

# MODELLING OF FLAT-PLATE SOLAR COLLECTOR BY USING EXPLICIT FINITE DIFFERENCE METHOD

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## **ABSTRACT**

Solar energy is becoming a major source of sustainable energy and a valid alternative to the traditional form of energy due to the limited resources of our planet. Therefore, the use of solar collectors has a central role to play. They are one of the most direct applications of sustainable energy with conversion of solar radiation into heat. The solar energy can be used in a pipe system to heat up water. The solar collectors considered in this work are flat-plate collectors. There is a significant amount of research that is conducted to analyse flat-plate collector's operation to enhance their efficiency and performance. This report takes part in that research and aims to derive a one-dimensional heat transfer model looking at simulating the performance of a flat-plate solar collector to heat up water flowing in a pipe system. The model is based on fundamental concepts of thermodynamics and will implement the explicit finite difference method to compute the heat exchange through a four nodes solar collector. The four nodes represent the constitutive elements of the flat-plate collector that are: (i) glass cover, (ii) air gap, (iii) absorber, and (iv) working fluid in the pipe going through the collector. The model will be derived in the Matlab environment and will look at the rise of water temperature during a two-hour period subject to specific ambient condition.

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## NOMECLATURE

### Notations

| Symbol           | Item                                                | Units                                |
|------------------|-----------------------------------------------------|--------------------------------------|
| A                | Flow rate                                           | (m <sup>2</sup> )                    |
| C                | Specific heat                                       | (J/(kg.K))                           |
| D                | Diameter of the collector tube                      | (m)                                  |
| G                | Heat flux of solar radiation                        | (W/m <sup>2</sup> )                  |
| H                | Heat transfer coefficient                           | (W/(m <sup>2</sup> .K))              |
| I                | Specific enthalpy                                   | (J/kg)                               |
| K                | Thermal conductivity                                | (W/(m.K))                            |
| L                | Length of the analysed collector                    | (m)                                  |
| $\dot{m}$        | Mass flow rate                                      | (kg/s)                               |
| M                | Number of nodes perpendicular to the flow direction |                                      |
| N                | Number of solar collector tubes                     |                                      |
| N                | Number of cross sections (nodes in flow direction)  |                                      |
| P                | Tube pitch                                          | (m)                                  |
| R                | Radius of collector tube                            | (m)                                  |
| T                | Temperature                                         | (K)                                  |
| V                | Volume                                              | (m <sup>3</sup> )                    |
| W                | Flow velocity                                       | (m/s)                                |
| Z                | Spatial co-ordinate                                 | (m)                                  |
| A                | Absorption coefficient                              |                                      |
| B                | Collector inclination angle                         | (rad)                                |
| $\Delta$         | Thickness                                           | (m)                                  |
| $\Delta\tau$     | Time step                                           | (s)                                  |
| $\Delta z$       | Spatial size control volume                         | (m)                                  |
| E                | Emissivity                                          |                                      |
| P                | Density                                             | (kg/m <sup>3</sup> )                 |
| $\Sigma$         | Stefan-Boltzmann constant                           | (W/(m <sup>2</sup> K <sup>4</sup> )) |
| T                | Time                                                | (s)                                  |
| ( $\tau\alpha$ ) | Effective transmittance-absorption coefficient      |                                      |

### Subscripts

|    |                                          |
|----|------------------------------------------|
| a  | Air gap between glass cover and absorber |
| ab | Absorber                                 |
| am | Ambient                                  |
| c  | Convection                               |
| f  | Working fluid                            |
| g  | Glass cover                              |
| i  | Insulation                               |
| in | Inner                                    |
| j  | Subsequent control volume                |

|   |           |
|---|-----------|
| o | Outer     |
| r | Radiation |
| t | Total     |

## **CHAPTER 1 INTRODUCTION**

### **1.1 Background**

Energy has always been one of the world's most important and valuable commodities.

This is even more evident as energy is becoming an integral part of people's everyday lives. The availability of modern day energy allows the use of the increase of the level of comfort in homes through heating, ventilation and air conditioning, and the access to medical care. In addition, agriculture, construction, transportation, computing, telecommunications, and many other essential activities would not be possible without access to energy. Undoubtedly, energy is not just an accessory, it is essential in order to survive. Today, this statement is more applicable than it has ever been due to several reasons that will be presented in detail below such as the increase in energy needs, unsure security of supply and its economic consequences and the general concern about climate change.

Today, the most discussed to subject is how to produce affordable and environmental friendly energy. Consequently, the issues of increasing rate of global warming as a result of excessive emission of carbon dioxide is forcing the government to look for less pollutant sources of energy. Despite being the most reliable source of energy that can cater for the rising demand in the market, fossil fuel burning is the highest pollutant of environment through excessive emission of carbon dioxide. In addition, the depletion of the supply of fossil fuels is reaching critical levels (Roberts, 2004). The solar energy is regarded as the most environment friendly source of energy since it is less pollutant generates sufficient energy, and it is safer as compared to other sources of energy. In fact, solar photovoltaic

and solar heat generation are regarded as the safest sources of energy and they have attracted more customers to the market.

According to The World Energy Outlook 2009, the global energy demand grew by 66% over the past 30 years. An increase of this scale or higher should be expected for the forthcoming years. The total population worldwide is expected to increase drastically to approximately 9 billion by 2030 something which will lead increase of standard living especially in developing nations. The industrial development itself is expected to grow even faster than ever and, in addition thus leading to fresh water shortage. Consequently, water shortages will definitely result in energy-intensive desalination plant that in return, will increase production level of hydrogen used for transport something which will increase the amount of electricity as well as the temperature heat. All of these events will lead to increased energy consumption overall and in particular a doubling of electricity consumptions by the year of 2030 (Ranjitha, *et al.*, 2013). Clearly, the 'energy age' (Kyriakides, 2006) is taking shape in front of us – and unlike the other 'ages' that have gone before, there is an almost universal acknowledgement that it is occurring.

There are strong indications that the effect of human activity since 1750 has led to a net global warming, and that the use of fossil energy resources must be reduced in order to prevent irreversible climate changes (IPCC, 2007). The consequences of global warming are worsening with increasing temperature change. Some of the regional impacts associated with global warming are increased water stress, sea level rise and loss of biodiversity and food security. The demand of energy is gradually increasing around the world due to total population growth thus increasing the amount of pollution since the fossil are the major sources of energy. The global heating can be reduced by reducing

the emission of greenhouse gases and hence there is a need for developing and improvement of methods for utilizing renewable resources (IPCC, 2007).

Today, solar is the major source of energy since most of the production industries uses it as the main source of operating energy. Consequently, it is regarded as less pollutant, clean, and reliable source of energy. Most scientific researches shows that sun intercepts many times by earth compared to how its energy is consumed for commercial purpose. Additionally, usage of solar energy in expense of other pollutant sources will be of great benefit both in terms of cleanliness and monetary gain.

The solar energy from the sun can efficiently be converted to the electricity power by use of solar cells as well as concentrating solar cells. Consequently, solar collectors are largely used in conversion of radiant from the sun to heat. Additionally, solar collector tends to converts radiation from the sun to heat, and the heat is transferred to a circulating heat carrier as it passes through the absorber. Heat contains less energy than electricity, and can hence be regarded as energy with lower quality than electricity.

Approximately 40 percent of the end-user energy consumption in world is moderate temperature heat (Rekstad, 2007). This demand does not require high quality energy. Taking this into account, there is huge need to reduce the consumption of fossil fuels through reduction of oil burners and electric water heaters via use of sun energy. The IEA (International Energy Agency) has calculated the amount of energy savings that glazed and unglazed solar collectors contributed with by the end of 2010 approximately corresponds to 53 million tons of CO<sub>2</sub> per year (Weiss & Mauthner, 2012). This is comparable to Norway's annual emission of greenhouse gases (StatistiskSentralbyrå,

2013). 55 countries, with an installed capacity corresponding to more than 90 percent of the global solar thermal market were taken into account in these calculations.

In the recent years, solar power technology has seen important improvements, both in solar heating technologies and solar photovoltaic technologies. This discussion will mainly focus on solar heating technologies. There are two criteria commonly used to classify solar heating technologies: the solar radiation received per surface area of the collector distinguishes concentrating collectors from non-concentrating collectors; the tracking of the sun distinguishes stationary collectors from sun-tracking collectors. Nonconcentrating collectors only absorb solar radiation that is intercepted by their surface area. For instance, they include; evacuated tube collectors, as well as the flat-plate collectors. Concentrating collectors receive solar radiation and redirect it on a point-focus to heat a working fluid. The working fluid, also known as the transport medium, which can be water, oil or air runs through the collector and receives the energy accumulated in the collector. Examples of this category include parabolic trough systems, parabolic dish, power towers, etc. Both concentrating and non-concentrating collectors can either be stationary or sun-tracking.

Consequently, solar energy is widely used since it is regarded as clean and environment friendly. Scientifically, it comes after the nuclear fusion reacts with sun radiance. Despite radiating in any direction, this energy forms a tiny fraction of  $1.4 \times 10^{14}$  kW out of the total amount of radiation released by the sun and contacting earth. Moreover, it is assumed that the amount of solar energy that hits the ground amounts to  $<1,000$  watts/sq.m based on the sky. However, the amount depends on several factors such as the location, weather,

orientation of surface, and conditions (Rekstad; 2013). Despite the small amount that hits the ground, it is believed that 30 minutes' energy is enough to serve the world for a year.

