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Computational Fluid Dynamics Modelling and Experimental Verification to Enhance Productivity of Distillate Water in Three Dimensional Single Slope Basin Type Passive Solar Still

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Institute of Engineering for acceptance, a thesis entitled "**Computational Fluid Dynamics Modelling and Experimental Verification to Enhance Productivity of Distillate Water in Three Dimensional Single Slope Basin Type Passive Type Solar Still**" submitted by Shah Nawaz Ansari in partial fulfillment of the requirements for the degree of Masters of Science in Renewable Energy Engineering.

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ABSTRACT

The research entitled "Computational Fluid Dynamics Modelling and Experimental Verificationto Enhance Productivity of Distillate Water in Three Dimensional Single Slope Basin Type Passive Solar Still" highlights the problem of need for clean water in the areas where there is unavailability of electricity to afford costly means of water desalination techniques. Solar still could be better option for desalination of water from renewable source since it is cheap, simple, pollution free and easy to fabricate. The major challenge of the solar still is its low productivity. The main objective of this research is to identify various parameters for enhancing the productivity of solar still by the application of computational fluid dynamics and verify obtained result with the experimental results.

This research employs use of the ANSYS Workbench software for modelling and simulation of single slope solar still. Furthermore, experimental setup has been fabricated from locally available material. The experiment was performed at Balaju School of Engineering and Technology, Kathmandu. The experiment was performed initially without the use of internal reflectors and without any kind of black paint on the basin. Afterward the experiment was performed by using internal reflectors and black basin. The result of both the condition was compared and it was seen that the use of internal reflector and applying black paint increased the productivity by 45%.Similarly, computational fluid dynamic modelling was performed on ANSYS and the result was in good agreement with experimental result. The experimental productivity was 1.2 kg/m^2/day whereas the simulation productivity was 1.6 kg/m^2/day. Similarly, the effect of different volume of water was simulated by keeping the volume of input water to 20 litres and 10 litres. The comparison showed that the productivity was enhanced by 7% when 10 litres of water was feed initially. Based on the result obtained from the research, necessary conclusions and recommendation is given.

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LIST OF SYMBOLS

Symbols		Descriptions	Units
A_w	:	Area of water basin of solar still	(m^2)
c_{pw}	:	Specific heat of water	(kJ/kgK)
h_{Cwgi}	:	Heat transfer coefficient due to conduction from inner glass surface to outer glass surface	(W/m^2K)
h_{Ewgi}	:	Heat transfer coefficient due to evaporation from water and inner surface to the glass cover	(W/m^2K)
h_{Rwgi}	:	Heat transfer coefficient due to radiation from water to inner surface of glass cover	(W/m^2K)
h_w	:	Heat transfer coefficient due to convection between basin liner and water mass	(W/m^2K)
$I(t)$	:	Solar radiation intensity	(W/m^2)
L_{ev}	:	Latent heat of evaporation	(kJ/kg)
m_{ew}	:	Hourly productivity from solar still	(kg/m^2) or (l/ m^2)
M_{ew}	:	Daily yield from solar still (daily productivity)	(kg/m^2) or (l/ m^2)
P_g	:	Partial pressure of vapour	(Pa)
P_w	:	Pressure of water	(Pa)
Q_{Cwgi}	:	Heat transfer rate within solar still due to convection from water to surface of glass cover	(W/m^2K)
Q_{Ewgi}	:	Heat transfer rate within solar still due to evaporation from water to surface of glass cover	(W/m^2K)
Q_{Twgi}	:	Total heat transfer rate from water to surface of glass cover	(W/m^2K)
Q_{Rwgi}	:	Heat transfer rate due to radiation within solar still from water to inner surface of glass cover	(W/m^2K)
Q_w	:	Heat transfer rate between basin liner to water mass	(W/m^2K)
T_a	:	Ambient Temperature	(ºC)
T_b	:	Temperature of basin (ºC)	(ºC)
T_g	:	Temperature of glass cover (ºC)	(ºC)
v_w	:	Wind velocity	(m/s)
d	:	Depth of water	(m)
ε_w	:	Emissivity of water	
ε_g	:	Emissivity of glass cover	

LIST OF ABBREVIATIONS

CFD	:	Computational Fluid Dynamics
FEM	:	Finite Element Method
FVM	:	Finite Volume Method
FDM	:	Finite Difference Method
SS	:	Solar Still
SSSS	:	Single Slope Solar Still
PCM	:	Phase Change Material
VOF	:	Volume of Fraction
WHO	:	World Health Organisation

CHAPTER ONE: INTRODUCTION

1.1 Background

Water is known to be the most essential and basic need for human beings, along with food and air required for sustaining life on Earth. Water and the life of human beings are immensely interrelated to each other. Water is considered to be playing as one of the pivot roles in the development and welfare of any civilisation. Each and every field associated with human life are directly or indirectly dependent on clean drinking water. Due to this reason, the availability of pure and clean drinking water is considered one of the major global issue as per the current scenario of the world.

Water is the most unique and invaluable gift to living beings from nature that is abundantly present on Earth. More than seventy percent of the surface of the Earth is covered by water, but the majority of this percentage is not suitable for direct human usage. Out of total available water on Earth, ninety-seven percent is in the ocean in the form of saline water, approximately two percent of water is covered by ice in polar regions, and only remaining one percent can be used to fulfil the need of plants, animals and human life that is available in the forms of lakes, rivers and underground water. Though this small share of accessible clean water is sufficient to lead human life and other usage, the rapid population growth and fast industrialisation is narrowing the access to potable water.

Desalination of water is an effective technique to enhance the supply of clean potable water as per the increasing demand. Water desalination is a traditional and old method for converting brackish or saline water into potable clean water. It is one of the sustainable solution for providing clean drinking water in most of the countries. Desalination of water provides access to clean potable water which can result in many socio-economic benefits such as better health and hygiene, improvement in quality of life, enhanced living standards, improvement in social interactions and so on.

More than one billion people of the world are facing the challenge of unavailability of pure drinking water in which majority of the people are from rural areas as per the estimation of the World Health Organization. Water purification techniques such as electro dialysis, multi-stage evaporation and reverse osmosis are power-intensive processes, making it not feasible for remote areas. Such difficulties could be easily solved by the integration of desalination process with renewable energy sources. Solar energy is present in abundance quantity in remote areas due to which opportunity of using solar energy sources for desalination of water can be utilised. Application of solar energy for the desalination of water is considered as one of the most promising and economical method. The main reason for using solar desalination process is that solar energy is present in abundance and there is no challenge of spacing in the remote areas (Pakdel, Hedayatizadeh, Tabatabaei, & Niknia, 2017).

Solar still is a device which is used for distillation or desalination of water by the application of solar energy actively or passively as a result of which potable and clean water is obtained for consumption of human beings. The working of solar still is based on the principle of evaporation and condensation (Hanson, et al., 2004). Solar still has emerged out as alternative method for fulfilling potable water demand in the remote areas as commercial distillation process in remote areas are not feasible due to unavailability of electricity and expensive fossil fuels. Since solar energy is immense, abundance, clean and pollution free, the device is very economical and feasible to use (Solanki, Bhumit, & Patel, 2017). Despite of various advantages, solar still suffers from the issue that the production of distillate water or desalinated water is very low. The major challenge with solar still is to enhance the productivity without compromising its low cost.

1.2 Problem statement

Human requirement for water is increasing rapidly with growing population and industrialization. There is abundant water available on the earth, but only 2.5 percent of the available water is fresh water. Apart from that, presence of impure water due to pollution of water and industrial wastage mixing with water is increasing. Thus, the need for clean water is increasing. There are various desalination techniques, such as multi-stage distillation and reverse osmosis (RO) processes for purifying water in order to meet the current demand. These methods are highly helpful, but their setup, installation, operation, maintenance and repair cost is costly.

Thus, their high cost makes these methods unsuitable for use in rural areas. Solar distillation could be the possible solution to this problem. Although solar still has the advantage of being economical, simple design, environment friendly and use of abundant solar energy, it has one disadvantage of being less productive, i.e. the distillate yield is very low. Integration of solar still with other devices like collectors, solar ponds, concentrators etc., could be used to increase productivity, but these integrations will increase the cost of solar still significantly. The problem of low distillate yield, to a great extent, could be improved by knowing various performance parameter of solar still and optimizing it. To optimize the performance parameters, modelling of solar still using CFD analysis can be done

1.3 Objectives

Main Objective

The main objective of this thesis is:

- To investigate various key parameters of three dimensional single slope basin type passive solar still both by performing modelling and simulation using computational fluid dynamicsas well as by performing experiments in order to enhance the productivity of distillate water.

Specific Objectives

The specific objectives of the present research are as follows:

- To design, fabricate and perform experiment on single slope solar still
- To perform modelling and simulation of single slope solar still and verify it with experimental results
- To identify the parameters affecting the productivity of single slope solar still.

1.4 Rationale

The demand for economical freshwater production has resulted in the research and development of various water desalination techniques. These water desalination techniques must be economical, simple to build, pollution free and efficient in energy to be feasible for remote areas. The single slope solar still meets all these requirements for becoming a sustainable method of water desalination. Solar still uses solar energy, which is renewable energy, for its operation, due to which no electricity is required for its operation. It is also environment friendly and its design is very simple such that anyone with minimum skills can also design it. Furthermore, solar still could be made from locally available material. The major cost is only the fabrication cost.

One of the major issues that solar still faces is its lower production of output distillate or desalinated water. It is a big challenge to enhance the productivity of the device without increasing the cost of it. Solar stills could help in solving the freshwater demand by becoming an alternative source for freshwater production. Enhancing the productivity of distillate water without compromising with its low cost could be overcome by optimizing various parameters that affect the performance of solar still. This can be achieved by proper modelling and determination of various parameters for the efficient design of solar still. CFD modelling of solar still can help in enhancing the productivity of the device as CFD tools have the ability to model condensation and evaporation phenomena by altering various performance parameters

1.5 Assumptions

- There will be no any kind of dust on the surface of the condensing glass during the experiment.
- The radiation falling on the front surface of the solar still will be uniformly distributed.
- There will be no any kind of leakage during the experiment.

1.6 Limitations

- The material for the fabrication was based on the availability and the cost of it.
- Fabrication was done from locally available material. There was escaping of water vapour and some leakage along the outlet of distillate channel of the solar still.

- The experiment was performed in the month of August at Kathmandu. This month observed cloudy weather and rainfall throughout the month due to which the solar radiation level appeared to be low. Due to this reason, the productivity might be affected during experiment.
- Due to time constraints and weather constraints, only few experiment was being able to be conducted. The result would have better if large number of experiments would have conducted.

1.7 Outline of the Report

This report has been divided into four chapters. A brief outline of each chapter is given below.

- **Chapter 1:** It gives background of the problem associated with clean water. It discusses about the problem statement, rationale and objective of the report.
- **Chapter 2:** This chapter gives summary of research work done in area of solar distillation and solar still in different books, journals, etc.
- **Chapter 3:** This chapter elaborates about the research methodology involved in performing the research. It includes everything from experimental setup, instrumentation method, data collection method and detailing about the research to be performed. It also elaborates about fabrication method, location, components along with the computational fluid dynamics method and simulation.
- **Chapter 4:** This chapter discusses the results obtained from the experiment and simulation. The simulation result was verified with the experimental results.
- **Chapter 5:** This chapter gives the overall conclusion of the research. Based on the research recommendations and future scope for the research have been also mentioned in this chapter.

CHAPTER TWO: LITERATURE REVIEW

2.1 Solar Still

It is a device based on the principle of distillation of saline water by the application of solar radiation. Installation of commercial water distillation methods in remote areas is not feasible due to the unavailability of fossil fuel or electric power. Thus, solar still can be used as one of the effective methods of distillation of water since solar energy is abundant, unlimited and free from pollution (Haddad, Chaker, & Rahmani, 2017)The working of solar still is based on the principle of evaporation and condensation of salt water. Initially, solar energy is used in order to increase the temperature of liquid water, producing vapour from evaporation. Finally, the vapour is allowed to condensate that is collected as potable water (Tiwari & Tiwari, 2006).

Application of solar energy for desalination of water is an ancient and most economical methods for providing potable water in places where there is an unavailability of electricity. The device for performing distillation of water using solar energy is usually known as solar energy. The major advantage of solar still is its low cost, low maintenance and ease in construction, etc. The major limitation of simple solar still is its low efficiency and low productivity of potable water (Tiwari & Tiwari, 2006).

According to the experimental and theoretical studies by Al-Karaghouli and Alnaser on single slope solar stills, the performance of both single slope as well as double slope solar, still was evaluated. Two types of experiments were performed by them, with insulated sides and without insulated sides. It was observed that side insulation has a considerable effect on the productivity of solar still (Al-Karaghouli & Alnaser, 2004).

Nijmeh et al. (2005) studied the consequences of using different types of absorbing materials on the distillate yield of solar still. Various materials were used to enhance the absorptivity of saline water for solar radiation, such as charcoals, salts (potassium permanganate and potassium dichromate) and violet dye. The result was quite good, i.e. enhancement of efficiency by 26%. Similarly, various other researchers and scholars also studied the role of water depth on the heat and mass transfer phenomena of water. It was also observed that daily production of solid still can be enhanced dramatically by using different mediums such as sponge cubes. Furthermore, many other researchers developed and integrated various technologies and tools to trace and enhance the daily productivity of solar still (Nijmeh, Odeh, & Akash, 2005).

Hanson et al. (2004) stated that single slope basin type solar is still one of the most efficient methods for removing non-volatile water impurities. Some researchers also suggested solar still for the distillation of alcohol (Hanson, et al., 2004).

Madhlopa (2012) studied the effect of depth of water on the internal heat and mass transfer in basin-type double slope solar still. Galvanised iron sheet was used to fabricate the setup for the experiment. The cover was made from transparent glass with a thickness of 3 mm. Sealing was done to avoid vapour leakage to the surroundings. The study concluded that the productivity of the still is inversely proportional to the depth of water in the basin. That means the productivity of the solar still is increased when the depth of the water basin is increased in the basin (Madhlopa, 2017).

Qahtan A. et al. (2014) experimentally and numerically researched the effect of water film flowing over the transparent inclined glass. The research stated that it is appropriate to use glazed water film to improve thermal and decrease the cooling loads for glazed buildings (Qahtan, Rao, & Keumala, 2014).

Deshmukh and Thombre (2017) stated that the effect of various parameters such as operational, design and climatic parameters on the performance of the solar still based on different numerical and experimental studies. One major parameter examined was the solar radiation, a tilt angle of glass angle, depth of saline water and blackened material (Deshmukh & Thombre, 2017).

According to the finding of Balamurugan et al. (2017), various parameters such as the orientation of solar still, the inclination angle of the glass cover, the material of the cover plate, and the material of the basin plays a crucial role on the productivity of the solar still. Double slope stills are more suitable for lower latitudes as compared to single slope solar basin. Furthermore, a deep basin is preferable for places with higher intensity solar radiation, whereas a shallow basin is preferable for place with lower solar intensity. Black dye is considered as one of the effective medium for enhancing absorption, and rubber is considered a decent material for the basin (Balamurugan, Sundaram, Marimuthu, & Devaraj, 2017).

Zhou et al. (2019) stated that the productivity of solar still was increased by 51% by the introduction of basin liner and sprinklers in solar still. Furthermore, the study also showed that the increase in the depth of water resulted in a decrease in the productivity of solar still. It also concluded that there is a direct effect of wind velocity and ambient temperature on the productivity of the solar still (Zhou, Gong, Liu, & Shen, 2019).

The major identified parameter by Zhou et al. (2019) is shown is following chart.

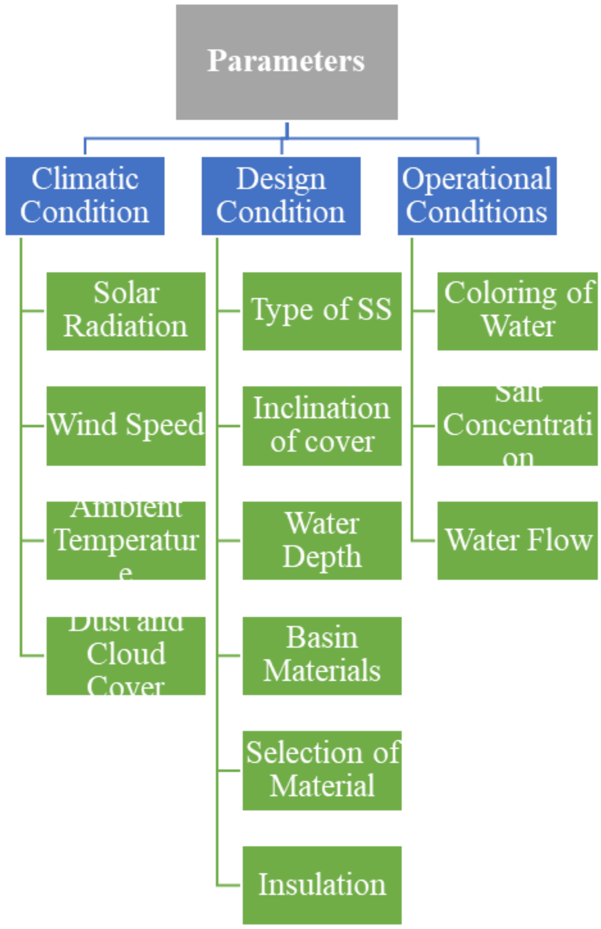


Figure 2.1: Parameters of SS affecting productiviy

The branch of fluid mechanics using different algorithms and numerical methods in order to solve and analyze qualitatively the problems associated with a fluid flow is known as Computational fluid dynamics (CFD). The computer is used for solving various governing equations associated with flow numerically. Use and application of CFD in expanding every single day over time in various areas such as aerodynamics, heat and mass transfer, vibration analysis, analysis of combustion in IC engines etc. Efforts for conducting experiments and consumption time for experiment is significantly reduced due to the use of CFD software packages. The outcome could be forecasted even before an experiment is conducted with the application of CFD software. Thus, CFD plays a crucial role in the field of research and development. Various problems such as heat and mass transfer phenomenon, fluid flow problems, emissions and combustions from IC engines and various other phenomena can be modelled with the help of a good CFD software package (Ansys Inc., 2011).

For modelling any problem in CFD, a virtual model is created capable of obtaining the experimental results. The virtual model is converted to a number of smaller cells or grids, after which governing equation is applied on every grid of the problem domain. Finally each equation is solved on each cell by the CFD solver. The result will provide detailed information on various variables associated with flow, such as flow parameters, temperature gradient, pressure gradient etc., on every individual cell. The major advantage of CFD modelling is the reduction of physical efforts and time consumption for experimentations (Ansys Inc., 2011).

2.2 Principle of Working of Solar Still

Solar still is an immovable insulated basin consisting of saline water covered by transparent glass material. Basin is usually constructed by GI sheet, and the top cover is made up of transparent material, i.e. glass or plastic. Glass cover is usually made inclined to the angle of latitude of a particular location. Solar still works on the principle same as the hydrological cycle of nature (Kabeel & Abdelgaied, 2016). Solar radiation falls upon the transparent glass cover and passes through it to the inner surface of the basin. The inner surface of the basin is made black to absorb more solar radiation, resulting in saline water getting heated and evaporation. Vapour starts to form, leaving behind the salts and heavier impurities.

The vapour formed reaches the glass cover and starts condensing. The condensed water gets fallen into the collecting channel due to the gravity action, and finally, the desalinated distilled water is taken out of the device for direct use (Alwan, Shcheklein, & Ali, 2019).

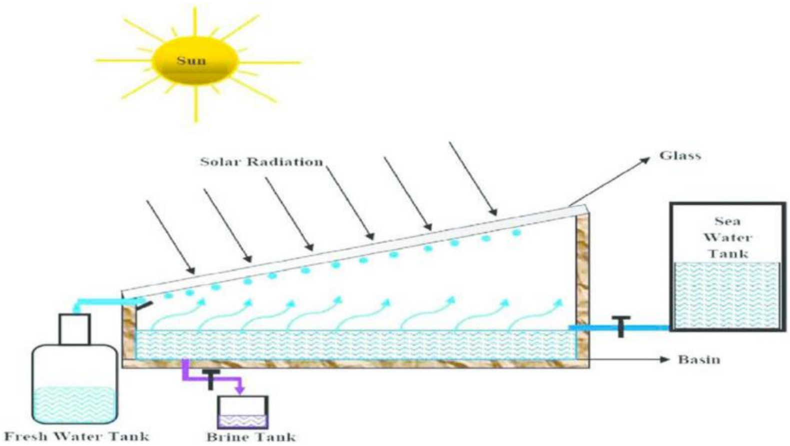


Figure 2.2: Schematic of Solar Still *Source: (Panchal et al., 2021)*

2.3 Importance of Computational Fluid Dynamics (CFD) in Solar Still

Despite having many advantages of being simple to construct, ease in maintenance, low cost and clean operation, solar still faces the challenge of being less productive in terms of producing distillate water. Many researchers have studied and focused on enhancing the productivity of solar still by using various means and modifications such as integrating solar still with collectors, using phase change materials, solar ponds or using concentrators. These methods resulted in enhanced productivity of distillate water, but all these modifications increased the cost drastically, losing the prominent unique feature of solar still. Thus, it is a challenging job to enhance productivity without compromising the beauty of being a cheap device.

