Chapter

Thermosyphon Heat Pipe Technology

Bala Abdullahi, Raya K. Al-dadah and Sa'ad Mahmoud

Abstract

Heat pipes play vital roles in increasing heat transfer performance of many engineering systems such as solar collectors and this leads to an increase in their usage. Investigation on the performance of heat pipes under different operation conditions and inclination angles is required for effective utilization. In this chapter, a general overview on the construction, operation, advantages, and classifications of heat pipes is presented. Particular attention is given to the heat pipe without wick material in the inner diameter (thermosyphon). Intensive discussions are presented on the construction, operations, advantages and applications of thermosyphon heat pipe. The experimental and numerical approaches on the performance evaluation and characterization of thermosyphon are discussed. A detailed procedure on how experimental work is carried out on thermosyphon is discussed including instrumentation and calibration of the devices. Modelling and simulation of the performance of thermosyphon are discussed, including the model set-up procedure. Factors affecting the performance of thermosyphon such as fill ratio, working fluid, heat input, inclination angles, are analysed based on the overall thermal resistance and thermosyphon performance. Current researches on the effects of major factors affecting the operation of thermosyphon are presented, as well as their current development and various applications in engineering systems.

Keywords: thermosyphon, evaporator, condenser, thermal resistance, inclination angle

1. Introduction

The world's needs for effective heat transfer devices/mechanisms are increasing so as to minimize heat losses, minimize systems cost, enhance heat removal and transportation as well as to increase lifespan of some devices. In some instances, heat is required to be removed from a system (like solar photovoltaic, electrical devices, turbine blades, etc.) in order to keep it at a certain operation temperature, while in other cases, it is required to be transferred to a certain region to keep it at high temperature. Some elements/metals such as copper and aluminium are found to be good conductors of heat as they transfer heat effectively from one region to another. Their ability to transfer heat effectively is due to their molecular arrangements and type of bonds between their molecules. Various systems such as aircraft, electronics, heat exchangers, solar collectors, etc. require effective means of heat transfer. One of the devices recognized as effective means of heat transfer is heat pipe, whose idea was introduced by Graugler in 1942, but its first unit was invented by Grover in 1962;

then, its important properties were studied and identified, and its development started [1]. Hence, with the growing need for efficient heat transfer devices, interest in the use of heat pipes for various applications is increasing due to the roles they play in improving the thermal performance of solar collectors and heat exchangers particularly in energy savings and increasing efficiency of the systems.

Heat pipe is an efficient two-phase heat transfer device which uses latent heat of fluids to transfer energy from one place to another by means of simultaneous evaporation and condensation in a sealed container. It consists of evaporator and condenser sections with or without adiabatic section in between them. Depending on the type, heat pipe may have wick materials on its internal surface where the simultaneous evaporation and condensation take place in the wick structure. In such types of heat pipe, evaporator section can be placed at the top, since the wick structure can return the condensate from the condenser section against gravity. Hence, in a wick heat pipe, the condensed liquid is returned to the evaporator by capillary effects with the assistance of the wick materials as shown in **Figure 1**.

However, many applications do not require inserting wick material on the inner surface of the pipe, because the condenser section can be placed at the top, so that the condensed liquid returns to the evaporator by gravity. This type of wickless heat pipe is called thermosyphon as shown in **Figure 2** Hence, for thermosyphon, the condenser must be above the evaporator, while for the wick heat pipe, the capillary forces in the wick ensure the condensate returns to the evaporator regardless of its position.

1.1 Working principles of heat pipe

Heat pipes consist of sealed vessel usually made from aluminium or copper with or without wick material lined on the inner surface and working fluid charged under a vacuum condition. It is made up of two main sections: evaporator, where the working fluid absorbs heat, and condenser, where the working fluid rejects heat (**Figures 1** and **2**). As heat is added to the working fluid in the evaporator section, it evaporates into vapour when it reaches its saturation temperature. It rises to the condenser with the assistance of buoyancy force and due to the vapour pressure difference between the two sections. The liquid condenses by giving out its

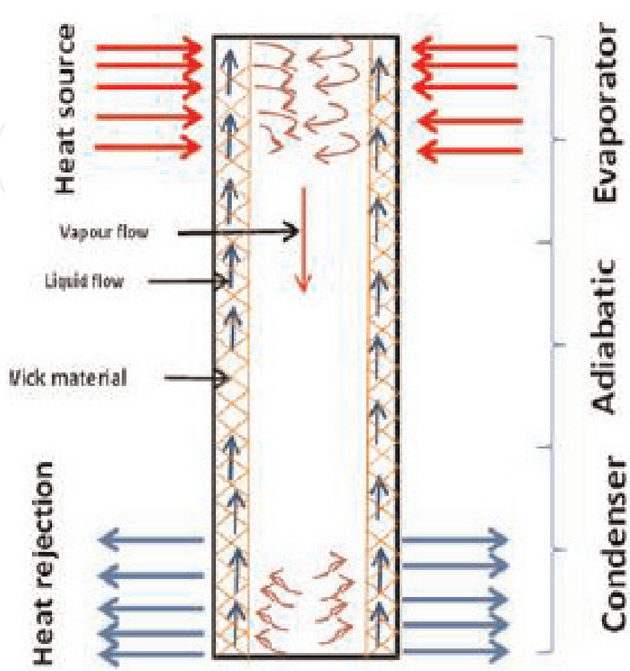

Figure 1.
Operation of wick heat pipe [2].

