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EFFECT OF LOOP DIAMETER ON TWO-PHASE NATURAL CIRCULATATION LOOP PERFROMANCE

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Abstract: *This paper aims to present the effect of loop diameter on steady state performance of the two-phase rectangular natural circulation loop (NCL). A one dimensional homogeneous equilibrium model is developed to estimate the two-phase pressure drop across each section of the loop. Thermophysical properties and state properties are considered at local pressure. Uniform heat flux is applied at both evaporator and condenser sections. Mass flux is obtained by solving loop momentum equation using iterative procedure. Results are presented for different loop diameters under same heat load, gravitational head and fluid quantity. The effect of the loop diameter on the mass flow rate is also analysed.*

Keywords: Two phase, Natural Circulation Loop (NCL), Mass flow rate, Homogeneous equilibrium model, Quality.

1. Introduction

In the present scenario, effective utilization of energy plays prominent/important role in day to day life. versatile needs of energy, demands various transporting mechanisms. Among many methods adopted for different industrial and commercial applications, Forced Circulation Loops (FCLs) and NCLs play key role in the vicinity of energy transport. The fluid circulation can be attained either by external power sources like pumps or by the natural circulation due to buoyancy. In natural circulation, thermally developed density gradients are the driving force. One cannot rely on the external source to run the loop for longer period.Therefore, NCL is a lucrative choice. In NCL, riser and down comer connects the source and sink for energy transfer. Simplicity in configuration and reliability in performance grabs the attention of researchers to make it useful for diversified applications like cooling of nuclear reactor, gas turbine blades, solar heaters, and waste heat recovery boilers so on (Close 1962; Hagen et al., 1997; Heisler 1982; Shitzer et al. 1979).

Based on the state of working fluid NCLs can be either single phase or two phase. Two–phase NCLs have advanteges over single phase NCLs due to large density gradients accross the loop.

From the past few decades, different analytical approaches are reported in the literature to study the performance of two phase NCL. Thermally equilibrium based homogeneous model (Chen et al., 1988; Rao et al., 2006) and drift flux models (Rao et al., 2006; Jeng et al., 1999) and one dimensional two fluid model with thermodynamic non equilibrium Basu et al. (2009) are developed to analyze the loop.The present work, aims to develop a model to study the performance of two phase NCL with one-dimensional approach. Pressure drop in two phase regions is estimated by using homogeneous equilibrium model. Viscosity of two phase mixture is estimated based on correlation developed by McAdams et al. (1942). The effect of diameter on loop performance is also analyzed.

2. Mathematical Modeling

Fig. 1 shows the schematic representation of two phase NCL considered for the analysis. A uniform cross sectional rectangular loop is considered. Evaporator and condenser sections are positioned on horizontal arms at an elevation difference to add the favorable gravity gradients to the loop fluid. Constant heat flux

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boundary condition is considered at evaporator and condenser sections. Based on the loop fluid state the loop is categorized into six regions which are represented in Fig. 1 and Tab. 1.

Nomenclature			
A	Flow cross sectional area, m^2	D	Diameter, m
G	Mass flux, kg/m^2 s	g	Acceleration due to gravity, m^2/s
h	Enthalpy, kJ/kg	H	Length of horizontal arm, m
Δh	Change in enthalpy at evaporator, kJ/kg	L	Loop height, m
l_{sh}	Sub cooled length in evaporator, m	$l_{h=}l_{evap}$	Heater length, m
l_{sc}	Sub cooled length in condenser, m	$l_c = l_{cond}$	Cooler length, m
$\dot{m}$	Mass flow rate, kg/s	p	Pressure, bar
P	Heat load, kW	dp/ds	Pressure gradient, N/m^2
Q_h	Heat input per length, kW/m^2	Q_c	Heat flux at condenser, kW/m^2
s	Space coordinate, m	v	Specific volume, m^3/kg
x	Dryness fraction	v_{bar}	Mixture specific volume, m^3/kg
Subscripts			
a	Acceleration	avg	Average
f	Saturated liquid/frictional	g	Saturated gas (vapour)
fg	Difference between gas (vapour) and liquid properties at saturated state		
i	Inlet	tp	Two phase
μ	Viscosity, kg/m.s		

