Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the papaer is accepted)

Influence of Aspect Ratio on The Steady State Performance of A Two Phase Natural Circulation loop

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Abstract

The influence of aspect ratio on the steady state behaviour of two phase natural circulation loop (tpncl) is numerically analysed. A one dimensional homogeneous equilibrium model (HEM) is used to analyse the performance of the tpncl. In the present study, a particular loop volume capacity of 551.26 cc with different aspect ratios (ratio of loop height to loop width 'AR') 1, 1.5, 2.33 and 4 are considered. The performance of the loop in terms of mass flow rate studied over a heat input range of 0.2 kW to 5.2 kW. Results show that the mass flow rate increases with heat flux. However, with the increase in heat flux, the mass flow rate increases initially up to a certain value and thereafter decreases. Also, increase of aspect ratio increases the mass flow rate. The average enhancement in mass flow rate is 56% for AR-4 as compared with AR-1. This happened because of the developed pressure gradients in the loop was high.

Keywords Aspect ratio, Two Phase NCL, Vapour quality.

Introduction

Natural circulation loops (NCLs) opt as a lucrative choice in engineering industries especially with cooling applications as in nuclear reactor cooling, gas turbine blade cooling, energy conversions, and electronic components cooling purpose [1]. The circulation of the fluid is mainly developed due to the difference in densities in the loop. This density difference is achieved either by varying the loop fluid temperature (single phase NCL) or by phase change process (Two phase NCL). Single phase NCLs have its own constraints about loop fluid saturation point. If the heat capacity at source is increased or geometrical modifications are done in the loop, it leads to initiation of phase change or flashing in the system. As the circulating fluid undergoes phase change or flashing in one section and condensation or phase separation taking place at other section, resulting high density single phase fluid at one section and low density two phase mixture at other. This causes high density differences in the loop and actuates stronger buoyance forces, which promotes more circulation rate and higher performance of the system.

Generally, for all NCLs, based on its applications for nuclear reactors, solar evaporators etc., the constraints like the fluid volume of the system and space availability for the installation is directly related to the initial investment cost and maintenance cost. So that the optimum loop configuration is to found in terms of maximum mass flow rate under the given constraints. From the past decades onwards, theoretical and experimentally studies are explore the influence of the following parameters such as heater and condenser orientations, geometrical and operating conditions and use of different working fluids on NCL performance. For example Chen and Chang [2] analytically examined the two phase NCL under steady state conditions using homogeneous equilibrium model (HEM) with saturated water–vapour as working fluid. Square and toroidal configurations are considered for their analysis with the assumption of a linear variation in quality of working fluid. The mass flow rate strongly depends on the flow cross sectional area and the two phase zone length. . Lee and Mittal [3] experimentally investigated the two phase thermo-syphon loop performance and validated with the theoretical analysis. N M Rao et al. [4] presented the steady state performance of a two phase NCL with vertical heater and condenser using HEM and thermally equilibrium drift flux model (TEDFM).They reported that loop mass flow rate is depending on geometrical parameters and operating conditions such as heater length, loop height, inlet temperature, pressure & heat flux.

So, for the given loop fluid volume of 551.26cc the NCL behaviour is analysed by varying the aspect ratio (ratio of loop height to loop width 'AR'). The above considered constraints directly replicate on the geometrical parameters such as loop height and width and diameter. Hence in the present study, a uniform cross section is considered and the loop height and width varied in terms of aspect ratio. The pressure drop in two phase regions is estimated by using the homogeneous equilibrium model. The influence of aspect ratio on loop performance studied in terms of the mass flow rate.

MATHEMATICAL MODELING

The schematic representation of two phase rectangular NCL as shown in Fig.1. The heating and cooling sections are placed in horizontal arms of the loop centrally. To get favourable buoyance force, cooling section is placed at a higher elevation than the heater as shown in Fig 1. In order to investigate this NCL behaviour, the following assumptions are considered.

1. Uniform and constant heat flux boundary condition is considered at heater and condenser sections.
2. The thermo-physical properties are considered as per the loop fluid state.
3. Viscous dissipation effect and axial conduction are neglected.
4. The riser and downcomer are completely insulated.
5. The flow is in counter clockwise direction.
6. The minor losses in the loop are neglected.