Hitesh and Shah (2011) developed 3D modelling of multiphase solar still to perform simulation of evaporation and condensation phenomena. The FLUENT package was used for simulation and study associated with the velocity of the gas, volume fraction of liquid and roughness. Simulation results were compared with the experimental results for validation (Hitesh & Shah, 2011).

Badusha and Arjunan modelled solar still using CFD analysis to analyse the evaporation and condensation phenomenon occurring within the solar still. During the stud, solar still was modelled in quasi-steady state condition and was simulated using ANSYS CFX. After the simulation was done, the result related to the inside temperature, distillate output and heat transfer coefficient of solar still compared with the experimental results, which was in good agreement with minimum errors (Badush & Arjunan, 2011).

From the literature review, the major parameter responsible for the productivity of the water in solar still are dependent upon the design parameter as well as operational parameter. Very few works have been done on modelling and simulation of the solar still. The research gap identified is the modelling of physical model to variable model and simulate it according to the different physical and operational properties. If proper modelling and simulation will be done, the parameters responsible could be identified and further improvement will result in the enhancement of the productivity of the solar still.

CHAPTER THREE: RESEARCH METHODOLOGY

In this chapter, the methodology that is applied for the work from the start of the project till the completion is described. The theoretical background of heat and mass transfer inside a single slope solar still and the computational details are also elaborated. A brief discussion of numerical methods available for solving a problem numerically is as well presented in this chapter. The chapter also gives information about the experimental setups, analysis tools, materials used and CAD geometry.

3.1 Theoretical Framework

The research methodology will involve a different level for the completion of the research. The methodology consists of prior investigation to identify the underlying mechanism and the significant variable that determine the productivity of solar still. It is vital to theoretically determine from various studies and literature reviews the existing relationships and principles associated with single slope solar still. After that, going parallel with the literature review was developing a conceptual or modified design for the functionality and performance enhancement. Following that, empirical testing needs to be performed to identify the key parameters and their relationships. After that, the development of the theoretical model of heat and mass transfer along with the evaporation and condensation phenomenon of single slope solar still mentioning the effect of significant variables on the system's productivity was developed. This model was based on fundamental principles of engineering. The plan of action of the research has been divided into six levels which are explained below. Each level consists of functional element or decisions which needs to be addressed for the progress of the research. The various levels are:

- **L1:** Prior Study and Research
- **L2:** Confirmation of Conceptual Design (If Any)
- **L3:** Empirical Testing
- **L4:** CFD Modeling and Simulation
- **L5:** Validation of Model
- **L6:** Thesis Writing and Presentation

3.1.1. L1: Prior Study & Research

The first level of the research involved formulation of fundamental model on the basis of literature review. Formulation of fundamental model was necessary to get information about the experimental design, instrument required for experiments and modelling. This level is shown in Figure 3.1along with explanation.

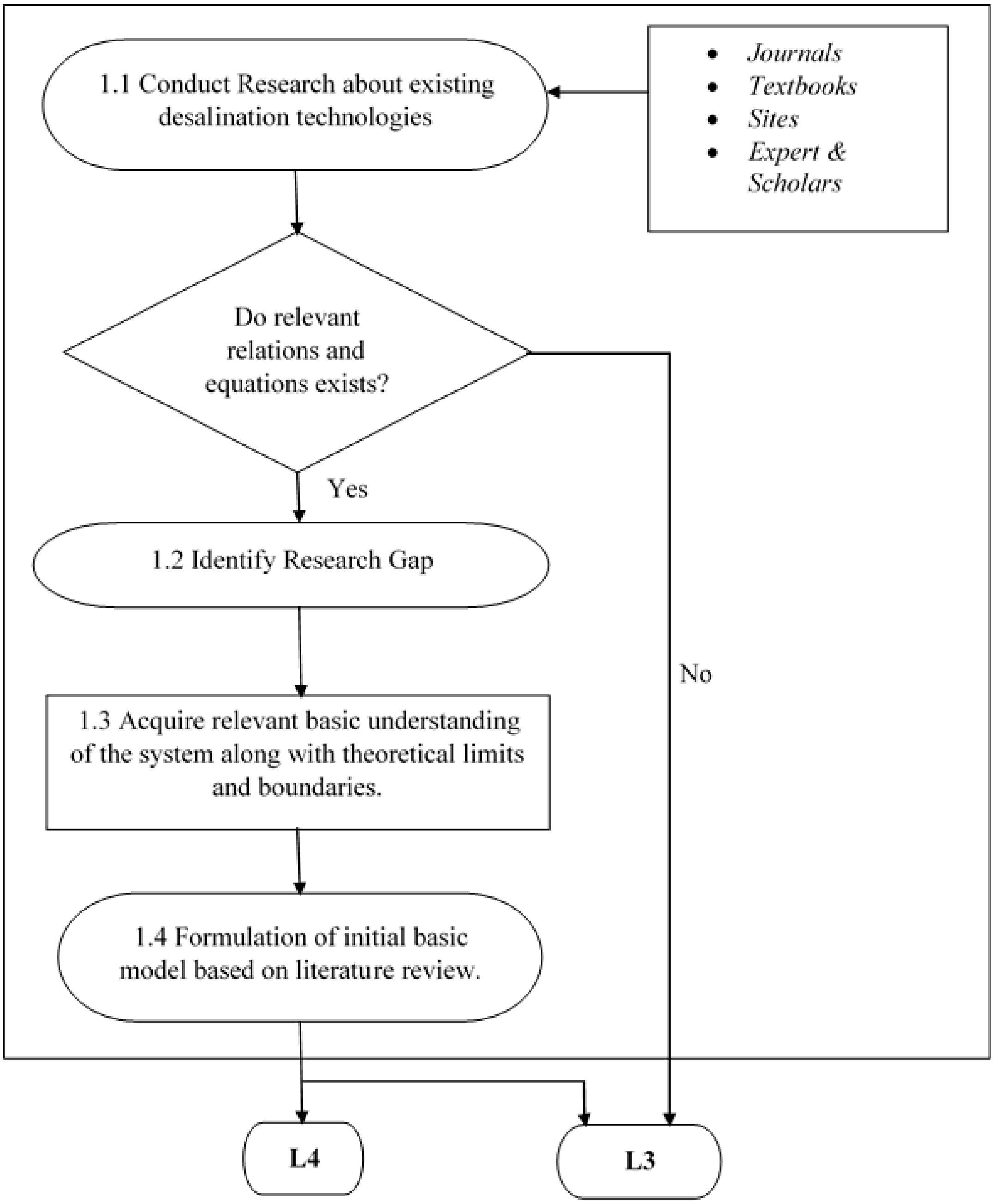


Figure 3.1: Flowchart of L1

L1.1: Various literature was studied and examined on various passive solar desalination method. This study helped in determining the major design elements for further derivation of relationships and helped in knowing which variable and aspect of the current design requires further study through experimental testing and simulation. The literature also helped in indentifying different alternatives and methods currently available based on which depth knowledge of solar still was obtained.

L1.2: The existence of governing equation and relation among the key elements was found on the basis of which research gap was identified. If no relation was found to be existing then the research went straight to experimental level (L3) to develop relationships. Various relations and equations from the literature were utilized in order to collect data so that it develops the insights of previous work.

If particular design problem has not been addressed earlier, gaps were identified. The research further goes on filling the research gap known to be existing.

L1.3: The outcome of this level was the evaluation of collective knowledge in solar desalination methods. The study helped in confirming the existing limits and boundary condition to provide direction for empirical testing.

L1.4: The outcome of this level resulted in the initial representation of heat and mass transfer model of solar still. The key elements which was identified from the literature review was combined by the usage of fundamental principles. The result and outcome of this level helped in initiating framework for subsequent model in L4 and helped to gain information about instrumentation and testing.

3.1.2. L2: Confirmation of Conceptual Design (If Any)

The second level of the research was to ensure the commercial relevancy of the research. This level is shown in Figure 3.2 and explained further.

L2.1: The functional element of the design was identified and mechanism were approved. This level consist of meeting and discussion with supervisor related to the functionality in case of design modification.

L2.2: The major factors which needs to be considered for the functionality of design include unit size, suitability, construction, maintenance and ease integration with other unit. The end result of this level was clarification and evaluation about the modified concept and design.

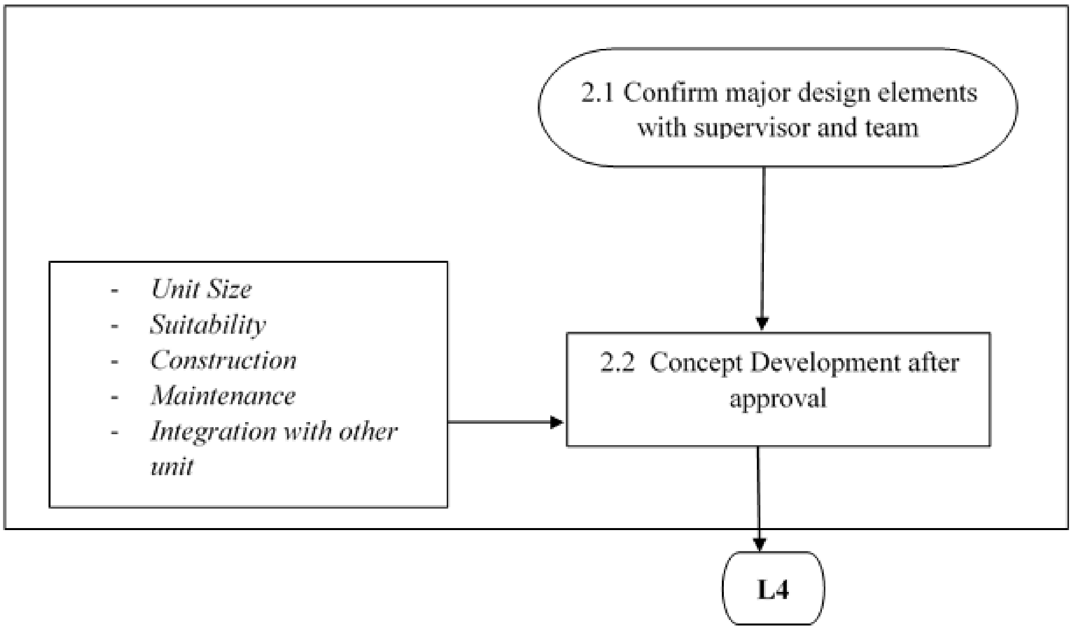


Figure 3.2: Flowchart of L2

3.1.3. L3: ExperimentalTesting

The third level of the research was to develop and build experimental setup, specify necessary instrumentation for collection of data and obtain required data understand the behavioral pattern of various parameters tested. This level is shown in Figure 3.3 and explained in following.

L3.1: The first level of research was focusing on obtaining relationships among various crucial operational, design and climatic parameters. The test was conducted in order to understand the effect of various parameters. Experimental set up was developed. Solar still was fabricated to conduct the test.

L3.2: The major effect of the identified parameters was obtained from the initial testing. Most critical parameter was identified which has great influence on evaporation and condensation rates inside the solar still.

L3.3-3.4: Once the most critical parameter affecting the productivity of solar still was identified, sufficient data related to it was collected through test that will be used in building the theoretical system model in Level 4.

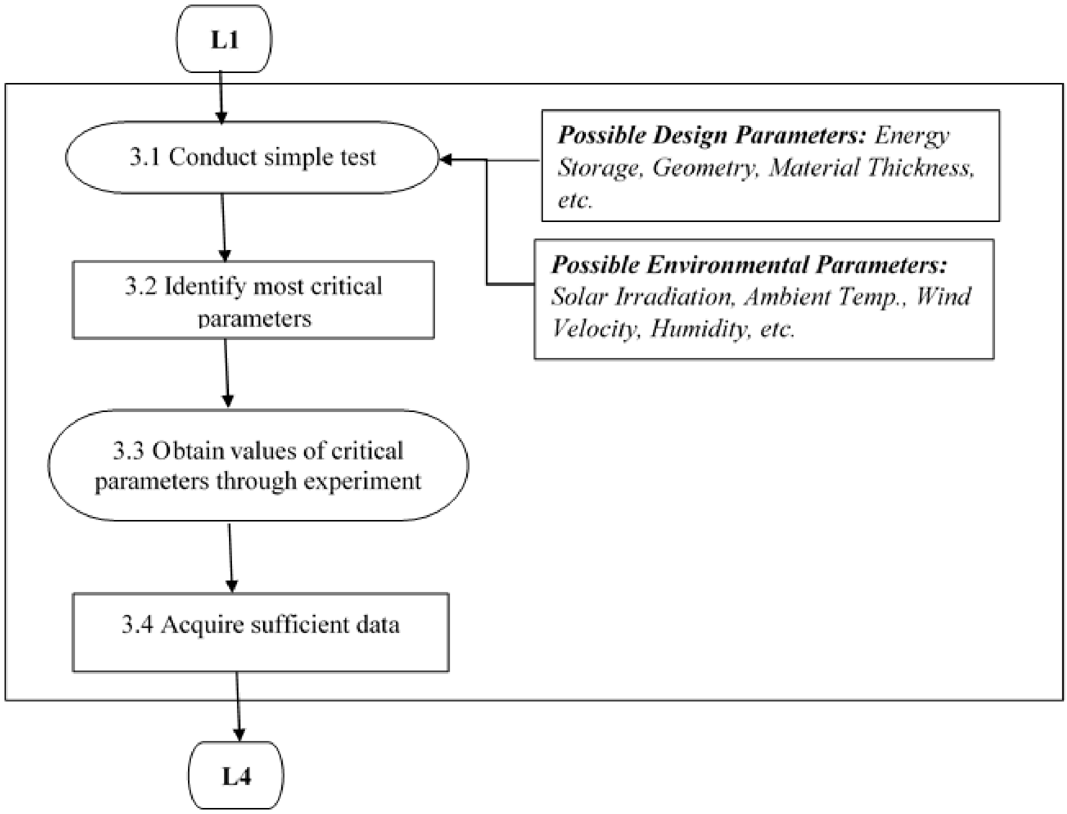


Figure 3.3: Flowchart of L3

3.1.4. L4: Development and Optimisation of Simulation Model

The fourth level of research involved integration of theoretical and empirical knowledge into developing a simulation model that will depict the behavior of various operational, design and climatic parameters. The flowchart is shown in Figure 3.4.

L4.1: First step of CFD analysis is to create geometric model of the problem domain as per specification. Geometric model can be drawn from the design tool that is design modeler integrated in ANSYS workbench. Design modeler provides different commands and tools for creating two dimensional and three dimensional drawings of related problem domain. Geometric model of solar still was created with the help of design modeler in ANSYS workbench.

L4.2: After creation of geometric model, meshing is done. During meshing, the problem domain is divided into large number of tiny cells on which various equation is applied by the software.

L4.3-4.8: After generation of mesh, boundary condition and various parameters and equations are defined. The initial condition, final conditions, governing equations etc. help in computing the solution of problem domain. It the solution obtained is in agreement with experimental results then the research is successful. In case the simulation result is not in agreement with experimental result then the parameters are revised and simulation is performed again.

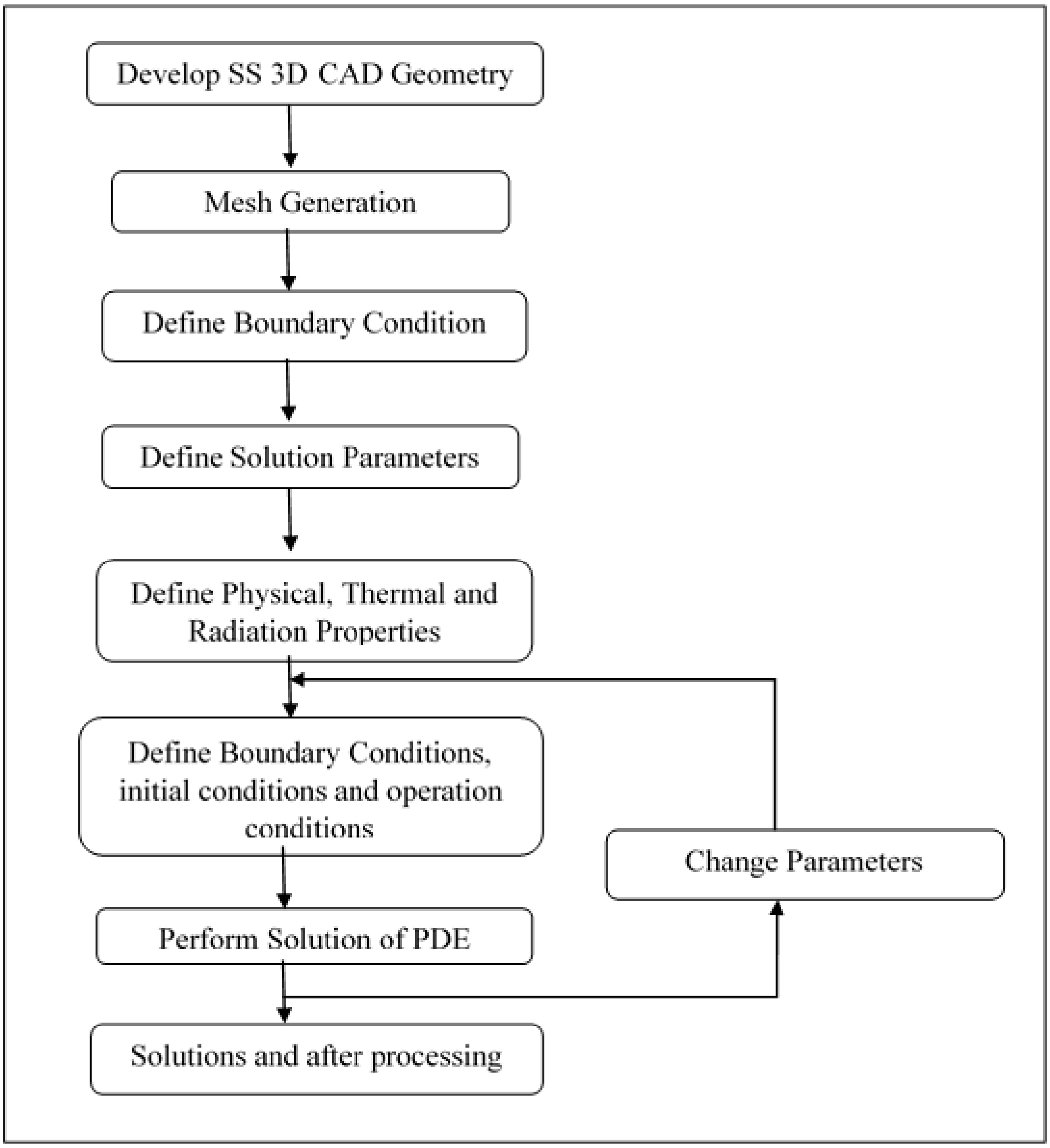


Figure 3.4: Flowchart of L4

3.1.5. L5: Verification of Model

The result obtained from the solutions of the CFD analysis will be compared with the experimental results. After that proper conclusion will be drawn along with the recommendations for future improvements of the research.

3.1.6. L6: Report Writing and Presentation

Once the result have been achieved, everything associated with the research from idea generation to the future scope will me mentioned in the report and final presentation will be given on the date prescribed by the concerned authority.

3.1.7. Integrated Research Plan Schematic

The overall plan for the completion of this research, integrating above individual levels is shown inFigure 3.5.