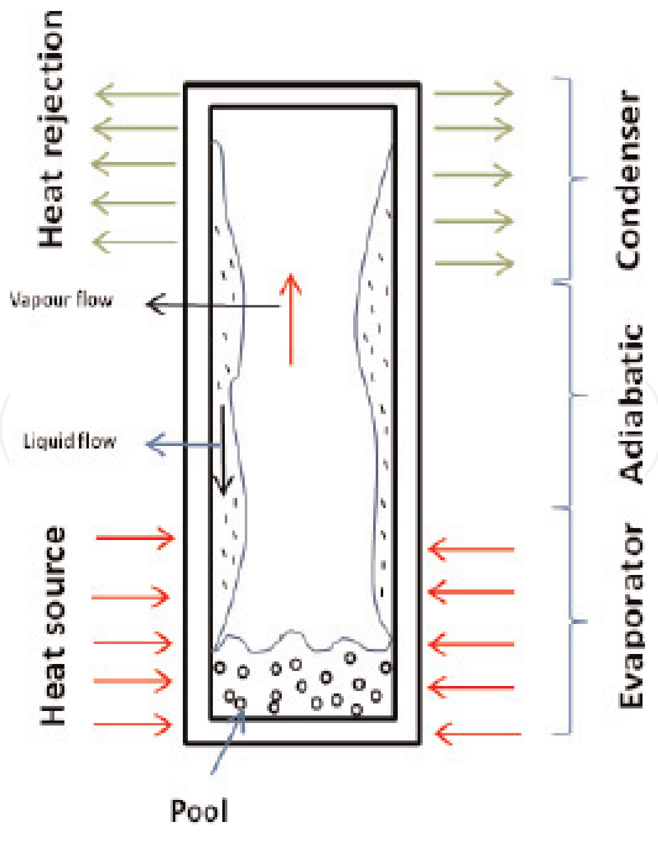

Figure 2.
Operation of thermosyphon [2].

enthalpy to the cooling water in the condenser section and returns back to the evaporator for another cycle.

1.2 Advantages of heat pipe

Heat pipes offer advantages over other heat transfer devices used for various applications in engineering systems. The technology has undergone rapid development due to their operational advantages [3]. Some of these advantages include:

i. High thermal conductivity: In terms of heat transfer, heat pipes are better than the best conductor; hence, they are referred to as 'superconductors'.

ii. Light weight.

iii. Efficient heat transfer.

iv. Flexibility in design.

v. Isothermal operation.

vi. Tolerance to freezing, shock and vibration.

vii. Low cost.

1.3 Classifications of heat pipe

There are different types of heat pipes, classified based on [4]:

I. Nature of fluid circulation, such as capillary driven, rotating heat pipes, flat plate, two-phase close thermosyphon, etc.

II. Control of heat transfer: They are 'controlled heat pipes', such as variable-conductive, thermal switch and thermal diode.

III. Electrostatics-driven heat pipes such as electro hydrodynamic heat pipe.

IV. Osmosis-driven heat pipe such as osmotic heat pipe.

V. Others including inverse, micro, reciprocating, cryogenic, capillary pumped loop heat pipes, etc.

1.4 Applications of heat pipe

Due to the advantages of heat pipes, the technology found its applications in many fields of engineering such as:

i. Spacecraft thermal control [5]: the first test of heat pipe in space was in 1967 [6] and the first heat pipe used for satellite thermal control was on GEOS-B launched from Vanderburgh Air force Base in 1968 [7].

ii. Component cooling, temperature control and radiator design in satellites. Other applications include moderator cooling, removal of heat from the reactor at emitter temperature and elimination of troublesome thermal gradients along the emitter and collector in spacecraft.

iii. Heat pipes for dehumidification and air conditioning: The heat pipe is designed to have one section in the warm incoming stream and the other in the cold outgoing stream. By transferring heat from the warm return air to the cold supply air, the heat pipes create the double effect of pre-cooling the air before it goes to the evaporator and then re-heating it immediately.

iv. Heat exchangers [8].

v. Solar energy systems [9, 10] as shown in **Figure 3**.

vi. Electronic cooling [12, 13], etc.

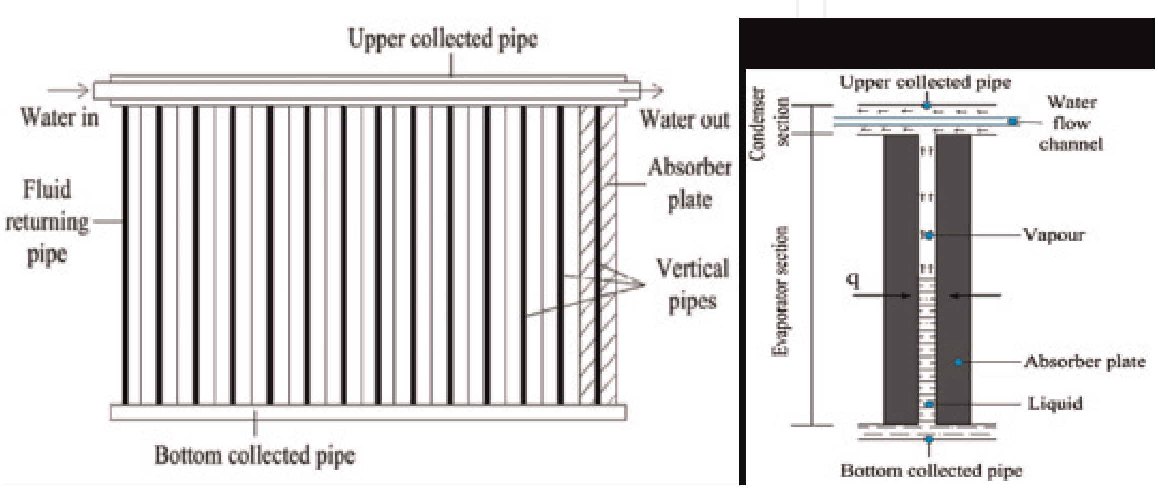

Figure 3.
Developed thermosyphon heat pipe solar collector [11].

