EXPERIMENTAL INVESTIGATIONS OF EFFECT OF SOUND WAVES ON OSCILLATION AND STARTUP CHARACTERISTICS OF OSCILLATING HEAT PIPE AT DIFFERENT ORIENTATIONS

by

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This research deals with the effects of working fluid and use of sound waves on the startup and heat transfer characteristics in terms of thermal resistance of a closed loop oscillating heat pipe. The performance of the oscillating heat pipe is checked for different orientations as 90° (vertical position), 60°, and 30°. Initially water is used as working fluid and performance of the oscillating heat pipe is checked with and without sound waves. Then 0.1 wt.% Al_2O_3-water nanofluid is utilized as working fluid in oscillating heat pipe and its performance is analyzed with and without sound waves. In this work, sound waves of 1 kHz frequency are passed through the evaporator section of closed-loop oscillation heat pipe. Application of sound waves improved the oscillation characteristics of the CLOHP with reduced startup time and enhanced thermal performance at all orientations. In comparison between working fluids, 0.1 wt.% Al_2O_3-water nanofluid showed better oscillation characteristics at all orientations of CLOHP except at 90° where use of sound waves leads to dry-out condition.

Key words: *pulsating/oscillating heat pipe, sound waves, thermal performance, working fluid*

Introduction

Nowadays electronics field is developing very fast, producing compact electronic devices with high functionality. This results into the problems of total heat dissipation and critical level heat fluxes *i. e.* high heat dissipation per unit areas. If this high heat density problem is not handled carefully it leads to malfunctioning of the component. To achieve such high local heat removal rates two-phase passive device such as oscillating/pulsating heat pipe (OHP/PHP) finds to be promising technology.

There are many parameters such as geometric parameters, working fluids, orientations, *etc.* affecting the OHP performance. Researchers worked on OHP for improving and enhancing its performance through variation of design and other parameters. One of the important parameter affecting the performance of OHP is found to be its orientation. In 2008, Yang *et al.* [1] studied the different operating parameters limiting performance of CLOHP including its operational orientation. They checked the performance of CLOHP with 2 mm and 1 mm internal diameter (ID) tubes. They found that, 2 mm ID tubes giving best performance in the vertical orientation while CLOHP with 1 mm ID tubes have same performance in all the orientations,

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this was because surface tension dominates the fluid flow in the smaller tube. Charoensawan *et al.* [2] investigated effects of variation of inclination angle, number of turns, internal diameter and working fluid on CLPHP. The results indicated that gravity strongly affects the performance of PHP if it does not have tube turns above certain value. When the turns were less than a certain value, the PHP operation is not possible at horizontal orientation. Jahan *et al.* [3] studied the effect of working fluid and inclination angle on thermal performance and heat transfer characteristics of CLPHP. They checked the performance characteristics for two different working fluids as ethanol and water. After the experimentation, they found that best performance is obtained at 75° orientation; also in the given experiment, CLPHP performed better for water than ethanol. Xian *et al.* [4] had done the experimental analysis to study the effect of inclination angle and filling ratio on OHP for two working fluids as water and ethanol. They found that OHP with higher filling ratio showed good heat transfer characteristics at inclined position because of fast return of working fluid to the evaporator section. In the similar fashion, if more working fluid is pumped to the condenser side OHP operation is possible at inclined position also.

Many researchers have performed for improving heat transfer characteristics of OHP. The change of existing working fluid by nanofluid had become attraction point for the investigators due to its good thermal characteristics [5]. Ma *et al.* [6] have successfully done experimentation on an OHP filled with 1.0 vol.% of diamond/water nanofluid. Due to oscillating motion in OHP caused by thermal excitation, the diamond nanoparticles remained suspended in the base fluid, which resulted in increased heat transfer of OHP. Lin *et al.* [7] have used silver nanofluid as working fluid for PHP and investigated the effects of nanofluid concentration and filling ratios under different input heating power. The heat pipe performed better for 60% filling ratio and 100 ppm concentration of silver nanofluid water solution since higher concentration lead to the higher viscosity which reduced liquid slug movement. The effects of silver nanofluid concentrations, ratios of evaporator length to inner tube diameter and inclination angles on the heat transfer rate of a CLOHP with check valves (CV) were studied by Wannapakhe *et al.* [8]. They found that CLOHP/CV perform better for 0.5 %w/v concentration of silver nanofluid; also the best inclination for using CLOHP/CV was 900 with reference to horizontal. Experiments have also been done with alumina nanofluid. Qu *et al.* [9] studied the effects of mass fractions on total thermal resistance of OHP in which they found 0.9% as the best mass fraction of alumina particles to be used. While Ji *et al.* [10] checked the Al_2O_3 nanoparticle size effect on OHP where they found best heat transfer performance of a thermal resistance of 0.113 °C/W when charged with 80 nm particles.

