Study and CFD Analysis on different test plate specimens with different nozzles for thermal striping Phenomenon in LMFBR Reactors

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Abstract - *Thermal stripping is a phenomenon is defined as the thermal fatigue occurred due to the flow of hot and cold streams at different temperature with a temperature difference of about 100*c mixing in a fluid domain, result in an arbitrary change of temperature field of the fluid domain with respect to time. This random temperature fluctuation is termed as Thermal Striping which leads to random temperature fluctuations in the interface between the non-isothermal streams arising out of jet instability Thermal stripping is analysis is carried out by both experimentally and by using CFD analysis, for experimentation an experimental set up is fabricated and the results from experimentation is taken by data logger software, results from the experiment recorded and these are the input values taken for CFD analysis, importing recorded valves in CFD we get output results.This both experimental valves and CFD analysis results are compared and finally power spectral analysis is carried out for three metals for utilization of this metals for future use in fast breeder reactors as inner core, The condition for satisfying the utilization of metals as inner core without thermal striping phenomenon is that the metals should not exceeds the frequency(0.1-10)Hz*

KeyWords: Thermal stripping phenomenon, Experimental Analysis, CFD analysis, Power spectral density

1. INTRODUCTION

1.1.1Thermal stripping phenomenon

The Fast Breeder Reactor (FBR) is known for its ability to produce more fissile material than it consumes. In the reactor, heat generated in the core from nuclear fission is carried by primary sodium and is transferred to the secondary sodium in the Intermediate Heat Exchanger. Finally, the secondary sodium exchanges heat to water in the steam generator leading to the production of superheated steam to generate power (Chetaletal., 2006). Numerical sub-assemblies of various types constitute the reactor core. The central portion of the core consists of Fuel sub-assemblies. This zone is surrounded by Blanket, Reflector, Storage and Shielding subassemblies. A major fraction of the energy is released in the fuel zone and hence the sodium jets coming out of the fuel core will be at higher temperature. On the other hand, the coolant passing through the blanket takes away less amount of heat because of low heat generation in the blanket zone. Both the cold and hot streams exit from the

reactor zone as high- velocity jets. The improper mixing of the jet issued from these sub-assemblies results in jets temperature fluctuations in the fluid. This may lead to the damage of above core structural components. This phenomenon is known as thermal striping.
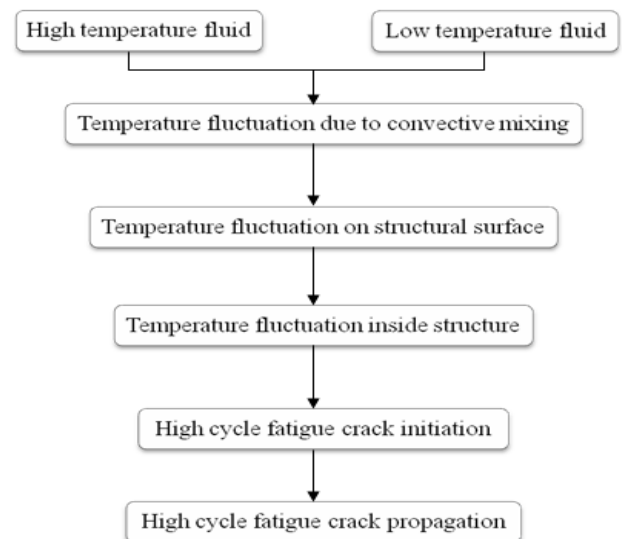
1.1.2Mechanism of Thermal stripping phenomenon

Fig. 1.1: Mechanism of thermal striping phenomena

Two flow streams at different temperatures, mixing in a fluid domain, resulting in an arbitrary change of temperature field of the fluid domain with respect to time.This random fluctuation is termed as Thermal Striping. This temperature fluctuation phenomenon is mainly caused due to the instability of fluid jets. Because of the high heat transfer coefficient associated with liquid metal coolants such as sodium, the temperature fluctuations are transmitted to the adjoining structures with minimal attenuation, which eventually leads to high cycle fatigue and crack initiation in the structures. In a Liquid Metal cooled Fast Breeder Reactor (LMFBR), thermal striping potential exists in the upper plenum as a result of the mixing of sodium jets from fuel subassemblies (SA), breeder SA and control SA. There exists a temperature difference of about 100 ºC between the flow streams emanating from these SA.

