newspaper. Glass wool seems to be the effective heat insulation in the solar oven. The amount of the heat loss is less and could be reduce by adding the thickness. In this experiment the thickness is constant with 0.005 m and the area of the wall is $0.051 m^2$. The graph shown is connected with the thermal conductivity of the material.

$$K_{\text{glass wool}} < K_{\text{cotton}} < K_{\text{crumpled paper}}$$

4.6 Insulation system

Thermal insulations consist of low thermal conductivity materials combined to achieve an ever lower system thermal conductivity. In conventional fiber, powder, and flake type insulations, the solid material is finely dispersed throughout an air space. Such systems are characterized by an effective thermal conductivity, which depends on the thermal conductivity and surface radiative properties of the solid material as well as the nature and volumetric fraction of the air or void space. A special parameter of the system is its bulk density (solid mass/ total volume) which depends strongly on the manner in which the material is packed.

If small voids or hollow spaces are formed by bonding or fusing portions of the solid material, a rigid matrix is created. When these spaces are sealed from each other, the system is referred to as cellular insulation. Examples of such rigid insulations are foamed systems, particularly those made from plastic and glass materials. Reflective insulations are composed of multilayered, parallel, thin sheets or foils of high reflectivity which are spaced to reflect radiant energy back to its source. The spacing between the foils is designed to restrict the motion of air, and in high performance insulations, the space is evacuated. In all types of insulation, evacuation of the air in the void space will reduce the effective thermal conductivity of the system.

It is important to recognize that heat transfer through any of this insulation system may include several modes: conduction through the solid materials, conduction or convection through the air in the void spaces, and radiation exchange between the surfaces of the solid matrix [20].

CHAPTER 5

CONCLUSION AND RECOMENDATION

As a conclusion, the author successfully achieved the objective of this project to study the relevant insulation material for the solar oven. The author concludes that glass wool is the best insulation material compared with cotton and crumpled paper. The glass wool is chosen based on low cost, market availability and low thermal conductivity. Result from the experiment also shows that glass wool is a good insulator with less heat loss to surrounding. The amount of heat loss through glass wool is just about 8 W at 333 K at the same temperature with other material. This result clearly indicates that glass wool is the best and cheaper solution.

The author also makes recommendation to improve this project:

I. Consider few factors during the execution of the experiment such as the location, the equipment used, the procedure and types of insulation material.
II. Follow the standard of the procedure during the experiment stage to improve the professionalism of the studies and research.

REFERENCES

[1] N.M Nahar, 1981, Design, development and testing of a double reflector hot box solar cooker with a transparent insulation material. New York: Pergamon Press, Pg 1-5.

[2] Ghai ML. Design of reflector type direct solar cooker. J Sci Ind Res 1953; 12A:165–75

[3] Ghai ML, Pandhar BS, Dass H. Manufacture of reflector type direct solar cooker. J Sci Ind Res 1953; 12A:212–6

[4] Abot CG. Smithsonian Misc. Cells 1939;98

[5] Alward R. Solar steam cooker. In: Do it yourself leaflet L-2. Quebec (Canada): Brace Research Institute, 1972

[6] Garg HP, Thanvi KP. Studies on solar steam cooker. Indian Farming 1977; 27(1):23–4.

[7] Parikh M, Parikh R. Design of flat plate solar cooker for rural applications. In: Proceedings of the National Solar Energy Convention of India; Bhavnagar. Bhavnagar (India): Central Salts and Marine Chemical Research Institute, 1978:257-61.

[8] MNES. Annual Report 1998–99. New Delhi: Ministry of Non-conventional Energy Sources, Government of India, 1999.

[9] Gupta JP, Purohit MM. Role of renewable energy sources for mitigation of cooking fuel problem. Trans Indian Soc Desert Techno Univ Centre Desert Stud 1986; 11(1):7–17.

[10] Nahar NM, Marshall RH, Brinkworth BJ. Studies on a hot box solar cooker with transparent insulating materials. Energy Conv Mgmt 1994; 35:784–91.

[11] Hollands KGT. Honey comb devices in flat-plate solar collectors. Solar Energy 1965; 9:159–64.

[12] Goetzberger A, Schmid J, Wittwer V. Transparent insulation system for passive solar energy utilization in buildings. Int J Solar Energy 1984; 2:289 308.