Use of all nanofluids in OHP does not lead to an improved thermal performance but it will depend on the change of evaporator and condenser surface conditions caused due to deposition of different nanoparticles. This has been experimentally proved by Qu and Wu [11]. They checked the thermal performance of two same OHP filled with Al_2O_3-water and SiO_2-water nanofluids, respectively. For the alumina nanofluid-filled OHP, nanoparticles mostly deposited at evaporator thus enhanced the heat transfer of OHP by increasing surface nucleation sites. While in case of silica nanofluid-charged OHP, nanoparticles deposited at both condenser and evaporator which decreased the contact angle and surface nucleation sites and thus heat transfer was deteriorated. Wang *et al.* [12] studied the thermal performance of PHP charged with microcapsule fluid FS-39E and nanofluid Al_2O_3, and compared it with that of pure water. The results show when bottom heating mode was used, microcapsule fluid FS-39E was the best working fluid and its best concentration was 1.0 wt.% while Al_2O_3 nanofluid was the best working fluid for horizontal heating mode and its best concentration was 0.1 wt.%. The heat transfer characteristics and internal flow patterns of a CLOHP having check valves were studied by Bhuwakietkumjohn and Rittidech [13] for the working fluids as ethanol and a silver nanoethanol mixture. Silver nanoethanol mixture showed higher heat flux than the ordinary ethanol.

Now instead of varying the design parameters and changing the working fluids researchers are trying to improve the thermal performance of CLOHP by means of external means such as sound waves. The ultrasonic sound effect on oscillating motion and heat transfer in an OHP was investigated by Zhao *et al.* [14]. After the application of 1 kHz ultrasound on OHP they found that addition of ultrasonic sound with a total electric power of 4.48 mW, reduced the input power needed to start the oscillating motion from 30W to 18W and the effective thermal conductivity was increased from 672.8 W/mK to 1254.7 W/mK. The usefulness of sound waves has already been proved in boiling and phase change phenomenon. Douglas *et al.* [15] worked on enhancing boiling heat transfer with the help of acoustic waves. They studied the parameters affecting the interfacial instabilities such as frequency and pressure amplitude and their effect on bubble diameter. They found the acoustic enhancement at the frequencies ranging between 0.7 to 1.2 kHz. Use of acoustic waves detached the vapor bubbles from the heated self-contained forcefully which delayed nucleate to film boiling transition, resulting into the increment of 34% in critical heat flux at 19.8 °C sub-cooling. Kim *et al.* [16] found out the flow behavior induced by ultrasonic vibration and its relationship with the consequent heat transfer enhancement in pool boiling regimes and natural convection. They found that the effects of ultrasonic vibration on flow behavior depend on the amount of dissolved gas and the heat transfer regime. In saturated boiling, there is no cavitation thus reducing thermal bubble size at departure and hence acoustic streaming was major factor to enhance heat transfer rate. In natural convection regime, highest enhancement ratio was obtained due to violent motion of cavitation bubbles caused by ultrasonic vibration. Zhou [17] had investigated the effects of fluid sub-cooling, nanofluid concentration and acoustical parameters on heat transfer characteristics around a horizontally placed heated copper tube. He found that with regard to pool boiling of the nanofluids, addition of a small amount of Cu nanoparticles enhanced single phase convection heat transfer while boiling heat transfer was reduced, but if an acoustic field is produced into the working fluid, heat transfer was enhanced by Cu nanoparticles, irrespectively of heat flux.

From the literature reviewed following things regarding operation of OHP at inclined position, choice of nanofluid as working fluid in OHP and effect of sound waves on heat transfer phenomenon are cleared:

- performance of OHP gets affected when it is operated at any orientation other than vertical due to the reduction of perturbations caused because of reduced gravity,
- the use of nanofluid as working fluid in CLOHP significantly enhances its thermal performance by changing the surface condition on the evaporator with settlement of nanoparticles, and
- application of the acoustic field leads to interfacial instabilities affecting contact line between bubble and heated surface which results into detachment of bubble.

The CLOHP may perform better for the orientations other than vertical if the slug oscillations are increased by any means. Sound waves can be used to improve the thermal performance of CLOHP through forced motion of bubbles through acoustic cavitation as in case of boiling and sub-cooling. Therefore, the main objective of this research is to experimentally analyze the effect of sound waves on oscillation characteristics of CLOHP to make its operation possible at different orientations.