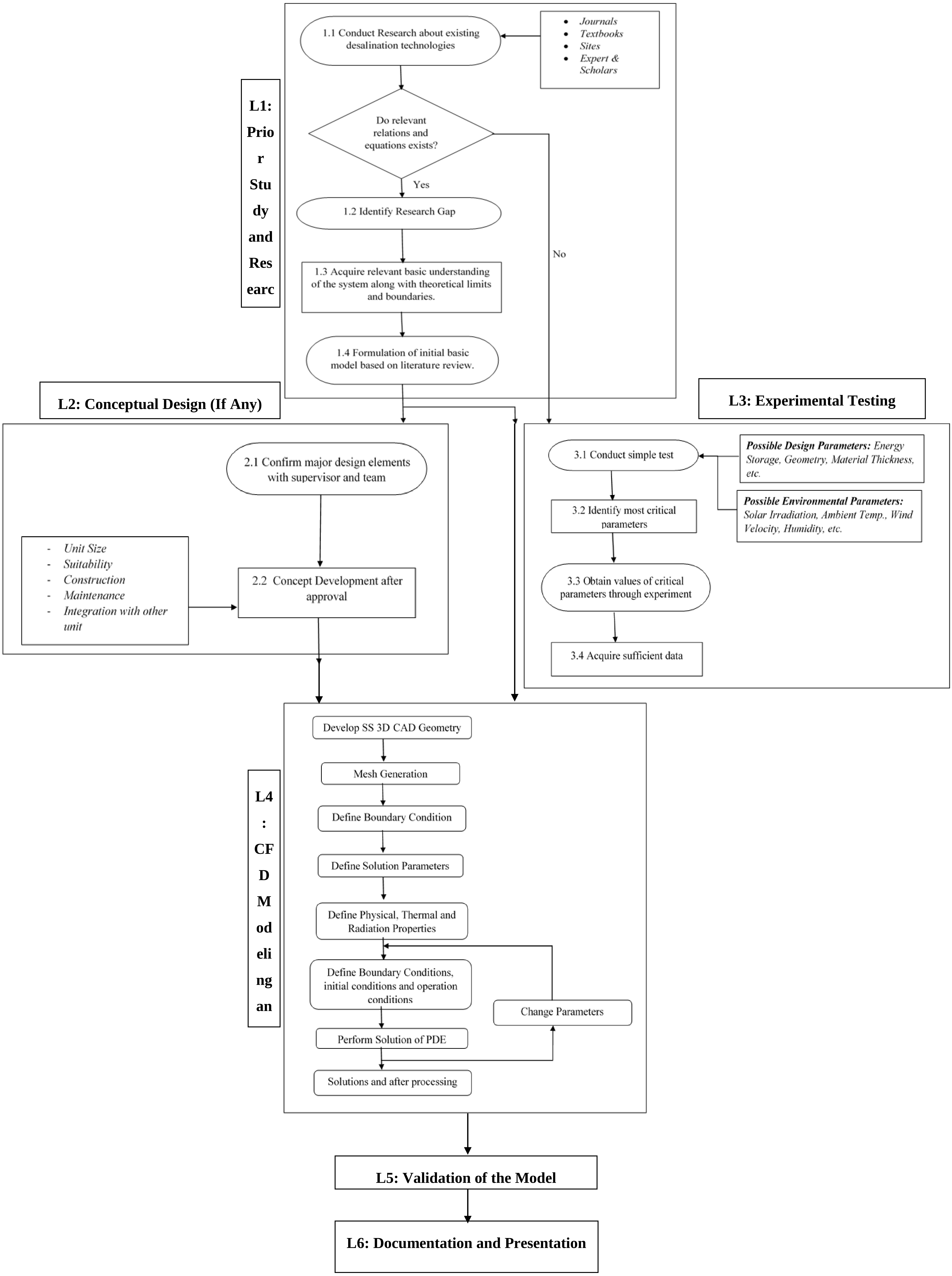


Figure 3.5: Integrated flowchart of research plan

3.2 Numerical Model

Mathematical model can be considered as an alternative and efficient technique for investigating and developing effective designs of solar stills under different critical operational parameters. The present model takes the reference of equations developed by Dunkle. Various conditions were assumed for the simplicity of the analysis (Dunkle, 1961)

- There is no vapor leakage in the solar still
- The heat capacity of water in basin and insulating material used in solar still is considered to be negligible.
- The physical properties of water is considered to remain constant with different temperatures.

Figure 3.6portrays different types of processes causing heat transfer inside the solar still. Solar still is divided into various parts such as glass, basin, basin water heat transfer process for the ease in evaluation of heat transfer distribution and temperature rates inside solar still (El-Samadony, El-Maghlany, & Kabeel, 2016).

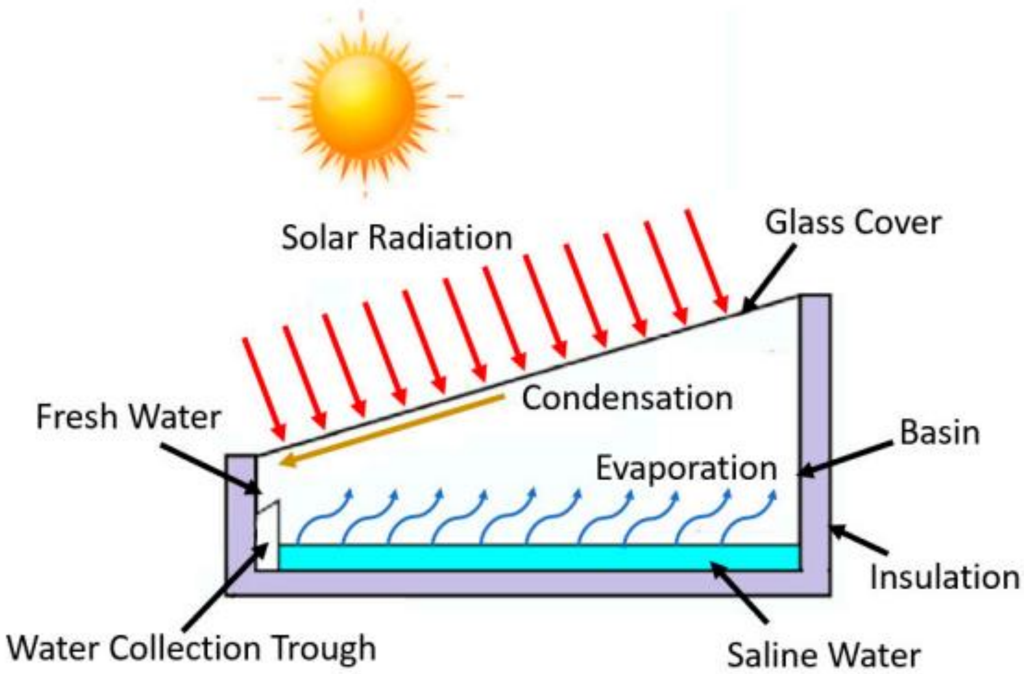


Figure 3.6: Various Heat Transfer Process in SS

Source: https://pdfs.semanticscholar.org/cd0d/b843a3ce75a822fd87c6267a5511c37df4fd.pdf

Srivastava, 2017).

$$P_w = \exp\left(25.317 - \frac{5144}{T_{wi} + 273}\right) \quad (1)$$

$$P_g = \exp\left(25.317 - \frac{5144}{T_{gi} + 273}\right) \quad (2)$$

Temperature difference between the water and the internal surface of the glass is the main reason for natural convection. Rate of convective heat transfer (Q_{Cwgi}) and heat transfer coefficient (h_{Cwgi}) between water and the inner surface of the glass is expressed as following.

$$Q_{Cwgi} = h_{Cwgi} \times (T_w - T_{gi}) \quad (3)$$

$$h_{Cwgi} = \left[(T_w - T_{gi}) + \frac{(P_w - P_g)(T_w + 273)}{268900 - P_w}\right]^{1/3} \quad (4)$$

The generation of evaporation heat transfer takes place when the vapour pressure is less than the saturation pressure of the liquid inside the solar still. It occurs between the mass of water and the inner surface of the glass of solar still.

$$Q_{Ewgi} = h_{Ewgi} \times (T_w - T_{gi}) \quad (5)$$

$$h_{Ewgi} = 16.28 \times 10^{-3} \times h_{Cwgi}\left(\frac{(P_w - P_g)}{(T_w + T_{gi})}\right) \quad (6)$$

The production of radiation heat transfer takes place due to the emission of internal energy among two bodies having different temperatures. The two bodies in this case is mass of water and the surface of glass of solar still. The expression for radiation heat transfer and heat transfer coefficient is expressed as following.

$$Q_{Rwgi} = h_{Rwgi} \times (T_w - T_{gi}) \quad (7)$$

$$h_{Rwgi} = \varepsilon_{eff}\sigma\left[\frac{(T_w + 273)^4 - (T_g + 273)^4}{(T_w - T_{gi})}\right] \quad (8)$$

Where,

$$\sigma = the\ Stefan\ Boltzmann's\ constant = 5.67 \times 10^{-8} \frac{W}{m^2K^4}$$

ε_{eff} = Effective emissivity between water and glass

It depends on the emissivity of water (ε_w) and emissivity of glass (ε_g) and is given by the following equation:

$$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)^{-1} \quad (9)$$

The total internal heat transfer rate (Q_{Twgi}) and the total internal heat transfer coefficient (h_{Twgi}) can be expressed as the summation of convection, evaporation and radiation rates which are expressed as follows.

$$Q_{Twgi} = Q_{Cwgi} + Q_{Ewgi} + Q_{Rwgi} \quad (10)$$

$$h_{Twgi} = h_{Cwgi} + h_{Ewgi} + h_{Rwgi} \quad (11)$$

3.2.2. Temperatures and Productivity

The hourly productivity of the solar still can be calculated as follows.

$$m_w = \frac{Q_{Ewgi}}{L_{ev}} \quad (12)$$

From equation (5),

$$m_w = \frac{h_{Ewgi} \times (T_w - T_{gi})}{L_{ev}} \quad (13)$$

The daily productivity of the solar still can be then obtained as follows.

$$M_w = \sum_{i=1}^{24} m_w \quad (14)$$

3.3 Experimental Setup and Modelling

The test rig was fabricated as per the size and dimensions taken in 3D design in SpaceClaim. The fabrication was performed at Mechanical workshop of Balaju School of Engineering and Technology, Balaju, Kathmandu.

The dimension for solar still is calculated as follow:

From simple trigonometry,

$$H = Y + S$$

$$H = Y + L tan\beta$$

Transparent Cover:

$$cos\beta = \frac{L}{Z}$$

$$Z = \frac{L}{cos\beta}$$

Area of Basin:

$$A = L \times B$$

Figure 3.7:Solar Still Calculation

Figure 3.8shows different components of solar still. The major components of

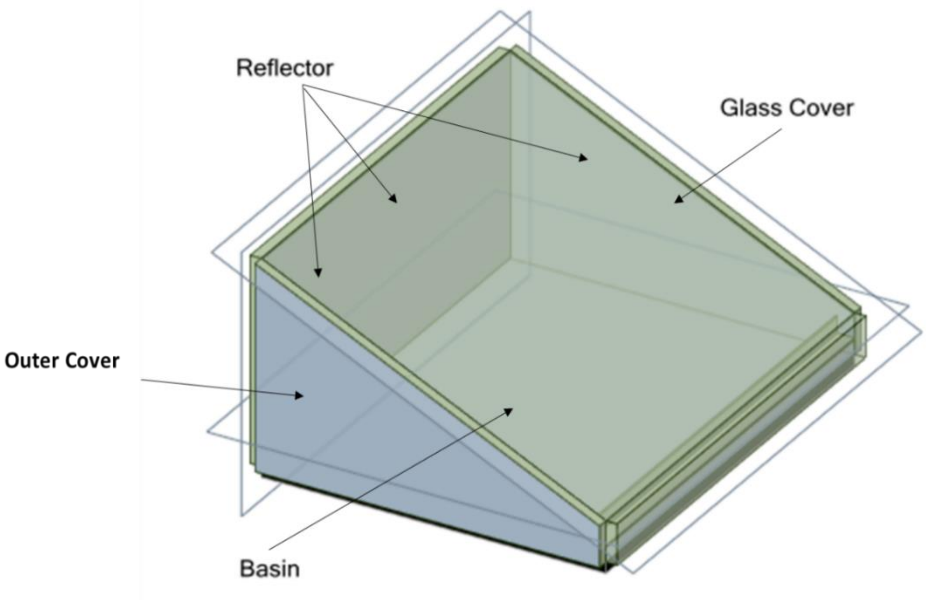


Figure 3.8: Solar Still Major Components (Modeled from SpaceClaim)

solar stills to be fabricated are:

- Basin: Basin is fabricated by the used of GI sheet. Base is painted black to absorb the incident solar radiation.
- Glass Cover: Glass cover of solar still is required after basin. It will allow transmission of maximum solar radiation in order to increase the temperature of saline water in basin.
- Distilled water collector: Water collector is also fabricated by GI Sheet. Distillate water channel is made inclined so that the water get collected to the collection beaker due to the action of gravity.
- Internal Reflectors: Aluminium foil isused as internal reflectors. Three cut of aluminium foils was placed on three side walls. No internal reflectors isused on remaining one side wall because of not falling of radiation. The main purpose of these reflectors is to reflect the solar radiation and prevent loss.
- Input water: PVC pipe is used for filling the solar still with water on the rear side of solar still.

The major component for solar still along with their criteria for selection is shown in the table below:

Table 3.1: Various Component Material and Properties

S.No.	Component	Material	Properties
1.	Glazing Surface (Transparent Surface)	Glass	- Low water absorptance - High thermal conductivity - Low iron content - Can withstand the effect of weather, wind, sunshine, dust etc.

2	Basin (Absorber)	GI Sheet	- High radiation absorptivity - Stable to corrosion - High thermal conductivity - Low cost
3	Solar Reflector	Aluminium foil	- Minimum corrosion problem - High thermal conductivity - High reflectivity - Cheaper and readily available
4	Cover (Casing)	Plywood	- Has uniform strength - Durable - Stronger, light weight - Good insulator
5	Insulation	Glass Wool	- Very Good insulator
6	Sealant	Araldite	- Withstand high temperature - Resistant to organic liquids - Joint bounded with it are difficult to break - Poor adhesive strength - Soften under high temperature - Cheap and readily available
7	Drain Pipe	PVC	- Stable to Corrosion - Not poisonous to water - Cheap and readily available
8	Collection Trough	Stainless Steel	- Stable to corrosion - Not poisonous to water

3.4 Construction of Solar Still

SS is a type of insulated box made by metal and wood which is covered by inclined transparent glazing material. A detail of the dimensions of the solar still is shown in figure. The present fabrication of solar still consist of a rectangular basin which is made up of GI sheet. The basin area is taken as 0.8 m X 1.0 m. The double walled body is constructed and a thick layer of glass wool is sandwiched between the inner GI sheet wall and out plywood wall in order to insulate the basin.

During the first experiment GI sheet was not painted black and internal reflector was not used. Later, The inner basin area which is responsible for absorbing heat is painted black to increase the absorptivity. Furthermore, Mirrors or aluminium is placed on the inner side walls of the basin for proper reflection of solar radiation towards the basin surface.Figure 3.9shows the dimensions of the solar still for the research purpose which is made by SpaceClaim Module in ANSYS.

A 5 mm thick transparent glass cover is used for glazing material which is placed over the solar still. The glass cover is inclined at angle of between $25^0$to 30^0 on the basis of literature review. In the current research the glass was kept at an inclination angle of approximately 27 degrees which is the latitude angle of Kathmandu.

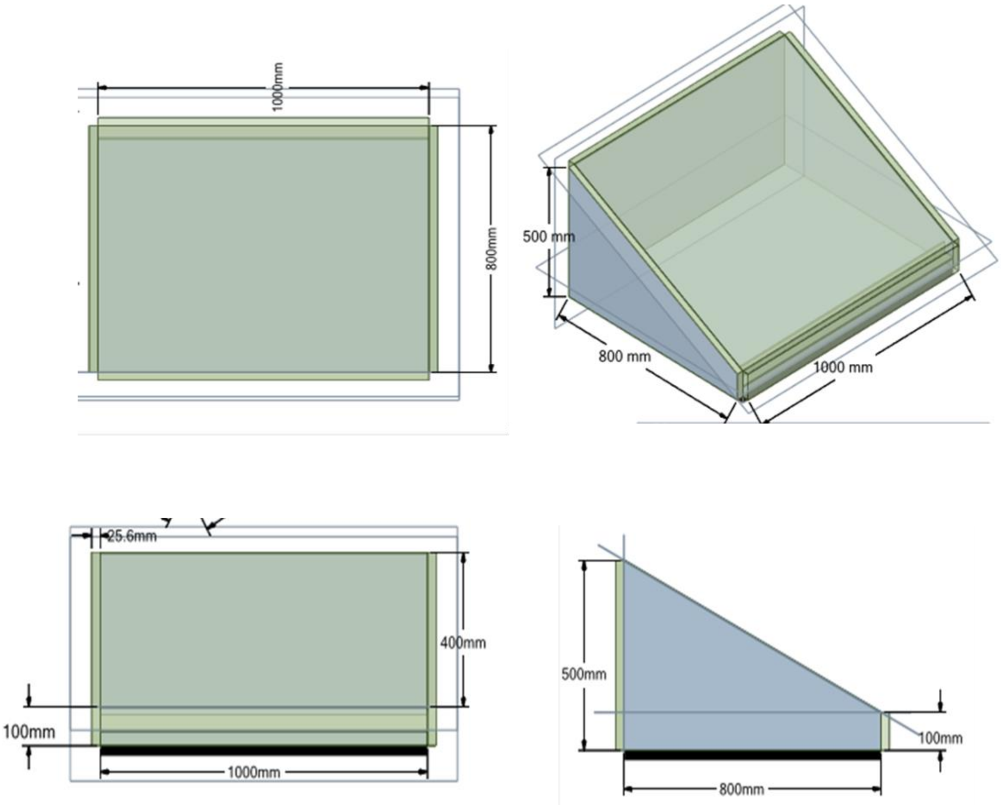


Figure 3.9: Dimensions of SS (Drawn from SpaceClaim)

3.5 Measuring Device Used

The main measuring instrument which is required while performing experiment are

1. **Thermocouple** for temperature measurement (Basin, internal and external face of absorption surface, internal and external face of condensation surface, internal air, ambient air and saline water).
2. **Digital Multimeter**: Digital multimeter is used in the current research for taking reading of various temperature. Digital multimeter was connected to the thermocouple for getting reading of the temperature.
3. **Graduated Beaker:** Water volume productivity

3.6 Data Collection

The project will be based on both primary as well as secondary data. The focus of the research is maximizing the productivity of solar still using CFD analysis. The project was conducted at Kathmandu as major location. Other location which could be included for further validation and accuracy of result are Pokhara, Birgunj, Nepalgunj and Butwal.

*Data for Operating Temperature :*It is the major input parameter, the data collection method for which will be completely primary. Thermocouple will be installed at different points solar still which will provide the data for temperature at different location over a period of time. Initially, thermocouple will be calibrated and then it will be placed at the solar still. Furthermore, multimeter used to take the temperature readings from the thermocouple.

*Data for Solar Radiation :*The data for hourly radiation for different day was obtained from the Department of Hydrology and Meteorology, Kathmandu.

Data for Wind Speed: The data for hourly radiation for different day was obtained from the Department of Hydrology and Meteorology, Kathmandu.

Output Data (Productivity): Productivity of the distillate water from solar still was obtained by the observation in the collecting trough.

Placement of thermocouple

1. *Thermocouple 1:* emerge in water to know the basin/ water temperature.
2. *Thermocouple 2:* will be placed over condensing glass surface to give the temperature inside of the glass

3.7 Procedure of Fabrication

In order to get the experimental setup ready, the fabrication of the solar still was one of the most important aspect of the current research. Proper fabrication work was needed to be done in order to get better result from the experiment. The various steps involved in fabrication are:

1. **Fabrication of support structure**: Initially the support structure was made by angle plate made up of mild steel. The angle was measured, cut and

Figure 3.10: SS support structure fabrication

welded as per the dimension of the solar still it would support. The size of support structure was taken as per the dimension of solar still with some tolerance for proper fitting. Figure 3.10 shows the welding and support structure after fabrication.

2. **Making Outer Body of Solar Steel:** The outer body of the solar still was made by plywood. Initially plywood was marked as per the dimension of solar still and cutting was done with the help of hand cutter. After cutting has been done, all sides are placed inside the support structure and joined with the help of the screw.Figure 3.11shows the cutting and assembling of plywood to make outer wooden cover of solar still.
3. **Marking and Cutting of GI sheet:**As per the dimension for internal basincomponent of SS, the GI sheet was marked and folding operation was performed rather than cutting. Cutting of GI sheet was performed with the help of sheet cutter. Figure 3.12 shows the marking and and cutting of GI sheet.

Figure 3.12: Marking and Cutting of GI Sheet

Figure 3.11: Outer cover made from plywood

4. **Folding and Painting the Base of Basin**: After cutting operation, folding was done in order to make leakage proof basin. The base of the basin area was painted black to enhance the absorptivity of the basin. Figure 3.13 shows the folded and black painted basin during experimental fabrication.
5. **Adding Insulation in between outer body and GI sheet:** Glasswool was used as insulation material and was sandwiched between the GI sheet and plywood outer cover in order to prevent heat loss from the solar still. Figure 3.14 shows glass wool as insulating material in solar still.

Figure 3.14: Glass wool as insulating material

Figure 3.13: Folded and black painted basin base

6. **Adding Internal Reflectors and distillate channel for water outlet**: Aluminium foil was used as internal reflector once experiment without reflector and black basin was done. Internal reflector was used in order to direct the radiation and reflect it towards the basin to enhance the water temperature. Distillate channel was made in inclined manner so that condensed water gets collected to beaker or jar easily due to action of gravity.Figure 3.15 shows the aluminium reflector and distillate channel inside solar still.

Figure 3.15: Aluminium foil reflector and distillate channel in solar still

7. **Placement of Glass:**Cutting and placing 5 mm thick glass as glazing material on the top of the SS. Placement of glass is shown in Figure 3.16.

Figure 3.16: Placement of glass cover

8. **Finishing work and final inspection:** Once the fabrication was done and major components were ready, finishing was done such as painting the support, fixing irregular support etc. Final inspection was done and then experiment was done on the fabricated structure of solar still. Figure 3.17shows the solar still after the completion of fabrication of solar still.