Thermal striping phenomenon will be simulated by experimentally and in CFD analysis process, for experimentation an experimental set up is fabricated and the results from an experimentation is taken by data logger software by connecting to lap, results from the experiment recorded and this is the input values taken for CFD analysis, importing recorded valves in CFD we get output results.This both experimental valves and CFD analysis results are compared and finally power spectral analysis is carried out for three metals for utilization of this metals for future use in fast breeder reactors as inner core, The condition for satisfying the utilization of metals as inner core is that the metals should not exceed the frequency(0.1-10)Hz, the frequency of oscillations while doing operation should be in between (0.1-10)Hz. if the frequency is satisfied then that metals stated as that metal is capable for future use as inner core metal fast breeder reactor

1.1.3 Analysis of thermal stripping phenomenon

Thermal stripping is random temperature fluctuation produced by the incomplete mixing of fluid streams at differing temperatures. Structures exposed to such temperature fluctuations may suffer thermal fatigue damage. For an engineering component containing a defect and situated in such a flow, the stress intensity factor (SIF) and strain energy density factor associated with the defect, will fluctuate in response to the imposed component surface temperature fluctuations

Thermal striping fatigue damage has the potential to Occur in a number of areas where there is good heat transfer between fluid and component. It can arise in certain liquid metal-cooled fast breeder reactor structures, notably those situated above the core, because of the large temperature differences (up to about 100 ∘C) which exist between liquid sodium emerging from both the core and the breeder sub-assemblies. Other areas of potential occurrence include piping systems in pressurized and boiling water reactors where hot and cold flows meet. Thermal stratification can occur in horizontal pipes and high-cycle temperature fluctuations can be observed at the interface between the flows. This may result in thermal fatigue cracking on the inside of the pipe at the interface of the fluids. 'T junctions' in piping systems is another area of potential thermal striping fatigue damage.

In the first phase, Thermal hydraulics analysis, in which the fluid temperature oscillation is predicted and frequency of fluctuation is found. The second phase is thermo-structural analysis, in which the structural response is predicted by taking the fluid temperature frequency of oscillations from the thermal hydraulic analysis.

1.1.4 Problem description

To predict thermal striping phenomena on core cover plate of a control plug and converting that to a basic and simplified model i.e., parallel water jet model in which rectangular plate simulates the core cover plate of the control plug and two water jet nozzle simulates the coolant coming out of subassemblies (SA) and also to examine the effect of length, velocity, gap between the nozzle and outlet height on thermal striping.
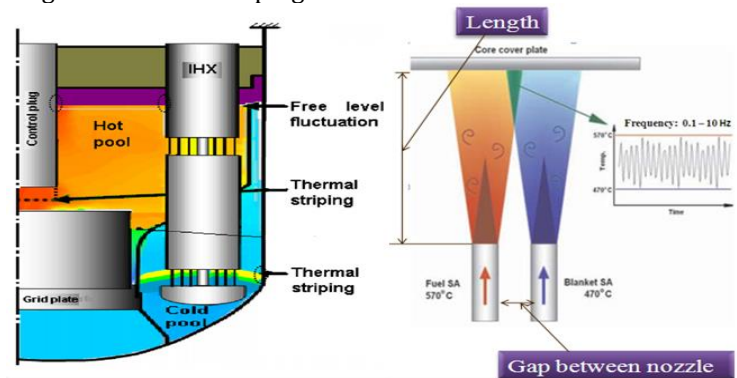

Fig. 1.2: Thermal striping phenomena in the vicinity of core cover plate

Show the pattern of fluctuations at different locations of pool type reactor in thermal striping phenomenon and shows different places of thermal striping

OBJECTIVES

➢ To predict fluctuation at the bottom of test plate specimen in mixing zone region.

➢ To study the effect of different nozzle ends (Trapezoidal and star).