Details of experimental set-up

The schematic of the designed CLOHP, fig. 1, consists of eight meandering turns. It is fully made of Cu capillary tubes with inner diameter of 2 mm and the total length of 7.2

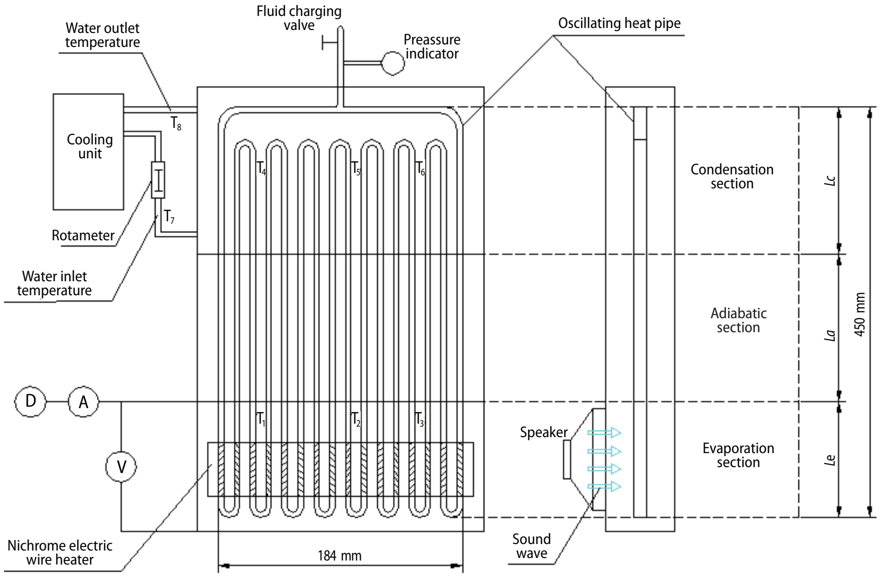

Figure 1. Schematic diagram of experimental set-up

meter. The overall length from top to the bottom is 450 mm. Nichrome wire heater is fixed in the evaporator section to give the input heating load. Dimmerstat is used to vary the temperature of evaporator section by changing voltage and current of heater. Voltage and current can be measured by voltmeter and ammeter, respectively. The total length of heating section, *L*e, is 150 mm. The middle of this OHP has adiabatic section, *La,* of 150 mm which is covered by 8 cm thick polyurethane foam for perfect thermal insulation. The condenser part of the CLOHP is cooled by circulating water from cooling unit. Rotameter is installed at the inlet of condenser to measure and control the flow rate of coolant flowing through condenser. The inlet temperature of cooling water is maintained at 28 °C. The length of cooling section, *L*c, is 150 mm. There are eight thermocouples (T1-T8) located as to measure the temperature fluctuations of the evaporator and condenser sections of CLPHP and the inlet and outlet of cooler box. Three thermocouples (T1-T3) are located in different tubes to give an average value of evaporator temperature. Three thermocouples (T4-T6) are placed in the corresponding tubes to provide an average temperature of condenser. Pressure indicator is installed at the Cu tubes to measure the pressure variation of working fluid inside the Cu tubes.

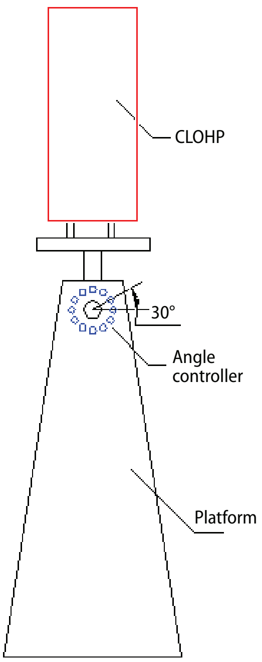

Figure 2. Sketch diagram of experimental platform

Audio speaker is installed at the evaporator section to pass the sound waves to the tubes of the evaporator section. The input to the speaker is given by the PC having freeware software AUDACITY with the help of which, sound of different frequency is generated and passed to the evaporator section through the amplifier. In order to change the orientation of CLOHP a rotating component is used and an angle controller bolt is coupled to have the variation of angle from 0° to 90° with reference to the ground, fig. 2.

Before the experiment, CLOHP is evacuated firstly by a vacuum pump and then it is charged with a working fluid. Two working fluids, pure water and 0.1 wt.% Al_2O_3-water nanofluid, are used, respectively, at 50% filling ratio.

