EFFECTS OF CONDENSER VOLUME ON THE PERFORMANCE OF A SOLAR THERMO-SYPHON

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ABSTRACT

One of the alternative sources of energy is solar energy which is available in abundance throughout the world. The energy contained within the solar rays is capable of starting natural convection within closed mechanical systems containing a suitable working fluid. One such system is commonly known as a Thermo-syphon which transfers solar energy into internal energy of the working fluid, commonly water. In the present study, an attempt has been made towards better understanding of the flow structure within a thermo-syphon by analysing the natural convection phenomenon using Computational Fluid Dynamics based techniques. A commercial CFD package has been used to create a virtual domain of the working fluid within the thermo-syphon, operating under no-load condition. The effects of the condenser volume, on the performance of the thermo-syphon, have been critically analysed in this study. The results depict that as the condenser volume increases, the average temperature of water within the condenser decreases. Hence, CFD can be used as a tool to design, analyse and optimize the performance of a thermo-syphon with reasonable accuracy

Keywords: Computation Fluid Dynamics (CFD), Thermo-syphon, Bossinesq Approach, Natural Convection, Solar Energy

1. INTRODUCTION

Due to depleting fossil fuels, rapid escalation in the fuel prices globally, the greenhouse effect and environmental pollution, the need to find alternative sources of energy is becoming increasingly significant. One of the most important sources of alternative energy is solar energy. It is play a vital role in various aspects of life. The sun radiates 13 million times the energy that is generated by all the electricity consumed around the world in one year (Khan, 2011). It has more advantages than fossil fuels have; it is friendly to the environment as well as cheap and renewable. A mechanical system is readily available in the market that converts the solar energy into thermal form. This system is commonly known as a Thermo-syphon. There are many advantages of a thermo-syphon hot water system such as; its use avoids using a conventional pump, which keeps the complexity and costs of a thermo-syphon system low.

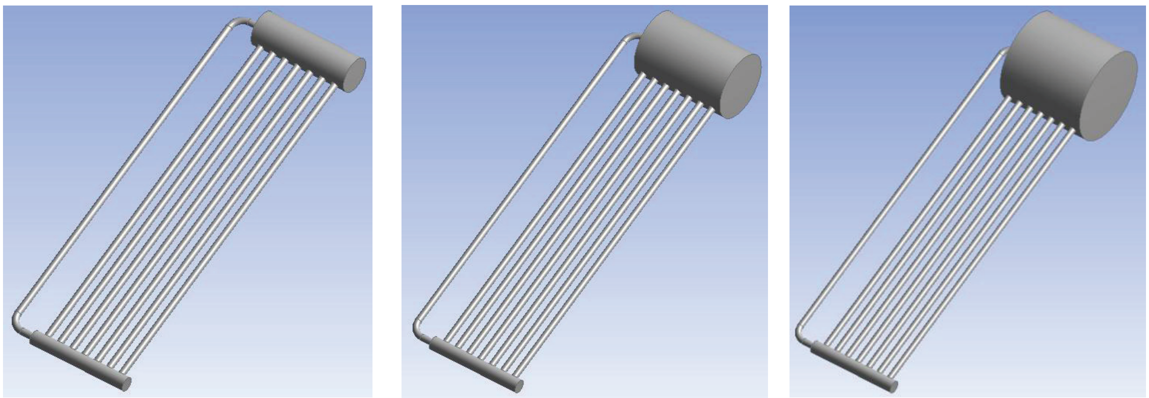
Soin et al., 1979 studied the effect of insulation and the liquid level on the condenser performance and investigated the thermal performance of a thermo-syphon condenser containing boiling acetone and petroleum ether. The results have shown that the relationship between the condenser efficiency and liquid level is linear. Downing et al., 1980 has used R-11 and R-114 as working fluids inside solar condenser pipes. The results have shown that the working fluids, that have phase change, are more efficient and respond faster to heat transfer than working fluids that have single phase only. Fanney et al., 1985 conducted experimental study on solar domestic hot water system to analyse the effect of irradiance level on thermal performance of a refrigerant within the solar condenser. The results have shown that the effect of the irradiance level on thermal performance of refrigerant is negligibly small. Radhwan et al., 1990 conducted experimental studies on two integrated solar water heaters for both forced and natural circulation water flows. R-11 was used as working fluid. The results show that the natural circulation water flow has a remarkable impact on the thermal performance while the forced circulation has relatively weaker impact. Mehmet et al., 2005 experimentally studied three refrigerants, R-134, R-407 and R-410.The three systems have been tested under the same working conditions in an attempt to find out the most effective refrigerant among the three. The results have shown that R-410 as a working fluid is more efficient than other refrigerants for both the non-loading and loading operations. Samanci et al., 2011 studied comparative performance of single-phase and two-phase closed loop thermo-syphons. R-134 has been used as the working fluid in two-phase thermo-syphon, whereas water has been used as the working fluid in single-phase thermo-syphon under same working conditions.