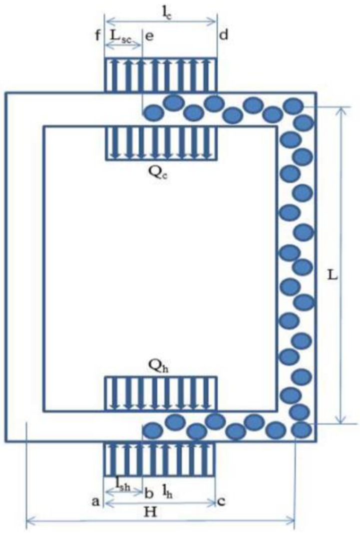

Fig. 1: Schematic diagram of a two phase NCL.

Tab. 1: Loop regions.

S.No	Regions	Zone description
1	a-b	sub-cooled heating region
2	b-c	vaporization region
3	c-d	adiabatic two-phase region
4	d-e	condensation region
5	e-f	sub-cooled cooling region
6	f-a	adiabatic single phase region

The following assumptions are made to simplify the solution.

1. Bulk temperature of the loop fluid reaches saturation temperature in the evaporator section.
2. Thermo physical properties are considered at local pressure only instead of system pressure.
3. Loop is perfectly insulated.
4. Minor losses in the loop neglected.
5. Quality in the loop linearly varies.
6. Flow is in counter clockwise direction.

The mass flow rate, heat transfer rate and pressure drop in the loop are inter related. Loop mass flow rate is evaluated by iterative procedure. Since the total pressure drop in NCL is zero, the one dimensional momentum equation of loop by considering frictional, gravitational and acceleration pressure drop is as follows

$$\oint\left(\frac{dp}{ds}\right)_f ds+\oint\left(\frac{dp}{ds}\right)_g ds+\oint\left(\frac{dp}{ds}\right)_a ds=0 \tag{1}$$

The pressure drop in each section of the loop is tabulated in Tab. 2.

Tab. 2: Pressure drop at various sections of loop.

Regions	Friction pressure drop	Gravitational pressure drop	Acceleration pressure drop
ab	$\frac{2C_{foavg}G^2 v_{avg} l_{sc}}{D}$	0	$G^2(v_f - v_{fi})$
bc	$\frac{2C_{\overline{ftp}}G^2 v_{\overline{avg}}(l_{evap}-l_{sc})}{D}\left(1+\frac{x}{2}\frac{v_{fg}}{v_f}\right)$	0	$G^2 v_{fg} x$
cd	$\frac{2C_{ftp}G^2 v_{bar}(H-l_{evap}+L)}{D}\left(1+x\frac{v_{fg}}{v_f}\right)$	$\frac{gL}{v_{bar}}$	0
ef	$\frac{2C_{\overline{ftp}}G^2 v_{\overline{avg}}(L_{cond}-l_{sc})}{D}\left(1+\frac{x}{2}\frac{v_{fg}}{v_f}\right)$	0	$-G^2(v_f - v_{fi})$
fa	$\frac{2C_{foavg}G^2 v_{avg}(H-l_{cond}+L)}{D}$	$\frac{gL}{v_{fi}}$	0

Where C_{favg}, v_{avg} are the average of the properties at inlet and saturation state of the liquid.

$C_{\overline{ftp}}$&$v_{\overline{avg}}$ are average of the properties at quality 0 and x

Appropriate energy balance equations are applied at every section to find the lengths.

3. Result and discussion

By keeping the mass of the loop and height of the loop constant, the required diameter, horizontal section length and heat section length are derived. These values are shown in Tab. 3. Fig. 2 shows the effect of diameter on loop mass flow rate for different heat inputs. As the heat flux increases mass flow rate increases up to certain limit and then after decreases. As diameter increases mass flow rate increases and the peak value is shifted to right. This happens because of the quality and pressure drop in the riser section.

