Stability Behaviour of Natural Circulation Studies for Unusual Orientations in a Rectangular Loop using Relap5/Mod3.2 Computer Code

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Abstract - *According to other power generation system, basically in a plant of nuclear energy has primary utility of the natural circulation system is progressively considered for passive safety system. It plays important role in NC system providing for a cooling of the reactor inner space in emergency breakdown of pumping power.*

RELAP5/MOD3.2 Code was developed to estimate the best transient simulation systems cooling water reactors under postulated accident due to failure of the pumping power in the nuclear plant. These characteristics are studied for estimation of the loop temperature, establish maximum flow rate and the heat removal in sink of the loop. As this test is carried out before the system is to be designed, it is expected that the results of this test will be taken into account after the installation and the test plan have been completed.

However, unusual orientation still needs to be investigated. Here, to study NC for unusual orientation of heater and cooler in a rectangular loop. In unusual orientation cooler placed just above the heater in a vertical leg as per requirement. As per requirement of NC used in Light Water Reactors (LWRs) in future, A pretest analysis needs to be carried out get clearance for installation of the loop in Bhabha Atomic Research Centre (BARC) as orientations involved are unusual and also analysis of NCL by using RELAP5/MOD 3.2 Computer code.

Key Words: *Rectangular loop natural circulation, RELAP5 / MOD3.2 computer code, single and two phase flow.*

1. INTRODUCTION

According to natural circulation scenario fluid or any other gas particles flow only by the force of buoyancy [1] and the force of gravity [2]. In any system of NC, it is impossible to build if you are not working on natural laws. It consists of natural circulation is divided into three main parts such as a heater, cooler and overall rectangular loop. Always place the source at the bottom of the sink for the liquid stream by effective driving force. The other way, cold fluid is displaced with the aid of gravity as a result of a higher density. These phenomena can be supplied to another point from colder to a warmer place to remove heat during a cyclical operation. NC is based on existence of a natural cycle system used in renewable resources, e.g. based on geothermal system [1] and a solar energy [2]. In the nuclear power plant (NPP), the performance of natural circulation is mainly examining safety systems [3]. Above all three systems are included in the process type of renewable energy source.

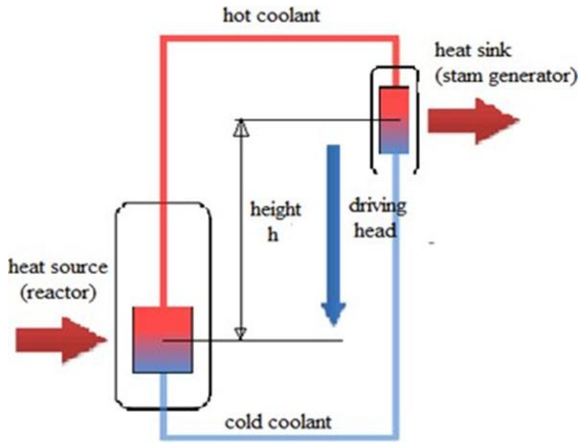

Fig. 1 VHVC orientation

Passive safety is a primary system of NC, in which is not requirement of any external energy source and it is based on work flow phenomena by natural laws. The need for passive safety is much essential factor in case of accidental failure in the plant, which was previously passed at the Fukushima Daiichi nuclear plant in which all sources of heat loss from the system for use. In that case of barriers, the natural circulation system is used to remove heat from the inside core. Some models of compact nuclear standard type containing the passive safety of the natural cycle. As per nuclear research, passive safety and part of the NC that play an important role in maintaining safety to ensure the necessary reliability, performance and availability and the stability concept of the system is continued with heat dissipation in NC. Centre for Technology and Security of nuclear reactors and the National Atomic Energy Agency of Indonesia (Batan) in past years began the development as well as research program utilizes of NC for the safety of nuclear reactors.

The study used computer code RELAP5 / MOD3.2 specially designed to simulate existing NCL unusual orientation. The objective is to evaluate the effect of the energy of the heater (power) and the diameter of the pipe (D) to test the properties of natural circulation of primary variables. The purposes of code are to evaluate the effect of two variables to consider the strength of the preheater (power) and the diameter of the tube to the significance of the NC. These characteristics of NCs are to evaluate temperature inside loop, maximum mass flow in loop and maximum heat removal from the cooler. This type of case study is carried out before the assemble of the facility and evaluate results by using computer code expected to be considered in the fulfillment of the experimental design.