This study is the continuation of Freegah et al., 2013 and hence the thermo-syphon model considered in the present study is the same. Computational Fluid Dynamics tools have been used to carry out an extensive study on the effects of condenser volume on the performance of a closed-loop solar hot water thermo-syphon system. The effects of thermal loading in a thermo-syphon have not been explicitly analysed and hence this study is important for the design process of such systems.

2. NUMERICAL MODELLING

The thermo-syphon models considered in this study comprises of seven pipes, connecting the condenser with the collector (Fig. 1). There is a separate pipe, emerging from one end of the condenser, called as recirculation pipe, through which the cold water returns to the collector. The connecting and recirculation pipes have a diameter and thickness of 25mm and 2mm respectively, whereas the diameter of the collector is twice the diameter of the connecting pipes. The length of the connecting pipes is such that the length-to-diameter ratio of the connecting pipes (L/d) is 50. Three different condensers having diameters of 5, 10 and 15 times the diameter of the connecting pipes, have been chosen for analysis. A practical solar heat flux of 250W/m^2 has been specified to the walls of the connecting pipes. As mentioned in Freegah et al., 2013, the model is made inclined by 30º to the horizontal as it is the optimal tilt angle for this type of thermo-syphon.

Boussinesq approximation has been used to accurately model buoyant forces being generated. This approximation states that the density differences are sufficiently small to be neglected, except where they appear in terms multiplied by g i.e. the acceleration due to gravity. The essence of the Boussinesq approximation is that the difference in inertia is negligible, but gravity is sufficiently strong to make the specific weight appreciably different. It has been observed by Sato et al., 2012 that the Boussinesq approach for the density of the working fluid in a thermo-siphon predicts fairly accurate results and thus has been used in the present study. Three dimensional Navier-Stokes equations, in addition to the continuity and the energy equations, have been numerically solved in an iterative manner to simulate the laminar but transient flow of water within the thermo-syphon for one hour of operation.



(a) (b) (c)

Figure 1. Thermo-syphon models having condenser diameter equal to (a) 5 * d (b) 10 * d and (c) 15 * d

3. RESULTS AND ANALYSIS

The numerical analysis carried out on the closed thermo-syphon hot water solar system clearly depicts the natural convection phenomena and the distribution of flow velocity and temperature within the model. Figure 2 depicts the velocity distribution within the central connecting pipe, the collector and the condenser for the thermo-syphon model with condenser having diameter equal to 5 * d. The natural convection phenomena can be clearly seen in the figure, i.e. as the water gets heated, it expands due to increase in temperature and volume (decrease in density). Due to the inclination of the connecting pipe, the water propagates along the top wall of the pipe and enters the condenser. Furthermore, it can be seen that the velocity of water increases as it climbs up the pipe. This happens because more thermal energy is being absorbed by the water as it is propagating along the connecting pipe further decreasing its density. The water attains highest velocity at the junction of the condenser with the connecting pipe.