3.8 Performing Experiment of the Fabricated Solar Still

The experiment was performed for various days. Initially the test was performed without black paint and internal reflector inside the solar still. Later the experiment was performed by applying black paint on the basin base and aluminium foil was used as internal reflectors. Then the result of both the situation was compared to each other.

1. **Location of Experiment**

   The experiment was performed at Balaju School of Engineering and Technology, Balaju, Kathmandu. The solar still was placed at the roof of the location and hourly data of temperature of basin, glass and

Figure 3.17: Fabricated solar still

   corresponding productivity was noted.

2. **Timing of Experiment**

   The reading was taken for the period of 11 hours from morning 7:00 AM to evening 18:00 PM. The first experiment was performed without the application of black paint and internal reflectors. The second experiment was conducted using black paint on basin area and internal reflectors.

3.9 Procedure for performing experiment

The experimental procedure for performing experiment and taking adequate data are as follows:

1. Initially, the solar still was cleaned properly and the water in the basin is drained if already there exist any kind of water or liquid.
2. Every component of the solar still was checked properly whether they are in decent working condition or not. Such checks include checking of any leakage, seals etc.
3. Thermocople was placed at the basin and glass for taking the reading.
4. Thermocouple was connected with the digital multimeter to obtain the temperature data.
5. The hourly productivity of the distillate water was measure with the help of the beaker or measuring cup.
6. U-rubber was used to seal the glass and outer cover of solar still.
7. The reading of the temperature and the volume of output water was recorded every hour.
8. Same procedure was repeated for the day on which experiment was performed.

Figure 3.18: Experimental setup of solar still

3.10 Solar Still Modelling

Initial step in the analysis of problem using computational fluid dynamics involves the development of geometric model of the solar still with required necessary specifications of design. In the present research, analysis is done by computational fluid dynamics using ANSYS Workbench. The DesignModeler is a module of ANSYS Workbench which facilitates tool for developing the model of problem domain as per the geometric dimensions. The three dimensional model (3D) of single slope solar still as per the given dimensions and specifications made with

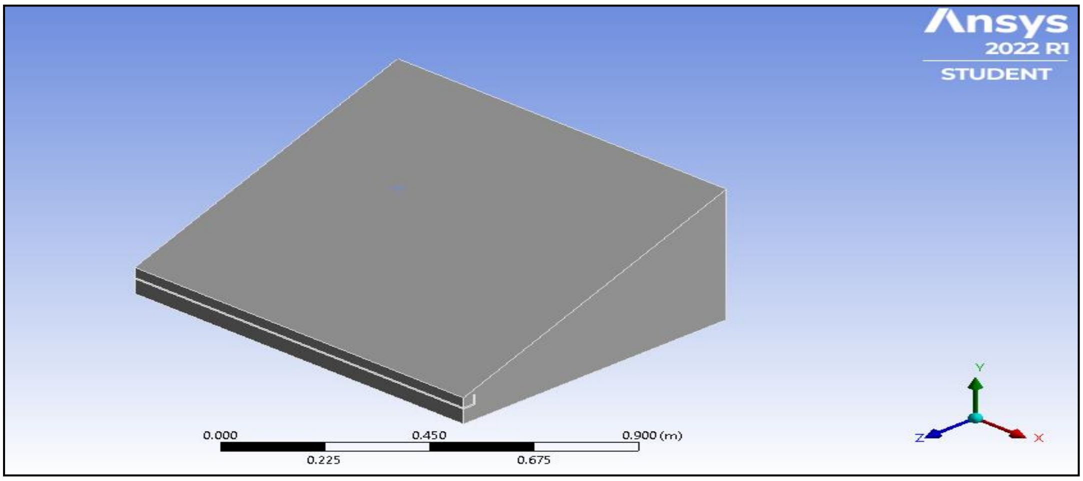


Figure 3.19: SS CAD geometry modeled from DesignModeler in ANSYS Workbench

the help of design modeler is shown in the Figure 3.19.

Solar still was made by a box provided with necessary insulation that was covered by the transparent glass inclined at some angle. Feed water was stored in the basin of the solar still which was made shallow and rectangular in shape. Basin was made by GI sheet and the basin area was painted black to absorb maximum radiation and enhance the absorptivity. In the present research, aluminium foil was placed at the sides of the inner walls of solar still so that maximum reflection of solar radiation towards basin surface could be achieved. Apart from this, a transparent glass of thickness 5 mm was used as a glazing/ condenser glass over the top of solar still at angle between 20-30^{0}C or near to the latitude angle of Kathmandu.

Design modeler is one of convenient module provided with ANSYS workbench which offers different types of commands and options for creating both two dimensional (2D) as well as three dimensional (3D) shapes and geometries.

3.11 Meshing of the Solar Still

Once the geometric model has been created, the next step in CFD analysis of solar still involves the generating of the mesh of the problem domain that is solar still. Meshing is generally a process of dividing large problem domain into numerous amount of tiny and fine cells. Large numbers of relationships and equations are applied to each tiny cells with the help of software used for CFD as a results of which simulation is done considering the real physical problem. There should be sufficiently large number of tiny cells after meshing so that more realistic behavior of the domain could be achieved after simulation is performed.

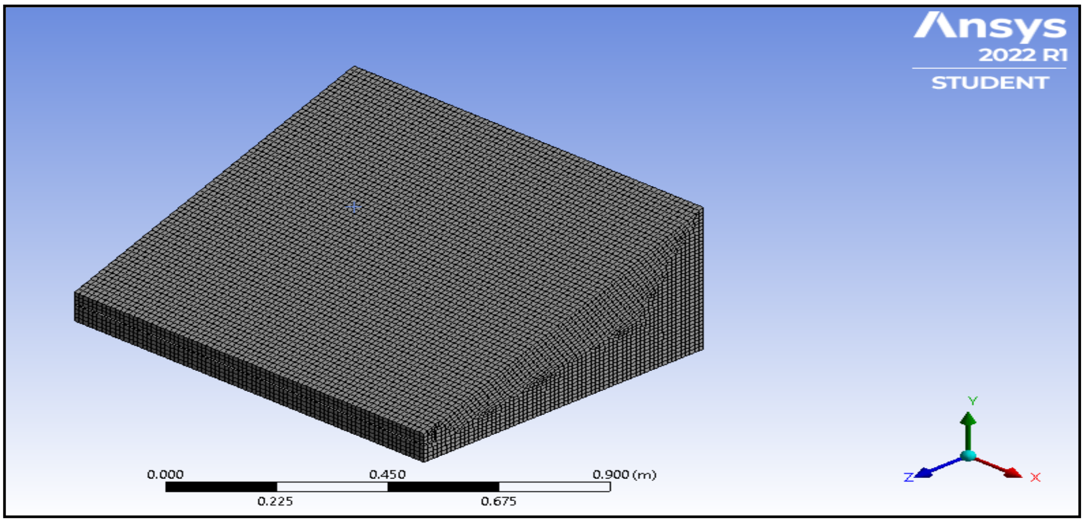


Figure 3.20: Meshing of Model of Solar Still

The number of tiny cell during meshing is such chosen that the time required for solution is minimal with best possible replica of physical environment of domain. Also, an optimum number for cell should also be known which could give better results in given period of time. Generally, the number of cell and time required by the solver depends upon the difficulty and complexitylevel of the problem. In the present research, considering the current geometry of solar still as there is absence of any curved or complex surface, the type of the meshing chosen was Hexahedral meshing on the basis of literature review. Hexahedral meshing was also chosen because of the simpler rectangular geometry of solar still in the current problem. This would result in accurate solution in limited period of solver time. Other type of meshing also involve tetrahedral shaped meshing which is generally employed for meshing of curved surfaces or complex geometries.

The element size was taken as 0.013m and maximum size was also taken as 0.013 m. Smoothing was kept as high. Element order is taken linear. After the generation of mesh, total number of nodes is 123240 and the total number of element present in the generated mesh is 114345 that is sufficiently enough with respect to the current complexity of the problem of solar still.

3.12 Quality of Element Size

Checking of the quality of mesh should be done because inadequate quality of mesh will result in the poor accuracy of the solution that is highly undesirable for the CFD analysis. Thus, the quality of mesh is associated with the accuracy of the solution obtained to significant extent. The various mesh metric which is responsible for checking the quality of the generated mesh in ANSYS workbench are given in the meshing module. These are named as element quality, skewness, orthogonal quality and the aspect ratio of mesh generated (Fluent, 2017). In the present research, the quality of mesh is checked by the use of only two parameters that is skewness and aspect ratio.

The criteria of skewness states that the perfect element with good quality of mesh have skewness of zero. The element which have value of skewness greater than unity is consideredas unfeasible element. The problem domain with good meshing should have the minimal number of elements having the value of skewness equal to or greater than unity. On an average, it is referred to as good quality mesh if skewness value is less than 0.3. In the graph shown in Figure 3.21, there are very few number of elements with skewness number less than 0.3. Hence, the current meshed domain could be considered as good quality mesh as per the skewness

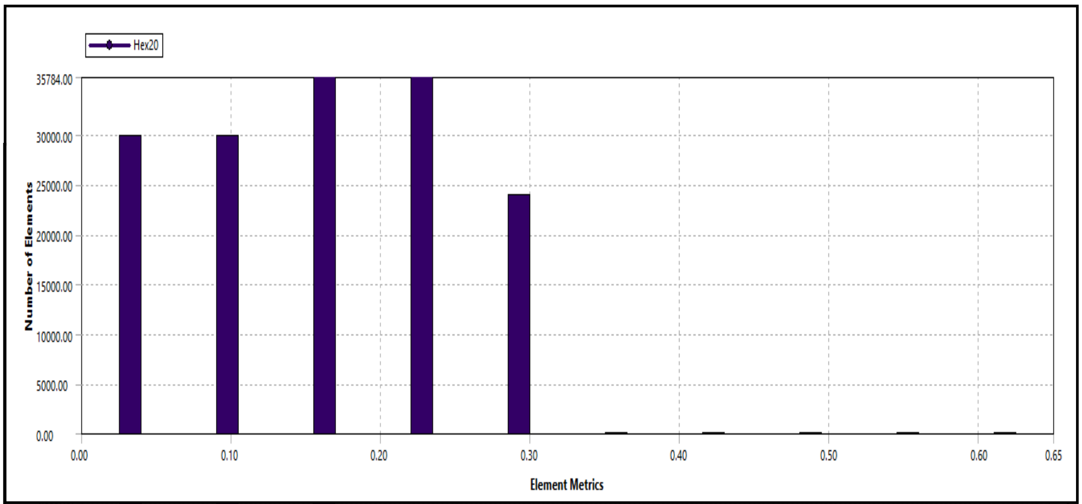


Figure 3.21: Skewness for quality of mesh

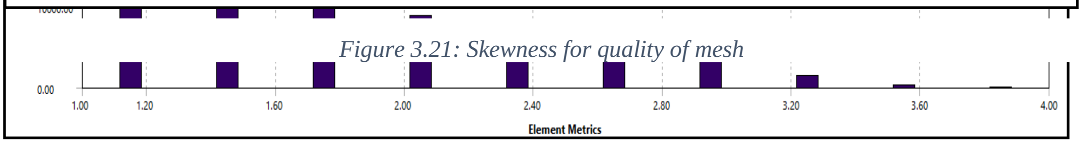


Figure 3.22: Aspect Ratio for quality of element of mesh

criteria of quality.

The other criteria for checking mesh quality is the aspect ratio of the element meshed. Good quality mesh should have an aspect ratio value less than 2. Maximum elements in the current meshed section have the value of aspect ratio below 2 as shown in graph of Figure 3.22. Thus, the quality of mesh as per aspect ratio is good enough to provide better result of the problem (Fluent, 2017). From the above statements, it can be said that the quality of mesh is good enough to achieve accurate result as per the skewness and aspect ratio criteria for quality checking.

3.13 Computationa Fluid Dynamics (CFD) simulation of solar still using ANSYS

Fluid Flow (FLUENT) is one of the very convenient module or tool of the ANSYS which allows the transfer of heat and mass to the described boundary and region of the model. Different types of problem involving convection, radiation and mixed flows can be easily simulated by the application of FLUENT for fluid flow incorporated in ANSYS(Fluent, 2017). The current research in modelling of single slope basin type passive solar still by the application of CFD. In the current research, the major study focuses on the simulation of evaporation and condensation process of water inside the solar still. Various assumptions have been made for proper simulation of solar still for CFD analysis.

3.14 Numerical Method Employed

Computational fluid dynamics is a tool which is based on numerical method. Simulations through CFD is mainly available in four types of numerical methods which are as follows:

1. Finite Element Method (FEM)
2. Finite Volume Method (FVM)
3. Finite Difference Method (FDM)
4. Spectral Galerkin Method (SGM)

All of these method are involved in the discretization of the Navier-Stokes equation to simulate the problem related with fluid flows. Out of the given four numerical methods, FDM and FVM is mostly preferred for the application in the commercial packages of CFD. In the present work, FLUENT has been used which is based on FVM approach for the fluid problem simulations.

In term of discretization, FEM focuses on finite elements that is small problem domains, FVM focuses on control volumes and FDM is focused on elements of the domain. The summary of different numerical methods is shown in the table below (Ansys Inc., 2011).

Table 3.2: Different method for analysis

Method	**Discretization**	**Type of Representation**	**Results / Solutions**	**Applicable Medium**
FEM	For small domains (finite elements)	Piecewise in term of basis function	Continuous Solution	Solid and Fluid
FVM	For control volumes	Partial Differential Equation in Integral form	Discrete Solution	Fluid Only
FDM	For elements	Partial Differential Equation in Differential form	Discrete Solution	Fluid Only

3.15 Assumption Made During Simulation Of Solar Still

In order to perform the simulation of three dimensional multiphase single slope basin type passive solar still, following assumptions has been made during the work.

1. The walls of the solar still during simulation is assumed to be adiabatic since the insulation has been done in the physical model so that no heat is lost from the walls.
2. Leakage is absent in the system.
3. The physical properties of materials such as thermal conductivity, specific heat and density is assumed to be constant.

4. The process of condensation is assumed to be filmwise instead of dropwise condensation process.
5. The inlet velocity of solar still is assumed to be negligible.
6. Free convection is taken into consideration.
7. The temperature inside the basin and cover of the glass is assumed to be homogeneous.

Modelling of heat transfer phenomenon is perquisite and important to achieve the physical model of the problem. To do so, all the necessary properties of material along with the boundary condition needs to be defined. The modelling of physical problem into the virtual model in the FLUENT needs the sufficient parameters to be modeled for simulation. The major models involved during the current research in FLUENT are as follows:

- Multiphase model
- Energy model
- Viscous model
- Radiation model

3.16 Selecting Multiphase Model

There are numerous amount of general as well as engineering applications available practically in the physical world which consists of mixture of multiple phases. Generally, solid, liquid and gases are the phases of matter. The theory of multiphase system has application in broader sense. The advancement of the computational mechanics of fluids have resulted in the development of basis for the dynamics ofmultiple phase flow problem domains. At present, two methods are available for calculating the multiphase flow problems numerically which are Euler- Euler Method and Euler-Lagrange Euler-Lagrange Method is mainly based on the problem domain involving solid-liquid flows while Euler-Euler method involved in fluid-fluid problems. In this, the volume of one phase cannot be occupied by other phase due to which the principle of volume fraction is generated. The assumption is made regarding volume fraction that it is continuous and function of time and space. Furthermore, their summation is equal to unity. Derivation of conservation equation for each phase is done in order to get the required equations having identical structure for every phases involved. Empirical relations and information are required in order to get the solutions of these equations (Fluent, 2017).

Multiphase model could be modeled as group of four pair which are : liquid-liquid/liquid-gas flows, solid-liquid flows, solid-gas flows and three phase flow. In the current simulation, vapor-liquid has been selected that is gas-liquid model has been selected in multiphase model.

Various multiphase model which are available in ANSYS FLUENT for simulation are

1. Volume of Fluid (VOF) model: It is the technique used for tracking of surface which is applied to the stationary or fixed Eulerian mesh. It is generally employed for two or more than two non-miscible fluids. In this type of model, common momentum equation is applied between the fluids and the tracking of volume fraction in each of the cell being computed is done. VOF models is usually used for large bubble motion in liquid, post dam break liquid motion, surface tension prediction, steady and transient behavior of any multiphase phenomena. This model is based on the volume fraction of the available phase. The sum of the volume of fraction is considered as unity for the researched control volume. The characteristics in this model represents purely either one phase or the mixture of the phase relying on the value of volume of fraction. This, model can also be used for the current research problem.
2. Mixture model: It is homogeneous model which is employed for process involving two or more than two phases. In this model, the momentum equation associated with the mixture is solved and relative velocity for particular phase is assigned to describe the phase. Mixture model is generally used for flows with bubble flows, cyclone separators and sedimentation process. This model can also be applied without the application of relative velocities in order to model the homogeneous flow for multiphase flow model.
3. Wet-Steam model: It is homogeneous model. The continuous and rapid expansion process of steam causes condensation phenomena which crosses the vapor-saturation line after short period of time. Due to this process of expansion, formation of double phase saturated vapor and fine droplet is

obtained which is known as wet steam. Such type of analysis is very essential during steam turbine design. This model is only for density based solver.

4. Eulerian model: It is inhomogeneous model of multiphase flow.Eulerian model is the most complex model among the three model discussed. N number of continuity and momentum equation is solved in every phase of the model. Coupling takes place due to the interchange of pressure and other coefficients. The pattern of coupling is decided by the phases involved in it. The phases which are involved in the mixture model are fluid-solid and fluid-fluid flows. Granular flows are called fluid-solid flows and nongranular flows are fluid-fluid flows. Kinetic theory of gases gives the properties of fluid-solid flows. The type of mixture model also depends upon the exchange of momentum between the phases.

In the present research, mixture model is chosen in multiphase model. The selection of mixture model has been done due to the fact that this model is capable of modelling the evaporation and condensation process in closed region. Apart from this, this model is simple and requires less time for solver to compute. The multiphase model box in ANSYS FLUENT is shown below.

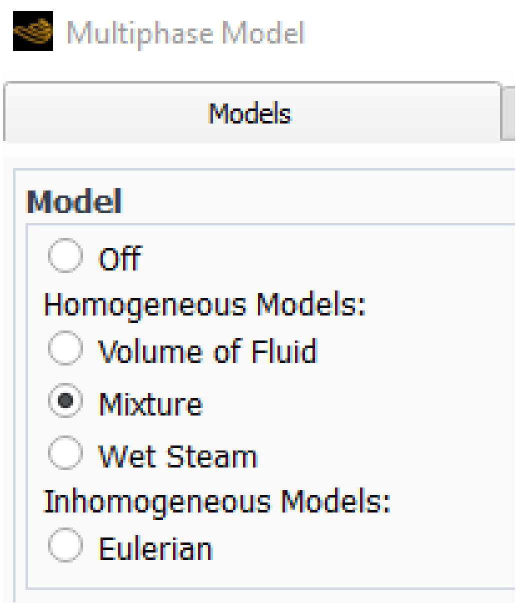


Figure 3.23: Multiphase model in FLUENT

3.17 Mass and Heat Transfer Equation by User Defined Function

The evaporation and condensation phenomenon in the current simulation has been simulated by the use of following equations:

Evaporation rate is determined as:

$$\dot{m}_{evap.} = \frac{r_v a_L \rho_L (T_L - T_{sat})}{T_{sat}} \tag{15}$$

Condensation rate is determined as:

$$\dot{m}_{cond..} = \frac{r_L a_v \rho_v (T_{sat} - T_v)}{T_{sat}} \tag{16}$$

Where,

‘r’ denotes time relaxation parameter.

Sub-script L and v denote for liquid and vapor phase.

ρdenotes density and T denotes liquid, vapor and saturation temperature.

$a$denotes the volume fraction of vapor and liquid phase in the model.

3.18 Selecting Energy Model

After the selection of multiphase flow model, energy model is choses. It is activated as the interaction of energy inside the solar still takes place. Energy equation is enabled due to the fact that there is involvement of energy balance equations inside the solar still.

3.19 Selecting Viscous Model

It is generally a turbulent model. Irregular flow and fluctuations of fluid particles is known as turbulence flow. It is represented with respect to the diffusivity, greater Reynolds numbers, fluctuation in three dimensional vorticity, and continuum. Such model are required in ANSYS FLUENT in order to find the solutions of unknown variables. It is one of the most difficult task in the CFD modelling to correctly and accurately perform the analysis of turbulent problem. Certain assumptions needs to be taken in order to model appropriate turbulent model of the problem. Certain assumption means the various mechanism of fluid flow problem, required accuracy and the available resources (Fluent, 2017).