➢ To study the capacity of metals(copper, steel, brass) as inner core in reactors for future use by spectral density analysis

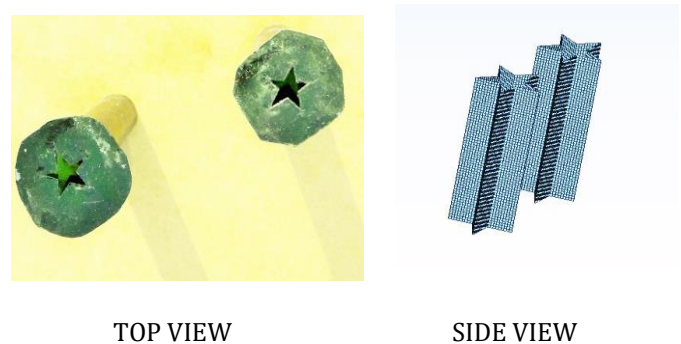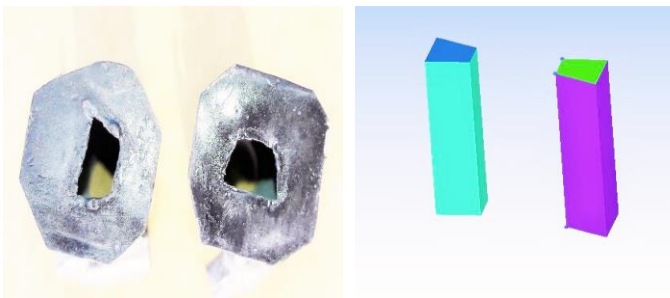➢ Modeling /Simulation for the system.

2. Experimental analysis

TOP VIEW   SIDE VIEW

Fig. 2.1.1. Star nozzle

TOP VIEW   SIDE VIEW

Fig. 2.1.2. Trapezoidal nozzle

Above Two nozzles are used in this project

This are the two pairs of nozzles are made of steel sheets of carbon alloy as per our dimensional requirement, these two nozzles are placed at the bottom of parallel water jet box, one nozzle is used as cold stream fluid flow and the another nozzle is used for hot stream fluid flow, each cycle of experiment One pair of nozzles are taken for the selected test plate specimen

Three types of test plate specimen are taken for this project they are

1. Copper
2. Steel
3. Brass

Fig. 2.1.3. COPPER

Fig. 2.1.4. Steel test plate

Fig. 2.1.5. Brass test plate

As per the thermal conductivity and availability of metals, these three metals are taken for experiment

PROPERTY	COPPER	STEEL	BRASS
Thermal conductivity,w/Mk	379.0	128.1	67.5

EXPERIMENTAL SET UP

Fig. 2.1.6. ENTIRE SET UP OF EXPERIMENT

Main parts in this entire set up are:

- Parallel water jet box

- Pumps

- Control valves

- Hot water tank and cold water tank

- Data logger

- Laptop

Thermal striping phenomenon is carried out inside the parallel water jet box with dimensions 300x200x300mm on the test plate by mixing two non-isothermal jets coming out of the parallel nozzle. M-seal sealant and Araldite epoxy resin are used to avoid the leakages within the box. The centrifugal pump having the capacity of 0.5HP each is used to pump hot and cold water from their respective tank. The hot water tank is having the capacity of 200 liters and is well stirred to gain uniform temperature. The temperature drop is found to be 15 min / °C. The maximum experiment duration is 2 minutes so that the tank is well enough to maintain the required temperature during the experiment. The cold water tank with the capacity of 100 liters is used and water is filled till the cooling system copper tube coils is immersed completely in water to avoid temperature drop ice flakes are used to maintain it to the required temperature. The length of the test plate is varied by using screw mechanism. The thermocouple is placed in the test plate by making a hole. The Test plate is adjusted to bring the thermocouple exactly at the middle of the two nozzles. The Thermocouple is fixed to the data logger and then by using data logger software configuration is set and the input is detected and time of recording is set in the scan button and quick graphs are obtained and finally, it is exported to the excel spread sheet format. Those output time and graphs are the outputs for the CFD Analysis