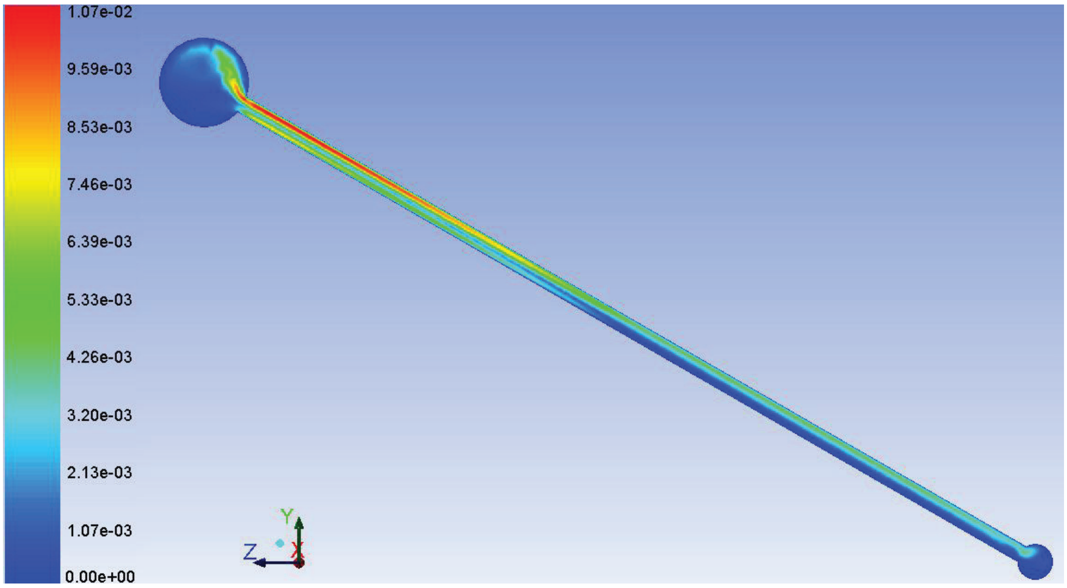


Figure 2. Velocity variations within the thermo-syphon after 1 hour of operation

Figure 3 further depicts the natural convection phenomena occurring in the thermo-syphon model with condenser having diameter equal to 5 * d. As mentioned earlier, the water heats up and rises in the connecting pipe. Along the pipe, more thermal energy of the solar rays is transferred to the internal energy of the water, increasing its temperature further. Highest temperature of water is observed at the junction of the connecting pipes and the condenser. Due to its lower density, the water further rises within the condenser and gets accumulated along the top wall of the condenser, whereas the cold water from the bottom of the condenser is transferred back to the collector via recirculation pipe.