Results and discussion

Effect of heat input on startup time

Figure 3 shows the variation of pressure occurring inside vertically oriented water filled CLOHP for different heat inputs. This is mainly observed to check when CLOHP starts functioning. It is well known that when there is continuous drop and rise in pressure is observed, working of OHP gets started. It can be seen that within the trial of 30 minutes, no pressure fluctuations are observed when the heat inputs are 15.4 W and 30 W. The continuous rise in the pressure is observed for these two heat inputs. Further when the heat input is increased to 48.1W, initially pressure goes on increasing but after 23 minutes fluctuations in the pressure get started. Similarly, when the heat input is further increased to 56.8 W, at beginning no fluctuations in pressure are observed, but after 17 minutes there is distinct drop and rise in pressure is seen. This clears that, as the heat input increases, startup time of CLOHP decreases. As compared to other heat inputs startup of CLOHP takes place early for 56.8 W, hence further all trials are taken at 56.8 W.

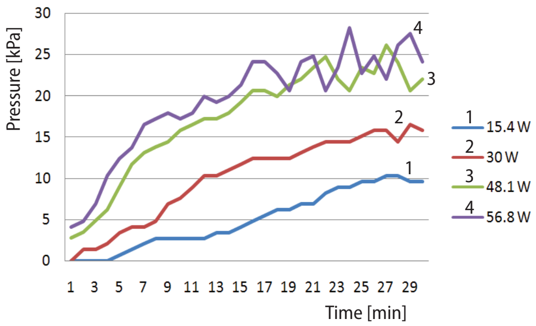

Figure 3. Pressure distribution into water filled CLOHP at different heat inputs
(*for color image see journal web site*)

Variation of pressure for water filled CLOHP at different orientations

Figure 4 shows pressure variation inside OHP tubes at different orientations. Water is used as working fluid and at all the orientations constant heat input of 56.8 W is applied. It clearly exhibits that at all orientations, pressure continuously increases at the beginning and in later stage pressure starts fluctuating indicating the startup of CLOHP. When the CLOHP is in vertical position (angular orientation = 90°), pressure fluctuations starts early *i. e.* after 17 minutes. For 60° and 30° orientations of CLOHP, pressure fluctuations are observed after 25 and 33 minutes, respectively. This shows that, as the orientation of CLOHP decreases startup time of CLOHP increases.

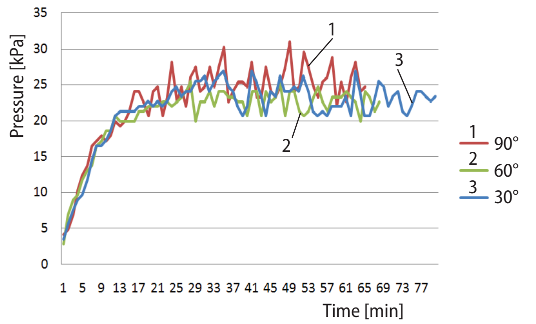

Figure 4. Pressure distribution into water filled CLOHP at different orientations
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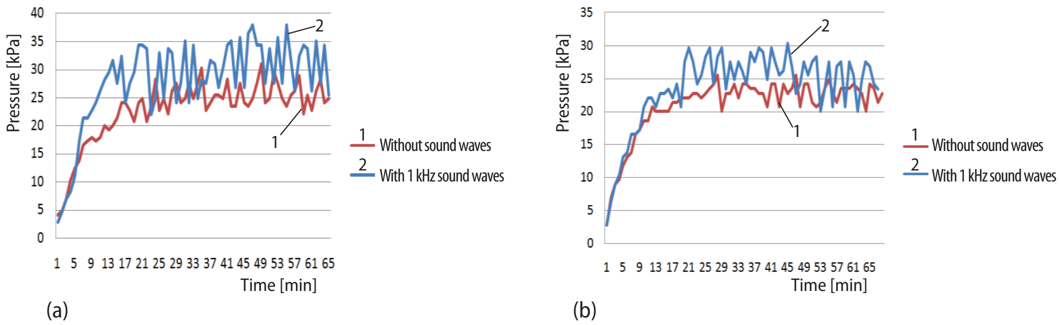
Also from the pressure distribution, fig. 4, it is clear that pressure fluctuations are more continuous at 90° orientation as compared to that for 60° and 30° orientations of CLOHP. Pressure line fluctuations are most discontinuous with reduced amplitudes for 30° orientation of CLOHP in comparison to that for 90° and 60° orientations. So as the CLOHP orientation decreases, amplitude of pressure fluctuations get reduces and pressure fluctuations become discontinuous indicating the reduced heat transfer.