2. EXPERIMENTAL SETUP

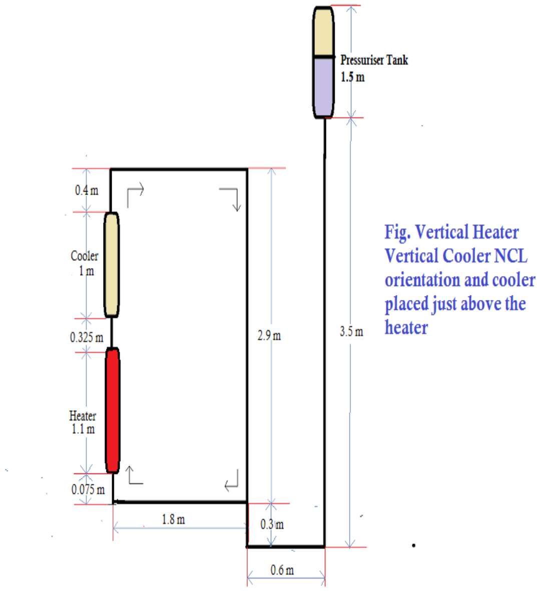

Fig. 2 VHVC setup

In above figure shows that vertical heater vertical cooler is placed at the one side of the loop. It consists of heater, cooler, expansion tank and piping system. It should be arranging as per design specification to analysis of an unusual orientation. Heat source is always placed below the heat sink because heat always flows from high temperature to low temperature. So, heater placed just below the cooler.

It is proposed to Study natural circulation for unusual orientation in a rectangular loop. Hence, a rectangular loop has been proposed to be setup in Bhabha Atomic Research Centre (BARC). A Literature review shows that the natural circulation in a rectangular loop has been extensively studied for most common orientation of heater and cooler. i.e. HHHC, HHVC, VHVC & VHHC is shown in Fig.1 Vijayan et al. (2008) & Sharma M. (2001).

However, unusual orientation still needs to be investigated. Here, to study NC for unusual orientation of heater and cooler as shown in Fig.2. Design orientation, when cooler placed just above the heater in a vertical leg

A pretest analysis needs to be carried out get clearance for installation of the loop in BARC as orientations involved are unusual and also analysis of NCL by using RELAP5/MOD 3.2 Computer code as following.

TABLE I

Characteristics length of an unusual natural circulation loop

COMPONENT NAME	Length(m)
Heater	1.1
Hot leg	0.325
Cooler	1
Cold leg	6.975
Total length of loop	9.4
Secondary pipe	1
Pressurize pipe	4.4
Pressurize tank length	1.5

TABLE II

Loop Size as per ASME Standards

Component Name	Designation	Outer Dia.(mm)	Inner Dia.(mm)	Wall Thickness(mm)
Rectangular loop	DN40 schedule 80	48.3	38.14	5.08
Secondary pipe	DN65 schedule 80	73.0	58.98	7.01
Pressurize pipe	DN15 schedule 80	21.3	13.84	3.73
Pressurizer tank	DN150 schedule80	168.3	146.36	10.97

3. METHODOLOGY

3.1 Experimental method using RELAP5 computer code

Primary function of experimental design in RELAP 5 is to discretization of total loop and parts of NC system into the small number of volumes. As shown in Fig. 3 Rectangular loop subdivided into 56 numbers of volumes and arranged into serial as shown in Table III.

Power input giving to the heater by calculating in terms of heat flux (w/m^2) and cooler arranged above the heater for removing amount of heat generate in the loop. Secondary flow pass into the system by using counter flow because, effectiveness of counter flow heat exchanger is high as compared to parallel flow.

Final assemble done in RELAP by using computer code as per design and system will run as per given input power and secondary flow. Check whether system is to operate in single phase or two phases and also check stability behavior of NC at same power. Evaluate temperature in the loop, maximum flow rate in loop and threshold power in the system to run properly.