There are large number of viscous model available in ANSYS FLUENT for simulating viscous and turbulent model which are described as follows:

1. Laminar: It is employed for the problem which is concerned with the laminar flow problems.
2. Spalart-Allmaras (1- equation) model: This model comprised of one equation which helps in solving the transport modelling equation for the turbulent viscosity (kinematic). This model was mainly developed for its application in aerospace sector which consist of boundary wall flows and provide better solutions for the boundary layer that is subjected to extreme pressure gradients. It is also used in turbomachineries in the recent times. This model is a low Reynolds number model in which boundary layer of the region with viscosity needs to be solved. This model was initially designed for its application in aerospace due to which calibration of this model was not done for general application. As a result of this, Spalart-Allmaras model produces large percentage of errors for some application involving shear flows mainly in round jets and planes. Furthermore, Spalart model is not suitable for predicting homogeneous and isotropic turbulence flow problem.
3. k-epsilon (2 equation) model: This model is considered as one of the most convenient and useful model for practical engineering flow applications and calculations. It consist of three model inside it i.e. standard, RNG and realizable model. The main difference between these three model lies in the calculation method of turbulent viscosity, prandtl number responsible for governing the diffusion of turbulent between k and epsilon. Finally, the difference is associated with the term in the equation which is responsible for the generation and destruction.

   Standard k-epsilon model is based on the transport process equation of turbulence kinetic energy (k) and their rate of dissipation (ε). The transport equation for the model was achieved by the physical reasoning and the quantities defined are as follows.

$$k = \frac{1}{2}(u^2 + v^2 + w^2) \tag{17}$$

$$\varepsilon = \rho C_p \frac{k^2}{\mu_\tau} = \frac{k^{9/2}}{l_\tau} \tag{18}$$

$$\omega = \frac{\varepsilon}{k} \tag{19}$$

The standard k-epsilon model is only valid for totally turbulent flows. The flow is assumed to be completely turbulent, and molecular viscosity is neglected during the derivation of this model.

Renormalization group theory, a kind of statistical method, was employed to derive the RNG k-epsilon model. It is most like the standard k-epsilon method with some modifications and refinements.

- RNG model consists of an additional term in the equation which is responsible for the accuracy of rapid flow
- RNG model involves the swirl impact on the turbulence, which, as a result, improves the accuracy of the flows for swirlings.
- The standard k-epsilon model is associated with a constant value specified by the user, whereas the RNG model is related to analytical relations.
- RNG model is a low Reynolds number model, whereas the standard model is a high Reynolds number model.

Due to all the above reasons, RNG model is considered to be more accurate and used in broader perspective as compared to the standard k-epsilon model. This model is derived by the application of mathematical method which is known as “renormalization group (RNG)” that is through the use of Navier-stokes equations.

The model in the k-epsilon method of modelling is selected on the basis of the complexity of problem and desirable accuracy of solution. On the basis of this, k-epsilon model with standard wall function has been selected for the simulation of the current problem domain.

The transport equation of RNG k-epsilon is similar to standard k-epsilon model.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[a_k \mu_{eff} \frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_K \tag{20}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\left[a_k \mu_{eff} \frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}G_k + C_{3\varepsilon}G_b - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - R_\varepsilon + S_\varepsilon \tag{21}$$

Where,

G_k= Turbulent Kinetic Energy Generation due to mean velocity gradient

G_b= Turbulent Kinetic Energy Generation due to buoyancy

Y_M= Fluctuating dilatation

C = model constants

The current model uses k-epsilon model with standard model along with standard wall function for the simulation of present research. All other value are kept as per default.

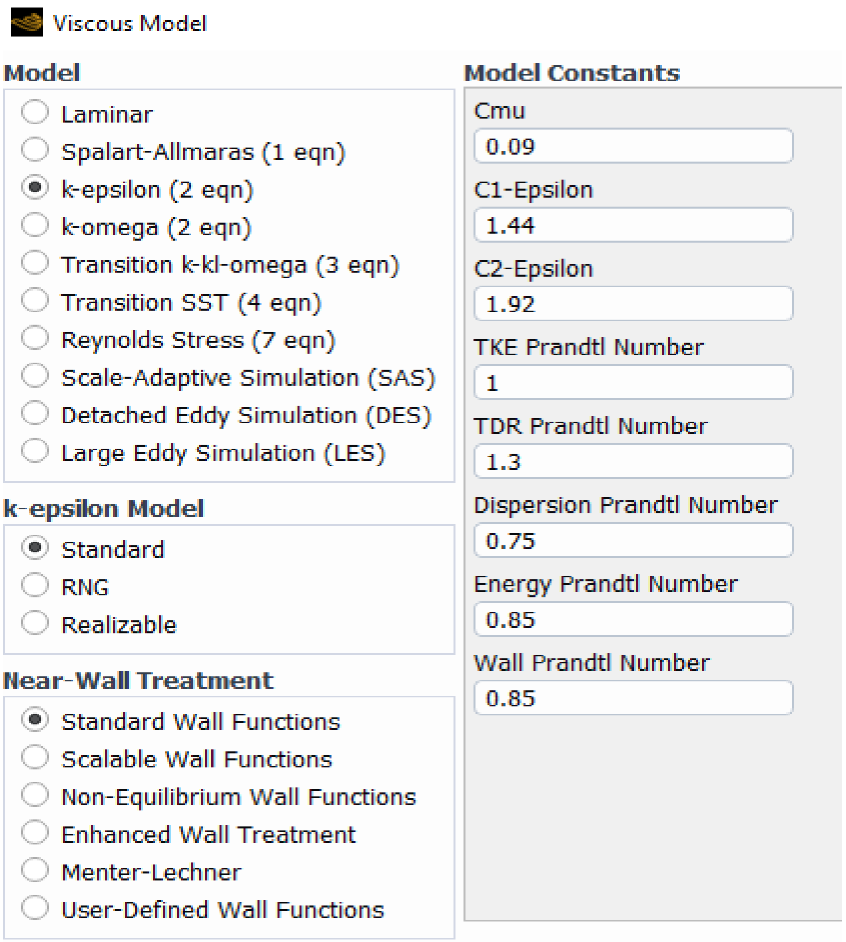


Figure 3.24: Viscous Model options in ANSYS FLUENT

3.20 Selecting Radiation Model

There is provision of different types of radiation model included in ANSYS FLUENT which allows the heat transfer through radiation process in the simulation of heat transfer process. The cooling and heating of the surfaces because of the radiation could be simulated by the implementation of any one model listed in radiation model.

- Rosseland Model
- Discrete Transfer Radiation Model (DTRM)
- P-1 Radiation Model
- Surface to Surface (S2S0 Radiation Model
- Discrete Ordinates Model

- Monte-Carlo Radiation Model

Along with these model, radiation model is also provided with solar loading which consist of the impact of solar radiation during simulations. Rosseland model is chosen for the current study because it is efficient for high optical thickness cases. In the current study solar loading and solar ray tracing has been used for the simulation as shown in the figure. The latitude and longitude data was taken as that of Kathmandu, Nepal.

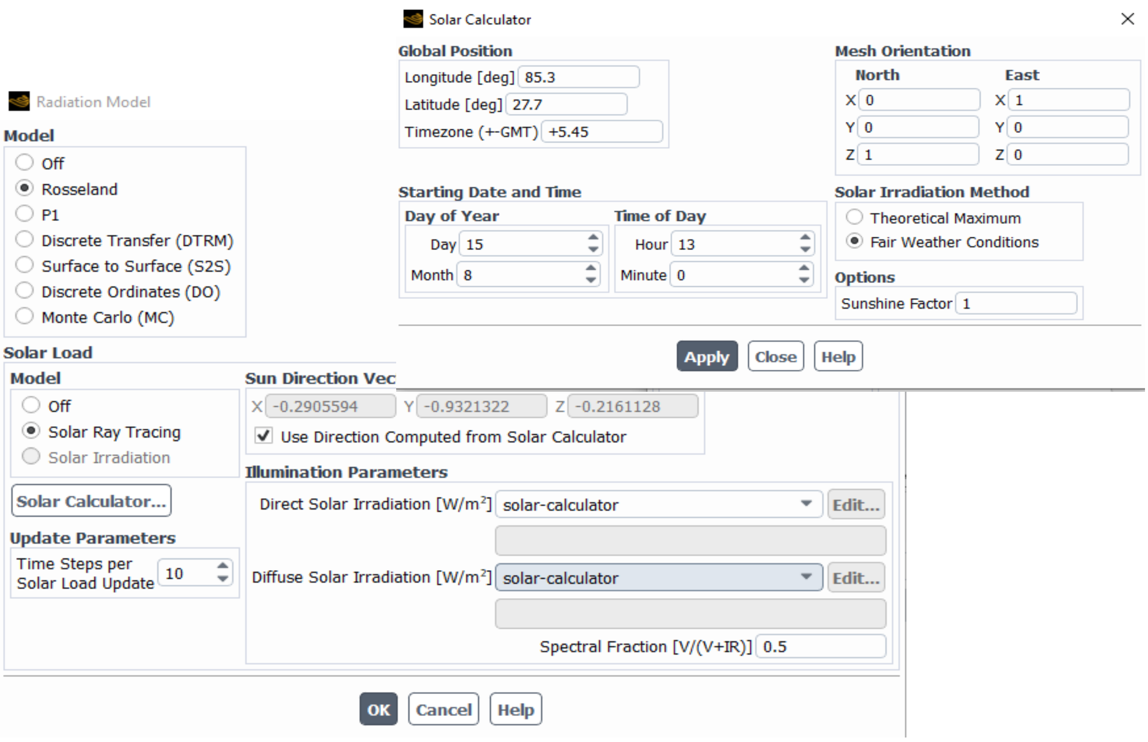


Figure 3.25: Radiation model criteria in ANSYS FLUENT

3.21 Specifying Materials

It is one of the very important parameters for simulation. Material selection plays an important role in simulation of heat and transfer model. Solids and fluids was involved in the current research. In fluids, there are air, water and vapor choosen as material from FLUENT Database for inner volume. In solid, the material of side walls were chosen as wood and aluminium, basin was GI sheet and the top of inclined cover was chosen as glass. The data for GI sheet and glass was chosen manually whereas data for other material was specified from FLUENT database. The properties of GI Sheet and glass was specified manually as follows.

Table 3.3: Material Properties

Selected Material	Air	GI Sheet	Glass
Density (kg/m^3)	1.225	2235	2500
Sp. Heat Capacity (J/kgK)	1006	750	1.15
Thermal conductivity (W/mK)	7196	502	55

3.22 Specifying Boundary Conditions

Boundary condition plays an important role in simulation of any problem domain. The accuracy of the result and authentication of the result depends upon the correct specification of the boundary layer. Most condition are chosen as per practical applications whereas some are chosen by the inbuilt algorithm of simulation software. In this section of the research, the boundary condition of the geometric model is specified for various components associated with it.

Specifying of the boundary condition is one of the major steps in the simulation of the problem. The boundary condition generally involves various constraints associated with the problem domain based upon which various equations are solved by the solver in computing process. The physical or practical boundary conditions of the problem are converted in term of the simulation software. For example, the experimental solar still has its side walls insulated due to which the side walls during the simulation is considered to be adiabatic wall with zero heat flux boundary condition. The pressure-outlet condition was specified as boundary condition for the outlet of water in solar still.

Initially, all the components was named as its components for the ease of the problem. Named selection was chosen during naming of the components. The brief of the boundary condition of solar still components are as follows.

Table 3.4: Boundary Conditions

Name and Type of Zone	Description	Wall thickness (m)

glass_top (wall)	Radiation	0.005
Adiabatic_walls(All the side walls)	Adiabatic wall (Heat flux = 0)	0.025
Basin_absorber (wall)	Adiabatic wall (Heat flux = 0)	0.025

3.23 Use of Solver

There are mainly two types of solver which is employed for solving of numerical problems in ANSYS FLUENT. They are implicit type and explicit type numerical solver. Both the implicit and explicit type of numerical solver are responsible for solving the mass, momentum and energy conservation governing integral equations along with other scalar quantities. Implicit type is also known as segregated solver whereas explicit type is known as coupled solver. The implicit equation is more concerned about solving the governing equation individually one after another associated with variables such as temperature, kinetic energy, velocity etcDuring solving of the equations, the equations are either segregated or decoupled. In the present research, implicit type solver has been taken into consideration because it uses memory efficiently and the solved equations need to be stored once(Fluent, 2017).

Method of Generating Solution

There are two methods for generation of solution in ANSYS FLUENT whose sole aim is to discretize the solution of governing equations involved. They are 1st order upwind solution method and 2nd order upwind solution method. Initially, the face value of the cell is considered equal to the central cell value in 1st order upwind method whereas 2nd order method uses taylor series expansion for the solution of governing equation. ANSYS FLUENT recommends the implementation of 1st order if the highest level of accuracy is not of primary concern whereas 2nd order is recommended for highest requirement of accuracy in the solution. First order takes less computational time whereas second order takes more time for computation of the solution(Fluent, 2017). On the basis of time taken for calculation, the current research employed the use of 1st order upwind solution method.

Criterion for Convergence

Initially, the residuals of the X, Y and Z were observed till it reaches the convergence. The value for energy equation is kept as 10^{-6} and it is kept 10^{-3} for all other variables. While defining the converging criteria, it is assumed that the obtained result will no longer diverges once the convergence has been achieved with more iterations.

3.24 Initialization of Solution

After all the parameters and variables have been specified, initialization of the solution was done. Number of iteration was chosen as per convenience and time for computation.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Result obtained after performing experiments

The experiment was performed at the roof of Balaju School of Engineering and Technology (BSET), Kathmandu for the period of 11 hours from 7 AM in the morning to 18 PM in the evening. Each major parametric data such as ambient temperature, basin temperature and glass temperature of solar single was taken with the help of thermocouple connected to the digital multimeter. Furthermore, the data of wind speed and solar irradiance was taken of TIA substation from the Department of Hydrology and Meteorology (DHM), Kathmandu. The graph shows that solar radiation pattern for the period of 8 days from 16th august to 23rd august.

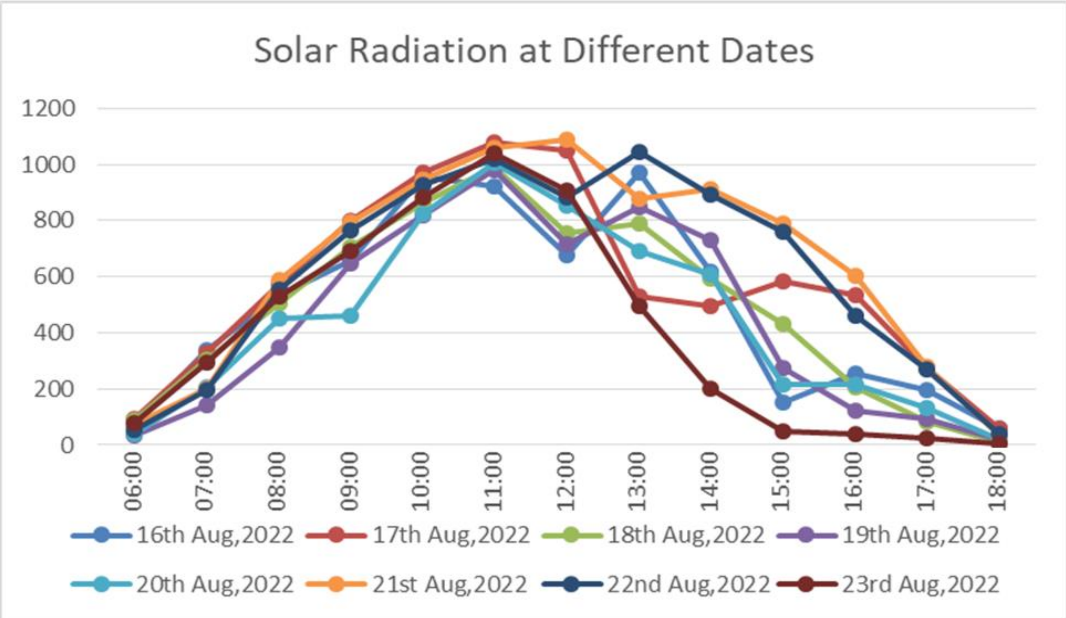


Figure 4.1: Hourly Solar Radiation on various days

From the graph in figure 4.6, it can be observed that the solar radiation everyday in the month of August varies mainly after 12:00. The reason for this might be unfavorable and cloudy weather. Due to this there could be variation in the result obtained for particular day. Apart from this, it can be clearly observed that solar radiation is maximum during during afternoon from 11:00 to 14:00. Solar radiation increases gradually from morning to afternoon and again decreases gradually till evening.

Experiment without black paint and internal reflector in the solar still (E1)

Initially, experiment was performed on 16th August, 2022. In this experiment the solar still was not painted black at the base of the basin. Along with this, there was no any kind of internal reflector during this experiment. The result obtained in this experiment is discussed in the graph below.

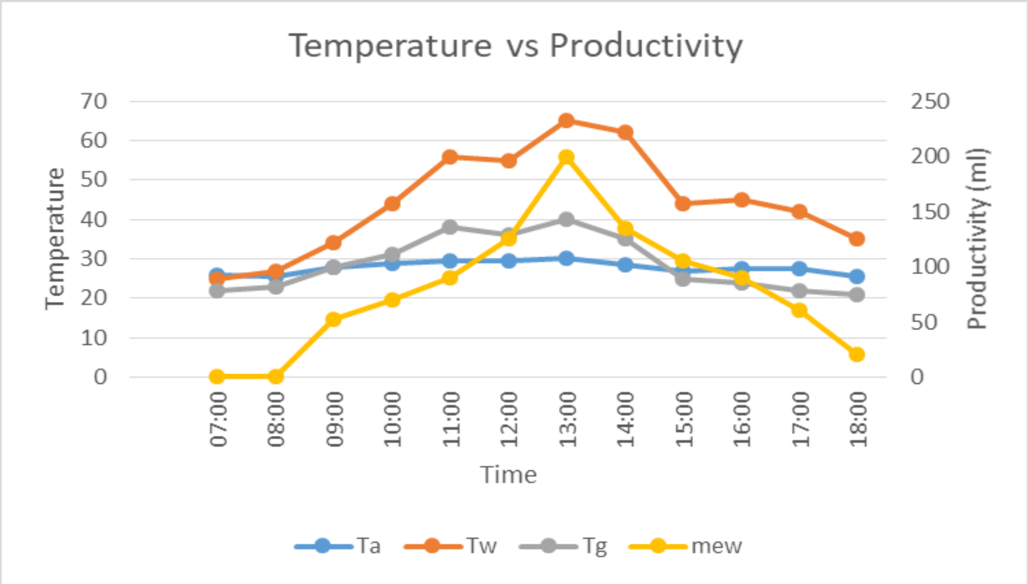


Figure 4.2: solar radiation vs different temp. (16th August, 2022)

From the graph in Figure 4.2, it can be seen that the glass and water temperature is maximum when solar radiation is maximum from 12:00 to 2:00. The glass temperature and water temperature follows similar profile as observed from the graph.

Similarly, the graph between the solar radiation and productivity in Figure 4.3 shows similar behavior. It shows that the productivity is maximum when the solar radiation is maximum and gradually productivity decreases with decrease in solar radiation.

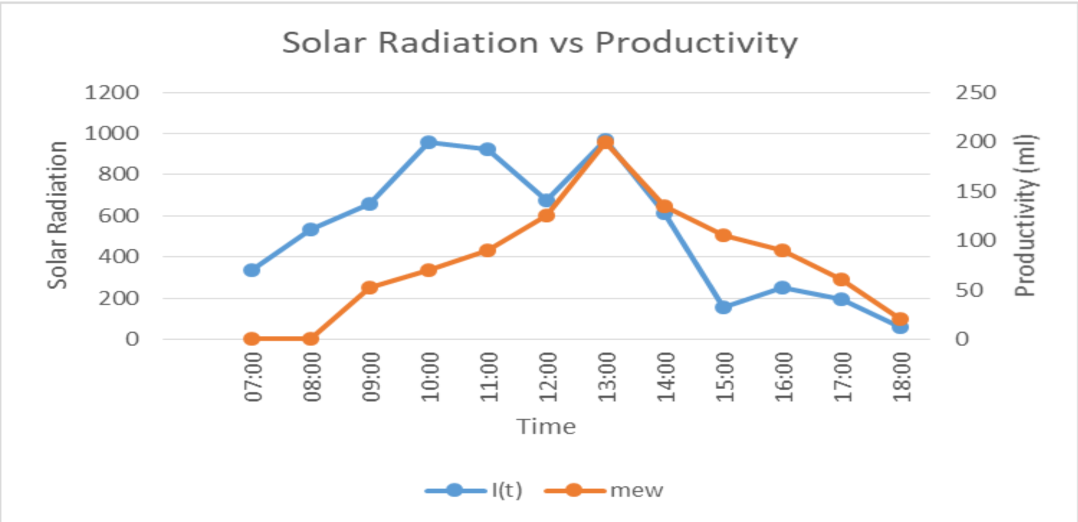


Figure 4.3: Solar radiation vs Productivity (without black basin and internal reflector)

Experiment with black painted basin and internal reflectors on side walls (E2)

Experimental setup and different process taking part in experiment is shown in APPENDIX. Equation discussed in the earlier section was used to determine the productivity of solar still. Finally the theoretical productivity is compared with the experimental productivity. The overall result for 17th August, 2022 of the solar still taken over a period of 11 hours at Kathmandu is provided in given table.

