“**ENERGY ANALYSIS OF DIFFERENT GEOMETRIES OF BOX TYPE SOLAR COOKER**”

A Thesis submitted to the

University of Petroleum and Energy Studies

For the Award of

Doctor of Philosophy

In

Engineering

By

Geetanjali Raghav

May.2022

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Geetanjali Raghav

ABSTRACT

Cooking has been identified as one of the most common house hold work for every house. In rural villages the transportation of fuel like LPG is a major challenge and the continuously rising demand of energy for cooking is diverting the shift towards solar cookers and various researches have been carried out for improvement in the performance of the solar cookers.

In a box type solar cooker, the process of thermal analysis is very tedious and complex as a three-dimensional transient heat transfers are involved in the analysis.

There are various standards being used for thermal performance analysis and BIS Standard describes the analysis in terms of two figures of merit .The first Fig of merit is determined by from steady state test and also known as no load test, while second figure of merit is known as full load test.

Present work involves preliminary analytical and then the experimental studies on the effect of climatic and operating variables viz. sky temperature (T_s), ambient temperature (T_a), solar radiation (I), plate temperature (T_p) and wind heat transfer coefficient, (h_w), on thermal performance (overall heat loss coefficient (U_L) and on first Figure of merit and second Figure of merit of solar cooker.

Based on the effect observed of the above-mentioned variables on thermal performance, the correlations were developed for first Fig of merit, overall heat transfer coefficient and wind heat transfer coefficient in terms of directly measured and simple variables. The developed correlations were established against the correlations reported in literature.

The testing of different geometries of solar cookers has been carried out as per BIS standard without external reflectors under similar environmental condition using the developed correlations. Experiments were conducted on an experimental setup of box type solar cooker test setup and its different geometries along with a test plate which were fabricated and installed in the alternate energy lab, University of Petroleum and Energy Studies, Dehradun, India. The integrated system was evaluated to achieve the enhancement in thermal performance of the system.

Present work analyzes the effects on thermal performance of box-type solar cookers of various climatic and operating parameters and compares different geometries and their effects on thermal performance enhancement. An analysis of the standard correlation available is performed to determine the accuracy of predicted results.

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NOMENCLATURE

A	aperture area of cooker (m^2)
A_p	aperture area of absorber plate of unglazed test plate (m^2)
C_p	specific heat of unglazed test plate (J/kgK)
h_w	wind heat transfer coefficient (W/m^2K)
I	instantaneous value of solar radiation (W/m^2)
k	thermal conductivity of air (W/mK)
k_a	thermal conductivity of cement asbestos ((W/mK)
k_{gw}	thermal conductivity of glass wool (W/mK)
L	thickness of glass cover (m)
L_1	air gap spacing between absorber plate and inner glass cover (m)
L_2	air gap spacing between inner and outer glass cover (m)
a_L	thickness of asbestos sheet (m)
L_{cs}	thickness of cement slab (m)
L_{gw}	thickness of glass wool (m)
Q_a	rate of heat absorbed by test plate per unit area (W/m^2)
$Q_{b''}$	bottom heat loss flux (W/m^2)
Q_c	rate of convective heat loss per unit area of test plate (W/m^2)
Q_r	rate of radiative heat loss per unit area of test plate (W/m^2)
Q_s	Sensible heat absorbed rate to test plate temperature rise per unit area (W/m^2)
$'T_p$	thickness of test plate (m)
T_{as}	ambient temperature at stagnation (K)
Tp	average test plate temperature (K)
T_{mp1}	mean temperature of absorber plate and inner glass cover (K)
T_{m12}	mean temperature of inner and outer glass cover (K)
U_L	overall heat loss coefficient ($W/m^2\ °C$)
U_t	top heat loss coefficient ($W/m^2\ °C$)

U_b	bottom heat loss coefficient ($W/m^2\ °C$)
U_s	side heat loss coefficient ($W/m^2\ °C$)
α_p	absorptivity of the test plate
ε_p	emissivity of the test plate
εg	emissivity of glass
ρ	mass density of test plate (kg/m^3)
σ	Stefan-Boltzmann constant (W/m^2K^4)
dT	difference of temperature of test plate during the time interval (*sec*)
T_{it}	top insulation temperature of the test plate (K)
T_{ib}	bottom insulation temperature of the test plate (K)

1 CHAPTER:

INTRODUCTION

1.1 INTRODUCTION

सविता प्रसवानामधिपतिः ॥ Sun is the ultimate source of energy and responsible for all the life forms exist on Earth. In ancient Indian texts such as Atharva Ved are also telling the importance of Sun as the energy source: is a basic ingredient needed to sustain life and development. Energy is required in various forms to fulfil our day-to-day requirements. Per capita energy consumption is the reflection of the health of any economy. Responsibility of the government is to provide clean and sustainable options to its citizens (SDG 7). With the governments there are two options to opt from renewable and non-renewable sources of energy. Non-renewable energy sources such as fossil fuels (coal, crude oil and natural gas) are limited in amount and also produce environmental hazards and therefore provides dirty power. Therefore, governments are trying to search for more sustainable energy source from the bouquet of renewable energy sources. Here also challenges are plenty. The biggest challenge is feasibility of converting it into useful energy. After exhaustive research in solar energy, now this perineal source of energy is feasible to use even at the household level.

1.2 SOLAR ENERGY

Energy from sun is received in the form of radiation on Earth. To design any solar equipment or system a knowledge of solar radiation characteristics is required. The intensity of solar radiation is not constant and vary with variation in the geographical location in terms of longitude and latitude. Sun can easily be assumed as a sphere of a gaseous matter having a diameter of 1.39×10^6 km and is around 1.5×10^8 km far from earth. The central region of the earth contains the temperature in the range of 8×10^6 to 40×10^6 K .The fluid density of the sun is 80 to 100 times that of the density of water (Sukhatme,1986). The surface of the sun can considered to be an effective blackbody with temperature of approximately 5762 K. The energy received by the earth surface is approx. 1.8×10^{11} MW, much greater than our present energy consumption (Beckman et al., n.d.) The solar radiation that is received by the earth's surface consists of two main components (Beckman et al., n.d.).

Direct radiation which is also known as beam radiation as it falls on the earth surface without any fluctuation in direction.

Diffuse radiation, which falls on the earth after being scattered and also includes re-radiation of solar energy by dust particles, water vapors and air molecules.

1.3 SOLAR ENERGY UTILIZATION

As discussed previously, Sun is responsible for all life forms found on Earth. Winds are flowing because of uneven heating of earth surface. The plant kingdom stores the solar energy in terms of carbohydrates which is the result of photosynthesis. So, one can easily say that all the renewable energy sources is because of Sun. All these forms of renewable source of energy can be termed as indirect solar energy usage. Solar energy is directly used in the form of thermal and photovoltaic application. In the present work, the thermal application of solar energy was utilized in the box type solar cookers.

1.4 SOLAR COOKING

In developing and under develop world, households are chiefly dependent on biomass for cooking. The biomass stoves which are used in this part of the world are very inefficient and generates lot of smoke and primarily responsible for ill health of women folk. In the early 60's solar cooking concept was come up. In 70's this concept was gaining the required traction in Indian scientific community, and mainly because of smoke less cooking and cleaner environment.

In India, the lower middle class and lower class households spending around 70%

of their earnings on energy requirements for cooking. Although in the urban sector is inclined towards LPG.As per the data released by ministry of statistics still 60% of houses are still using wood for cooking food .and there is a decline of only twelve percent.

Even after 5 decades, solar cookers are not very popular in the modern Indian household because of many reasons. The first and foremost cooking time and also the principle of cooking being adopted in Indian scenario ,which is different from rest of the world , is also a major factor.

1.4.1 Principles of Cooking

There are four types of cooking, namely boiling, frying, baking and roasting. When In case of boiling the heat is being .transferred to the solid food from the heated medium .Frying is similar to boiling. While in baking, heat is being transferred by both modes like convection from surrounding to heated air and also radiation from hot surfaces to the. In any cooking process, food has first to be raised to the cooking temperature It should then be kept up with at this temperature for a period adequate for viable decomposing, coagulating, separating, concentrating or different changes required. The amounts of intensity of heat required for the majority of these physical and compound changes associated with cooking are negligible. These chemical heat conversions are not significant in comparison with the heat required to raise the temperature, and the heat losses normally being considered in cooking.

Most foods contain a high portion of water and heating them to cooking temperature requires nearly 1 kcal/kg ºC. The higher the heat input rate to the container (food +cooking liquid) the food will be the faster heated to the cooking temperature. Then except where water vaporization is necessary part of cooking process, the speed of cooking is practically independent of heat rate as long as thermal losses are supplied. Therefore difference in time required for equal quantities of food being cooked in cookers of different heat capacity are mainly due to different heat up periods.

1.4.2 Types of Solar Cookers

Solar cookers can be classified into three broad categories. Different classifications has been mentioned in Fig 1.1 and 1.2.

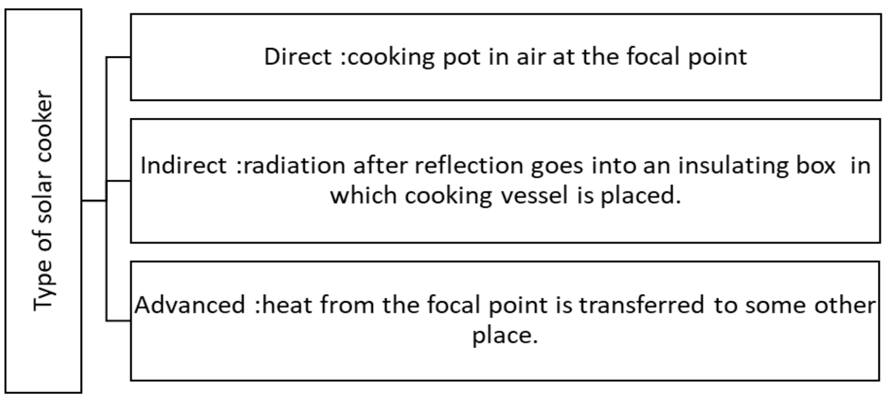

Figure 1.1Classification of solar cookers based on principle

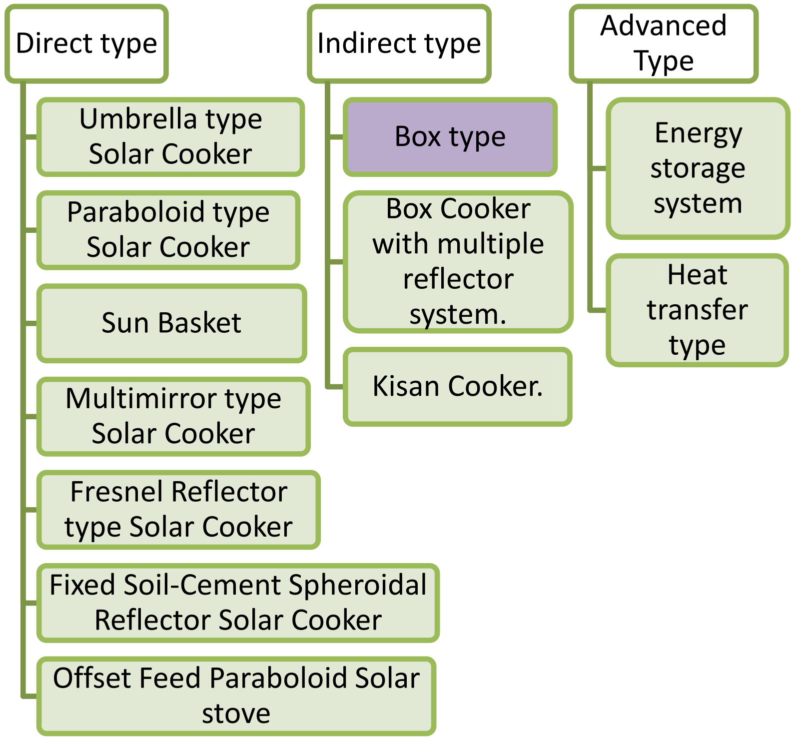

Figure 1.2 Classification of solar cooker

1.4.2.1 Box Type Solar Cooker

A box type solar cooker consists of a rectangular enclosure which is usually fabricated with fiber-reinforced plastic (FRP)/galvanized iron (GI)/aluminum sheet as shown in Fig. 1.3. A trapezoidal, blackened aluminum tray is housed in the enclosure to absorb solar radiation. Generally, thick glass wool padding of 5 cm (or more) is used to insulate the tray from the outer enclosure. The tray is covered with a double glass lid that has a separation of 1 cm between two 3-4 mm thick glass plates. The lower glass plate is usually toughened to avoid cracking during cooking. A reflector is usually attached with inner side of the cover to enhance solar radiation input. Flat bottom, circular, blackened aluminum/stainless steel pots are normally used for cooking. In a box type solar cooker, temperature around 100˚C is achieved which is suitable for boiling type cooking.

The great advantage of box type solar cooker is its design which is simple to operate. It does not need any attention because of the fact that the food never gets overcooked or damaged. Food is cooked without any fuel consumption. User can cook not only food, but roast and bake are also the applications of this cooker. The solar cooker find its application in both rural and urban households. In the rural sector it saves village people from travel miles in search of scraps of firewood. In the urban sector it saves energy on kerosene and LPG and makes the cooking process comfortable.

Figure 1.3 ***Box type solar cooker***

1.4.2.2 Reservoir Cooker

Reservoir cooker is also known as cooker with storage capacity which gathers sunlight based energy during the day and can store it in a medium like unrefined petroleum (petrol) for some time during non-sunshine hours. The oil is stored in a profoundly protected container with insulation to store the thermal energy for quite a while, regularly 24 hours, this makes it possible for the system to be used even at night in the rooms.

While cooking, the detachment plate ought to be eliminated to put the cooking pot on an iron plate lying underneath it. It tends to be worked with something like three reservoirs and three pot spaces at removal. These cooker are up to this point better with just a single drawback of a significant expense during fabrication.

1.4.2.3 **Steam Cooker**

This cooker collects the sunshine in a large area which is transformed, into steam. The steam produced is floated in upward direction to the uppermost area where pot being used for cooking has been placed on an insulated container. The design receives maximum solar thermal energy collection because of the large surface area of the collector. Whereas the energy expense of this device is relatively low and its highest temperature is around 100℃.

1.4.2.4 Dish Solar Cooker

Dish type solar cooker is a concentrating type used in homes & small areas. A typical dish type solar cooker has an aperture diameter of 1.4 m and focal length of 0.28 m .The reflecting material used for this cooker is anodized aluminum sheet, having a reflectivity 80%. The tracking system is manual and requires adjustment in every 15 to 20 minutes during cooking time. The highest temperature achieved in the container ranges from 350 to 400^{o} C, which is sufficient for roasting, frying and boiling.

The cooker claiming a thermal efficiency of approximately 50% and can cater the needs of at least 15 people therefore suitable to use for one hour after sunrise. It can be dismantled and again assembly is also easy for the user therefore transportation is easy .pot is placed at a user convenient location hence these characteristics make the cooker user friendly. Thus, at the small level, a solar cooker proves to be financial saving option for the consumer, while at the larger level; it plays a significant role in preserving precious natural resources .Moreover, it also helps in reducing the greenhouse effect as shown in Fig 1.4

Figure 1.4 Dish type solar cooker

1.4.2.5 **Community Solar Cooker (Scheffler)**

The solar cooker developed by Scheffler, of Switzerland, has the advantage of cooking food inside the kitchen itself as shown in Fig 1.5. This is the latest in community solar cooker designs.

There has been a significant research in the area of development of solar cookers and various other aspects such as thermal performance of solar cookers, performance testing standards and their comparison and a lot more. This has been discussed in detail in subsequent chapter.

Figure 1.5Community solar cooker
(https://solarcooking.fandom.com/wiki/Community_Solar_Cooker_3_SQ_MT)

2 CHAPTER: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter deals with the literature associated with development of solar thermal energy collection devices, their performance analysis and the review of the standards used for the testing and performance evaluation of the solar cooker.

2.2 HISTORY AND DEVELOPMENT OF SOLAR COOKERS

The history of development of solar thermal energy collection devices goes back to 16^{th} century when a German physicist, E.W. Von Tschirnhousen, uses big lenses to boil water in a pot made with clay. Nicoholas-de-Saussure (1740-1799) reported this in his first study .In Africa, John Fedrick Herschell, an Englishman was the first user. He designed a black box of hardwood containing a double glass window sand was acting as an insulation material and a temperature of 116ºC was attained. The first solar furnace in modern times was fabricated in France by George Louis Leclere Buffon n (1707-1788). Whereas the first reference relating to solar cooking was that of Nicholas-de-Saussure (1740-1799)(Kroposki & Margolis, 2009).

Augustin Mouchot(1860s and 70s) combined the container heat trap and burning mirrors concepts and develop a solar oven and subsequently a solar pump and finally the first solar steam engine.

Dr. Charles G. Abbot, Secretary of the American Smithsonian Institution, was the main kept designer of solar cookers in which the thermal collector was outside in the sun yet the actual cooker was in the house, with heat conveyed from collector to cooker by circling oil.

In 1876, in India an octagonal oven with 8 mirrors was developed by W. Adams for the purpose of cooking food for 7 soldiers in a duration of 2 hours .In 1884, atop

Mount Whitney at an altitude of over 4 km in California, Dr. Samuel P. Langley, solar cooked meals using box type solar cooker. While Clarence Kemp 'father of solar energy in the USA,' designed a solar water heater which gained a high traction in California.

In 1940s - 70s few mix kinds of sun based cookers, incorporating some with heat maintenance synthetic compounds were explored by Maria Telkes in the USA.

In 1945, India also inclined towards exploring solar energy as an alternative to dwindling wood and soil erosion and depletion from burning crop residues and dung, keeping this issue in mind, Indian pioneer Sri M. K. Ghosh proposed the first commercially produced solar box cooker

Indian scientists in government laboratories designed and manufactured commercial solar ovens and solar reflectors, but they weren't readily accepted, partly because there were still lower-cost alternatives.

Farrington Daniels University of Wisconsin, USA, presented concentrator cookers in northern Mexico, which gained some appreciation t, and Tom Lawand et al, Brace Research Institute at McGill U., Canada, tried steam cookers in a few developing l nations, yet here there were still cheaper alternatives for families

In 1955, The International Solar Energy Society started as an Association for Applied Solar Energy, where practical solar cookers were displayed in first conference in Phoenix, AZ, USA. Exhibited solar cookers were of various researchers like parabolic by J.L. Ghai of India, Adnan Tarcici (Lebanon) and S. Goto (Japan), Georg O.G. Löf (US), and box type cookers by Freddy Ba Hli (Burma) and Maria Telkes (US).

In 1959 The U. N. Food and Agriculture Organization (FAO) measured water-heating capacities of a parabolic cooker and an oven type cooker.

In 1960s The U.N. tried a few pilot projects with a variety of elaborate devices designed by engineers with little or no attention to consumer needs, then blamed 'resistance to change' for lack of immediate intensive use.

In1970s Spreading deforestation prompted research and promotion of solar cooking by governments of China and India. A petroleum shortage temporarily created new interest in renewable energy worldwide.

In 1973 Barbara Kerr, USA, developed various concentrator and box type solar cookers, including Ghosh's box cooker in India. She developed low cost, simple solar cooker through the utilization of simplest materials inspired by retained heat cookers ('hay boxes') and aluminum foil.

In 1979 The Organization of African Unity held the first of 7 meetings on New, Renewable and Solar Energies. The latest was in 2000 in Dares Salaam, Tanzania. Dr. Metcalf, with understudy Marshall Longvin archived water purification in sun powered box cookers.

In 1980s, the governments of India and China extended public advancement of box cookers and concentrators separately.

In India, Nahar *et al.* (1996) and Singh (1993) tried and tested the larger versions of such box-type cookers. The Chinese type and Brace Research Institute Designs, called food warmer (1HVITA 1961) appear to be similar designs. It is called as Sun stove. Kumar and Kishore (1994) made the box circular.

Various other areas in box type solar cooker were explored through research like changes for the cooking vessels, like fixing knobs for the lid, making a concave lid of the vessel.

The performance evaluation of solar cookers has been attempted by various researchers since 1960.

2.3 THERMAL PERFORMANCE OF SOLAR COOKER

The demand for cleaner and sustainable energy resources in the present scenario leads to the use of solar energy as an effective alternative to conventional fossil fuels. As the food is required on daily basis and by everyone thus if the utilization of solar cooking is taken up by a large population, then a huge amount of energy required from fossil fuel can be saved. The basic principle of solar cooking is based on the extraction of solar energy and its conversion to heat and its conduction to the cooking pot. Continuous investigations are being carried out to bring out a design of solar cooker that proves to be highly effective and with a better performance. Various geometrical and operating parameters are investigated by researchers to fulfil the aim. Thermal performance testing is one of the most prominent aspects of box-type solar cooker. A lot of research was focused on improving their efficiencies of various types of solar cookers such as concentrating type, parabolic, panel solar cookers, cookers with variation in shapes or geometry as square and rectangular and cookers with storage.

The first thermal performance analysis was led by VIT(Volunteers Technical In Assistance, 1981), Volunteers in Technical Assistance (VITA) the evaluation was on different measures, for example, cooking execution, strength, cost, weight, straight forwardness to move simplicity of activity, simplicity of assembling and versatility to local aptitudes and materials. Different techno monetary psychological factors scaled on 100 pointer scale was evaluated by an examination announced by Bowman and Blatt(Bowman & Blatt, 1978), the transient model for a single glazed box type solar cooker was proposed by Garg et al.(Garg & Datta, 1983). That transient model included a simple steady-state model of a solar cooker neglecting heat capacity terms. The values obtained theoretically were much higher than the observed values from the experiments. Certain improvements were added by Vaishya et al. (Vaishya et al., 1985) in a box-type solar cooker with certain improvements in the form of the double glass cover and a plane reflector, keeping it horizontal in sunlight with reflector vertical. Data were recorded and analyzed for the highest temperature for different months at Delhi. Literature by Kandpal and Mathur (Kandpal & Mathur, 1986) reported having a study on the economic feasibility of using a simple box-type solar cooker using simple engineering economics and represented it graphically using certain numerical calculations. The major contribution was reported by Mullick et al. (Mullick et al., 1987). The researchers proposed a new performance parameter named as the first and second Fig of merit F_1 and F_2 , respectively of box-type solar cookers. The methodology presented includes the no-load stagnation test and full load water boiling test to find F_1 and F_2 of box type solar cookers. The above method was extremely helpful and given a proper method to look at the presentation of various kinds of sun-oriented cooker. Chaaniwala and Doshi (Channiwala & Doshi~, 1989) developed a correlation for top heat loss coefficient based on indoor experimental data. The proposed correlation was based on the analysis that the heat loss coefficient of a solar box cooker directly varies with plate temperature and wind velocity. Jurban and Alsaad (Jubran & Alsaad, 1991) were reported to develop a theoretical model for single- and double-glazed box-type solar cookers with or without reflectors. The mathematical model was created using a heat balance analysis of the various components of the cooker, the variation of various parameters such as material composition properties and the overall heat loss coefficient as a function of the absorber plate and temperature of the food item. An improved strategy to evaluate the top heat loss factor of flat plate collector with single coating and twofold coating was accounted for by Mullick and Samdarshi (Samdarshi & Mullick, 1991). The values of heat loss factor at the top were less than three percent of the values acquired by the iterative arrangement of the energy balance condition for single glazing. Thus, for authorities with two fold coating, the values of top heat loss factor were less than three percent contrasted with numerical arrangement of the warmth balance condition for twofold coating.

Suharta et.al (Suharta et al., 1999) devoted three years in Indonesia in promotion of solar cookers. A mathematical model speaking to the heat transfer forms required inside a box-type sunlight-based cooker, containing nourishment, was created by Pejack (Pejack, 1991). The outcomes announced that the nourishment temperature was influenced by scope, month, wind, mists, nourishment amount, thermal obstruction of the sides of the case and direction of the box during cooking. Mullick et al. (Mullick et al., 1991) have also proposed the testing procedure for paraboloid-type solar cookers. While the impact of wind on the exhibition of paraboloid type concentrator sun powered cookers was talked about by Kumar and Kishor (A. Kumar & Kishor, 1994). Das et al. (Thulasi Das et al., 1994a) created thermal models for the solar box-cookers stacked with one, two, or four vessels. A thermal model was proposed by Thulsi Das et al. (Thulasi Das et al., 1994b) for box type solar cooker with one to four vessel variation using heat transfer coefficient as main parameter calculated experimentally. Research also proposed that stainless steel and aluminum vessels can be used with black paint. Said and Medhat (Ibrahim & El-Reidy, 1995) recommended formulae for calculating orientation angle and tilt angle of the reflector of the sun-based cooker. El-Sebaii et al.(El-Sebaii et al., 1994) Literature answered to build up a mathematical model for a box type sunlight-based cooker with external and inward reflectors. The performance of the cooker was researched utilizing a PC simulation as characteristics and specific boiling time. Sharan and Naik (Naik & Sharan, n.d.) Endeavored to find the socio-psychological components determining the acknowledgment of SBCs in India. In Brunei Darussalam, a program to create, test and evaluate a sun powered cooker was done.

Various studies were carried out on the analyses of the effect of the number of pots and different load conditions. Mullick et al. (Mullick et al., 1996) recommended that that the cooker must be tested with full load distributed equally in all pots based on the test results for box-type solar cooker with different loads and number of pots. The performance of the box-type solar cooker with auxiliary process of heat supply was studied and reported by Hussein (Hussain et al., 1997), using heating oil to provide continuous supply during cloudy days.

Nandwani (Nandwani et al., 1997) reported the performance of two solar box cookers with two similar compartments and compared the behavior of a metallic slab filled with a phase change material for short term heat storage, with a conventional absorbing sheet, the use of a selective coating, as compared to a normal black painted. Amer et al. (Amer et al., 1998) experimentally evaluated four procedures to test solar cookers and analyzed the results and compared them in steady-state condition-based on ASHRAE 93-86 standard. The experimental results have been compared with Saunier's method, ASHRAE standard and Exell's method.

Literature reported by Amer et. Al (Amer et al., 1997) built up a transient model with an intends to describe the dynamic conduct of flat plate sun-powered collector-based utilizing model of one node where the mean temperature is evaluated considering the heat capacity of the plate, cylinders, and the fluid, lumped together. On the other hand, Funk and Larson (Funk & Larson, 1998), proposed a model for estimation of the cooking intensity of a sun-based cooker dependent on sun-powered catch territory, overall heat transfer coefficient, and absorber plate thermal conductivity is known as three controlled factors and three uncontrolled factors insulation, temperature distribution and load distribution.

Gaur et al. (Gaur et al., 1999) proposed a cooking vessel that gave a sunken cover. Their experimental investigation demonstrated a decrease of 10-13% in cooking time contrasted with and standard cooking vessels under similar conditions. Biermann et al. (Biermann et al., 1999) conducted experiments on seven distinct types of sun-powered cookers for one year which include around 66 families in South Africa, the results revealed that the Fuel utilization estimations show overall fuel reserve funds of 38%, coming about in assessed take care of periods (through monetary fuel investment funds) from multi-month onwards, contingent upon the sort and area. Akhtar and Mullick (Akhtar & Mullick, 1999) proposed correlations for the estimation of heat loss coefficients in sun-based collectors with single glazing. Semi-analytical amendment factor (f) was utilized as the proportion of internal to external heat loss coefficients as a component of collector parameters and ambient variable. They also proposed a method for precise estimation of glass cover temperatures, individual heat transfer coefficients and top heat loss factor of flat plate sun-based collectors with single and two-fold glazing without the necessity of arrangements of heat balance conditions. Funk (Funk, 2000) had distinguished five uncontrolled factors wind, ambient temperature, pot substance temperature, insolation and sun powered altitude-azimuth and three controlled factors loading, tracking, temperature detecting influencing cooker performance. Sharma et al. (Sharma et al., n.d.) developed and performed the thermal analysis an imaginative design of sun-powered cooker in which there were isolated parts for energy collection and cooking along with a capacity unit utilizing commercial evaluation erythritol as storage liquid. It was seen that early afternoon cooking has no impact on night cooking and night cooking utilizing heat storage was seen as quicker than early afternoon cooking. The cooker performance under a variety of working and climatic conditions was learned at Mie, Japan. Suharta et al. (Suharta et al., 2001) compared three Indonesian solar cookers, namely the newest design HS 5521 with HS 7033 and HS 5521 with and without the load of heat collection rate and of cooking performance. Mullick et al. (Mullick et al., 2005) analyzed the effect of some of the parameters such as optical efficiency, the latitude of location, season on the performance of box-type solar cookers. Shaw (Shaw, 2002) compared the different Test standards for solar cookers. Right now, there are three significant testing standards for sunlight-based cookers utilized all through the world. These standards contrast generally in their degree, unpredictability, and expectations. Ekechukwu and Ugwuoke (Ekechukwu & Ugwuoke, 2003) had reported that the performance of the cooker with a plane reflector in place was improved tremendously as compared to that without the reflector.