Solar collector is defined as the device which collects the solar thermal energy. However, a flat-plate collector is the most suitable device to use where a moderate heat is needed since it has ability to increase the fluid temperature up to 100°C (Rekstad; 2013). Consequently, its design is simple since it has no any moving part thus needs little maintenance. For this reason, it can be concluded that plate collector and tube collector are the common types of collector which are marked with an installed capacity of 56.6% and 31.7% respectively. China is the world leader in total installed capacity in operation and has a marked focusing very much on evacuated tube collectors (Weiss & Mauthner, 2012). China accounts for approximately 98% of the evacuated tube capacity while the flat-plate dominates in about ten nations that install capacity (Weiss & Mauthner, 2012). For that reason, the distribution channels of the flat-plate are wide and broader as compared to that of evacuated tube collectors.

Unlike evacuated tube collector, flat-plate converters are affordable, widely applied, and have four elements which include;

1. The transparent cover
2. Absorber plate
3. The collector box, and
4. Tube chi are fixed tightly to the absorber plate

It is the primary role of the collectors' plates to absorb or get the heat which comes from the solar radiant energy and transport it to the water inside tubes. Typically, the water flows

freely throughout the device transport heat. For this reason, the tubes must be made of metallic so as to enhance heat absorption rate. Some of the metallic which are highly recommended to be used in making the tubes includes; aluminium, copper, and steel since they are good conductors of heat. Consequently, the tubes must black in colour so as to enhance absorption rate. The outer cover of the box should be made of insulator material such as plastic and wood so as to reduce the heat loss into the surrounding environment. Finally, the top cover or front cover should be transparent so as to enable observation from outside but should be protected from dirt and humidity.

Water or water with antifreeze are the most recommended fluids to be used in solar collector for heat transportation and also they reduce heat loss. However, heat is also lost due to temperature variation which is experienced between ambient air and the absorber. Consequent, flat-plates is highly recommended to be used since has the ability to utilize defectively diffuse elements as well as the beam of solar. However, the study shows that the efficiency of the flat-plate largely depends on the temperature on the plate. Finally, the tracking system is considered as important in enhancing the effectiveness of the plate.

Solar collectors with high efficiency are on the market today, but economically these have difficulties competing with conventional energy. According to Tsilingiris (2002, p. 137) the future of this technology depends on the development of “reliable, cheap, widely applied, and easy to use”. The potential for cost reduction has motivated the development of solar collector components made of polymer materials. The temperature in solar collectors may exceed the boiling temperature of the heat carrier. As boiling can damage the collector it must be avoided and this is normally done by letting the heat carrier drain from the absorber and back into the tank.

## 1.2 Solar heat generation

The basic idea in generating solar heat is by converting the sun radiation to heat with aid or use utilization of thermal collectors. Different kind of solar collectors can be applied depending on the amount of heat required. In conditions when high amount of heat is required, evacuated tubes collector are the most preferred collectors.

### 1.2.1 Elements of solar thermal systems:

#### 1.2.1.1 *Collectors*

Solar collector is referring to a diverse collection which consist of the water panel as well as other several water tubes that are tightly connected on the upper and bottom side of the device. The heat produce in the device which in this case is solar collector is reported using the energy emitted or generated by the absorber plate. For that reason, collector is the part which is used to conduct heat from the sun into the solar panel. The heat from the sun is directly absorbed in the water tubes thus warming the water to produce the required amount of energy in the downstream system. The surface on which the heat is collected should be wide enough so as to utilize the part of manufactures as well as the literatures depicted on the geometry of the collector panel.

- The surface on the solar collector reflects directly the sunlight or radiant that hit on it thus end up being absorbed by the water in the tubes.
- The top area of absorbing sunlight should be always in conduct with the absorber panel.
- The top surface is well measured and accurately fitted on the outside parts so as to ensure it effectively absorbs the light.

### ***1.2.1.2 Thermal Storage***

The power provided by the sun cannot be so much effective itself when the heat is required in the thermal system; consequently, the produced solar heat should be stored it would be better if the collected heat was store in the tank during morning hours (when the rate of daylight is high) to the late hours in the evenings. For this reason, the thermal as the ability to store water which is greatly used in absorbing hear thus transporting it throughout the tubes. Indeed, the water enables the solar thermal system to function effectively (Ranjitha, et al., 2013).

### ***1.2.1.3 Solar Circuit***

The solar circuit is used to transmit thermal stored in the tank from the collector where its Generated. Some of the elements involved in the process of transporting thermal;

- The pipelines, which interface the collector on the rooftop to the thermal storage Unit,
- The transport medium, which transports the heat from solar based circuit,
- The exchanger which is fitted on the solar circuit is used to exchange heat collected from the surface and transport to water inside the tubes.
- The solar circuit has also some well-defined fittings which are installed with hardware for removal and bleeding.
- The equipment used for safety purpose
- The security valve is wide enough to prevent the system from any possible damage such as spillage of the fluid due to high pressures in the tubes.

#### **1.2.1.4 Controller**

The controller of the thermal framework should control the circulating pump as well as regulating the amount of energy from the sun thus involving suitable electronic temperature. As the technology advances, modernized controllers are also invented that can control different system circuits just like are single circuit. Consequently, they have other added functions which include; data logging, heat measurement, and error diagnostics (Ranjitha, *et al.*, 2013).

### **1.3 Motivation**

Different technologies have been developed over the years to harness the energy from the sun. Most of this energy is used for heating applications, water desalination, and electricity production. The model is based on fundamental concepts of thermodynamics and will implement the explicit finite difference method to compute the heat exchange through a four nodes solar collector. The four nodes represent the constitutive elements of the flat-plate collector that are:

- (i) Glass cover,
- (ii) Air gap,
- (iii) Absorber, and
- (iv) Working fluid in the pipe going through the collector.

### **1.4 Project Aim**

The aim of this project is to create an initial MATLAB simulation of a solar collector with an output that is a reasonable approximation of the output of a physically existing solar

collector. This first stage of the creation of a simulation does not expect to obtain a 'perfect' simulation, because of the disregarding of some parameters.

## **1.5 Main Objectives**

1. Design and modelling of a flat plat solar collector by finite difference method.
2. Determine how heat is transferred in a flat-plate solar collector particularly using explicit Finite Difference Method for the Heat Equation.
3. Evaluation of the system by MATLAB coding.

## **1.6 Structure of the Dissertation**

This Chapter has explored the background of solar collectors, and indicated the aims and objectives of the project. The next Chapter reviews the available literature on the subject, critically examining the work done by others that relates directly to the subject under discussion. This is followed by Chapter Three – Theoretical modelling. This Chapter explains what a mathematical model must do, and how it will do it. This Chapter explains the governing equations used in the programme, and how they are used to simulate each of the nodes that are represented in the model. Chapter Four discusses the materials and methods, with details of how the collector works, and what parts it is made up of. This Chapter also explains the way that heat is transferred in each separate part, and finishes with the computational analysis. Chapter Five examines and discusses the results of the simulation, making a comparison to the results obtained by Saleh (2012) using an actual flat-plate collector. Finally, Chapter Six draws conclusions from the results, and discusses and recommends future and further research into flat-plate collectors, and the relative success of the simulation.

## CHAPTER 2 LITERATURE REVIEW

The idea of harnessing energy from the sun in order to perform useful work has been around since prehistory. The first recorded attempt to use solar energy was by the Greek philosopher Socrates (470-399) who might have taught how to correctly orient dwellings so as to identify the house which will be cool during summer and hot during winter; this is recorded in Socrates memorabilia by Xenophon. Legend also has it that in the year of 212 B.C. the physicist Archimedes attempted to develop a method to burn the Roman fleet specifically through using a concave mirror to reflect all the incoming radiation on one ship. Whether or not the Greek scientist's attempt actually succeeded is a subject of controversy. It is also suggested that in ancient Mesopotamia, the priests may have used highly polished bowls as parabolic mirrors to ignite fires on the altar. What is certain is that around the year of 1000 AD, the work of the Egyptian mathematician Ibn al-Haytham (965-1039 AD) in optics catapulted the developments in concave mirrors (burning mirrors). Around the year of 1515 AD, the Italian artist and scientist Leonardo Da Vinci proposed to build a large 6.5-kilometer diameter concave mirror to focus the sunlight and provide enough heat for commercial enterprises. The focal point was located at a distance of 4 meters. He conducted experiments to validate his design using large silver-varnished concave mirrors. Solar energy technologies saw major advances in the late 19th century and early 20<sup>th</sup> century. In 1878, Augustin Mouchot presented a solar device at the Universal Exposition in Paris. He had built a prototype a decade before that led Napoleon III to fund his project. This device had a form of a cone with a total reflecting surface area of 5 m<sup>2</sup>. A boiler was placed along the axis of the device and provided steam to drive a

0.5 hp engine at 80 rpm. In 1880, John Ericsson built an engine to run on solar heat. The driving force from the pistons could push the flywheel at the speed of 400 rpm.

Holland et al. (1976) exhibited new trial estimations on free convective heat exchange rates through slanted air layers of high perspective proportion, heated from underneath. The Rayleigh number range secured is from subcritical to 105; the scope of the edge of slant,  $\phi$  measured from the horizontal is:  $0 < \phi < \sim 70$  deg. In spite of the fact that it was expected that the outcomes may be indistinguishable to the outcomes for the even layer in the event that one supplanted  $Ra$  by  $Ra \cos \phi$ , noteworthy take-offs from this conduct were watched, especially in the range  $1708 < Ra \cos \phi < 104, 30 \text{ deg.} \leq \phi < 60 \text{ deg.}$  A suggested relationship giving the Nusselt number as a component of  $Ra \cos \phi$  and  $\phi$  is accounted for. This relationship fits all information nearly.