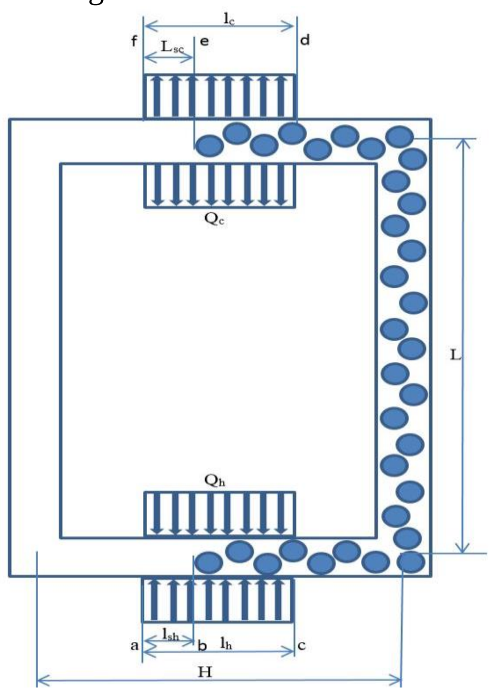


Fig.1 Schematic diagram of NCL [5]

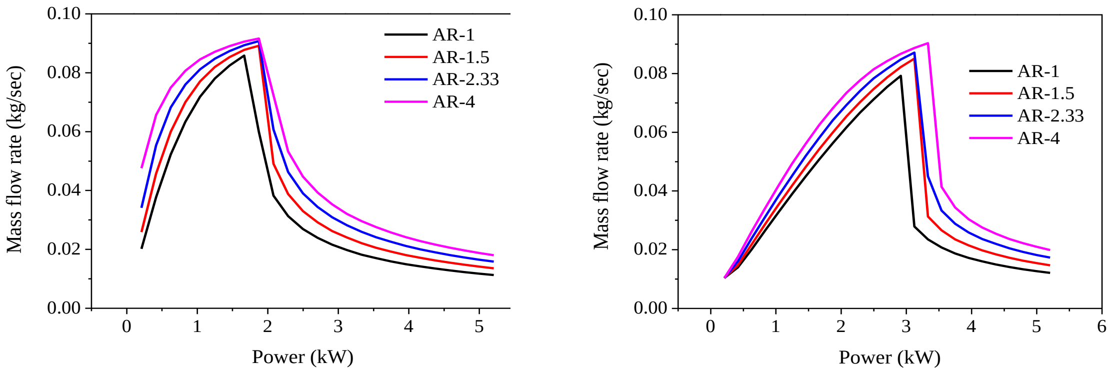
The authors earlier presented a numerical model to analyse the two phase NCL[5]. So, in the present work the same governing equations and solution procedure is used for investigating the effect effect of aspect ratio on the steady state two phase NCL behaviour.

Result and discussion

In the present study, the effect of aspect ratio on two phase NCL is investigated. Water is used as the loop fluid. NCLs configuration is obtained with aspect ratios of 1, 1.5, 2.33 and 4 by keeping the diameter and total volume of the loop constant (551.26 Cc). The detailed NCL geometrical parameters and operating conditions considered for the analysis are given in table 1. In order to simplify the calculation, heater length is taken the same as horizontal length for respective aspect ratios of the loop.

Table 1: Geometrical parameters and operating conditions of the loop.

Parameter	**Value/Range**
Aspect ratio (L/H)	1,1.5,2.33 and 4
Diameter of the pipe	0.01325 m
Loop horizontal length	1,0.8,0.6 and 0.4
Inlet temperature (T_i)	(90 and 95) ^oC
Pressure inside the loop (p)	1.01325 bar
Heat interaction at source/sink ($Q_h = Q_c$)	0.2-5.2 kW



(a) Heater inlet temperature 95 ^oC (b) Heater inlet temperature 90 ^oC

Fig.2. Variation of mass flow rate w.r.t. heat input

Fig.2(a and b) shows the effect of heat flux, aspect ratio and heater inlet temperature on the loop mass flow rates. The mass flow rate of the NCL is increases linearly with the heat input. For a fixed configuration, as the heat input increases the quality of loop fluid increases at heater exit which is shown in Fig. 4. This is due to the fact that, the density difference between heater outlet and condenser outlet increases with increasing heat input. However, it can be observed from the Fig. 2 that further increase of heat input results in decrease in flow rates. This is due to the increase in frictional drag at higher dryness fractions. So it can be concluded that there is a limiting heat input value for each configuration of the loop.

