A NUMERICAL STUDY TO SIMULATE TRANSIENT BEHAVIOR OF TWO PHASE NCL

Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of

MASTER OF NUCLEAR ENGINEERING

By

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ABSTRACT

A circulating fluid system in a gravity field whose motion is generated due to density difference caused by heat transfer is called natural circulation loop. In case of two phase NCL's, the circulating fluid undergoes alternate boiling and condensation in two distinct part of the loop. The density difference between a liquid phase and a two phase mixture is much larger than the density difference generated in single phase flow, so two phase flow is can generate powerful driving force. Thus two phase flow NCL is capable of generating high circulation rate, for this reason two phase natural circulation loop finds many industrial applications. One of the basic requirement of such loop is to predict steady state, transient and stability behavior reliably .In case of steady flow natural circulation loop the driving pressure differential due to the buoyancy force is balanced by frictional losses and inertia. More than 90% of thermal hydraulics research in nuclear industry is related to reactor's passive safety system. One of the major problem in operating a two phase flow NCL is the flow instabilities which can cause mechanical vibration of system component, flow reversal and flow stagnation in the system.

In present thesis we investigated the flow dynamics of a two phase square NCL. For this purpose a RELAP5 based code has been developed to simulate a NCL at different power levels. The experimental data presented by Filho et al. [1] have been validated using the code. The results shows transition of system dynamics from steady to oscillatory to flow reversal behavior with the increase of power. A FFT (Fast Fourier Transformation) analysis is also performed to determine the mass flux oscillation pattern.

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NOMENCLATURE

AHWR	Advanced Heavy Water Reactor
CATHARE	Code for Analysis Of Thermal hydraulics
CANDU	Canada Deuterium Uranium (Heavy Water Reactor)
CHF	Critical Heat Flux
DC	Down Comer
FIG	Figure
LOCA	Loss of Coolant Accident
NPP	Nuclear Power Plant
RELAP	Reactor Excursion and Leak Analysis Program
NRC	Nuclear Regulatory commission
W	Watt

CHAPTER 1

OVERVIEW

1.1 INTRODUCTION

New generation nuclear reactors and many other cooling applications are widely using the mechanism of natural circulation (NC), since it is very attractive option for easy energy transport from heat source to sink. The natural circulation system is very useful because of their simplicity and passive nature. NCL or natural circulation loops are passive system because it does not need any pump or any other kind of active systems in case of transporting heat from sink to source. Generation four type of reactors (AHWR) transport the normal fission heat via passive natural circulation system and also in case of decay heat removal AHWR uses natural circulation loop (NCL) system. For any forced circulation system we need a pump or other kind of active system to circulate the flow by creating the driving force to overcome the pressure drop generated in the system loop .The driving force in natural circulation system is the buoyancy force created by the density difference of circulating fluid. In single phase natural circulation system, there is no change of phase of circulating fluid (in this present case water is considered) .In case of two phase flow, with the increase of source strength or with varying geometrical parameter we can initiate phase change in the loop. One of the major problem in operating a two phase flow natural circulation system is the flow instabilities which can be the cause of mechanical vibration of system component, flow reversal and flow stagnation in the system .System instability and related oscillations are undesirable for two phase flow NCL In two phase NCL the flow rate depends on the void generation in the system. Hence, accurate estimation of void fraction and friction pressure loss, are the key parameters for the prediction of instability,

In past five decades many research has been done by researchers to understand the flow behavior of two phase flow and developed computer codes like RELAP, ATHLET, CATHARE .Reactor Excursion and Leak Analysis Program (RELAP) is a system code, which can simulate a wide range of system transients and safety and accident behavior. RELAP code was developed at the Idaho national engineering laboratory (RELAP development team 1995) for NRC. RELAP5 uses two fluid model that solves eight equations for eight flow variables (RELAP 1997) using a semi implicit numerical solution scheme.

In this present study we will use RELAP5/MOD3.2 code **[2]** for modeling and simulation of the natural circulation behavior of a square loop model in various power condition. The biggest challenge in natural circulation system is the instability of the system. Instability can occur at low power level as well as high power level with the initiation of boiling in the loop. But in forced circulation in which instability occur mainly at high power level. There are two main type of instability in natural circulation loop. Static instability and dynamic instability .In static instability there is Ledinegg-type of instability, Geysering-based instability, and flow pattern transition related instability**.**

Ledinegg instability is generally associated with a rapid change in flow rate or by flow reversal. It is a common type of instability in two phase flow NCL.

Flow pattern transition instability is generally caused due to different pressure drop characteristic of different flow regimes. When system is operating close to the point of slug-annular transition, a momentary increase in bubble formation may lead to the flow pattern to annular flow regime. Annular flow regime has lower pressure drop compare to slug regime. Hence flow rate increases with same heat supply. By which the bubble generation rate will decrease and the system will transforms to slug regime. This cycle may continue to be repeated.

Acoustic oscillation. It is another type of pure and fundamental dynamic oscillation along with density wave oscillation, with the major difference being in the frequency of oscillation. DWO generally produces low frequency wave but acoustic or pressure wave oscillation has higher level of frequency in the range of 10 -100HZ.It is generally observed generally under highly sub cooled condition.

Boure et.al. [3] categorized dynamic instability into three main group: fundamental, compound dynamic instability (pressure drop oscillation), Density wave oscillation is the form of pure dynamic instability.

There are two type of Density wave oscillation(DWO) instability .First type occur at the initiation of boiling and at low vapor quality and it is governed by gravitational head. Friction dominates the Second type of density wave oscillation at high vapour quality and high operating power condition (Fakuda & Kobori [4]).

Several studies related to two phase natural circulation loop have addressed in last fifty years .Some of them are discussed in the present study. Wissler et al. **[5]** studied the oscillatory behavior of two phase natural circulation flow .He found that the system can go to undamped oscillation if a small disturbance is given.

Jain et al. **[6]** also investigated NCL with different raisers and heater geometry. Chexal & Bergles **[7]** also suggested that low pressure CHF data may be strongly dependable with the non-periodic flow pattern in heater section.

Faduka &Kobori **[4]** also studied parallel channel two phase NCL .they considered pressure and heat flux but did not described flow pattern in detail. There are also many research has been done by Lee et al. **[8],** Bergles et al**.** **[9]** related to two phase flow NCL.

All the above given studies are done by theoretically and experimentally and by some early days computer codes. There are limited number of studies related to RELAP5 Code to simulate the natural circulation system. A review of these works are given below:

Mahaffy et al. **[10]** presented on the numerical methods that the codes (RELAP5, TRAC, RETRAN, CATHARE) uses for simulation purpose. The authors found that the numerical method that TRAC and RELAP5 uses have both some advantages and flaws. The frictional and heat transfer closure relations are required for simulating codes. It may also affect the results of measurement.

Misale et al. **[11]** analyzed a single phase NCL using RELAP5/MOD3.2 and CATHARE codes. They compared the CATHARE and RELAP codes simulation result with experimental result at different power levels. They experimented in rectangular natural circulation loop with one heater and one cooler at bottom and top position respectively. They found that at lower power level CATHARE code predicted nearly same characteristic curve as experimented result. But RELAP5 indicates some fluctuations at lower power. CATHARE code simulated the single phase behavior at low power level very accurately

.In case of RELAP code, the qualitative behavior of the loop when the system is unstable is accurately simulated .however the dependence of oscillation amplitude and frequency of oscillation upon supplied power is not calculated .At maximum power level (900W) RELAP result showed the frequency and amplitude comparable to experimental result.

Kaliatka & Uspuras [12] published a work on pump trip events at the Ignalina NPP with the help of RELAP5/MOD3 code. RELAP5 code originally developed for PWR. But Ignalina nuclear power plant is two RBMK-1500 type of graphite moderated reactor. Although they estimated a successful model to simulate pump trip event. The comparison between calculated and measure parameters show that RELAP5 calculated was in favour of the plant experimental data. However the instability related to parallel channel flow is not considered in that study.

Dupleac et al. [13] used RELAP5 code to simulate CANDU6 plant in severe accident analysis. A station blackout and loss of coolant accident (LOCA) was simulated by the authors.. The comparison between the data of RELAP5 code and MAAP4-CANDU Version 4.04A+ code employed by Petokhov & Mathew [14], which came up with major difference in LOCA event sequence.. The difference in results may be due to different thermal hydraulic nodalization considered by the researchers

Omar et al. [15] published a paper on analysis on MNSR research reactor by RELAP5/MOD3.2 Code .they simulated the entire reactor under RELAP code .The comparison between the RELAP result and the experimental result showed a good agreement.so the modeling and nodalization of the reactor was perfect and it can be used for studies.

Mangal et al. [16] experimented a natural circulation the capability of the Relap5 code to simulate natural circulation behavior in test facilities. They solved the basic two fluid model's field equations numerically by the help of RELAP5 code and found the thermal hydraulic behavior of a rectangular loop. They simulated different kind of loop such as Parallel Channel Loop (PCL), High Pressure Natural circulation Loop (HPNCL). In case of HPNCL they used the same loop as Kumar et al. [17] used,. For PCL they used same loop as Jain et al. [6] used in their respective experiments. Mangal et al. [16] .simulated the above loops with RELAP5 and compared with the experimented data. As a result they found that, nodalisation scheme is very much important for Relap5 predictions of NCL behavior. The moderate nodalisation gave relatively close to the experimented result but fine or coarse nodalisation gave a large error. For HPNCL and PCL single phase flow prediction by RELAP5 was great. Two phase stable flow prediction by RELAP5 in HPNCL was accurate but for PCL, it had some fluctuation. Flow instability was wrongly predicted by Relap5 in HPNCL For PCL it predicted much more amplitude of instability oscillation. Prediction of flow instability by Relap5 depends mostly on nodalisation scheme that we choose.

Singh et al. **[18]** investigated Natural Circulation thermal hydraulic characteristic numerically. They used Relap5/Mod3.2 code to simulate the NCL in single channel as well as multichannel loops. They showed that Relap5 is able to predict the boiling induced instabilities in the power range 0 to 2000 W. In case of single channel loop RELAP 5 predicted slightly higher mass low rate compare to experimental result for same step increase in power. At a power of 1500 W, the two phase flow initiation happened and two phase flow oscillation was found to occur .It was found that RELAP5 easily predicted nearly same oscillation data as experiment gave them. However the amplitude of oscillation predicted by Relap5 was not same as experiment. It was also found that Frequencies was closer to measurement especially at higher power.

Lee & Mital **[19]** experimentally studied two phase flow NCL with two different loop fluid, R11 and water. The results indicate that the system exhibits same behavior, irrespective of loop fluids. The heat transfer coefficient was observed to be dependent on heater to condenser length ratio, along with .system pressure and temperature.

Sudheer et al. [20] numerically analyzed the two phase NCL under atmospheric and sub atmospheric conditions. The authors applied homogeneous equilibrium model for two-phase flows and solved the governing equations by a MATLAB code which they had developed. They carried out the investigation at different heater inlet pressure, heat fluxes and temperatures. Atmospheric NCLs showed low mass flow rates at lower heat fluxes, compared to sub atmospheric NCL.

Rohatgi & Duffey **[21]** presented critical sub cooling number as a function of Froude number, for natural circulation two-phase flow and showed that the loop loss coefficient is dependent on the ratio of the heated channel to down comer heights. They proposed a stability map for loop flow rate.

A two-phase NCL was considered by Guanghui et al. [22] theoretically and experimentally. They analyzed the influences of mass flow rate, pressure, inlet sub cooling, heat flux and exit quality on density wave oscillation (DWO) and developed a correlation for DWO period. They concluded that the system changes to stable region with the increase in system pressure. The stability also depends on mass flux, with the increase in mass flux the stability also increases.

Prasad et al. [23] reported Stability analysis and nonlinear dynamics of natural circulation undergoing boiling .The geometric parameters of different loop changes the effect of void reactivity and the fuel time constant. Riser shows a chaotic oscillations at lower values of VR (void reactivity) compared to the channel without riser. The presence of riser is very influencing parameter in the system dynamics.

Kozmenkov et al. [24] demonstrated simulation of flashing induced instabilities in the natural circulation by RELAP5 at low-pressure systems. According to them, the frequency of oscillation of circulating fluid becomes higher with the increase in core inlet temperature.RELAP5 predicted the frequency of oscillation of the system very correctly with experimental data.

Basu et al. [25] carried out an analysis to characterize two phase steady state behavior of a rectangular NCL. .They employed an one dimensional correlation based two fluid model to relate various system parameters .They mainly focused on the sub cooled boiling zone .They observed the quantitative variation of mass flux between equilibrium (no sub cooled boiling) and non-equilibrium (considering the effect of sub cooled boiling).Sub cooled boiling induces the longer two phase zone length and corresponding higher frictional losses and thermal interactions.

Dewangan et al. [26] investigated the effect of flashing and ledinegg instability mechanism on steady state behavior of two phase NCL. Their analysis emphasized that flashing has a significant effect on the loop performance in certain range of operating condition. The properties of the circulating fluid change locally due to flashing. If flashing is ignored, the temperature was observed to vary significantly along the length of loop. The effect of flashing was observed to be important at lower operating pressure and low heat input. And the most important thing is that, there is a reduction in Ledinegg instability with the presence of flashing in the loop.

Filho et al. [1] has done a comparative study between experimental data and RELAP 5 simulated data flow both two phase and single phase flow natural circulation loop. They applied three linear equation solving technique. LUD (lower upper decomposition) ,BPLU(border profile lower upper decomposition),GMRES(generalized minimal residual method). Simulations showed that RELAP5 has the tendency to over-predict the heater outlet temperature during the single-phase flow but BPLU solver gave better result for two phase flow. They predicted the onset of nucleate boiling and the flow oscillations in the NCL. All numerical solvers predicted the low instability amplitudes compare to the experimental data.

1.2 OBJECTIVE

From the literature review, we found that only a few researchers have said that RELAP5 is able to make correct prediction about two phase flow natural circulation loop. Many of them concluded that RELAP5 is good for prediction of single phase flow behavior or steady low conditions. But in case of high power application (i.e. two phase flow) transient analysis of instability problem is not correctly predicted by RELAP5. Some research found that nodalisation of experimental setup by RELAP5 code is very sensitive to transient analysis. The proper choice of the two phase flow models, such as homogeneous flow model, two fluid model or more importantly drift flux model may be a reason for incorrect prediction of RRELAP5 simulation. In this Present study we will consider a Square loop to understand the thermal hydraulic behavior of Two Phase flow Natural Circulation System. We will evaluate the mass flux in the loop, two phase flow pressure drop, temperature variation, and flow regime in the riser and down comer sections.

CHAPTER 2

LOOP DESCRIPTION

2.1 LOOP DESCRIPTION OF INVESTIGATED LOOP

We have considered the same square NCL loop that we have already investigated in our previous work for single phase NCL (Saha et al. [27]). A 4m square Natural Circulation loop for our numerical simulation. Length of each side is 1 m with 30 mm internal loop diameter and a thickness of 2 mm. The length of the heater is 400 mm placed in the horizontal bottom section .Cooler length is 600mm, placed with a 100 mm offset on the upper horizontal section. Loop description and diagram are given below:

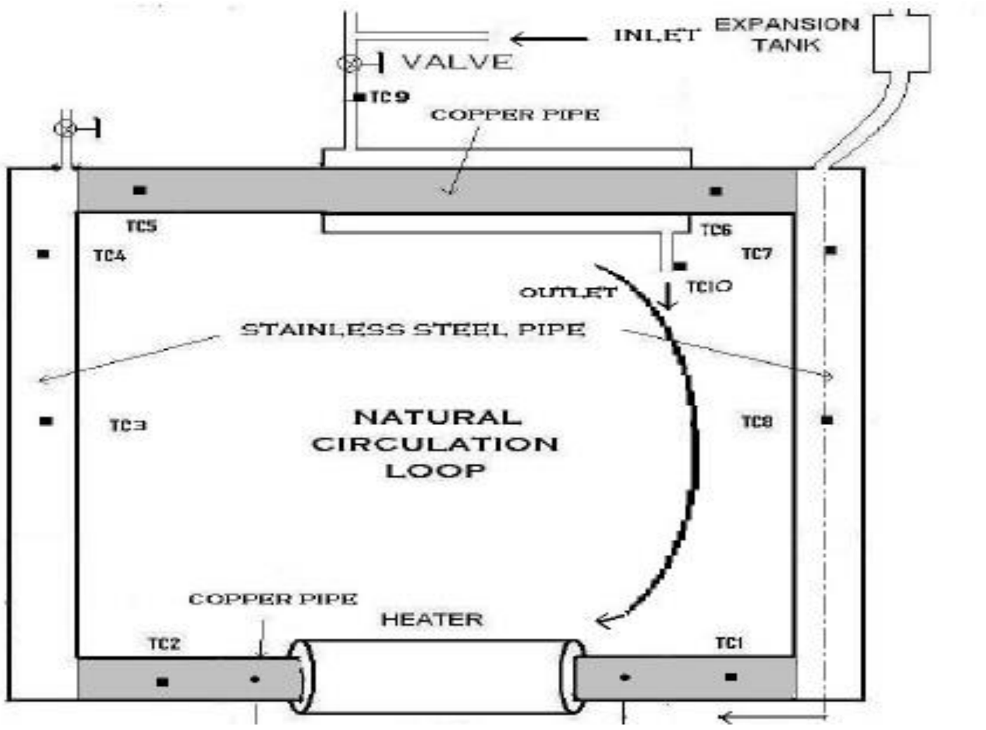

FIG 2.1: schematic diagram for square NCL (Saha et al.[27])

The loop is made up of stainless steel. The heater portion is made up of copper. The cooler (cooling jacket type heat exchanger) is situated in the upper horizontal section with constant cooling water mass flow rate .0464 kg/m^2 , temperature 293K .We can vary the power of the heater in the rage of 0 to 3000W.initially the loop is totally filled with water at 296K.An expansion tank is fitted at the top as shown in the figure. The proper dimensions and positions of the loop components are given in table 1.

2.2 LOOP DESCRIPTION OF VALIDATED LOOP

The schematic figure of their experimental facility is shown in FIG 2.2.Total experimental loop is made up of a rectangular glass loop. The expansion tank, which is situated at top of the loop has connected to the bottom horizontal leg. Heater Power is controllable in the range of 0 to 7000W. Initially the loop was filled with water at ambient temperature. The expansion tank is partially filled with water. The bottom leg of expansion tank is connected to the lower horizontal section of the loop to deal with the water specific volume changes.