Table 4.1: Experimental data with painted basin and internal reflectors at side

T(h)	**I(t) (W/m^2)**	**V_w (m/s)**	**T_a (^{0}C)**	**T_w (^{0}C)**	**T_g (^{0}C)**
07:00	94.6	1.4	20.4	20.8	16
08:00	327.2	1.2	23	25	19
09:00	575.9	3.1	24.7	33	25
10:00	799.8	2.9	26.1	46	35
11:00	969.1	4.3	27	52	37
12:00	1078.6	4.4	27.9	70	47
13:00	1049.2	4.9	28.3	68	44
14:00	527.4	4.6	27.8	59	43
15:00	497.3	4.4	27.6	53	37
16:00	584.1	5.2	27.7	52	36
17:00	533.1	4.3	27.8	50	34
18:00	273.5	3.8	27.1	41	32

Based on the result and data obtained in table above, various curves was plotted

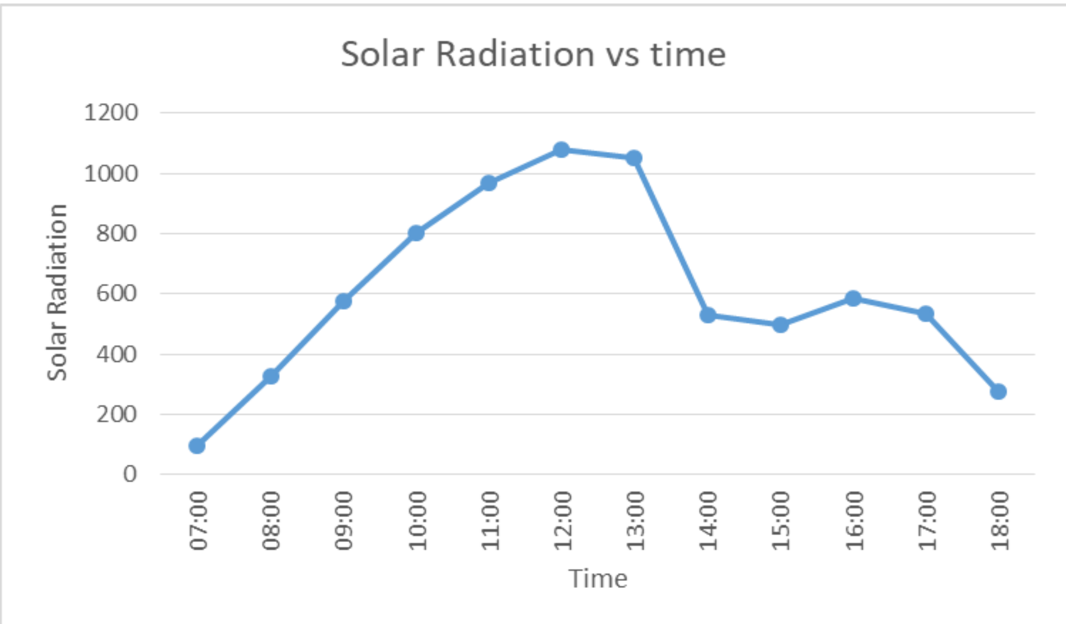


Figure 4.4: Plot between solar radiation and time

using excel software in order to obtain the behaviour pattern of various parameter.

Figure 4.4shows the plot for the solar irradiation verses time of the day. The curves shows that maximum solar radiation occurs at 12:00. The sudden decrease was due to the cloudy weather formed at that period of time

Figure 4.5 shows the plot for the ambient temperature, water temperature and glass temperature verses the time of the day on 17^{th} August, 2022. The curves are quadratic in nature with maximum value occurring as 27.9^{0}C, 70^{0}C and 47^{0}C at 12:00. It was noticed that this high temperature is due to high irradiance and various heat transfer process going to the glass.

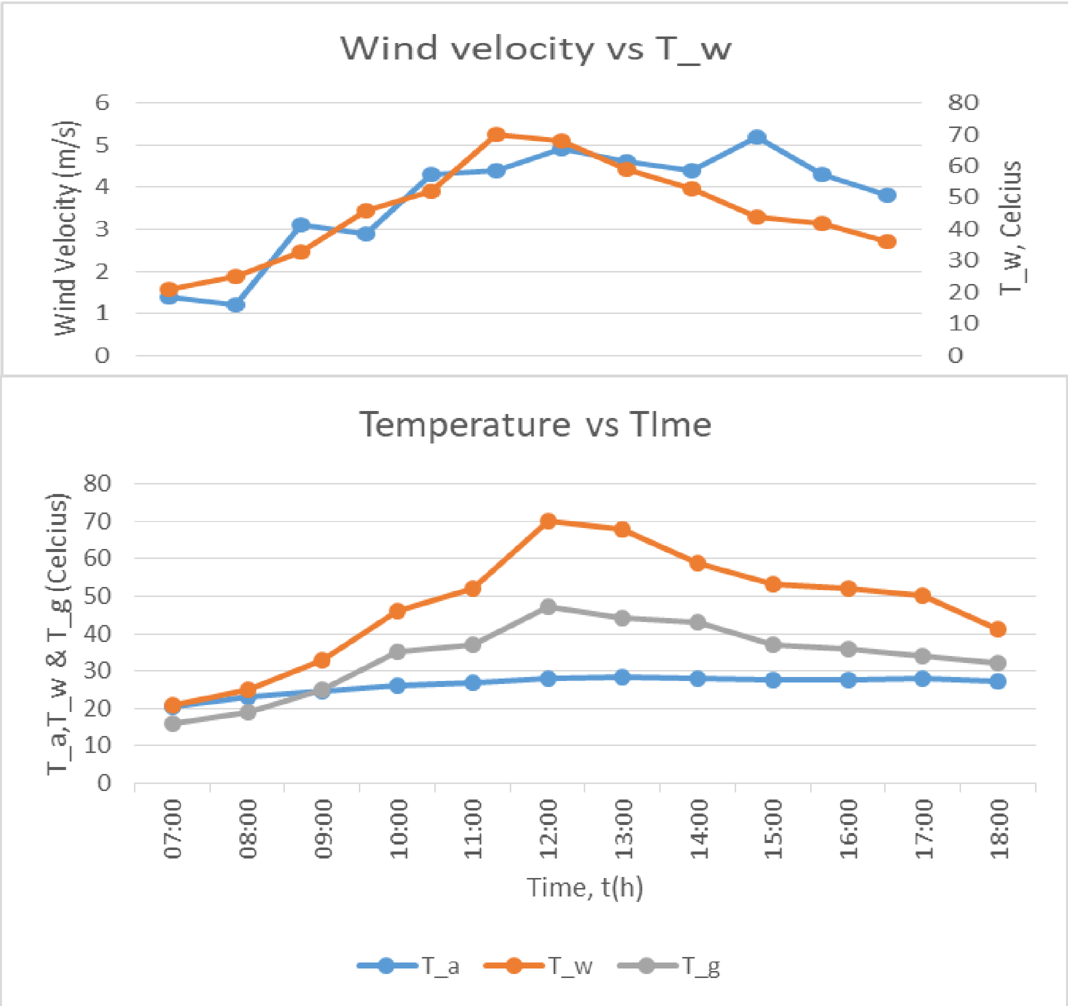


Figure 4.5:Different temperature vs time

Figure 4.6 shows the curve behavior between wind velocity and water temperature. As the wind velocity rises basin temperature also rises. After some time, temperature decreases as wind velocity decreases.

Figure 4.7 shows the curve between wind velocity and hourly productivity. It shows till some point productivity increases with increases in wind velocity but after certain point productivity starts decreasing.

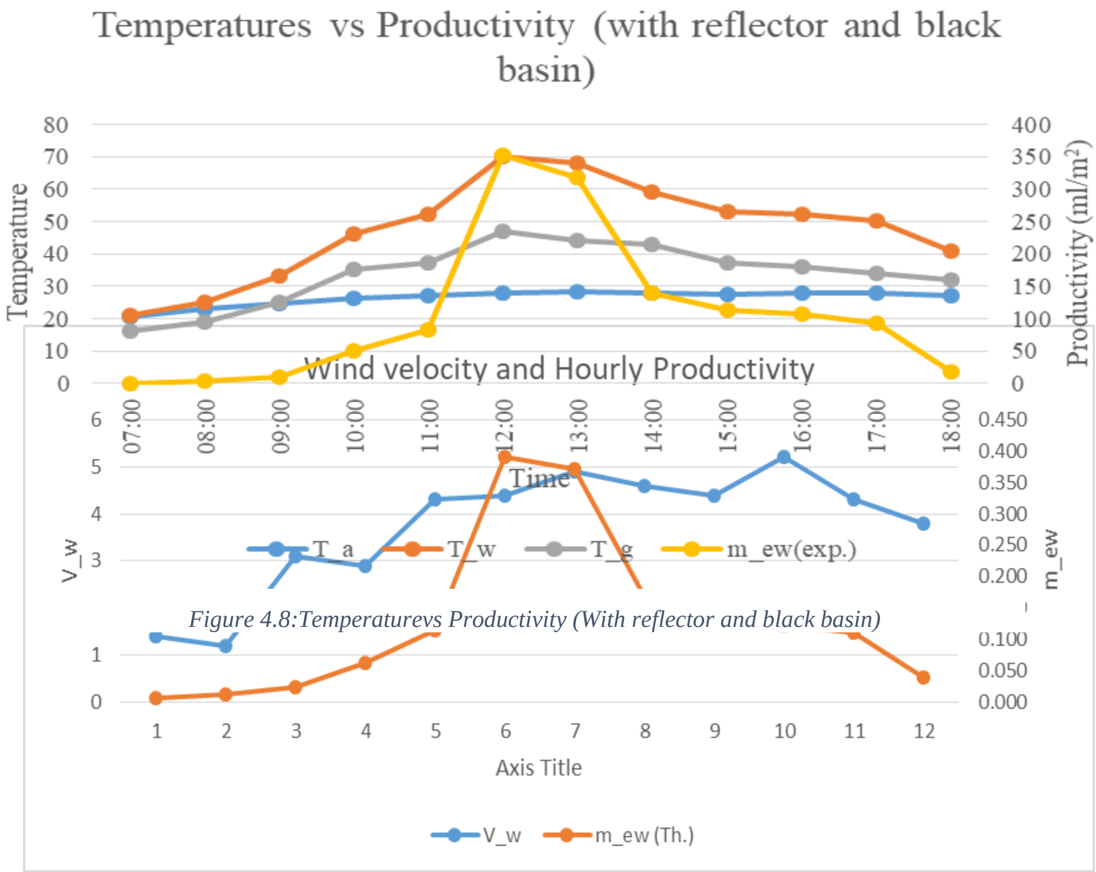


Figure 4.8:Temperaturevs Productivity (With reflector and black basin)

Figure 4.7: Wind Velocity vs Hourly Productivity

Figure 4.13 shows the behavior of hourly productivity with respect to ambient temperature, water temperature and glass temperature. It shows that as the temperature of glass and water rises, the production of distillate also rises. In other words, the productivity of the distillate is dependent on the temperature difference between the glass temperature and water temperature.

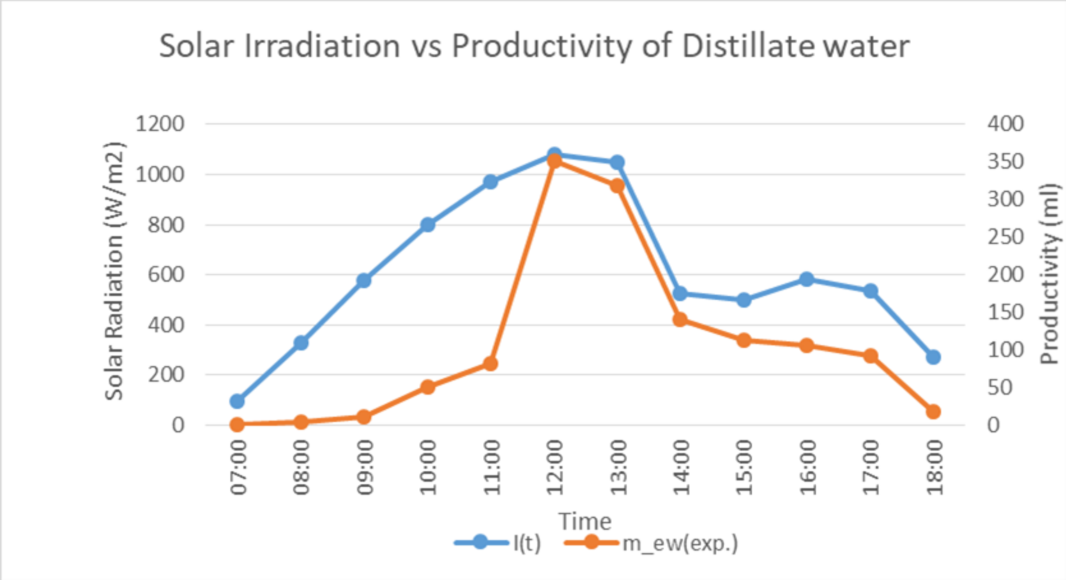


Figure 4.9: Solar Irradiation vs Hourly Productivity

Figure 4.9shows how solar irradiance impact on hourly productivity. The curve shows similar trend. As solar radiation falling upon solar still goes on increasing, hourly productivity also increases. As solar irradiance decreases, hourly productivity also goes down.

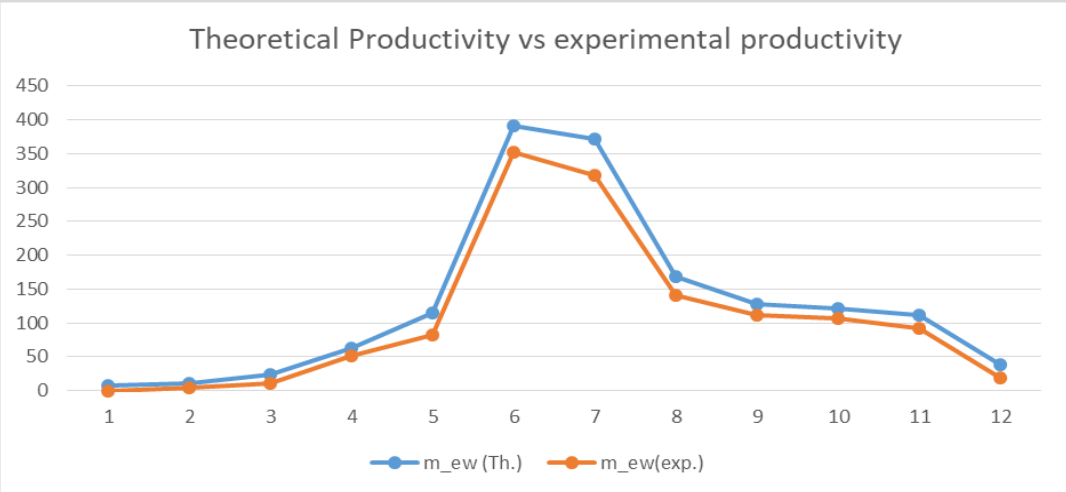


Figure 4.10:Theoreticalvs Experimental Productivity

Figure 4.10shows the comparison between the value obtained by using equations and the experimental value of hourly productivity. Both theoretical and experimental productivity are in good agreement with each other as they show similar trend. The equations and mathematical formula were used to calculate the theoretical productivity of distillate on the basis of measured temperature of the glass and water basin.

The comparison of theoretical cumulative productivity and experimental cumulative productivity is shown in the graph of Figure 4.11. The total daily productivity of distillate water output through experiment was approximately 1.3 kg/m^2/day (1300ml) whereas the theoretical daily productivity was 1.6 kg/m^2/day (1600 ml) on 17th of August, 2022 with internal reflectors and black basin. There was error of approximately 22 % between the cumulative productivity of experiment and theoretical value. The error is due to the fact that there is occurrence of different types of losses during the real experiment while no losses is assumed in theoretical solution.

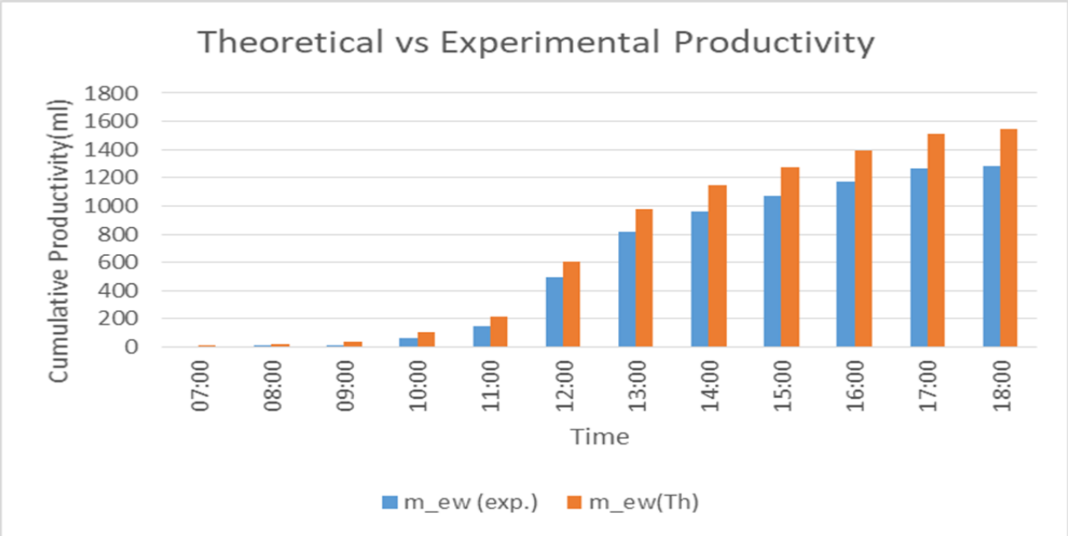


Figure 4.11: Theoretical vs Experimental Cumulative Productivity

Comparison between the productivity obtained from E1 and E2

The daily productivity obtained from first experiment performed on 16th August, 2022 in which there was absence of internal reflector and no any kind of black painting was done on the base of the basin resulted in lower daily productivity as compared to the experiment performed on other day.

The experiment performed on the next day constituted of the aluminium foil as internal reflectors on the side walls. Apart from this, the basin surface was painted black. When experiment was performed, on the basis of the result it can be concluded that the daily productivity was enhanced by significant value when internal reflectors and black base was used.

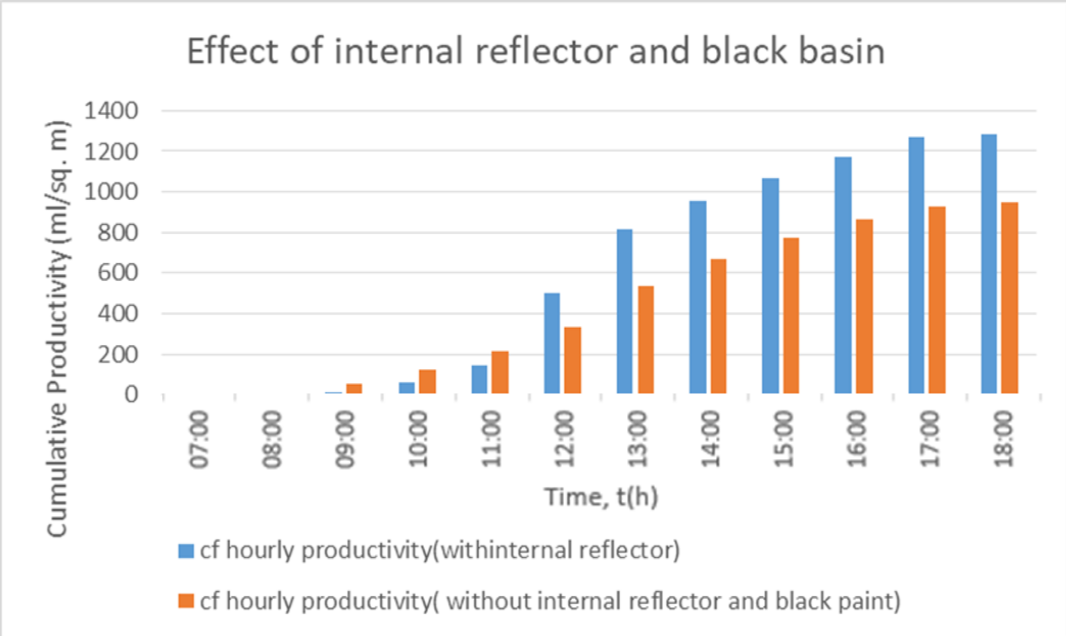


Figure 4.12: Graph showing the effect of internal reflectors on the productivity of distillate output

Figure 4.12shows the cumulative hourly productivity of the both the experiment. It can be clearly seen that the use of internal reflector and black paint enhances the productivity of solar still. The daily productivity in E1 was 0.9 kg/m^2/day whereas the daily productivity in E2 was 1.3 kg/m^2/day. Thus, approximately 45% more productivity was achieved by the used of internal reflector and black basin. The reason for this increment is that black basin increases the absorptivity as a result of which basin temperature increases. Apart from that use of internal reflector directs the solar radiation towards the basin as a result of which basin temperature increases and evaporation rate increases due to which productivity also increases.