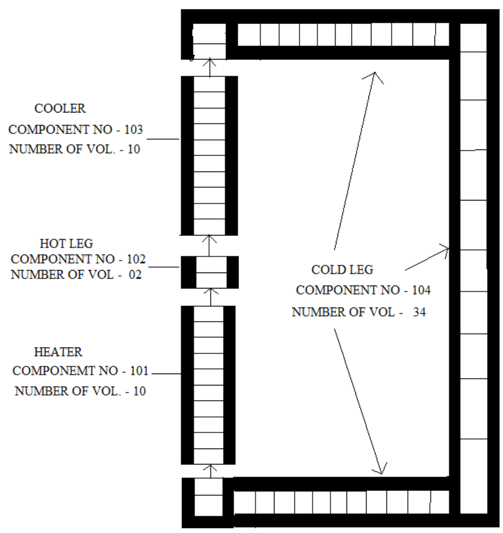

Fig. 3 Input Deck arrangement in RELAP5

Table III
NC loop code arrangement for VHVC

Vol. no.	Total length (m)	Flow area (m^2)	Hyd. Dia. (m)	Angle (degree) VA	Angle (degree) HA	No of vol.	Length of each vol. (m)
101	1.1	0.001142	0.0086	90	0	10	0.11
102	0.325			90	0	2	0.1625
103	1		0.026	90	0	10	0.1
104	0.4		0.0086	90	0	2	0.2
	1.8			0	0	10	0.18
	2.9			-90	0	10	0.29
	1.8			0	180	10	0.18
	0.075			90	0	2	0.0325

3.2 Analytical Method of loop design

Buoyancy force to due to effect of density difference in warmer region, whereas gravitational force due to effect of density difference in colder region.

If, NC working on purely steady state condition then phenomena can be implemented by equation as follows:

1) Retarding frictional force in cold region (right side of eq.1)

2) Buoyancy force generate in hot region (left side of eq.1)

$$- g\oint \rho dz = \frac{R_h * \dot{m}^2}{2\rho} \text{ ....1}$$

In general, hydrodynamic resistance R_h derived as follows

$$R_h = \sum_{i=1}^{n} \left(\frac{f*L}{D} + K\right)\frac{1}{A^2} \text{..............}2$$

Arranging Eq.2,

$$A^2 R_h = \sum_{i=1}^{n} \left(\frac{f*L}{D} + K\right) \text{................}3$$

Integrating eq.2

$$g(\rho_h - \rho_c)*H = \frac{\dot{m}^2 R_h}{2\rho} \text{..........................}4$$

Rearrange eq.4

$$m^2 = \frac{2\rho g(\rho_h - \rho_c)H}{R_h}$$

For laminar flow pipe friction derived by,

$$f = \frac{64\mu}{\rho v D} \text{..............}5$$

Substitute in eq.3

$$R_h = \frac{64\mu L + \rho v K D^2}{\rho v D^2 A^2} \text{ .... } 6$$

Eq.6 substitute by eq.2 $\dot{m} = \rho A v$

$$\frac{-64\mu L + \sqrt{(64\mu L)^2 + 8gHK\rho(\rho_h - \rho_c)D^4}}{2\rho K D^2} \text{.....}7$$

From eq.7 flow rate of NCL derivate from natural laws. In another way to say that, effect of all parameter like temperature (T), loop diameter (D), driving head between source and sink (H), overall length of loop etc.