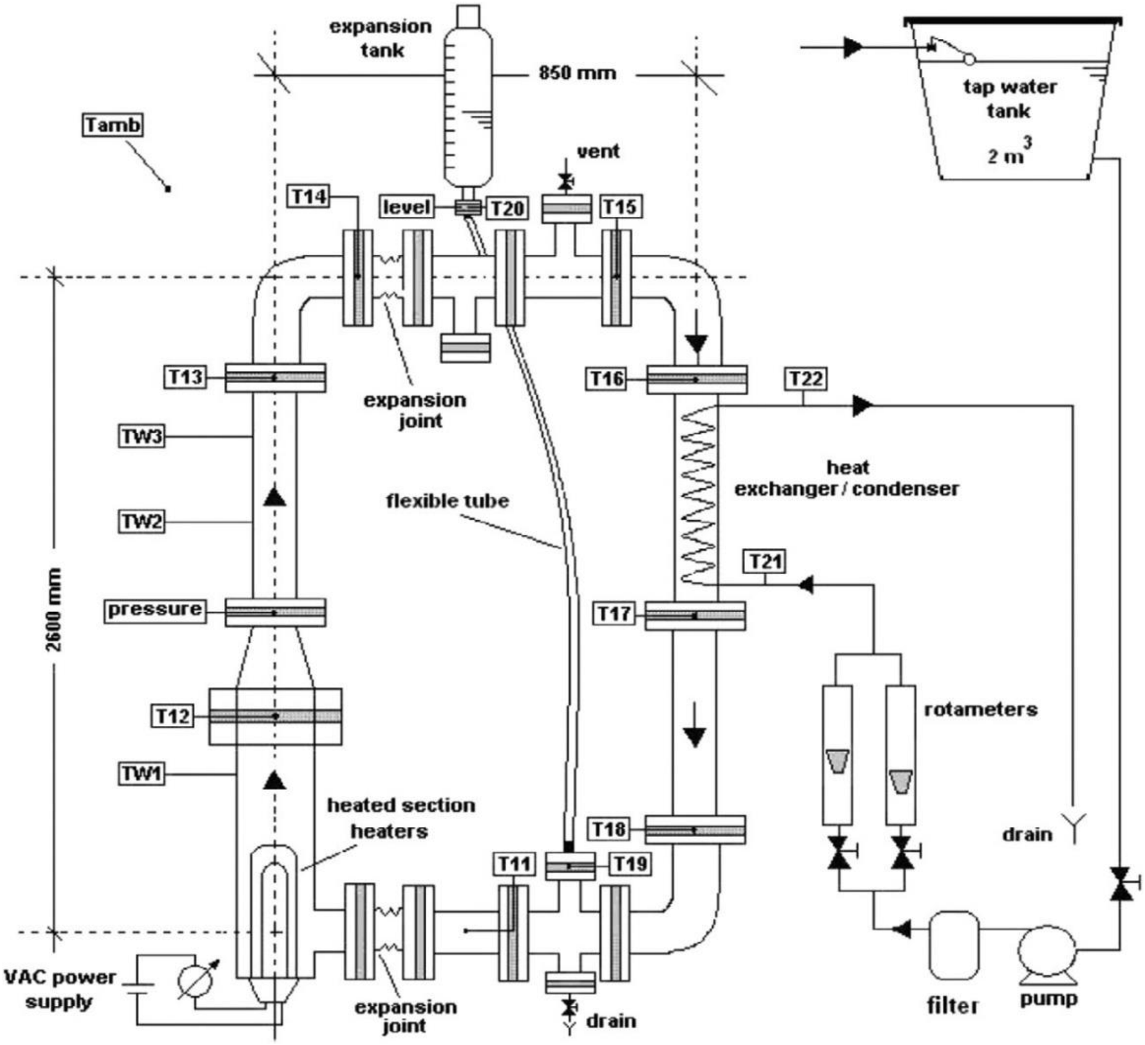

FIG 2.2: schematic diagram for validated loop (Filho et al**. [1])**

2.3 RELAP 5 MOD 3.2 NODALIZATION SCHEME FOR INVESTIGATED LOOP

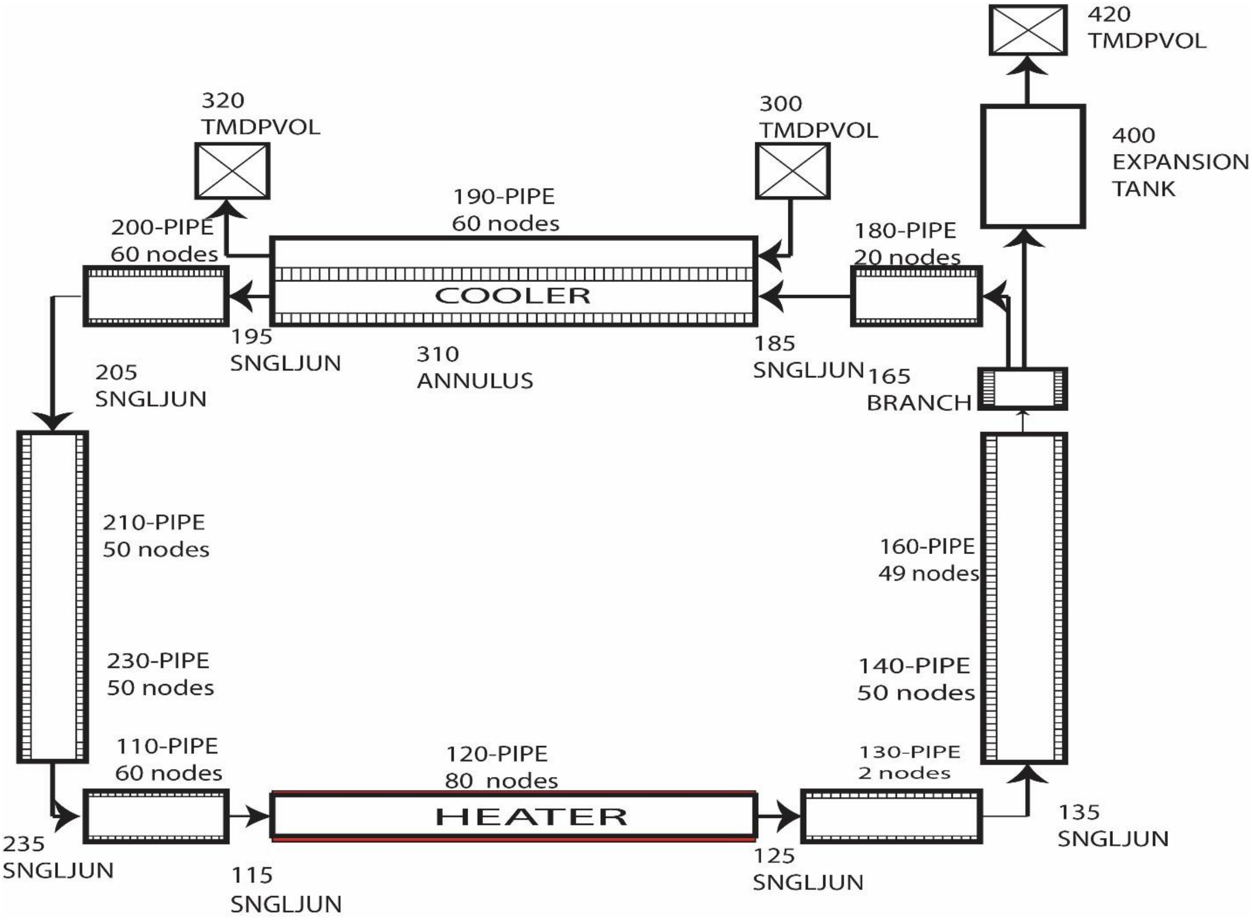

FIG 2.3: RELAP5/MOD 3.2 nodalization schematic for investigated loop

According to the FIG2.3 we can easily see that, our loop has been divided into 11 sections. “120-PIPE” indicates heater section ,”140-PIPE”, “160-PIPE” shows the riser pipe section,“190-PIPE” indicates cooler section,”210-PIPE”, “230-PIPE” indicates down comer sections,110,130,180,200-PIPE represents other pipe sections.”165-BRANCH” is a branch section for multiple connections.310-ANNULUS indicates the heat exchanger for cooler section.”400-PIPE” is used for expansion tank.420-TMDPVOL is time depended volume connected to the upper side of expansion tank. 300-TMDPVOL and 320-TMDPVOL are two time dependent volume connected to the heat exchanger.

Two sections are connected via single junctions. SNGLJUN module is used for single junction simulation. Heat exchanger in cooler section simulated by ANNULUS module. 300 time dependent volume is used to specify coolant mass flow rate and temperature. 320 outlet time dependent volume specify the pressure at outlet of heat exchanger .The exact length of the above described components are given below in the table 1.

TABLE 1: Nodalization dimension description of investigated loop

component name	**component number**	**component type**	**component dimension length(mm)**
HORIZONTAL HEATER LEFT PIPE SECTION	110	PIPE	300
HEATER	120	PIPE	400
HORIZONTAL HEATER RIGHT PIPE SECTION	130	PIPE	300
VERTICAL RIGHT HAND PIPE SECTION	140 160 165	PIPE PIPE BRANCH	500 490 10
HORIZONTAL COOLER LEFT PIPE SECTION	180	PIPE	100
COOLER	190	PIPE	600
HORIZONTAL COOLER RIGHT PIPE SECTION	200	PIPE	300
VERTICAL LEFT HAND PIPE SECTION	210 230	PIPE PIPE	500 500
EXPANSION TANK	400 410	PIPE TMDPVOL	255 15
AUXILIARY LOOP (INLET)	300 310	TMDPVOL PIPE	15 600
AUXILIARY LOOP (OUTLET)	320	TMDPVOL	15

2.4 RELAP 5 MOD 3.2 NODALIZATION SCHEME FOR VALIDATED LOOP

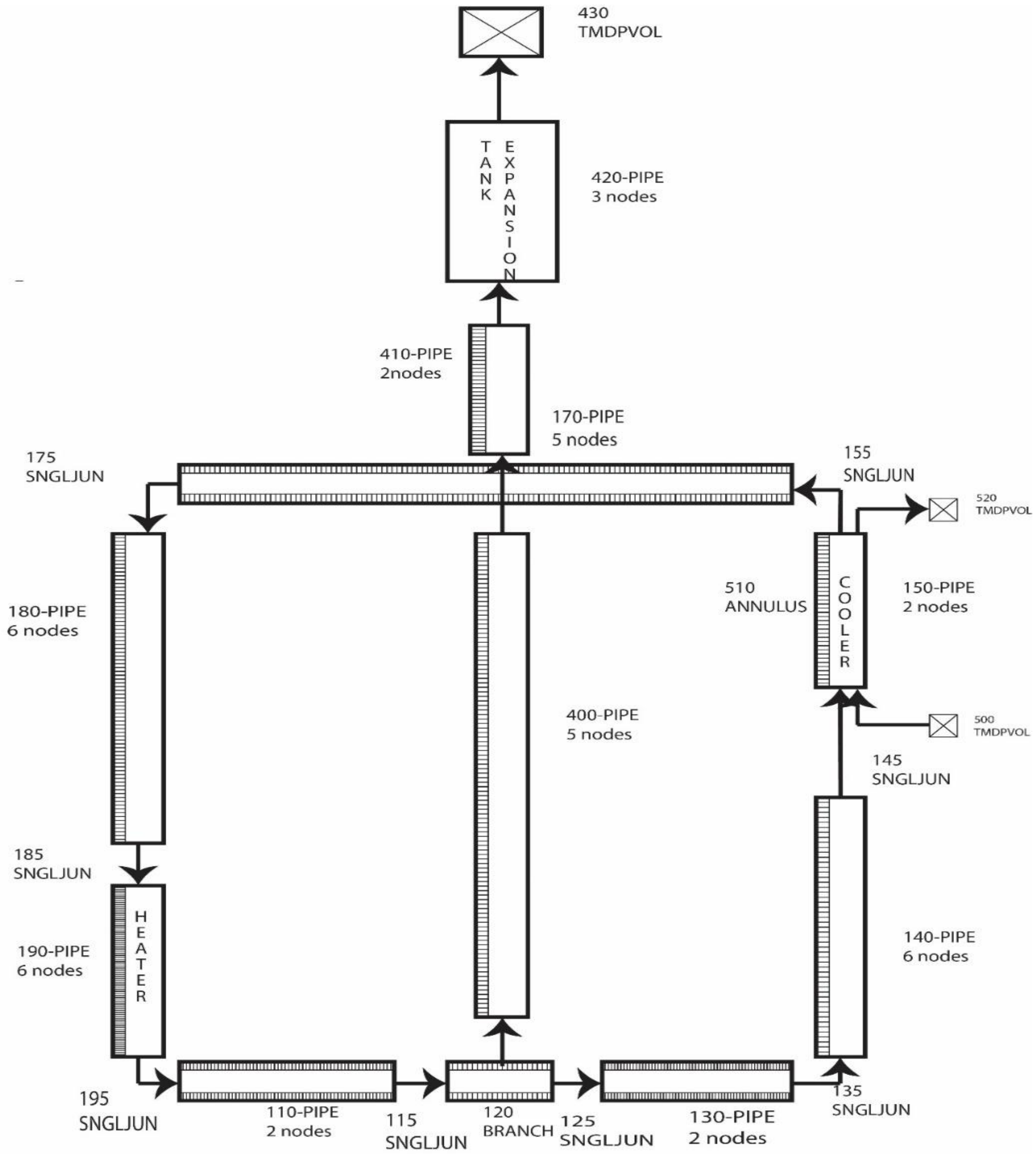

FIG 2.4: Validating loop Nodalisation at RELAP 5/MOD 3.2

For validation of our developed code and to simulate thermal hydraulic behavior of the FIG 2.2 loop, a proper nodalization of the loop has been done .We can see the FIG 2.4 of nodalization. Heater pipe is defined as “190-PIPE” with 6 nodes.”150-PIPE” indicates cooler section with 2 nodes.110, 130,140,170,180- PIPE all are pipe section connected via junction and branches module of RELAP5 code.

Surge line 400,410 is connected to expansion tank 420 –PIPE. Time dependent volume ,430-TMDPVOL is connected to the expansion tank and opened to the atmosphere.500and 520 are the time dependent volume connected to the heat exchanger annulus section 510-PIPE.Proper dimensions of above components has given in the table 2.

TABLE 2: Nodalization dimension description of validated loop

component name	**component number**	**component type**	**component dimension length(mm)**
HORIZONTAL COLD LEG	110 120 130	PIPE BRANCH PIPE	170 340 340
VERTICAL COLD LEG	140	PIPE	1560
COOLER	150	PIPE	610
HORIZENTAL HOT LEG	170	PIPE	850
VERTICAL HOT LEG	180	PIPE	1720
HEATER	190	PIPE	880
SURGE LINE	400 410	PIPE PIPE	2600 700
EXPANSION TANK	420 430	PIPE TMDPVOL	1270 170
AUXILIARY LOOP (INLET)	500 510	TMDPVOL PIPE(ANNULUS)	305 610
AUXILIARY LOOP (OUTLET)	520	TMDPVOL	305

CHAPTER 3

RESULTS AND DISCUSSION

3.1 VALIDATION

Our developed code validated against the Experimental data presented by Filho et al. The schematic figure of their experimental facility has shown in FIG. 1.2.Here in the FIG 3.1, We are comparing our RELAP5 data with their experimental heater outlet temperature presented by them. The range of heater power is 0 to 7000W and constant cooler or auxiliary loop mass flow rate of .023 kg/m^2

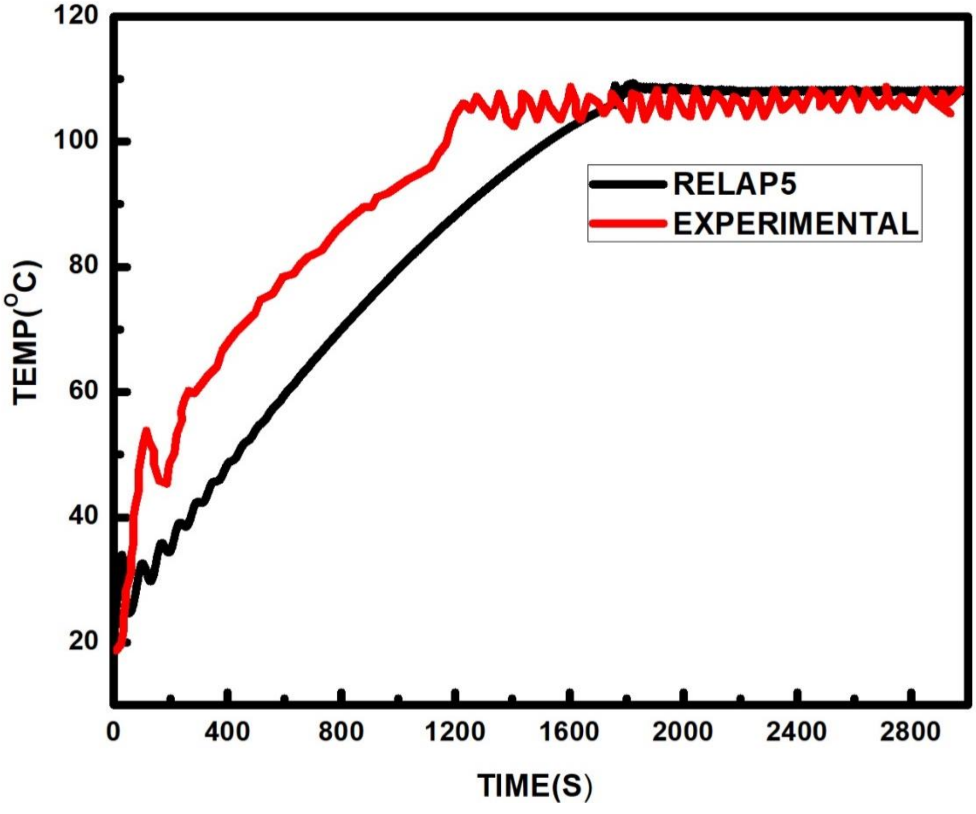

FIG. 3.1: comparison with the Experimental data of heater outlet temperature

According to FIG 3.1 we can clearly see that our developed code has shown a comparable result with the experimental data.