Larson, et al. (1980) examined on Optimization of Flat-Plate Collector-Flat Mirror Systems. The utilization of a level-plate authority with mirror gives improved sunlight based gathering, a superior coordinating of sun powered accumulation to load prerequisites and satisfactory efficiencies at higher working temperatures.

Yeo, et al. (2003) examined the progressions and late vitality sparing capability of private heating in Korea, and demonstrated that present day flat structures with boiling hot water brilliant floor heating yield less heat misfortune because of the more tightly envelope, additionally yield higher vitality utilization because of the utilization of vitality all the more adequately.

Badran and Hamdan (2004) did a similar review for underfloor heating utilizing sun oriented authorities or sun powered lakes. In their work, a hypothetical and exploratory review is

made for underfloor heating framework utilizing sun powered authorities. Additionally, a review for a comparative framework utilizing sun oriented lakes is made with similar fundamental conditions. Comes about acquired demonstrate that the sun oriented authority framework is 7% more proficient than the sun based lake framework.

Haddad, et al. (2007) managed sunlight based helped brilliant floor heating frameworks for private application. The oddity of the present review is to reproduce an underfloor heating framework utilizing sun powered vitality with TRNSYS programming, looking at the execution of two sorts of sun based authorities Flat-plate gatherer and CPC gatherer. The model is for a residential house in North Cyprus climate condition with the point of finding the base conceivable space without losing the execution. With a specific end goal to look at the execution of the authorities, every one of the parameters of alternate parts of the framework are the same aside from the sort of sun powered gatherers.

Kurtay, et al. (2009) taken a shot at a story heating framework utilizing sun powered vitality in Ankara, Turkey. The point of their review was to research a story heating framework for an office by applying the sun based vitality. Level-plate gatherers are the safeguard of sun powered vitality and the vitality picked up will be put away in a capacity tank. The examination technique for hot solace of the workplace is played out that is influenced by ecological and individual parameters. The got result demonstrates that utilizing sun oriented vitality as a supplementary heat source can expand the level of solace in Ankara climate condition. This technique for examination of the hot solace is pertinent for different frameworks too.

Candanedo, et al. (2011) explored prescient control techniques connected to brilliant floor heating framework in a net-zero vitality sun oriented home, through the usage of a disentangled exchange work demonstrate. Prescient control is utilized to keep up an agreeable indoor condition by suspecting the building's reaction to expected climate conditions.

Haddad (2011) reproduced a model for a house outfitted with a brilliant floor heating framework associated with sunlight based gatherers used to assess the capability of utilizing sun based vitality for space heating in the northern Chicago atmosphere. The sun powered part of the framework is anticipated when the supply temperature to the brilliant circles is consistent and when this temperature is changed by outside temperature reset control. In his review the impact of a local heated water framework on the execution of the close planetary system is not considered.

Șerban, et al. (2011), recreated a model of a sun powered house by utilizing TRNSYS situated in the city of Brașov, România. In their review, they have played out a vitality examination for a little scale sun oriented house with two stories. The work depicts the area, size and hot administration of the sunlight based house; they are likewise exhibited the heating framework office and gear parts, intended for the sun based house situated in Transylvania University Campus. The review comprises of two request sources: household boiling hot water and underfloor heating. In light of the accomplished recreations it is demonstrated that contrasted with the standard control the vigorously based control gives wonderful points of interest and investment funds 6 concerning the helper heating vitality. This outcome ought to be substantial for any frameworks like the specific one in Brașov.

Amori, et al. (2012) did a review for hot change of sunlight based water framework utilizing quickened tubes in level-plate authority. This review incorporates a correlation between the exhibitions of two privately created comparative level-plate sun oriented gatherers. One of these authorities is another plan of quickened safeguard, its risers are of joining conduits (the leave territory is a large portion of that at the passageway). The other gatherer is of regular safeguard (its risers have a similar cross sectional range along its length). Comes about demonstrate that a significant upgrade of hot execution roughly (60%) of assimilated warmth (valuable pick up) at sun powered twelve is gotten for the new outline in correlation with the ordinary sort.

Nandurkar, et al. (2012) coordinated examinations in which reducing zone of liquid levelplate gatherer by extending tube remove crosswise over and diminishing riser length. Daylight based level-plate gatherer having extending separation crosswise over of copper compartment of level-plate specialist with fundamental sharp edges presentations is better than the ISI level-plate expert. The present work is a survey on the comparable execution examination of ISI level-plate gatherer with balanced level-plate expert. It is found that the changed level-plate specialist with addition in estimation of test section, Nusselt number and Reynold's number is extended with second vitality of tube separation over.

Amrutkar, et al. (2012) considered on Solar Flat-plate Collector Analysis. The objective of present survey is to evaluate the execution of FPC with different geometric protect setup. It is ordinary that with a comparative expert space higher hot profitability or higher water temperature can be procured. In this way, cost of the FPC can be further bring around enhancing the gatherer adequacy. A test setup is made and trials prompt think these

points of view under research office conditions (as per IS standard available for the level-plate gatherer testing).

Raj et al. (2012) analysed another sun arranged level-plate gatherer which is of sandwich sort. The new sort of gatherer is the water sandwich sort specialist which is made by supporting two collapsed metal sheets on each other. The defend is made of 2 sheets of GI (1 mm) with composed trenches, painted silica based dull paint. The outer bundling which gives mechanical quality to the apparatus is shielded to lessen the glow adversities from back and sides of the expert. The new expert is difference is the nonappearance of heat passing on metallic tubes. The working fluid is made to adhere to the procedures that are surrounded when two wrinkled metal sheets are propped one over another. Efficiency of the level-plate conventional is 24.17 and adequacy of the new expert is 20.19%.

Kostic, et al. (2012) proposed an ideal position for the reflectors to enhance the hot proficiency of level-plate authority SWH. For that reason they were led contemplate on hot gatherers with and without level-plate sun oriented radiation reflectors. Kumar, et al. (2012) fabricated the model on the idea of cutting edge sun oriented water radiator i.e. customary sunlight based water radiator with concentric gatherer. They tried the model in two phases. In the main stage the sunlight based water radiator was tried without concentrator and in second stage with concentrator. They led tests in two unique stages. In first stage the analysis were directed without illustrative concentrator. At that point concentric gatherer is joined to it and examination was directed. The acquired outcomes demonstrate the effectiveness of cutting edge sun oriented water radiator is 15.3 percent higher than traditional level-plate water heater. Ranjitha et al. (2013) concentrated a

numerical and also an exploratory examination of stream and temperature was performed. The impact of tube shape in regular gatherers was examined utilizing CFD.

Khatik, et al. (2014) directed an exploratory work on the execution of recently proposed safeguard plate having concavities and contrasted and the ordinary safeguard plate. Investigations were led on two safeguard plates independently. In one plate, little cavities were created while the other plate was kept essentially smooth. Making concavities in the plate expands the surface zone of the plate the outcomes demonstrates that there is a change in the heat exchange rate. The heat exchange rate is expanded by 5.12%. It demonstrates that the expansion in outlet temperature because of the arrangement of concavities which increment the dispersion territory for radiation diminishing the reflection misfortunes.

Fatigun, et al. (2014) coordinated investigation in which the effect of tube isolating on the execution of a level-plate gatherer is takes a gander at. Two same opening locale of sun arranged level-plate expert is dissect of ordinary close-by tube isolating of 11 cm (An) and 20 cm (B). Ordinary of 11 cm isolating between bordering lines yielded 15 turns while 20cm typical line partitioning yielded 9 turns of tubing for each Flat-plate. The adequacy of specialist (B) was seen to be through and through higher than that of gatherer (An), i.e. 10% and 21% was gotten for specialists (An) and (B) independently.

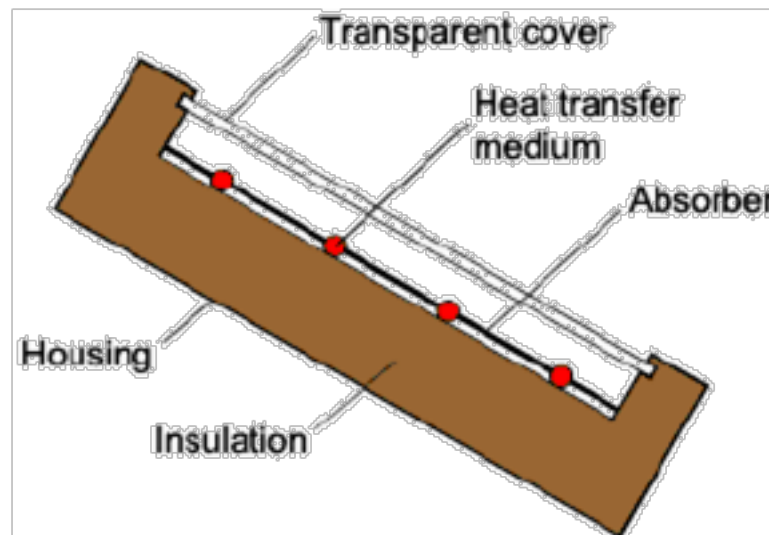
## CHAPTER 3 THEORETICAL MODELLING

In this chapter, the modelling of a flat-plate solar collector in the MATLAB environment is described in more detail, with assumptions, ruling equations, and methods.

### 3.1 The Mathematical Model Development of a Flat-plate Solar Collector

The MATLAB model represents a mathematical simulation of the real collector. It can then be tested in much wider ranging conditions than it is likely to be subjected to when in use. The model will consider four nodes; the glass cover, the air-gap, the absorber, and the working fluid. In this simulation, the insulation has been disregarded because it makes a very small contribution and is almost a constant – however, it is intended to include this in any future, up-rated, version of the simulation.