4. RESULT AND DISCUSSIONS

Design VHVC orientation at Pressure 70 bar and secondary flow 12 lpm

4.1 Power at 30 Kw

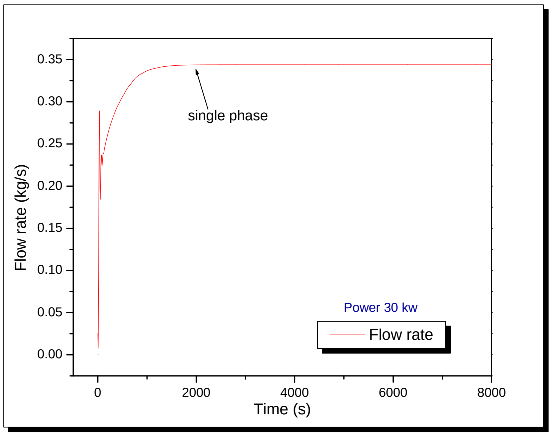

Fig.4 Flow rate variation

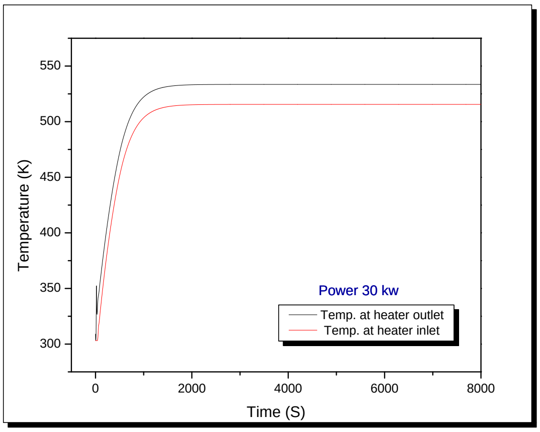

Fig.5 Variation of temperature with time

Start up from rest power at 30 kW raise flow rate in the NC system up to period 1500 seconds, after it will stable in single phase as shown in fig. 4. In this system secondary flow keep constant at 12 lpm. At power 30 kW or below 30 kW system runs smoothly in single phase flow. Because temperature difference at heater is sufficient i.e. 17.98 °C for maintain stability in the system as shown in fig.5. Design the system to run only in single phase, power must be taken 30 KW at flow 12 lpm secondary flow.

Secondary inlet at 27 °C with flow 12 lpm has sufficient for stable performance in single phase flow up to 30 kW power and it is desirable as per design. Maximum flow rate achieve without phase change in the system is 0.34 kg/s at 30 kW power as shown in fig.4.

4.2 Power at 35 kW

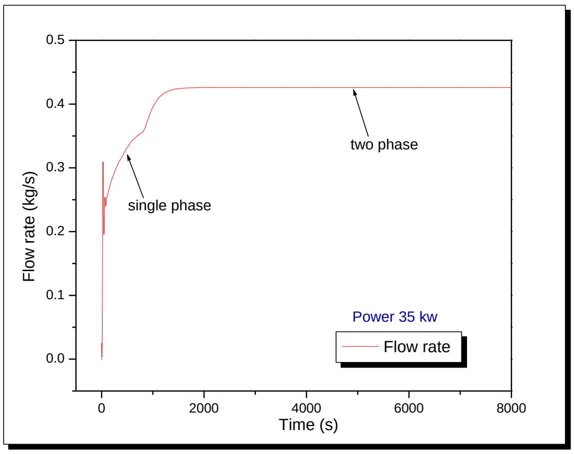

Fig. 6 Flow rate variation

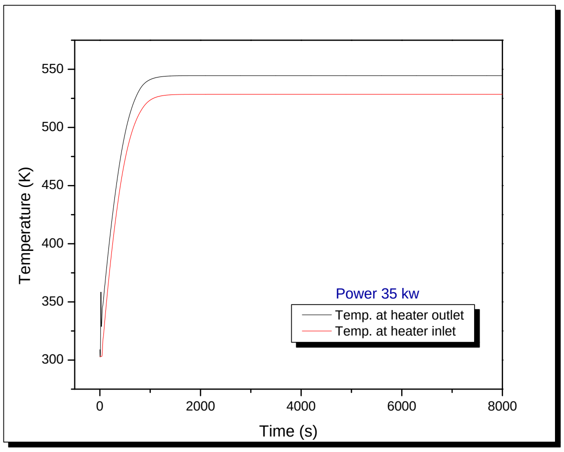

Fig. 7 Variation of temperature with time

As shown in fig.21 power raising from 30 kW to 35 kW system flow in single phase up to certain duration (1000 seconds) and then converted into two phases. Because at 70 bar pressure temperature difference at heater has 16.04 °C so for removing this much amount of heat generated in system secondary flow requires 31 lpm as per analytical calculation. Even system run below saturation temperature but small amount of void generates in the system up to 2% as shown in fig.8. After converting into two phase it will run stable continuously and maximum flow rate 0.42 kg/s achieve from the system.