Figure 5 shows the pressure distributions inside the water filled CLOHP at 90°, 60° and 30° orientations, for both cases of with and without application of sound waves. All these pressure variations are noted at constant heat input of 56.8 W. In all cases, initially pressure increases continuously for certain time and then it starts fluctuating, indicating the startup of the CLOHP. Figure 5(a) shows that when CLOHP is oriented at 90° (vertical position), pressure inside the CLOHP starts fluctuating after 17 minutes in the absence of sound waves. When the sound waves of 1 kHz are applied at the evaporator section, fluctuation in pressure is observed early *i. e.* after 13 minutes. Also, the amplitude of pressure oscillations increases when the sound waves are applied.

Similarly, application of sound waves reduces startup time from 25 to 19 minutes and from 33 to 24 minutes for 60° and 30° orientations of CLOHP, respectively, fig. 5(b) and 5(c). Also, due to the application of sound waves pressure fluctuations become more continuous with enhanced amplitudes at all orientations indicating the improved heat transfer.



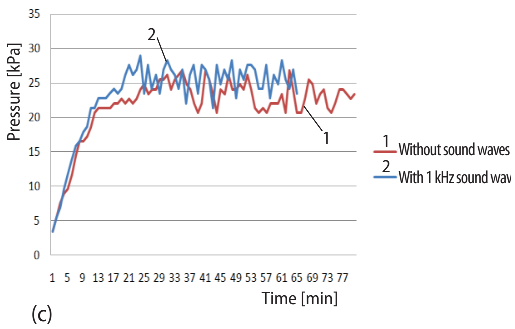


Figure 5. Pressure distribution into water filled CLOHP at: (a) 90°, (b) 60°, and (c) 30° orientations with and without sound waves
(*for color image see journal web site*)

Variation of pressure for 0.1 wt.% Al_2O_3-water nanofluid filled CLOHP at different orientations

Figure 6 shows pressure variation inside OHP tubes for 0.1 wt.% Al_2O_3-water nanofluid as working fluid. Pressure distribution is plotted for the same three orientations 90°, 60° and 30°of CLOHP, keeping the constant heat input of 56.8 W at all orientations. The same observations are observed as that for water as working fluid. At all orientations, initially pressure goes on increasing and after particular values pressure line starts fluctuating indicating the startup of CLOHP. For 90° orientation, startup of CLOHP takes place after 7 minutes while it will start after 11 minutes and 13 minutes for 60° and 30° orientations, respectively. This again clears that, startup time varies inversely with respect to angular orientation of CLOHP resulting into increase of startup time with the decrease of CLOHP orientation.

Pressure distribution, fig. 6, also clears that, CLOHP at 90° orientation shows better oscillation characteristics (regarding the continuity and amplitude of pressure fluctuations) as compared to that of 60° and 30° orientations of CLOHP. In comparison between oscillation characteristics for 60° and 30° orientations, pressure line fluctuates less for 30° orientation of CLOHP. This shows with decrease of angular orientation, pressure oscillation characteristics become poor with reduced pressure fluctuations and amplitude indicating reduced heat transfer performance.