1.5 Difference between wick heat pipe and thermosyphon

The wick and wickless (thermosyphon) heat pipes have many features in common in their construction, operation and applications. However, they differ in some aspects such as:

a. Wick material: unlike in thermosyphon, wick materials are lined on the inner parts of the wick heat pipe. This enables the return of the condensed liquid even against gravity.

b. Orientation of the pipes: the condenser section of the thermosyphon must be located at the top of the evaporator because the return of the condensate is basically by gravity, while in the case of the wick heat pipe, the evaporator can be placed at the top because the return of the condensate is based on the capillary effects due to the presence of the wick materials.

c. Need of adiabatic section: thermosyphon may or may not have adiabatic section whereas most of the wick heat pipes have it, as to separate the evaporation and condensing sections.

d. When working fluid is charged into the sealed container, it forms a liquid pool (in case of thermosyphon) while in case of wick heat pipe, it saturates the wick materials.

2. Thermosyphon heat pipe

This is a natural fluid circulation heat pipe which has no wick material presence. It is a simple heat pipe consisting of a sealed vessel charged with working fluid under a vacuum condition. It is made up of evaporator and condenser sections, sometimes with adiabatic section in between them. The vessel is usually made from aluminium or copper to facilitate high conduction of heat. Unlike wick heat pipe, the condenser of thermosyphon must be at the top, for the condensed liquid to return to the evaporator under gravity. Furthermore, some applications of thermosyphon require that the pipe be tilted to an angle from the horizontal for it to have maximum exposure to solar radiation [9, 14–16].

2.1 Construction of thermosyphon heat pipe

Thermosyphon is a vessel closed at both ends and attached with a small charging pipe placed at one of the ends. The air in the vessel is evacuated creating a vacuum, then charged with working fluid through the charging pipe. The pipe is usually divided into the following sections:

i. Evaporator, where heat is supplied to the working fluid.

ii. Adiabatic section (optional): space between evaporator and condenser, where no heat or cooling is applied.

iii. Condenser, where the vapour from the evaporator section of thermosyphon heat pipe is condensed usually by cooling water flowing through a water jacket.

iv. Insulation: the evaporator section is insulated to minimize heat losses.

The materials for the manufacturing of thermosyphon are carefully selected to ensure its effective performance. Other considerations are the type and the quantity of working fluid to be charged into the pipe.

2.2 Operation of thermosyphon heat pipe

The working principles of thermosyphon are similar to that of the wick heat pipe, but differ in the process of the return of the condensed liquid in the condenser due to the absence of wick structure. For proper operation of thermosyphon, the condenser is placed at the top of the evaporator so that the condensed liquid will return to the evaporator by gravity. **Figures 4** and **5** show a schematic diagram and a model of a typical thermosyphon (constructed in the University of Birmingham, UK) with heat supplied by coil of wire and heat rejected to the flowing water in the water jacket provided on the condenser section [17]. However, in some operation set ups, the heat can be supplied by hot water surrounding the evaporator of the pipe.

2.2.1 Operation limits of heat pipe

Heat pipe (with or without wick materials) operates within certain limits which are shown in **Figure 6**. For the heat pipe to operate, the maximum capillary pumping pressure must be greater than the total pressure drop; thus:

$$\Delta P_{c,\max} \geq \Delta P_l + \Delta P_v + \Delta P_g \tag{1}$$

The pressure drop is the sum of the following:

ΔP_l = Pressure drop necessary for the liquid to return from the condenser to the evaporator.

ΔP_v = Pressure drop necessary for the vapour to rise from the evaporator to the condenser.

ΔP_g = Pressure due to gravity whose value depends on the angle of inclination of the pipe.

If condition in Eq. (1) is not met (capillary limit), then the wick materials will dry out and the pipe will not operate. Detailed discussions on the heat pipe limits (shown in **Figure 6**) are available in heat pipe books, which can be referred.

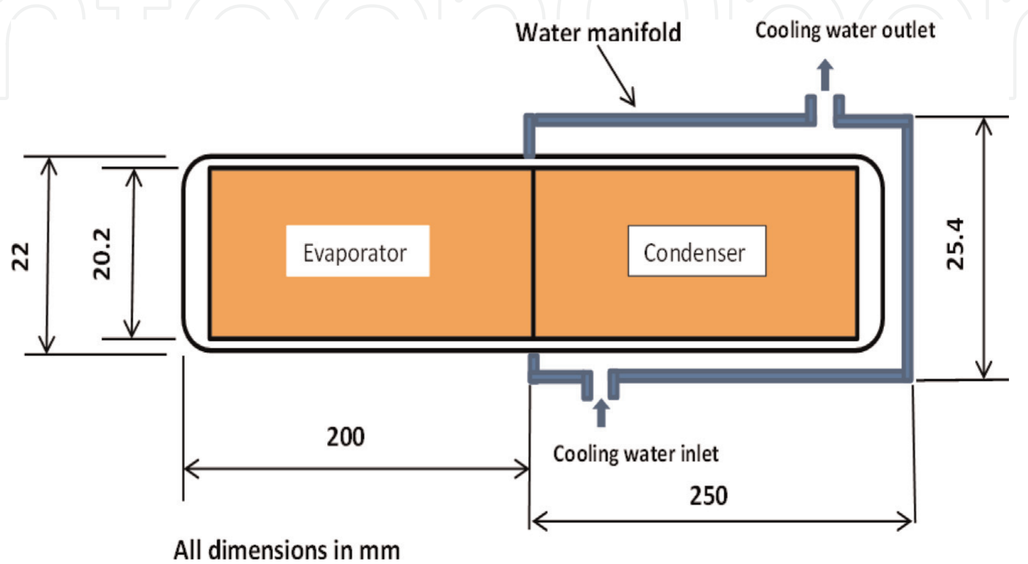

Figure 4.
Dimensions of a typical thermosyphon with water manifold [17].