Amer (Amer, 2003), experimentally researched the exhibition of a double exposure sun-powered cooker, which was exposed to radiation from the top and base with a set of the plane diffuse reflectors. The presentation was contrasted with the conventional sun-oriented cooker under the same environmental conditions. Results demonstrated that the absorber of the sun-oriented cooker achieved stagnation temperatures of 140 ºC and 165 ºC individually. The structure of the sunlight-based cooker was improved where the safeguard is presented to sun-powered radiation from the top and the base sides. Along with the plane diffuse reflectors with a reason to coordinate the radiation onto the base side of the safeguard plate. The exhibitions of the improved plan were contrasted and the conventional one utilizing heat balance condition. Results revealed that the safeguards of the case type cooker and the twofold presentation cooker achieved a temperature of 140°C and 165°C respectively, it was also seen that cooking time was diminished by around 30–60 min. Abdullah et al. (Algifri & Al-Towaie, 2001) modified the designs, constructed, and tested two full tracking solar cookers, a paraboloid dish solar cooker (PDSC) and a booster mirror solar box cooker (BMSBC) to compare the performance under the same operating conditions. It was reported that the cooking rate was higher in paraboloid dish type solar cooker as compared to others, it can also cook well during intermittent conditions of sunny and cloudy days. The thermal execution also indicated a decrease of 24 to 35% in the heat loss from the recipient within the sight of the windshield. Nahar et al. (Nahar et al., 1996) developed and performed the investigation on the performance of box stockpiling sun-oriented cooker with utilized engine as storage material utilizing stagnation temperature as one parameter so cooking can be performed in late night. The effectiveness of the hot box storage type sunlight-based cooker was seen as 27. Suresh et al. (S. Kumar & Mullick, 2010) proposed a semi-log plot method and an approximate method to find $F2$ known as second Fig of merit of box-type solar cookers. Ibrahim and Medhat (Ibrahim & El-Reidy, 1995) used the standard procedure of cooking power and analyzed a box type solar cooker to adjust four cooking pots under different weather conditions prevailing at in Tatna

(Egypt) during July 2002.The cooker has the ability to cook variety of food with a utilization efficiency of 26.7%. A simple test procedure for the determination of various design parameters was proposed by Kumar (S. Kumar, 2005) used for the prediction of thermal performance of box-type solar cooker. Based on the experimental analysis, a correlation for the second Fig of merit as a function of load was proposed. The experimental and calculated $F2$ values were found in proximity.

A cylindrical single glazed with a plane reflector box-type sun-powered cooker with one cooking pot was developed and tried by Kurt (Kurt et al., 2008) under the predominant climate conditions in Karabuk, Turkey. Nandwani (Nandwani, 2007) designed and analyzed a half-breed multi-reason sunlight-based cooker, which is utilized for food making, for warming up the water to inactivate organisms and refining procedures to evacuate different minerals and items drying. Schwarzer and Vieira da Silva (Schwarzer & Vieira da Silva, 2003) analyzed general sorts of sun-oriented cookers, their fundamental attributes, and experimental systems to test the various kinds of sun-powered cookers, and they proposed a simplified analytical model to plan a basic cooking framework. Literature suggested by Kurt et al. (Kurt et al., 2008) reported using ANN for the purpose of prediction of thermal performance parameters of the experimentally investigated box-type solar cooker.

Arezki et al. (Harmim et al., 2008) proposed a modification in the shape of the cooking vessel to reduce the cooking time, which further can improve heat transfer to the food through the pot walls.

Grupp et al. (Grupp et al., 2009) developed to record food temperature, atmospheric temperature, and solar radiation incident on a solar cooker and evaluated the number of the cooking cycle, cooking times and food mass. The results were compared with actual conditions for box-type and concentrating solar cookers. Performance evaluation of two different types of solar cooker viz. rectangular and square box type was conducted by Garba (Garba & Danmallam, 2011) at Usmanudanfodiyo University Energy Research Centre, observations revealed that the rectangular box type cooker performed better than the square type. Dasin et al. (Dasin et al., 2011) performed an evaluation of a parabolic concentrator type solar cooker in Abubakar Tafawa Balewa University Bauchi in Nigeria, results reported that attainment of stagnation temperature was achieved on three different days during June and July, it was also observed that it took 75 mins to boil 200g of white rice. Pinar (Cuce, 2018) analyzed and compared the performance of box- type solar cookers with and without thermal energy storage using as storage material as Bayburt stone due to its low density and notably high specific heat capacity, in prevailing climatic conditions at Bayburt, Turkey, results indicated a considerable improvement in the performance of solar cooker.

Geddam et al. (Geddam et al., 2015) worked on experimental analysis experimentally obtained $F2$ using a test procedure to determine these parameters under different load conditions of water and used the procedure to generate heating characteristic curves.

Manuel et al. (Collares-Pereira et al., 2018) proposed a revision and formulated the revision in the existing standards i.e., Figs of merit used for solar cooker thermal performance evaluation using easily variable and sorted instrumentation allowing these tests applicable anywhere in the World, with a minimum investment along with simple lab conditions. S. Bhavani et al. (Bhavani et al., 2019) worked on certain funny logic rules while analyzing the thermal performance of a box-type solar cooker with respect to the local climate prevailing at Chennai. Different tests were performed using this logic on the solar cooker. The sun-based cooker was equipped with PCM ($C_{18}H_{36}O_2$) and Nanoparticles (Al_2O_3).

Certain researchers raised the concern of fire in the buildings, and the main reason observed was cooking application (Kodur et al., 2019) solar cookers are safe to operate and have negligible fire concern as they are operated in an open environment.

Figure 2.1Clean energy cooking road map

According to reported article a Clean Cooking Energy Roadmap had been developed in association with NITI Aayog. and GIZ,which envisage to remove all such cooking arrangements and options that causes household air pollution (HAP) in India by 2025 Solar collectors/cookers are the key component of active solar-heating systems(Clean energy road map., 2018)

The literature review reveals that almost all the investigations are carried out using the standard correlation available for wind-heat transfer coefficient, side heat loss coefficient, outer glass cover temperature and inner glass cover temperature. The experimental analysis of any type of cooker should be carried out across the year covering all season's .by calculating these parameters experimentally for accuracy in the results. Some important research has been mentioned in table 2.1

Literature also reveals that the testing of different geometries under the similar environmental conditions (real time conditions) has not been carried out therefore the experimental analysis of different geometries under similar environmental conditions should be carried out.

2.4 EXERGY AND ENERGY ANALYSIS

Energy and exergy comparative analysis of community-size (CSC) and domestic-size paraboloid solar cooker(DSC) was performed by S.C. Kaushik et al(Kaushik & Gupta, 2008) .

Panwar et al. (Panwar et al., 2012) made energy and exergy analysis of a domestic size parabolic solar cooker. It was accounted for that greatest energy and exergy efficiencies of the cooker were tentatively assessed, and it is around 46.82% and 32.97%, individually. Exergy based analysis on solar cookers was carried out by Naveen Kumar et al.(N. Kumar et al., 2012) . It was found that the exergy power yield and exergy lost with temperature distinction for various load of water for box type cooker and the four parameters , use for exergy based test convention for cookers. The experimental results showed the possibility of late night cookingdue to the three reflectors and also claimed an enhancement in the incident solar radiation.

Many literature reported in the area of thermal test of box type solar cooker in terms of exergy.

2.5 EFFECT OF SKY TEMPERATURE

A flat plate collector and solar cooker operate under different climatic conditions hence their thermal performance is affected .For evaluation of thermal performance of these devices, estimation of heat losses is necessary. Upward heat losses contribute around 85% of total heat losses. Analytical equations for estimation of top heat loss coefficient in flat plate collectors have been proposed by various researchers. The upward heat losses from the glass cover of collector/cooker to surroundings include both convective and radiative heat losses.

Experimental studies related to convective heat loss from glass cover to ambient in flat plate collectors/cookers have already been reported in certain studies .Estimation of sky temperature is required to predict the radiative heat losses from glass-cover to surroundings. In the subsequent paragraphs the studies of previous researchers have been mentioned for estimation of sky temperature.

The effective black body sky temperature, T_s can be obtained from

$$T_s = \varepsilon^{0.25} T_a \qquad (2.1)$$

Where

ε = emittance of a gray body at air temperature emitting the same radiation as sky and

Generally written as effective emissivity of sky

T_a = ground level air temperature (K)/ambient temperature

Since the pioneering work of Angstrom (Angstrom, 1915)a lot of models were proposed, from the most fundamental to the most empirical for estimation of long wave sky radiation. The basic parameters included in the models were the partial water vapor pressure p (mb) or dew point, T_{dp}, relative humidity,R_h and the surface air temperature,T_a. Detailed discussions are available in the literature reported by Kondratyev(Varotsos et al., 1999) . Angstrom(Angstrom, 1915)proposed an equation for

Effective sky emissivity as:

$$\in = A - Be^{-c} \qquad (2.2)$$

Where A, B, and C were empirical constants which was assigned values in the ranges A (0.75-0.82), B (0.15-0.33) and C(0.09-0.22) respectively. The most usually used values, according to Kondratyev(Varotsos et al., 1999), were A = 0.806, B = 0.236 and C as 0.092. The above mentioned equation was similar to the Beer's law.

Another relationship used to calculate effective emissivity of clear sky was suggested by Brunt (Brunt, 1932.) Given as

$$\varepsilon = a + bp^{1/2} \tag{2.3}$$

Where, p is the screen level water vapor pressure (mb).

The above equation is similar to Angstrom's equation(Angstrom, 1915)and includes only two adjustable constants in spite of three constants. The values for ‘a’ lie in the range (0.34-0.71) and the values for ‘b’ lie in the range (0.023-0.110). Sellers (Sellers, 1965)suggested the use of the median of 22 observations and obtained the value of a to be 0.605 and b was found 0.048. Brunt(Brunt, 1932)obtained a = 0.55, b = 0.056 and finally suggested a new relation.

$$\varepsilon = 0.52 + 0.065\, p^{1/2} \tag{2.4}$$

Brunt's explained the involvement of square root of the water vapor pressure in his correlation as an analogy between heat transfer by conduction and heat transfer by radiation. Brunt suggested the form of his formula on the fact that the solution of unsteady heat conduction problems often involves the square root of thermal diffusivity. Since it was initially assumed that radiative transfer in the atmosphere was similar to molecular conduction and the coefficient replacing the diffusivity was shown to be inversely proportional to the vapour pressure. Bliss(R. W. Bliss, 1961) related the effective sky temperature to water vapour content of air and ambient sky temperature. Bliss acclimatized the atmosphere to a column of gas and considered it to be constituted like a plane of parallel layers each of them was at the same temperature, same pressure and includes the same composition. The expression given for T_s was

$$T_s = T_a \left[0.8 + \frac{T_{dp} - 273}{250} \right]^{1/4} \tag{2.5}$$

Where T_a = ambient temperature K, $T_{d\,p}$ = dew point temperature K

Swinbank (Swinbank, 1963), proposed a correlation for effective black body sky temperature on the basis of atmospheric data from Australia, England and France .A simple correlation for estimation of T_s in terms of T_a was proposed .

$$T_s=0.0552T_a^{1.5} \qquad (2.6)$$

The range of T_a was from 2-29 ^{0}C

Y. Viswanadham and R. Ramanadham(Viswanadham & Ramanadham, 1967) used observed data of night sky radiation, of nine years duration at five Indian Stations, Waltair, Nagpur, New Delhi ,Chennai and Poone, to suggest an empirical correlation for effective sky emissivity. The expression given was:

$$\varepsilon = 0.88 - (0.32 * 10^{-0.069p}) \quad \text{or} \quad 276\text{ K} < T_a < 313\text{ K} \qquad (2.7)$$

Where P = water vapor pressure in mm of Hg

Kondratyey (Kondratyev, 1969.) Reported correlation explaining that clear sky emissivity is a function of the water vapor pressure only.

$$\varepsilon = 0.66 + 0.40\,p^{0.5} \qquad (2.8)$$

p is the water vapor pressure in mb.

Idso and Jackson (Idso & Jackson, 1969) developed an equation for long wave clear sky radiation which was considered to be valid for any air temperature reached on earth. They expressed sky emissivity is related to air temperature alone given by

$$\varepsilon = \left\{1 - 0.261\exp\left[-7.77X10^{-4}(273 - T_a)^2\right]\right\} \qquad (2.9)$$

T_a is in K

Staley and Jurica (Staley & Jurica, 1972) made separate computations for emissivity of H_2O, CO_2, CO_2 and H_2O overlap, and O_3 .The atmospheric emissivity was calculated by taking sum of emissivity values of all above constituents of atmosphere. They reported the fact that effective emissivity of the atmosphere depends solely on vapour pressure of the surface and is purely independent of the temperature of the surface. The emissivity of CO_2 decreases from 0.19 to 0.17 as the elevation of the surface raises from sea level to 710 mb. The expression for effective atmospheric emissivity, for surface vapor pressure of 1013 mb, was given as:

$$\varepsilon = 0.67e^{0.080} \tag{2.10}$$

Wartena et.al (Wartena et al., 1973) examined the validity of numerous formulae for calculating the amount of long wave radiations from a cloud free atmosphere . He concluded on the basis of the observations obtained over a period of two years at Deelen aerodrome. The Brunt(Brunt, 1932a),Swinbank (Swinbank, 1963) formulae were examined and 6 modifications of these were suggested by Warenta et.al(Wartena et al., 1973). Of those eight formulae, the Brunt (Brunt, 1932a)correlation appeared to be best fitted to the observations.

Brutsaert(Brutsaert, 1975) derived an analytical formula for effective clear sky emissivity by performing an approximate integration of the Schwartzs child's transfer equation over all directions and over all wavelengths through the definition of slab emissivity by assuming nearly standard atmospheric vertical profiles of the values of temperature and vapor pressure.

$$\epsilon_0 = \{0.107 \left(\frac{0.622}{R_{da}(K_w+0.065)}\right)^{1/7} * B(z,w) * \left(\frac{\frac{4\gamma}{T_{dp}}+K_w+0.065}{K_w+0.065}\right)\left(\frac{p}{T_{dp}}\right)^{1/7}\} \tag{2.11}$$

Here R_{da} is explains about the ratio of the constant of the perfect gases and molecular mass of dry air whereas B (z, w) denotes the beta function . The included parameters were substituted in the above equation by their standard values, leading to a more simplified expression as follows

$$\varepsilon = 1.24\left(\frac{p}{T_a}\right)^{1/7} \tag{2.12}$$

p in mb and T_a in K

Idso (Idso, 1981) proposed an equation, based on observations obtained at phoenix, Arizona, with air temperature values in the range from (-10 to 45) ºC to calculate effective emissivity of the clear sky including both water vapor pressure and screen air temperature. Equation was given as:

$$\varepsilon = 0.70 + \left\{5.95X10^{-5}\, p \exp\left(\frac{1500}{T_a}\right)\right\} \tag{2.13}$$

Centeno (Centeno, 1982)developed a formula for determination of clear sky night emissivity, based mainly upon measurements of the equivalent sky temperature performed at several sites Venezuelan for a total duration of twenty years. The author expressed the clear sky emissivity as a function of site's altitude, the ambient temperature, the relative humidity. The following formula was suggested.

$$\varepsilon = \left[5.7723 + 0.9555(0.6017)^{Z}\right] x T_a^{\,1.1893} x h^{0.0665} x 10^{-4} \tag{2.14}$$

Where,

z = altitude of site of observation above mean sea level.

T_a = absolute temperature of the atmosphere (in K) at the moment of observation

h = relative humidity of ambient air (9 %)

The above formula is valid for a range of T_a from 263-303 K, for range of h from (40-100) % and for a range of z from 0-3 km.

M.Pospisil and L.Pospisilova (Pospíšil & Pospíšilová, 1982) conducted experimental study for long wave sky radiation. For this purpose an experimental model was offered in which sky hemisphere has been substituted by a single point radiating source along with a diffuse background. For estimating all the value of four parameters such as zenith angle, azimuth in the model, a four-segment photocell was proposed and tested.

Berdahl et al (Berdahl & Martin, 1984) , measured the spectral radiation during summer corresponding to the zenith angles of 0°, 60° and 75° in 1979, in six cities of U.S.A. After these experiments were performed it was proved that the emissivity of the clear sky was a function of the zenith angle.

Berdahl and Fromberg (Berdahl & Fromberg~, 1982)suggested two empirical correlations for estimation of effective sky emissivity during night and day time. The proposed correlations were:

$$\epsilon_{0(night)} = 0.741 + 0.62(T_{dp}/100) \quad (2.15)$$

$$\epsilon_{0(day)} = 0.727 + 0.60(T_{dp}/100) \quad (2\ .16)$$

Llebot and Jorge(Llebot & Jorge, 1984) conducted measurements of long wave sky radiation and ambient temperature in Manresa during the summer season. By using experimental data they developed an equation for effective sky emissivity:

$$\varepsilon = \left\{ 1 - \left(\frac{f(T_a - 273)^2 + H}{i(T_a - 273)^8 + J} \right) \right\} \quad (2.17)$$

Where,

T_a is in (K) and f, H ,i and J are constants .The values of constants suggested were f=7.5 x 10^{6} , H= 7.5 x 10^{10}, i=0.2 and J=3 x 10^{11}

Berdhal and Martin (Berdahl & Martin, 1984) used extensive observations from United states to relate the effective emissivity of the sky to the,dry bulb temperature ,hour from midnight (t)and dew point temperature by following equation:

$$\varepsilon = \left[0.711 + 0.0056T_{dp} + 0.000073T_{dp}^{\ 2} + 0.013\cos(15t)\right] \qquad (2.18)$$

T_a in degree Kelvin, T_{dp} is dew point temperature in degree Celsius. The experimental data covered a dew point temperature range from -20 to 30 ºC.

The results of Berger et al (Berger et al., 1984)suggested that the sky temperature were based on analysis of 5 year data obtained by meteorological station in Carpentras(France) .They correlated daytime clear sky emissivity with dew point temperature of air. The empirical formula for sky emissivity suggested was

$$\varepsilon = 0.752 + 0.0048T_{dp} \qquad (2.19)$$

Where

T_{dp} denotes the dew point temperature of air in degree Celsius.

The dew point temperature observed in experiment ranges from -12 to 20 ºC..

Berger et al. (Berger & Bathiebo, 2003) suggested that the directional emissivity of the clear sky can be expressed through the below mentioned correlation .

$$\in_{\theta} = \{1 - (1 - \in_{v}) \cos\theta\} \qquad (2.20)$$

Where $\in_{v}$ is the emissivity in the zenith direction (ɵ = 0), ɵ is the zenith angle.

Marc (Aubinet, 1994) developed two variable model and three variable model for sky temperature by using one year data observed at weather station in Belgium Sky temperature, by two variable model, was given by

$$T_s = -29 + 1.09T_a - 19.9K_0 \tag{2.21}$$

Where, T_s = sky temperature in Kelvin, T_a = ambient temperature in Kelvin, K_o = clearness index of the day.

The measurements taken were of total downward radiation, solar radiation of short wave, the temperature of air and humidity.

The clearness index (K_o) was defined by

$$K_o = H/H_o$$

Where H is the daily global solar radiation (J/m^2) and H_o is the daily extraterrestrial solar irradiation intercepted by a plane parallel to the earth surface (J/m^2). It was estimated by

$$H_0 = \varphi_{sc}\left(\eta s \sin\phi \sin\delta + \cos\phi \cos\delta \sin\eta s\right)\left(\frac{86400}{\pi}\right) \tag{2.22}$$

Where,

φ = latitude of site radian

δ = declination in radian

η_s = half-length of day radiation

φ_{sc} = extraterrestrial solar irradiance intercepted by a plane normal to the solar beam and is taken equal to solar constant, neglecting the annual variation of about ± 3.3 %.

The days with clearness index greater than 0.6 were considered as clear days.

Sky Temperature from three variable model was given by

$$T_s = 94 + 12.6 \ln(P_0) - 13K_0 + 0.341T_a \tag{2.23}$$

Where, P_o = water vapour pressure of air (Pa)

The observed values of ambient temperature at experimental site were below 300 K and observed values of vapor pressure were in the range 2-18 mb

Prata (J Prata, 1996) proposed a model in which the slab emissivity data was adjusted by Brutsaert (Brutsaert, 1975) . This model includes the contribution of atmospheric components other than water vapor like CO_2 and O_3 towards effective sky emissivity. The equation given was:

$$\varepsilon = \left\{1 - \left(1 + \frac{46.5p}{T_0}\right)\exp\left[-\left(1.2 + \frac{3x46.5p}{T_0}\right)^{1/2}\right]\right\} \tag{2.24}$$

Where

p is in mb and T_0 is screen level air temperature in K

He obtained good results in all latitudes, with air temperature in the range (–40 to +40)°C.

Crawford and Duchon (Crawford & Duchon, 1999) presented an improved parameterization for estimating effective atmospheric emissivity during day time based on temperature, humidity, pressure and solar radiation observations. They reported the following expression for effective sky emissivity.

$$\varepsilon = cloudf + (1 - cloudf) * \left(1.22 + 0.06 * \sin\left[(M+2) * \frac{\pi}{6}\right]\right) * \left(\frac{p}{T_a}\right)^{1/7} \tag{2.25}$$

Where,

Cloud f= cloud fraction

P = pressure in mb

T_a = ambient temperature in K

M is the numerical month

Where,

s is the ratio of measured solar irradiation to the clear sky irradiation

Duarte et al (Duarte et al., 2006) tested several well-known parameters for the downward long wave radiation of clear sky and cloudy sky at an experimental site at Ponta Grossa (Parana State, Brazil) where all the radiation components and meteorological data were measured during spring, summer, fall and winter in 2004 and 2005. Best results for downward longwave radiation for the clear-sky were obtained with Brutsaert's relation(Brutsaert, 1975).

Kjaersgaard et.al (Kjaersgaard et al., 2007) tested twenty simple and widely used models utilized for calculating the clear sky daytime long-wave irradiation and compared it with the measured long-wave irradiance data. Input parameters for the models was air temperature or water vapour pressure and air temperature .Meteorological data and long-wave irradiance measurements from 32 continuous years at the Climate and Water Balance Station of Taastrup in eastern Denmark and from 7 consecutive years at the Agrometeorological Station at Foulumin western Denmark were used. A set of statistical procedures was used to evaluate the performance of the models. . Based on the results of the study and the fact that the Prata (J Prata, 1996) and Brutsaert (Brutsaert, 1975) clear sky models were found on a physical basis, these models were recommended for use with the Crawford and Duchon (Crawford & Duchon, 1999) all sky models when calculating daytime long-wave irradiance in a temperate climate. Sky temperature plays an important role in estimating the heat losses occurring in solar collector/cooker and its effect should be considered.

2.6 OVERVIEW OF EXISTING TEST STANDARDS

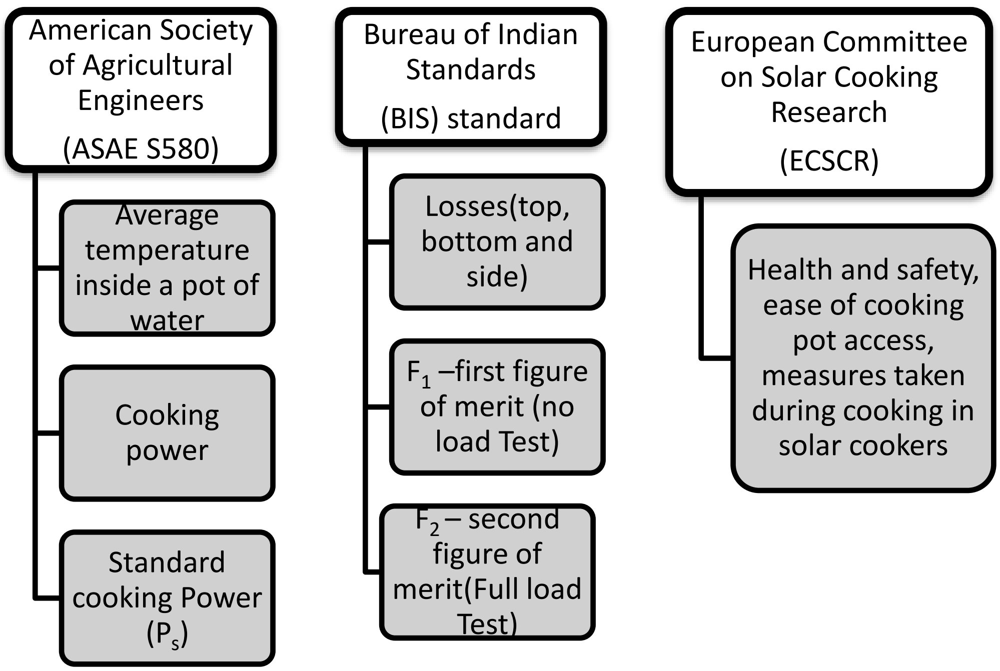

Figure 2.2Various test standards for performance evaluation *of box type solar cooker*

2.6.1 Test Procedure Adopted by American Society of Agricultural Engineers

ASAE S580 records the average temperature inside the pot of water while the cooker operates under defined guidelines mentioned in the standard for the purpose of tracking procedure, thermal loading etc. Temperature of water is continuously measured and after 10- minute intervals data is being averaged . Simultaneously, ambient temperature and normal solar radiation per unit area are also recorded. During the conditions of high wind velocity, less insolation and reduced ambient temperature tests has not been conducted. The prominent Figure of merit by ASAE S580 is the Cooking Power (P) in watts, which are calculated as:

$$P = \frac{m_w C_w (\Delta T)_{10min}}{600} \quad (2.26)$$

C_W =Specific heat of water (J/kgK)

$(\Delta T)_{10min}$ = Temperature rise of water in ten minutes (600seconds) during heating test (Deg. C)

The cooking power is standardized at a reference solar insolation of 700W/m^2 by defining a standardized cooking power P_{eff} in watts as:

$$P_{eff} = \frac{P\ 700}{I_{av}} \quad (2.27)$$

Where I_{av} is the average solar radiation in ten minutes in which water temperature rise of t =10 min is observed.

By linear regression, the following relation for cooking power (P) is developed.

$$P = 125 - 1.58(T_w - T_a)_{10\ min} \quad (2.28)$$

While ASAE S580 achieves a target of proposing and providing a simple test to establish an simplified Fig of merit, still the procedure of testing the cooker lacks in several areas as it addresses issues relating to the thermal performance of the cooker only. For example, this standard does not consider the measurement of heat losses. Without considering the heat losses the single Fig of merit as proposed by ASAE S580 is not practically relevant for assessing a cooker's performance. Therefore, the standard to evaluate the performance of solar cooker , rather than simply compare its performance with other cooker is not acceptable (Shaw, 2002).

2.6.2 Test Procedure Adopted by Bureau of Indian Standards

The BIS standard as compared to ASAE S580 proposes a more technical framework It provides two Figs of merit F_1 and F_2. These Figs of merit are considered to be independent of environmental conditions such as wind speed, insolation etc. The two Figs of merit are defined as the following equations:

$$F_1 = \frac{\eta_0}{U_l} \tag{2.29}$$

$$F_2 = \frac{F_1 (MC)_W}{A\tau} \, Ln \left(\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{I}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{I}\right)} \right) \tag{2.30}$$

2.6.3 Test Procedure Adopted by European Committee on Solar Cooking Research standard (ECSCR)

The procedure suggested by the European Committee on Solar Cooking Research proposed a wider scope than the above mentioned two standards. In this standard maximum test is inclined towards the safety factors, ease of access of cooking pot , estimated durability and other significant parameters . The ECSCR procedure (Shaw, 2002) also includes an exhaustive thermal testing procedure The assessment interaction is driven by a few point by point detailed data sheets, which are filled up by the analyzer. Extra information given by the manufacturer is additionally included. For the 'Basic Test' Data is collected under the following conditions:

1. Water at 40°C is contained a pre-heated cooker, temperature is recorded for two hours during solar noon.
2. The cooker is oriented and facing the sun. The time taken is recorded for the water to cool around 80°C.
3. Oil, at temperature of 40°C, is heated from 4 hours in solar noon and the maximum temperature attained is recorded.
4. Heated oil from the previous test is allowed to cool inside the cooker and the

time taken for the oil until it reaches 100°C is recorded.

5. The test mentioned above is repeated in step-1 now with a non-preheated cooker.
6. The pot lid(s) are removed and with frequent stirring, the time is recorded for the water to cool around 80°C.
7. Water at 40°C is heated with the sun at a lower angle. Temperature is recorded as a function of time

The general conditions considered for above tests

Atmospheric temperature: 25°C-35°C

- Velocity of wind < 4 m/s (at the cooker)
- Global solar radiation (horizontal) >800 W/m^2
- Diffuse fraction < 20%

Shaw (Shaw, 2002) has explained various limitations of the above ECSCR standard.