Tab. 3: Two phase NCL configuration.

Diameter [m]	Horizontal section length [m]	Height of the loop [m]	Heating section length [m]
0.01225	1.5098	2	0.5408
0.01325	1	2	0.5
0.01425	0.5937	2	0.4649

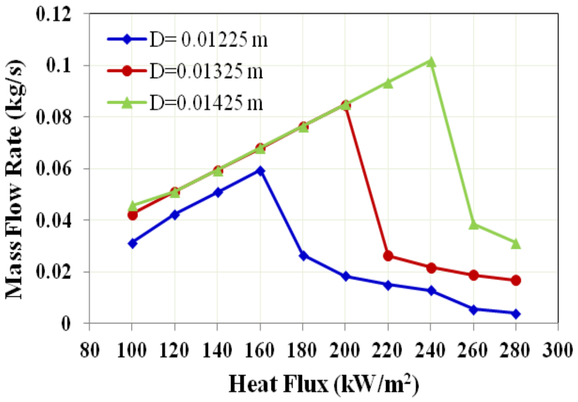

Fig. 2: a) Effect of diameter on loop mass flow rate.

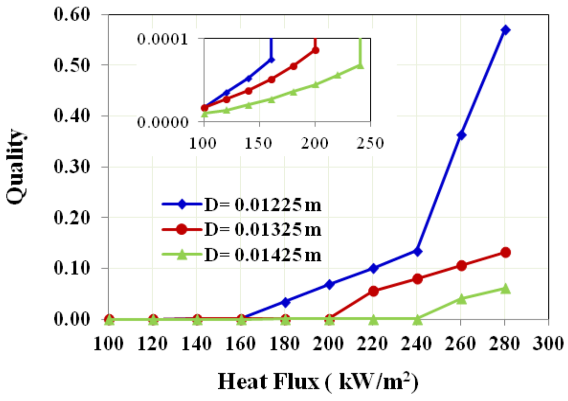

Fig. 2: b) Effect of diameter on loop quality.

Fig. 2b shows the variation of quality in the loop. In homogeneous 1D modeling, quality is estimated as the area averaged value. As diameter increases the evaporator length decreases, even though the fluid quantity in the evaporator increases. Thus, for the same amount of heat flux supplied at evaporator, exit quality of loop fluid decreases and higher quality can be obtained at higher heat fluxes. Fig. 3 shows the two phase pressure drop in the loop for different diameters. As loop diameter increases the friction loss and quality reduces. The decrease in quality provokes gravitational head in the riser. Hence the overall two phase pressure drop increases.

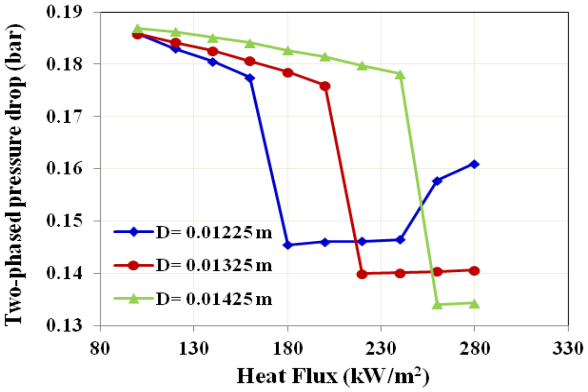

Fig. 3: Two phase pressure drop in the loop at different heat flux.

4. Conclusions

The steady state performance of a two phase natural circulation loop by varying loop diameter is analysed. One dimensional homogeneous model is used. Loop steady state solution is obtained in terms of mass flux by solving the momentum equation. The following important findings are noted during the analysis

- NCLs performance is strongly affected by loop diameter.
- For a particular loop height and quantity of loop fluid, loop diameter has significant influence on quality.

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