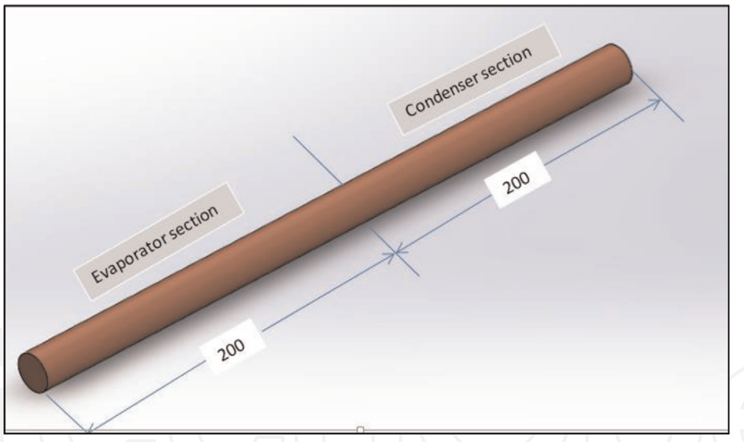

Figure 5.
3D view of a typical thermosyphon pipe.

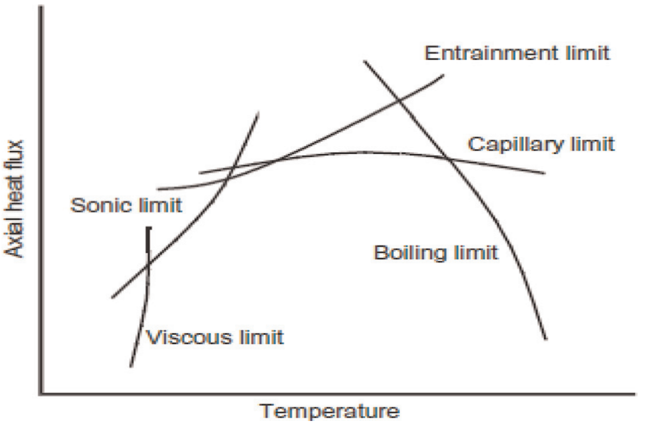

Figure 6.
Limitation of heat pipe for heat transport.

2.3 Advantages of thermosyphon over wick heat pipe

Apart from the general advantages of heat pipe, thermosyphon has other advantages over wick heat pipe, some of which are listed below:

i. Relative low-temperature difference between the heat source and heat sink

ii. More compactness

iii. High durability and reliability

iv. Cost-effectiveness

v. Less weight due to the absence of wick materials

vi. Simplicity in construction

2.4 Measurement of the performance of thermosyphon

The performance of thermosyphon under different conditions is evaluated based on the overall thermal resistance R_{th}, given by:

$$R_{th} = \frac{T_{ae} - T_{ac}}{Q_{in}} \quad (2)$$

where T_{ae} and T_{ac} are respectively the average temperatures on the evaporator and condenser while Q_{in} is the heat supplied to the evaporator.

However, the performance of the thermosyphon can also be calculated as the ratio of the heat transfer to the cooling water to the heat input as [18]:

$$\eta = {}^{Q_{out}}/_{Q_{in}} \tag{3}$$

The rate of heat transfer to the cooling water, Q_{out}, can be evaluated by:

$$Q_{out} = \dot{m} C_p (T_{out} - T_{in}) \tag{4}$$

where T_{in} and T_{out} are respectively the inlet and outlet temperatures of the cooling water, while $m^{\cdot}$ and C_p are the mass flow rate, kg/s and the specific heat capacity of water, kJ/kg-K respectively.

Two approaches are usually employed in the performance characterization of thermosyphon, namely:

- Experimental
- Numerical

2.4.1 Experimental study on the performance of thermosyphon

The thermosyphon heat pipe can be experimentally characterized and the effects of some parameters on its performance evaluated. **Figures 7** and **8** show a schematic diagram and picture of a typical test rig for the performance characterization of thermosyphon constructed at the University of Birmingham, UK, for analyzing the performance of a two-phase closed thermosyphon. It consists of a 0.4-m-long two-phase closed thermosyphon heat pipe, heating coil, water jacket and other instrumentations.