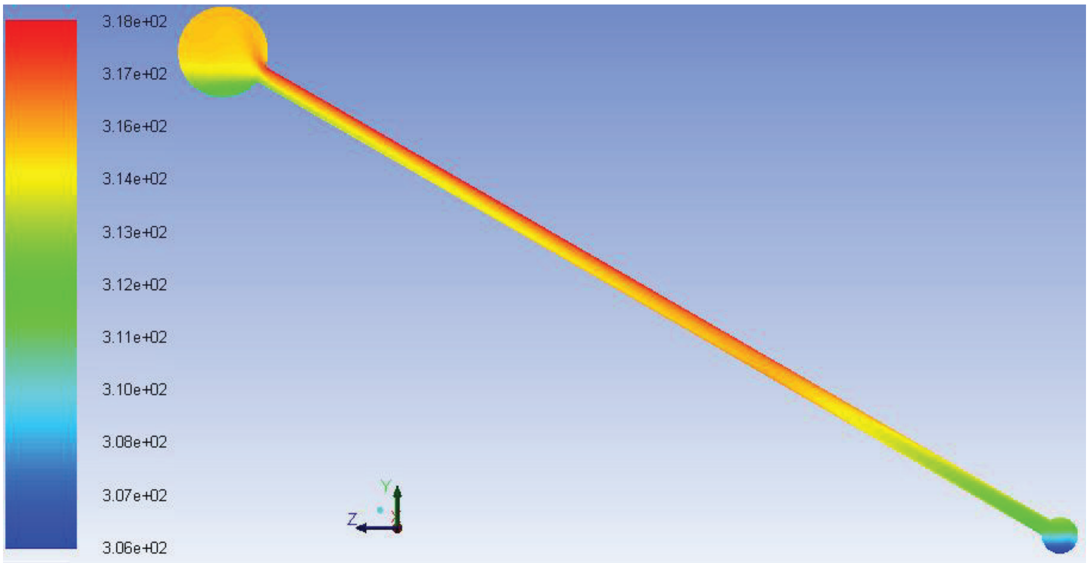
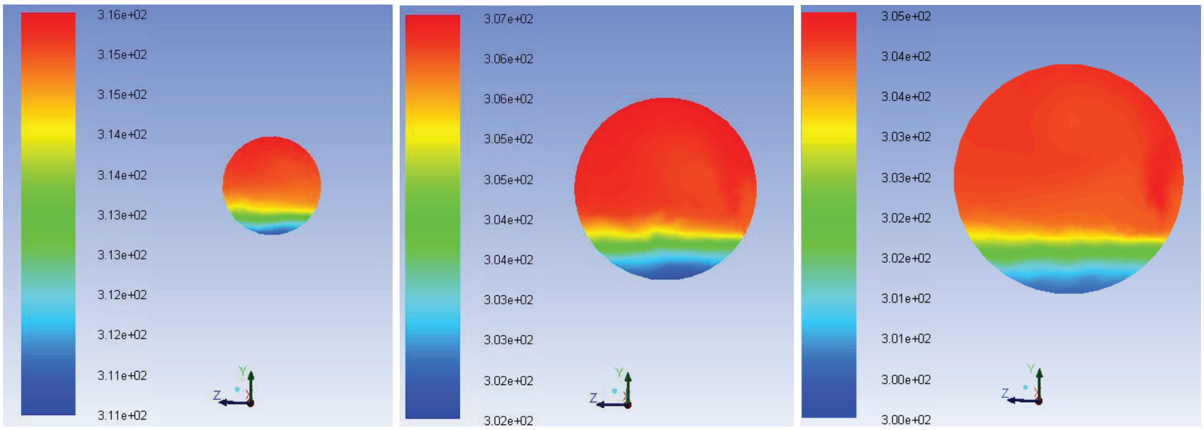


Figure 3 Temperature variations within the thermo-syphon after 1 hour of operation

Figure 4 depicts the temperature distribution within the three different condensers of the thermo-syphon models considered in the present study. It can be clearly seen that the hot water occupies the upper section of the condensers while the cold water is accumulated on the lower sections of the condensers. Furthermore, it can be seen that the average temperature of water is higher for condenser having diameter of 5 * d, as compared to the condenser having diameters of 10 * d and 15 * d. This indicated that increase in the condenser volume decreases the average temperature of water within the condenser. This is because the bigger condenser holds more volume of water and hence more solar energy is required to heat up the water to a specified temperature, as compared to heating up the water in a condenser of comparatively smaller volume.



(a) (b) (c)

Figure 4 Temperature variations within various condensers after 1 hour of operation (a) Condenser diameter = 5 * d (b) Condenser diameter = 10 * d and (c) Condenser diameter = 15 * d

Table 1 enumerates the average temperature of water within the different condensers considered in this study, after one hour of operation. Furthermore, percentage difference in average temperature w.r.t. the smallest condenser has also been included in the table. It can be clearly seen that as the volume of the condenser becomes twice, the average temperature of water within the condenser increases by 21.5%. Moreover, if the condenser volume increases thrice, the average temperature of water within the condenser increases by 26.82%.