INPUT EXCEL GRAPHS FOR CFD ANALYSIS:
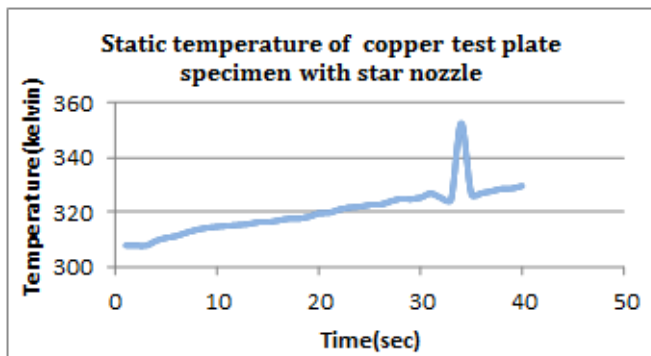
Fig. 2.1.7. Copper test plate with star nozzle
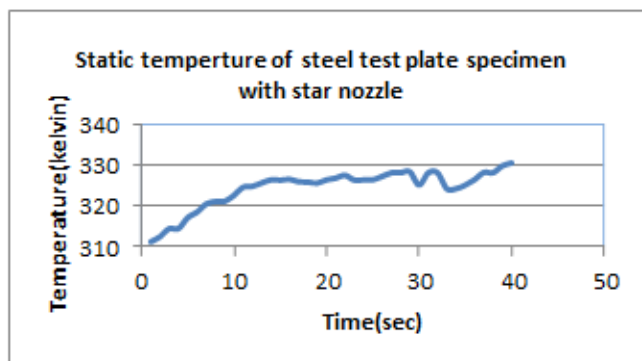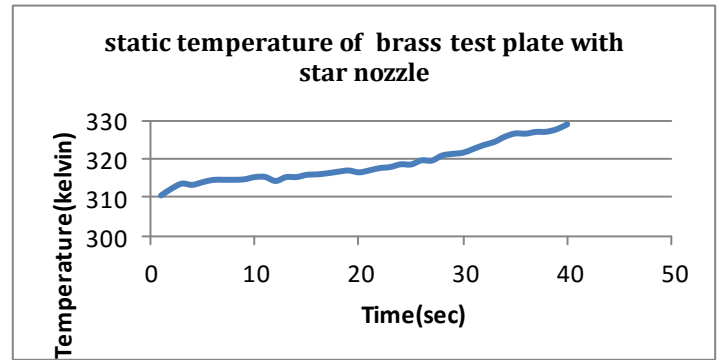

Fig. 2.1.8. Steel test plate specimen with star nozzle

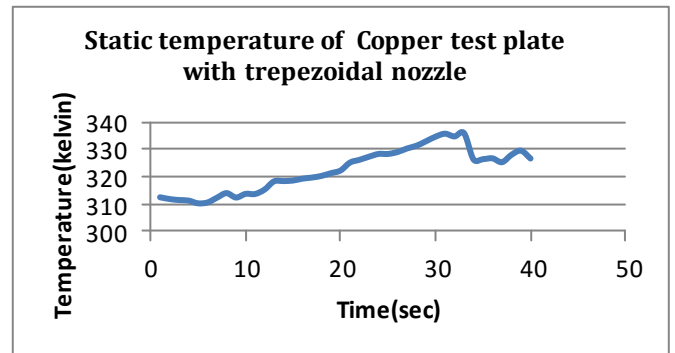**Fig.2.1.9.** Brass test plate specimen with star nozzle

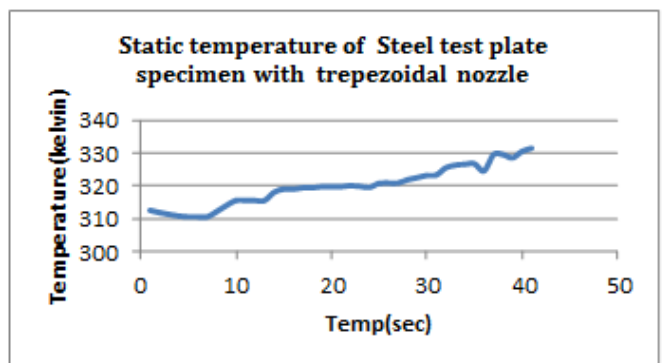**Fig. 2.1.10.** Copper test plate with trapezoidal nozzle

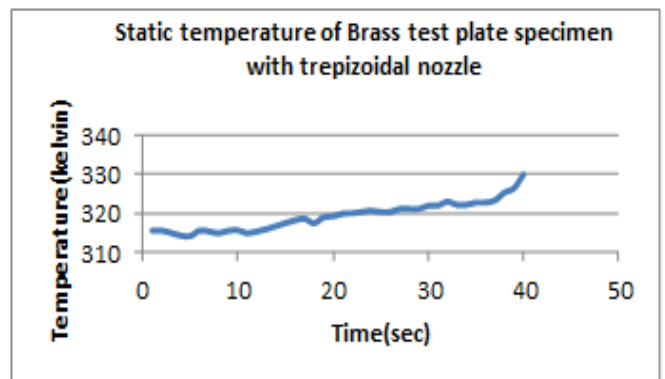**Fig. 2.1.11.** Steel test plate specimen with trapezoidal nozzle

Fig. 2.1.12. Brass test plate specimen with trapezoidal nozzle

Experimental procedure

The thermal striping experiments are conducted in the following sequence.