2.7 RESEARCH GAP

On the basis of the review of various literature reported above it was observed that:

- The BIS method of testing box type solar cookers takes care of parameters that relate to the thermal performance of the cooker. Two Figs of merit F_1 and F_2 have been suggested for evaluating thermal performance of solar cooker. However, in order to calculate F1 and F2 heat losses are to be estimated in outdoor conditions .Estimation of heat losses require knowledge of heat transfer principles, a detailed study of the factors, which are affecting the parameters of heat transfer in the cooker and lots of experiments in outdoor conditions. In total it is a tedious process.
- The effect of box geometry, such as triangular, truncated and rectangular, on the cooker performance has not been investigated using a common standard.

Different geometries have been studied on the basis of different parameters (cooking power, cooking time or boiling time).

- Correlations for F_1 and F_2 in terms of operating and climatic variables (those can be measured directly) are required to simplify testing procedure.

2.8 OBJECTIVE

- The objective of the proposed work is to conduct theoretic al and experimental heat transfer studies on different geometries of box type solar cookers for thermal testing and to do a comparative analysis of different geometries with enhanced thermal efficiency.
- To analyze the effect of sky temperature on performance of box type solar cooker under similar outdoor conditions.
- To suggest simplified correlations for thermal performance measurement by using experimental data.

2.9 NOVELTY IN THE PROPOSED WORK

2.9.1 Performance improvement

Different geometries are required to be tested under similar environmental conditions prevailing at a particular location. The performance analysis of three different geometries is based on the objective of identifying a geometry which has a high thermal efficiency and performance as compared with the existing and conventional geometry keeping in view thermal and cooking efficiency.

2.9.2 Testing facility for box type solar cooker of all type of geometries

Development of a simplified procedure and correlations to evaluate the performance of different geometries of box type solar cooker, so that a testing facility can be established at particular location with a simplified procedure and correlation in terms of simply and easily measured variables.

The developed testing facility is universal and can test different geometries of box type solar cookers in rural areas

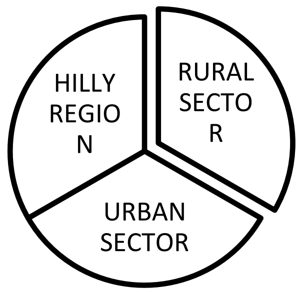

Figure 2.3Significance from the perspective of society

3 CHAPTER: METHODOLOGY

3.1 INTRODUCTION

In order to achieve the objectives of the present investigation, experiments were conducted on an experimental setup of box type solar cooker test setup and its different geometries along with a test plate which were fabricated and installed in the alternate energy lab, University of Petroleum and Energy Studies, Dehradun, India. The integrated system was evaluated to achieve the enhancement in thermal performance of the system.

Present research work started with preliminary analytical and then the experimental studies on the effect of climatic and operating variables viz. sky temperature (T_s), ambient temperature (T_a), solar radiation (I), plate temperature (T_p) and wind heat transfer coefficient, (h_w), on thermal performance (overall heat loss coefficient (U_L) and on first Fig of merit (F_1) and second Fig of merit (F_2) of solar cooker.

Based on the effect observed of the above mentioned variables on thermal performance, the correlations were developed for first Fig of merit, overall heat transfer coefficient and wind heat transfer coefficient in terms of directly measured and simple variables .developed correlations were established against the correlations reported in literature.

The testing of different geometries of solar cookers has been carried out as per BIS standard without external reflectors under similar environmental condition using the developed correlations.

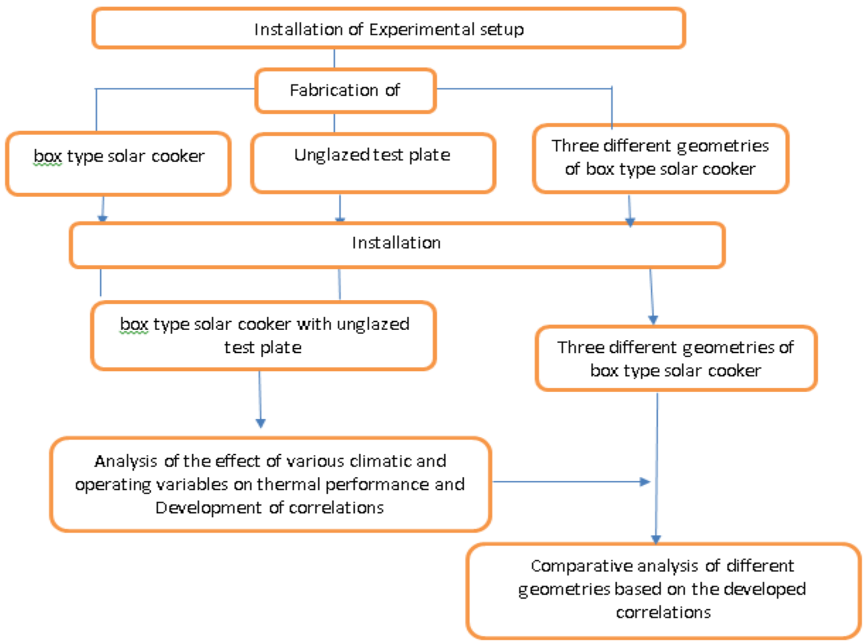

Figure 3.1Methodology adopted for the present work

3.2 EXPERIMENTAL SETUP (FABRICATION AND INSTALLATION)

To determine the performance of the solar cooker an experimental facility has been designed and fabricated as per the BIS standard (*BIS Standard on Solar Cookers Parts I, II & III*, 2000).

3.2.1 Test setup of box type solar cooker (fabrication and Installation)

The photographic view of the experimental box-type solar cookers set up along with the test plate and its specifications are shown in Fig 3.2, 3.3, 3.4 and Table 3.1, 3.2 and 3.3, respectively. The solar cooker test setup has the dimension of (length × width × height) of 980 × 980 × 980 (mm), respectively, made of 12 mm ply board (k=0.1154 W/mK). The absorber plate of the cooker is made up of aluminum sheet and painted with blackboard paint. The bottom and the sides of the cooker are well insulated by using glass wool (k=0.037 W/mK).

The air spacing between the plate and inner glass cover is 98 mm and that between glass covers is 12 mm. Temperatures at 21 locations were measured with the help of calibrated Chromel Alumel (K-type) thermocouples to ascertain the accuracy of temperature measurement, thermocouples have been calibrated under laboratory conditions against a dry block temperature calibrated instant. (Presys Instruments T-25 N) , having least count of 0.01 °C. Pre-calibrated chromel- alumel thermocouples were fixed at the center of the absorber plate, inner and outer glass surface of both glass covers, at the center of glass wool insulation layers of 25 mm each with an objective to calculate the bottom and side losses as shown in the Fig 3.2. Solar radiations were recorded by pyranometer (KIPP and ZONEN). The stagnation test experiments to determine the thermal performance of the cooker have been conducted and the environmental temperature was measured at the site of the experiments.

The experimental solar cooker and the unglazed test plate were kept side by side at the same height to minimize the uncertainty due to wind heat transfer coefficient.

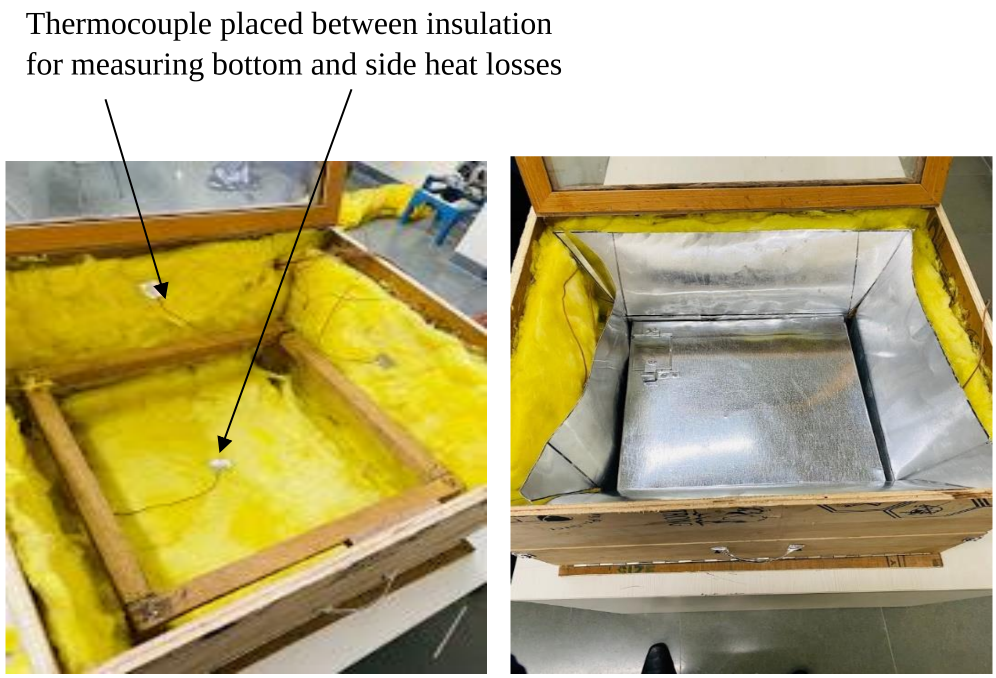

Figure 3.2Thermocouple placed at various location of Experimental test setup at UPES, Dehradun

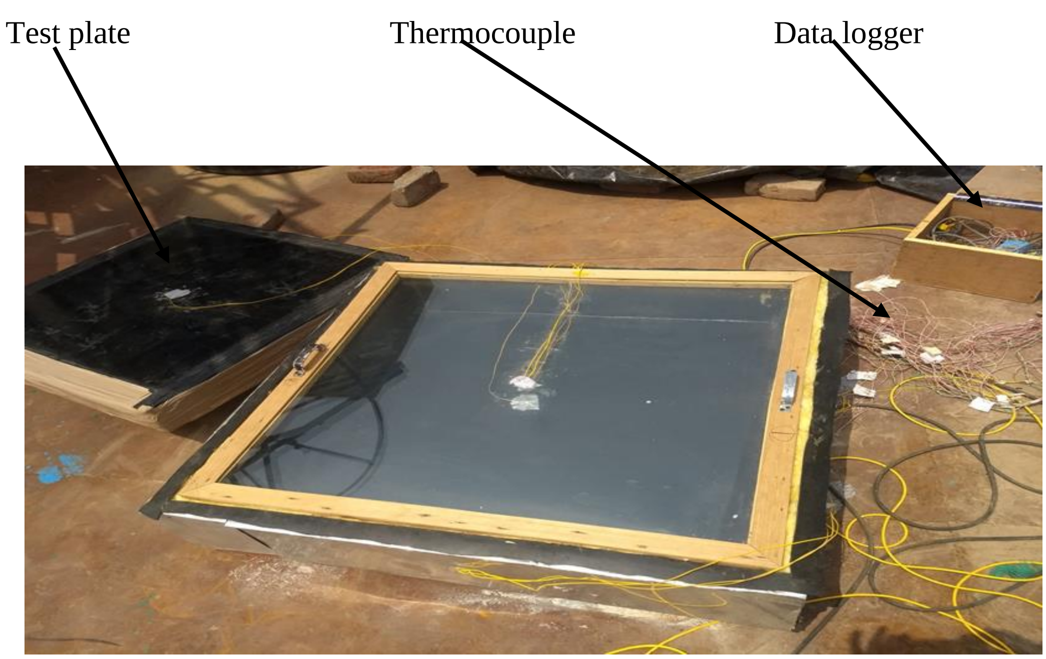

Figure 3.3 Experimental test setup along with test plate @ alternate energy lab UPES, Dehradun

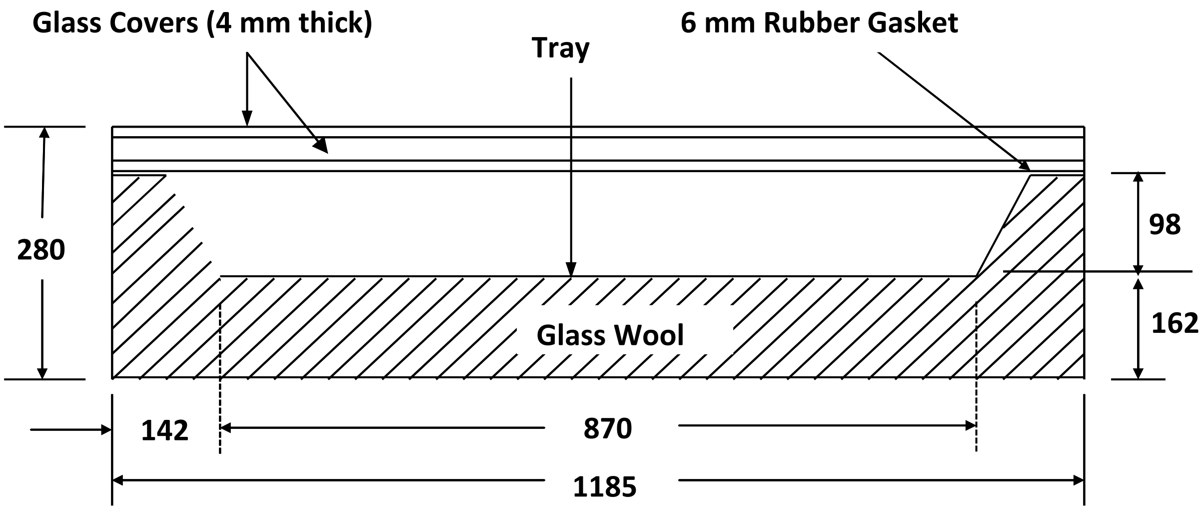

Figure 3.4Schematic of test setup of box type solar cooker.

Table 3.1 **Specifications of the test Setup**

Box type cooker test setup dimension		
Parameters	**Unit**	**Dimension**
Material Size Box Wooden Board	m	1.185×1.175×0.28
Tray 24 Gauge Aluminum Sheet	m^2	0.87×0.87
Glazing(Double) ordinary glass sheets thickness	mm	4
Aperture area	m	0.98×0.98 m
Air gap spacing between tray and inner glass	mm	98
Air gap spacing between inner glass and outer glass	mm	12

Test plate dimensions		
Area exposed to sun (aluminum sheet)	mm	870×870
Thickness of asbestos sheet	mm	5
Thickness of insulation (3	mm	25 each

Table 3.2 Measuring instruments

Parameters measured	Symbol	Measuring equipment
Solar insolation	I	Pyranometer
Wind velocity	V	Ultrasonic wind sensor
Plate temperature	T_p	K type thermocouple
Outer glass temperature	Tg_1	K type thermocouple
Inner glass temperature	Tg_2	K type thermocouple

Table 3.3Measuring instruments specification

Equipment	Make	Range	Sensitivity	Accuracy (%)
Pyranometer	KIPP &ZONEN (CMP6)	285 to 2800nm	5 to 20µV/W/m^2	<0.1
Wind sensor	(16470) Combined Ultrasonic Wind sensor u[sonic] LAMBRECHT meteo	wind direction: 0...359.9 ° wind speed: 0...75 m/s	Response rate : 0.1 m/sec	wind direction: < 2° (> 1 m/s) RMSE wind speed: ± 0.2 m/s
Data loggers	ADAM's (4117: analog for wind			4117:Accuracy: – Voltage mode: ±0.1% or better –

	velocity and insolation 4118 : digital for temperatures 4560 convertor)			Current mode: ±0.2% or better 4118: ±0.1%
Thermocouple	K type thermocouple	0-1370℃	Cal liberated – Persys T-25M	Leastcount:0.01 ℃

3.2.2 Test Plate Setup

The aluminum plate was taken for the experiment and its top surface was coated with dull black paint. A composite slab 3mm thick asbestos sheet, 50 mm thick fiber glass wool sheets of 25 mm thickness and thermocol slab of 45 mm thickness were fixed at the bottom of the aluminum plate., with an aim to reduce bottom heat losses. Composite slabs were taken slightly larger as compared to test plate because 45 mm thick thermocole slabs were placed and fixed on all four outer sides of composite slabs in order to avoid the side heat losses.

Three calibrated Chromel-alumel thermocouples (type K) as mentioned in table 3.2 were fixed at the center of each test plate assembly at different locations for the measurement of test plate temperature, insulation top temperature and insulation bottom temperature. Ultrasonic wind sensor was used for the measurement of the wind speed shown in Fig 3.5 . Wind speed using ultrasonic sensor was measured at a height of 110 mm above the top surface of aluminum test plate. Ambient insolation and ambient temperature were measured at site of experiments using a setup . Solar radiation falling on surface was measured with the help of a Kipp and Zonen pyranometer.as shown in Fig 3.6

Figure 3.5Ultrasonic wind sensor

Figure 3.6Kipp and Zonnen type Pyranometer

3.2.3 Setup for measuring ambient Temperature

Ambient temperature has been measured in a designed set up according to BIS standard in which the thermocouple was placed inside a hut like structure, to prevent the effect of solar radiation on air passing through that structure for achieving the accuracy. The setup as shown in the Fig 3.7 was oriented keeping its back towards the sun and placing thermocol on that side to prevent the heating effect on ambient air .

Figure 3.7Setup for measuring the ambient Temperature

3.2.4 UPES Data logging software

Data collected through the Data logger was recorded in a specially customized software named as UPES solar cooker software .In this software following data was recorded as shown in the Fig 3.8 and 3.9

1. Temperatures at all location in solar cooker
2. Wind velocity
3. Solar insolation

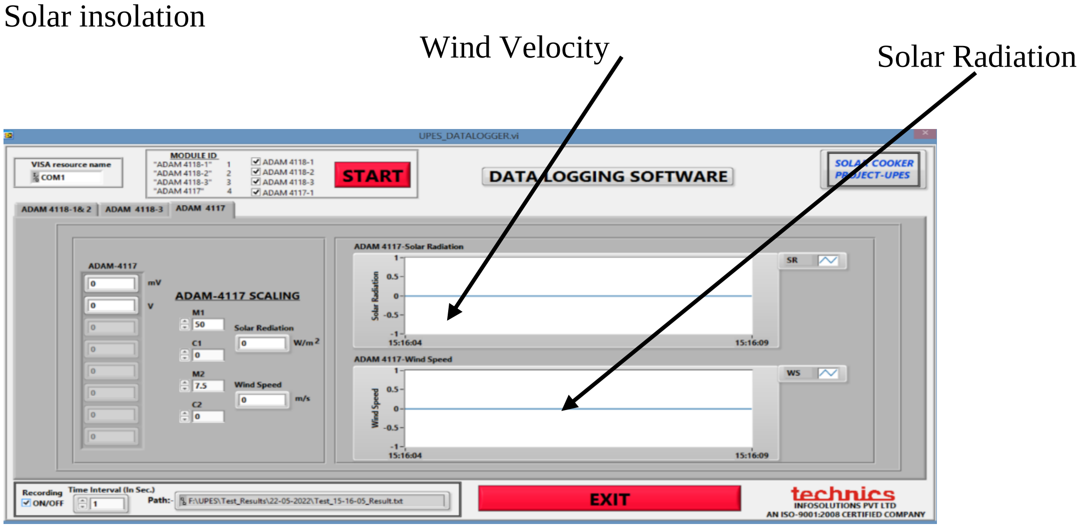

Figure 3.8UPES Data logging software

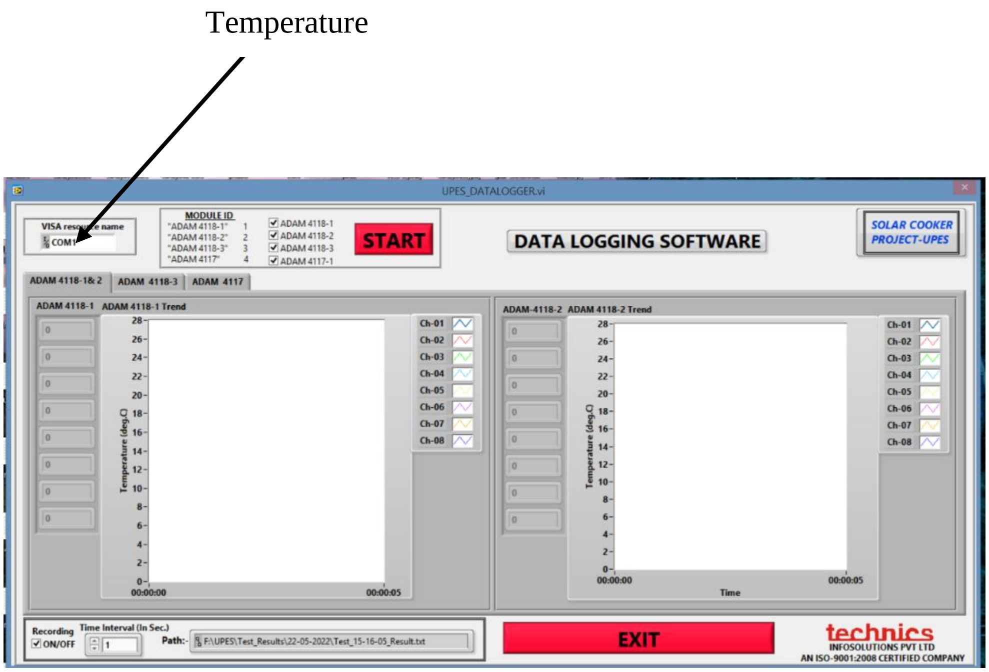

Figure 3.9Temperature record in UPES Data logging software

3.2.5 Test setup with different geometries

Three different geometries have been taken for comparative performance analysis viz rectangular, MNRE solar cooker geometry and proposed triangular geometry. The geometries were selected based on the literature review and for comparative analysis the geometries were fabricated keeping the aperture area, placed in similar environmental conditions. Fig 3.10 shows the setup of three geometries placed side by side @UPES alternate energy lab Ultrasonic wind sensor was used for the measurement of the wind speed. Ambient temperature and solar radiation were measured at site of experiments. Solar radiation were measured using pyranometer. The table 3.4 shows the specifications of three geometries taken for experimentation and testing.

Table 3.4Specification of different geometries

Specifications	units	
Glazing(Double) ordinary glass sheets thickness	mm	4
Aperture area	m^2	0.8m×0.8m
Air gap spacing between tray and inner glass	mm	98
Air gap spacing between inner glass and outer glass	mm	12

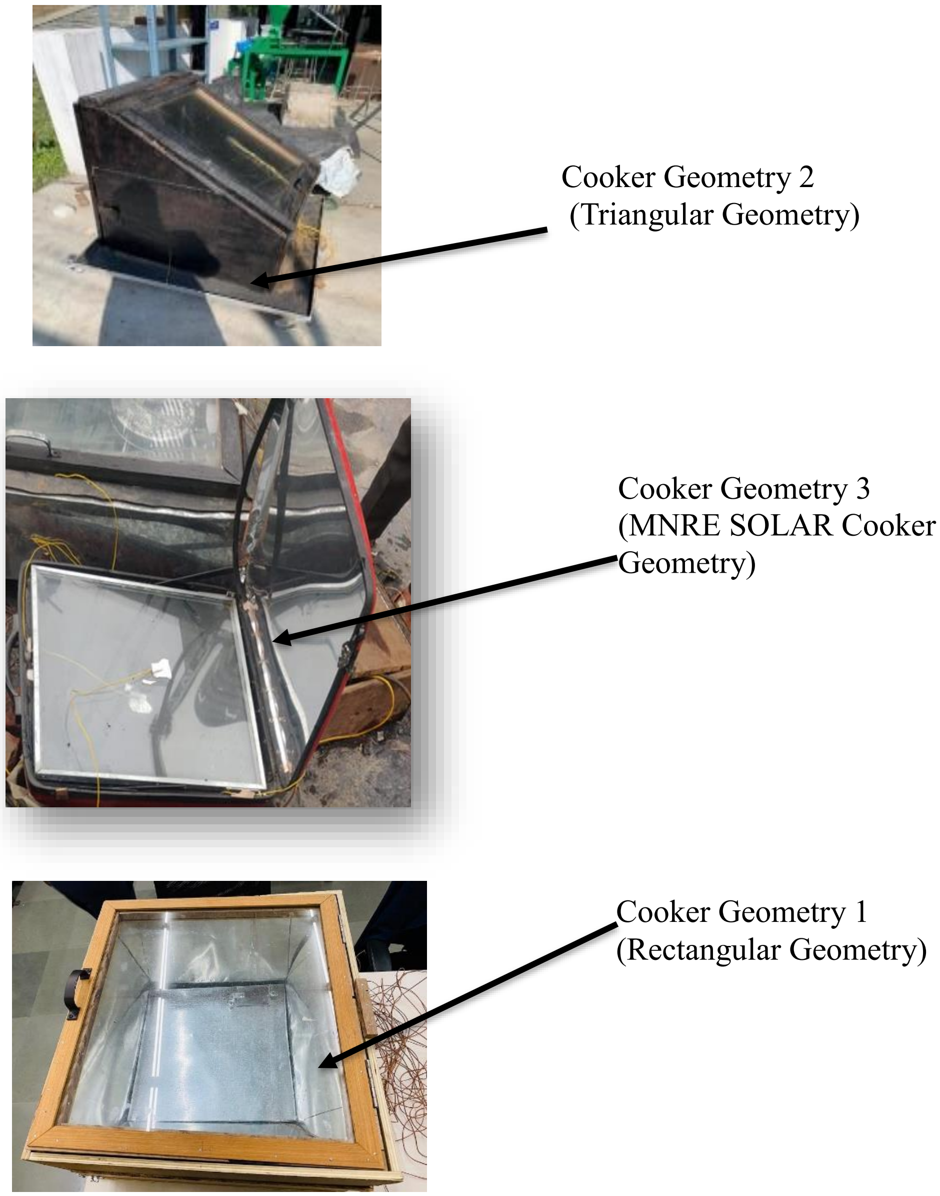

Figure 3.10Geometries of box type solar cooker for comparative thermal performance analysis

All three Cooker geometries were placed under similar environmental conditions for the whole year at same height to minimize the uncertainty due to hw . Temperatures at 9 locations were measured with the help of calibrated Chromel Alumel (K-type) thermocouples to ascertain the accuracy of temperature measurement. Pre-calibrated chromel-alumel thermocouples were fixed at the center of the absorber plate, inner and outer glass surface of both glass covers, at the center of glass wool insulation layers of 25 mm each with an objective to calculate the bottom and side losses of each geometry.

The stagnation test experiments to determine the thermal performance of the cooker have been conducted and the environmental temperature was measured at the site of the experiments.

To evaluate the effect of various parameters on the performance of different geometries of box-type solar cooker, various parameters were measured and recorded in UPES data logging software customized for the setup.

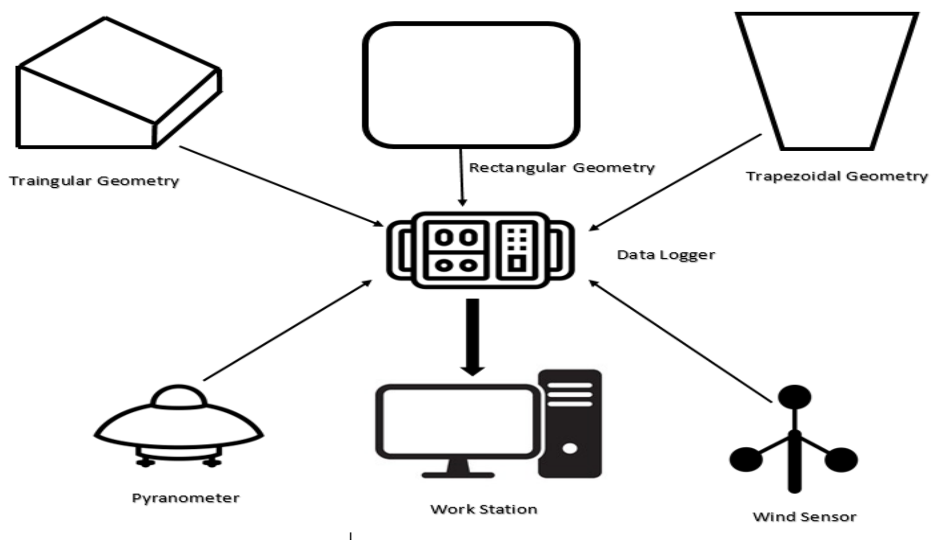

Figure 3.11Schematic diagram of experimental setup

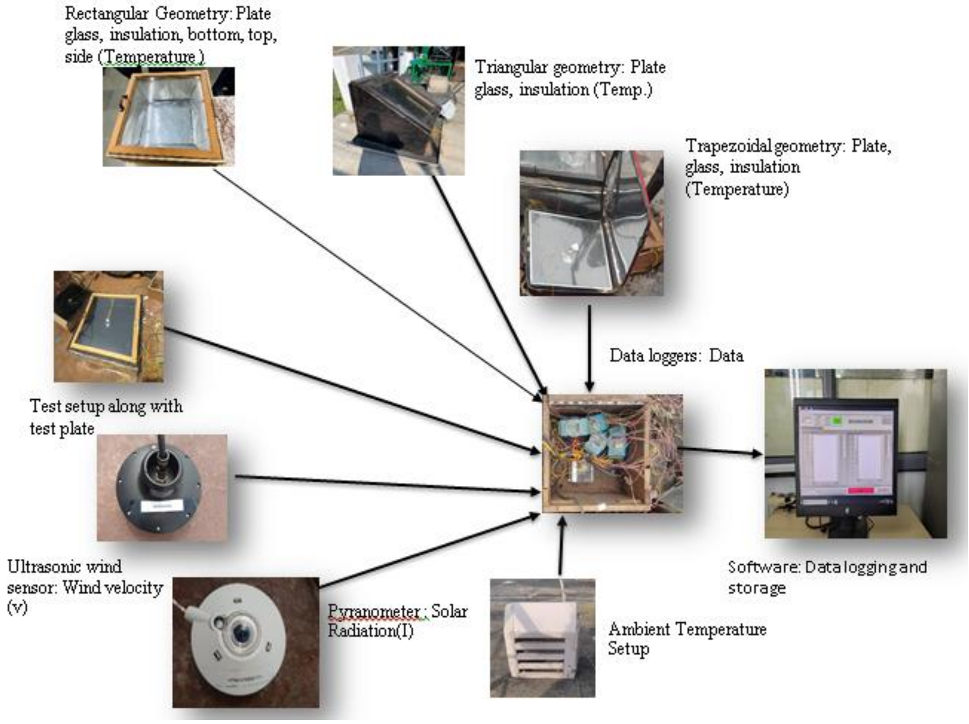

Figure 3.12Experimental setup along with three different geometries at UPES, Dehradun Location - (Alternate energy Lab –UPES)

3.3 EXPERIMENTAL PROCEDURE

The experiments have been conducted on the rooftop of center for alternate energy lab at UPES on clear sunshine days excluding the cloudy days as per the BIS standards(*BIS Standard on Solar Cookers Parts I, II & III*, 2000). The experiments have been performed every day covering all seasons from January to December excluding July and August as they are heavily rained months in the Dehradun region in India in the year 2018 and 2019.