The heat can be supplied by hot water circulating around the evaporator or by electric power supply. In **Figures 6** and **7**, the evaporator section is wrapped evenly with electric wire with electric energy supplied and controlled by TSx1820P Programmable DC PSU 18 V/20A power regulator to provide the heat required for boiling the working fluid inside the pipe. A multimeter is used for measuring the voltage input which is connected close to the pipe to account for the voltage drop

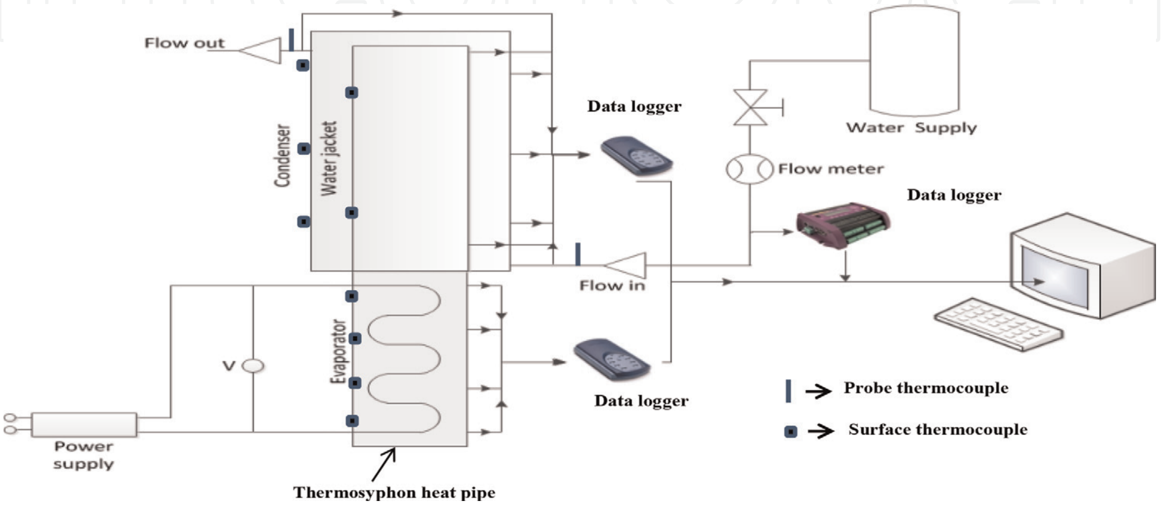

Figure 7.
Schematic diagram of the experimental test rig for thermosyphon characterization [17, 19].

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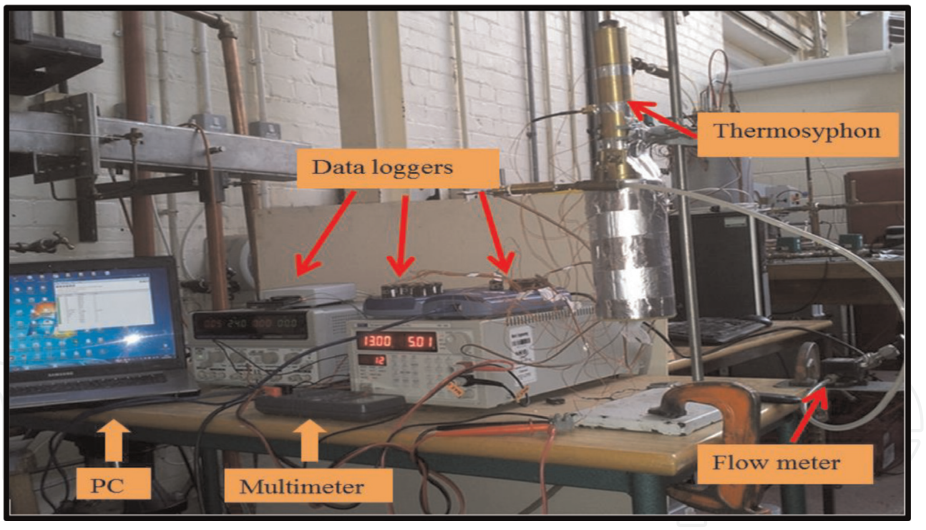

Figure 8.
Picture of the heat transfer characterization of thermosyphon test rig [17, 19].

while the current was read from the power regulator. The evaporator section is also insulated with 25-mm-thick pipe insulator to reduce the heat loss to the ambient environment (**Figure 8**). For measuring the temperature distribution along the pipe, 12 surface thermocouples were placed at different locations on the test pipe; 4 on the evaporator wall (at 0.02, 0.07, 0.12 and 0.17 m from the tip of the evaporator) and 2 on the condenser wall at 0.25 and 0.35 m as shown in the figures. The electric wires were wrapped in such way that they are not directly on the thermocouples so as to not affect their readings. Two probe thermocouples were installed at the inlet and outlet of the manifold to measure the temperatures of the cooling water. Three other thermocouples were used on the water jacket and one on the insulator to measure the effectiveness of the insulation and the jacket. All the readings were sent to Pico TC-08 data loggers connected to a PC.

2.4.1.1 Instrumentation and calibration

The test rig has to be provided with different measuring devices of temperature, water flow rate, heat (power) input and angular orientation to enable investigating the flow and heat transfer characteristics of the selected thermosyphon. The instruments include:

- ☐ Thermocouples, both surface and probe types.
- ☐ Flow meter.
- ☐ Electric power regulator (or hot water supply in some cases).
- ☐ Data logger.
- ☐ Angular measurement instrument such as protractor

The instruments are calibrated against standard devices and error analysis and uncertainties of their measurements are evaluated.

2.4.1.2 Experimental procedure

The test facility was completed and ready for investigations when all the parts were connected and water circulation system was checked for possible leakages. The operating conditions are set based on the type of the investigation to be carried out. However, in all the cases, the system is allowed to run and stabilize before readings are taken. Preliminary tests are required to determine the time when the system reaches steady state. Certain number of readings are set to be taken for each boundary condition at a set interval of time (usually in seconds). The reading recorded includes the temperatures, flow rates, voltage and current. Various investigations can be carried out using the test rig such as the effects of heat inputs, cooling water flow rate, inclination effects of the pipe, fill ratio, etc. Detailed procedure for each case depends on the type of the investigation to be carried out.