This system can't design with flow greater than 12 lpm, because above 12 lpm system becomes saturated state and does not effect on the system, if increasing secondary flow.

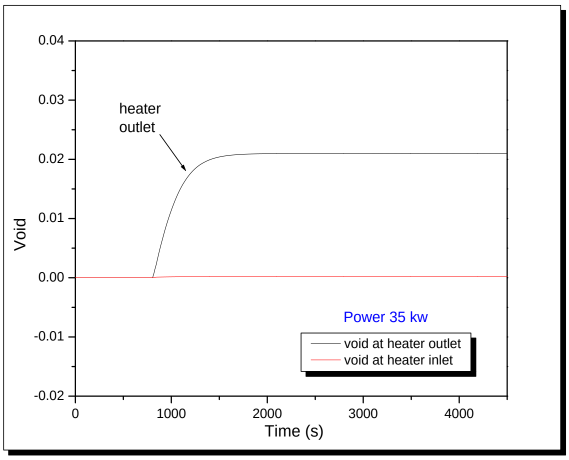

Fig. 8 Variation void fraction with time

4.3 Power at 40 kW

As per design specification of area and flow rate of secondary flow must be constant but power continuously goes on increasing so, temperature difference at heater 12.67 °C decreasing respectively as shown in fig.10 and system becomes stable even in two phase flow as shown in fig.9 with maximum flow rate in the loop is 0.55 kg/s. Stability in two phase flow becomes continuously because flow at 12 lpm with inlet 27 °C is sufficient to maintain flow at 70 bar pressure. If system can't keep on single phase, because increasing secondary flow up to 12 lpm and after that it will goes on saturated state. System will run continuously in two phases, due to 3% void generation in system at 40 kW power as shown in fig.11.

This system is more stable even in two phase flow as compared to secondary flow at 1.2 lpm and achieve maximum flow rate in the system up to 0.39 kg/s at same power.