3.2 RESULTS OF INVESTIGATED LOOP

Now we know that our code is capable to investigate two phase flow Natural Circulation loop, in next stages we will show the thermal hydraulic behavior of two phase flow square Natural Circulation loop .We have already analyzed the nonlinear dynamics of single phase NCL in our previous work. We divided the flow dynamics in three category, from steady to periodic and ultimately flow reversal chaotic region. Regime in our present study, we will be concentrating in two phase flow .We started the simulation at 1400W, which is steady single phase flow.

Middle sections of Both riser and down comer pipes has been consider to evaluate the Mass flux, temperature variation and void fraction at variation with time at different power level are shown in FIG 3.2 to FIG 3.27.

FIG 3.2 and FIG 3.3 are the figures of mass flux variation with power at 1400W and 1470W. Both are single phase flow.1400W indicates the steady state variation, constant mass flux at 137 kg/m^2.But a periodic oscillation of small amplitude is there at 1470W.

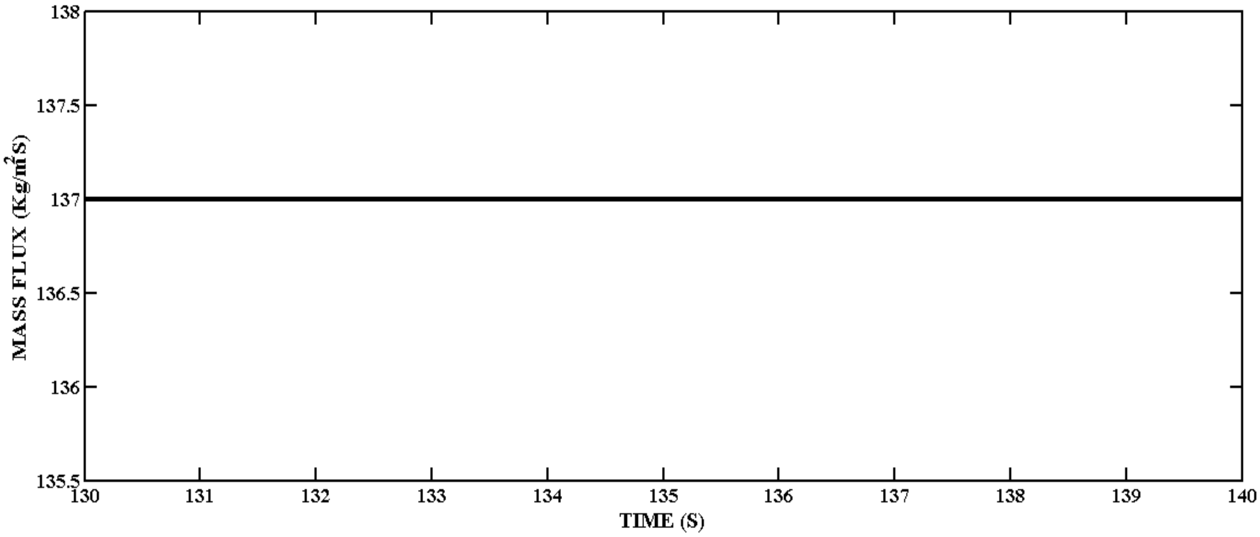

FIG 3.2: Variation of Mass flux with time at 1400W

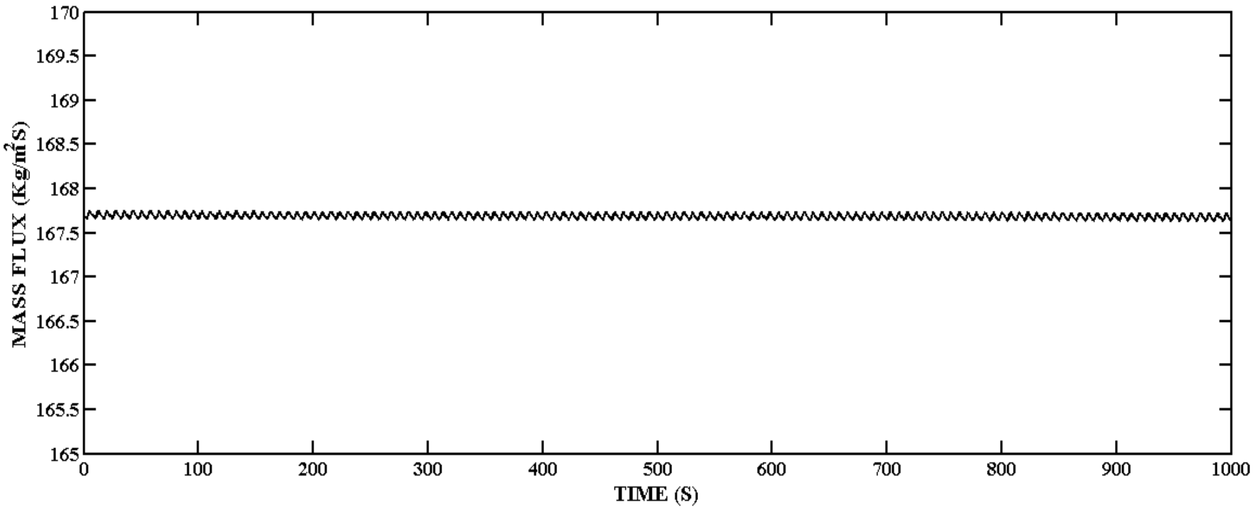

FIG 3.3: Variation of Mass flux with time at 1470W

Further increase in power indicates increase in amplitude of oscillation of mass flux, which has been shown in FIG 3.4 and FIG 3.5.

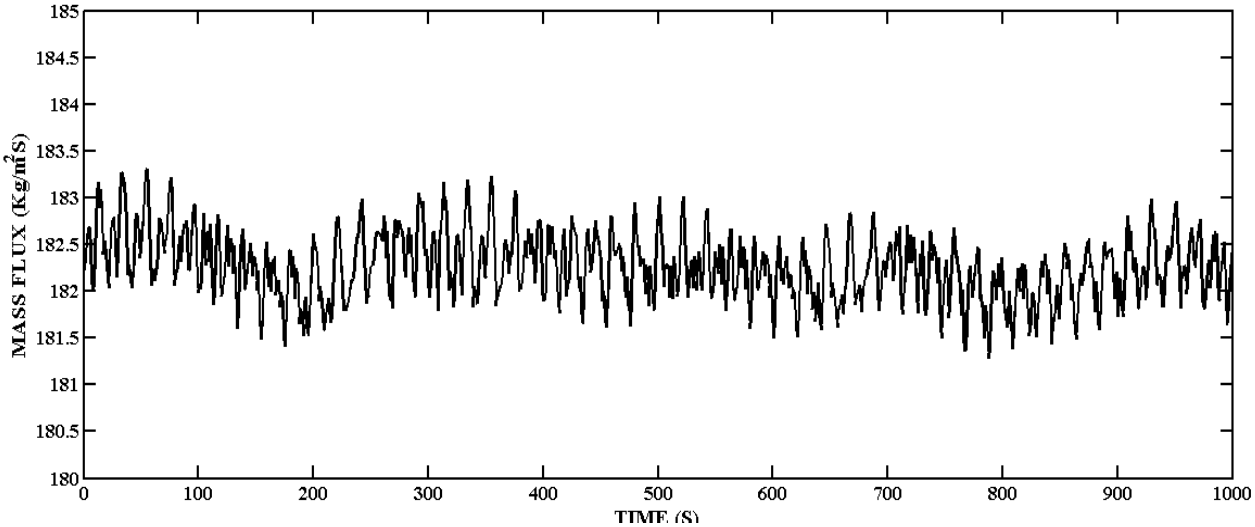

FIG 3.4: Variation of Mass flux with time at 1500W

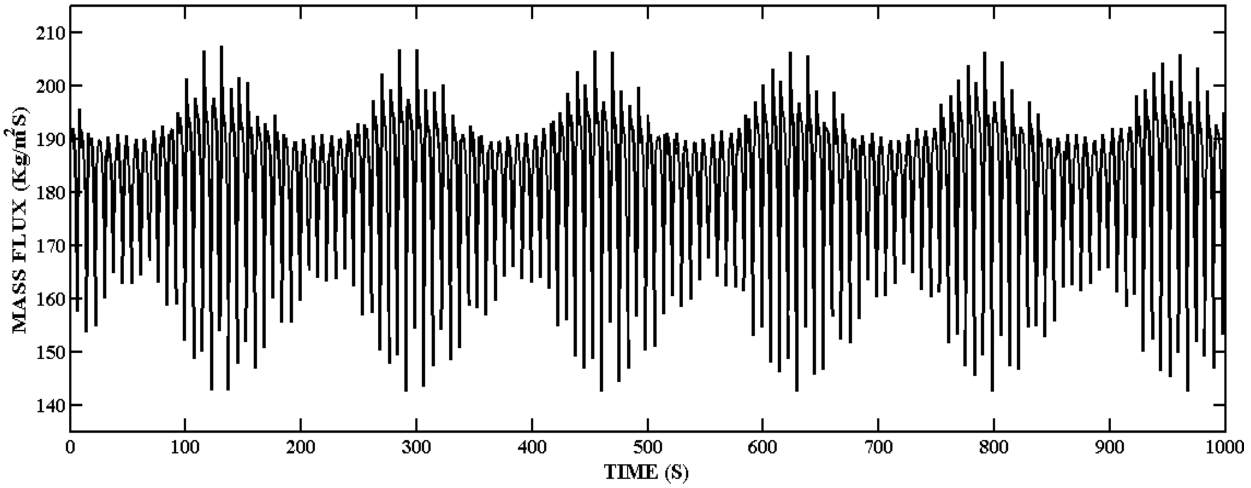

FIG 3.5: Variation of Mass flux with time at 1550W

Both 1500W and 1550W are single phase flow. FIG 3.7 indicates the liquid void fraction is 1 throughout the loop but the amplitude of oscillation of mass flux is increased in 1550W. But oscillation range is small. The temperature of riser section and downcomer section are shown in FIG 3.6 .Riser temperature oscillating at 101^{0}C and down comer section temperature is also oscillating in a periodic nature. The loop, operating at this power level implies single phase condition that why we are getting the lower mass flux value.

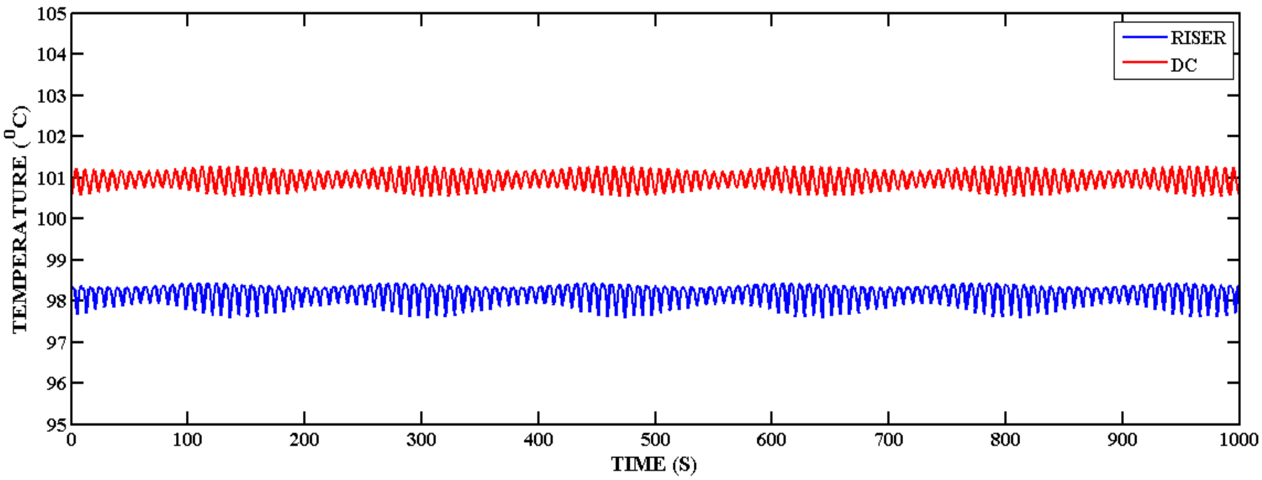

FIG 3.6 Temperature variation of Riser and Downcomer (DC) section (1550W)

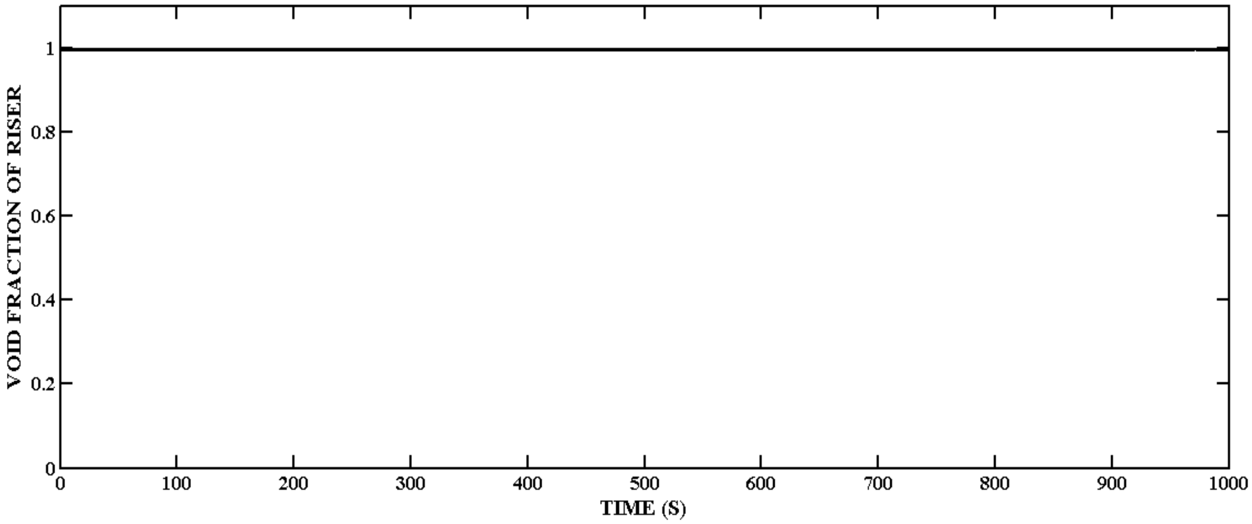

FIG 3.7: Riser Section Liquid void fraction variation with time (1550W)

FIG 3.8 shows the mass flux variation with time at 1600W.We can easily see that the mass flux value is increased. Now the oscillation is periodic and have the higher amplitude. Sudden increase in amplitude of oscillation is due to vapour generation in the riser section. This water vapour goes the cooler section and get condensed and again goes to heater section through down comer.

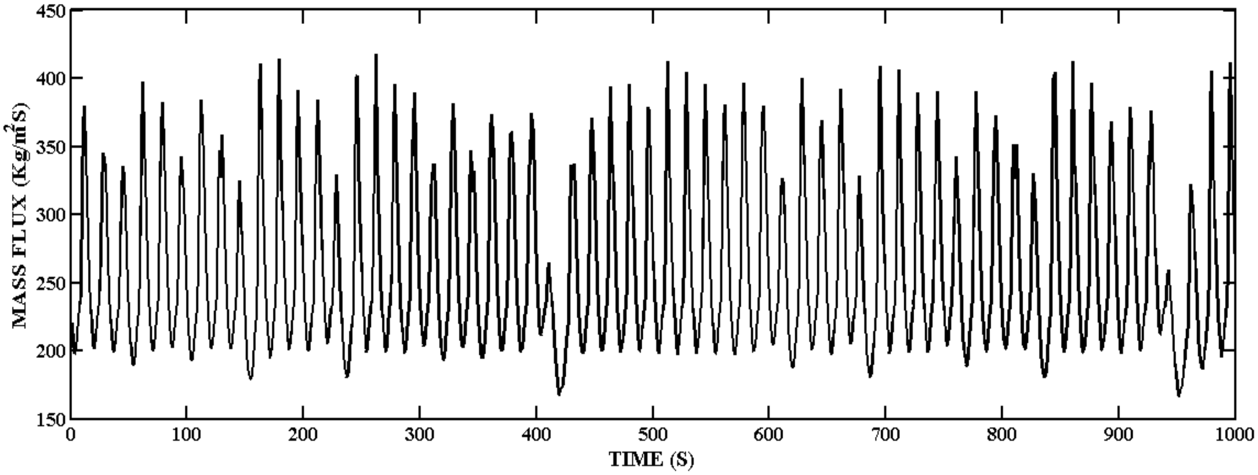

FIG 3.8: Variation of Mass flux with time at 1600W (single phase)

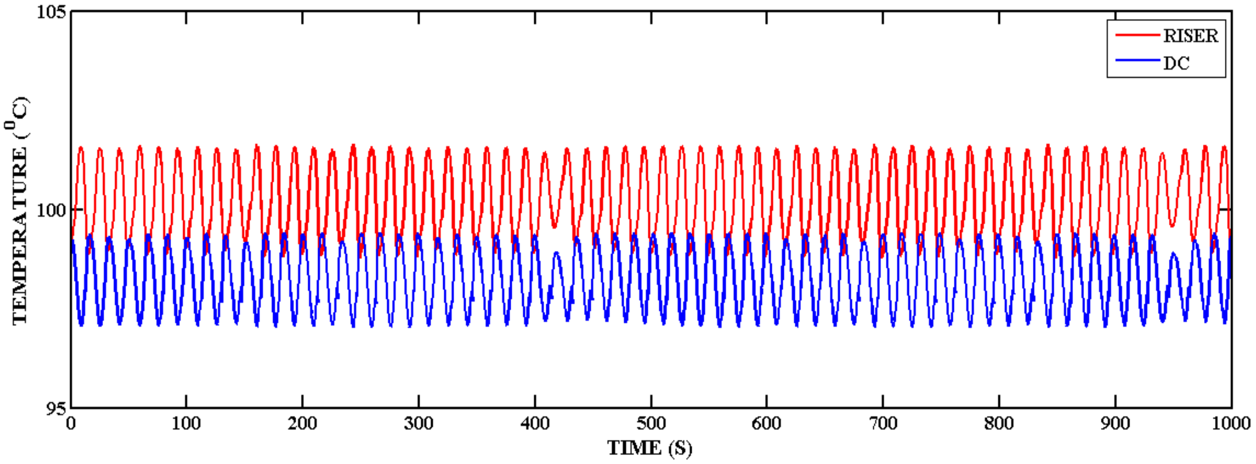

FIG 3.9: Temperature variation of Riser and Downcomer (DC) section (1600W)

FIG 3.9 is the temperature variation figure, we can see that the liquid temperature is oscillating in riser and down comer section. The reason of this oscillation is because the continuous change in flow regime of the working fluid.