**Figure 1: The Four Nodes Modelled - Insulation was disregarded in this initial model. Source: (Saleh, 2012)**



In the following sections describing the nodes, the governing equation for each is given.

This is the equation which the MATLAB code calculates during the simulation.

### 3.1.1 Glass Cover

Because the glass cover is not thick, it is reasonable to assume that it has no temperature gradient, and the temperature is uniform through the thickness. If this assumption is made, then the governing equation is simplified to that given in Equation 1.

$$T_{gt,+j\Delta t} = \frac{1}{F_j\Delta t} T_{gt,j} + \frac{B}{F_j} T_{amt} + \frac{C}{F_j} T_{abt,j} + \frac{D}{F_j} T_{at,j} + \frac{E}{F_j} G_t$$

$$j = 1, 2, \dots, N$$

**Equation 1: Governing Equation for the Glass Cover**

### 3.1.2 The Air Gap

The next node considered is the air gap between the glass cover and the collector. This requires consideration of the transient thermo-physical properties of the air, the heat transfers into the air gap by convection between it and the glass in upper side and the absorber in the other side figure.

$$T_{gt,+j\Delta t} = \frac{1}{H_j\Delta t} T_{at,j} + \frac{G}{H_j} (T_{gt,+j\Delta t} + T_{abt,j})$$

$$j = 1, \dots, N$$

**Equation 2: Governing Equation for the Air Gap**

### 3.1.3 The Absorber

The absorber itself needs similar considerations to be calculated, and for this, the governing equation used in the MATLAB simulation is that shown below in Equation 3.

$$T_{gt,+j \Delta t} = \frac{1}{N} T_{abt,j} + \frac{K_j}{Q_j \Delta t} G_{t+\Delta t} + \frac{L_j}{Q_j} T_{gt,+j \Delta t} + \frac{M}{Q_j} T_{at,+j \Delta t} + \frac{O}{Q_j} T_{ft,j} = 1, 2, \dots N$$

$$j = 1, 2, \dots N$$

*Equation 3: Governing Equation for the Absorber*

### 3.1.4 The Working Fluid

The final node considered in this model is for the working fluid, and is shown in Equation 4.

$$T_{f,j}^{t+\Delta t} = \frac{1}{U_j \Delta t} T_{f,j}^{t-\Delta t} + \frac{R_j}{U_j} T_{abt,t+\Delta t} + \frac{S_j}{U_j \Delta z} T_{f,t,j-1}$$

$$j = 1, 2, \dots N$$

*Equation 4: Governing Equation for the Working Fluid*

## 3.2 The Numerical Solution for the Solar Collector Mathematical Model

These partial differential equations are discretised using the explicit finite difference method. The time and dimensional derivatives are represented in finite difference form by using forward difference, such as;

$$\frac{dT_m}{dt} = \frac{T_{mt,j+1} - T_{mt,j}}{\Delta t}$$

$$\frac{dT_f}{dx} = \frac{T_{ft,j+1} - T_{ft,j}}{\Delta x}$$

where  $m = \text{an index of values } g, a, ab \text{ and } f$   
 $j = \text{the node number in the flow direction}$

### ***Equation 5: Forward Difference Equations***

In addition to the governing equations, stability factors and temperature limitations to control the number of iterations are built into the MATLAB code.

### **3.3 The Heat Transfer Correlations**

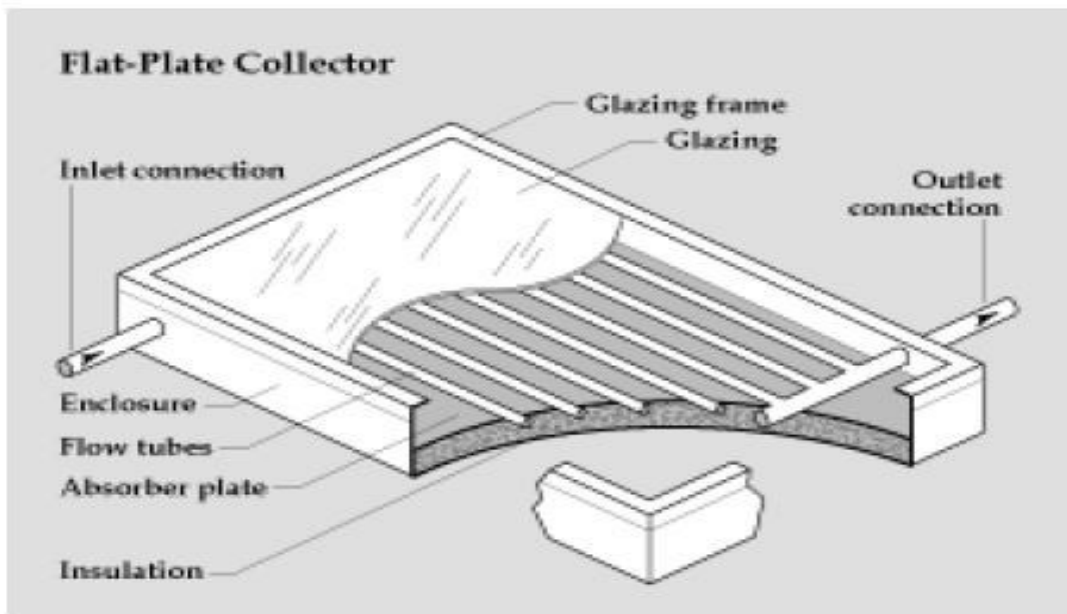
The calculations used for this step are shown in detail in the following chapter, but it is necessary to know the Reynold's number, Stefan-Boltzmann constant, and calculate the Nusselt number (Duffie and Beckmann, 2006).

## CHAPTER 4 MATERIALS AND METHODOLOGY

### 3.1 Flat-plate Collectors

These specific collectors are a very broadly used type of collectors. These collectors are mostly used for low temperature applications up to 100°C. Recent advances have been made in improving insulation materials and special coatings that allow FPCs to reach temperatures of 200°C or higher. The main parts of a FPC include the flow tubes, the absorber plate and glazing (figure 1). Solar radiation goes through the semi-transparent cover as well as is soaked by the absorber plate which has a very high absorptivity. The energy absorbed is then forwarded to the fluid (air, oil or water) in the flow circular tubes and is then moved away for the purpose of storage or direct use.

*Figure 2: A Flat-plate Collector. Source: (Saleh, 2012)*

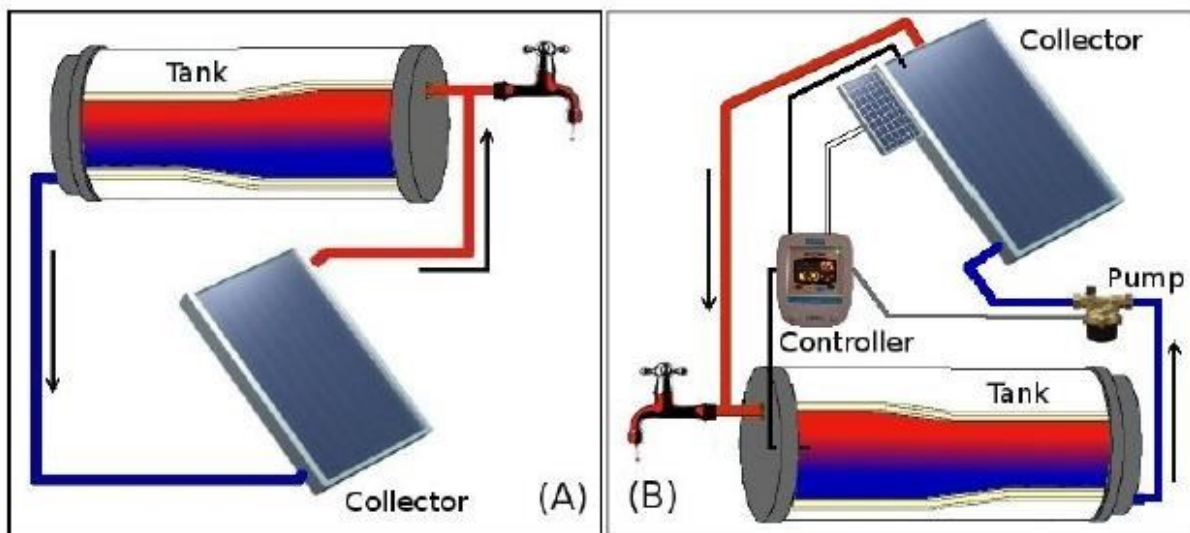


The objectives in the design of flat-plate collectors are to absorb as much energy as possible from the sun's radiation and to minimize the heat losses: conduction heat losses, convection heat losses as well as radiation heat losses. In order to capture the maximum

possible radiation from the sun, the choice of the material and coating plays an important role. By using the appropriate electrolytic and chemical treatments, it is possible to produce surfaces with high absorption and low long wave emittance. There is likewise the utilization of a thin upper layer that is saved on the safeguard surface. This thin layer is exceedingly permeable to shortwave sun based radiation however moderately straightforward to long wave hot radiation, while the surface on which it is stored has a high reflectance and a low emittance for long wave radiation. Most business safeguards are made by electroplating, anodization, vanishing, sputtering and by applying sunlight based specific paints.

The utilisation of a straightforward cover helps in diminishing the vitality misfortunes from the safeguard plate by holding set up the air between the plate and the glass. It additionally lessens radiation misfortunes from the authority as the glass is straightforward to the short-wave radiation gotten by the sun yet it is about hazy to longwave hot radiation transmitted by the safeguard plate.

**Figure 3: Collector Assemblies. Source: (Saleh, 2012)**



The conduction losses are minimized by putting the flow tubes and the absorber plate in a well-insulated enclosure. Figure 2 shows the configuration of flat-plate collectors for solar water heating.