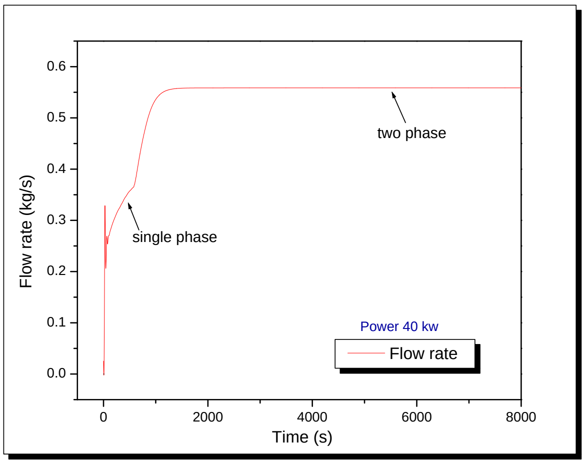

Fig. 9 Flow rate variation

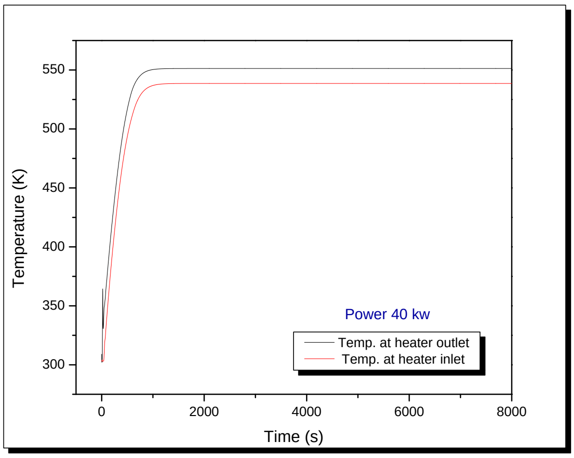

Fig. 10 Variation of temperature with time

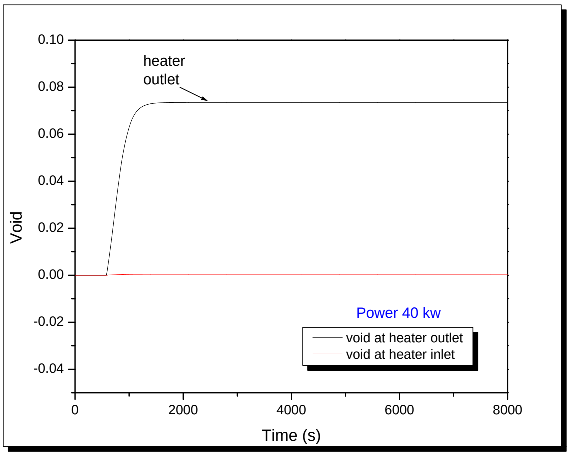

Fig. 11 Variation void fraction with time

4.4 Power at 45 kW

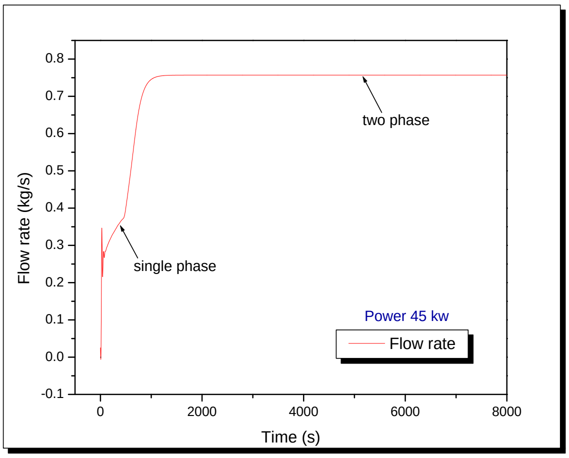

Fig. 12 Flow rate variation

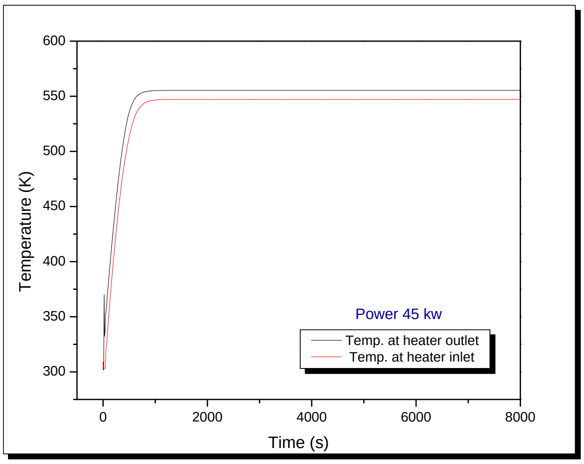

Fig. 13 Variation of temperature with time

At power varying from 40 kW to 45 kW stability in two phase flow keep constant and achieve maximum flow rate with flow 0.72 kg/s at 12 lpm as shown in fig.12 Because temperature in the system goes on increasing with respect to the power and 16 % amount of water start converting into vapour as shown in fig.14 Temperature difference at heater has becomes 8.18 °C and for removing amount of heat generated in the system requires secondary flow 78 lpm but system becomes saturated at 12 lpm at pressure 70 bar and the system still runs stable in two phase flow continuously as shown in fig.12.

Maximum secondary flow achieving from the system at pressure 70 bar is to 12 lpm because above 12 lpm system will converted into saturated state and even further increasing in flow does not effect on the system at 45 kW power.

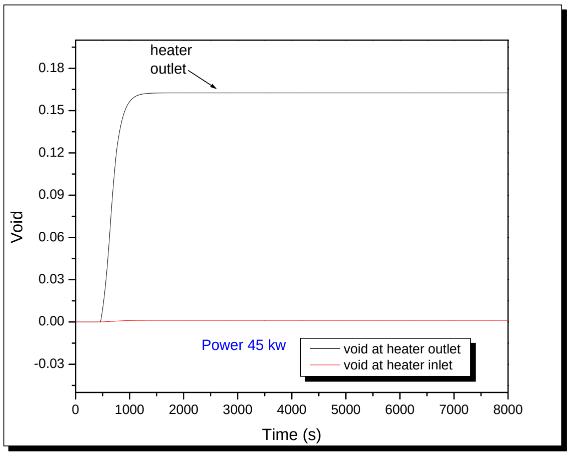

Fig. 14 Variation void fraction with time

4.5 Power at 50 kW

Stability in two phase flow system runs well up to power at 49 KW and further increasing power up to 50 kW, temperature difference at heater reduces to zero or negative as shown in fig.16. Negative temperature difference in the system, because of flow becomes reverse direction. Temperature at heater outlet becomes 287°C but at 70 bar pressure saturation temperature is 285.8°C so, it cross saturation temperature and converted into superheated state and overall system goes on superheated region. At this condition cooler does not work properly and temperature in the cooler also increasing and design must be failed at this condition.