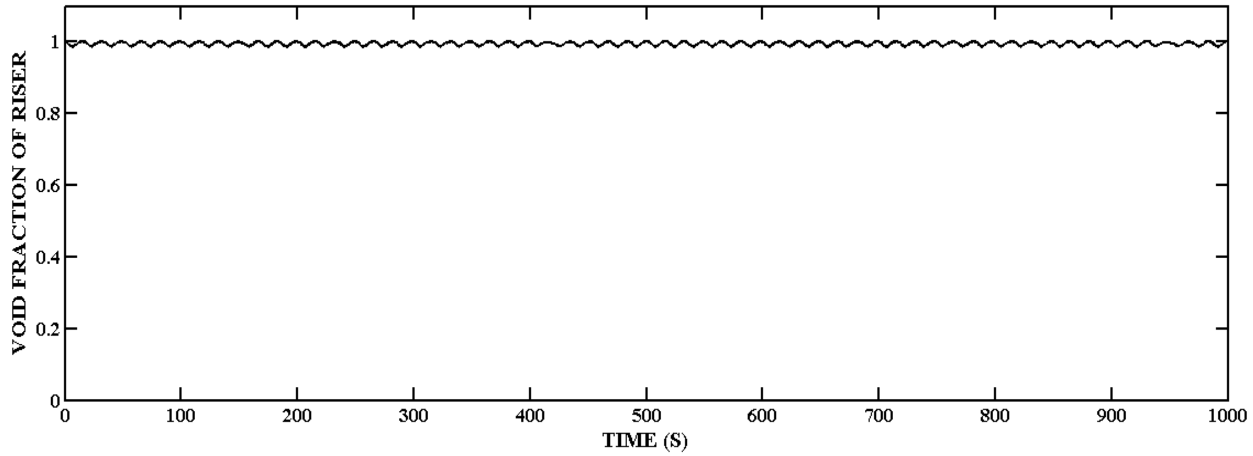

FIG 3.10: Riser Section Liquid void fraction variation with time (1600W)

1600W is the initiation of two phase flow. FIG 3.10 indicates that the void fraction in the riser section is fluctuating between 1 to .9. The figure represents that the void fraction is oscillating in periodic manner.

FIG 3.11 indicates that the mass flux variation at 1700W.It is oscillating in greater amount than previous power.200kg/m^2 to 750 kg/m^2 is the range of oscillation. More and more amount of vapour is generating in the loop which implying the greater diving force of oscillation and increased mass flux value. The flow regime is transition is occurring in the loop with different pressure drop, which is mainly governing the mass flux variation.

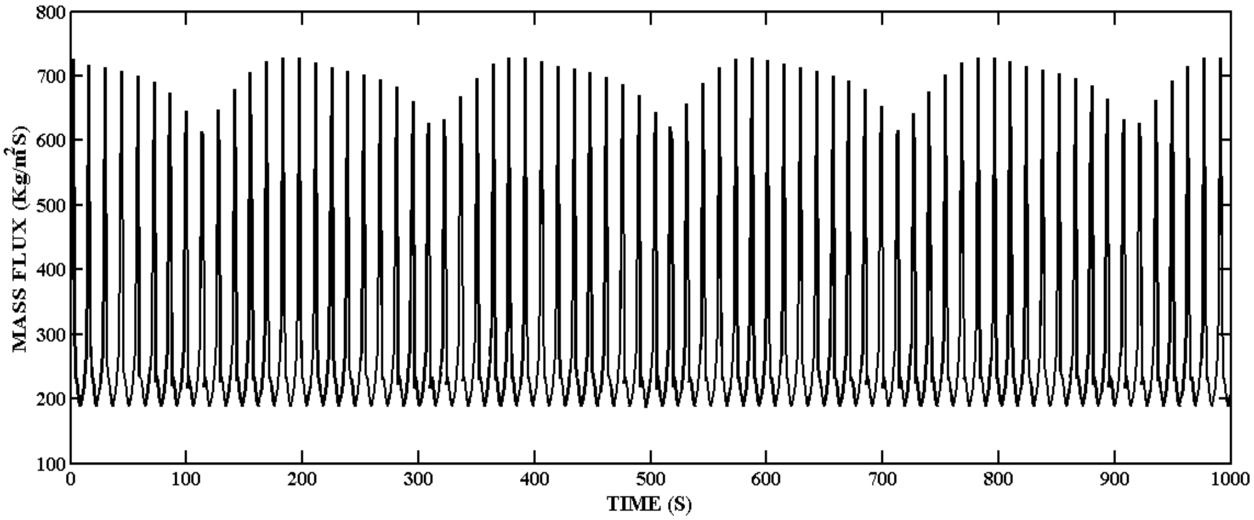

FIG 3.11: Variation of Mass flux with time at 1700W (single phase)

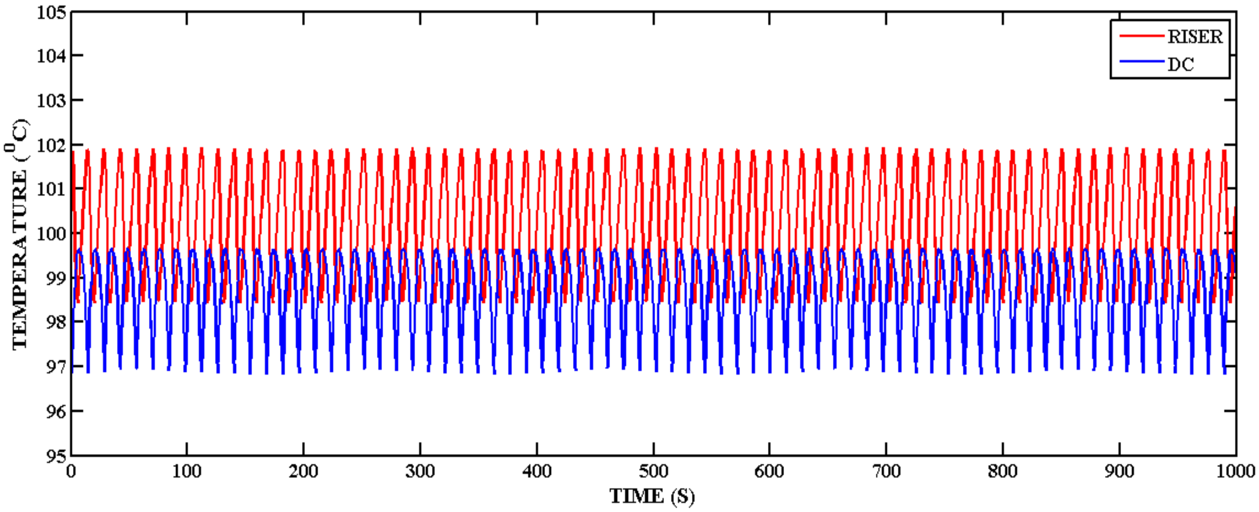

FIG 3.12: Temperature variation of Riser and Downcomer (DC) section (1700W)

Temperature variation is shown in FIG 3.12, it is oscillating in in both riser and downcomer section. The amplitude of oscillation is increased than previous power level and oscillating in periodic oscillation. FIG 3.13 is void fraction variation figure, which is also oscillating in periodic manner.

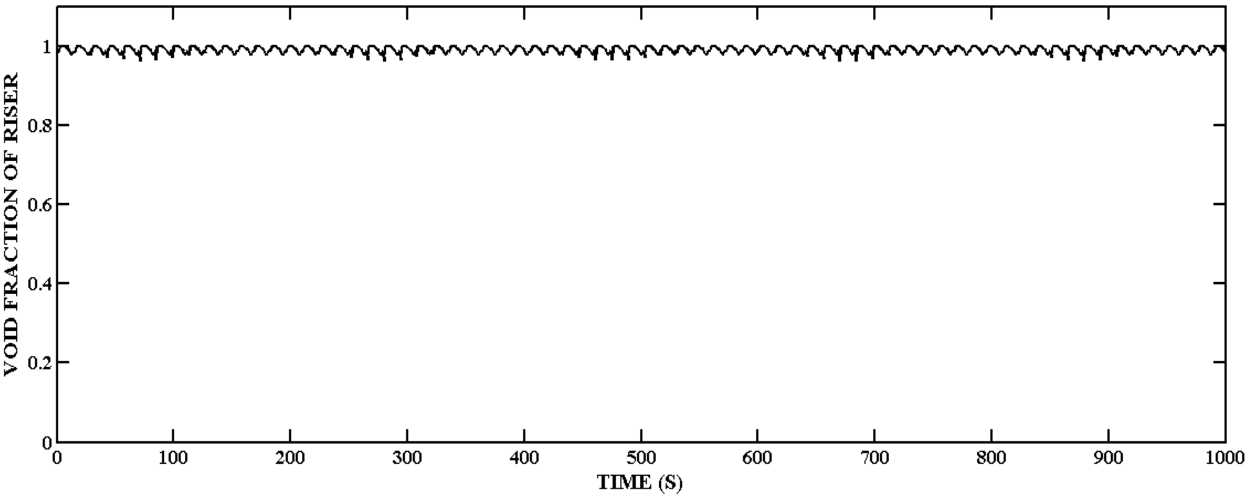

FIG 3.13: Riser Section Liquid void fraction variation with time (1700W)

FIG 3.14 is indicating the mass flux variation with time at power 1725W. We can be seen from the figure that, at this power we have the flow reversal in the loop. The mass flux is oscillating in a non-periodic manner with very high amplitude. FIG 3.15is the temperature variation curve with time. We can see that at some point the down comer temperature is showing a value near riser temperature, those are the point of flow reversal. FIG 3.16 indicating the Liquid void fraction variation in riser section. The void fraction has changed very interestingly. It is oscillating in the range 1 to .2, which is much unexpected.

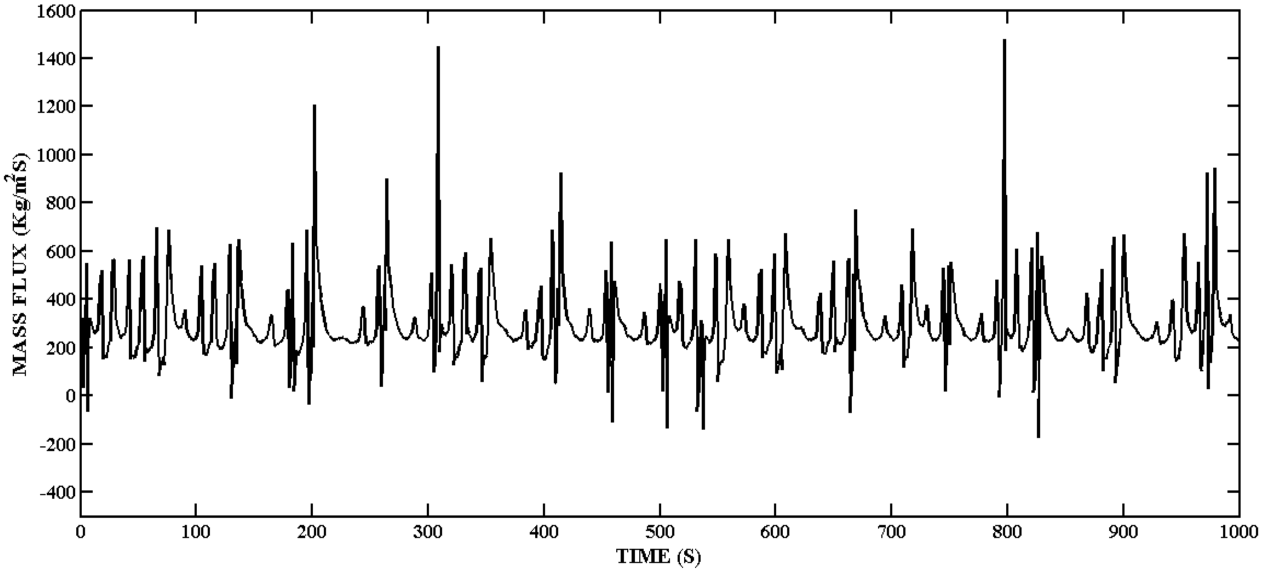

FIG 3.14 : Variation of Mass flux with time at 1725W(Two Phase)

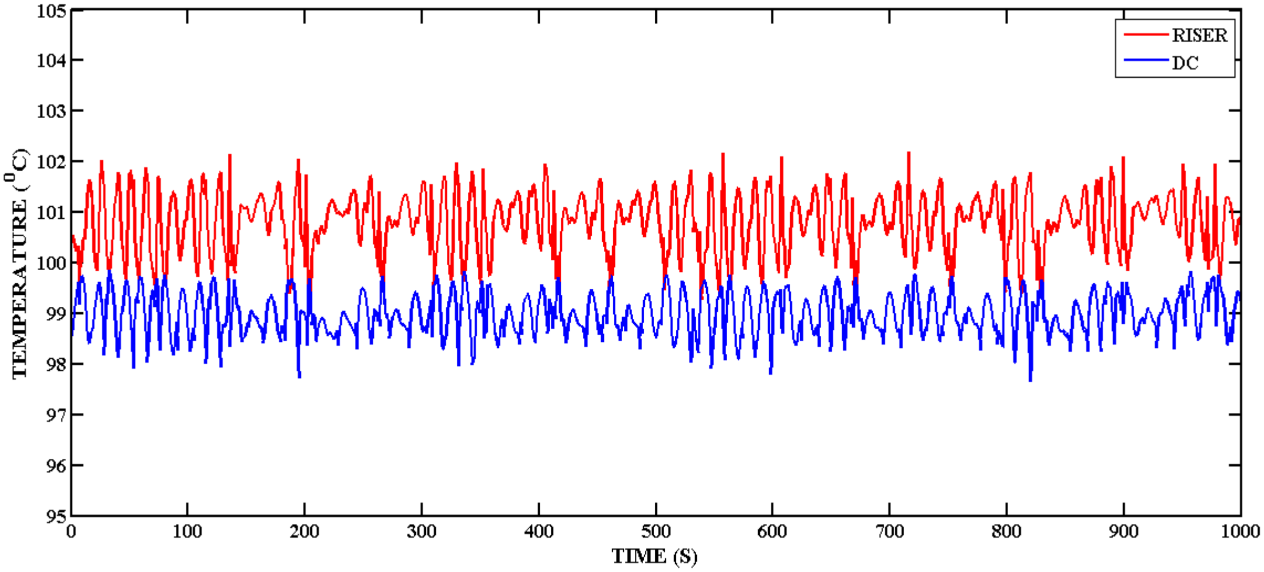

FIG 3.15: Temperature variation of Riser and Downcomer (DC) section (1725W)

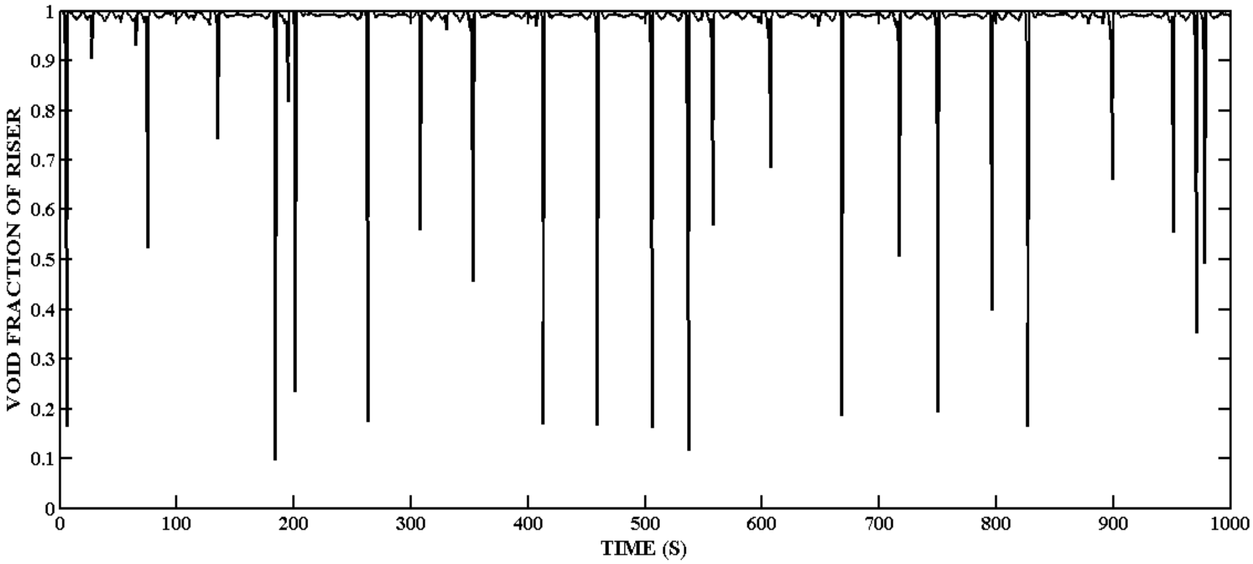

FIG 3.16: Riser Section Liquid void fraction variation with time (1725W)

Further increase in power to 1800W indicates the mass flux variation oscillation .The amplitude of oscillation also increases ,its varies from -1700 to 1700 kg/m^2.Negative sign in mass flux implies the flow reversal. FIG 3.18 shows the temperature variation in riser and down comer section. It is cleared from the figure that the oscillation is increased with compared to previous power condition. The liquid void fraction variation with time has been shown in FIG 3.19 .More amount of vapour is generated in the riser section. The liquid void fraction varies between 1 to .1 which implies very high vapour concentration.