#### **4.1 Heat exchanger**

In an underhanded sort of SWH system, a heat exchanger (HX) is utilized to trade held sun based heat from the working fluid to the limit tank. The HXs are all around delivered utilizing conductive material, for instance, aluminium, stainless steel, cast squeeze, copper, steel, and bronze. To ensure awesome hot conductivity and impenetrability to disintegration, copper is unmistakably used as a piece of SWH structure. A couple of setups of HXs have been expected for underhanded water heating stockpiling tanks and the most generally perceived plans are: the soaked circle in-tank, the shell-and-tube, and the mantle hot exchanger. A couple outlines of HXs have been proposed to upgrade the general execution of the SWH system.

The twist in-tank heat exchanger is a twist containing a couple circles of tubing involved either single or twofold divider doused in the limit tank. Farrington and Bingham attempted and explored the viability of load side submerged HX and confirmed that a smooth twist HX defeated the finned HX with the same outside surface area. The survey had declared that the store side HX moreover filled in as a hindrance and in this way improved the stratification in the limit tanks.

#### **4.2 Hot trade fluid**

Hot trade fluid (HTF) expect a to a great degree gigantic part in a sun situated gatherer structure. In a SWH system, HTF holds essentialness in the gatherer and transmits the

imperativeness through the glow exchanger to the water in the limit tank. The HTF properties, for instance, limit, the purpose of hardening, burst point, thickness, and hot utmost accept a section in the decision of a working fluid for a SWH structure. Fig. 10. Schematic arrangement of Tanks A, B and C. (Shukla, et al. (2013) 173–190) For example, a SWH structure will require a HTF with a low the purpose of cementing and a high limit in frigid and hot airs, independently. A segment of the ordinary HTFs used are air, water, hydrocarbon oils, Glycol/water mix, and refrigerants/organize change liquids. Air and water have been typically used as HTFs in SWH systems. Air has certain central focuses appeared differently in relation to water. That is, it is non-damaging in nature and has no issues, for instance, foaming/cementing. Nevertheless, its low heat restrain approves hindrance to low temperature applications and is not used for private water heating purposes. On the other hand, water's high specific heat, for instance, its low thickness, non-deadly, and more reasonable components have arranged water to be the most surely understood working fluid in SWH structures. Nevertheless, its dangerous nature (especially at high temperatures) and what is more cementing and scaling issues speaks to a test in the layout of gatherer tubing and pipes. To overcome modestly high the purpose of hardening of water, a glycol included substance is all things considered used close by water to go about as a radiator liquid. Refrigerants are generally used as HTFs in heat pumps, ice chests, and air circulation and cooling frameworks. The use of refrigerant-filled sun arranged experts in a glow pump system is one of the fundamental upgrades in the glow pump and daylight based development. Refrigerants are more reasonable than various fluids especially in the midst of cloudy conditions because of their low limits, and high heat limits. A couple explore wanders have been directed to pack the sufficiency in

working the SWH system including 2-arrange hot trade gets ready. The focal hot execution of two thermosyphon sun arranged specialists, blamed for  $\text{CH}_3)_2\text{CO}$ , and oil ether, was analysed by Soin, et al. 2011. It was represented that the capability of a two-organize specialist was simply around 6% to 11% which is stunningly lower stood out from a direct thermosyphon SWH structure. In circuitous (close circle) SWH systems, chlorofluorocarbon (CFC) refrigerants are more generally used as HTFs for their robustness, non-combustible, and noncorrosive properties, low hurtfulness and low the purpose of cementing. Specific representations incorporate: R-11, R-12, R-13, R-113, R114, and R-115.

### 4.3 The vitality adjustment

The created hot model depends on the vitality move wonder in the various segments of the gatherer.

#### 4.3.1 The outside glass

$$\delta_v \rho_v \frac{C_{pv}}{2} \frac{\partial T_{ve}}{\partial t} = \frac{G \alpha_v}{2} + h_{r, v-c} (T_c - T_{ve}) + h_{vent} (T_a - T_{ve}) + h_{c, v} (T_{vi} - T_{ve})$$

**Equation 6: Outside Glass Adjustment** where,  $G$  is the energy of the event sun arranged radiation;  $\delta_v$ ,  $\rho_v$ ,  $C_{pv}$  and  $v \alpha$  are separately thickness, mass thickness, specific heat and osmosis of glass cover.  $T_c$ ,  $T_a$  are independently temperature of sky and temperature of enveloping air.  $h_{r, v-c}$  is radiation hot trade coefficient between glass cover and sky;  $h_{vent}$  is the convective heat trade coefficients due to the wind.  $h_{c, v}$  is the conduction hot move coefficient in the glass cover.  $\alpha_v$ , depends on upon the scene purpose of the sun controlled radiation  $\theta_1$ , and can be procured by Hollands et al. 1976.

$$\alpha_v = 1 - \tau_v$$

**Equation 7: Hollands Equation** where  $\tau_v$  is

the transmittance of glass cover

$$\tau_v = e^{-\lambda \delta_v / \cos \theta_2}$$

**Equation 8: Transmittance of Glass Cover**

$$\theta_2 = \arcsin \left( \frac{\sin \theta_1}{n_v} \right)$$

**Equation 9: Refraction Through Glass**

with:  $\theta_2$  is the refraction angle.  $n_v$  is the refraction index of the glass and  $\lambda$  is the extinction coefficient of the glass.

#### 4.3.2 The inside glass

$$\delta_v \rho_v \frac{C_{pv}}{2} \frac{\partial T_{vi}}{\partial t} = \frac{G \alpha_v}{2} + (h_{v,pv-v} + h_{r,pv-v}) (T_{pv} - T_{vi}) + h_{c,v} (T_{ve} - T_{vi})$$

**Equation 10: The Equation for the Inside Glass**  $h_v$ ,  $pv-v$ ,  $h_r$ ,  $pv-v$  are separately the convective coefficient and radiation heat exchange coefficient between glass cover and PV board.

#### 4.3.3 PV module

$$\delta_{pv} \rho_{pv} C_{pv} \frac{\partial T_{pv}}{\partial t} = G(\alpha \tau)_p - E + h_{c,p-pv} (T_p - T_{pv}) + (h_{v,pv-p} + h_{r,pv-p}) (T_{vi} - T_{pv})$$

**Equation 11: The Photo-Voltaic Module Equation**

Where,  $E$  is the electrical power yield.  $\delta_{pv}$  is the thickness of PV.  $\rho_{pv}$ ,  $C_{pv}$  is the mass thickness and the specific heat of PV board separately.  $(\alpha \tau)_p$  is the viable absorption of the PV board

$$(\alpha \tau)_p = \frac{\tau_v \tau_r \alpha_p}{1 - (1 - \alpha_p) r}$$

**Equation 12: Absorption of PV Panel**  $\tau$  and  $r$  are the transmission (because of the reflection halfway of the accidental radiation)

And the reflection coefficients separately

$$\tau_r = \frac{1 - r}{1 + r}$$

**Equation 13: Transmission and Reflection Coefficients And**

$$r = \frac{1}{2} \left[ \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} + \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)} \right]$$

**Equation 14: Coefficient Equation II**

The electrical power output  $E$  depends on the temperature of the cells  $T_{pv}$ ; it is calculated by as

$$E = G P \tau_v \eta_0 \times [1 - \phi_c (T_{pv} - 25)]$$

**Equation 15: Electrical Power** where,  $\eta_0$  is the electrical change effectiveness at the reference temperature  $T_r = 25^\circ\text{C}$ .  $\phi_c$  is the temperature coefficient of the sun powered cell with  $\phi_c = 0.0045^\circ\text{C}^{-1}$ .  $P$  is the pressing element of the cell.  $h_{c,pv-p}$  is the conduction hot move coefficients in the cement layer.

#### 4.3.4 The plate safeguard

$$\delta_p \rho_p C_p \frac{\partial T_p}{\partial t} = h_{c,p-pv} (T_{pv} - T_p) + \frac{A_{pt}}{A_p} h_{c,p-t} (T_t - T_p)$$

**Equation 16: The Plate Safeguard Equation**

Where  $\delta$ ,  $\rho$ ,  $C_p$  are respectively thickness, mass density and specific heat of the plate.

$h_{c,p-t}$ : conduction heat transfer coefficients between plate absorber and tubes.  $A_{pt}$ :

surface between the plate absorber and the tubes, given by the following relation:

$$A_{pt} = \frac{\pi}{4} N D_e l$$

**Equation 17: Absorber/Tube Relation**

With,  $N$  is the aggregate number of tubes and  $D_e$  is the outside distance across of tubes.

#### 4.3.5 Tubes

$$\delta_t \rho_t C_{p_t} \frac{\partial T_t}{\partial t} = \frac{A_{pt}}{A_t} h_{c,p-t} (T_p - T_t) + \frac{A_f}{A_t} h_{v,t-f} (T_f - T_t) + \frac{A_i}{A_t} h_{c,i-t} (T_{ii} - T_t)$$

**Equation 18: Tube Equations** where  $\delta_t$ ,  $\rho_t$  and  $C_p$  are individually thickness, mass thickness and specific heat of the tubes.  $v$ ,  $t$   $f$   $h$  – are the convective heat exchange coefficients between the tubes and the

Liquid.  $A_f$  is the contact surface of tube-liquid given by the connection.

$$A_f = N \pi D_i l$$

**Equation 19: Tube to Liquid Interface**

$A_i$  is the insulation surface.