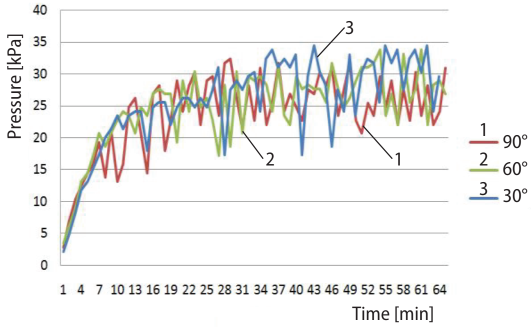


Figure 6. Thermal pressure distribution into water filled CLOHP at different orientations
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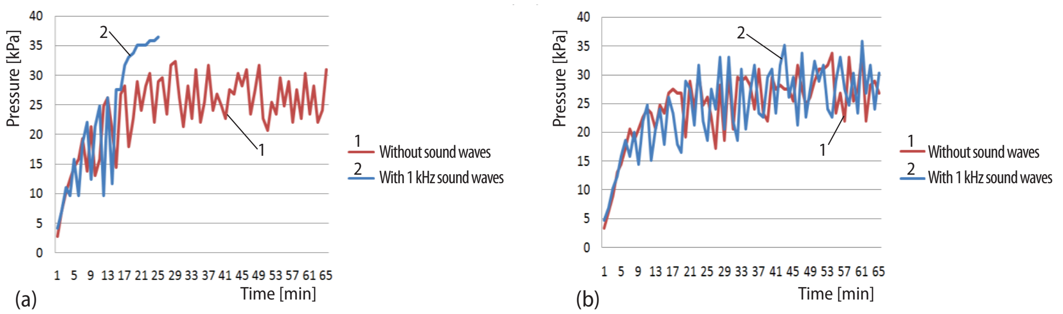
The pressure distributions into 0.1 wt.% Al_2O_3-water nanofluid charged CLOHP at 90°, 60°, and 30° orientations, for both cases of with and without application of sound waves is shown in fig. 7. The heat input of 56.8 W is kept constant at all the orientations. For this heat input the pressure line fluctuations indicating the startup, starts after different time period for different orientations. But the sound waves application at the evaporator section has reduced the startup time at all orientations. The startup of CLOHP takes place after 7 minutes at 90° (vertical position) orientation when no sound waves are applied while application of sound waves of 1 kHz starts CLOHP early *i. e.* after 5 minutes, fig. 7(a). The same results are obtained in case of other orientations. Figures 7(b) and 7(c) clears that, application of sound waves reduce startup time from 11 to 7 minutes and from 13 to 8 minutes for 60° and 30° orientations of CLOHP, respectively.



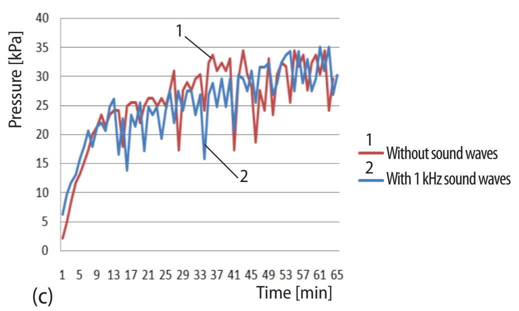


Figure 7. Pressure distribution into 0.1 wt.% Al_2O_3-water nanofluid filled CLOHP at (a) 90°, (b) 60°, and (c) 30° orientations with and without sound waves
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Also, due to the application of sound waves pressure fluctuations become more continuous with enhanced amplitudes at all orientations indicating the improved heat transfer, fig. 7. However, in case of 90° orientation, the amplitude of pressure oscillations goes on increasing with time. After 14 minutes, pressure peak reaches to 27.56 kPa and become stable for two minutes. Then pressure suddenly increases and continues to increase further with time indicating the dry-out condition of CLOHP. Thus the application of sound waves is not suitable at 90° orientation of CLOHP for 0.1 wt.% Al_2O_3-water nanofluid as working fluid since it leads to dry-out condition within less time indicating the reduction in heat transfer.

Comparison of pressure variations at different orientations of CLOHP for water and 0.1 wt.% Al_2O_3-water nanofluid as working fluids

Pressure distribution inside CLOHP at different orientations and for water and 0.1 wt.% Al_2O_3-water nanofluid as working fluids is shown in figs. 8 and 9. The results are plotted with and without use of sound waves for constant heat input of 56.8 W. In the absence of sound waves, CLOHP starts after 17 minutes, 25 minutes, and 33 minutes for water as working fluid, while for 0.1 wt.% Al_2O_3-water nanofluid as working fluid it starts after 7 minutes, 11 minutes, and 13 minutes at 90°, 60°, and 30° orientations of CLOHP, respectively. However, the application of sound waves reduces the startup time of CLOHP for both the working fluids. For water as working fluid startup of CLOHP takes place after 13 minutes, 19 minutes, and 24 minutes on the other hand, for 0.1 wt.% Al_2O_3-water nanofluid as working fluid it starts after 7 minutes, 11 minutes, and 13 minutes at 90°, 60° and 30° orientations of CLOHP, respectively. This clears that as the orientation decreases startup

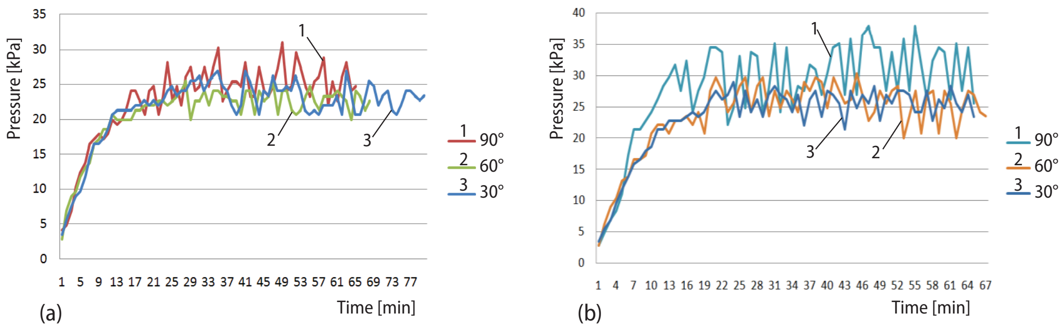

Figure 8. Pressure distributions into CLOHP at 90°, 60°, and 30° orientations for water as working fluid; (a) without sound waves and (b) with sound waves (*for color image see journal web site*)