Instantaneous solar radiation have been measured with sampling time of 1 second and is averaged over a period of 5 minutes. Adams Data loggers were used to record the data.

Ultrasonic wind sensor is used to measure the wind velocity with sampling time of 1second. To evaluate the effect of various parameters on the performance of box-type solar cooker, various parameters were measured and recorded.

The data was recorded in the above sheet for every second such as

1. T_p plate temperature using a thermocouple fixed at the center,
2. Inner and outer glass temperatures of first and second glass covers using two thermocouples per glass (total four for glass temperature measurement) fixed at the center on inner and outer surface of both glass covers.
3. To measure wind heat transfer coefficient, h_w, three thermocouples are fixed: one at the center of bottom of unglazed test plate, one at the center of insulation (glass wool) top and one at the center of insulation bottom, to measure unglazed test plate temperature, temperatures at top and bottom of the insulation.
4. Ambient temperature by placing a thermocouple in shade and its tip is exposed to free stream of air
5. Solar radiation on a horizontal surface using a pyranometers. The experiments have been performed in the winter and summer season.
6. Temperature on side and bottom of the cooker through the thermocouples placed at center of various layers of insulation.

Data was recorded in UPES solar cooker software specially customized for the present work through Adams data logger.

Fig 3.13 shows a sample data sheet created and used for the purpose of data collection for each day. There were various parameters measured and based on those measured parameters the performance analysis has been carried out.

Time /date	T_P	T_{G1}	T_{G2}	V	T_a	T_{sky}	I	U_b	U_s	U_t	U_L	η_0	F1

Figure 3.13Sample data sheet used to record data every day for all seasons of the year.

3.3.1 Experimental Procedure for no load test for obtaining first Fig of merit (F1)

The empty solar cooker was placed in clear sunshine at 10:00 A.M. to allow plate temperature to attain stagnation. Testing was performed according to BIS standards(IS, 1992).

3.4 METHODOLOGY FOR THERMAL PERFORMANCE ANALYSIS

Effect of climatic and operating variables on thermal performance of box type solar cooker has been analyzed. As per the literature, the complete thermal analysis is complex in a box type solar cooker, due to the three dimensional transient heat transfers involved. Therefore to make the analysis simple, the efforts has been made in the present work to represent the first Fig of merit (F_1) in terms simple and directly measured parameters. In phase 1 analysis was performed using experimental data collected in real time condition to develop the correlations as shown in Fig 3.14.

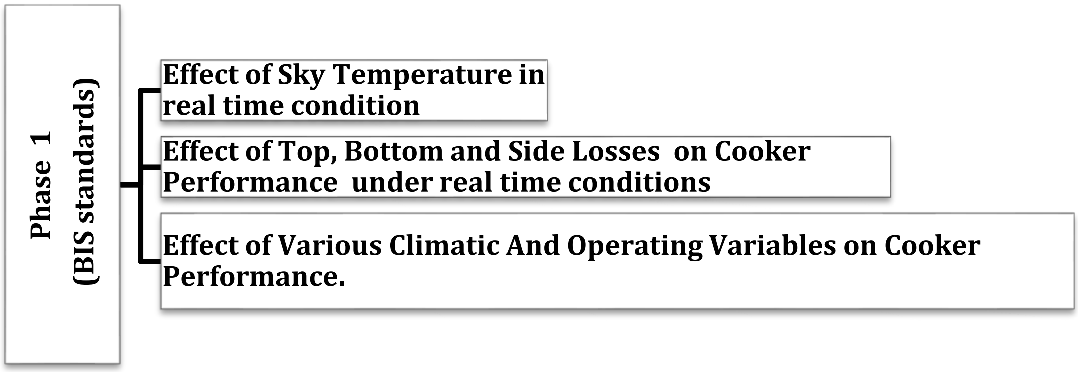

Figure 3.14Development of correlations in real time conditions

*In phase 1 various parameters which can be measured directly such as plate temperature, ambient temperature, and wind heat transfer coefficient are measured and their effect on thermal performance has been analyzed in order to develop the correlations of first Fig of merit as shown in Fig 3.14.

Attempts have been made to represent the first Fig of merit in terms of above said directly measured parameters using following calculation procedure.

In order to evaluate the thermal performance of box type solar cooker as per the Indian standard, two Figs of merit F_1 and F_2 will be estimated as suggested by Mullick (Mullick et al., 1991).

The first Fig of merit F_1 denotes the ratio of optical efficiency and the heat loss factor by the absorbing plate placed at the bottom of the cooker.

The second Fig of merit,F_2 is quite independent of the climatic conditions and indicates the heat transfer from absorbing plate to the water in the containers placed on the plate.

These Figs of merit are obtained by performing two different experiments I,e Stagnation /no load t Test and Water Load Test.

The first Fig of merit,F_1, is obtained by performing the outdoor experiments in the clear Sunshine days, around solar noon on the empty solar box cooker to be tested and the second Fig of merit,F_2, is obtained by performing sensible heating on fully loaded cooker with a known amount of water placed in the cooking pots in clear Sunshine.

The two Figs of merit are evaluated as mentioned below

$$F_1 = \frac{\eta_0}{U_l} \tag{3.1}$$

The First Fig of merit (F_1) is a function of optical efficiency (η_0) corresponding to the glazing and absorber system used and also the overall coefficient of heat loss U_L, of the solar cooker. The overall heat transfer factor, U_L, is the sum of top heat transfer factor (U_t), bottom heat transfer factor U_b and sides heat transfer factor U_s

$$U_l = U_t + U_b + U_s \tag{3.2}$$

The overall heat loss coefficient (U_L) depends upon the cooker design parameters and operating variables.

3.4.1 Evaluation of top heat loss coefficient

The heat loss coefficient at the top is evaluated by considering convection and radiation losses from the absorber plate in upward direction .For evaluating the top heat loss factor, individual heat transfer coefficients should be calculated. Top heat losses from a flat-plate collector with a double glass cover are schematically shown in Fig 3.15

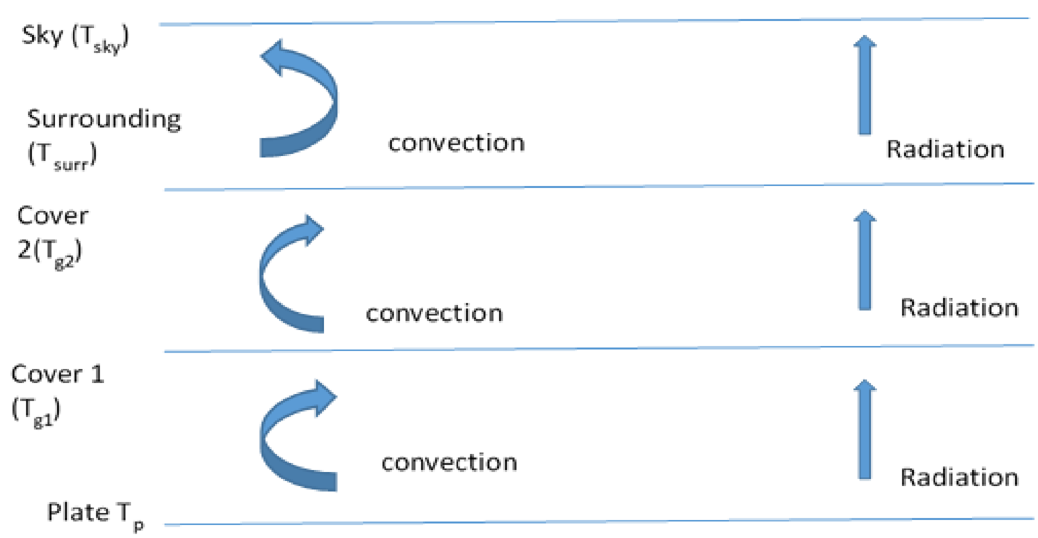

Figure 3.15Heat transfer mechanism through cover system with two glass covers.

Under steady state conditions the rate of heat loss per unit area from the absorber plate to the inner glass cover:

$$Q_t'' = (h_{cpg1} + h_{rpg1})(T_p - T_{g1}) \quad (3.3)$$

Equals that from the inner glass cover to the outer glass cover:

$$Q_t'' = (h_{cg1g2} + h_{rg1g2})(T_{g1} - T_{g2})$$

$$Q_t'' = (h_{rg2a} + h_w)(T_{g2} - T_a) \quad (3.5)$$

Where

h_{rpg1} And h_{cpg1} are the radiative and convective heat transfer coefficient from absorber plate to inner glass cover and is calculated as:

$$h_{rpg1} = \left(\frac{\sigma}{\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_g}-1}\right)(T_p^2 + T_{g1}^2)(T_p + T_{g1}) \quad (3.6)$$

$$h_{cpg1} = \frac{K_1 * Nu_1}{L_1} \quad (3.7)$$

h_{rg1g2} *and* h_{cg1g2} are the radiative and convective heat transfer coefficient from the inner glass cover to the outer glass cover ,calculated as

$$h_{rg1g2} = \left(\frac{\sigma}{\frac{2}{\varepsilon_g}-1}\right)(T_{g1}^2 + T_{g2}^2)(T_{g1} + T_{g2}) \quad (3.8)$$

And

$$h_{cg1g2} = \frac{K_2 * Nu_2}{L_2} \qquad (3.9)$$

h_{rg2a} is the radiative heat transfer coefficient from the outer glass cover to the atmosphere ,calculated as

$$h_{rg2a} = (\sigma \varepsilon_g) \frac{(T_{g2}^4 - T_a^4)}{T_{g2} - T_a} \qquad (3.10)$$

Top heat loss coefficient may be given as

$$U_t = (h_{cpg1} + h_{rpg1})^{-1} + (h_{cg1g2} + h_{rg1g2})^{-1} + (h_w + h_{rg2a})^{-1} + \frac{2L_g}{k_g} \qquad (3.11)$$

k_g= thermal conductivity of glass

L_g= thickness of glass cover.

To calculate the convective heat transfer coefficient. Properties of air evaluated at the arithmetic mean of corresponding surface temperature.

$$T_m = \frac{T_p + T_{g1}}{2}$$

(3.12)

Air properties correlations as suggested by Mullick *et al. (*1991)

$K_1 = 0.0002067 T_m^{0.85}$

$V_1 = 9 * 10^{-10} T_m^{1.72}$

$Pr_1 = 1.0602 - 0.06 log T_m$

Rayleigh number for enclosed surface can be calculated as

$$R_{a1} = \frac{{L_1}^3 P_r (T_p - T_{g1}) 0.98}{V_1^2 (\frac{T_p + T_{g1}}{2})}$$

From Rayleigh number Nusselt number (Nu_1) will be calculated as suggested by Buchberg (1976).

If R_{a1}< 1708,then Nu_1=1

If (R_{a1}>1708) & (Ra_1<5900), then

$Nu_1=1+1.446(1-\frac{1708}{Ra_1})$

If (Ra_1>5900) & ($Ra_1<9.23* 10^4).then$

$Nu_1=0.229*{Ra_1}^{0.252}$

If ($Ra_1>9.23* 10^4$)&($Ra1 < 10^6).then$

$Nu_1= K_{1*} Ra_1^{0.285}$

Simultaneously $Nu_2$and Ra_2 will be evaluated using air properties at arithmetic mean temperature of first glass cover and second glass cover.

Top heat loss coefficient has been calculated using the above procedure and compared with the values obtained from the correlations reported in literature.

3.4.2 Bottom and side heat loss coefficient

The bottom and side loss coefficient were calculated and compared with the assigned value of 0.85 W/m^2°C reported by Khan (Khan, 2004).
The assumed value of bottom and side heat loss coefficient was compared with the value obtained from heat balance of the set up using formula.

$$U_{(b+s)} = (Q_b + Q_s)/(T_p - T_a)A_s \tag{3.13}$$

And bottom heat loss coefficient is calculated as:

$$U_b = \frac{K}{L_1} \tag{3.14}$$

Bottom and side heat losses were calculated using the above procedure and compared with that of the assumed values in the literature and further its effect of first Fig of merit has also been analyzed in this present work.

3.4.3 Comparative analysis of first Figure of merit

First Fig of merit obtained from above procedure has been compared with the values obtained from existing correlation and then a new correlation developed. The results obtained from developed correlation has been compared with the values obtained from existing correlation.

3.4.4 Measurement of Wind Heat Transfer Coefficient (h_w) in Outdoor Condition

The wind heat transfer coefficient depends upon wind speed V. To evaluate h_w a number of correlations have been suggested in the literature. Most of these correlations are based on wind tunnel test whereas in actual situation (especially in outdoor conditions) the test conditions cannot always be represented by the wind tunnel conditions.

Some of the relations available in literature used for analysis of the effect of various parameters on wind heat transfer coefficient are mentioned in table 3.5

Table 3.5Different Correlations for wind heat transfer coefficient (S. Kumar & Mullick, 2010)

S.No	Wind Heat transfer Correlations	Correlations
1	Charples and Charles worth	h_w=6.7+ 3.3 V
2	Kumar et al.	h_w = 7.15 + 3.19 V
3	Sparrow etal	J = ¼ 0:86R
4	Mc Adams	h_w = 5.7 + 3.8V

Wind heat transfer coefficient for the test plate was calculated using experimentally measured values of wind velocity using the heat balance equation

$$h_w = \frac{[\alpha pI - Ki\frac{(Tib - Tib)}{t} - \sigma\epsilon p(T_p^4 - T_s^4) - masCpas\frac{dT_{as}}{dt} - miCi\frac{dT_{mi}}{dt} - mpCp\frac{dT_p}{dt}]}{T_p - T_a} \quad (3.15)$$

The values of wind heat transfer coefficient obtained from above correlation has been compared with the experimentally obtained values and the developed correlation in terms of directly measured parameters was compared with the values obtained from the existing complicated formula.

3.4.5 Effect of Glass Cover Temperatures of Double Glazed solar cooker

The following empirical relations for the temperature of second (outer) glass cover of flat plate collector as mentioned in table 3.6.

Table 3.6Different correlations for glass cover temperature

S.no	Reported literature	Correlation
1	Akhtar (Akhtar & Mullick, 2007)	If T_{sky} □ T_a $$T_2 = T_a + {h_w}^{-0.4}\{0.002I.T_p + 0.37\in_p - 0.146\}(T_p - T_a)$$ $T_{sky}=0.0552T^{1.5}$ $$T_2 = T_a + {h_w}^{-0.4}\{0.002I.T_p + 0.37\in_p - 0.146\}(T_p - T_a) - (\frac{14}{h_w^{0.65}})\}$$ Correspondingly other glass temperature $$T_1 = T_p - (0.7 - 0.34\,\varepsilon_g(T_g - T_2)$$
2	Samdarshi(Samdarshi & Mullick, 1991)	Inner surface temperatures of second glass cover factor f_{2i} $$f_{2i} = \frac{(0.7-0.26\varepsilon_p)\left[\{12*10^{-8}(T_a+0.2T_p)^3+h_w\}^{-1}+1.1L_{g2}\right]}{\left[6*10^{-8}(\varepsilon_p+0.028)(T_p+0.5T_a)^3+0.6L_1^{-0.2}\{(T_p-T_a)\cos\beta\}\right.}$$ Therefore $$T_{2i} = \frac{(f_{2i}T_p + CT_a)}{(1 + f_{2i})}$$

		C =1 when T_{sky} □ T_a And $$C = \frac{({T_s}/{T_a} + {h_w}/{3.5}}{(1 + h_w)}$$ when T_{sky}=0.0552$T^{1.5}$ Outer surface of glass cover temperature $$T_{20} = T_{21} - 5(T_p - T_a)L_{g2}$$
3	Experimental values	Tg_1= measured experimentally Tg_2= Measured experimentally

The values of the glass cover temperature obtained from the above correlations have been compared with the values obtained during experimental analysis.

3.5 SECOND FIG OF MERIT (F_2)

The cooker was loaded with four aluminum pots (painted dull black) each containing 0.8 kg of water. The experiments have been performed in the winter and summer season for alternate days.

Second Fig of merit is the product of heat exchange efficiency factor □F'□, optical efficiency (□$_o$) and heat capacity ratio (C_R).

The second Fig of merit, F_2 is determined as

$$F_2 = F' C_R \eta_0 \tag{3.16}$$

Where F' denotes the heat exchange efficiency factor, C_R is heat capacity ratio

$$C_R = \frac{MC_w}{MC'_w} \tag{3.17}$$

Where (MCw) represents the product of mass of the water and its specific heat and (MC'_w) it incorporates the heat capacity of the pots and unknown portion of the cooker interior portion as well. F_2 Can be represented in termed as of F_1 as follows:

$$F_2 = \frac{F_1(MC)_W}{A\tau}\ Ln\left(\frac{1-\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{I}\right)}{1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{I}\right)}\right) \tag{3.18}$$

The second Fig of merit is determined using equation (3.2), which involves natural logarithm of a function with this dimensional group.

Analyzing over an infinitesimal time interval during the sensible heating of water, the time taken, $d\square$, for a water temperature rise dT_w, is

$$d_\tau = \frac{(MC)_w\, dT_w}{Q_w} = \frac{(MC)_w dT_w}{AF[\cap_o I - U_L(T_w - T_a)} \qquad \text{(Mullick et al., 1987)} \tag{3.19}$$

where Q_u , is the rate of useful heat gain by water, A is the aperture area, I the insolation on a horizontal surface, and F' is the heat exchange efficiency factor. $(MC)_w$ is the product of mass of water taken and its specific heat capacity. MC'_u includes also the heat capacity of the utensils and a certain portion of the cooker interiors.

The cooker parameter $F'\eta_o C_R$ can be calculated from equation (3.19) since $(MC)_w$, the heat capacity of water in the containers, is known. This parameter serves as the second Fig of merit, F_2. Replacing the ratio η_o/U_L by the factor F_1, equation can be written as

$$d_\tau = \frac{(MC)_w dT_w}{AF\cap_o[I - \frac{1}{F_1}(T_w - T_a)]} \quad (3.20)$$

3.5.1 Effect of different Water Temperature Ranges and its selection on Second Fig of Merit of Box Type Solar Cookers

The range of water temperature (T_{w1} to T_{w2}) for sensible heating has a significant effect on second Fig of merit, F_2. In the present work, the different water temperature ranges have been taken and the effect of its selection on F_2 has been analyzed using the standard method involving the integral equation for the time interval as well, it has also been compared with semi-log plot method. The comparative results for different water temperature ranges (T_{w1} to T_{w2}) has been discussed.

Once data collected for different seasons of the year and the input parameters have been measured during the experimentation across the year have been used for further analysis purpose on mat lab.

3.5.2 Semi-Log Plot Method for estimation of Second Fig of Merit

The second Fig of merit can also be obtained using Semi-Log Plot Method as proposed by (Khan, 2004)This method is described here as follows:

It requires the determination of two terms, X_1 and X_2 Expressing,

$$X_1 = \frac{T_{w1} - T_a}{F_1 I} \quad (3.21)$$

$$X_1 = \frac{T_{w2} - T_a}{F_1 I} \quad (3.22)$$

$$\tau_{12} = -\frac{F_1(MC)_w}{A\,F_2}[\ln(1 - X_1) - \ln(1 - X_2)] \quad \text{`} \tag{3.23}$$

Linear regression of the experimental data between T_{W1} to T_{W2} is obtained.

The slope m during linear regression is used to obtain F_2 by the following relation:

$$m = \frac{F_1(MC)_w}{F_2 A}$$

The following relation is used for the estimation of F_2 once the slope m is determined from linear regression of semi-log plot of the experimental results

$$F_2 = \frac{F_1(MC)_w}{mA} \tag{3.24}$$

Some studies have been done on the second Fig of merit of box type solar cookers. These studies includes:

a) Validation of semi-log plot method to estimate second Fig of merit of box type solar cookers.

b) Analysis of second Fig of merit of box type solar cookers by semi-log plot method.

c) Effect of different water temperature range on second Fig of merit of box type solar cookers.

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3.6 COMPARATIVE ANALYSIS OF THERMAL PERFORMANCE OF DIFFERENT GEOMETRIES

The experiments have been performed under similar climatic conditions prevailing at Dehradun on three geometries of solar cookers identical in aperture area .various parameters were compared such as plate temperature, glass cover temperature, boiling time and thermal performance of these geometries was also compared in terms of first Fig of merit and second Fig of merit as mentioned in Fig 3.16. The correlation developed from that preliminary analysis has been used here to do a comparative analysis of thermal performance of different geometries

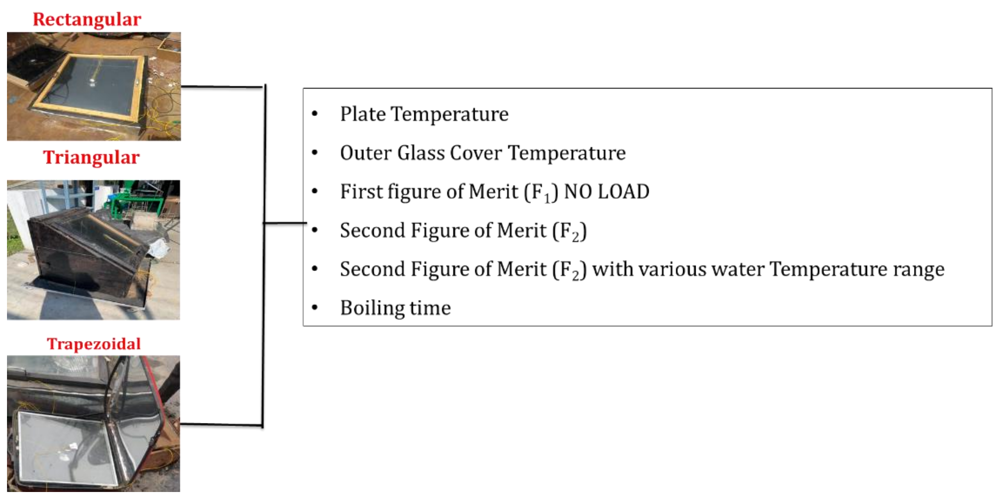

Figure 3.16Procedure for comparative analysis of different geometries

Similar procedure has been used for comparing the performance of different geometries in terms of F_1 and F_2.

All above mentioned parameters have been measured and evaluated and their variation has been discussed in the subsequent chapter.

4 CHAPTER:

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter the observations made during the experimental work, results of the effect of various climatic and operating parameters on thermal performance of box type solar cooker, comparative analysis of the different geometries and their subsequent effect on the thermal performance enhancement has been discussed.

On the basis of the observations, the effect of climatic and operating variables viz. sky temperature (Ts), ambient temperature (T_a), solar radiation (I), plate temperature (T_p) and wind heat transfer coefficient, (h_w), on thermal performance (overall heat loss coefficient (U_L) and on first Fig of merit (F_1) of solar cooker has been analyzed and discussed .

Based on the effect observed of the above mentioned variables on thermal performance, the correlations were developed for first Fig of merit, overall heat transfer coefficient and wind heat transfer coefficient in terms of directly measured and simple variables.

The results obtained from the testing of three different geometries of solar cookers under similar environmental condition using the developed correlations has been discussed and a comparative analysis has been performed.

- All data sheets of the measured parameters used for analysis has been attached in annexure.

4.2 VARIATION OF PLATE TEMPERATURE AND INSOLATION

The plate temperature has been measured in the test setup for all the seasons of the year except July and August (rainy season). The variation of plate temperature T_p with respect to the various seasons of the year has been depicted in Fig 4.1. It can be observed from the variation that initially the temperature fluctuates significantly as we place the solar cooker in ambient conditions in the morning but gradually as soon as the heat is trapped inside the cooker the temperature is stagnant and this state is referred as the steady state. The highest temperature of the plate was observed in the month of June whereas the minimum was observed in November. The reason of High plate temperature is the insolation falling on the earth surface.

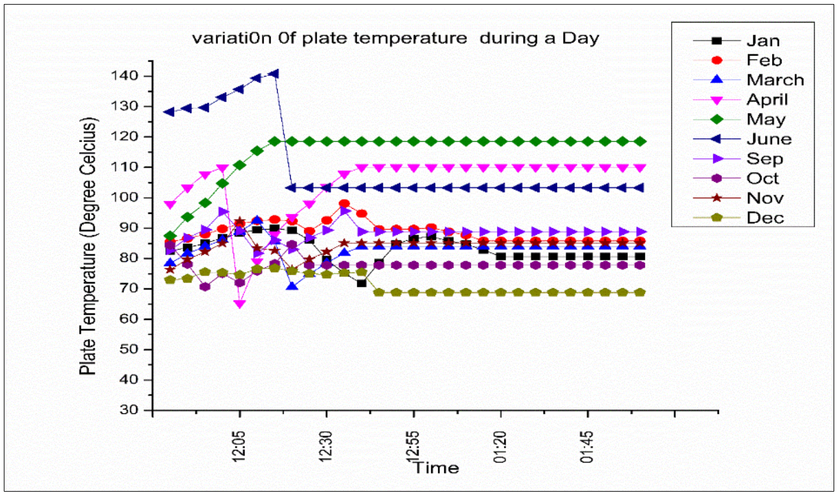

Figure 0.1Variation of plate temperature during different days of a year for a duration

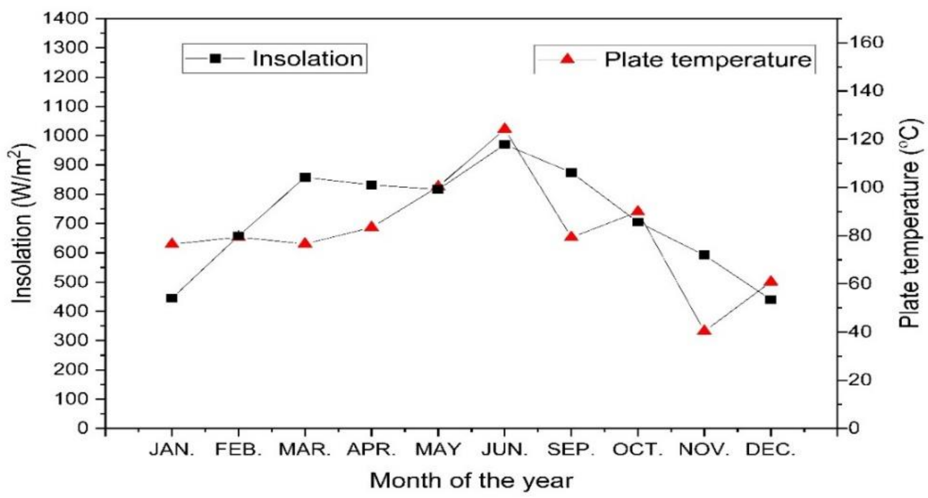

Figure 0.2Variation of plate temperature and insolation for different months of a year.

Fig 4.2 depicts the variation of plate temperature across various months of the year at the geographic location of Dehradun. Insolation seems to have a considerable effect on plate temperature and it is obvious from the fact that a higher value of insolation will result into higher plate temperature. The minimum and maximum plate temperature was observed to be 313 K in the month of November and highest value of 397 K during June. The value of insolation was observed between 444 W/m^2 to 970 W/m^2 throughout the year.

4.3 EFFECT OF SKY TEMPERATURE ON PERFORMANCE OF. BOX TYPE SOLAR COOKER

The climatic conditions prevailing at UPES (Dehradun) around the solar noon throughout the year have been considered to estimate the sky temperature (Ts) by using different correlations as mentioned in literature review. The values of sky temperature obtained from different correlations are listed in the Table 4.1.