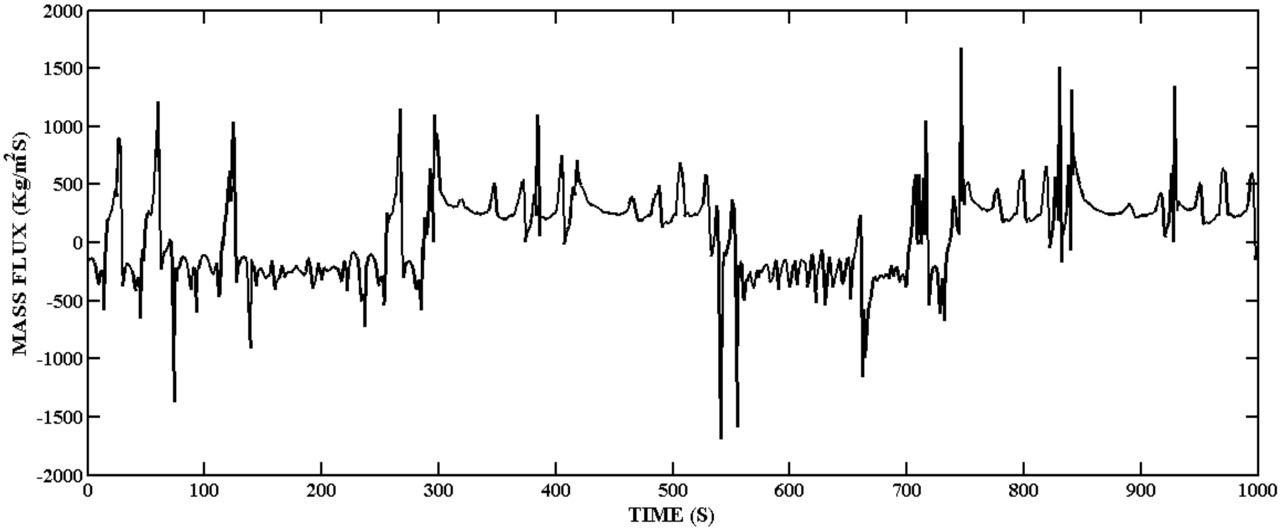

FIG 3.17: Variation of Mass flux with time at 1800W (Two Phase)

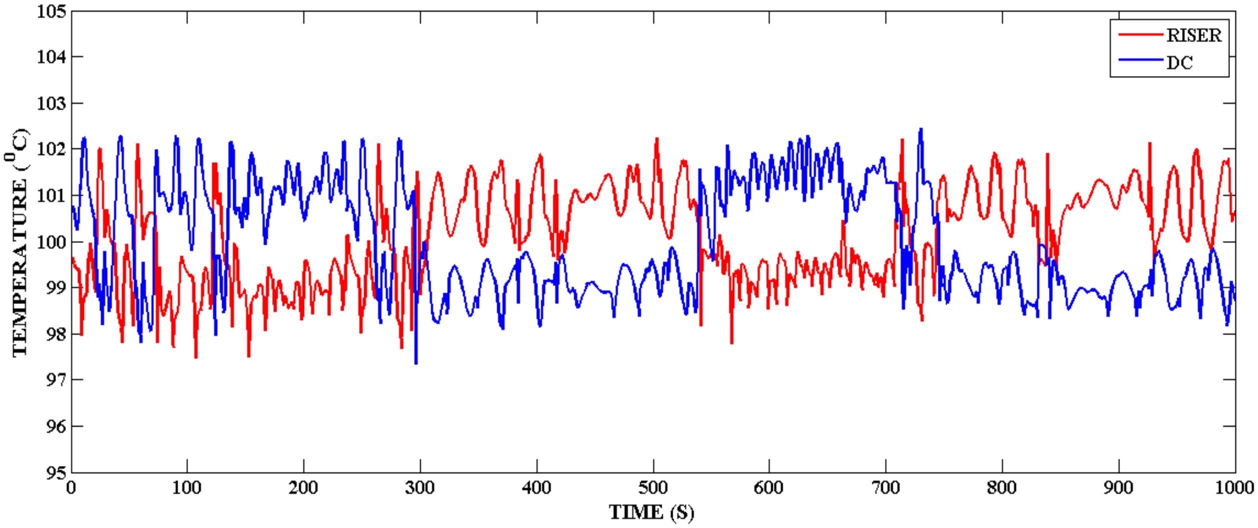

FIG 3.18: Temperature variation of Riser and Downcomer (DC) section(1800W)

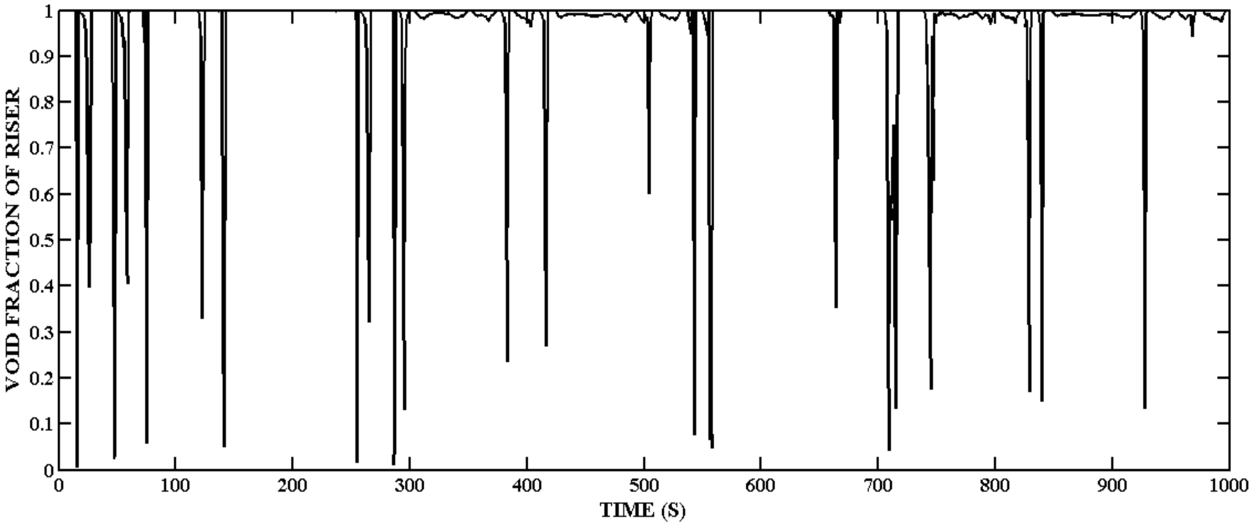

FIG 3.19: Riser Section Liquid void fraction variation with time (1800W)

Mass flux variation with time at 1950W has been shown in the figure 3.20 .The amplitude of oscillation is continuously changing in range -2000 to 2000 kg/m^2 .The oscillation is increased compared to 1800W power.

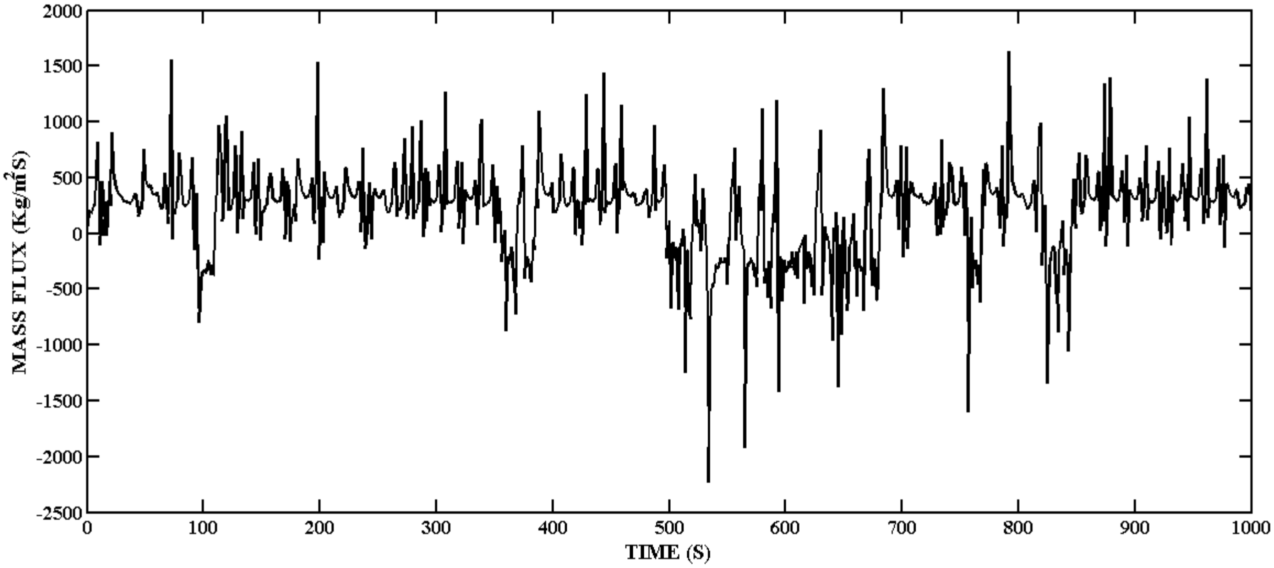

FIG 3.20: Variation of Mass flux with time at 1950W (Two Phase)

Temperature variation curve of riser at 1950W in FIG 3.21 iindicating that it is oscillating in higher frequency, higher than 1800W.

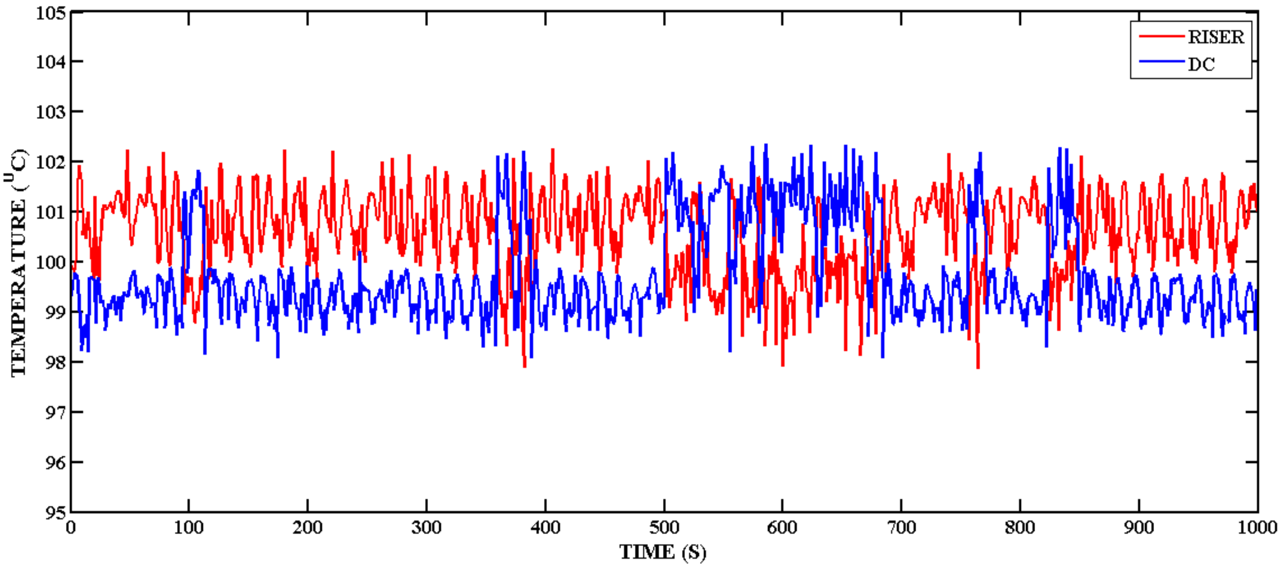

FIG 3.21: Temperature variation of Riser and Downcomer (DC) section (1950W)

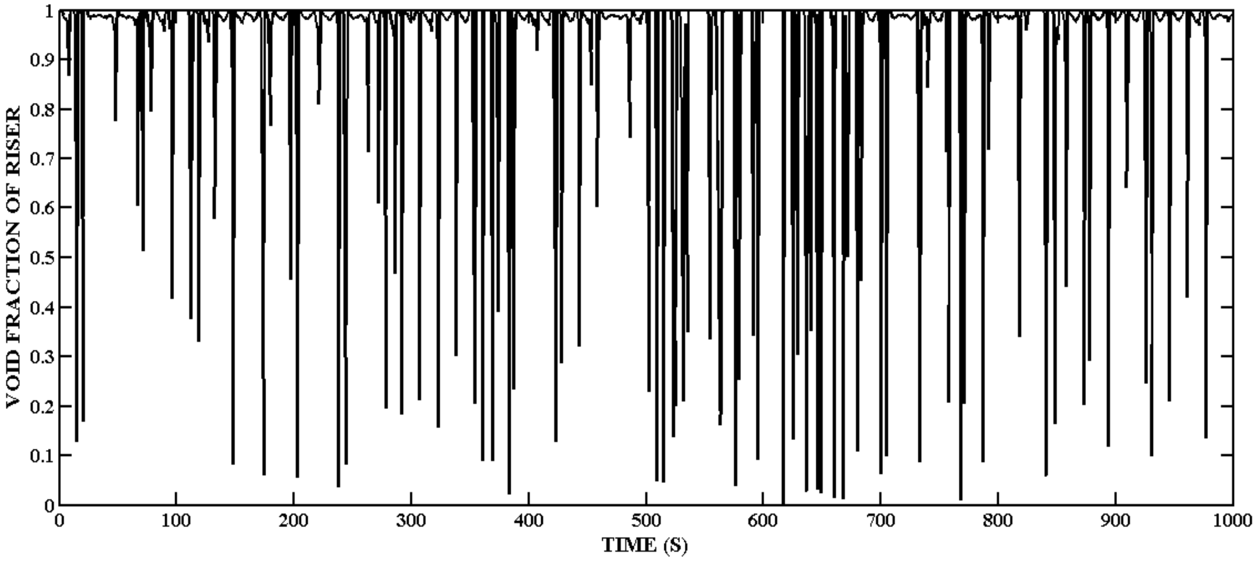

FIG 3.22: Riser Section Liquid void fraction variation with time (1950W)

FIG 3.23 indicating that, the mass flux is oscillating at high frequency at 2000W. Flow reversal is present at this power .Temperature of riser and down comer is also presented in FIG 3. 24. Both the riser and downcomer temperature is oscillating in the range 95^0C to 101^0C.FIG 3.25 represents the void fraction oscillation curve of riser section it has the higher frequency then 1950W.

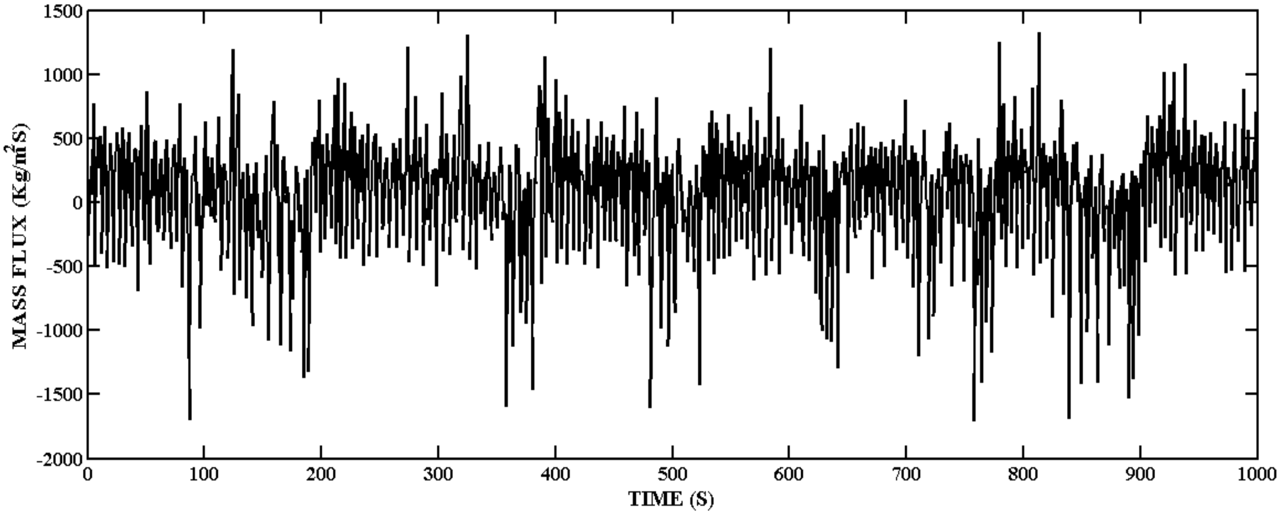

FIG 3.23: Variation of Mass flux with time at 2000W (Two Phase)

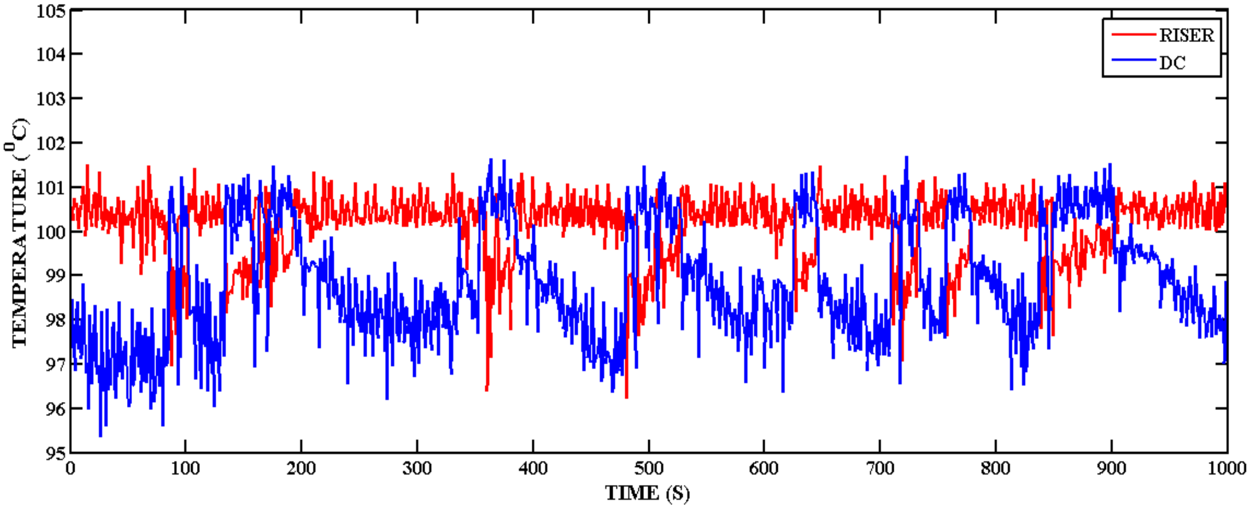

FIG 3.24: Temperature variation of Riser and Downcomer (DC) section (2000W)

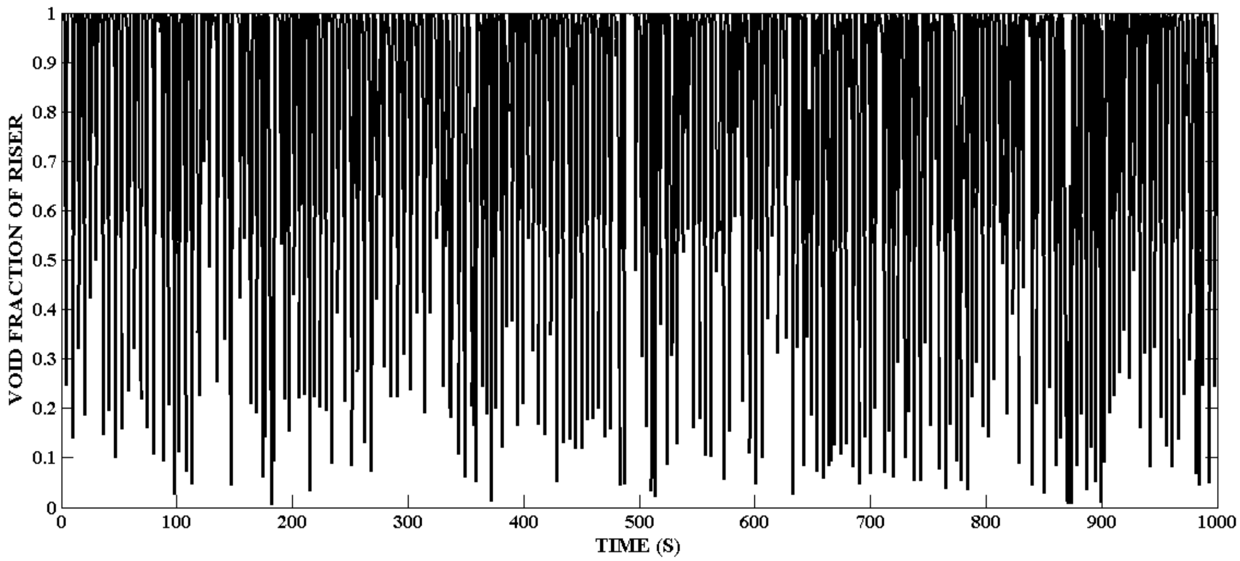

FIG 3.25: Riser Section Liquid void fraction variation with time (2000W)

At power 2300W, liquid void fraction fluctuating between .7 to .1. And after some time it reaches to 0 which indicates the loop is totally filled with vapour .FIG 3.26 also indicates that the mas flux is oscillating between small ranges and becomes zero after some time. FIG 3.27 shows that the riser section is completely filled with vapor.