#### 4.3.6 The fluid

$$\dot{m} C_{p_f} (T_f - T_f^*) = A_t h_{v,t-f} (T_t - T_f) + A_{if} h_{v,i-f} (T_{ii} - T_f)$$

**Equation 20: The Fluid Equation**

with,  $m$ : Flow mass rate of liquid.  $C_p$ : Specific heat of the liquid.  $h_{v,i-f}$ : Convective heat exchange coefficients between the protection and liquid,  $T_f$  the liquid temperature of the former area.  $A_{if}$ : the invented surface of the liquid stream on protection with

$$A_{if} = N D_e l$$

**Equation 21: Surface to Liquid Relation**

#### 4.3.7 The inside insulation

$$\delta_i \rho_i \frac{C_{p_i}}{2} \frac{\partial T_{ii}}{\partial t} = \frac{A_{if}}{A_i} h_{v,i-f} (T_f - T_{ii}) + h_{c,i} (T_{ie} - T_{ii}) + \frac{A_t}{A_i} h_{c,i-t} (T_t - T_{ii})$$

**Equation 22: The Inside Calculation**

where,  $\delta_i$ ,  $\rho_i$  and  $C_{p_i}$  are separately thickness and mass thickness and specific heat of protection;  $h_{c,i}$  conduction heat transfer coefficients in protection.,  $h_{c,i-t}$  conduction heat transfer coefficients in insulation.,

The outside protection

$$\delta_i \rho_i \frac{C_{p_i}}{2} \frac{\partial T_{ie}}{\partial t} = h_{r,i-s} (T_s - T_{ie}) + h_{c,i} (T_{ii} - T_{ie}) + h_{vent} (T_a - T_{ie})$$

**Equation 23: Outside Protection**  $h_{r,i-s}$  is radiation heat transfer coefficient between insulation and the ground.

#### 4.3.8 Heat transfer coefficients

Convective heat transfer coefficients due to the wind is given according to McAdams by the relation

$$h_{\text{vent}} = 5.7 + 3.8 V_{\text{vent}}$$

**Equation 24: Heat Transfer Coefficient**

$V_{\text{vent}}$  is the wind velocity (m.s<sup>-1</sup>)

Radiation heat exchange coefficients between the outside glass and the sky from one viewpoint and between the outside protection and the ground furthermore are individually given as

$$h_{r,v-c} = \varepsilon_v \sigma (T_c^2 + T_{ve}^2) (T_c + T_{ve})$$

**Equation 25: Radiation Heat Exchange I**

$$h_{r,i-s} = \varepsilon_i \sigma (T_s^2 + T_{ie}^2) (T_s + T_{ie})$$

**Equation 26: Radiation Heat Exchange II**

Natural convective heat transfer coefficient between the glass and the PV is given by the expression

$$h_{v,v-pv} = \frac{Nu k_{\text{air}}}{b}$$

**Equation 27: Natural Convective Heat Transfer**  $k_{\text{air}}$  is the hot conductivity of the air.  $b$  is the separation between the glass and the PV.  $Nu$  is the Nusselt number ascertained by utilizing the accompanying relationships

$$Gr < 1700 + 47.8\phi \quad Nu = 1.013$$

**Equation 28: Nusselt Number Equation I**

$$Gr > 80000 \quad Nu = 2.5 + 0.0133(90 - \phi)$$

**Equation 29: Nusselt Number Equation II**

Otherwise

$$Nu = \left[ 0.06 + 3.10^{-4} (90 - \phi) \right] Gr^{0.33}$$

**Equation 30: Nusselt Number Equation III Gr**

is the Grashof number defined by

$$Gr = \frac{g \beta \Delta T b^3}{\nu^2}$$

**Equation 31: Grashof Number Equation**  $\phi$  the inclination angle of the collector ( $^\circ$ ).  $\beta$  is being the thermal dilation coefficient; for the air  $\beta \approx T^{-1}$

The convective heat transfer coefficient between the absorber plate and glass cover is calculated from the Nusselt number obtained using equation given by Hollands, et al. (1976).

$$Nu = 1 + 1.44 \left[ 1 - \frac{1708}{\cos \beta \cdot Ra} \right] \left[ 1 - \frac{\sin(1.8\beta)^{1.6} \cdot 1708}{\cos \beta \cdot Ra} \right] + \left[ \left( \frac{\cos \beta \cdot Ra}{5830} \right)^{1/3} - 1 \right]$$

**Equation 32: Hollands Equation for Nusselt Number**

Where;

$$Ra = \frac{g \beta (\Delta T) d^3}{\nu^2} \times Pr$$

**Equation 33: ...continued**

The radiative heat exchange coefficient changes with the wind misfortune coefficient and the temperature contrast between the glass cover and the encompassing.

**4.3.9 The hot and electrical efficiencies of the gatherer**

The heat effectiveness of the gatherer is given by

$$\eta_t = \frac{Q_u}{A_c G}$$

**Equation 34: Heat Effectiveness**

The useful power  $Q_u$  is;

$$Q_u = \dot{m} C_p (T_{fs} - T_{fe})$$

**Equation 35: Useful Power**

$T_{fe}$ ,  $T_{fs}$  are the outlet and delta temperatures of the liquid. One can assess  $Q_u$  as indicated by the normal temperature of the plate  $T_{p,m}$  by the connection

$$Q_u = A_c [S - U_L (T_{p,m} - T_a)]$$

**Equation 36: Temperature Calculation**

With;

$$S = G \times (\alpha \tau)_p$$

**Equation 37: ... continued.**

$U_L$  is the overall loss coefficient.

Hottel, et al. modified the above relation and proposed the expression

$$Q_u = A_c F_t [S - U_L (T_{fe} - T_a)]$$

**Equation 38: Hottel's Modification** with,

$F_t$  is the thermal transfer factor.

The calculation of the factors  $U_L$  and  $F_t$  is given in appendix.

#### 4.3.10 The electrical efficiency is written

$$\eta_e = \eta_0 [1 - \phi_c (T_{pv} - 25)]$$

**Equation 39: Electrical Efficiency**

The approximation of the temperature in a photovoltaic board, which comprises of polycrystalline silicon cells, is given by

$$T_{pv} = 30 + 0.0175(G - 150) + 1.14(T_a - 25)$$

*Equation 40: PV Temperature Approximation*

#### **4.4 Computational Analysis display**

The entire investigation is completed with the assistance of MATLAB R2009b. MATLAB is a product bundle for elite numerical calculation and representation. It gives an intelligent domain several implicit capacities for specialized calculation, illustrations and movement. It likewise gives simple extensibility its own abnormal state programming dialect. The name MATLAB remains for Matrix Laboratory.

## CHAPTER 5 RESULTS AND DISCUSSION

### 5.1 Comparative Study of Inlet and Outlet Temperature with Time

In Table 1 the output figures from the MATLAB model are plotted, compared to outlet figures measured from real collectors (in an experiment by Saleh (2012)) and the error (the difference between the two) is shown in the final column.