Table 0.1Values of sky temperature (T_s) obtained from different correlations.

T_a (K)	P_s (mb)	R_h	P_a (mb)	T_{dp} (°C)	Brunt T_s(K)	Swinbank T_s(K)	Vishwa--nandham T_s(K)	Idso Jackson T_s(K)	Brutsaert T_s(K)	Berdhal T_s(K)	Berger T_s(K)	Prata T_s(K)	Staley T_s(K)	Bliss T_s(K)
283	0.36	80	0.288	6.71	244.25	262.80	245.98	264.11	233.49	262.38	266.31	256.15	250.86	269.86
288	0.5	75	0.375	10.6	249.12	269.79	250.68	270.73	239.72	269.39	272.62	260.82	256.97	275.91
293	0.69	70	0.483	14.36	254.05	276.85	255.46	277.85	245.94	276.54	278.90	265.52	263.13	281.95
298	0.94	60	0.564	16.7	258.80	283.96	260.15	285.24	251.38	282.87	284.62	270.17	269.28	287.54
303	1.25	50	0.625	13.59	263.44	291.14	264.76	292.66	256.38	285.44	288.09	274.78	275.36	291.31
308	1.66	45	0.747	15.78	268.34	298.38	269.62	299.93	262.12	291.70	293.78	279.49	281.50	296.87
313	2.18	40	0.872	17.6	273.23	305.67	274.50	306.93	267.70	297.77	299.34	284.20	287.63	302.32

It can be observed from the Table 4.1 that the lowest values of sky temperature are obtained with Brutsaert's(Brutsaert, 1975) correlation. Similar values of sky temperature are obtained by using correlations suggested by Brunt(Brunt, 1932b) and Viswanadham. The values of sky temperature at different ambient conditions obtained by using the results of studies of Swinbank(Swinbank, 1963), Idso and Jackson (Idso & Jackson, 1969)Bredahl (Berdahl & Fromberg, 1982) ,Berger (Berger & Bathiebo, 1989)and Bliss(R. W. Bliss, 1961)are almost similar. The study of Prata (J Prata, 1996) and Staley (Staley & Jurica, 1972), results in similar values of sky temperature in the present study. However these values are lower than the values obtained from Swinbank correlation.

The values of sky temperature have also been estimated by using results of different studies Crawford and Duchon (Crawford & Duchon, 1999), Llebot and Jorge (Llebot & Jorge, 1984), Centeno (Centeno V, 1982).The values of sky temperature are found to be similar to those obtained by Swinbank , Idso and Jackson , Bredahl ,Berger and Bliss . The radiative heat loss from upper outermost glass cover of solar collector /cooker to ambient has been estimated by using the values of ambient temperature and the corresponding estimated values of the sky temperature obtained from different correlations as listed in table 4.1 .The range of glass cover temperature has been taken 30 to 90°C. The Fig 4.3 shows the variation of radiative heat loss, calculated by using values of sky temperature obtained from different correlations.

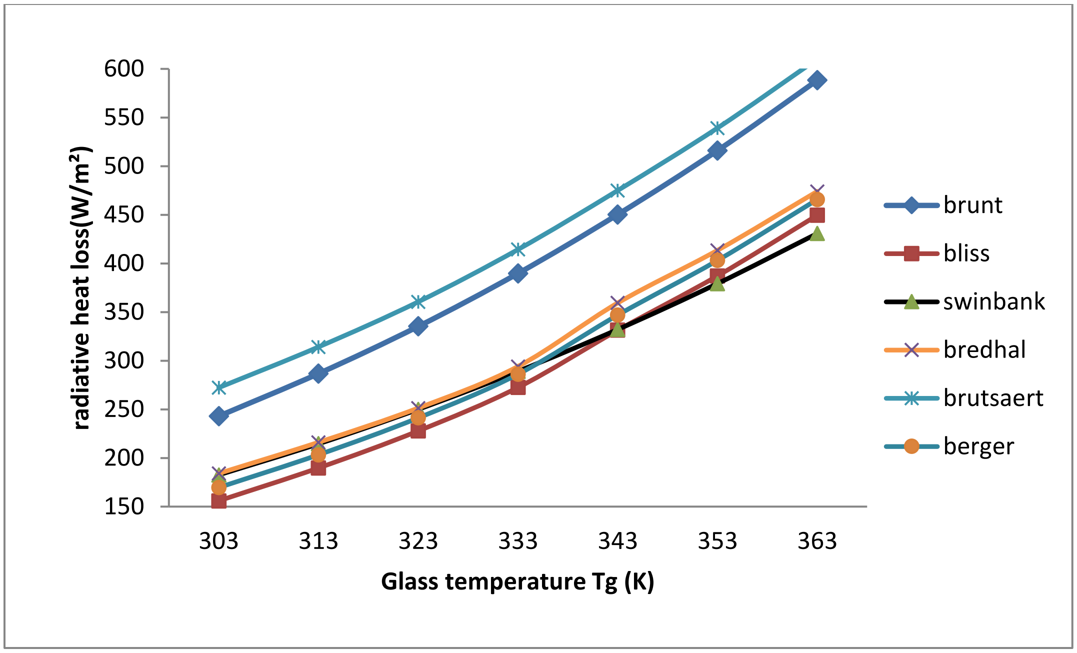

Figure 0.3Variation of radiative heat loss with glass temperature

It is observed that the higher values of radiative heat losses are obtained by using the values of sky temperature obtained from correlations of Brunt and Brutsaert .Almost similar values of radiative heat losses are obtained by using the values of sky temperature obtained from studies of Swinbank, Idso and Jackson, Bredahl, Berger and Bliss .

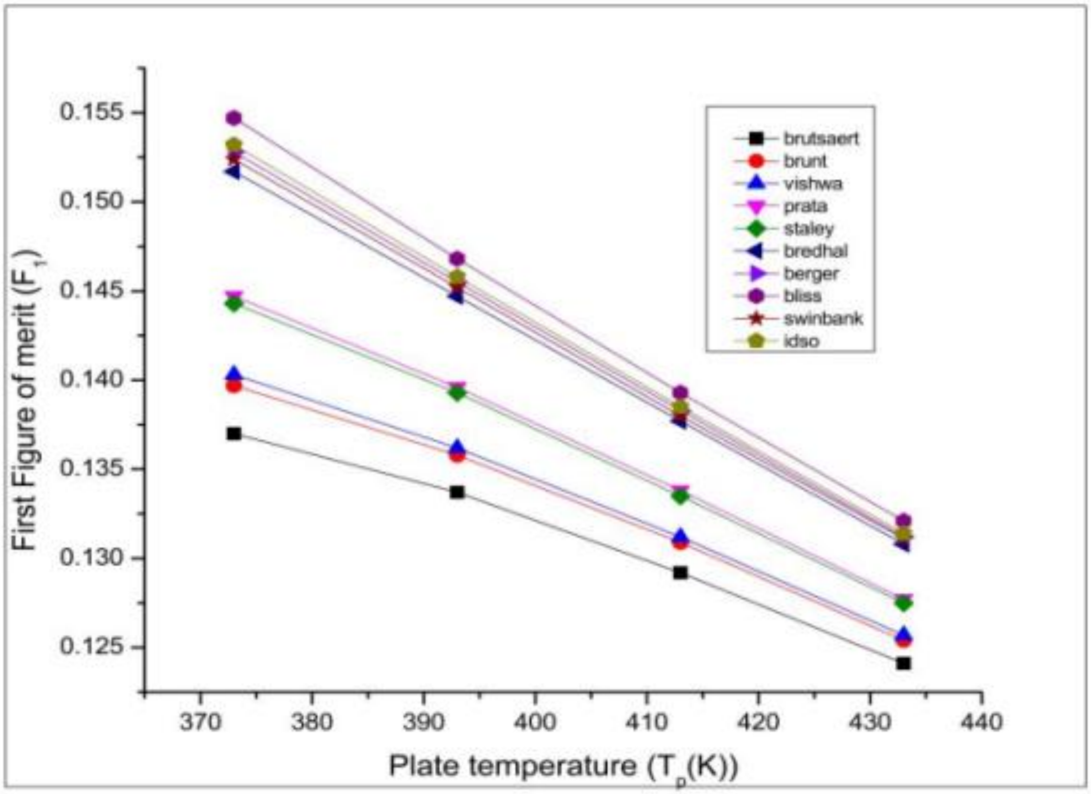

Figure 0.4Variation of first Figure of merit with plate temperature

It can be depicted It can be observed from the fig 4.4 that for a particular value of ambient temperature and wind heat transfer coefficient the lowest values of first Fig of merit are obtained with Brutsaert's(Brutsaert, 1975)'s correlation and highest values are obtained with Bliss correlation. For all the correlations of sky temperature the value of F_1 reduces as plate temperature increases. Similar values of F_1 are obtained by using correlations suggested by Brunt and Viswanadham. The values of first Fig of merit obtained by using sky temperature the results of studies of Swinbank, Bredahl ,Berger and Bliss are almost similar .The study of Prata and Staley , results in similar values of F_1. However these values are lower than the values obtained from Swanbank, and Bliss correlation.

It can be depicted from the Fig 4.4 that for particular ambient conditions and wind velocity at higher plate temperature all correlation of sky temperature holds good and yield almost similar values, however there is a significant difference at lower plate temperature.. Similar values of first Fig of merit is obtained in Bredahl, Berger and Bliss is due to the fact that these correlations are a function of dew point temperature.

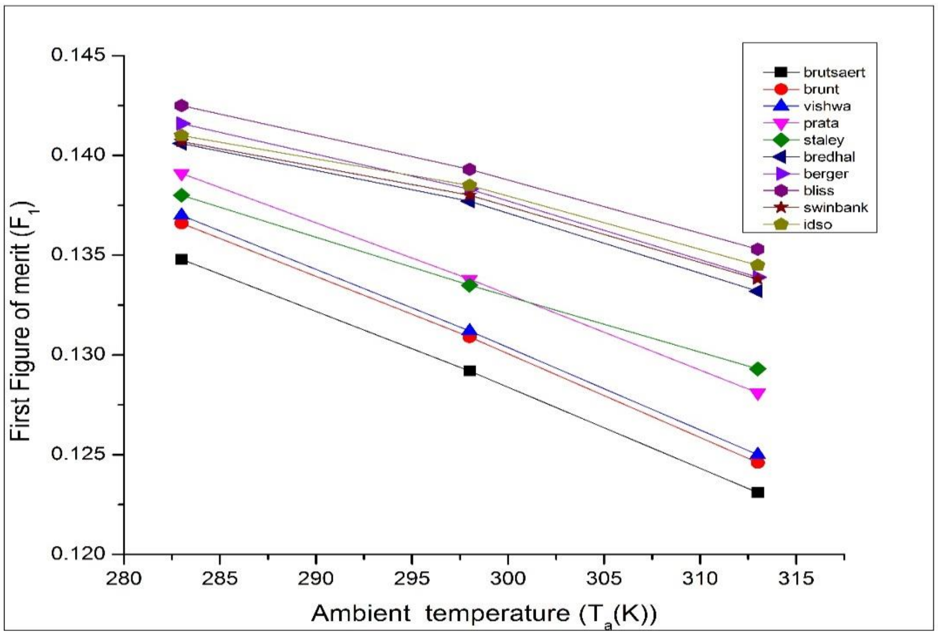

Figure 0.5Variation of first Figure of merit with ambient temperature

It can be observed from the fig 4.4 that for a particular values of plate temperature and wind heat transfer coefficient the change in ambient conditions has a significant effect on F_1 with different correlations of sky temperature at lower plate temperature. At higher ambient conditions the effect of dew point temperature and vapor pressure is significant on ambient temperature, which ultimately effect the radiative heat loss and hence effect the estimation of first Fig of merit F_1.

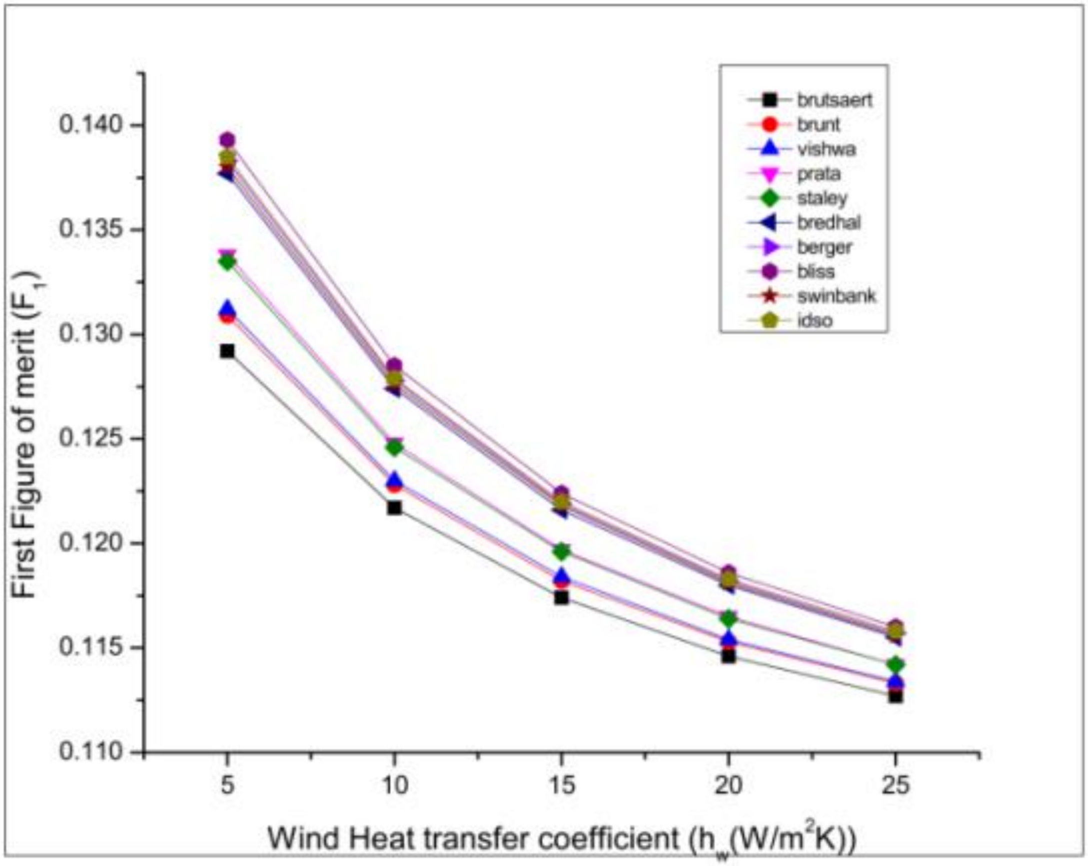

Figure 0.6Variation of first Fig of merit with *wind heat transfer* coefficient (h_w)

As shown from the Fig 4.5 at ambient temperature and plate temperature wind heat transfer coefficient has a significant effect on F_1. At lower wind heat transfer coefficient values the range of F_1 is wide as compared to the range at higher values of wind heat transfer coefficient.

The variation in F_1 at lower wind heat transfer coefficient (h_w =5 W/m²) is maximum i,e 7% and the range of F_1 lies between 0.1292 to 0.139, with all the correlations of sky temperature. However as the wind heat transfer coefficient increases this variation is reduced to a minimum of 2% at h_w =25 W/m² the range of F_1 lies between 0.1158 to 0.1127 with all sky temperature correlations.

Table 0.2Effect of Sky temperature on performance of solar cooker

S.no	Highest/lowest values	Variation in F_1 with different sky Temperature correlations
Effect of plate temperature	Higher Values: Bliss correlation LowestValue: Brutsaert's(Brutsaert, 1975). correlation	Maximum at 373 K:12%(0.137-0.154) Minimum at 433 K: 6% (0.124-0.132)
Effect of wind heat transfer coefficient	Lowest Value: Brutsaert's(Brutsaert, 1975)'s correlation Highest value : Bliss correlation	Variation in F_1 is low at lower ambient Temperature values and high at higher ambient Temperature (6%)
Effect of ambient Temperature	Lowest Value: (Brutsaert, 1975))'s correlation Highest value : Bliss correlation	7% (0.1292 to0.139) at h_w=5 (W/m^{2}K) 2%(0.1158 to 0.1127) at h_w=25 (W/m^{2}K)

It is evident from the above fig 4.3, 4.4 and 4.5 there is a slight variation in the values of first Figure of merit using different correlations of sky temperature in terms of ambient temperature, wind heat transfer coefficient and plate temperature. This variation is due to involvement of various other climatic parameters such as vapor pressure, dew point temperature in the estimation of effective emissivity of the sky which in turn affects the sky temperature and estimation of first Figure of merit .The variation is also due to the reason that all the correlations were developed using the experimental data prevailing at their respective geographical locations, therefore it is difficult to estimate the value of sky temperature accurately through any one of the correlation for any other location.

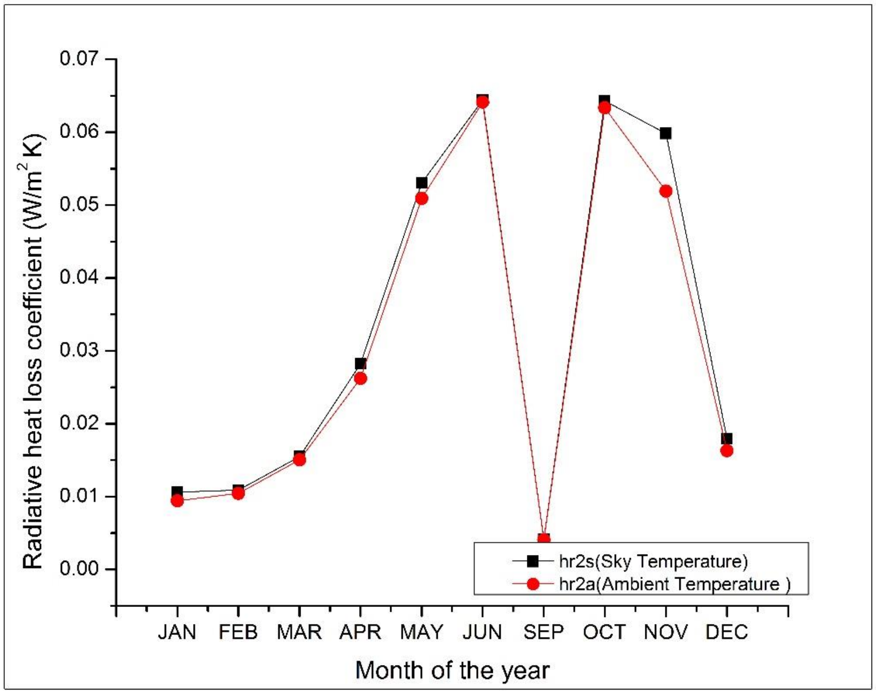

Figure 0.7Variation of radiative heat loss with ambient and sky temperature

To analyze the effect of sky temperature with respect to the ambient temperature on the radiative heat losses and first Figure of merit, ambient temperature and sky temperature has been obtained experimentally.

It can be observed from the fig 4.7 that there is slight variation in radiative heat losses when sky temperature is being considered as compared to the ambient temperature.

With ambient temperature the radiative heat losses produces a lower value as compared to the sky temperature consideration, throughout the year. Hence negligible effect has been observed in case of box type solar cooker

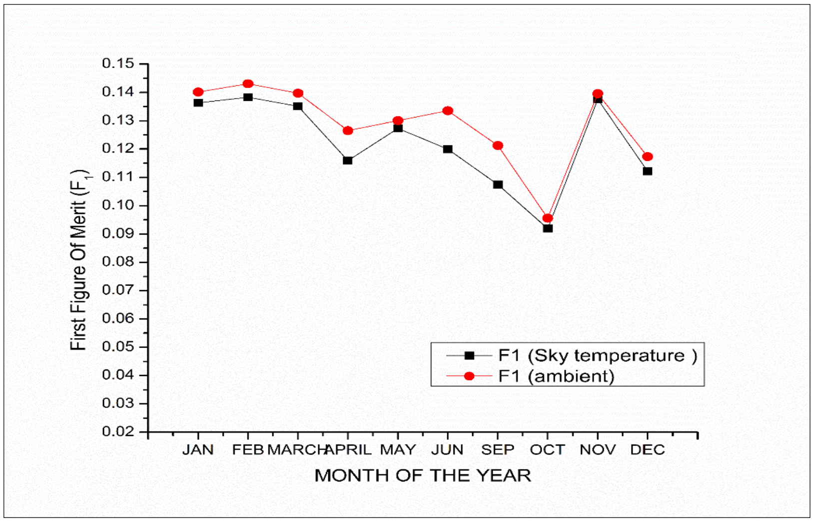

Figure 0.8Variation of first Fig of merit with ambient and sky temperature

Although Higher values of F_1 were observed across all seasons of the year in case of ambient temperature as compared to the sky temperature ,the variation was not very significant as shown in the Fig 4.8.

4.4 EFFECT OF OPTICAL EFFICIENCY

The effective optical efficiency in Dehradun, at noon with 20% diffuse fraction, with 25% diffuse fraction and with 30% diffuse fraction, reduces maximum (on a day of the year) by 2.2%, 2.8% and 3.4%, respectively (compared to the case when no diffused fraction in total radiation is considered) as shown in Fig 4.9. Fig 4.10 Fig 4.11, shows the variation of optical efficiency with time at Dehradun on different days of a year.

Since F_1 is directly proportional to optical efficiency ($\square_o$), any change in optical efficiency will reflect an equal change in the value of F_1.On clear sunshine days, an increase in diffuse component from 20% to 25% and 20% to 30%, reduces the value of effective optical efficiency maximum by 0.59% and 1.16%, respectively. Hence it can be observed that the range of optical efficiency at Dehradun lies between 0.71 to 0.76 therefore a value of 75 % can be assumed for the current location for further estimation of the thermal performance. Days were selected on the basis of insolation range.

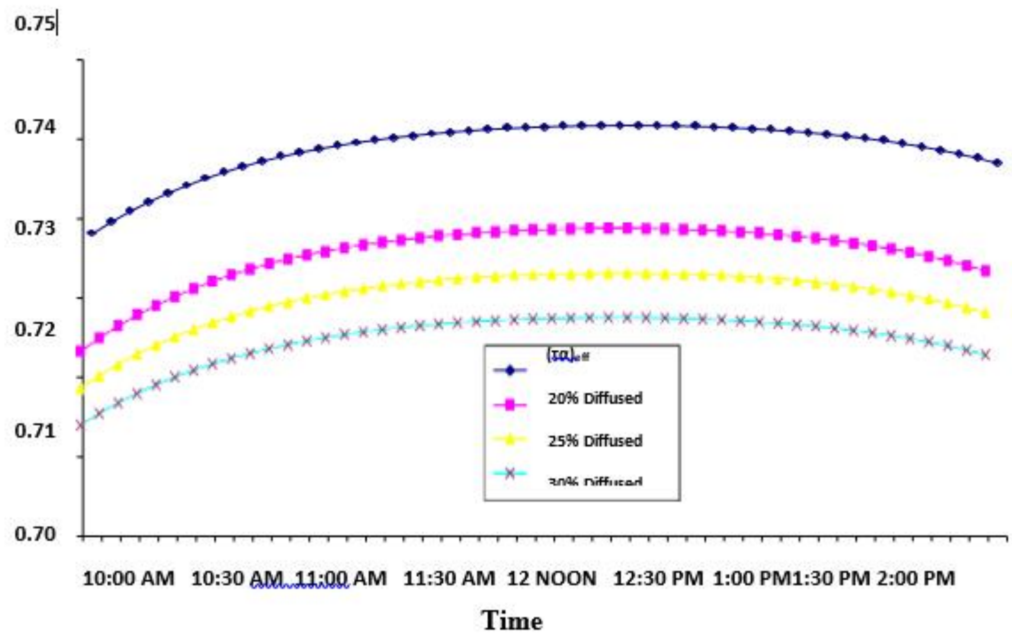

Figure 0.9Variation of Optical Efficiency with time of the day at Dehradun on Mar 21

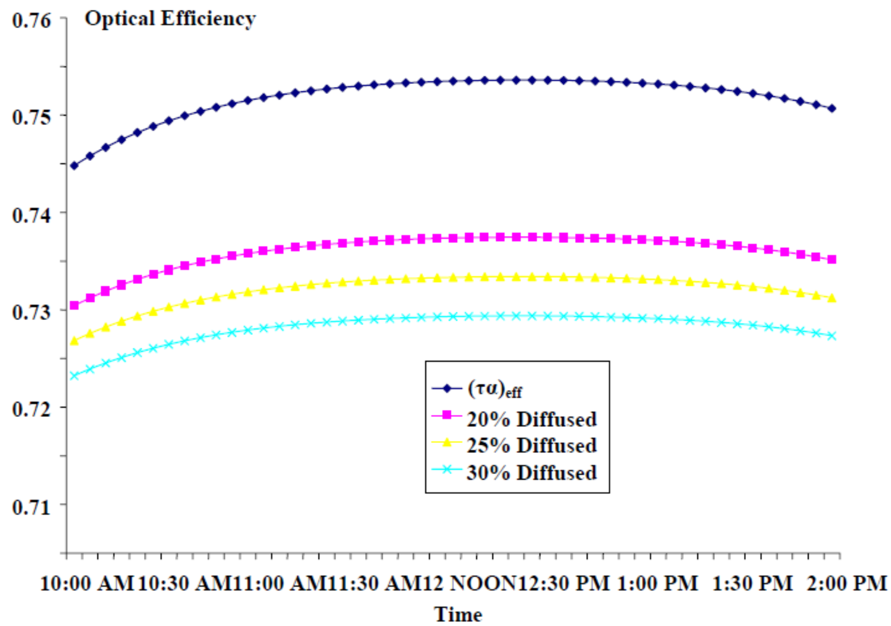

Figure 0.10Variation of Optical Efficiency with time of the day at Dehradun on MAY 11

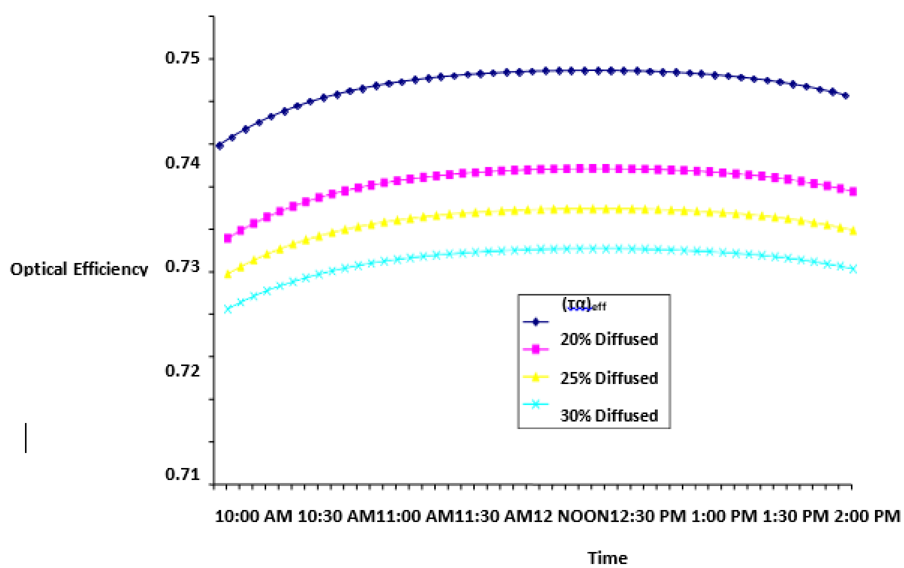

Figure 0.11Variation of Optical Efficiency with Time of the day on Oct .25 at Dehradun

4.5 EFFECT OF VARIOUS CLIMATIC AND OPERATING PARAMETERS

Effect of various climatic and operating parameters viz glass cover temperature, ambient temperature, absorber plate temperature wind velocity has been discussed on top heat loss factor, bottom and side heat losses and performance during no load test.