[13] Goetzberger A, Dengler J, Rommel M, Gottsche J, Wittwer V. A new transparently insulated bifacially irradiated solar flat-plate collector. Solar Energy 1992; 49:403–11.

[14] Hollands KGT, Iynkaran K, Ford C, Platzer W. Manufacture, solar transmission, and heat transfer characteristics of large-celled honeycomb transparent insulation. Solar Energy 1992; 49:381–5.

[15] Nordgaard A, Beckman WA. Modelling of flat-plate collectors based on monolithic silica aerogel.Solar Energy 1992; 49:387–402.

[16] Platzer WJ. Total heat transport data for plastic honeycomb-type structures. Solar Energy 1992; 49:351–8.

[17] Platzer WJ. Directional-hemispherical solar transmittance data for plastic honeycomb-type structures. Solar Energy 1992; 49:359–69.

[18] Nahar NM, Marshall RH, Brinkworth BJ. Investigations of flat plate collectors using transparent insulation materials. Int J Solar Energy 1995; 17:117–34.

[19] Dr Ed Pejack. Technology of solar cooking, pg 1-17.

[20] Incropera, Dewitt, Bergman, Lavine, 2007 Introduction to Heat Transfer, Wiley Asia Student Edition, Pg 66-67.

APPENDIX

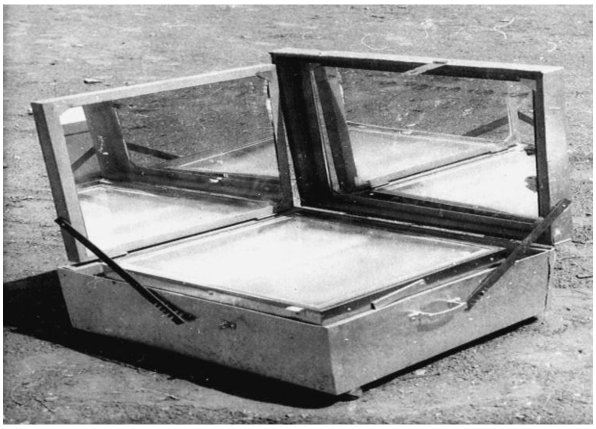


Figure 1: Double reflector solar cooker.

Experiment 1 : Solar Oven with No insulation material.

Date : July 28, 2008

Time : 8.40 AM- 5.00 PM

Venue : Level 3 Building 18

Equipments : Solar cooker, Digital Temperature.

Time	Temperature ambient (ºC)	Temperature in (ºC)
8.40 AM	27	27
9.35 AM	30	37
11:00 AM	33	46
12:00 PM	34	80
1:00 PM	34	97
2:00 PM	34	70
3:00 PM	34	62
4:00 PM	35	63
5:00 PM	35	56

Table 1: Temperature profile with no insulation

Experiment 2 : Solar Oven with Glass wool (1st day)

Date : July 30, 2008

Time : 8.00 AM- 5.00 PM

Venue : Level 3 Building 18

Equipments : Solar cooker, Digital Temperature.

Time	Temperature ambient (ºC)	Temperature in (ºC)
8.00 AM	26	26
9.00 AM	28	39
10.00 AM	30	51
11:00 AM	33	80
12:00 PM	33	106
1:00 PM	35	93
2:00 PM	35	86
3:00 PM	35	90
4:00 PM	35	73
5:00 PM	33	47

Table 2: Temperature reading for Glass wool insulation.

Experiment 3 : Solar Oven with Glass wool (2^{nd} Day)

Date : July 31, 2008

Time : 8.00 AM- 5.00 PM

Venue : Level 3 Building 18

Equipments : Solar cooker, Digital Temperature.

Time	Temperature ambient (°C)	Temperature in (°C)
8:00 AM	26	26
9:00 AM	28	27
10:00 AM	30	28
11:00 AM	30	31
12:00 PM	31	92
1:00 PM	32	92
2:00 PM	33	94
3:00 PM	36	90
4:00 PM	33	76
5:00 PM	33	70

Table 3: Temperature reading for Glass wool insulation

Experiment 4 : Solar Oven with Cotton Insulation (1^{st} Day)

Date : Aug 4, 2008

Time : 8.00 AM- 5.00 PM

Venue : Level 3 Building 18

Equipments : Solar cooker, Digital Temperature.