Because void generation in the system becomes 100% and total system runs on superheated region as shown in fig.18. Due to superheated state system becomes after certain duration converted into dead state or zero flow as shown in fig.15.

As shown in fig.19 it shows that temperature of vapour induced in the system after the 1600 seconds and cross limit of saturation temp. At this condition temperature of the system varies continuously and cooler does not work flow at 12 lpm, design must be failed at power 50 kW.

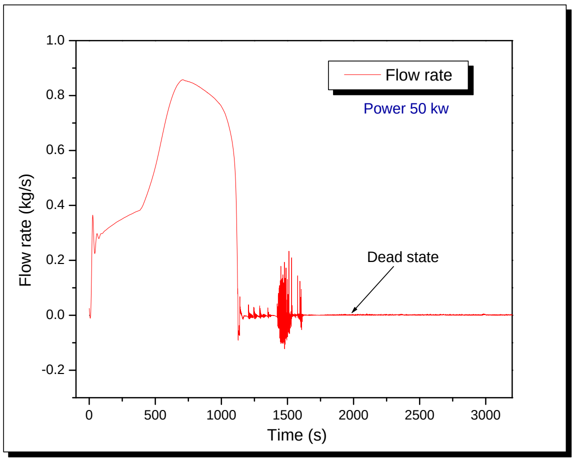

Fig. 15 Flow rate variation

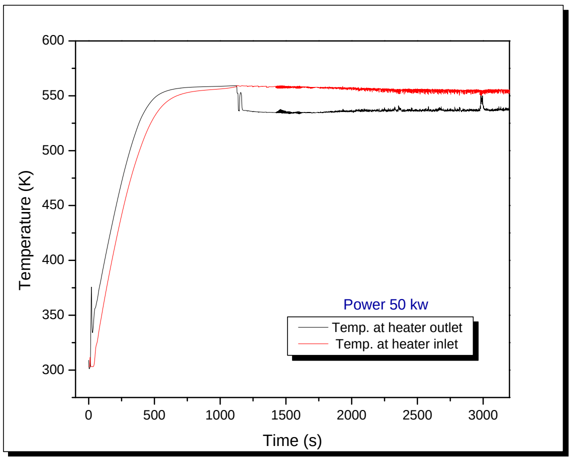

Fig. 16 Variation of temperature with time

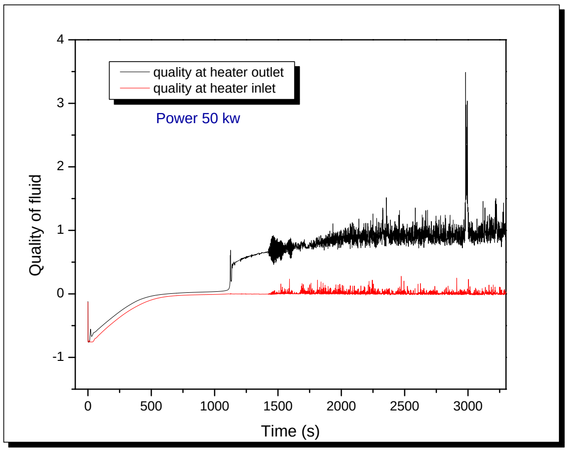

Fig. 17 Variation of quality with time

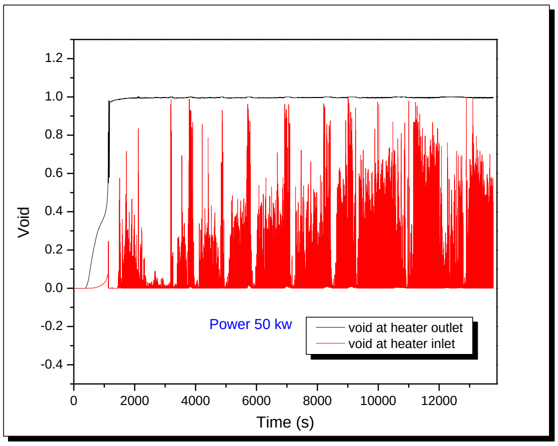

Fig. 18 Variation void fraction with time

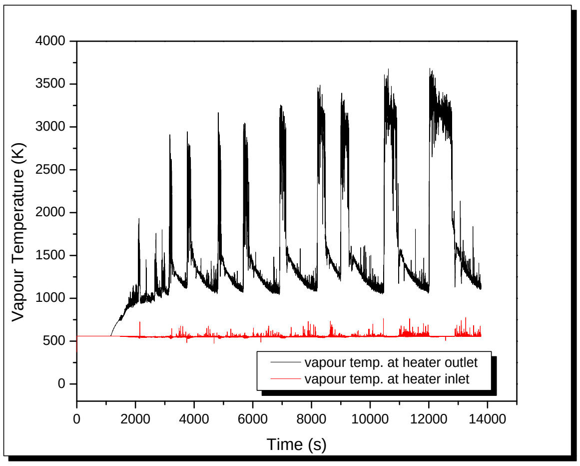

Fig. 19 Variation of Vapour temperature with time

TABLE IV

Following table design parameter for VHVC at Pressure 70 bar with flow 12 lpm

Power (kW)	Temp. diff. at heater (°C)	Flow rate in Loop (kg/s)	Void in loop (%)	Phase	Stability
30	17.98	0.34	0	Single	Stable
35	16.04	0.42	2	Two	Stable
40	12.67	0.55	3	Two	Stable
45	8.18	0.72	16	Two	Stable
50	0	0	100	Two	Unstable

As shown in above Table IV complete design system at pressure 70 bar with flow at 12 lpm and inlet temperature should be 27 °C at a different power from stable state to transient state. According to design, system run well at 30 kW power at stable state after it will go on unstable state to transient state at final power 50 kW. According increase in power at secondary flow constant at 1.2 lpm temperature in system also increasing respectively and finally at certain power it will converted into superheated state whereas, flow becomes zero in the loop so, system fails at this power. Up to threshold power runs at two phases but stability behaviour of the system fully depends on pressure and secondary flow.

5. CONLUSIONS