4.5.1 Glass cover temperatures of box type solar cooker

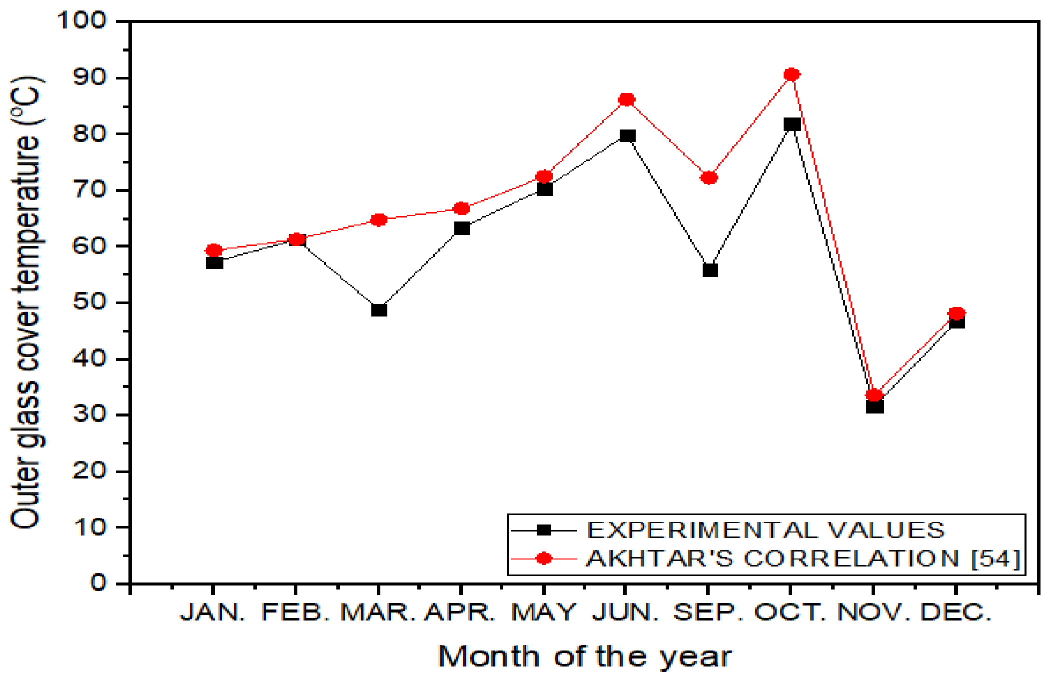

Figure 0.12Variation of experimental and predicted outer glass cover temperature

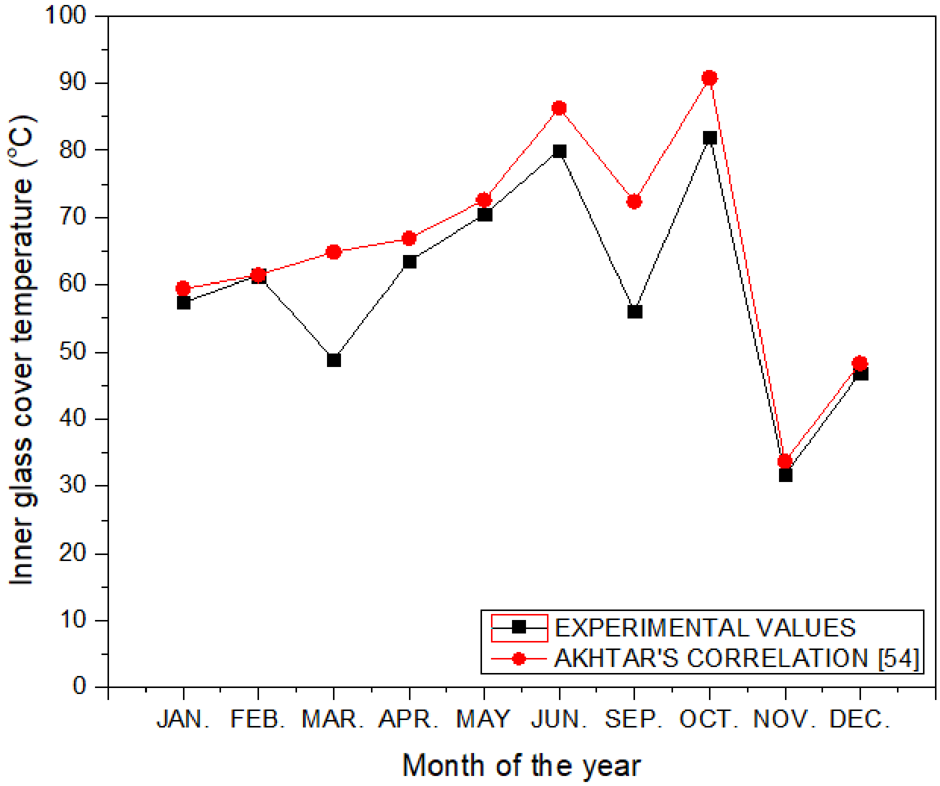

Figure 0.13Variation of experimental and predicted inner glass cover temperature.

Table 0.3. Variation of experimental and predicted inner glass cover temperature.

S.no	AKHTAR's Correlation	Variation (%) with correlation
1	Inner glass cover temperature(T	(3-20)%
2	Outer glass cover temperature(T	(4-20)%

Fig 4.12 shows the variation of outer glass cover temperature measured during different months of the year and compared with the values obtained using Akhtar (Akhtar & Mullick, 2007) correlation. The outer glass cover temperature is high in June and September and lowest in November. The variation between the experimentally

measured values and calculated values lies between 4% to 20%.this seasonal variations of glass cover temperature is due to the effect of combined effect of wind and insolation in case of outer glass cover temperature and hence also effect inner glass cover temperature.

The variation of inner glass cover temperature measured during different months of the year and compared with the values obtained using Akhtar (Akhtar & Mullick, 2007) correlation is depicted in Fig 4.13 . The inner glass cover temperature is highest in the month of September and lowest in the month of November. The variation between the experimentally measured values and calculated values lies between 3% to 20% as shown in Table 4.3.

4.5.2 Effect of various parameters on wind heat transfer coefficient

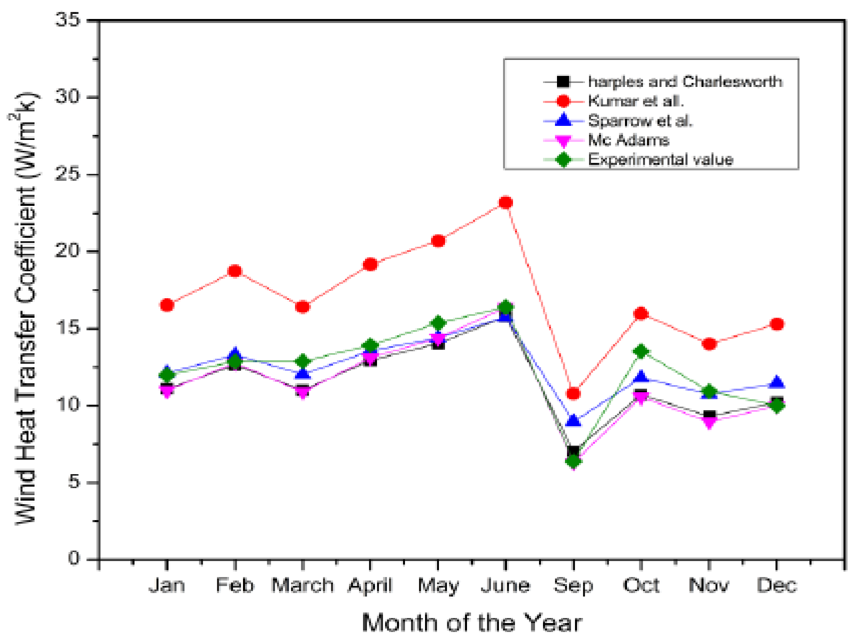

Figure 0.14Comparison of correlations for Wind Heat Transfer Coefficient

In the present work, test information of unglazed test plate during the months JAN-

DEC for a long time were utilized to evaluate wind-heat transfer coefficient. Wind speed was recorded at the site of investigations with a testing time of 1 second. Estimated wind speed was averaged over 5 minutes to give a delegate estimation of wind speed for that period.

Moreover, there is a considerable difference in the values of wind-heat transfer coefficient (h_w) obtained from different correlations at the same wind velocity. The comparative study of the above correlations is shown in Fig.4.14. At certain wind velocities, Harples and Charles worth (S. Kumar & Mullick, 2010)correlation gives the minimum value whereas the maximum value is obtained from the correlation proposed by the experimental data analysis using heat balance equation. The percentage difference is considerably higher at lower wind velocities, and it decreases with increasing velocities.

Fig 4.14 shows the comparison among the average values of wind-heat transfer coefficient obtained during experimentation throughout the year in respect to the values of wind heat transfer coefficient calculated using different correlation suggested by Kumar et al. , Mc Adams , Harples and Charlesworth and Sparro et al. (S. Kumar & Mullick, 2010), using the respective values of measure wind velocity as shown in table 4.4. The average value of insolation and plate temperature for a particular month is calculated for comparison. It is observed from the Fig that the values of h_w increase from January to June and then decreases during experimentation and theoretical investigation. This rise and decline is due to the fact of wind velocity variation across the month and change in ambient conditions, which directly affect the wind heat transfer coefficient. Experimental values were observed to be higher than the theoretical values resulted from various correlations. The reason is that most of the correlations were based on wind tunnel testing and only few correlations which were developed using outer door experiments were based on a particular location .from the above It shows that wind velocity measured in prevailing environmental conditions and the experimental determination of wind heat transfer coefficient is important, moreover requirement is for a correlation in terms of wind velocity and as well as ambient temperature. For correlation, the results of various investigations were normalized for a plate length.

The wind induced convective heat transfer from the uppermost surface plays a significant role in determining the magnitude of top heat transfer coefficient, U_t, and thereby affecting the performance of the solar box type cookers or flat plate collectors. It therefore, becomes necessary to decide up on the most appropriate values of h_w, to be used into the equations for analytically calculating the overall heat loss coefficient of a box type solar cooker

$$h_w = \frac{[\alpha pI - Ki\frac{(Tib - Tib)}{t} - \sigma\epsilon p(T_p^4 - T_s^4) - masCpas\frac{dT_{as}}{dt} - miCi\frac{dT_{mi}}{dt} - mpCp\frac{dT_p}{dt}]}{T_p - T_a} \quad (4.7)$$

Table 0.4comparative analysis of various wind heat transfer correlations with experimental values in outdoor conditions

S.No	Wind Heat transfer Correlations	W/m²°C	Variation with experime data
1	Charples and Charles worth	Lowest:7 Highest :15	3-15%
2	Kumar et al.	Lowest:10 Highest :23	15 to 40%
3	Sparrow etal	Lowest:: 8 Highest :16	12 to 40%
4	Mc Adams	Lowest: 6 Highest :16	0 to 15%
5	Experimental Values in outdoor condi	Lowest: 5 Highest :17	

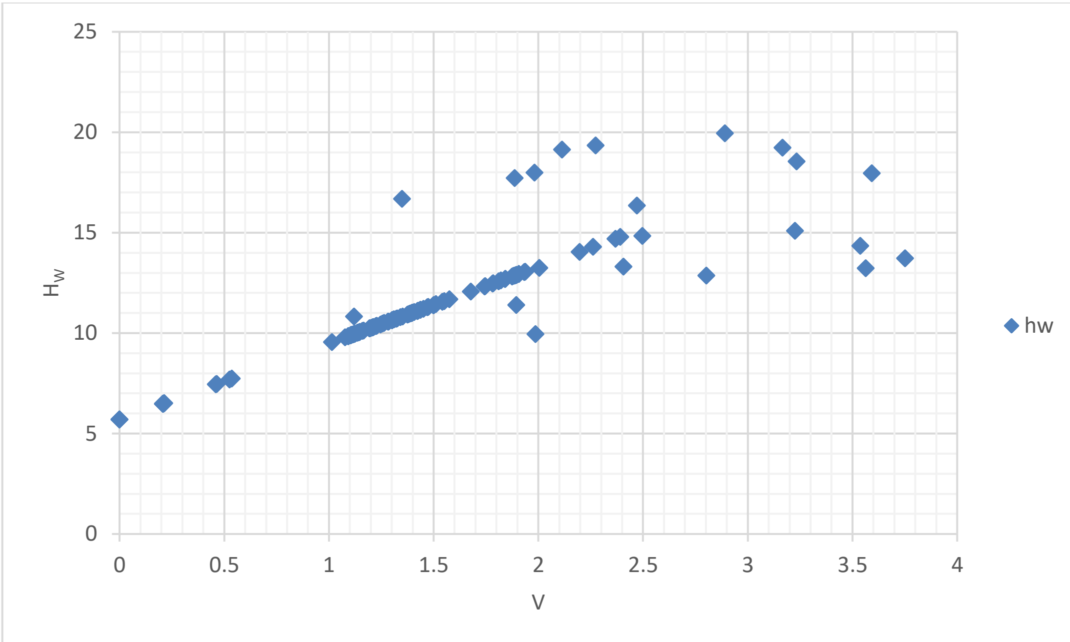

Figure 0.15Scatter plot of wind heat transfer coefficient for different wind speeds.

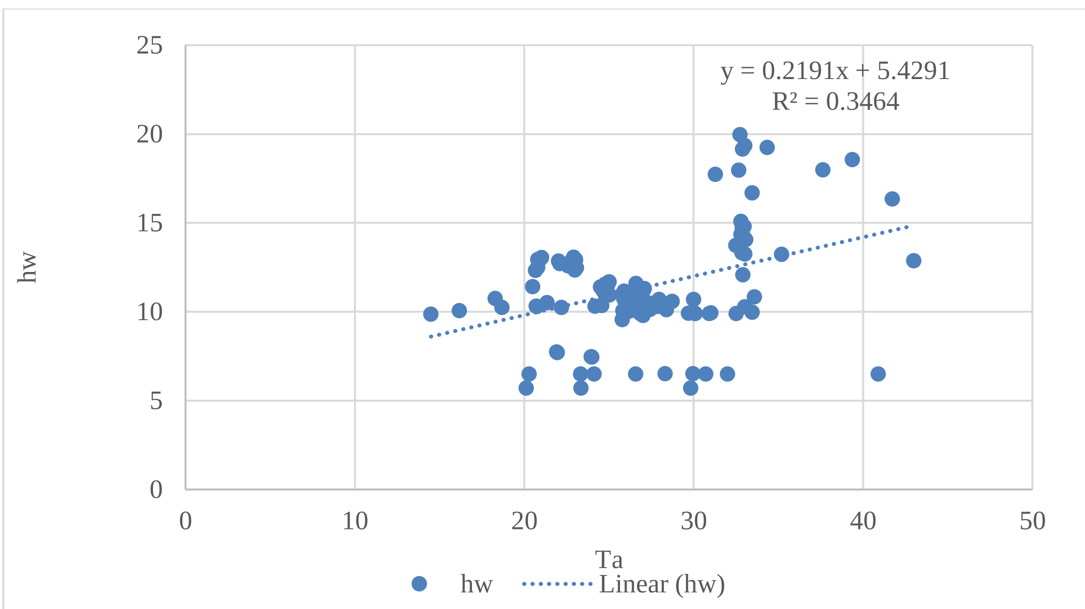

Figure 0.16Scatter plot of wind heatransfer coefficient for different ambient conditions.

From Fig 4.15 and 4.16 it is evident that the effect of wind velocity and ambient temperature plays an important role in estimation and effect wind heat transfer coefficient significantly and only wind velocity does not affect the coefficient there are other parameters too like ambient temperature as shown in fig 4.15, therefore a correlation should be developed and should include the effect of wind velocity as well as ambient temperature.

When the effects of ambient temperature *(T_a), and* wind heat transfer coefficient *(h_w)* is considered individually, the scatter obtained is high. An attempt is made to see if the scatter can be reduced by non-linear multiple regression of experimental data.

And the proposed correlation is

$$h_w = 5.67 * T_a^{0.27} * v^{0.33} \tag{4.8}$$

The proposed correlation find its applicability in the range of 0.2 to 3.5 m/s for wind velocity and 22 to 42℃ in case of ambient Temperature. The applicability of this correlation developed is in the regions like Himachal, Srinagar, and Chamoli etc. The proposed correlation has been validated with predicted values of wind heat transfer coefficient obtained from measured values as in Fig 4.17.

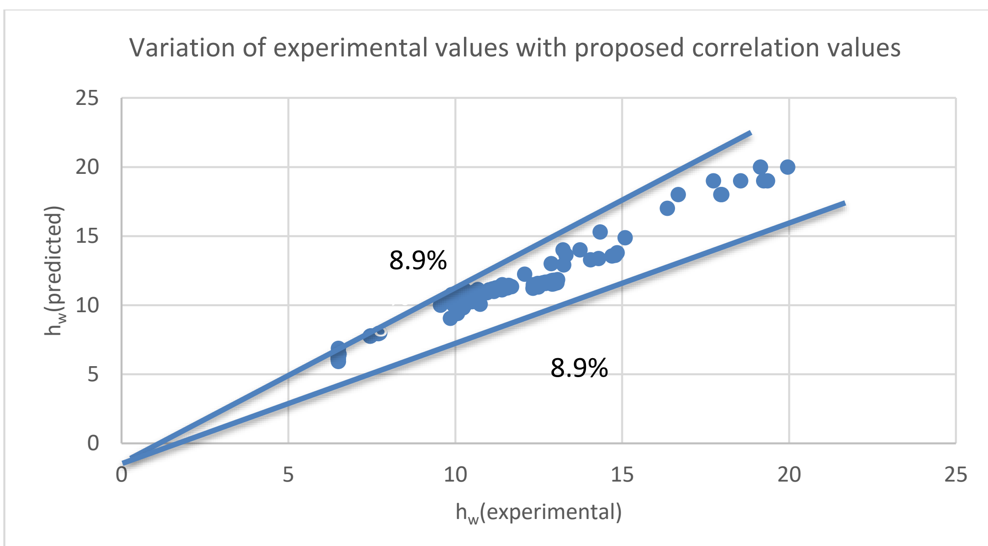

Figure 0.17Variation of predicted values from proposed correlation with that of estimated from experimentation

This wind heat transfer coefficient is further used during the estimation of topheat loss factor.

4.5.3 Effect of climatic and operatic parameters on top heat loss factor

The experimental data have been analyzed to estimate the top heat loss factor (U_t).it can be depicted from the Fig 4.18, the variation and fluctuation in the experimentally computed values of top heat loss factor is high in the morning and reaches to stagnation state during noon similar to the plate temperature. It was observed that the experimental value of U_t obtained i.e. $(U_{t.})_{exp}$ is more than the estimated values on all days of experimentation. The order of the values are $(U_{t.})_{exp} > (U_t)_{Samdarshi}$. Fig: 4.19 shows the graphical representation of $(U_{t.})_{exp}$, $(U_t)_{Samdarshi}$ obtained on various months of a year covering all the seasons.

The computed values of U_t obtained by measured values of glass cover temperatures Tg_1 and Tg_2 are close to the computed values of U_t using glass temperatures estimated by Samdarshi and Mullick [missing] as discussed in methodology.

$$U_t = (h_{cpg1} + h_{rpg1})^{-1} + (h_{cg1g2} + h_{rg1g2})^{-1} + (h_w + h_{rg2a})^{-1} + \frac{2L_g}{k_g} \tag{4.8}$$

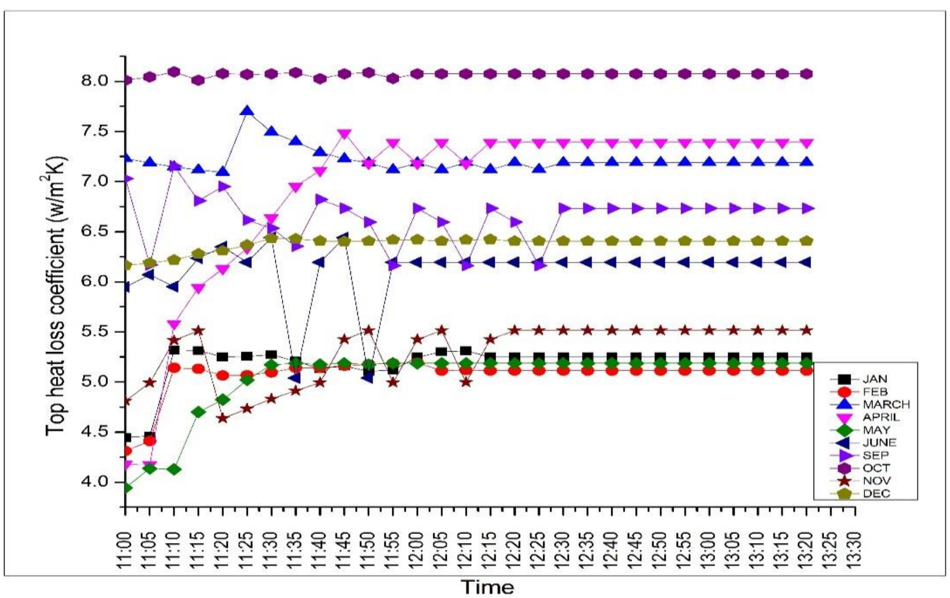

Figure 0.18Variation of top heat loss factor for different days for all seasons of the year

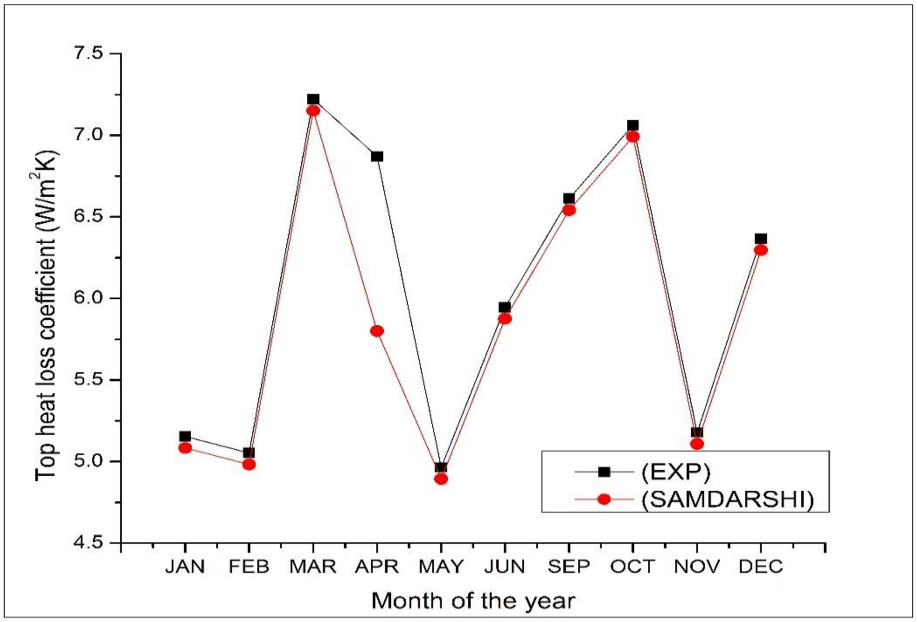

Figure 0.19Comparative analysis of top heat loss factor with experimental values and different correlations.

As mentioned above the variation of experimentally determined values of top heat loss factor and the values obtained from the mentioned correlation is from 3-12%(approximately),and it has been observed that the process of estimation and computation of the values of top heat loss factor is a tedious process therefore A correlation for top heat loss factor has been developed using regression analysis from the data containing the climatic and operating variable across all the seasons of the year for the cooker . The proposed correlation in terms of plate temperature and wind heat transfer coefficient is as follows:

$$U_T = 3.045 * T_P^{0.135} * v_{wind}^{(-0.02)} \quad (4.9)$$

The proposed correlation find its applicability in the range of

Wind velocity range: 0.2 to 3.5 m/s

Plate temperature Range: 65 ℃ to 160 ℃.

4.5.4 Bottom and side heat losses

In earlier analysis and previous researches reported the assumed values of bottom and side heat losses in box type solar cooker, however in present work bottom and side losses are determined experimentally by using the heat balance equations and compared with the assumed value. Moreover its effect on first Fig of merit has also been analyzed as in fig 4.20 and 4.21.

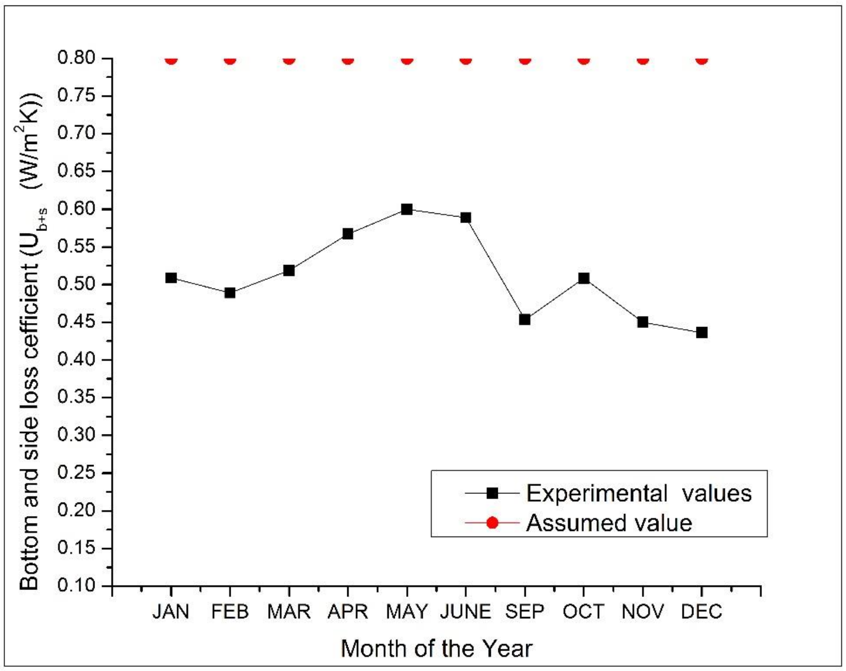

Figure 0.20Variation of bottom and side heat loss across the year

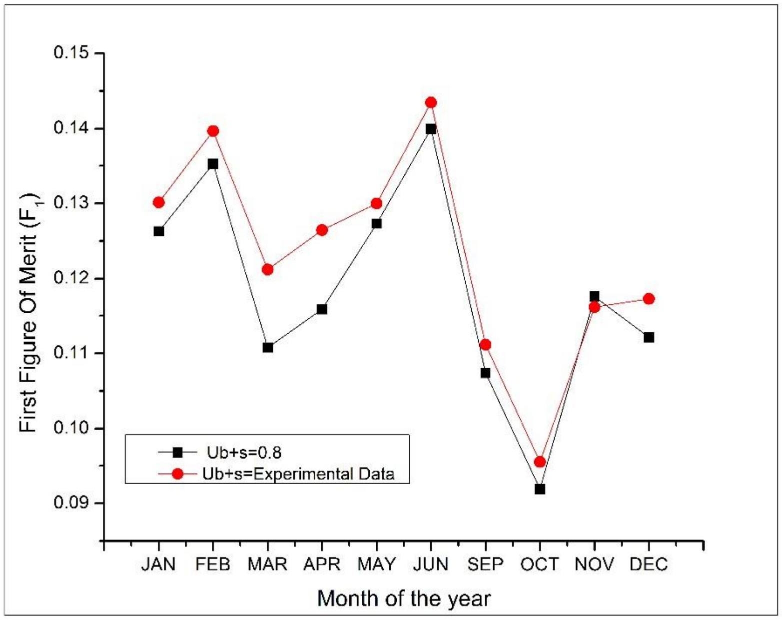

Figure 0.21Variation of first Fig of merit estimated with experimental values of bottom and side heat losses for different months of a year.

Fig 4.20 depicts the variation of the summation of bottom and side heat loss coefficient (U_{b+s}) across various months of the year and compared with assumed values (Khan, 2004), the value of loss coefficient varies between 0.4 to 0.5 throughout the year. It was observed that an average variation of 20% is observed between the calculated and assumed values throughout the year. There is an increase seen in the bottom and side heat loss coefficient from April to June because of the wind velocity factor.

Fig 4.21 depicts the variation of first Fig of merit across various months of the year and compared with assumed values (Khan, 2004),and experimentally obtained values It is observed that an average variation of 20% as depicted rom the table 4.5 is observed between the calculated and assumed values throughout the year. Due to the increment in bottom and side heat losses in October the performance i.e. the first Fig of merit has been reduced .

Table 0.5. Effect of experimentally evaluated bottom and side heat loss coefficient on performance of box type solar cooker

S.no	bottom and side loss coefficient(parameters)	u_{b+s}	Variation (%)
1	Assumed Value	0.8 (Khan 2005)	
2	Experimental values obtained across the year	0.4 to 0.6	Average 20%
3	Effect on first Fig of merit (F1)	0.09 - 0.146	1 to 20%

It can be stated through the observation that the bottom and side heat losses though contribute a very small portion still needs an experimental determination because significant variation has been observed. Therefore it is suggested that the bottom and side heat losses should not be assumed, but should be determined experimentally.

4.5.5 Comparison of Experimental Results of first Fig of merit

The comparison of first Figs of merit calculated through experimental data and through directly measured parameters has been discussed here.

Fig 4.22 shows the values of F_1 through different months of the year covering all seasons. Stagnation state has been observed around noon, which can be referred as steady state as reported in previous experimental analysis by various researchers .This stagnation state is due to the fact that in spite of increase in insolation there is a balance between the heat losses and the heat absorbed .