1. Initially, the required nozzles velocity is fixed by measuring the flow rate. The control valve is fixed in this position for a particular velocity.

2. Water is heated in hot water tank up to 95^0C. The water is stirred periodically to achieve the uniform heating. The temperature of the water is continuously monitored using a thermocouple as the temperature of the steam coming is very high to measure with the thermometer.

3. Water is cooled in cold water tank up to 5^0C and ice flakes are to maintain it to the required temperature. The water is stirred periodically to achieve the uniform cooling. The temperature of water in continuously monitored using a thermometer.

4. After attaining the required temperature i.e., hot water 95ºC and cold water 5 ºC, the heating and cooling are stopped and pumps are switched on.

5. Water jets coming out of the nozzles are allowed to hit on the test plate and wait till the test plate is completely immersed in the water.

6. After 1 minutes temperature data of thermocouple is recorded using data logger and stored in computer excel sheet.

7. The above procedure is repeated for different nozzles (star and trapezoidal).

8. Changing one parameter at a time and keeping other parameters constant, above procedure is repeated.
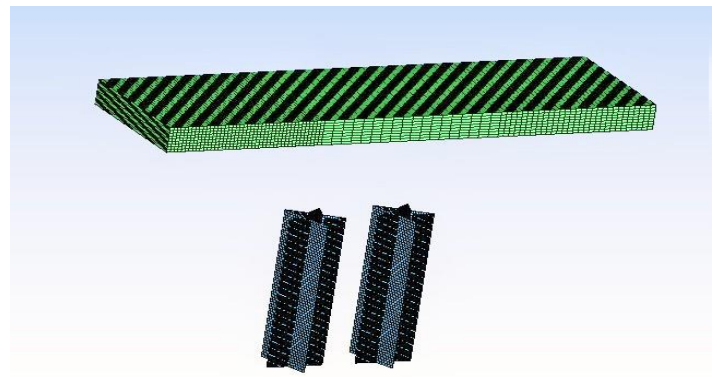
3. CFD analysis
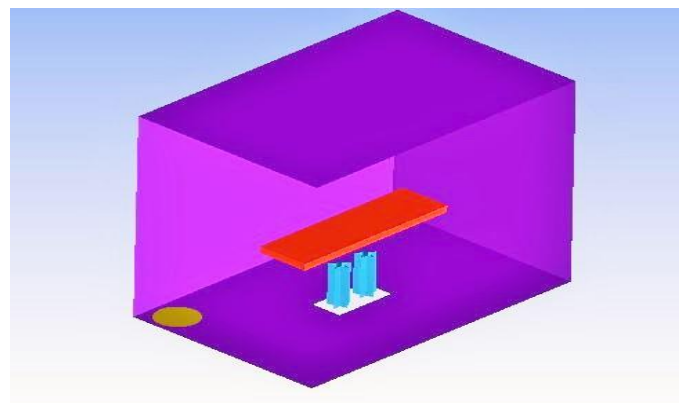
Computational fluid flow analysis will be completed By following 3 types of the process they are
   a. Creating the geometry model/Mesh
   b. Defining the physics of model
   c. Visualizing the results

(a)Creating the geometry model

Fig 3.1.1 Geometry model of star nozzle with test plate in Ansys

Fig. 3.1.2 Arrangement of Assembly of star nozzle with test plate specimen

Different Parts assembled in above figure are

   i.   Nozzle
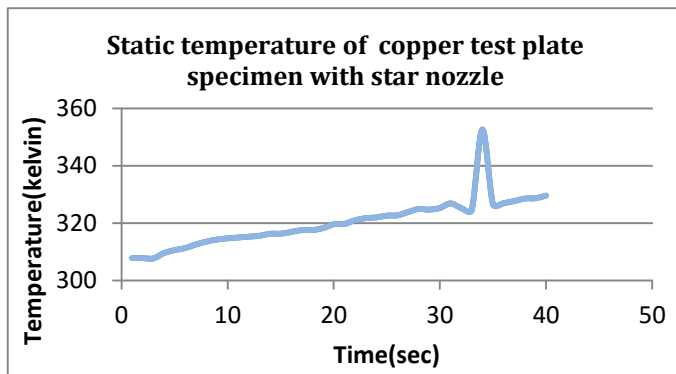   ii. Test plate specimen
   iii. Parallel water jet box