Table 1. Average temperature of water within various condensers after 1 hour of operation

Condenser Diameter	Average Temperature of Water within the Condenser	Difference w.r.t. 5 * d Condenser
(m)	(^{o}C)	(%)
5 * d	41.15	
10 * d	32.29	21.5
15 * d	30.11	26.82

The variations in temperature of water within the three condensers, at a heat flux of 250W/m^2, have been depicted in figure 5. It can be seen that as time increases, the temperature of water within the condenser increases linearly. Furthermore, the temperature within the condenser is considerably higher for 5 * d condenser as compared to 10 * d and 15 * d condensers. The difference between 5 * d and 10 * d condensers is significantly higher than the difference between 10 * d and 15 * d condensers. This is because the increase in the diameter from 5 * d to 10 * d is 100%, whereas from 10 * d to 15 * d is 50%. It can be seen in Table 1 that the difference in condenser temperature, after one hour of operation, between 5 * d and 10 * d condensers is 8.86°C, whereas the difference between 10 * d and 15 * d condensers is 2.18°C. Hence, the difference in temperatures reduces by 75%.

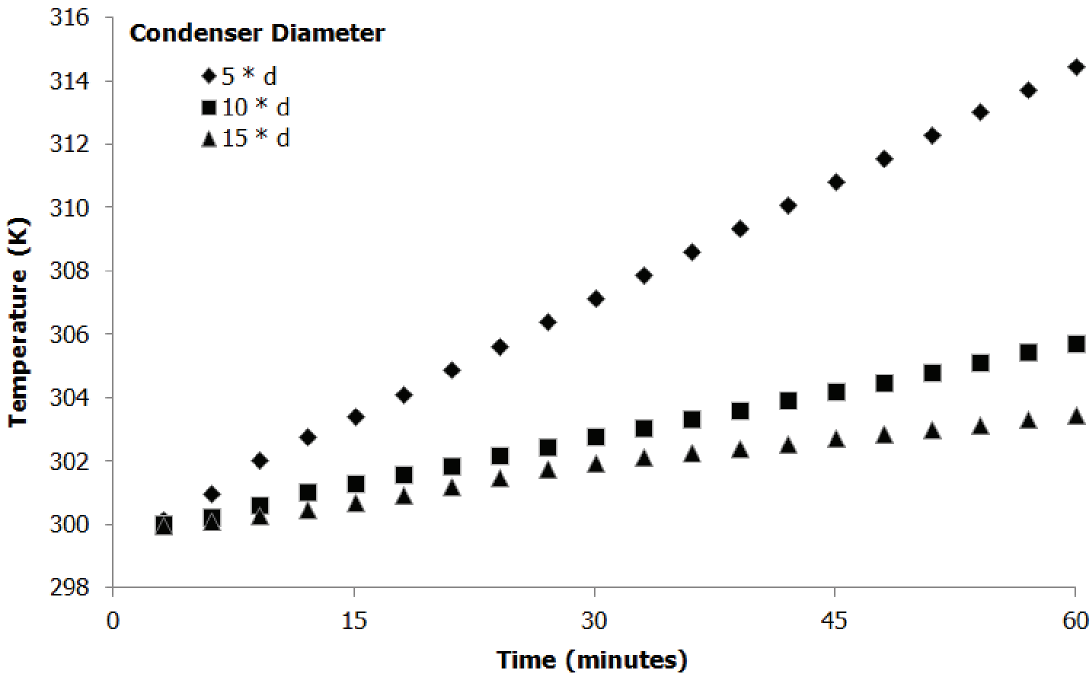


Figure 5. Temperature variations within the various condensers for 1 hour of operation

4. CONCLUSIONS

The effects of condenser volume on the performance of a thermo-syphon has been numerically analysed using Computational Fluid Dynamics. It has been observed that after receiving solar energy, water in the connecting pipes rises under natural convection and starts to accumulate at the upper section of the condenser. It has also been noticed that the velocity of water increases as it reaches towards the condenser. Furthermore, the temperature of water within the condenser increases with increase in time, as more and more hot water from the connecting pipes occupies the condenser volume. With regards to the condenser volume, it has been shown that as the condenser volume increases, the temperature of water within the condenser decreases. The information provided in this study can be used to design the thermo-syphon systems optimally. Moreover, it can be concluded that Computational Fluid Dynamics can be used as an effective tool to analyse the performance of a thermo-syphon with reasonable accuracy.

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