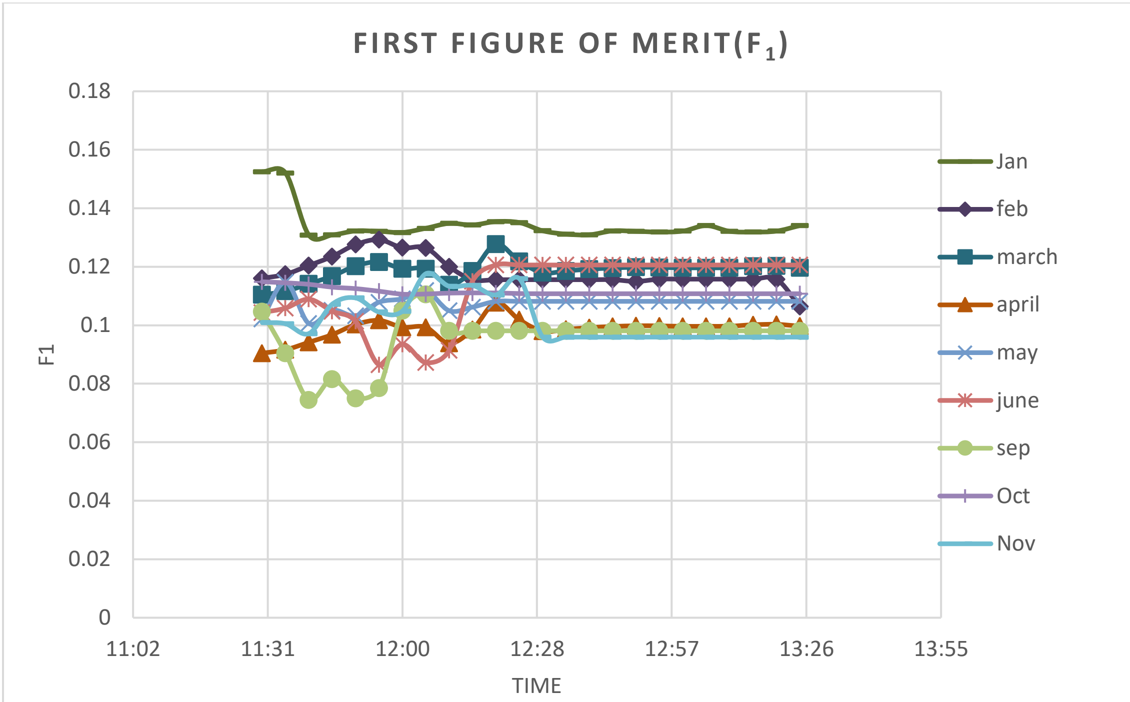

Figure 0.22Variation of first Fig of merit for different days of the months across a year.

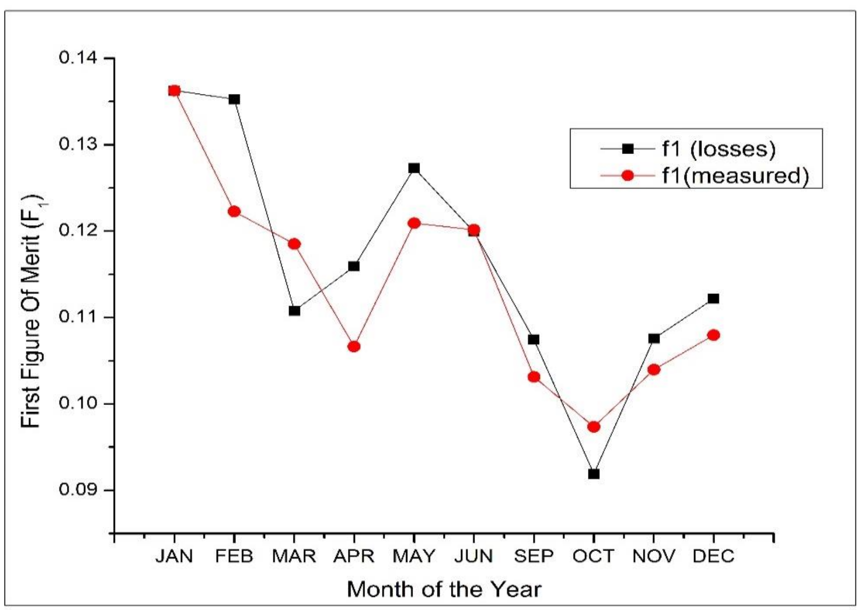

Figure 0.23Comparision of first Fig of merit estimated experimentally and measured value .

It can be depicted from the Fig 4.23 the variation of first Fig of merit through directly measured parameters and experimentally obtained values have a negligible variation (0.007-0.9)%. The negligible variation is due the errors in the measurement of variables which is negligible. Therefore its detailed analysis is required and hence the individual effect of various parameters on Fig of merit has been discussed as follows.

a) Effect of Ambient Temperature on First Fig of Merit

Since ambient temperature is an important climatic parameter therefore its effect on performance of solar cooker should be considered .The variation of F_1 vs T_a for different days of experimentation across the year is shown in Fig 4.24. Linear regression of experimental data gives value of R^2=0.38, which states that the first Fig of merit is a function of ambient temperature the plot also indicates that the effect of T_a on F_1 cannot be neglected. It is an important climatic variable. The large scatter in the plot is due to the effect of other variables also.

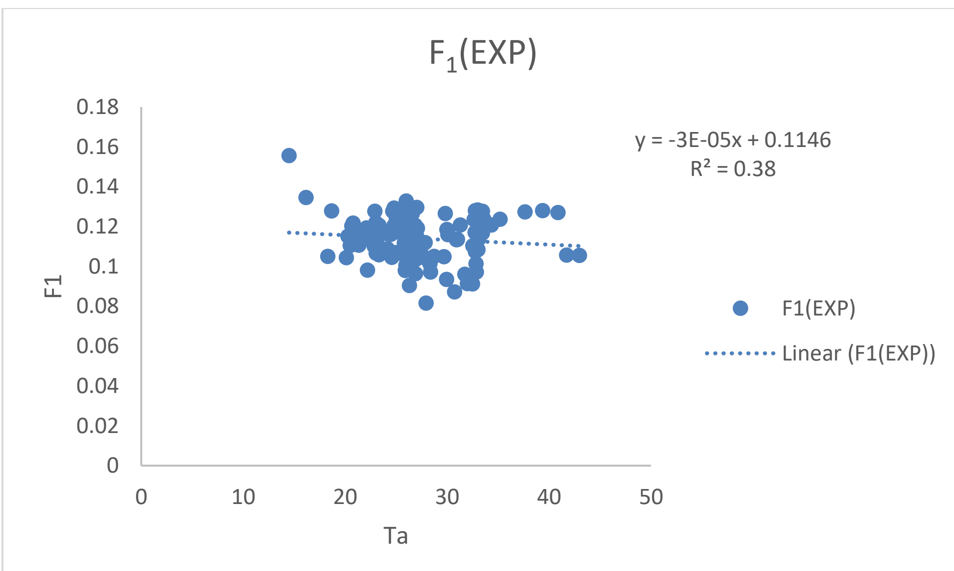

Figure 0.24Variation of first Fig of merit with ambient temperature

b) Effect of Wind Heat Transfer Coefficient on First Fig of Merit

The variation of F_1 vs h_w for different days of experimentation is shown in Fig 4.25 Linear regression of experimental data gives R^2=0.307. It indicates that the effect of h_w on F_1 cannot be ignored.

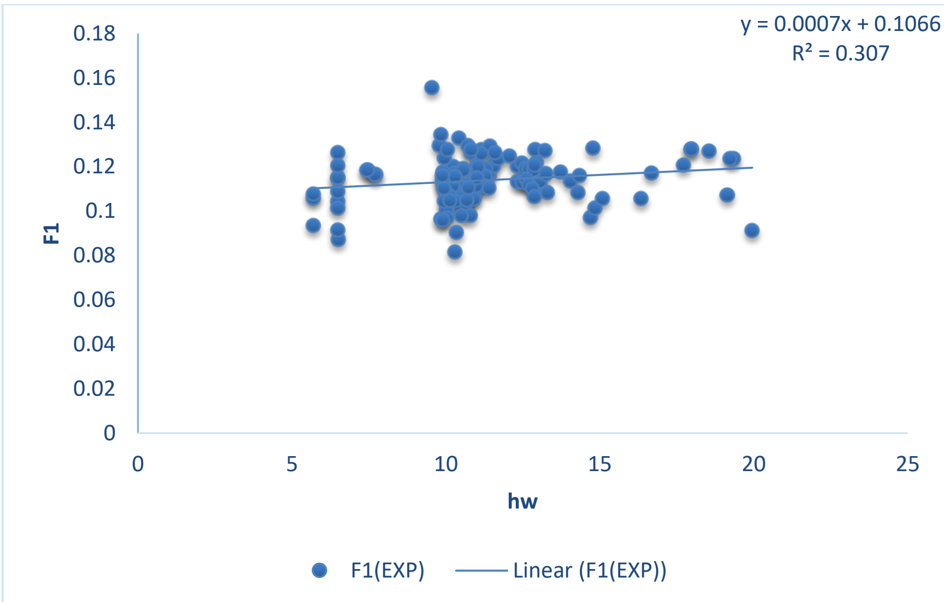

Figure 0.25Variation of first Fig of merit *with wind heat transfer* coefficient.

c) Effect of Incident Solar Radiation on First Fig of Merit

The variation of F_1 vs I for different days of experimentation is shown in Fig 4.26 . It implies that the effect of insolation on F_1 though seems to be small but should be included in correlating F_1 and it is an important climatic variable.

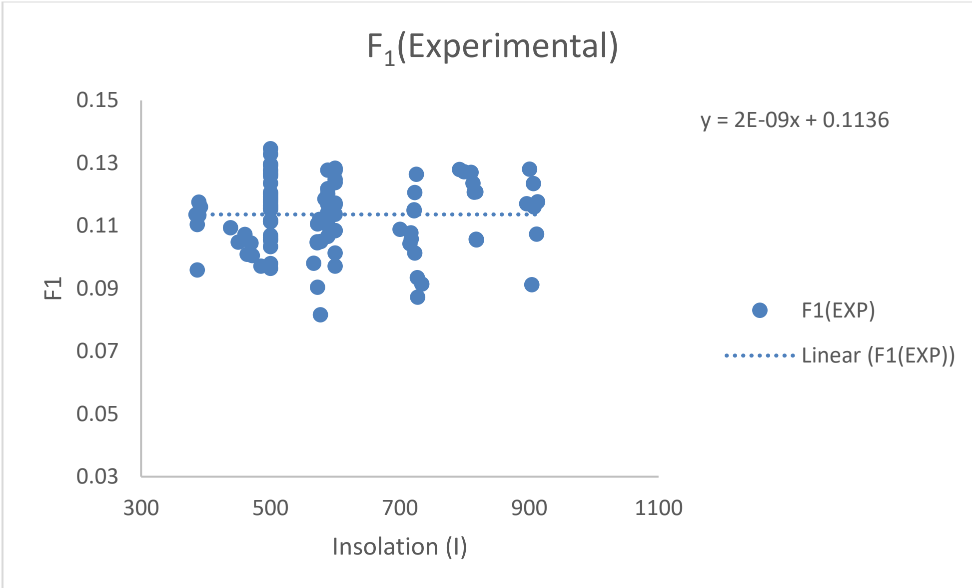

Figure 0.26Variation of first Figure of merit with insolation

d) Multiple Regression of Experimental Results of First Fig of Merit

When the effects of plate temperature *(T_p)*, ambient temperature *(T_a)*, solar insolation *(I)* and wind heat transfer coefficient *(h_w)* on first Fig of merit *(F_1)* is considered individually, the scatter obtained is high. Also the existing correlation does not include the effect of wind heat transfer coefficient .An attempt has been made to see if the scatter can be reduced by non-linear multiple regression of experimental data. The mean value of first Fig of merit *$(F_1)_{mean}$* is computed for all seasons of the of experimentation. The ratio of *$(F_1)_{mean}/ F_1$* is correlated by the following empirical relation:

$$\frac{F_{1\,mean}}{F_1} = a + bI + CT_p + dT_a + eh_w \qquad (4.1)$$

Where *a*, *b*, *c*, *d* and *e* are constants. These constants have been determined from the non- linear multiple regression of experimental data using SIGMAPLOT. The following regression equation is obtained:

$$\frac{(F_1)_{mean}}{F_1} = 1 + 0.0012I - 0.007T_p + 0.008T_c - 0.0018h_w \quad (4.2)$$

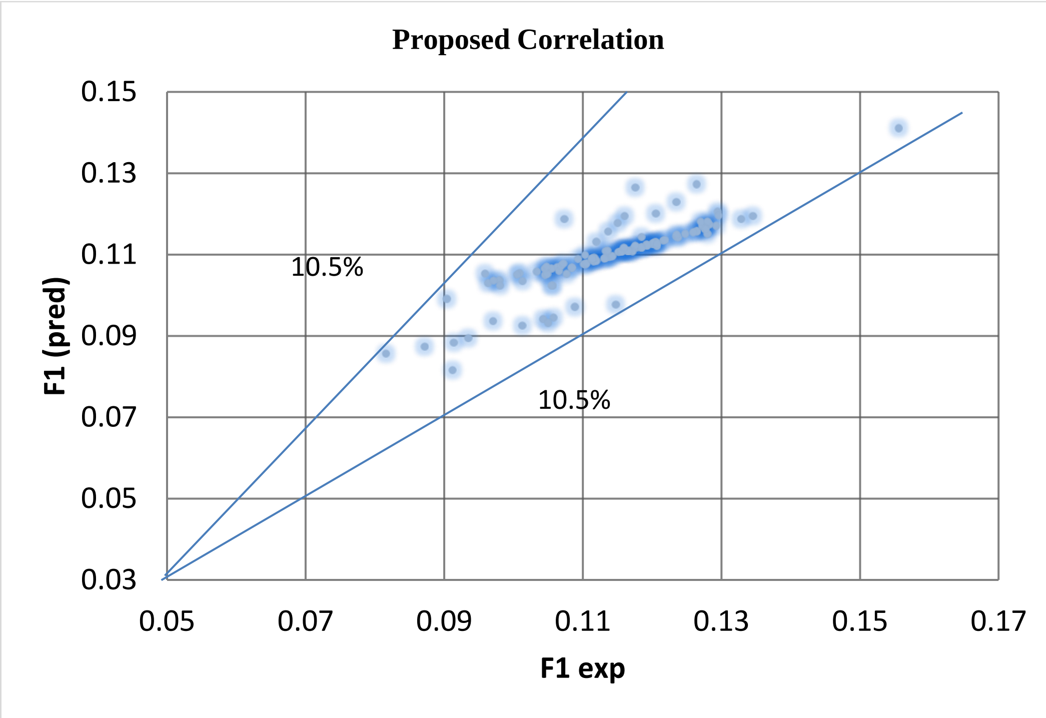

Figure 0.27Validation of proposed correlation with predicted values

The proposed correlation includes the effect of wind velocity in estimation of first Fig of merit of box type solar cookers, which is important while estimating the upward heat losses from the outer surface of the plate due to wind and also changes wrt time, day and a particular geographical conditions. The values obtained from the proposed correlations has been experimentally validated with predicted values as shown in Fig 4.27.

e) Correlation for Overall Heat Loss Coefficient

Similarly the correlation for overall heat loss coefficient can also be explained as follows.

Ratio of $(U_L)_{mean}/ (U_L)$ is defined by the following relation:

$$\frac{(U_L)_{mean}}{U_L} = \frac{(\eta_o)_{mean}/(F_1)_{mean}}{\eta_o / F_1}$$

$$\frac{U_l}{U_{lmean}} = 1 + 0.0012I - 0.007T_p + 0.008T_a - 0.00018h_w \qquad (4.3)$$

With root mean square error of 1.35% and $R^2=0.8$

4.6 PERFORMANCE ANALYSIS OF DIFFERENT GEOMETRIES OF BOX TYPE SOLAR COOKER

The developed correlations have been used to compare the three different geometries rectangular, trapezoidal and triangular .Comparative analysis has been carried out on the following basis.

1. Plate Temperature
2. Outer Glass Cover Temperature
3. First Fig of Merit (F_1) NO LOAD TEST
4. Second Fig of Merit (F_2) I,e full load test
5. Second Fig of Merit (F_2) with various water Temperature range
6. Boiling time

4.6.1 Plate Temperature

Fig 4.28 illustrates the absorber plate temperatures of the three different cookers tested under without load condition across all seasons of the year . The maximum enclosure plate temperatures is attained by the triangular .trapezoidal and rectangular model are mentioned in Table 4.8. Triangular geometry provide a higher plate temperature at prevailing ambient conditions at Dehradun across the year .The absorber plate temperature difference in this operating condition is 21℃ approximately at noon, respectively. According to without load condition observations, plate temperature of the triangular (proposed) model is much better than the rectangular model and trapezoidal geometry.

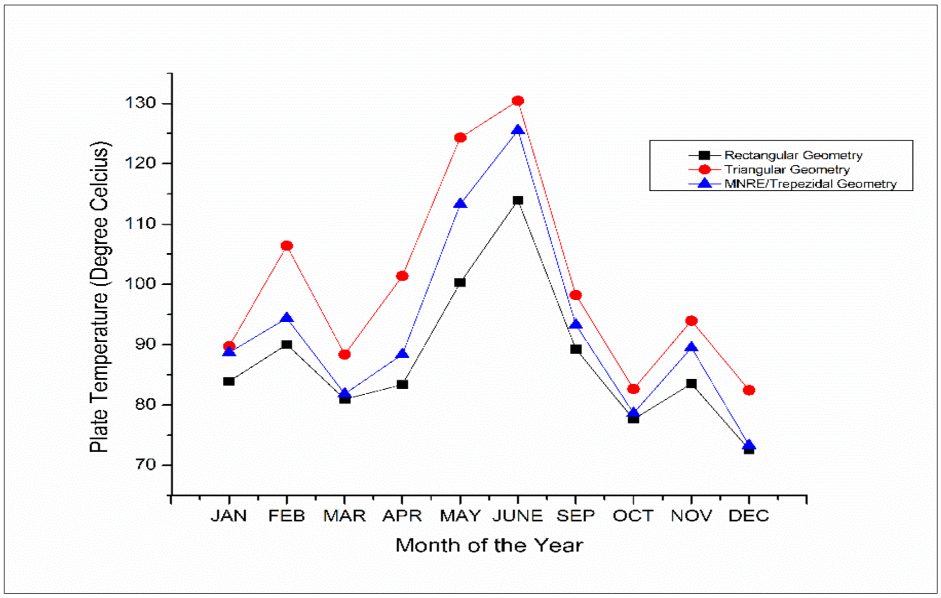

Figure 0.28Effect of different geometeries on plate temperature of solar cooker

4.6.2 Comparative analysis of different geometries on thermal performance

Three different geometries have been considered under prevailing environmental conditions of Dehradun .using the experimentally observed data, a comparative analysis has been performed with an aim to improve the performance.

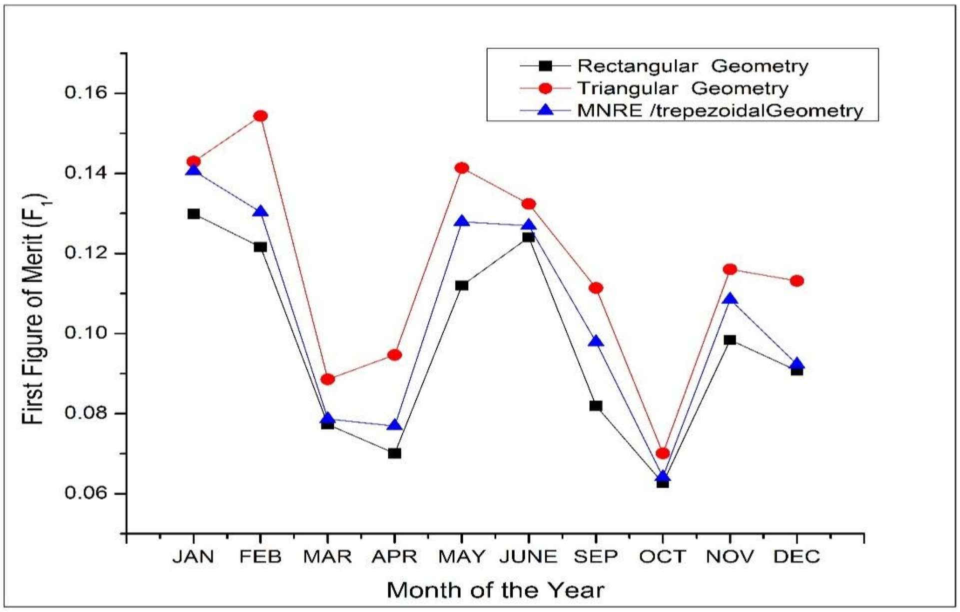

Figure 0.29Effect of different geometeries on performance (first Figure of Merit) of solar cooker

Fig 4.29 shows the comparison between performances (first Figure of merit) of the three geometries cookers tested for no load condition. It was observed that the triangular model's element temperatures were highest than the rectangular and trapezoidal model's. Performance is higher and significant for triangular geometry solar cooker under different weather conditions as compared with other two geometries. The improvement in the performance is due to heat collection of the cookers at the same conditions and same aperture areas and high heat collection and lower heat losses from the sides and the front surface because the area of the box is more efficient than of the rectangular geometry.

4.6.3 Effect of different geometeries on outer glass cover temperature of solar cooker.

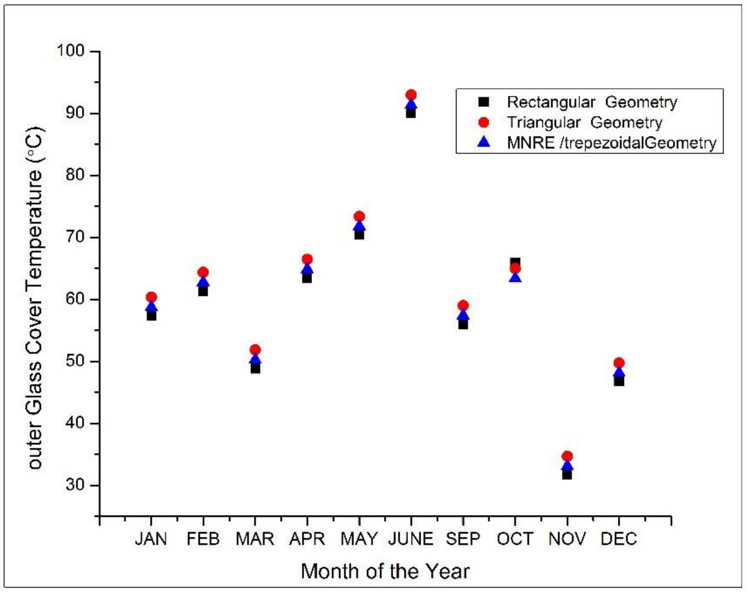

Figure 0.30Effect of different geometeries on outer glass cover temperature of solar cooker.

Similar trends were observed with the outer glass cover temperatures as depicted from the fig.4.30 According to without load condition observations, outer glass cover temperature of the triangular (proposed) model is much better than the rectangular model and trapezoidal models under similar prevailing environmental conditions.

Table 0.6.Effect of three different geometries on various parameters of box type solar cooker

Parameter	Rectangular (Standard Geometry)℃	triangular(Proposed Geometry)℃	trapezoidal /MNRE ((MNRE Geometry)℃
Plate temperature	Highest: (JUNE) 113 Lowest : (DEC)72	Highest: 130(JUNE) Lowest : 82(DEC	Highest: 73(JUNE) Lowest : 125 DEC
Outer glass cover temperature	Highest: (JUNE) 82 Lowest : (DEC) 31	Highest: (JUNE)85 Lowest : (DEC) 34	Highest: (JUNE) 83 Lowest : DEC 33
First Fig of merit	Highest: (JUNE)0.129 Lowest : (DEC)0.06	Highest: (JUNE)0.154 Lowest : (DEC)0.07	Highest: (JUNE)0.140 Lowest : (DEC)0.06

Table 0.7Comparative analysis of different geometries

Geometry	Variation in plate temperature (%)	Variation in Glass cover Temperature (%)	Variation in First Fig of Merit (%)
TRAINGULAR GEOMTERY	6-15% higher than rectangular geometry	3-8 % higher than rectangular geometry	9-25% higher than rectangular geometry
TRAINGULAR GEOMETRY	1-11% higher than trapezoidal geometry	2-6% higher than trapezoidal geometry	1-18% higher than trapezoidal geometry

The improvement in the performance of the Triangular geometry due to lower heat losses from the absorber plate .this reduction in losses is due to the reduction in radiative heat transfer coefficient *(h_{rp1})* between the absorber plate of box type solar cooker and inner glass cover and Ratio of aperture area of sides of absorber plate to aperture area of cooker as can be seen from the Fig 4.31.

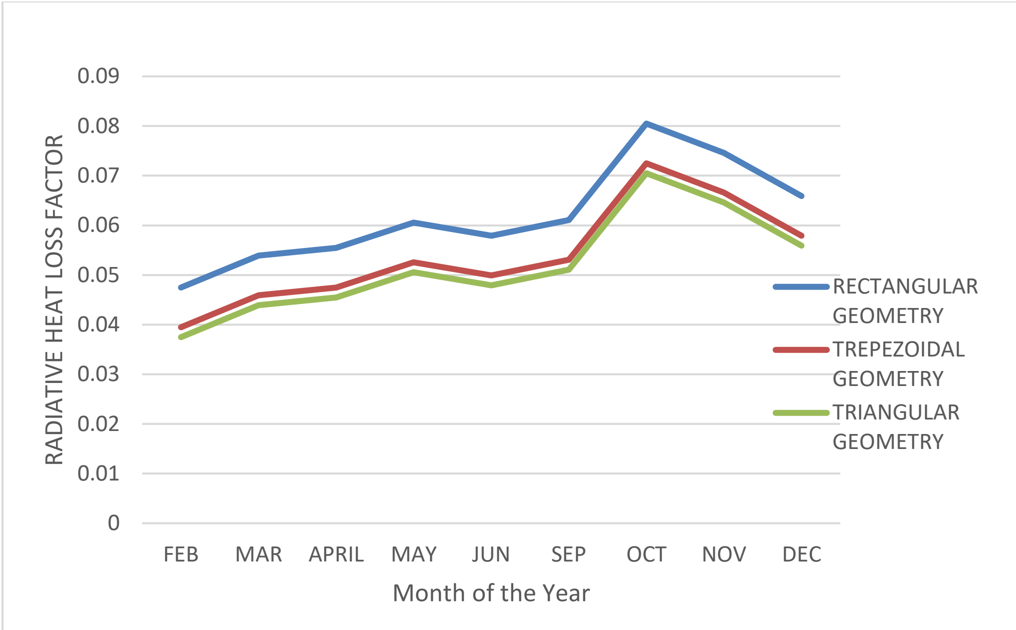

Figure 0.31Effect of different geometries on radiative heat loss coefficient of solar cooker.

The radiative heat loss coefficient of three different geometries has been compared in Fig 4.31. It can be observed that radiative heat loss is minimum in case of triangular geometry and maximum in case of rectangular geometry. The variation in the shape factor of the geometries leads to a better heat collection

4.6.4 Effect of various parameters on Second Fig of Merit (F_2) of Box Type Solar Cookers

Second Fig of merit is the performance of solar cooker during full load test where cooker was loaded with water and its performance has been analyzed. Using semi log plot method the performance has been analyzed. Fig 4.32 shows the average values of pot temperature for different months across the year.

4.6.4.1 Pot Temperature

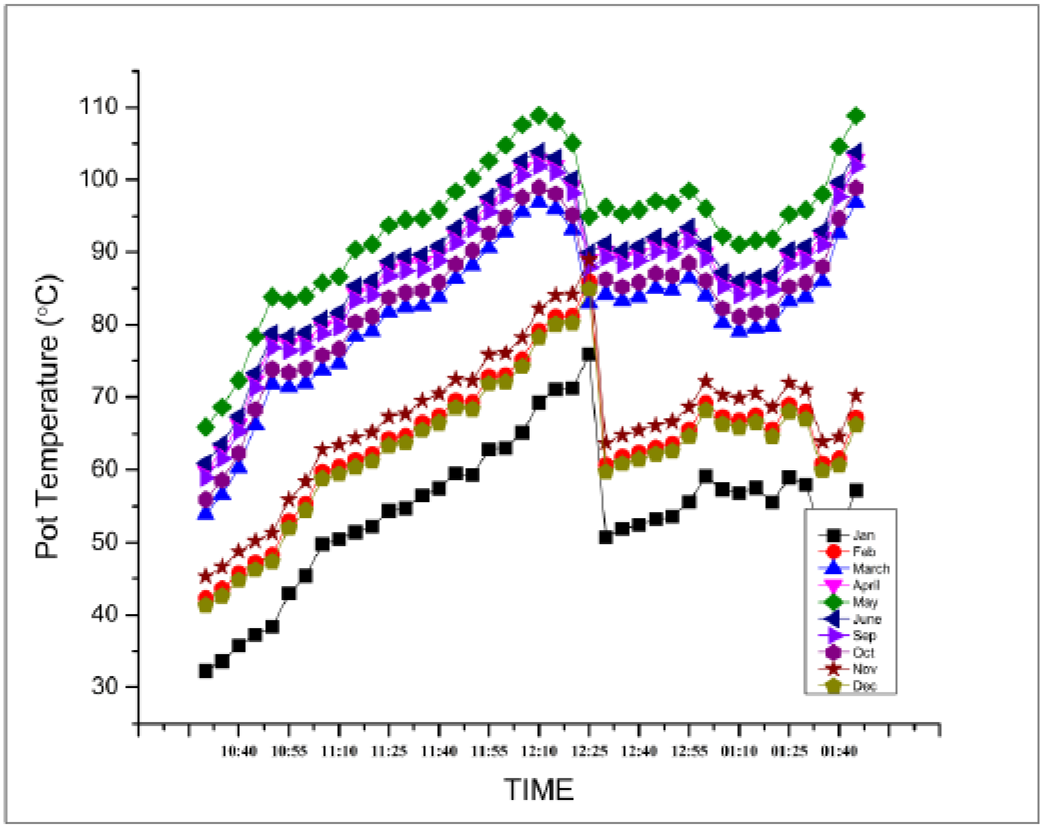

Figure 0.32Variation of pot temperature with respect to time of different days of the months of a year

It was observed that after certain duration while exposed in sunlight the pot temperature become stagnant after certain duration. The time taken by the pot temperature to achieve stagnation is higher than the absorber plate temperature. This delay is due to the fact that initially cooker absorber plate absorbs the heat and collect it and achieve stagnation and thereafter heat is transferred from absorber plate and pot exposed elements to water and then stagnation or steady state is achieved.