4.2 Results obtained from CFD Simulation of Solar Still

The modelling and simulation has been carried out for the three dimensional single slope passive solar still by specifying different parameters and values by the application of Computational Fluid Dynamics (CFD). After initialization of the solution, the results have been obtained in the form of different types of contours and graphs in following chapters.

The major parameter which plays important role in the working of the solar still is the inside basin water temperature, temperature of the condensing glass and temperature inside solar still where the phenomena takes place. Thus, it can be stated that the output productivity of the solar still depends upon the temperature difference between the water inside basin and the condensing glass. Contours showing the profile of the temperature has been generated in the simulation.

The temperature profile contour of the single slope solar still gives following information:

1. When solar radiation of the sun falls on the glass and it goes to the water through it, water starts getting heated up due to which evaporation of the water takes place and water gets converted in vapor. Due to the evaporation and conversion of water to vapor the inner temperature of the solar still rises with time.
2. The internal temperature of the solar still keeps on rising with the increase of the solar radiation till its peak after which it starts decreasing. The temperature shows the behavior similar to the solar irradiation.
3. Furthermore, the contour of the solar still shows that the temperature increases with increase in the solar radiation due to which the inside vapor temperature of the solar still also keeps on rising with glass and water.
4. On the other hand, it can be clearly seen from the temperature profile of the condensing glass that glass temperature is also increasing with time but glass temperature is always less than the water temperature.
5. Glass temperature also follows the pattern similar to that of solar radiation and water temperature. The lower temperature of the glass is responsible for the condensation phenomenon in solar still. Since there is temperature

difference between the temperature of evaporated water and glass inner temperature, condensation of the vapor takes place.

The snapshot of various contour of components is shown taken at peak period of time. First contour in Figure 4.13 represents temperature profile of basin at time 12:00 to 14:00. It shows that the temperature is maximum and the front surface of the basin has less temperature. It is due to the presence of distillate water channel

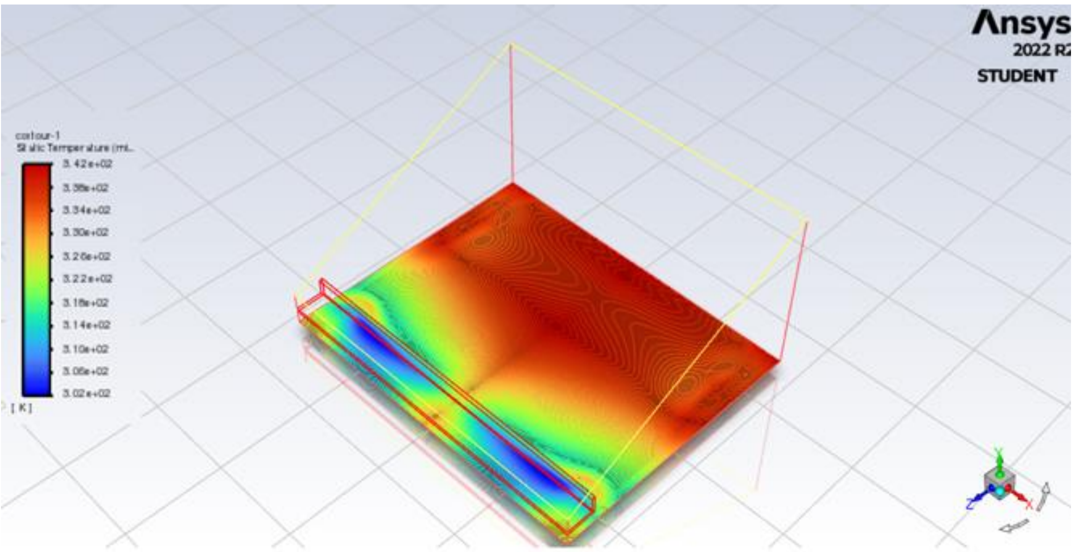


Figure 4.13: Temperature Profile of absorber basin

at front wall.

Similarly, the temperature profile of the glass as shown in the Figure 4.14. It represents the temperature of the condensing glass at time 12:00 to 14:00 during which the solar radiation is high and basin temperature is high.

- From the contour of condensing glass shown in figure, it can clearly be

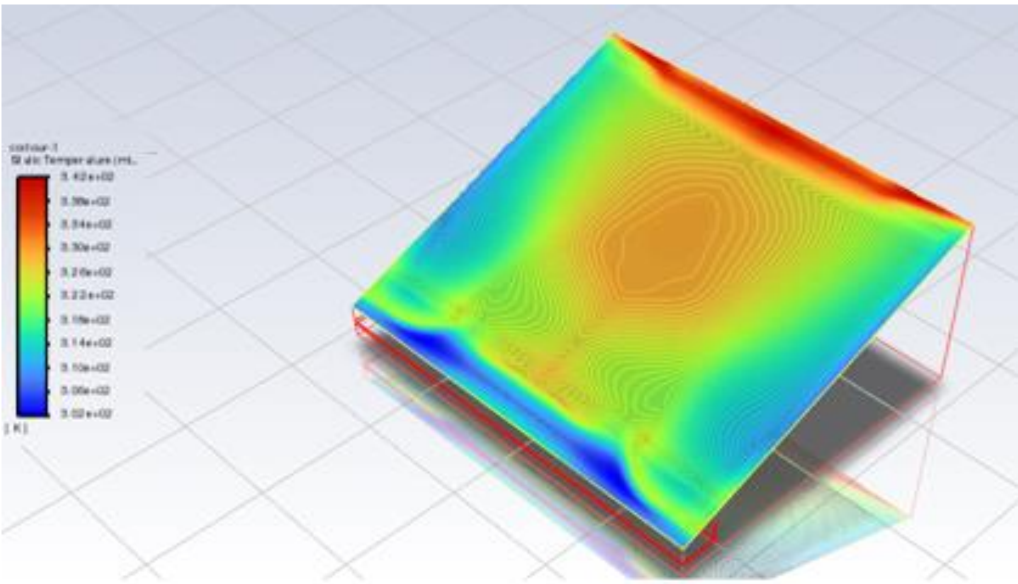


Figure 4.14: Temperature Profile of Glass

seen that there is greater temperature at the top edge of the glass where as there is lower temperature at the lower end of the glass. The lower temperature at the lower end of the condensing glass is because of the distilled water which slides from upper end of glass to the lower end of the glass.

Since the evaporation takes place at basin and there is maximum heat at the basin and water. The temperature at the basin is much greater than the glass and inlet vapor as shown in the Figure 4.15

The front end of the basin has lower temperature as compared to center and the upper end because of the presence of the distillate channel on which condensing water is collected. This is why, the temperature at front end of inlet water or basin

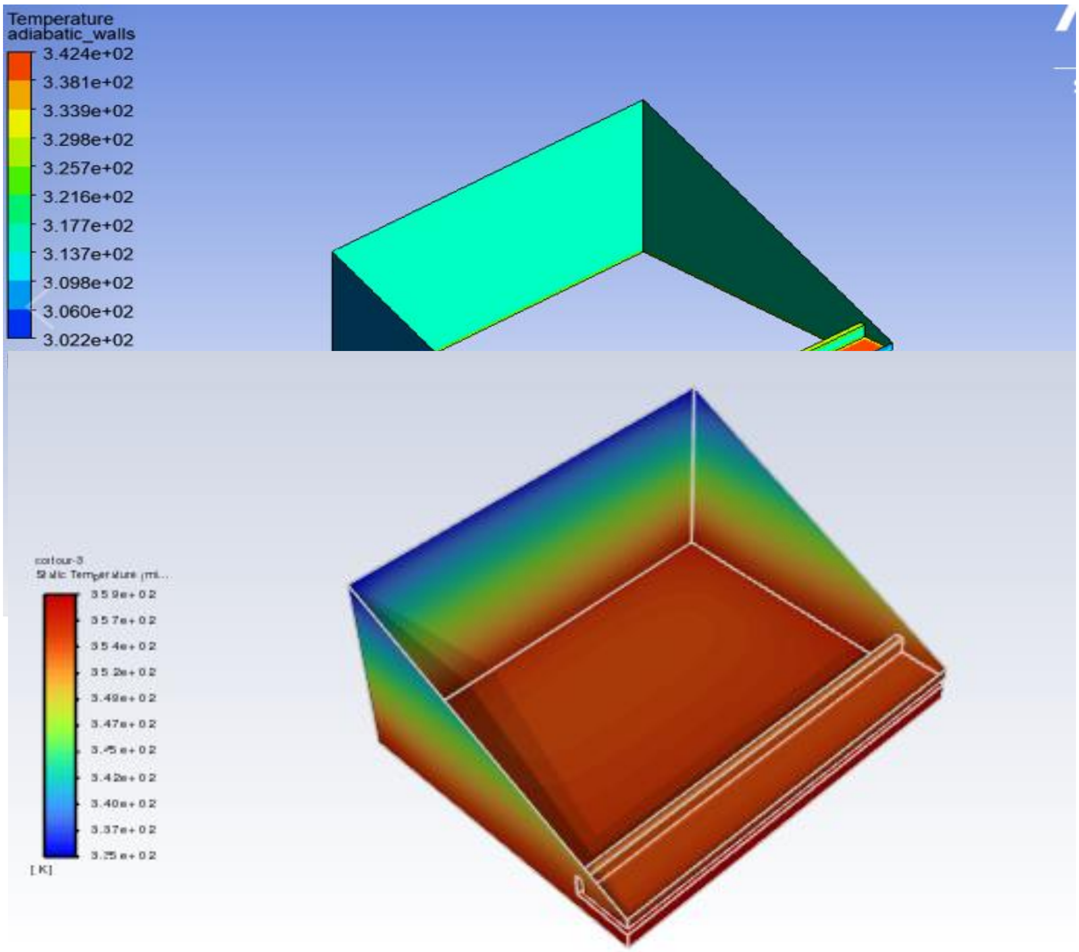
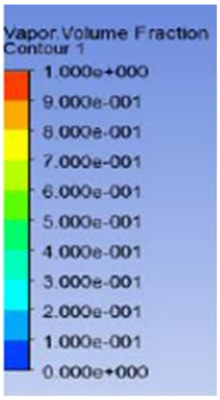


Figure 4.15: Basin water temperature

is lower than the remaining area.

The side wall of the solar still is kept as adiabatic during the CFD simulation because the walls of the solar still are insulated. Due to this, reason, the wall have minimum temperature due to adiabatic conditions as shown in the Figure 4.16. The distillate channel collects the distillate output of the water. Apart from that the volume fraction of liquid obtained in the distillate channel was 0.7 which meant that the condensed water is being collected in the distillate channel after



condensation.

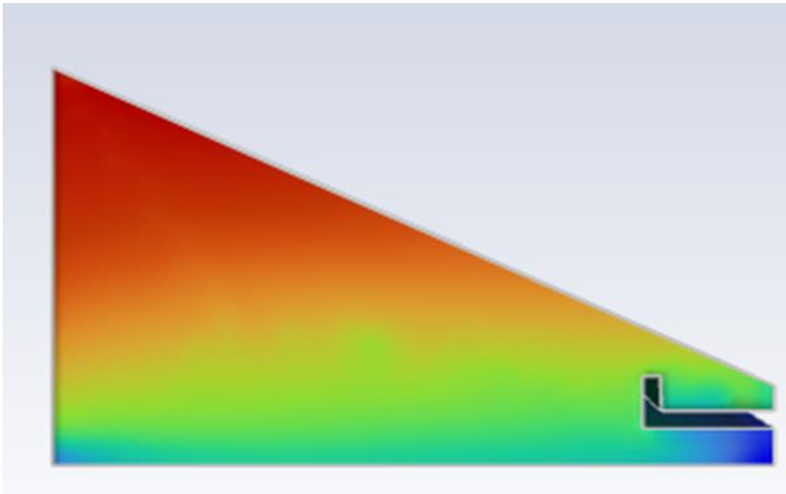


Figure 4.17: Volume fraction of vapor in solar still at 12:00 to 14:00

Figure 4.17 shows the contour of volume fraction of vapour inside the interior of solar still during the peak radiation of the day. It shows that maximum volume of vapor lies near the upper surface of the solar still after which the condensation of the water takes place.

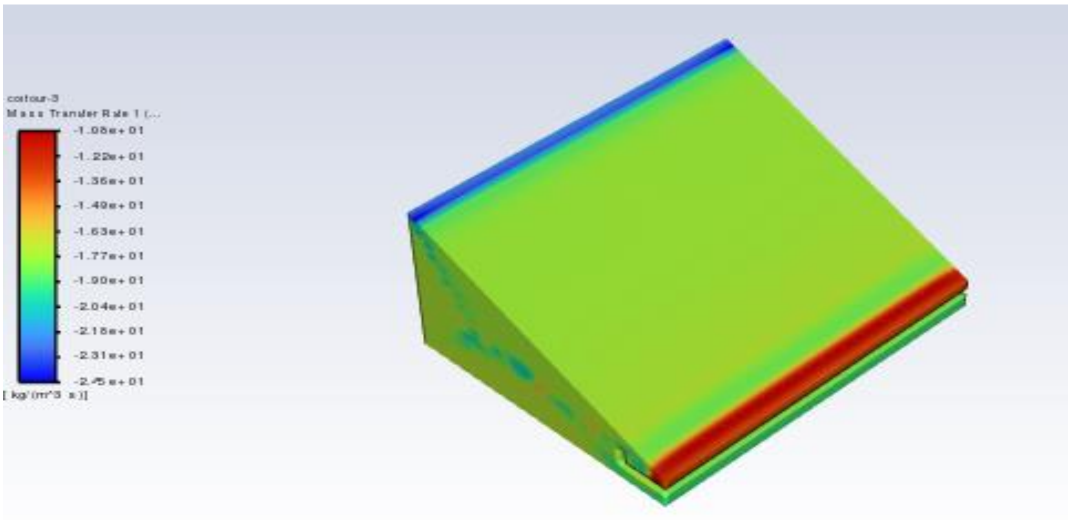


Figure 4.5 shows different mass transfer of water from basin in single slope solar still. It shows that the water is collected to the distillate channel in solar still.

4.3 Model Verification

The simulation of the various temperatures such as basin water temperature and the temperature of glass was done in order to verify the simulated result with the experimental result. Since, the simulation result and the experiment performed on 17th August, 2022 at Balaju School of Engineering and Technology was compared with the data obtained after simulation.

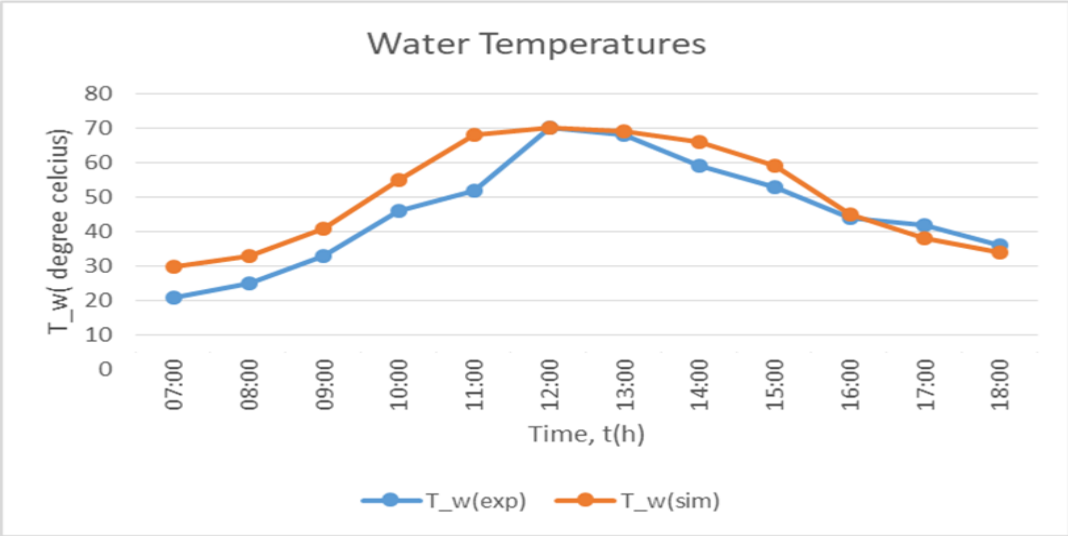


Figure 4.18: Plot between water temperature obtained from experiment and simulation results

Figure 4.18 shows the comparison between the experimental result and simulation result of the temperature of the water of the solar still. The graph shows that till 3rd fourth of the time experimental result shows similar trend as of the simulation result but at the final three hour the temperature obtained in experimental data is more than the simulation data. The difference in the result might be due to the fact that CFD considers ideal characteristics and constant physical properties.

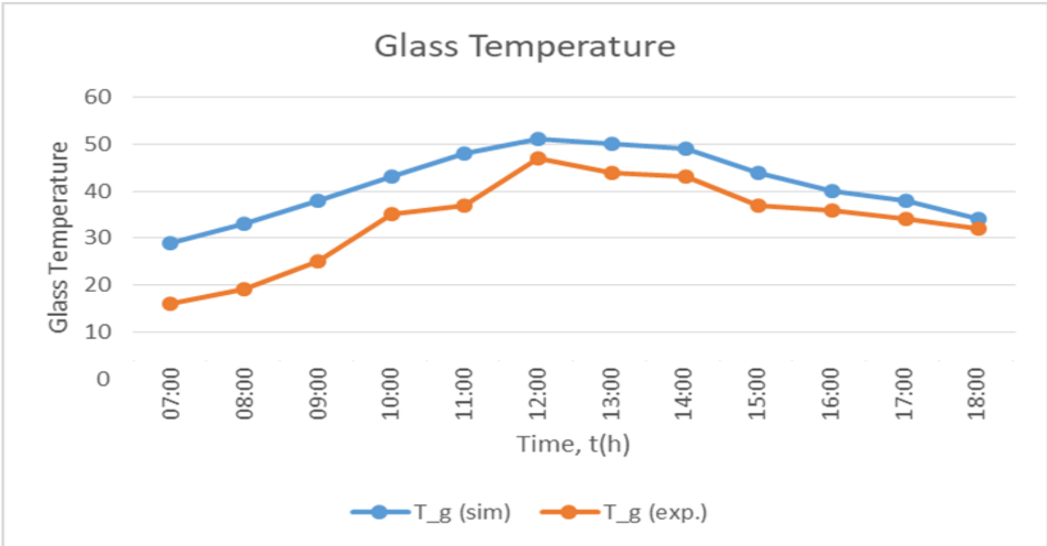


Figure 4.19: Glass temp. vs time

Figure 4.19 shows the comparison of simulated result and experimental result of the glass temperature. Both follow similar trend with some differences between them. This difference might be due to the reason that CFD tool does not consider natural attenuation for the simulation. Also the properties which CFD tool considers during the simulation might differ to the actual physical condition. Both glass temperature and water temperature similar pattern as that of solar radiation. The temperatures are high when the radiation are high.

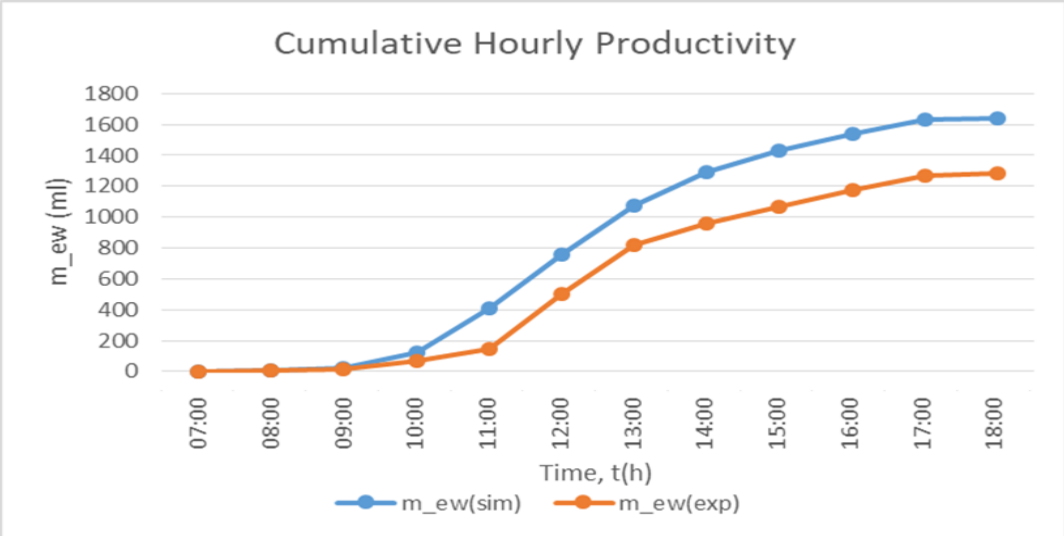


Figure 4.20: Experimental and simulated hourly cumulative productivity variation with time

From the Figure 4.20, it shows that the simulation follow similar pattern but there are few times where the productivity is less. This might be the result of the losses from the solar still while performing the experiment.