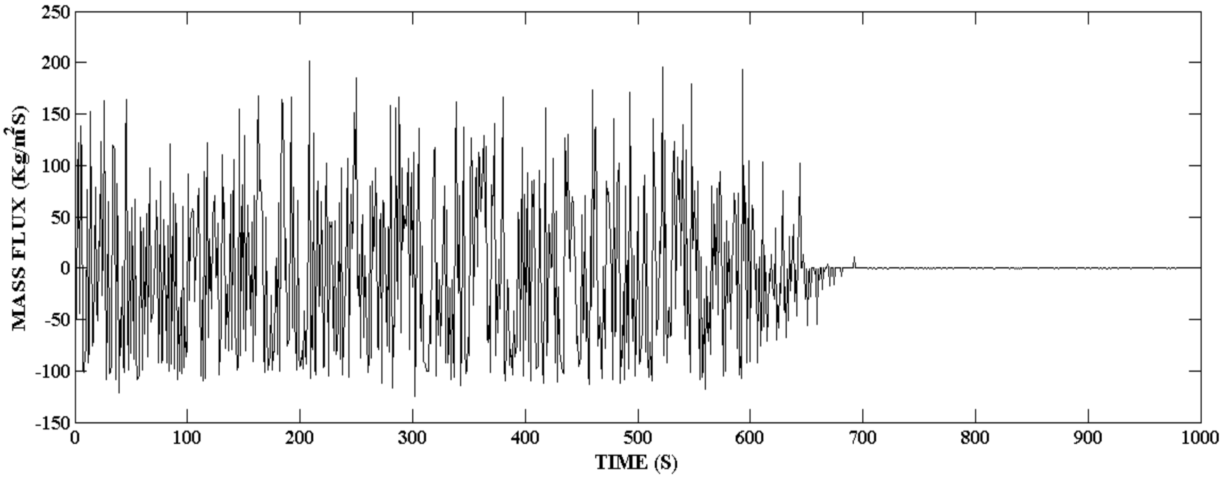

FIG 3.26: Variation of Mass flux with time at 2300W (Two Phase)

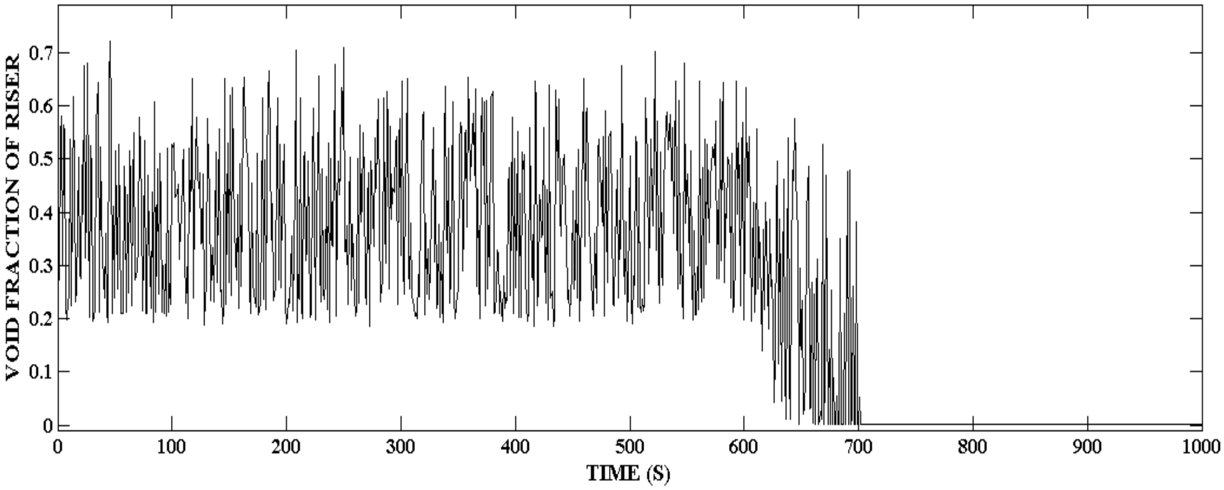

FIG 3.27: Riser Section Liquid void fraction variation with time (2300W)

3.3 MASS FLUX VS POWER CHARACTERISTICS

In a two phase flow natural circulation loop, an increase in heat flux do not always increases mass flow rate. There is an optimum heat flux at which the two phase flow can be operated advantageously .With the increase of heat flux the exit dry ness fraction from heating region increases, causing higher density difference for circulation. However, with the increase of dryness fraction and flow rate the frictional pressure drop also increases. For this reason after a certain value of heat flux the mass flux decreases. In our work we have found that the mass flux is changing from steady to periodic oscillation and ultimately non periodic oscillation with flow reversal phenomenon. We have calculated the RMS value of mass flux at different power level from 0 to 2300W .The mass flux vs. power curve is shown in the FIG 3.28.

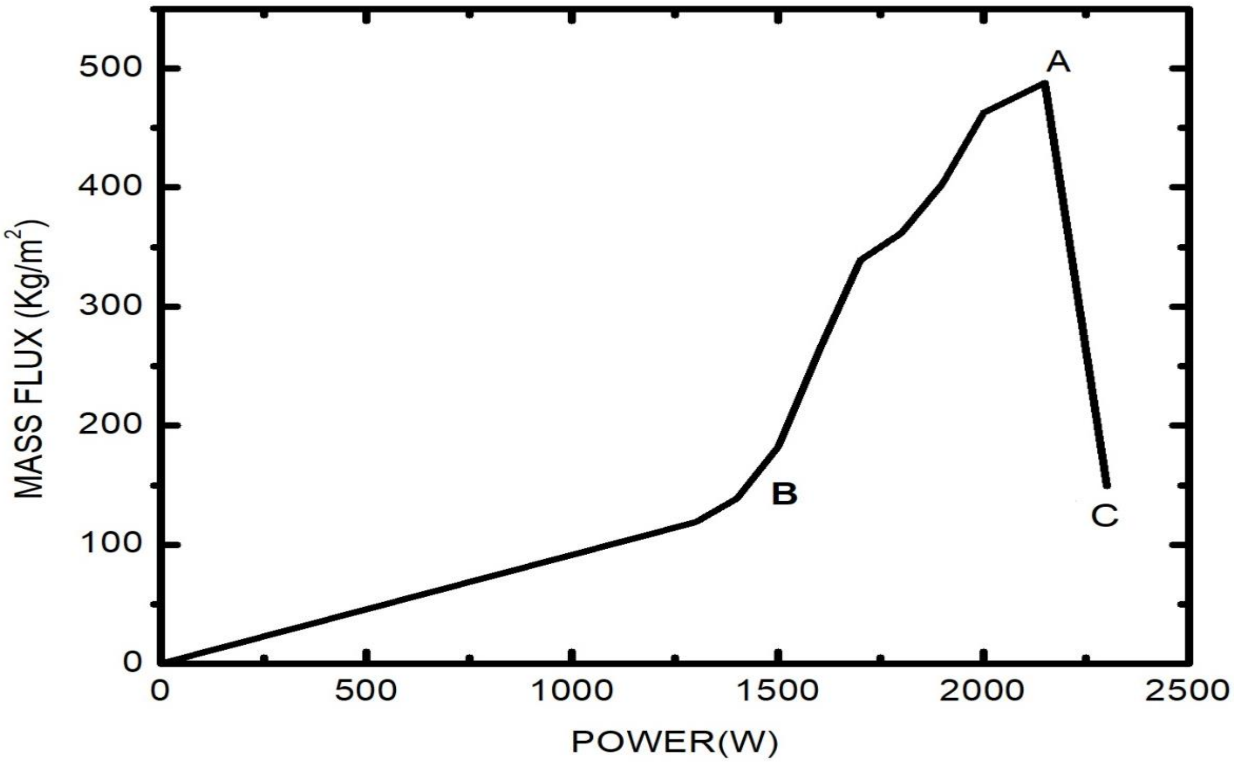

FIG 3.28: Mass Flux Variation with Heater Power

The point B in above figure indicates the point near which the boiling took place. From A to B power range indicates higher density difference and with the increase in power mass flux also increases. A is the optimal power condition at which we can operate the natural circulation loop advantageously .After point A the mass flux continuously decreasing and at point C indicates the deadline for NCL operation beyond that there will be dry out condition of the loop.

3.5 FLOW REGIME TRANSITION AND PRESSURE DIFFERENCE PLOTS

One of most important presentation in two phase flow problem is how flow regime is changing with the time, from bubbly to slug or to annular mist. We have already discussed, how pressure difference in loop is affected when flow regime changes from annular to slug flow. Instability is there related to flow regime transition. All the flow regime graphs presented here are specified with some numbers, 4 is the numerical value assigned for bubbly flow, 5 is for slug flow, 6 is for annular mist flow.

The flow regime transition and pressure drop variation at 1600W has been shown in figure 3.29 and figure 3.30 respectively. 1600W is the initiation of two phase flow in the loop, here the continuous changing of bubbly to slug flow regime is happing in the system with varying pressure drop in riser section

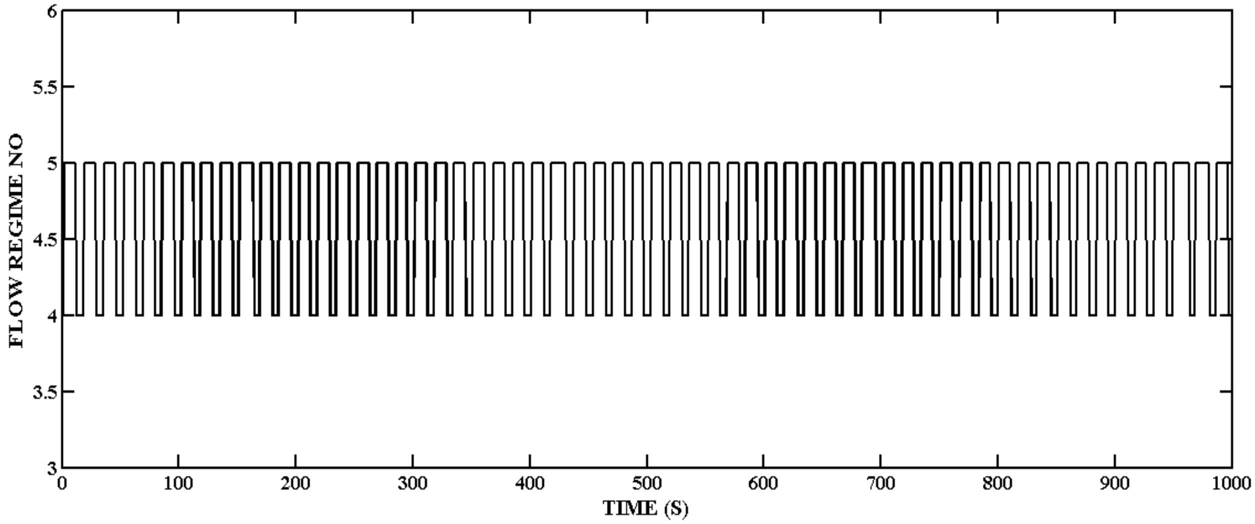

FIG 3. 29: Flow Regime variation in Riser section at 1600W

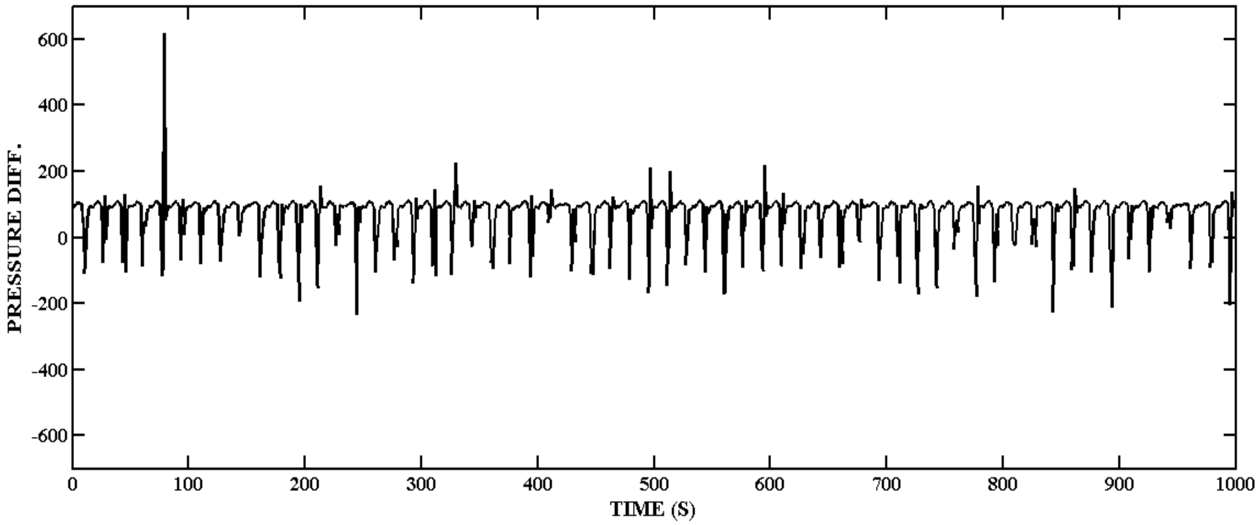

FIG 3.30: Pressure difference (Pa) (between Riser and Down comer) variation at 1600W

According to FIG 3.31 and FIG 3.32 we can say that Pressure difference is fluctuating between -1000Pa to 1500Pa in a periodic manner at 1700W, flow regime is also changing from bubbly to slug flow in a periodic pattern.