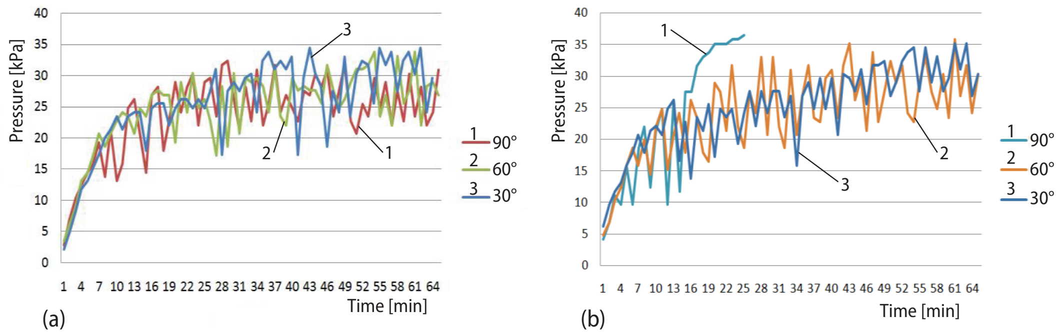

Figure 9. Pressure distributions into CLOHP at 90°, 60°, and 30° orientations for 0.1 wt.% Al_2O_3-water nanofluid as working fluid; (a) without sound waves and (b) with sound waves
(*for color image see journal web site*)

time increases for both the working fluids in both the cases of with and without application of sound waves. However, CLOHP starts much early for 0.1 wt.% Al_2O_3-water nanofluid as working fluid at all orientations and for both the cases of with and without application of sound waves.

Again, for both the working fluids, pressure line fluctuations become discontinuous with the decrease of orientation of CLOHP when no sound waves are applied. On the other hand, pressure oscillations get improved with the application of sound waves resulting increase of amplitude and continuity of pressure oscillations at all orientations of CLOHP excluding the dry-out phenomenon at 90° orientation of 0.1wt% Al_2O_3-water nanofluid filled CLOHP. Thus, for both the working fluids, 90° orientation *i. e.* vertical position of CLOHP is best without application of sound waves. But as compared to water, CLOHP shows better oscillation characteristics with 0.1 wt.% Al_2O_3-water nanofluid as working fluid when no sound waves are present at all orientations. When the sound waves of 1 kHz are applied, water filled CLOHP shows best oscillation characteristics at 90° orientation while 0.1 wt.% Al_2O_3-water nanofluid filled CLOHP shows best oscillation characteristics at 60° orientation.

Comparison of average thermal resistances at all orientations of CLOHP

Figure 10 shows variation of average thermal resistance with respect to angular orientation of water filled CLOHP. The results are plotted with and without the use of sound waves at constant heat input of 56.8 W. It clearly exhibits that, for both the working fluids, thermal resistance goes on increasing with the decrease in the angular orientation of CLOHP, when there are no sound waves are applied. Application of sound waves reduces the thermal resistance for the use of both working fluids at all orientations except at 90° orientation of CLOHP with 0.1 wt.% Al_2O_3-water nanofluid as working fluid. At 90° orientation of 0.1 wt.% Al_2O_3-water nanofluid filled CLOHP, fig 10(b), when sound waves are applied the oscillation characteristics is improved initially which leads to reduction in thermal resistance but afterwards when dry-out condition is reached thermal resistance goes on increasing continuously. Thus application of sound waves is not favorable at 90° orientation of 0.1 wt.% Al_2O_3-water nanofluid filled CLOHP.

When sound waves are not applied the minimum thermal resistance is obtained at 90° orientation for the use of both working fluids. However, as compared to water, 0.1 wt.% Al_2O_3-water nanofluid filled CLOHP shows lower thermal resistances at all orientations. For sound waves application, CLOHP filled with water shows lowest thermal resistance at 90° orientation while for 0.1wt% Al_2O_3-water nanofluid as working fluid, CLOHP shows lowest thermal resistance at 60° orientation without any dry-out as that of 90°orientation.