4.6.4.2 Experimental Validation of Semi-Log Plot Method to Evaluate Second Fig of Merit of Box Type Solar Cookers

The values of F_2 have been computed by conventional method and semi-log plot method as mentioned in methodology section for different water temperature ranges (T_{W1} to T_{W2}). The different ranges considered are initial water temperature to 95˚C, 55˚C to 85˚C, 60˚C to 90˚C, 60˚C to 95˚C, and 65˚C to 95˚C.

The semi-log plot method was tested for different water temperature ranges (T_{w1} to T_{w2}) to determine F_2 and the results were compared with the standard method involving the integral equation for the time interval.

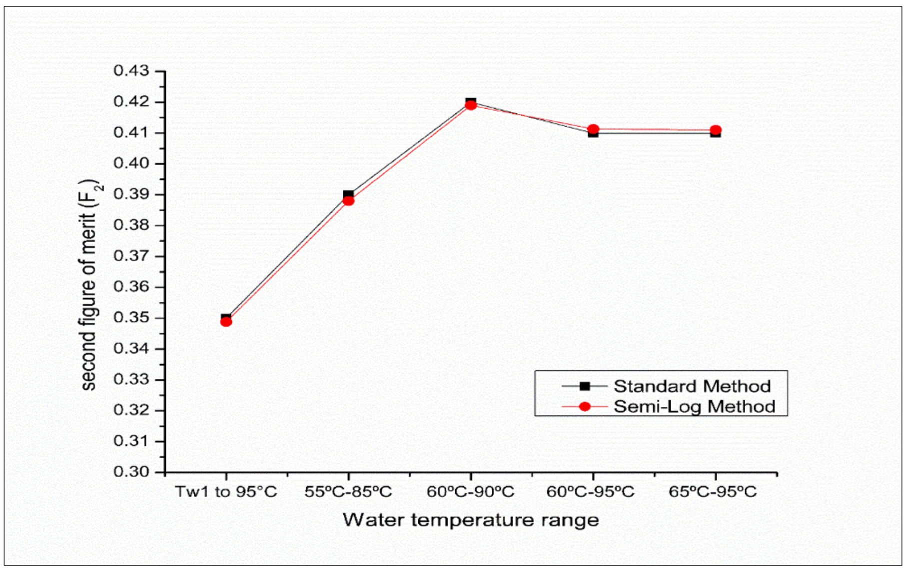

Figure 0.33Validation of *semi log* plot method with standard method on 18th June

Fig: 4.33 shows the semi-log plot for different water temperature range and its comparison with the values obtained using standard method for 18th JUNE 2018 as suggested by Mullick.

The comparison of the results obtained for F_2 for different water temperature ranges over different days show that the values of F_2 obtained from semi-log plot method match fairly well with the values obtained from standard method. It thus validates the semi-log plot method.

4.6.4.3 Effect of various Water Temperature Range on Second Fig of Merit of Box Type Solar Cookers

The values of water temperature range from T_{W1} and T_{W2} is arbitrarily fixed to 65˚C and 95˚C respectively. The effect of variation in the range of T_{W1} and T_{W2} is studied using the conventional and semi-log plot method. The different ranges considered are initial water temperature to 95˚C, 55˚C to 85˚C, 60˚C to 90˚C, 60˚C to 95˚C, 65˚C to 95˚C, 65˚C to 98˚C, and 95˚C to 98˚C.

For the different water temperature ranges, Fig 4.34, Fig 4.35 and Fig. 4.36 show the values of F_2 obtained by conventional method and semi-log plot method for cooker on different days in the month of April May and June of experimentation.

The highest values of F_2 are obtained for 60˚C to 90˚C water temperature range while the lowest values are obtained for 95˚C to 98˚C water temperature range. Lower than the highest values of F_2 are obtained for initial water temperature to 95˚C and 60˚C to 90˚C .

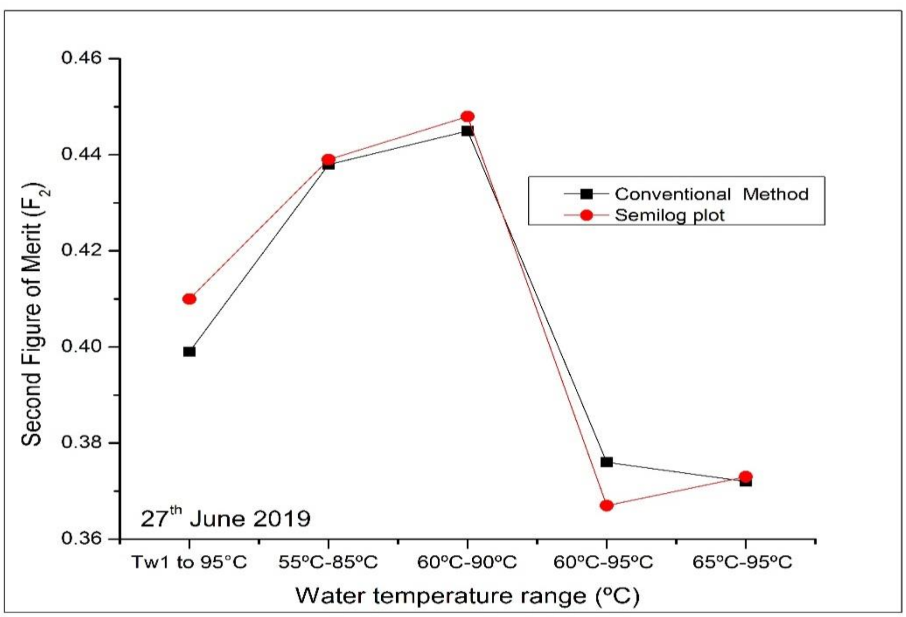

Figure 0.34Variation of F_2 for different water temperature ranges for experimental cooker on 27th June -2019

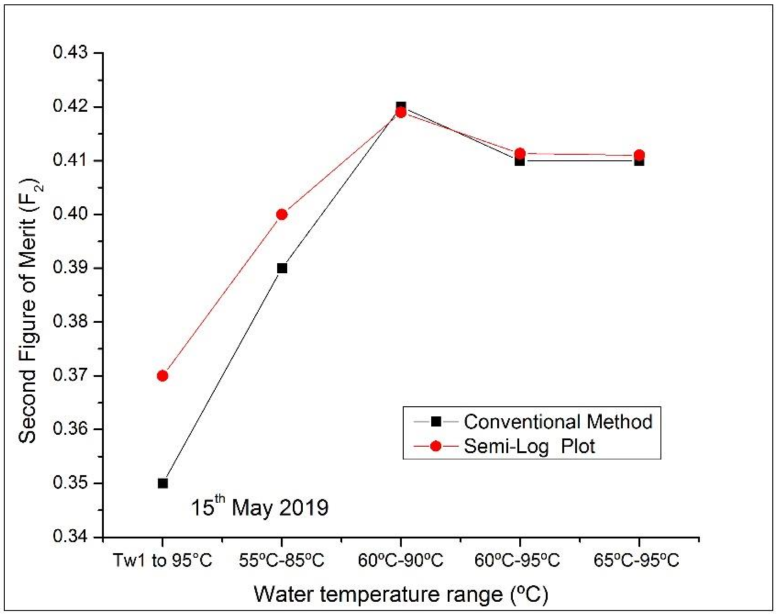

Figure 0.35Variation of F_2 for different water temperature ranges for experimental cooker

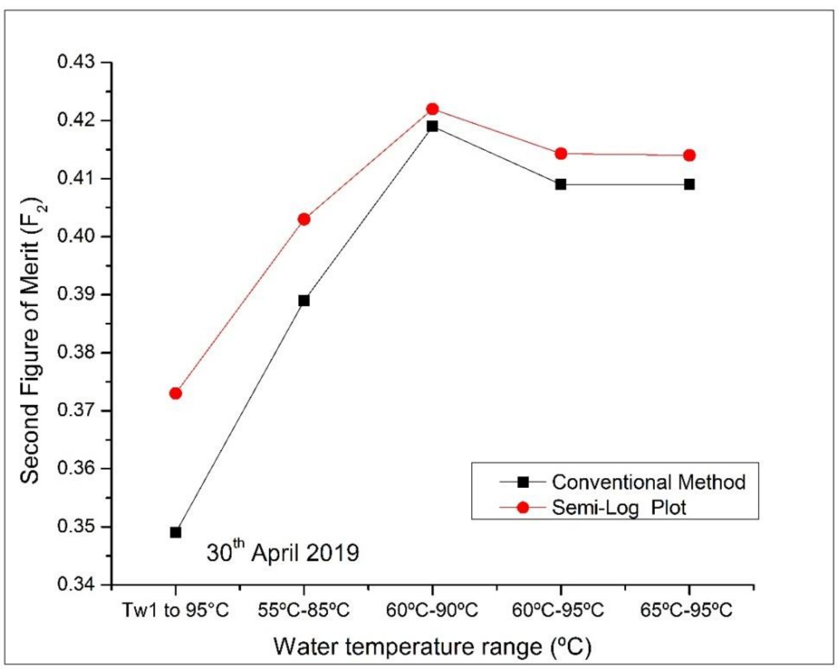

Figure 0.36Variation of F_2 for different water temperature ranges for experimental cooker

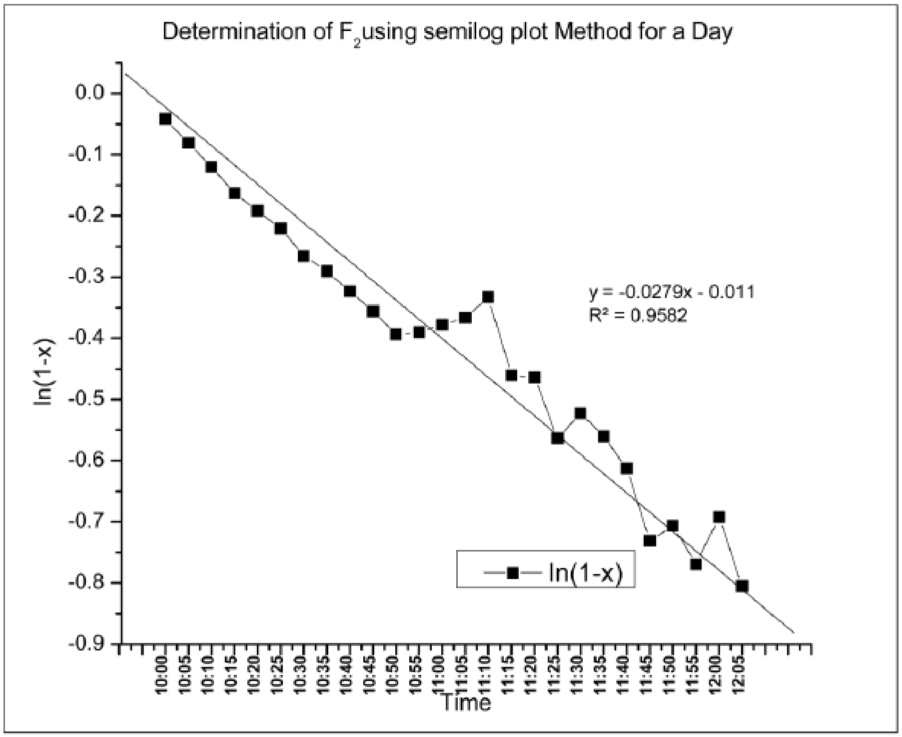

Figure 0.37Variation of F_2 using semilog plot method for experimental cooker on 06-05-2019

It can be depicted from the Fig.4.37 that semi log plot method can be used in place of the conventional method of estimation of second Fig of merit.

4.6.5 Comparative analysis of different geometries on Second Fig of Merit of Box Type Solar Cookers

The geometry of solar cooker has a significant effect on the performance as depicted above through first Fig of merit, therefore the effect on second Fig of merit was analyzed by placing three geometries at same location and performing full load test for different days of the months across all-season of a year.

Higher values of F_2 were observed for the triangular geometry as compared to the other two geometries

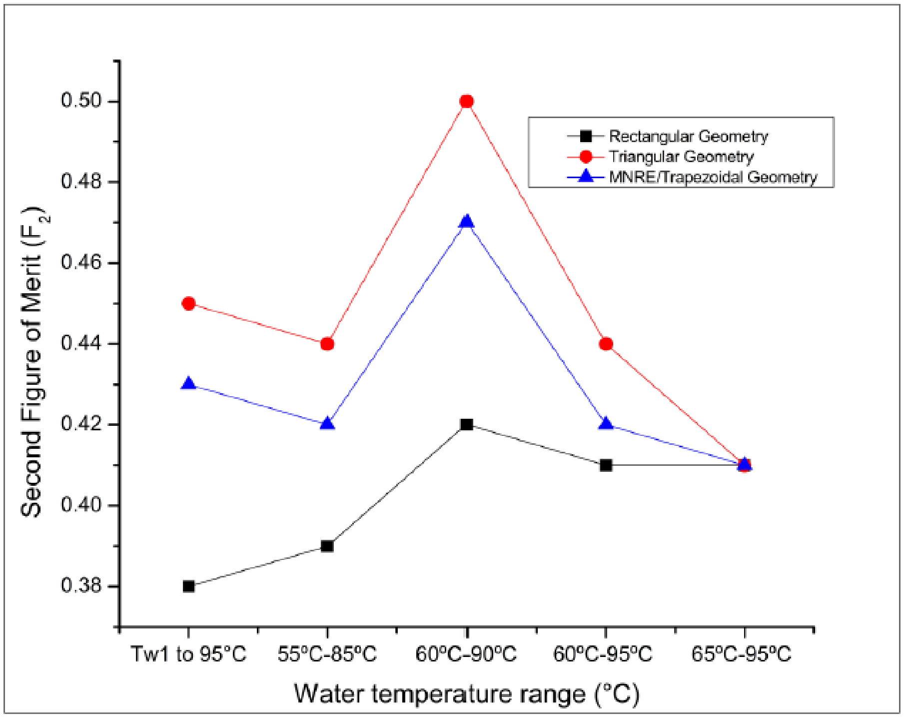

Figure 0.38Variation of second Fig of merit with different geometries 6th May 2019

Table 0.8Effect of various geometries on full load performance of box solar cookers

S.no	Standard Method	Variation
1	Proposed Geometry vs rectangular Geometry	7-13%
2	Proposed Geometry vs MNRE or trapezoidal Geometry	6-8%

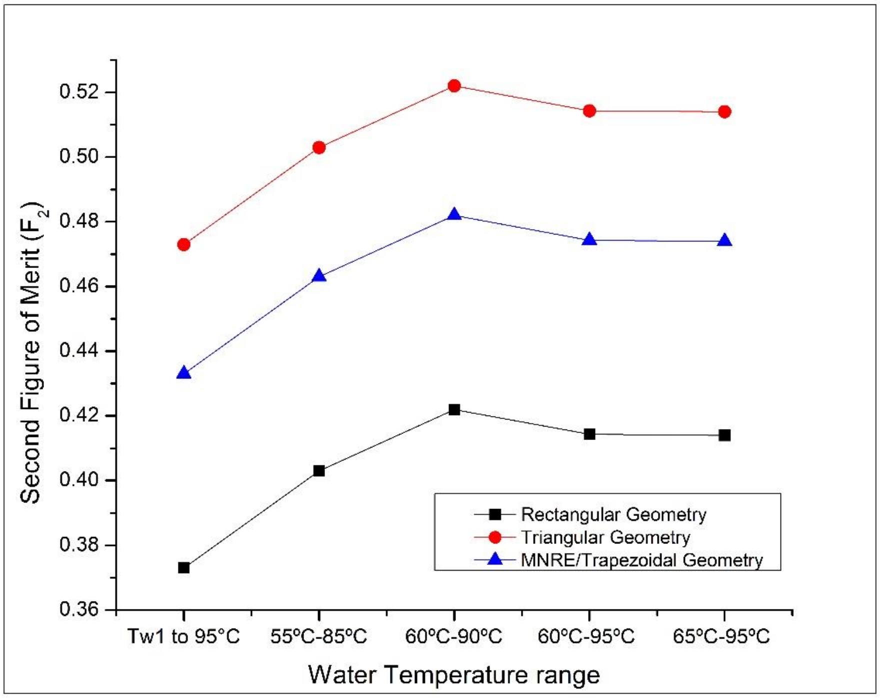

Figure 0.39Variation of second Fig of merit with semi log method with different geometries.

The values of water temperature range from T_{W1} and T_{W2} is arbitrarily fixed to 65˚C and 95˚C respectively. The effect of variation in the range of T_{W1} and T_{W2} is studied using the conventional and semi-log plot method for different geometries. The different ranges considered are initial water temperature to 95˚C, 55˚C to 85˚C, 60˚C to 90˚C, 60˚C to 95˚C, 65˚C to 95˚C, 65˚C to 98˚C, and 95˚C to 98˚C.

On different days of experimentation, for the different water temperature ranges, Fig: 4.38 and Fig 4.39 shows the values of F_2 obtained by conventional method and semi log plot method for three different geometries.

It was observed from the Fig that using semi log method also the highest values of second Fig of merit is attained by the triangular geometry and for different ranges of water temperature the behavior of the triangular geometry is same and the highest therefore it can be used for different temperature ranges according to the requirement or the application.

Table 0.9Effect of various geometries on full load performance of solar cookers using *semi log* method

S.no	Semi log plot Method	Variation
1	Proposed Geometry vs rectangular Geometry	8-14%
2	Proposed Geometry vs MNRE or trapezoidal Geometry	7-8%

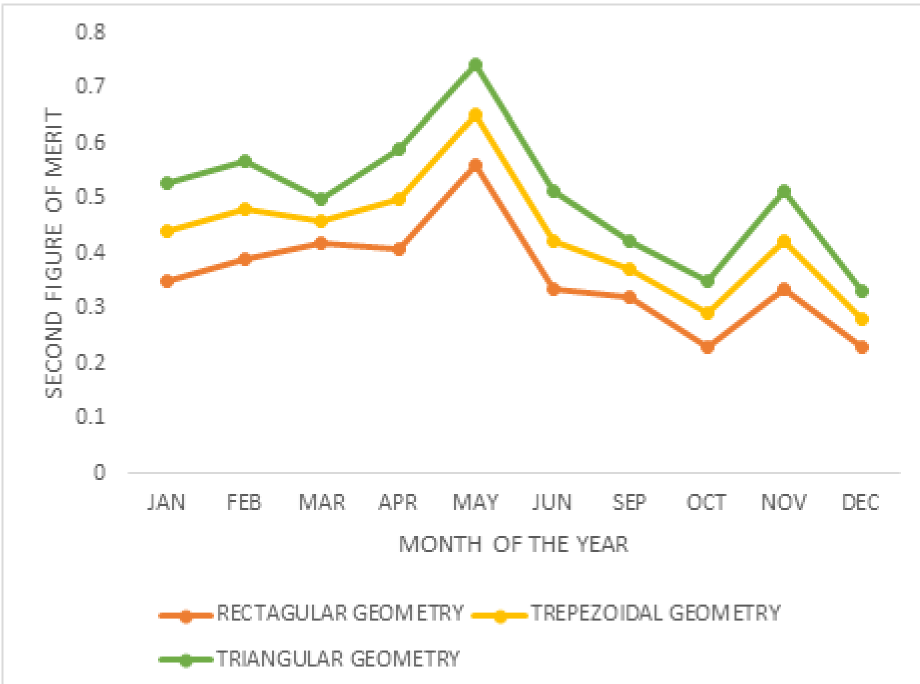

Figure 0.40Comparative analysis of second Fig of merit F_2 of different geometries under similar environmental conditions across the year

Fig 4.40 shows the variation of second Figure of merit of different geometries across all seasons of the year. As similar trends were observed as in case of first Fig of merit that the triangular geometry proves to have a higher second Fig of merit across all seasons of year as compared with the other two geometries it can also be seen from the graph that the highest value of second Fig of merit is attained in the month of June and Jan due the effect of insolation and wind velocity along with the geographical ambient conditions.

4.7 COMPARATIVE ANALYSIS OF BOILING TIME OF THREE DIFFERENT GEOMETRIES

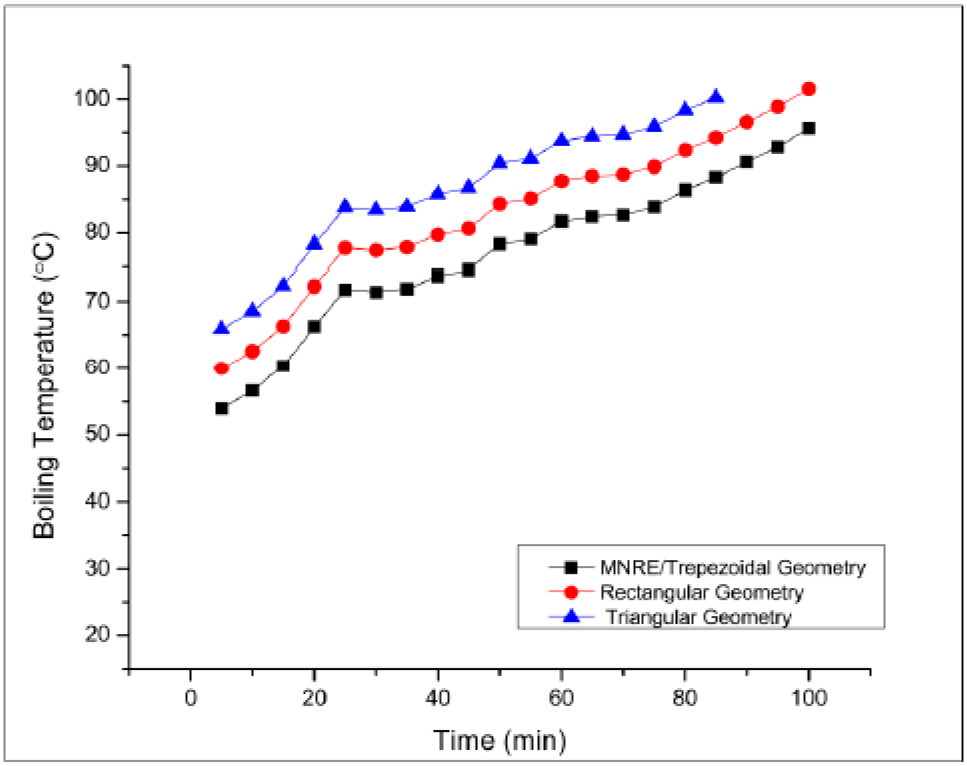

Fig: 4.41 Comparative analysis of boiling time of different geometries under similar environmental conditions

Fig. 4.40 shows the comparative analysis of water temperature in the attained in cooking pots for three different geometries (one test setup ,another one already in the market and one geometry is proposed) under the same test conditions .It was found that the time taken for attaining boiling temperature (99 °C) by the triangular or proposed geometry was 88 min ,for rectangular and MNRE based solar cooker it was around 98 min ,96 min respectively.

The water in the triangular geometry cooking pot achieved boiling temperature nearly 20 min earlier than time taken by the water to boil in the other two geometries. The plate temperature for cooker during investigation was observed to raise around 130℃ during the test period. Therefore for the applications like rice cooking and other boiling application this geometry is very useful as it takes less time for boiling keeping the plate temperature high

5 CHAPTER:

CONCLUSION

Based on the Present Study the following conclusions have been drawn:

5.1 EFFECT OF SKY TEMPERATURE

In the present work literature review on sky temperature has been presented. The results of these studies have been used to estimate the sky temperature for different climatic conditions prevailing at Dehradun throughout the year. Further an experimental analysis has been performed to estimate the radiative heat loss and first Fig of merit .It can be concluded that the sight variation suggests that it's difficult to decide the selection of a particular correlation for the estimation of sky temperature but its comparison with ambient suggests that sky temperature should be considered while analyzing the thermal performance of box type solar cooker since variation has been observed while using sky temperature in place of ambient temperature during experimental investigation conducted throughout the year. It can also be concluded that for lower values of wind heat transfer coefficient and plate temperature there is a variation in F_1 with different correlations of sky temperature however at higher values of h_w and plate temperature T_p all correlations can be used for estimation of F_1. But in case of ambient temperature at higher ambient temperature this differences are high as compared to the lower values of ambient temperature. I,e all correlations hold good at lower ambient conditions but slight variation is observed in F_1 values at higher ambient conditions.

5.2 EFFECT OF VARIOUS CLIMATIC AND OPERATIC PARAMETERS

An extensive review has been carried out to determine the testing standards for the solar cooker as well as the parameters that determine the performance of the cooker.

Finally, comparison of experimental data with that of correlations data of selected climatic and operating variables was carried out. The wind heat transfer coefficient, top heat loss coefficient, side and bottom heat loss coefficient, outer glass cover temperature and inner glass cover temperature data was compared with that of the standard correlations. It was revealed that there was a deviation of a maximum 20% for all the selected parameters, which can be in the acceptable range but leads to an increase the inaccuracy of the results. Therefore it is suggested that all these parameters should be calculated based on the geometry of the cooker and the geographical location of the experimentation to get accurate results. It is concluded that the geographical location plays a dominating role in the performance of the cooker and the operating parameters should be evaluated or measured experimentally.

The process of evaluation of the performance of the box type solar cooker includes tedious formulas through heat balance and hence required to be presented in terms of simply measurable parameters therefore the correlation for wind heat transfer coefficient, top heat loss coefficient and first Fig of merit has been developed based on the sigma plot method and regression analysis using the experimental data obtained for different months of a year.

Since losses and wind Heat transfer coefficient has a significant effect on performance of box type solar cooker so rather than estimating it in terms of ambient, plate temperatures factor of h_w should be included.

It can also be concluded that the developed correlations help in estimation of losses and performance of solar cooker in terms of easily measurable climatic and operating variables and include the effect of wind velocity also.

5.3 COMPARATIVE ANALYSIS OF DIFFERENT GEOMETRIES OF BOX TYPE SOLAR COOKER

The developed correlations were used to compare the thermal performance analysis of three different geometries based on the experimental data obtained during no load and full load test. During no load test , Triangular geometry provide a higher plate temperature at prevailing ambient conditions at Dehradun across the year. Performance is higher and significant for triangular geometry solar cooker under different weather conditions as compared with other two geometries due to high heat collection. The triangular box type solar cooker provides high thermal performance, which is indicated by high thermal efficiency and low characteristic boiling time, in comparison with the rectangular and trapezoidal box type solar cooker. The benefit of the triangular box type solar cooker is faster cooking time. The better performance is due to lower heat losses from the sides and the front surface because the area of the box is more efficient than of the rectangular geometry.

During full load test Triangular geometry provide a higher water temperature at prevailing ambient conditions at Dehradun across the year. The pot temperature was observed to be 12 % higher in case of triangular geometry as compared with other two geometries. Performance is higher and significant for triangular geometry solar cooker during cooking (full load Test) different weather conditions as compared with other two geometries as well as under different water loading conditions ,triangular geometry was proved to be approximately 10% higher than other two geometries .therefore It is suggested that the box type solar cooker, which has triangular geometry can be used for cooking due to high thermal efficiency and it is also advisable that the inclination of the box should be equal to the latitude of the particular location .

5.4 SCOPE OF FUTURE WORK

The following are the areas in which future research work may be undertaken in the study of box type solar cookers:

a) Effect of boosting (reflecting) mirror on the thermal performance of proposed geometry box type solar cooker with an aim to evaluate first Fig of merit (F_1) and second Fig of merit (F_2).

b) Effect of storage on the characteristic curve (i.e. the time Required to boil water).and performance of box type solar cooker is partially done and has a future scope.

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7 ANNEXURES

1. Experimental data record sheet

ENERGY ANALYSIS OF DIFFERENT GEOMETRIES OF BOX TYPE SOLAR COOKER

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