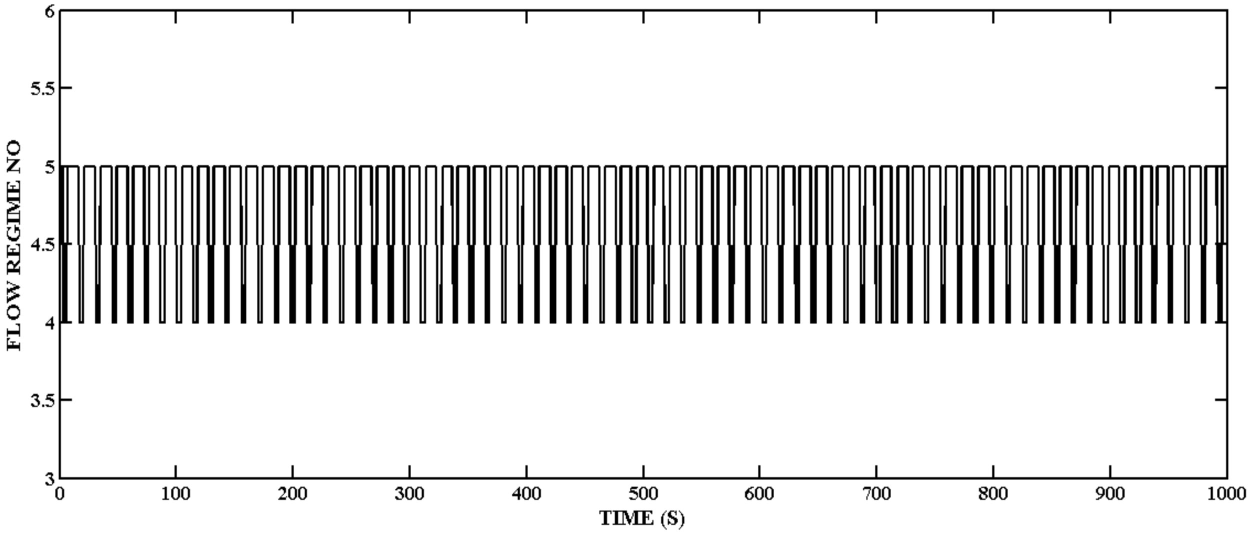

FIG 3. 31: Flow Regime variation in Riser section at 1700W

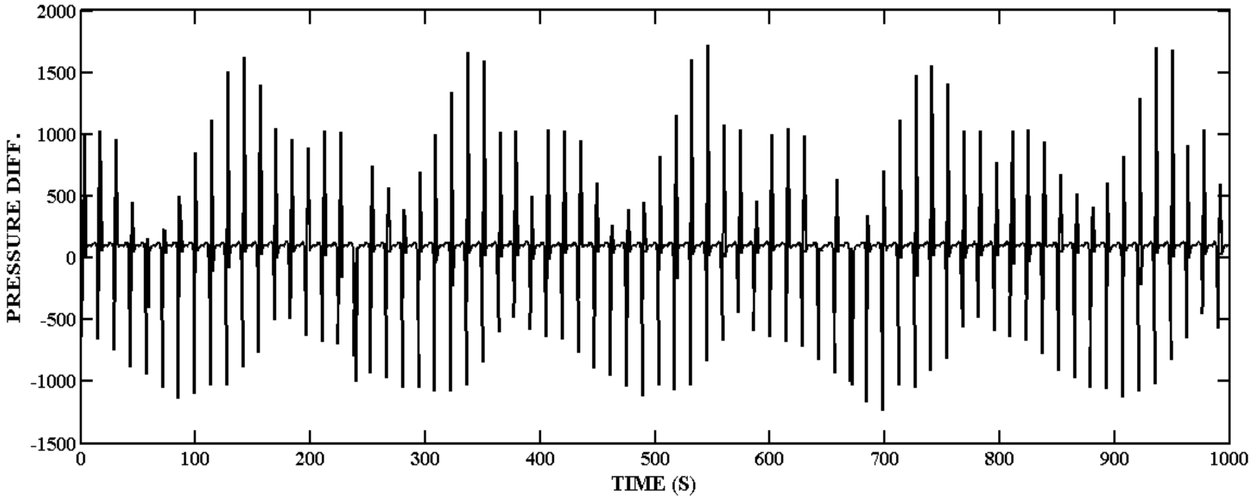

FIG 3.32: Pressure difference (Pa) (between Riser and Down comer) variation at 1700W

The flow regime variation and pressure drop variation has been shown in FIG 3.33 and Fig 3.34.for power 1725W. We already know that this is the flow reversal power and the mass flux variation is non periodic and flow reversal type. Flow regime is continuously changing between bubbly and slug flow regime with a non-periodic oscillation.

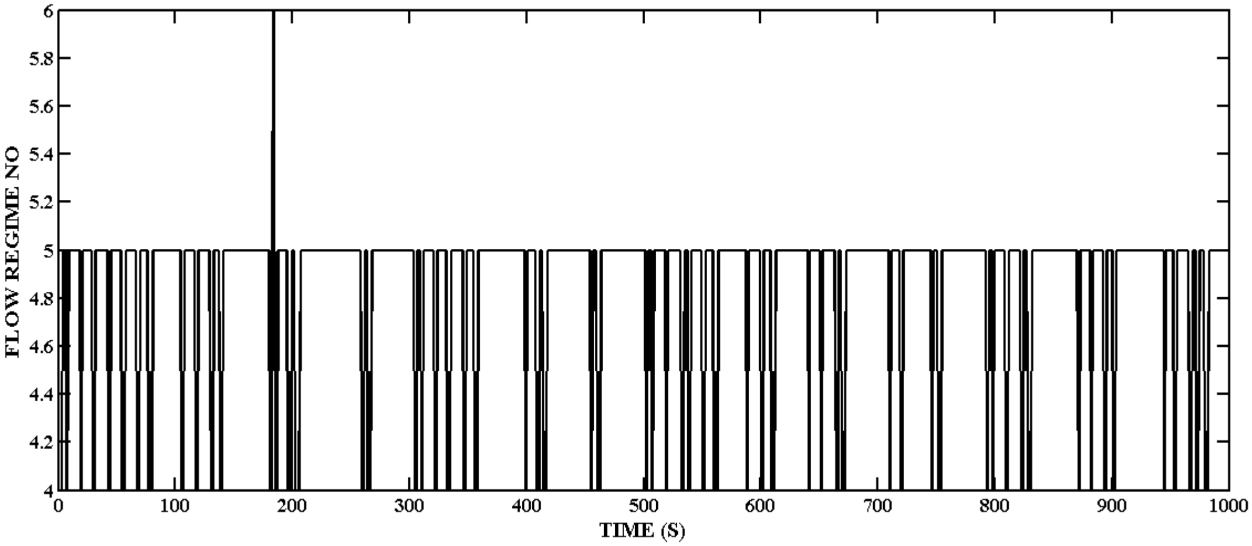

FIG 3. 33: Flow Regime variation in Riser section with time at 1725W

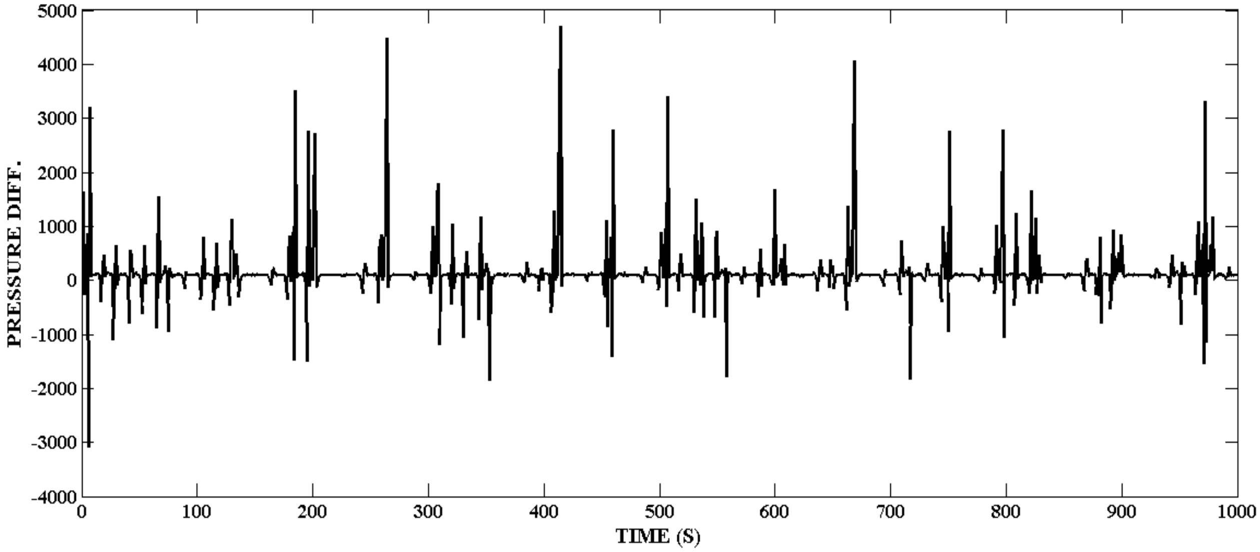

FIG 3.34: Pressure difference (Pa) (between Riser and Down comer) variation at 1725W

FIG 3.35 indicates the flow regime variation at power 1800W .The pattern is oscillation non periodic. The regime is oscillating between bubbly to slug and annular mist regime. The flow regime changes in decreased frequency compared to the previous power. The pressure drop oscillation is also non periodic with higher amplitude.

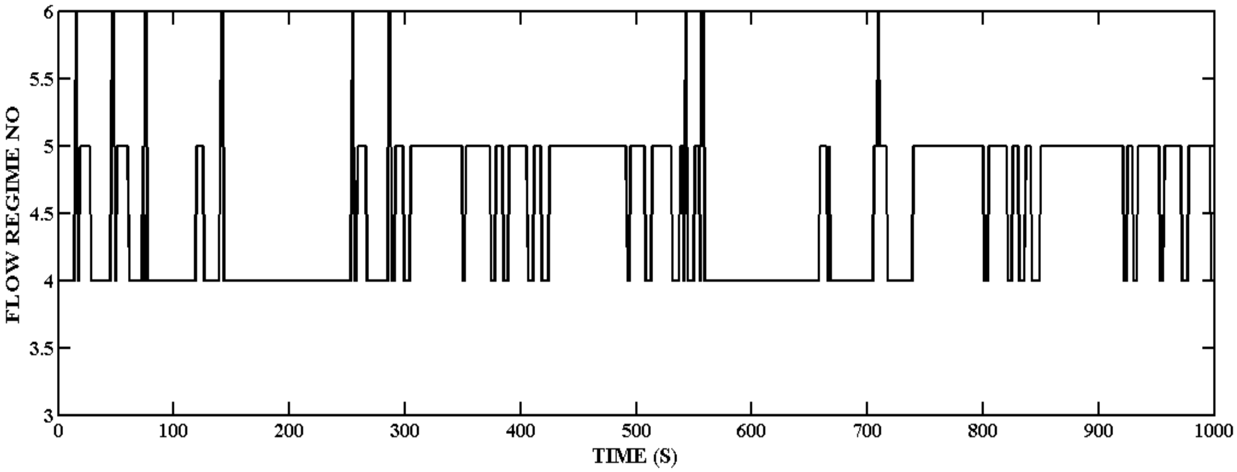

FIG 3. 35: Flow Regime variation in Riser section at 1800W

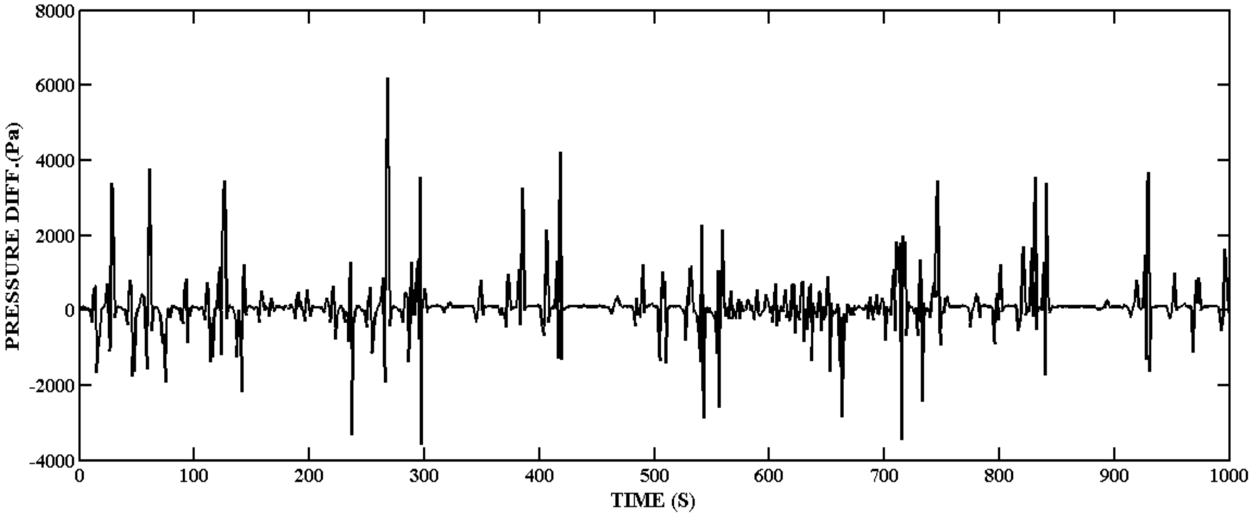

FIG 3.36: Pressure difference (Pa) (between Riser and Down comer) variation at 1800W

FIG 3.37 to FIG 3.38 indicates the flow regime variation and pressure drop variation at power 1950W and 2000W.In this case the flow regime changing oscillation is non periodic and the frequency of oscillation is very high. The rate of pattern changing from slug to annular mist is also increased. Pressure drop variation is non periodic and oscillating in greater frequency than previous power

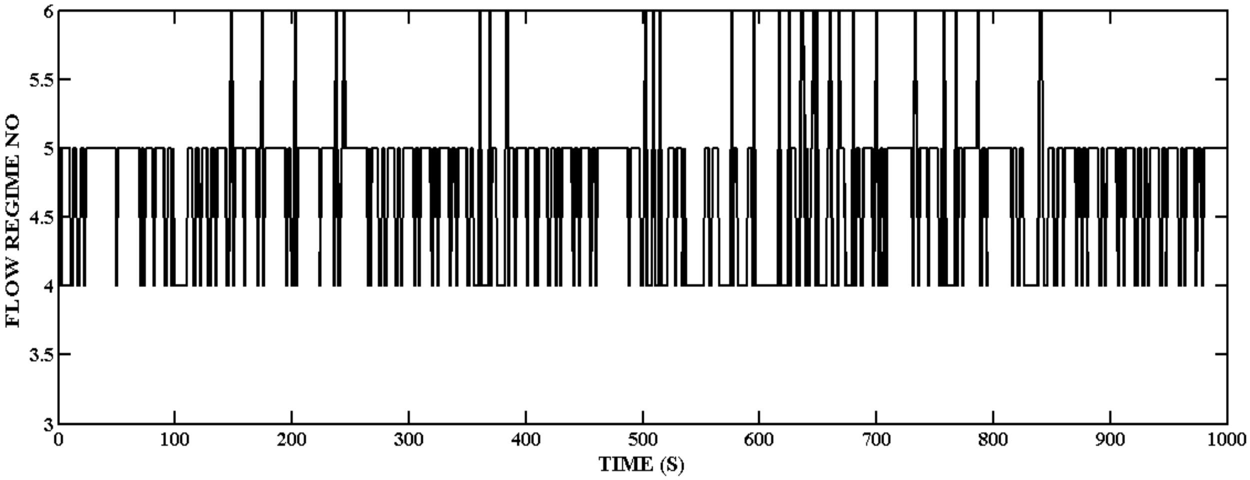

FIG 3. 37: Flow Regime in Riser section with time at 1950W

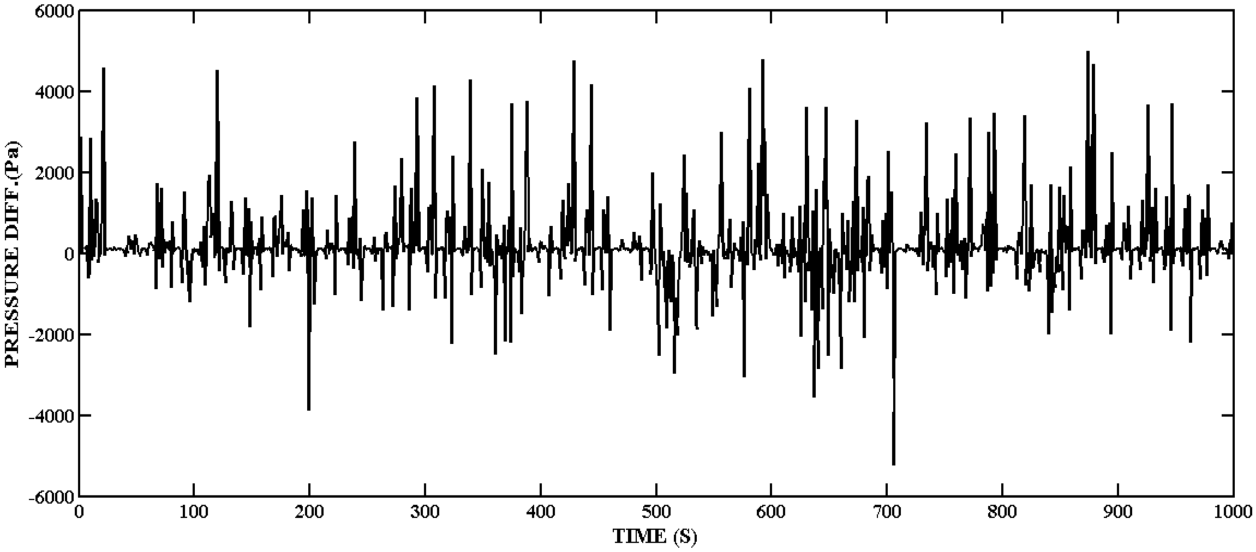

FIG 3.38: Pressure difference (Pa) (between Riser and Down comer) variation at 1950W

The flow regime variations and pressure drop variation for power 2000W has been shown in FIG 3.39 and FIG 3.40. Pressure drop oscillation frequency is continuously increasing with increase in power. The frequency of flow regime pattern transition from slug to annular mist has also increased