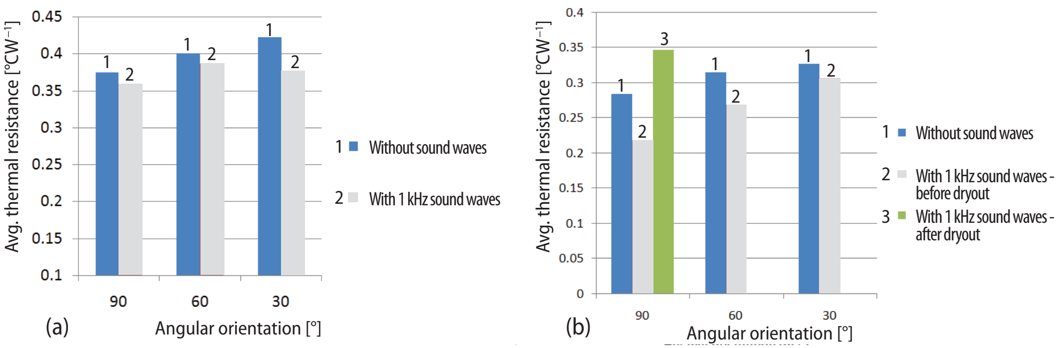

Figure 10. Comparison of average thermal resistances at different orientations of CLOHP for; (a) water and (b) 0.1 wt.% Al_2O_3-water nanofluid as working fluids (*for color image see journal web site*)

Conclusions

Experimental analysis is carried out to study the effects of working fluid and sound waves on the startup and thermal performance of CLOHP. During the experimentations, water and 0.1 wt.% Al_2O_3-water nanofluid are employed as working fluid in the CLOHP while the sound waves of 1 kHz frequency are used. The CLOHP is operated at three orientations as 90°, 60°, and 30° for each of the working fluid. Initially, water is charged into CLOHP and its performance is checked with and without applying sound waves for three orientations of CLOHP. Then 0.1 wt.% Al_2O_3-water nanofluid is utilized as working fluid in the CLOHP and again its performance is analyzed for the same parameters as that of water. The results obtained are then compared with each other. The results obtained with this experimental analysis can be summarized.

- For very low heat input CLOHP does not start working. It will start working only when heat input reaches to particular value. Also, the startup time of CLOHP is inversely proportional to the heat input thus when there is increase in the heat input, startup time of the closed loop heat pipe decreases.
- For both the working fluids, startup time of CLOHP is inversely proportional to the angular orientation of CLOHP thus when the OHP orientation goes on decreasing, startup time of CLOHP goes on increasing.
- In the absence of sound waves, pressure oscillations become discontinuous as the orientation of CLOHP goes on decreasing for both the working fluids. Also the amplitude of pressure oscillations decreases with decease in CLOHP orientation. On the other hand, application of sound waves at the evaporator section of CLOHP improves the oscillation characteristics for both the working fluids, resulting into continuous pressure oscillations with improved amplitudes at all orientations.
- In the absence of sound waves thermal resistance is inversely proportional to the angular orientation of thus when there is decrease in the orientation of CLOHP and its thermal resistance gets increase. Use of sound waves reduces the thermal resistance of water filled CLOHP by 4.27%, 3.49%, and 10.87% at 90°, 60°, and 30° orientations, respectively, while in the case of 0.1 wt.% Al_2O_3-water nanofluid filled CLOHP thermal resistance reduces by 14.60% and 6.12% at 60° and 30° orientations, respectively. Application of the sound waves for 0.1wt% Al_2O_3-water nanofluid filled CLOHP is not suitable at 90° orientation since it leads to the dry-out condition within less time.
- When sound waves are not applied, CLOHP shows better oscillation characteristics with minimum startup time and thermal resistance at 90° orientation for both the working fluids. However, CLOHP charged with 0.1 wt.% Al_2O_3-water nanofluid shows better oscillation characteristics at all orientations as compared to that for water as working fluid. In the presence of sound waves, CLOHP filled with water shows best performance regarding oscillation characteristics, startup time and thermal resistance at 90° orientation while for 0.1wt% Al_2O_3-water nanofluid as working fluid, CLOHP shows best performance at 60° orientation.

The flow patterns inside the CLOHP get changed while operating at inclined positions which results in different performances. However, the present research shows that the use of sound waves at evaporator section of CLOHP can make its operation possible at different orientations with improved oscillation and startup characteristics. Again, at inclined position more enhanced results are obtained in case of 0.1 wt.% Al_2O_3-water nanofluid as compared to water as working fluid.

Nomenclature

La – length of adiabatic section, [mm]
Lc – length of condenser section, [mm]
Le – length of evaporator section, [mm]
T – various temperatures, [°C]

Acronyms

CLOHP – closed-loop oscillating heat pipe
OHP – oscillating heat pipe
PHP – pulsating heat pipe

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