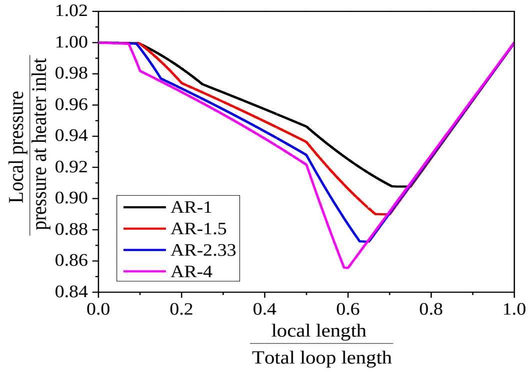


Fig.3 Variation of local pressure along the loop

Fig. 2 (a and b) depicts the mass flow rate variation with the heat flux for the aspect ratios of 1, 1.5, 2.33 and 4 at heater inlet temperature of 90°C and 95°C respectively. It is evident from Fig. 2 that, mass flow rate is a strong function of aspect ratio. With increase in aspect ratio, loop fluid circulation rate increases. The maximum loop fluid circulation rate is observed for the aspect ratio 4. The average enhancement in mass flow rate at 95 °C heater inlet temperature is 56% as compared with the loop having aspect ratio 1. Peak heat flux values are shifting towards the left and the optimum mass flow rate is obtained at high heat inputs. This is because of the developed pressure gradients in the loop.

Fig.3. depicts the pressure profile across the loop at a heat input of 2.08 kW for loop aspect ratios of 1, 1.5, 2.33 and 4. As the aspect ratio increases loop height increases and heater length decreases. This results in high density gradient across riser and downcomer sections which can be observed in terms of local pressure profile along the loop. The loop fluid absorbs the heat at the heater and undergoes phase change and then enters into the riser. In riser, low density vapour liquid mixture is available. The low density vapour liquid mixture rises in the riser and the corresponding local pressure drops. The local pressure drop across the riser develops the pressure gradient in the riser section which increases with increase of aspect ratio that is observed in Fig.3. The developed pressure gradient in the riser is compensated by the pressure gain in the downcomer and it also increases with aspect ratio. Therefore the pressure gradient across the riser and downcomer increases with increase in aspect ratio resulting enhanced mass flow rate.

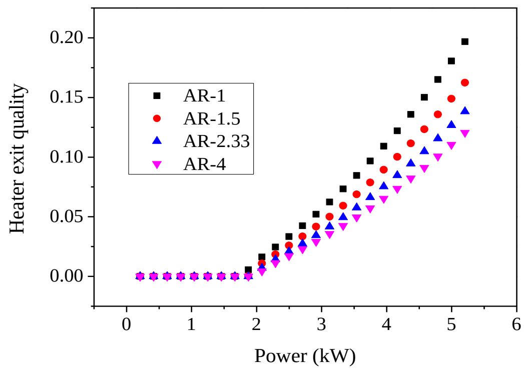
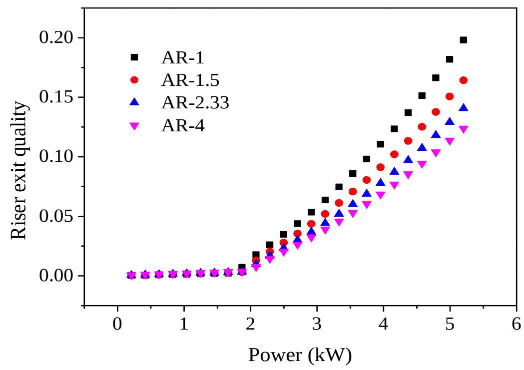
	

Fig. 4(a) Heater exit quality variation w.r.t. heat input	Fig. 4(b) Riser exit quality variation w.r.t. heat input

Fig. 4 shows the variation of heater exit quality and riser exit quality in the loop. As aspect ratio increases, vapour quality at heater exit and riser exit decreases that is observed in Fig. 4. This happens because of increase in mass flow rate, which is inversely proportional to the heater exit enthalpy. Thus for the same amount of heat input, decrease in heater exit enthalpy results in less vapour quality. It also observed that there is a difference in heater exit vapour quality to the riser exit vapour quality as a result of flashing phenomena [5].

Conclusions

The influence of aspect ratio (ratio of loop height to loop width ‘AR’) on the steady state performance of a two phase natural circulation loop is analysed. By keeping the diameter and total volume of the loop constant (551.26 Cc) loop aspect ratios of 1, 1.5, 2.33 and 4 are considered in this study. One dimensional approximation is considered to simplify the problem. Homogeneous equilibrium model is used for two phase flows. The mass flow rate in the loop is obtained by balancing the pressure gradients in the loop.

The major findings during the analysis are as follows

- From the results, it is clearly concluded that two phase NCLs performance is affected by different parameters such as inlet temperature of loop fluid, heat input and aspect ratio.
- As aspect ratio increase, the loop height increases and mass flow rate increases. This is due to high pressure gradient across the riser and downcomer sections.
- The average enhancement of mass flow rate for loop with aspect ratio 4 is 56% as compared to the loop with aspect ratio 1.
- For any configuration of the loop there is an optimum value of heat input.
- The increase of quality in the loop is not always favourable. There is a limiting quality beyond which further increment retard the loop performance.

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