2.4.2 Numerical approach

To enable several investigations on many parameters affecting the performance of thermosyphon with different boundary conditions, numerical approach is usually employed. This is because experimental approach requires more time, energy and huge investment, to investigate many cases under different boundary conditions. There are two numerical approaches that are employed in modelling multiphase flows, namely the Euler-Euler and Euler-Lagrange approaches. In the Euler-Euler approach, the several phases are considered as interpenetrating continua mathematically in which each phase a volume is occupied only without sharing with other phases, while Euler-Lagrange approach utilizes Navier-Stokes equations that are solved for the fluid phase with several numbers of particles tracked in order to solve the dispersed phase. It should be noted that this approach cannot be adopted for applications in which volume fraction is important, especially for the secondary phase. Hence, the Euler-Euler approach is usually used in modelling two-phase closed thermosyphon operations.

Using Euler-Euler approach, three multiphase models are available in ANSYS Fluent:

a. The Eulerian model

b. The Mixture model

c. The Volume of Fluid (VOF) model

The mixture model deals with modelling of sedimentation, bubbly flows, particle-laden flows, etc. While applications such as fluidized beds, particle suspension, risers are modelled using Eulerian approach, on the other hand, liquid-gas tracking under steady or transient, free-surface flows, large bubble in liquid are modelled using the VOF approach.

Numerical modelling like computational fluid dynamic analysis (CFD) is an alternative to experimental approach, whereby several studies can be carried out with small investment. In CFD, a set of discretized equations are solved with the help of computer to get an approximate solution [20]. CFD analysis can be carried out on the flow and heat transfer characteristics of a thermosyphon heat pipe in both vertical and inclined orientations using a commercial ANSYS Fluent or any software that can model the simultaneous evaporation and condensation processes taking place in a thermosyphon heat pipe. However, some approaches like volume of fluid (VOF) in ANSYS Fluent require the user to add a user-defined function (UDF) to the modelling process.

The first step in solving any multiphase problem is identifying the suitable multiphase regime which represents the flow needed to be modelled. In this chapter, emphases is put more on the VOF model.

2.4.2.1 Model building

For building a model for simulating the flow and heat transfer characteristics of thermosyphon, a researcher is required to have a good knowledge of the theory (physics) behind the processes. The processes involved in the CFD modelling of the performance of thermosyphon using volume of fluid (VOF) approach in ANSYS Fluent can be summarized as follows:

i. Generation of the pipe geometry (model).

ii. Meshing of the model: different meshes of different properties (number of cells, faces, quality, etc.) are required.

iii. Carrying out a grid independence test: this is done to find out the situation whereby the result is independent of the mesh configuration and to select the configuration which will give less computational time.

iv. Importing the selected meshed file for the investigations into the ANSYS Fluent.

v. Attaching the user-defined function (UDF); this depends on the modelling approach selected.

vi. Modelling and simulation set up, which includes.

- Defining the boundary conditions.
- Setting the thermophysical properties of the materials involved such as thermal conductivity, material properties, density, specific heat capacity, viscosity, etc.
- Defining of the solution method and convergence.
- Running the simulation and processing of the results.
- Validation of the model: to enable validation of the developed model, the boundary conditions and other definitions are made exactly as those set in the experiment.
- Once the model is validated with the experimental results, then it can be used for further investigations.

2.5 Factors affecting the operations of thermosyphon

Considerable experimental research works were published on the investigation of the effects of parameters like the geometry, working fluid, fill factor and inclination on the thermosyphon heat pipe performance [21–25]. Hence, apart from the material of the thermosyphon, other important parameters affect its performance, such as:

I. Type of working fluid charged: The common liquid used in thermosyphon is water due to its availability, low cost, safety, etc. Below are some of the prime requirements for a liquid to be used in heat pipe:

i. Compatibility with wick and wall materials

ii. Good thermal stability

iii. Wettability of wick and wall materials: it is necessary for the working fluid to wet the wick and the container material, that is contact angle should be zero or very small

iv. High latent heat: a high latent heat of vaporisation is desirable in order to transfer large amounts of heat with minimum fluid flow, and hence to maintain low pressure drops within the heat pipe

v. High thermal conductivity: the thermal conductivity of the working fluid should preferably be high in order to minimize the radial temperature gradient and to reduce the possibility of nucleate boiling at the wick or wall surface

vi. Low liquid and vapour viscosities: the resistance to fluid flow will be minimized by choosing fluids with low values of vapor and liquid viscosities

vii. High surface tension: in heat pipe design, a high value of surface tension is desirable in order to enable the heat pipe to operate against gravity and to generate a high capillary driving force

viii. Acceptable freezing or pour point

The selection of the working fluid must be based on thermodynamic considerations which are concerned with the various limitations to heat flow occurring within the heat pipe, like viscous, sonic, capillary, entrainment and nucleate boiling levels.

Some common liquids used in heat pipe include water, acetone, ethanol, ammonia, nitrogen and methanol. However, recent researches have shown potentials of using other liquids alone or mixed with water like nanofluids [26–28].

II. Quantity of the working fluid charged: the quantity of the liquid charged in relation to the volume of the evaporator, called fill ratio, FR or liquid ratio, plays a vital role in the performance of thermosyphon. Fill ratio is defined as the ratio of volume of the working fluid in an unheated pipe, V_{liq}, to the volume of the evaporator, V_e:

$$FR = {}^{V_{liq}}/_{V_e} = \frac{4V_{liq}}{\pi D^2 l_e} \tag{5}$$

The quantity of the fluid to be charged has to be properly selected, which depends on the intended applications, as insufficient amount of fluid causes dry out while excessive amount reduces performance and increases the cost of the pipe. FR of a thermosyphon should be between 40 and 60% for vertical pipes and between 60 and 80% for inclined pipes [4, 29] . For example, Emami et al. [30] and Asgar [18] obtained 45 and 50% as best FR respectively.