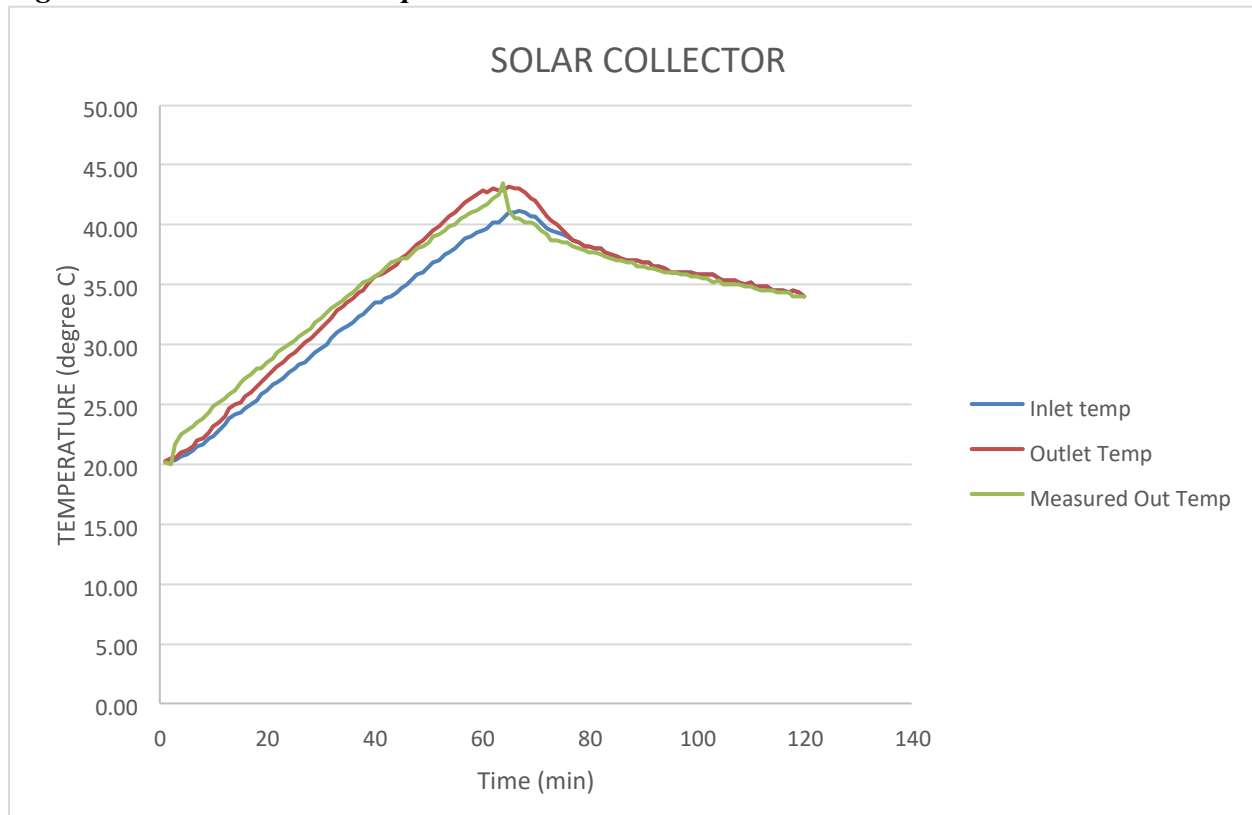
| <b>Time<br/>(sec)</b> | <b>A.<br/>Inlet<br/>Temperature</b> | <b>B.<br/>Outlet<br/>Temperature</b> | <b>C.<br/>MATLAB<br/>predicted Outlet<br/>Temperature</b> | <b>Error – (C-B)</b> |
|-----------------------|-------------------------------------|--------------------------------------|-----------------------------------------------------------|----------------------|
| 1                     | 20.20                               | 20.27                                | 20.10                                                     | -0.17                |
| 6                     | 21.10                               | 21.57                                | 23.20                                                     | +1.63                |
| 11                    | 22.80                               | 23.54                                | 25.20                                                     | +1.66                |
| 16                    | 24.70                               | 25.67                                | 27.20                                                     | +1.53                |
| 21                    | 26.60                               | 27.80                                | 28.80                                                     | +1.00                |
| 26                    | 28.30                               | 29.77                                | 30.70                                                     | +0.93                |
| 31                    | 30.10                               | 31.82                                | 32.70                                                     | +0.88                |
| 36                    | 31.90                               | 33.86                                | 34.40                                                     | +0.54                |
| 41                    | 33.60                               | 35.83                                | 36.00                                                     | +0.17                |
| 46                    | 35.10                               | 37.62                                | 37.20                                                     | -0.42                |
| 51                    | 36.80                               | 39.58                                | 39.10                                                     | -0.48                |
| 56                    | 38.50                               | 41.54                                | 40.50                                                     | -1.04                |
| 61                    | 39.70                               | 42.82                                | 41.80                                                     | -1.02                |
| 66                    | 41.00                               | 43.04                                | 40.50                                                     | -2.54                |
| 71                    | 40.20                               | 41.37                                | 39.50                                                     | -1.87                |
| 76                    | 39.10                               | 39.27                                | 38.50                                                     | -0.77                |
| 81                    | 38.00                               | 38.00                                | 37.70                                                     | -0.30                |
| 86                    | 37.20                               | 37.20                                | 37.00                                                     | -0.20                |
| 91                    | 36.80                               | 36.80                                | 36.40                                                     | -0.40                |
| 96                    | 36.10                               | 36.10                                | 36.00                                                     | -0.10                |
| 101                   | 35.80                               | 35.80                                | 35.50                                                     | -0.30                |
| 106                   | 35.40                               | 35.40                                | 35.00                                                     | -0.40                |
| 111                   | 34.80                               | 34.80                                | 34.70                                                     | -0.10                |
| 116                   | 34.50                               | 34.50                                | 34.40                                                     | -0.10                |

**Table 1: Table of figures from the simulation. Figures were obtained for every second between 1 and 120 seconds, but this table shows the figure every five seconds.**

The output is also plotted in the graph in Figure 4, and this shows that the simulation is quite accurate, despite the omission of the figures for insulation, which when added will

improve the accuracy further. The simulation behaves in a way similar to the real collector and the future enhancements will make it an excellent predictor of collector behaviour and performance.

**Figure 4: The Simulation Output**



An examination of the chart plotted in Figure 4 shows the close correlation between the red 'Outlet temp' line and the Green 'Measured out temp' (this is measured by MATLAB, *i.e.* predicted). Clearly, although the green and red lines do not coincide exactly, the difference is no more than 6.2% (at the worst point, after 66 seconds). This is such that, when the additional calculations for insulation losses are included in a future version of the simulation it will run closer still – a prediction of better than 3% would be a close enough approximation for most cases.

After the observation of the result data it was found that the input and output temperature was increased up to 67 minutes from 20.1 to 41.2°C for input fluid and from 20.23 to 42.32°C for output fluids and after that the temperature was decreased slowly due to heat loss in the system. But the decrement of temperature was slower than the increment of the temperature.

## 5.2 Variety of Useful Heat Gain Vs Inlet Temperature

A broad number of geometrical parameters affect the execution of a level-plate gatherer as specific surfaces, amounts of spreads, separating among spreads and defend plate and other similar measures. In this audit, the condition of tube is assumed to be round cross-sectional area. The tube associated with the shield plate is semi round, so that domain of holding surface is more than that of an indirect tubing structure in sun arranged level-plate specialist.

The one-dimensional stream of heat in the protect plate toward a way at right indicates the course of fluid is considered. Exactly when considered tube is affixed blow of tube, the impenetrability to heat stream to the tube from the plate may be contained three fragments; (i) the resistance as a result of the holding material between the plate and the tube; (ii) the resistance due to the temperature gradient in the fluid at the tube divider; (iii) the resistance due to the divider thickness of the tube. finally, figuring the significant heat grabbed by fluid per unit length. Exact when the volume of fluid contained by the round tube and semi-circular tube are the same. The estimation of the important heat gain was got from the condition (15) as:

$$T^b - T^f$$

$Q_u = 1 \frac{h_{fi} \pi D_{ci} (T_b - T_f)}{L}$  where  $T_b$ =Base temperature above the bond  $T_f$ =Fluid temperature,  
 $h_{fi}$ =Film heat transfer co-efficient, Inner diameter of tube ( $D_i$ ) =10mm and  $D_{ci}=1.414D_i$

By utilising the round tube beneath the safeguard plate, the helpful heat pick up is incremental. The diagram demonstrates that when utilizing the liquid at low temperature, the semi-roundabout sort tube consumed more heat than roundabout tube. This outcome likewise demonstrates that when utilizing the liquid having low softening point the helpful heat pick up by the liquid is more. Because of expanding retaining zone of tube the resistance lessened and because of the holding material between the plate and the tube and the resistance because of the divider thickness of the tube. Thus, this technique enhances the productivity of level-plate gatherer.

### 5.3 Variety of proficiency versus mass stream rate and temperature

From the outcomes, it is unmistakably the proficiency of the sun based liquid radiators increments with the expansion in mass stream rate and diminishing liquid bay weight. The remixing proportion likewise tremendously affects the proficiency of level-plate sun based liquid heater and the productivity increments with the expansion in the benefit of remixing proportion R. Essentially it is clear from the outcomes acquired that the estimation of mean safeguard plate temperature  $T_i$  and liquid outlet temperature to decrease with the expansion in mass stream rate.

## CHAPTER 6 CONCLUSION

Although the long-term aim is to make improvements to the efficiency of a flat-plate collector, this initial stage, to create a workable simulation, has been successfully completed. This simulation has provided a very strong start – it must be remembered that not only did this simulation disregard the insulation losses, it also had the  $h_{\text{co-efficient}}$  set at an arbitrary value of 0.2 in the code.

If these two steps are included in a future version of the simulation, it will greatly improve the accuracy of the predicted output from the collector. When that stage is reached, experimental changes to orientation, material, or other design constraints can be made in the knowledge that the output of the simulation will be a good indication of the output of the real collector. This has real potential to be a development tool for governments and international agencies interested in using solar energy for water heating. The panels can be part of a multi-purpose array, with solar PV panels, solar flat-plate collectors, and solar thermal electricity generators.

The necessity for the adoption of renewable energy sources (RES) has never been greater – oil will not last forever (Roberts, 2004), and the world can no longer rely on an ‘oil economy’. As the twenty-first century progresses, and the ‘energy age’ (Kyriakides, 2006) becomes reality, an on-grid combination of RES and energy storing will become essential. International ‘super-grids’ are already becoming a reality, and the export of electricity will hopefully overtake and replace the export of oil. The main appeal of solar energy of all types is its ubiquity – right now, the sun is shining on some part of the Earth with sufficient energy to provide all our electricity needs. Yes, that would require

international 'super-grids', government cooperation, and an international market for electricity, but these are all increasingly needed if the world is to have and maintain a decent standard of living, and allow countries to develop.

In the final analysis, this project could have an appeal for both developed and developing nations; both could greatly benefit from the introduction of more RES, and solar energy has the advantage that it is safe, there are no moving parts to wear out, and solar panels of all kinds can be incorporated into the roofs of buildings, or placed in desert areas (as is the case in Saudi Arabia), and can, thus be unobtrusive. Solar PV panels with multiple junction technology are reaching levels of efficiency that almost rival traditional electricity generation methods – 3<sup>rd</sup> generation solar PV panels can have an efficiency of around 45%. The solar thermal and solar collector technologies have not moved as fast as solar PV, but there is a lot of potential to improve this technology, and this simulation programme is hoped to be the next step.

## **6.1 Future and Further Research**

Both future and further research are indicated by the findings of this report – an improved version of the MATLAB will be more accurate in its output predictions, and this will, as suggested above, allow experimental variation of the design of the flat-plate collector. This could then improve the efficiency of various components of the collector, and thus its overall efficiency. The combination of RES also requires further research, and on-grid storage methods will become more commonplace, and will also need to be made more efficient.

The novel flat-plate sunlight based gatherer utilising the finite difference method of differential calculation of the safeguard has proposed enhancing hot execution of the comprehensive framework. The altered plan is given many favourable circumstances in the review, for example, cost viability, simple to manufacture and exceedingly effective.

A test setup was made to look at how the framework could be redesigned as far as work and heat exchange heightening strategy. At that point it could be monetarily connected in a genuine situational framework and in the event that it would be reasonable for down to earth applications over the long haul.