4.4 Impact of volume of water inside basin on the distillate productivity

There are various critical variable which is responsible for affecting the quantity of water obtained as an output in the solar still. Such critical parameters are the angle of inclination of glass cover, material of the basin, type of insulation, temperature, and the initial volume of the water inside the basin.

The present work tries to find out the effect of different volume of water in the basin on the production volume of distillate water from the solar still. The effect of different volume of the water inside the basin is investigated with the help of the CFD simulation. Glass temperature and water temperature was obtained from the simulation on the basis of which cumulative distillate output was calculated and graph was plotted.

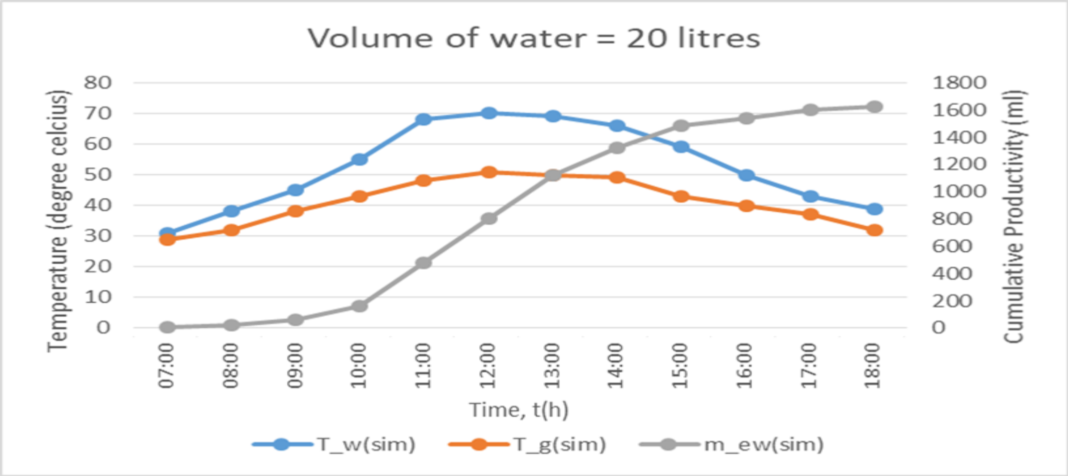


Figure 4.21: Variation of temperature and cumulative productivity with time (20 litre)

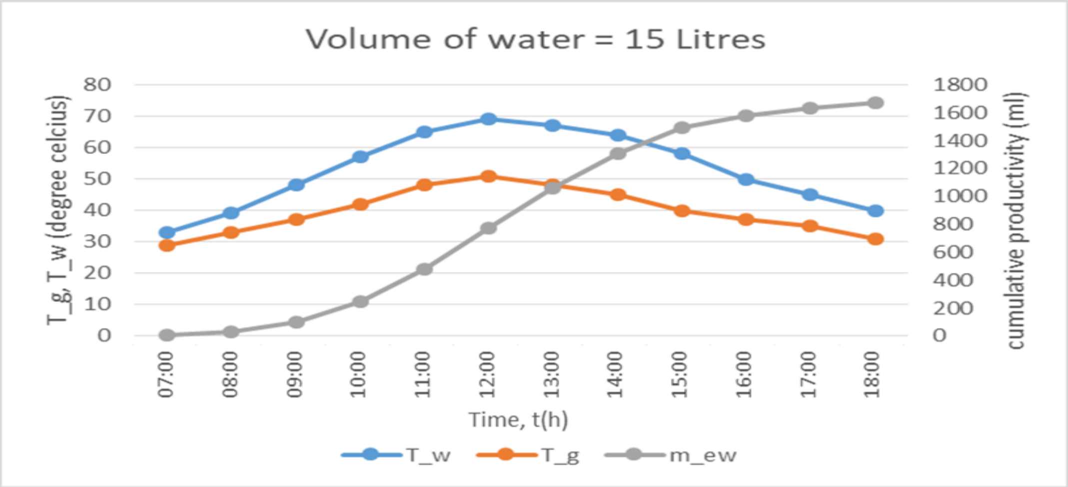


Figure 4.22: Variation of temperature and cumulative productivity with time (15 litre)

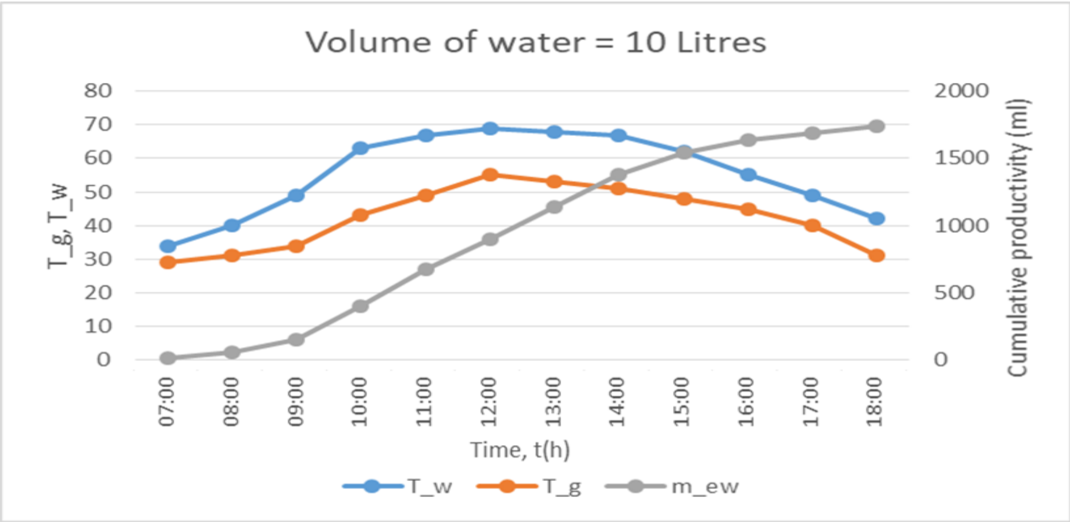


Figure 4.23: Variation of temperature and cumulative productivity with time (10 litre)

Figure 4.21shows the behavior of solar still when the initial water volume of the basin is kept at 20 litres. Figure 4.22 shows the behavior of the solar still when the initial water level is kept to 15 litres in the basin. The quantity of water plays a key role in the heating process of the water. If the volume of water in the basin is low, the temperature of water rises at higher rate due to which the rate of evaporation increases as a result of which productivity of output water is increasedas shown in graph inFigure 4.23.

The water output daily productivity was found to be 1620ml when the volume of the water is kept to 20 litres. Similarly it was found to be 1671ml when basin volume is 15 litres. On the other hand, it was found that the total productivity of water was 1738 ml when the initial volume of water was kept at 10 litres. Thus, it was found that the reduction in the volume of input water frome 20 litres to 10 litresresulted in the increase of the production output by 7%. The output water increased with decrease in the volume due to the fact that less water attains less heat capacity and gains temperature faster and higher.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The major objective of this research was toinvestigate the major parameters in order to enhance the productivity of distillate water by performing simulation and verifying it with experimental results. Initially, geometry of the solar still was created using design modeler module of the ANSYS Workbench. After that meshing was done checking proper element size and quality of mesh. Once the meshing was done, different model was selected as per the nature of the solar still. Multiphase flow model with radiation model was chosen for the current research. After that, appropriate material was chosen and boundary conditions was specified. After applying all the conditions, finally the solution was initialized by the solver and result was obtained for 17th August, 2022. Simultaneously, the experimental set up was designed and fabricated and two situation was compared. Initially the experiment was performed without black paint on the basin and without any internal reflectors on 16th August, 2022. On 17th August, the same experiment was performed by applying black paint on the water basin and using aluminium foil internal reflectors. The result of simulation and experiment performed on 17th August, 2022 was compared.

Following major points can be concluded for the present research:

- Experimental setup of the single slope solar was fabricated initially. Two experiment was performed in the experimental setups with some changes. Initially, the testing was performed without black paint on the water basin on and without any type of internal reflector on 16/08/2022. On the other day on 17/08/2022, the experiment was performed by applying black paint on water basin and using aluminium foils on the side walls as internal reflectors. The cumulative distillate output water obtained without internal reflector was 0.9 kg/m^2 in the period of 11 hours.On the other hand, cumulative distillate output water obtained with black basin and aluminium foil internal reflector was found to be 1.3 kg/m^2. The experiment with internal reflector and black paint showed 45% more productivity as compared to the solar still with normal unpainted basin and without internal reflectors.

- Modelling and simulation of the single slope solar still was done. The experimental result and simulation result of 17th August was showing similar trend but there was a different between the data. The difference between the data is due to the fact that simulated data doesnot consider losses that happens during the experiment. During simulation, investigation of input water volume on the output was also done. Different volume of water i.e. twenty litres (20 litres), and 10 litres (10 litres) volume was taken during simulation to find out the effect of volume of water on the productivity. The simulation result showed that the daily productivity of the water was increased by decreasing the volume of water in the basin. The result showed that the productivity increases by 7% with lower 10 litres of water in the basin. The daily productivity attained with 20 litres of water was 1620 ml/m^2, with 15 litres of water was 1671 ml/m^{2}whereas with 10 litres of water was 1738 ml/m^2.
- Based on the experimental evaluation and simulation result, it was found that the major parameter which is responsible for the productivity of the distillate water are water temperature, glass temperature, solar irradiation, volume of input water etc.

5.2 Recommendations

From the knowledge and experience gained while performing both experiment as well as simulation study of the single slope solar still, following recommendations are drawn that will help in getting better result and use the present research for future:

- Different material of basin can be used as the material of basin is directly related with the temperature of the basin.
- Modelling and simulation of the solar still by varying the shapes of the solar still and the obtained result could be compared with the result of the present research.
- The simulation of solar still with multiple layer glass and open type system of solar still could be researched in future.

5.3 Future Works

On the basis of the current research, following works can be done in future in order to get more precise result with minimum results.

- Performing experiment and simulation by using different material for the basin.
- Performing experiment during summer season and observing data for longer period of time to know the exact climatic variation in the result.
- Performing experiment and simulation of other type of solar still such as wick type, double slope, solar still with phase change material etc.
- Dropwise condensation could be simulated instead of filmwise condensation.

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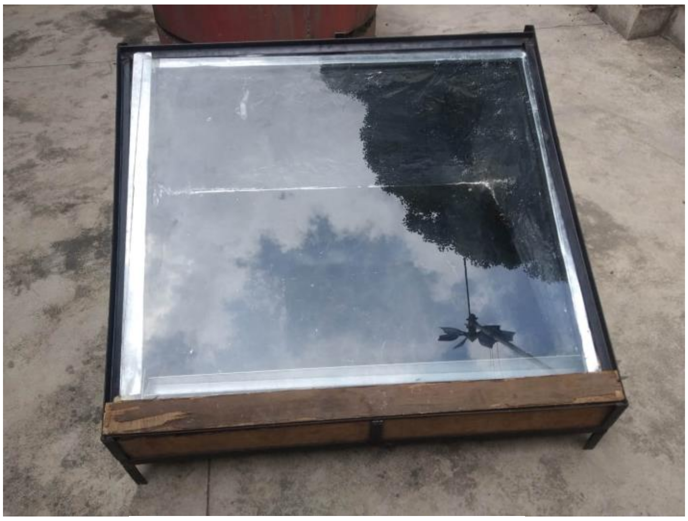
APPENDICES

1. Experimental Setup of Single Slope Solar Still



Experimental Setup of SS

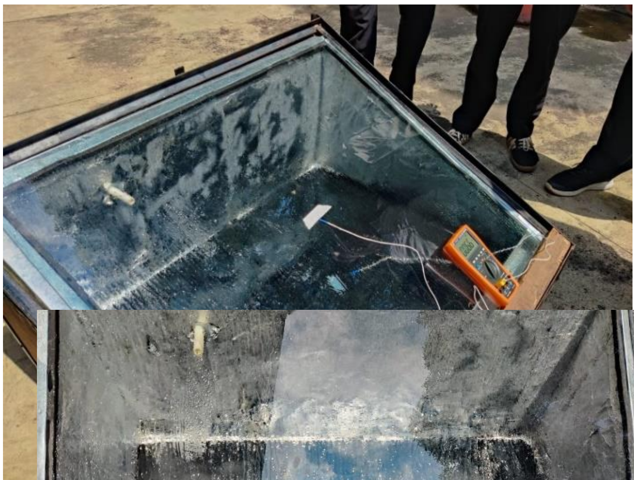
Inlet for feed water in SS

Outlet for distillate water

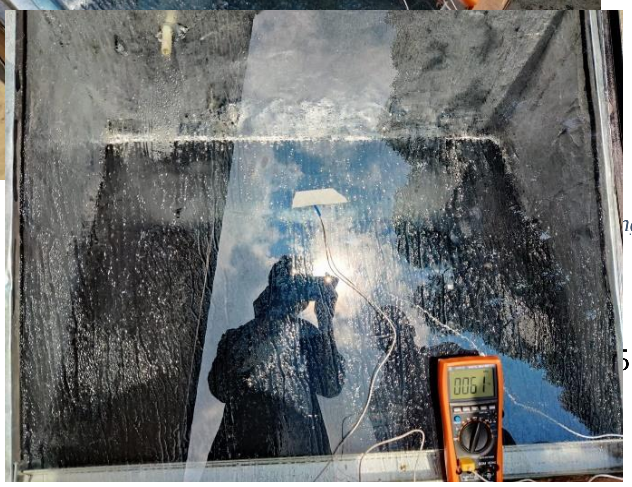
2. Different Process Observed During Experiment


Evaporation process during experiment in solar still

3. Types of Thermocouple




ng experimen




Distilled water collection during experiment from solar still

TYPE	MATERIAL	TEMPERATURE RANGE (^{O}C)
K	Nickel Chromium / Nickel Alumel	-185 to 1260
J	Iron / Constantan	0 to 760
T	Copper / Constantan	-185 to 370
E	Nickel-Chromium / Constantan	-180 to 870
N	Nicrosil /Nisil	0 to 1260
S	Platinum Rhodium 10% / Platinum	0 to 1480
R	Platinum Rhodium 13% / Platinum	0 to 1480
B	Platinum Rhodium 30% / Platinum Rhodium 6%	0 to 1760

(Source: User manual and specification catalogue)

4. Properties of Water

- Prandtl No., Pr = 0.71
- Kinematic viscosity, ν = 16.9 × 10-6 m2/s

- Thermal conductivity, k = 0.027 W/mK
- Enthalpy of evaporation, h_{fg} = 2335 kJ/kg

5. Properties of Different Material Used

Materials		**Properties**	
	Thickness (mm)	**Thermal conductivity (W/m.K)**	**Emissivity (ε)**
GI Sheet	0.5	18	0.88
Glass	5	0.80	0.97
Water	-	0.027	0.95

6. Solar Radiation Data

Solar Radiation Data from data from 16/08/2022 to 23/08/2022 in W/m^2.

Time	16th Aug, 2022	17th Aug, 2022	18th Aug, 2022	19th Aug, 2022	20th Aug, 2022	21st Aug, 2022	23rd Aug, 2022
06:00	72.2	94.6	86.9	36	39.4	73.3	76.6
07:00	336.7	327.2	303.5	141.9	203.8	201.6	294.8
08:00	534.1	575.9	505.9	347.8	451.6	588.2	528.8
09:00	655.9	799.8	704	647.7	459.3	796.1	692.2
10:00	955.9	969.1	863.2	818.2	825.5	947.5	881.2
11:00	923.7	1078.6	990.2	978.7	1006.9	1059.3	1040.8
12:00	674.9	1049.2	755.4	714.7	850.8	1088.5	906.7
13:00	970.7	527.4	790.7	845.7	691.3	879.3	497.3
14:00	615.3	497.3	592.3	728.3	609.4	913.8	199
15:00	154.1	584.1	432.3	273.1	215.6	789.6	49.2
16:00	254	533.1	203.4	123.9	216.8	602.6	37.9
17:00	194.1	273.5	84.2	94	129.9	278.3	24
18:00	60.4	57.4	9.6	20	20.8	34.8	2.4

7. Experimental Data

Experimental Data of Solar Still without Black Paint on Basin and Internal Reflectors (16/08/2022)

Time(t)	**I(t) (W/m^2)**	**v_w (m/s)**	**T_a (^0C)**	**T_w (^0C)**	**T_g (^0C)**	**m_{ew} (ml)**	**cumulative hourly productivity**
07:00	336.7	1	25.9	25	22	0	0
08:00	534.1	1.3	25.6	27	23	0	0
09:00	655.9	1.4	27.9	34	28	52	52
10:00	955.9	1.8	28.9	44	31	70	122
11:00	923.7	1.5	29.4	56	38	90	212
12:00	674.9	2.8	29.5	55	36	125	337
13:00	970.7	3.8	30.3	65	40	200	537
14:00	615.3	3.6	28.6	62	35	135	672
15:00	154.1	2.6	27	44	25	105	777
16:00	254	3	27.6	45	24	90	867
17:00	194.1	3.9	27.5	42	22	60	927
18:00	60.4	3.7	25.6	35	21	20	947
						947	

8. Theoretical Data (With internal reflector and black basin)

P_w (Pa)	**P_g (Pa)**	**h_{cwg}(W/m^2 ^{0}C)**	**h_{ewg}(W/m^2 ^{0}C)**	**m_{ew} (exp.) (kg/m^{2}h)**
2461.41	1840.32	1.5	3.15	0
3150.31	2209.59	1.61	4.12	0.004
4947.03	3150.31	1.78	6.52	0.01
9814.42	5517.62	2.01	12.78	0.051
13217.6	6145.35	2.25	17.25	0.082
30330.7	10321.7	2.71	38.39	0.352
27776.8	8865.04	2.73	34.96	0.318
18453.8	8421.3	2.33	23.8	0.142
13875.2	6145.35	2.3	18.08	0.112
13217.6	5824.05	2.3	17.26	0.106
11983.7	5225.47	2.29	15.72	0.092
7591.88	4681.75	1.87	9.84	0.018

9. Specification of Multimeter

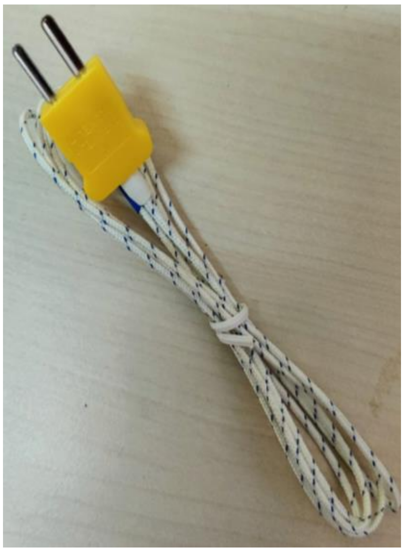
Temperature Specification of Digital Multimeter (From user's manual)

Temperature (^{0}C)

Range	**Accuracy**	**Resolution**
-40^{0}C-1000^{0}C	<400^{0}C $\pm$ (0.8%+4)	1^{0}C
0F-1832^{0}F	<750^{0}F$\pm$(1.0%+5)	^{0}F

Thermocople: K Type

Digital Multimeter



K-Type Thermocouple

10. Input Solver and Solution Parameters Used

Input Solver Parameters in ANSYS FLUENT:

1. Solver:
    - Space: Three dimensional Space used
    - Time: Transient condition, 1st order, implicit function
    - Viscous model: k-epsilon (2 equation) with standard wall functions
    - Multi-phase model: Mixture model
    - Radiation model: Rosseland model with solar tracking system and solar loading as per the value of Kathmandu
2. Materials Used:
    - Solid Material:
      Galvanized iron sheets (GI), Aluminium and Glass
    - Fluid Material:
      Air, Water-liquid, Water-vapor
3. Phases
    - Number of phases: 3
    - Phases involved: air, water-liquid, water-vapor
    - Primary phase: air
    - Secondary phase: water-liquid and water-vapor
4. Cell Zone: Source term – Energy source
5. Operating condition:
    - Gravity axis: Y-Direction
    - Gravity value taken: -9.81 m/s^2
    - Operating pressure and temperature: 1.01 bar and 288.16K

Parameters for method and controls of solution of solar still in ANSYS FLUENT:

1. Pressure-velocity coupling: Simple
2. Spatial Discretization
    - Pressure: PRESTO
    - Momenturm, Energy, Liquid Volume Fraction: 1st order upwind
3. Solution Controls
    - Governing equations: Momentum, Continuity, Energy, Std. Initialization Method.

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Date: September 14, 2022

To Whom It May Concern

This is to confirm that the paper titled "*Experimental Investigation of Parameters Affecting Productivity of Single Slope Basin Type Passive Solar Still*" submitted by **Shah Nawaz Ansari** with Conference ID **12132** has been accepted for presentation at the 12th IOE Graduate Conference being held in October 19 – 22, 2022 at Thapathali Campus, Kathmandu.

Khem Gyanwali, PhD
Convener,
12th IOE Graduate Conference