III. Heat input: The amount of heat supplied in the evaporator affects the performance of the thermosyphon depending on other factors such as size, fill ratio, its geometry and operating limits. Experimental results have shown that the performance of the thermosyphon increases with the increase in heat input up to their operating limits. It increases with increase between 350 and

500 W, but it decreases when the heat input is above 500 W [18] . But for Abdullahi et al. [19], the performance of the pipe increases as the heat input increases from 20 to 81.69 W, but it tends to decrease as more heat is supplied, showing the limit of this pipe has been reached under these operating conditions (**Figure 9**). Hence, the trend of the performance of the thermosyphon (based on the amount of the heat input in the evaporator section) depends on its operating limits. At low heat input, the vapour generated from the evaporator section is small, so there will be significant dry areas in the condenser section; hence, heat transfer is largely by free convection. As the heat is gradually increased, more vapour will rise to the condenser section, there will be high condensation rate on the condenser wall and the dominant heat transfer mechanism will be condensation. But at certain high heat input, thick layer of liquid can be formed on the wall of the pipe causing high thermal resistance and hence lower the heat transfer to the cooling water, hence reduction of performance.

IV. Inclination angle: since the condenser of thermosyphon must be at the top with the evaporator at the bottom for the condensate to return, this shows that the pipe can be inclined at any angle other than 90°. Regarding the effect of inclination angle on heat pipe performance, conflicting experimental results were reported like angles between 15 and 60° [24], between 40 and 45° [25] and 60° [30] gave the best performance. Others reported higher angles like 90° [31] and 83° [32] as the best performing angles while few reported that inclination angle has no effect [33]. The possible reasons for the contradicting results are the complex nature of the processes taking place in thermosyphon operations and various parameters affecting its performance. Furthermore, those researches are only experimental and considered a small range of inclination angles. With the contradictory experimental results in the literature and lack of, or limited, numerical studies on the effect of inclination, Abdullahi et al. [19] addressed these issues through the development of a CFD model that studied the effects of inclination angles (10–90°) and experimentally validated the model. Experimental and numerical results showed that increasing the inclination angle will improve the thermosyphon heat pipe performance to reach its maximum value at 90°, but this effect decreases as the heat input increases [19] (**Figure 10**).

V. Flow rate of cooling water: the rate at which cooling water is passing in the water jacket around the condenser of a thermosyphon affects its performance.

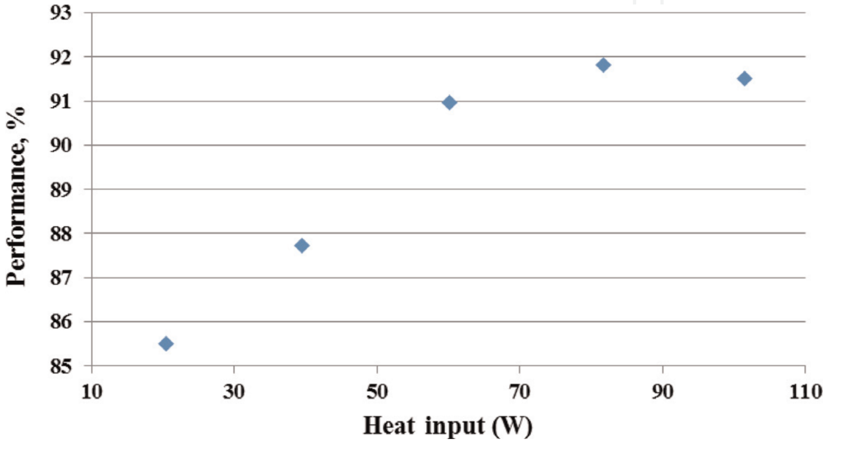

Figure 9.
Performance of thermosyphon aligned vertically at different heat inputs [17, 19].

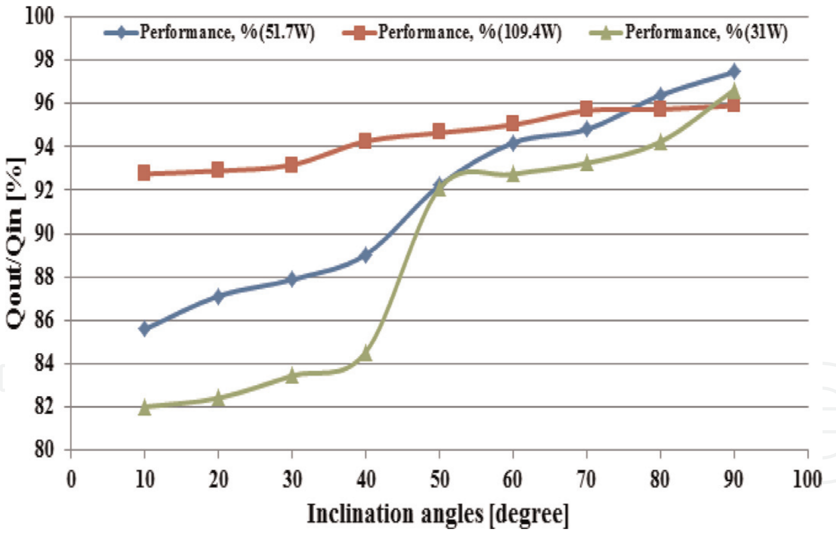

Figure 10.
Variation of the thermosyphon performance with inclination angle at different heat inputs [17, 19].