Thus, in view of the above discoveries, it is prescribed to utilise this product and monetarily suitable level-plate gatherer for the genuine applications which lessens the carbon from the earth as well as enhances the social existence of the general population of any nation.

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## Appendix:

### Completed Code:

```

clc
clear all

L=2;%pipe length in m
d=0.01;%pipe diameter
Vdot=0.0000158;%volumetric flow rate of the fluid (m^3/s)
wf=4*Vdot/(pi*d^2)%working fluid velocity (m/s)
mdot=Vdot*1000;%fluid mass flow rate (kg/s)
dT=0.1;%time step (s)
h=L/10;%grid spacing (m)
X=[0:h:L];%x coordinates of the nodes
[Rx Cx]=size(X);

%STABILITY CRITERION
SC=(wf*dT)/h;
if SC>1
    disp(['STABILITY CRITERION = ' num2str(SC) ' IT MUST BE <= 1'])
    dT=input('Re-enter time step: ')
    h=input('Re-enter grid spacing: ')
end

%BOUNDARY CONDITIONS
Tam=28+273.15;
Tinitial=293.15;
Tg=ones(1,Cx)*Tinitial;
Ta=ones(1,Cx)*Tinitial;
Tab=ones(1,Cx)*Tinitial;
Tf=ones(1,Cx)*Tinitial;
Fluid_BC=xlsread('Data_Temp.xlsx','Temp_In','B2:B121');

%INITIALISATION
NTg=Tg;
NTa=Ta;
NTab=Tab;
NTf=Tf;

%CALCULATION OF PARAMETERS
% SBC=5.67E-08;%Stefan Boltzmann constant W/m^2*K^4
% Eg=0.9;%Emissivity of glass
% Eab=0.1;%Emissivity of the absorber
% Tsky=0.0552*Tam^1.5;
hcoef=0.2;
p=0.127;%Tube pitch (m)
d_in=9.5/1000;%tube inner diameter (m)
r_out=5/1000;%Tube outer radius (m)
r_in=d_in/2;%Tube inner radius (m)
A=pi*r_in^2;%flow area (m^2)
c_g=720;%Specific heat for glass cover J/kg.K
c_ab=385;%Specific heat for absorber J/kg.K

```

```

c_a=1.0056e+003;%air specific heat (J/kg.K)
c_f=4.178;%water specific heat (J/kg.K)
rho_g=2500;%cover glass density kg/m^3
rho_ab=8795;%absorber density in kg/m^3
rho_a=1.127;%air density at 40 degree C in kg/m^3
rho_f=992.3;%water density at 40 degree C in kg/m^3
delta_g=3.81/1000;%thickness of glass cover
delta_ab=0.015;%absorber thickness
delta_a=0.025;%Air gap thickness
k_am=0.0262;%Ambiant thermal conductivity in W/m.K
k_a=0.029;%Thermal conductivity of air at 40 degree C in W/m.K
alpha=0.005;%absorption coefficient
tau_alpha=0.861;%effective transmittance-absorption coef
%*****B VECTOR
% a=0.00398;
% b=0.0114;
% Pr_am=0.711;
% Re_am=0;
% Nu_am=0.86*Re_am^0.5*Pr_am^(1/3);
% KD=(4*a*b)/sqrt(a^2+b^2);
% h_c_2=Nu_am*k_am/KD;
% h_g_am(1,:)=((SBC*Eg*(Tg.^4-Tsky.^4))/(Tg-Tam))+h_c_2
h_g_am(1,:)=ones(1,Cx)*hcoef;
B=h_g_am/(c_g*rho_g*delta_g);
%***** C VECTOR
% h_r1(1,:)=(SBC*(Tab.^2+Tg.^2).*(Tab+Tg))/((1/Eab)+(1/Eg)-1);
h_r1(1,:)=ones(1,Cx)*hcoef;
C=h_r1/(c_g*rho_g*delta_g);
%***** D VECTOR
h_c1=ones(1,Cx)*hcoef;
D=h_c1/(c_g*rho_g*delta_g);
%***** E VALUE
E=alpha/(c_g*rho_g*delta_g);
%***** F VECTOR
F=(1/dT)+B+C+D;
%***** J VECTOR
J=c_ab.*rho_ab.*(p*delta_ab+pi*(r_out^2-r_in^2));
%***** K VECTOR
K=(p*tau_alpha)/J;
%***** L VECTOR
L=(p*h_r1)./J;
%***** M VECTOR
M=(p*h_c1)./J;
%***** O VECTOR
h_f=ones(1,Cx)*hcoef;
O=(pi*d_in.*h_f)./J;
%***** G VECTOR
G=(p*h_c1)./(c_a.*rho_a.*(p*delta_ab-pi*r_out^2));
%***** H VECTOR
H=(1/dT)+2.*G;
%***** Q VECTOR
Q=(1/dT)+L+M+O;
%***** R VECTOR
R=(pi*d_in.*h_f)./(c_f.*rho_f.*A);
%***** S VECTOR
S=(mdot)./(rho_f.*A);
%***** U VECTOR

```

```

U=(1/dT)+R+(S./h);
%*****G_rk
G_rk=660;

%CALCULATION OF NEXT TEMPERATURE AT THE GLASS COVER
result=zeros(120,1);
counter=1;
cc=1;
Total_Iterations=(120*60/dT);
for t=0:Total_Iterations-1
%     t
%     Tg
%     Ta
%     Tab
%     Tf
    if t==counter*(Total_Iterations/120)
        counter=counter+1;
    end
    if t*dT<=3600
        G_rk=660;
        hcoef=0.2;
        h_g_am(1,:)=ones(1,Cx)*hcoef;
        B=h_g_am/(c_g*rho_g*delta_g);
        h_r1(1,:)=ones(1,Cx)*hcoef;
        C=h_r1/(c_g*rho_g*delta_g);
        h_cl=ones(1,Cx)*hcoef;
        D=h_cl/(c_g*rho_g*delta_g);
        E=alpha/(c_g*rho_g*delta_g);
        F=(1/dT)+B+C+D;
        J=c_ab.*rho_ab.*(p*delta_ab+pi*(r_out^2-r_in^2));
        K=(p*tau_alpha)/J;
        L=(p*h_r1)./J;
        M=(p*h_cl)./J;
        h_f=ones(1,Cx)*hcoef;
        O=(pi*d_in.*h_f)./J;
        G=(p*h_cl)./(c_a.*rho_a.*(p*delta_ab-pi*r_out^2));
        H=(1/dT)+2.*G;
        Q=(1/dT)+L+M+O;
        R=(pi*d_in.*h_f)./(c_f.*rho_f.*A);
        S=(mdot)./(rho_f.*A);
        U=(1/dT)+R+(S./h);
    else
        G_rk=0;
        if hcoef>0
            hcoef=hcoef-(0.0002*dT);
        else
            hcoef=0;
        end
        h_g_am(1,:)=ones(1,Cx)*hcoef;
        B=h_g_am/(c_g*rho_g*delta_g);
        h_r1(1,:)=ones(1,Cx)*hcoef;
        C=h_r1/(c_g*rho_g*delta_g);
        h_cl=ones(1,Cx)*hcoef;
        D=h_cl/(c_g*rho_g*delta_g);
        E=alpha/(c_g*rho_g*delta_g);
        F=(1/dT)+B+C+D;
    end
end

```

```

J=c_ab.*rho_ab.*(p*delta_ab+pi*(r_out^2-r_in^2));
K=(p*tau_alpha)/J;
L=(p*h_r1)./J;
M=(p*h_c1)./J;
h_f=ones(1,Cx)*hcoef;
O=(pi*d_in.*h_f)./J;
G=(p*h_c1)./(c_a.*rho_a.*(p*delta_ab-pi*r_out^2));
H=(1/dT)+2.*G;
Q=(1/dT)+L+M+O;
R=(pi*d_in.*h_f)./(c_f.*rho_f.*A);
S=(mdot)./(rho_f.*A);
U=(1/dT)+R+(S./h);

end
for j=1:Cx

NTg(1,j)=(1/(F(1,j)*dT))*Tg(1,j)+(B(1,j)/F(1,j))*Tam+(C(1,j)/F(1,j))*Tab(1,j)+
(D(1,j)/F(1,j))*Ta(1,j)+(E/F(1,j))*G_rk;
end
for j=1:Cx
    NTa(1,j)=(1/(H(1,j)*dT))*Ta(1,j)+(G(1,j)/H(1,j))*(NTg(1,j)+Tab(1,j));
end
for j=1:Cx

NTab(1,j)=(1/(Q(1,j)*dT))*Tab(1,j)+(K/Q(1,j))*G_rk+(L(1,j)/Q(1,j))*NTg(1,j)+(
M(1,j)/Q(1,j))*NTa(1,j)+(O(1,j)/Q(1,j))*Tf(1,j);
end
NTf(1,1)=Fluid_BC(counter)+273.15;
for j=2:Cx

NTf(1,j)=(1/(U(1,j)*dT))*Tf(1,j)+(R(1,j)/U(1,j))*NTab(1,j)+(S/(U(1,j)*h))*NTf(
1,j-1);
end
if t==cc*(Total_Iterations/120)
    result(cc,1)=NTf(1,end);
    cc=cc+1;
end

%Temperature matrices amendement
Tg=NTg;
Ta=NTa;
Tab=NTab;
Tf=NTf

end
result(120,1)=NTf(1,end);
xlswrite('Data_Temp.xlsx',result-273.15,'Temp_In','C2:C121');
dT
total_time_s=t*dT
total_time_m=(t*dT)/60
total_time_h=(t*dT)/3600

```