Time	Temperature ambient (°C)	Temperature in (°C)
8:00 AM	23	23
9:00 AM	25	25
10:00 AM	26	32
11:00 AM	28	39
12:00 PM	30	76
1:00 PM	32	94
2:00 PM	31	90
3:00 PM	31	85
4:00 PM	34	82
5:00 PM	33	56

Table 4 : Temperature reading for Cotton insulation.

Experiment 5 : Solar Oven with Cotton Insulation (2nd Day)

Date : Aug 5, 2008

Time : 8.00 AM- 5.00 PM

Venue : Level 3 Building 18

Equipments : Solar cooker, Digital Temperature, Solarmeter.

Time	Temperature ambient (°C)	Temperature in (°C)	Solar meter (W/m^2)
8:00 AM	25.00	26.00	-
9:00 AM	26.00	28.00	-
10:00 AM	29.00	32.00	-
11:00 AM	34.00	46.00	1.818
12:00 PM	33.00	60.00	1.809
1:00 PM	33.00	73.00	1.815
2:00 PM	33.90	83.00	1.806
3:00 PM	35.60	82.30	1.812
4:00 PM	33.00	75.30	1.863
5:00 PM	33.00	70.50	1.863

Table 5: Temperature reading for Cotton insulation.

Experiment 6 : Solar Oven with Crumple newspaper Insulation

Date : Aug 20, 2008

Time : 8.00 AM- 5.00 PM

Venue : Level 3 Building 18

Equipments : Solar cooker, Digital Temperature, Solarmeter.

Time	Temperature ambient (°C)	Temperature in (°C)	Solar meter (W/m^2)
8:00 AM	25.00	25.00	-
9:00 AM	26.00	27.00	-
10:00 AM	28.00	28.00	173.23
11:00 AM	28.00	36.00	227.50
12:00 PM	33.00	52.00	658.30
1:00 PM	33.00	50.00	380.00
2:00 PM	33.00	54.00	734.00
3:00 PM	34.00	60.00	719.00
4:00 PM	33.00	64.00	680.00
5:00 PM	33.00	60.00	676.00

Table 6: Temperature reading for Crumple newspaper insulation

Insulation material= Glass wool				
Ambient Temperature (K)	Inside solar oven Temperature (K)	Temperature Gradient (K)	Rate of heat loss (W/m^2)	Heat Loss (W)
299	299	0	0.00	0
301	312	11	83.60	4.2636
303	324	21	159.60	8.1396
306	353	47	357.20	18.2172
306	379	73	554.80	28.2948
308	366	58	440.80	22.4808
308	359	51	387.60	19.7676
308	363	55	418.00	21.318
308	346	38	288.80	14.7288
306	320	14	106.40	5.4264

Table 7: Heat loss through Glass wool insulation

Insulation material= Cotton insulation				
Ambient Temperature (K)	Inside solar oven Temperature (K)	Temperature Gradient (K)	Rate of heat loss (W/m^2)	Heat Loss (W)
298	299	1	12.00	0.612
299	301	2	24.00	1.224
302	305	3	36.00	1.836
307	319	12	144.00	7.344
306	333	27	324.00	16.524
306	346	40	480.00	24.48
306.9	356	49.1	589.20	30.0492
308.6	355.3	46.7	560.40	28.5804
306	348.3	42.3	507.60	25.8876
306	343.5	37.5	450.00	22.95

Table 8: Heat loss through Cotton insulation

Insulation material= Crumple newspaper				
Ambient Temperature (K)	Inside solar oven Temperature (K)	Temperature Gradient (K)	Rate of heat loss (W/m^2)	Heat Loss (W)
298	298	0	0.00	0.00
299	300	1	36.00	1.84
301	301	0	0.00	0.00
301	309	8	288.00	14.69
306	325	19	684.00	34.88
306	323	17	612.00	31.21
306	327	21	756.00	38.56
307	333	26	936.00	47.74
306	337	31	1116.00	56.92
306	333	27	972.00	49.57

Table 9: Heat loss through crumpled paper insulation