As the rate of the heat removal from the vapour increases, more condensate returns to the evaporator for another cycle. The effect of cooling water flow rate at constant heat input was investigated on the performance of thermosyphon heat pipe [19]. The heat input was fixed at 101 W while five different flow rates ranging from 0.00156 to 0.00611 kg/s were investigated. Temperature and the flow rate readings were recorded for each run and the effects of the cooling water flow rate were evaluated based on the overall thermal resistance, rate of heat transfer to the cooling water, outlet temperature of cooling water, performance of the thermosyphon, etc. The results from such work have shown that the performance of the pipe in terms of heat transfer to the cooling water increases with the increase in the cooling water flow rate. This is due to the mass flow of the cooling water which results in the enhancement of the rate of heat transfer from the pipe wall to the cooling water and subsequent increase in the efficiency.

2.6 Applications of thermosyphon

In addition to the general advantages of heat pipes, thermosyphon type is found to be highly durable, reliable and cost-effective, which make them useful for various applications, such as:

I. Solar heating of building [16].

II. Liquid circulation: thermosyphon system is used for circulating liquids and volatile gases in heating and cooling systems such as water heaters, furnaces and boilers. It simplifies transfer of liquid or gas without using conventional pump which adds cost and complexity to the system.

III. Cooling applications: thermosyphon is used in cooling of turbine blades, transformers, electronics, internal combustion engines and nuclear reactors [34, 35]. This is due to their ability to dissipate and transfer large amount of energy from small area without any significant loss.

IV. Aircraft cooling: due to their light weight, thermosyphon pipes are used in cooling of aircraft and spacecraft.

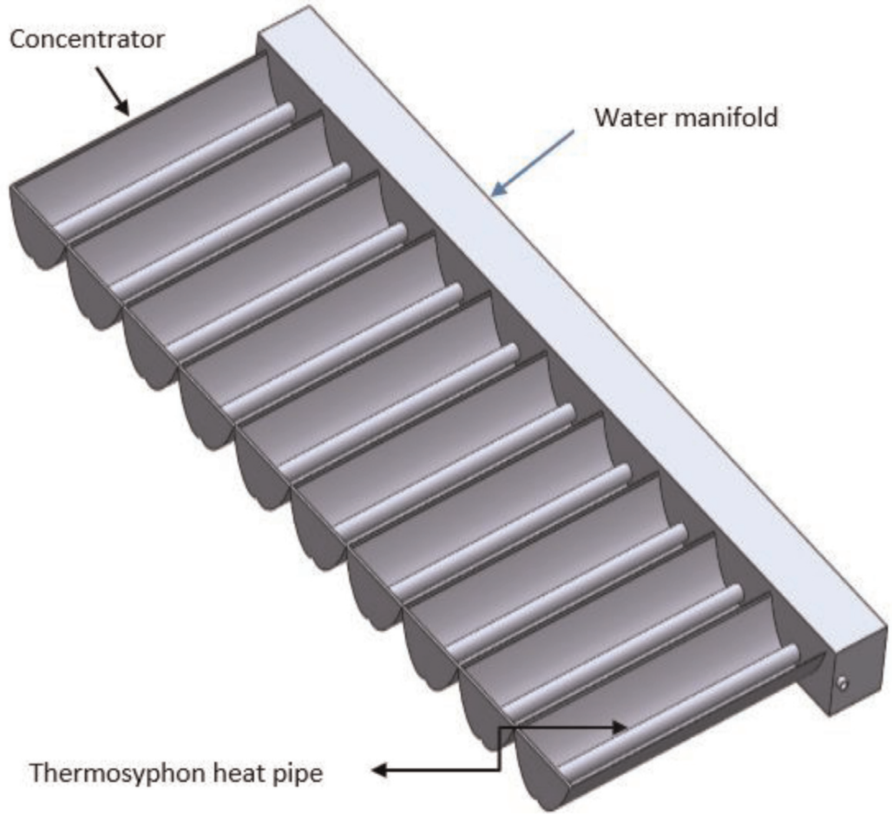

Figure 11.
Developed compound parabolic collector with thermosyphon as receiver [17].

Receiver in solar collector (solar systems): thermosyphon is proved to be a good choice as a receiver for solar concentration systems due to its advantages stated [36, 37] as shown in **Figures 3** and **11**.

3. Conclusions

Several parameters affect the operation of thermosyphon such as fill ratio, working fluid, inclination, geometry, heat input, cooling water flow rate, etc. Experimental and numerical (CFD) studies are usually carried out to enable the investigation of the effects of some of these parameters on the performance of thermosyphon heat pipe for use in various engineering applications. Investigations on the effects of heat input, fill ratio, flow rate of cooling water on the temperature distributions on the wall of the pipe, overall thermal resistance and overall performance of the pipe at vertical orientation were shown to be possible both experimentally and using CFD. Also, the effect of inclination angle of thermosyphon on those parameters was successfully added in the Fluent. Hence, the chapter has shown that volume of fluid (VOF) model's approach in ANSYS together with UDF and other software can fully simulate the complex evaporation and condensation processes taking place in thermosyphon for both vertical and inclined orientations.

Author details

Bala Abdullahi[1]*, Raya K. Al-dadah[2] and Sa'ad Mahmoud[2]

1 Department of Mechanical Engineering, Kano University of Science and Technology (KUST), Wudil, Kano, Nigeria

2 School of Mechanical and Manufacturing Engineering, University of Birmingham, United Kingdom

*Address all correspondence to: balabdullahi@yahoo.com

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