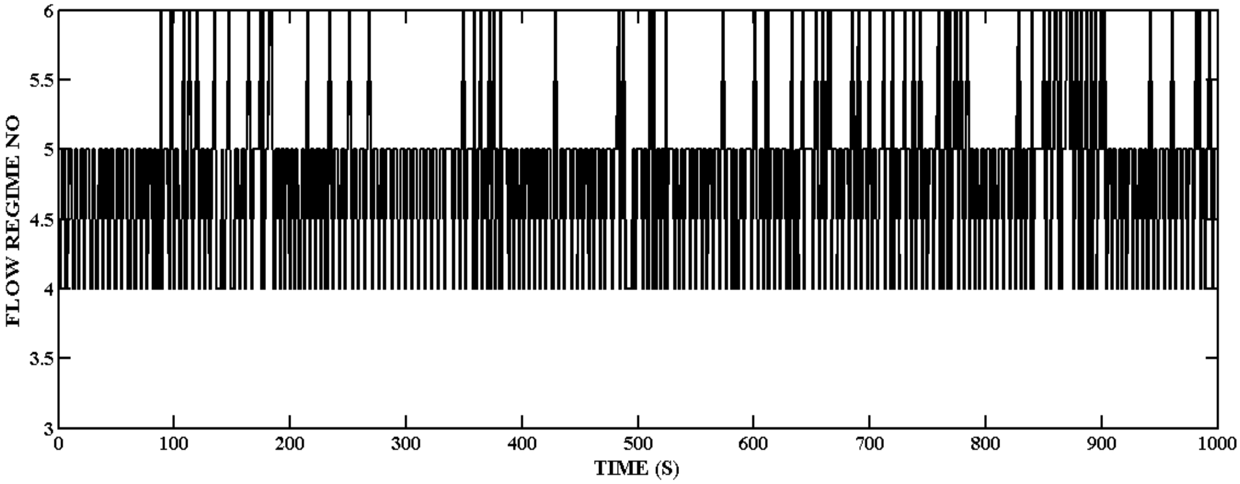

FIG 3. 39: Flow Regime in Riser section with time at 2000W

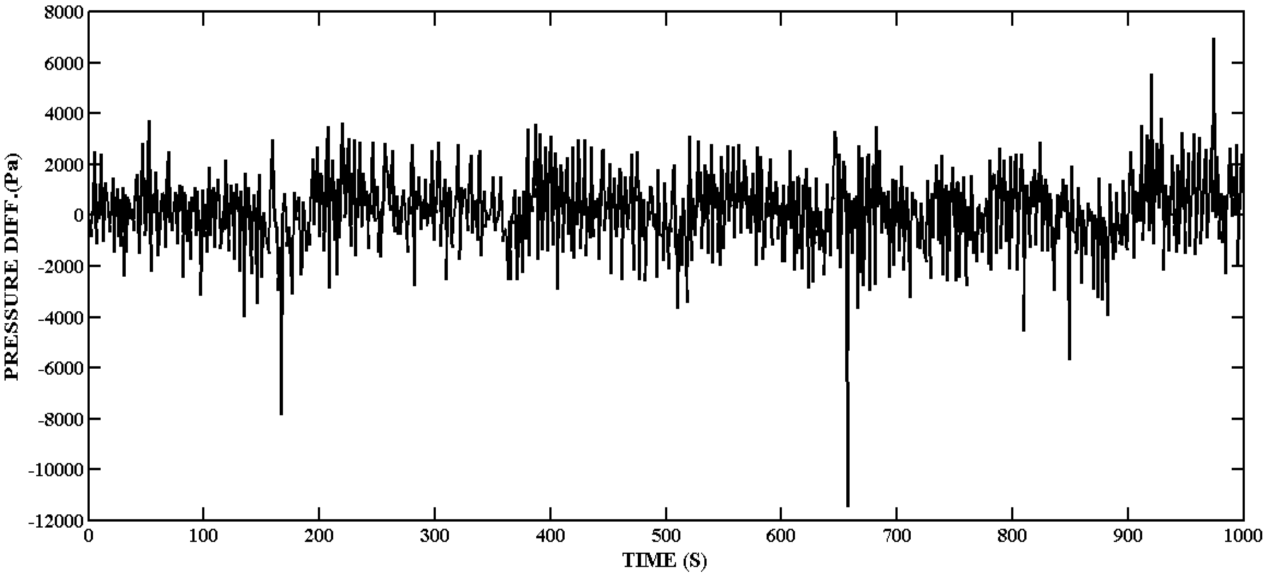

FIG 3.40: Pressure difference (Pa) (between Riser and Down comer) variation at 2000W

3.6 DYNAMIC ANALYSIS OF LOOP MASS FLUX

From previous figures of mass flux variation with time at different power level, we can see that mass flux patterns changing from steady to periodic and non-periodic oscillation. FFT analysis is required for identification of the frequency in which the mass flux is oscillating. We have done the Fast Fourier Transformation analysis on mass flux data on 1600W to 2000W power range and found some interesting results that we are presenting below.

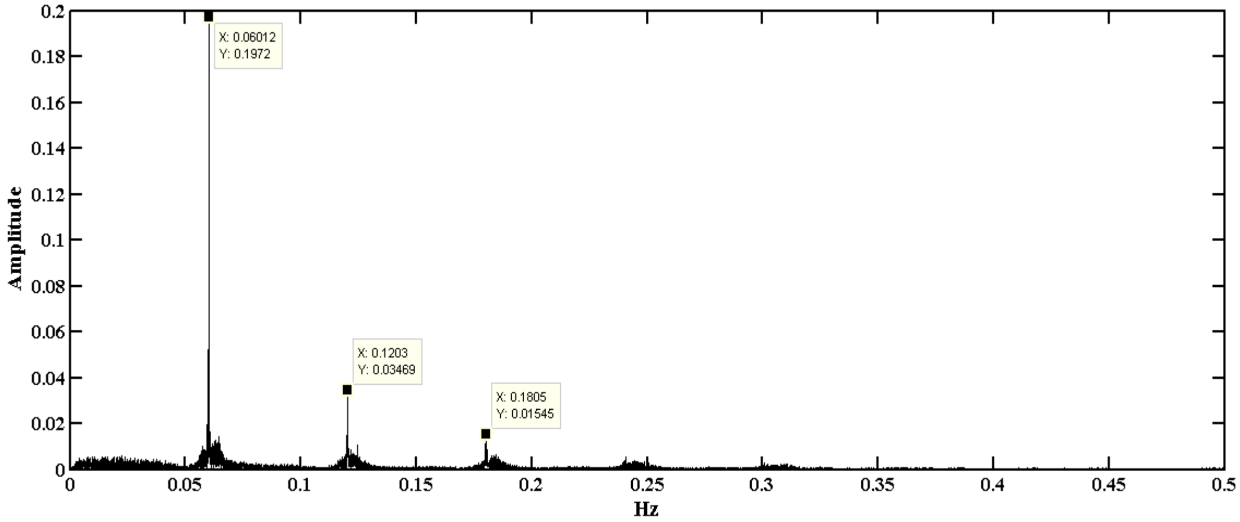

FIG 3.41: FFT of Mass flux time series data at 1600W

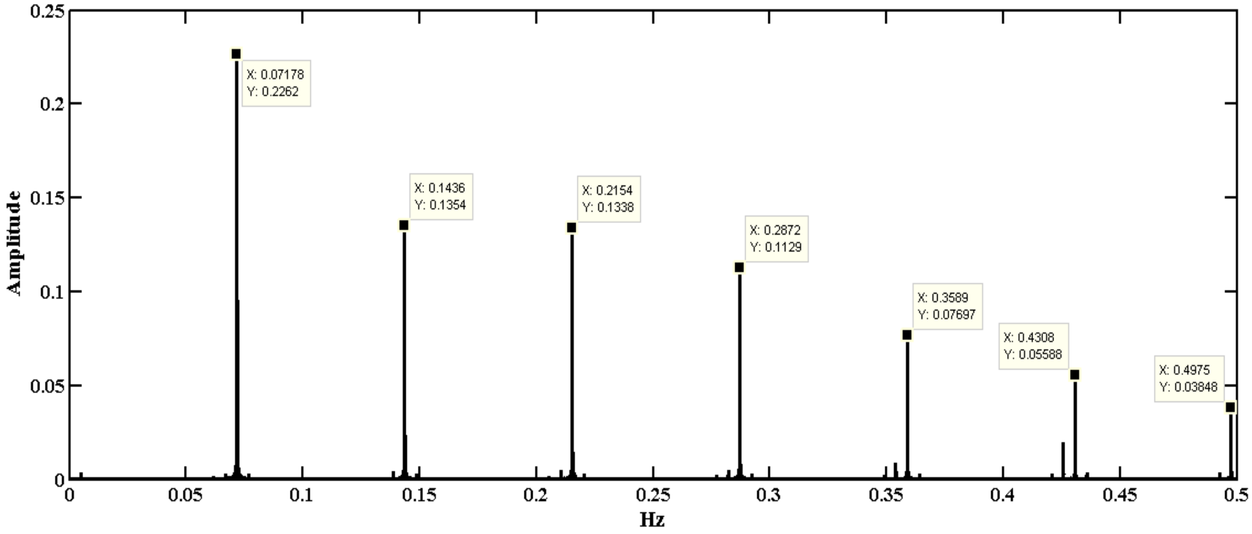

FIG 3.42: FFT of Mass flux time series data at 1700W

From FIG 3.41 and FIG 3.46 it is clear that mass flux variation is oscillating with some fundamental frequency and its harmonics, the oscillation is periodic up to 1700 W. It is impossible to find any fundamental frequency of oscillation from 1725W to 2000W. The reason for this nonlinear dynamics of oscillation is due to Flow reversal, which starts at power 1725W. FFT of each power from 1725W to 2000W has been shown form FIG 3.43 to 3.46 and each figure is incapable of finding any fundamental frequency or any harmonics of oscillation. This may be implying the underlying chaos in the system dynamics.

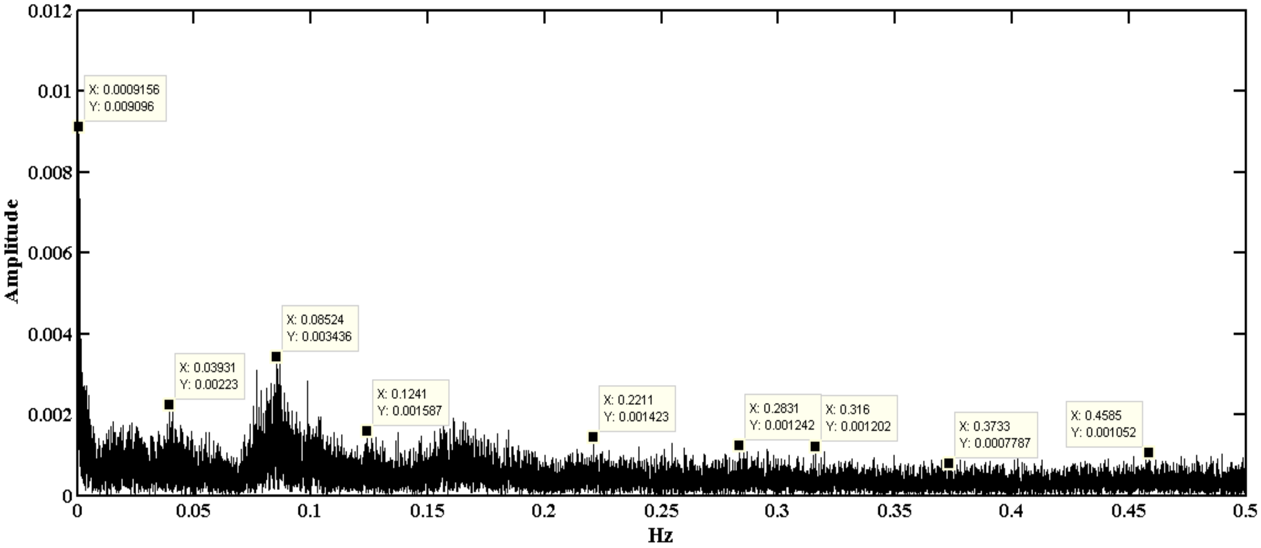

FIG 3.43: FFT of Mass flux time series data at 1725W

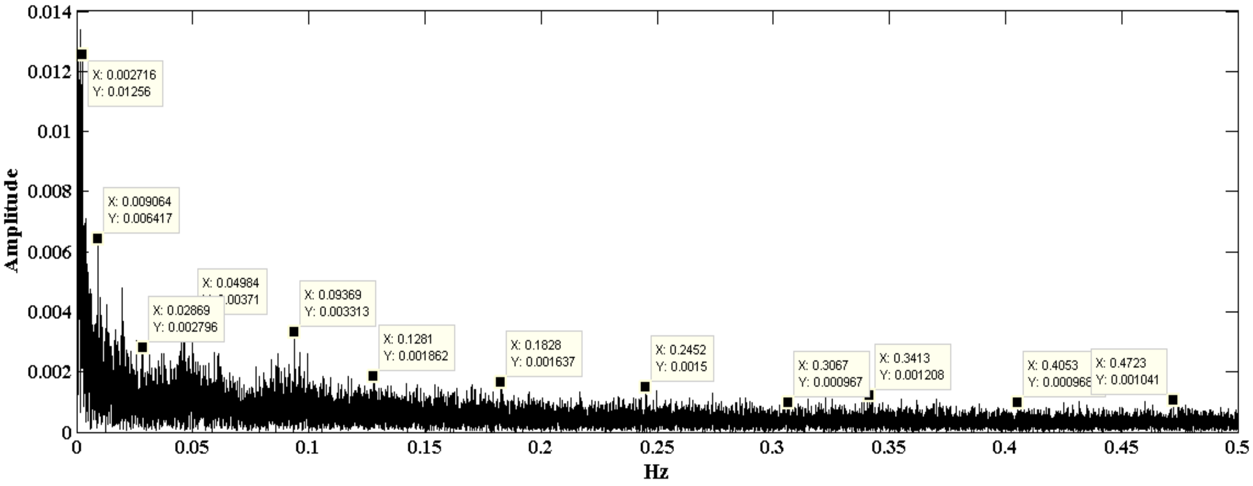

FIG 3.44: FFT of Mass flux time series data at 1800W

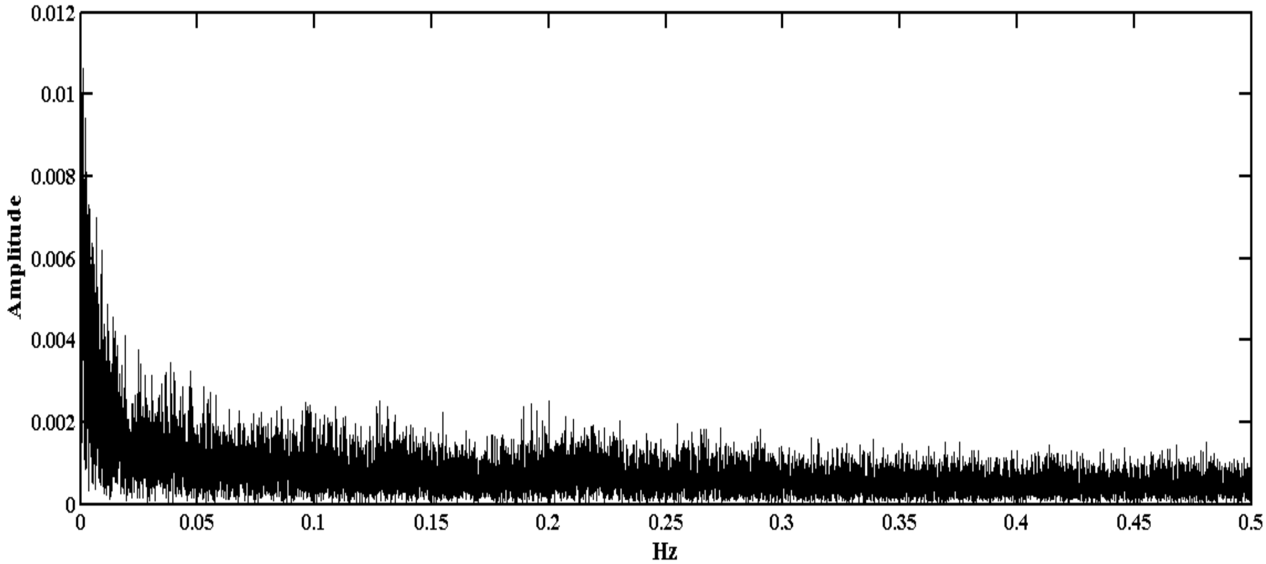

FIG 3.45: FFT of Mass flux time series data at 1950W

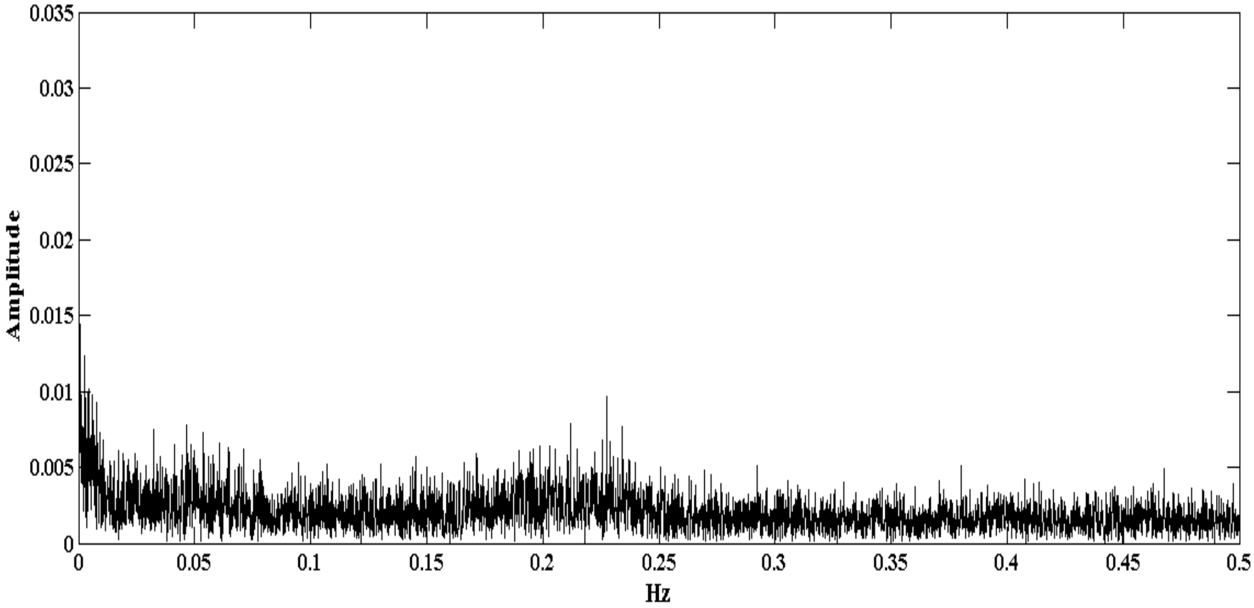

FIG 3.46: FFT of Mass flux time series data at 2000W

CHAPTER 4

CONCLUSION AND FUTURE SCOPE

4.1 CONCLUSION

Our simulation has predicted some satisfying results of the two phase flow square natural circulation loop. We can separate the system dynamics behavior as it changes from steady to periodic oscillation then non periodic flow reversal pattern with the increase in heater power. We can conclude that our whole simulation can be divided in three main category, a steady single phase flow up to 1400W.A periodic oscillation zone between 1470W to 1700W power range, after that there exists a non-periodic power range between 1725W to 2000W. Two phase flow initiation is at power 1600W.Mass flux oscillation is greatly influenced by heater power, the amplitude of oscillation is increased with increased power. The liquid void fraction decreases with high heat flux, which initiates friction dominated density wave oscillation. The mass flux variation, the flow regime changing phenomena, the pressure drop characteristics are example that RELAP 5/MOD 3.2 has the capability of analyzing the multiphase flow behavior. RELAP5/MOD 3.2 has a problem of time step calculation, we have to give proper time step in input file card otherwise it will terminate the program before completion.

4.2 FUTURE SCOPE

We have investigated the flow dynamics and we found that there exists some kind of non-linearity in system flow dynamics. Fast Fourier Transformation is not enough for the confirmation of system non linearity .So nonlinear dynamics of our simulated data is required

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