This report deals with the natural circulation in unusual orientation in a rectangular loop and study related to stability behavior of the system as following topics:

1) Effect of the heater and cooler orientation and heat addition path on the stability.
2) Characteristics of the unstable flow regime.

3) Study related to stability behavior of the system in case of variation of secondary flow.
4) Study related design of unusual orientation in a rectangular loop.
5) Study related to RELAP 5 computer code for the interpreting input code.

5.1 Stability Analysis

Design based on stability analysis has been carried out by using RELAP 5 computer code. In unusual orientation, system becomes more stable at pressure 70 bar. At 48 kW system operates on threshold power at which system runs stable with secondary flow 12 lpm. At power up to 30 kW system should be flow in single phase and after the increasing power, it goes on two phases. Finally, system will run up to saturation temperature after that it should become to dead state or zero flow in the loop.

Stability in two phase flow should become continuously and system has more stable at pressure 70 bar with flow 12 lpm. In unusual orientation, system must design at pressure 70 bar because system run more stable up to 48 kW threshold power.

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NOMENCLATURE

A - flow area (m^2)

D_h - hydraulic diameter (m)

f - friction factor

g - gravity factor

K - loss coefficient (enlargement or contraction)

L - total loop length (m)

ρ_h - density of fluid in hot region (kg/m^3)

ρ_c - density fluid in cold region (kg/m^3)

T_m - hot leg temp. (k)

T_c - cold leg temp. (k)

β - compressibility factor

$\dot{m}$ - flow rate (kg/s)

R_h - hydrodynamic resistance (m^{-4})

D - flow dia. of loop (m)

H - height between heater and cooler (m)

μ - dynamic viscosity of fluid (N-m /s)

VHVC - vertical heater vertical cooler

NPP- Nuclear Power Plant

LWR- Light Water Reactor