For this assembly of star nozzle, we are using different test plates specimens like
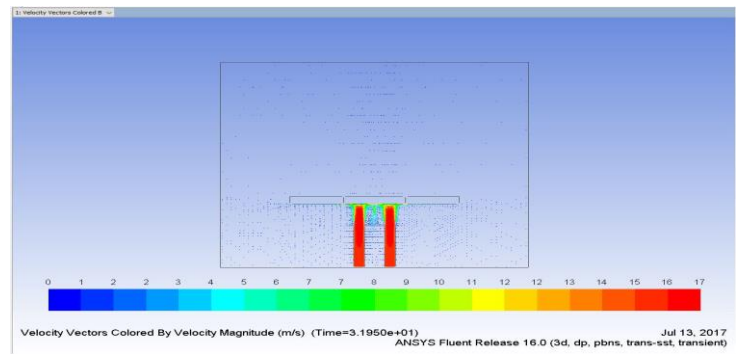
- Copper
- Steel
- brass

3.1 CFD analysis on Copper test plate specimen with Star nozzle

The above- meshed geometry is imported into CFD and input values are given for analysis

Input values are taken from experimentation as an excel graph (Temperature Vs Time)
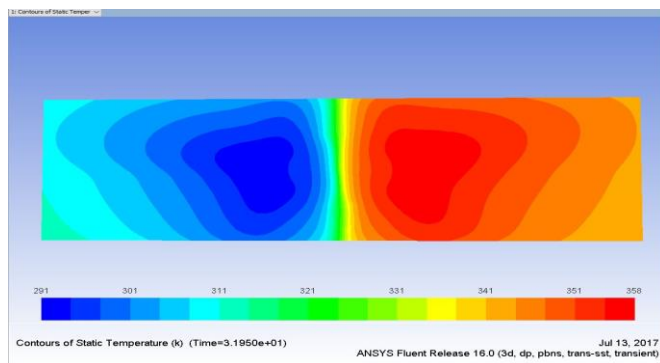
Fig.3.1.3: Input valves for CFD Analysis of copper test plate specimen with star nozzle

Results from CFD analysis for copper test plate with star nozzle

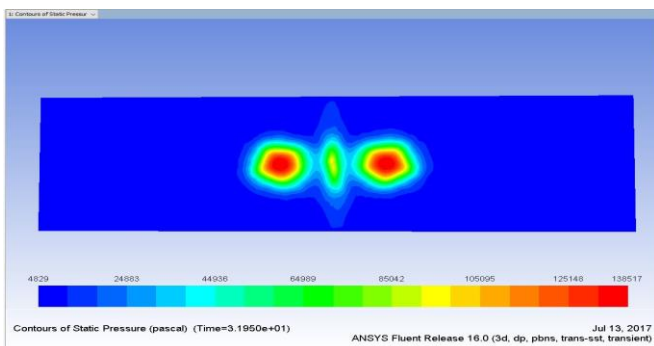**Fig.3.1.4** Static temperature at the bottom of copper test plate specimen (309-352) Kelvin

Fig.3.1.5 Static pressure at the bottom of copper test plate specimen (44935-105095) Pascal's

Fig.31.6 Fluid flowing with velocity inside water jet box copper test plate specimen with star nozzle (5-12) m/s

Above analysis values are stated below for Copper test plate specimen with star nozzle

AT   Max static temp   = 352 Kelvin
      Max static pressure   = 105095 Pascal's
      Max velocity of flow of water   = 15 m/s

Above Max static temp, Max static pressure, Max velocity is converted into Power Spectral density,

- Power spectral density is nothing but which is calculated by Max static temp, Max static pressure, Max velocity of flow of fluid inside water jet box

- Power spectral density factor is defined as the range of frequency oscillations under which thermal striping occur is found to be (0.1 – 10) Hz
- The frequency(0.1-10) Hz is taken by drawing graph with power density and frequency range(01-10)Hz

- If the resulted frequency is other than (0.1-10)Hz then it is said that the test plate specimen avoided from thermal stripping phenomenon

- Maximum frequency from the graph is taking as power spectral density factor

Here for copper test plate specimen CFD analysis valves are taken and tested for power spectral density factor

Graph is drawn as per power spectral density Vs Frequency range (0.1-10) IN ANSYS
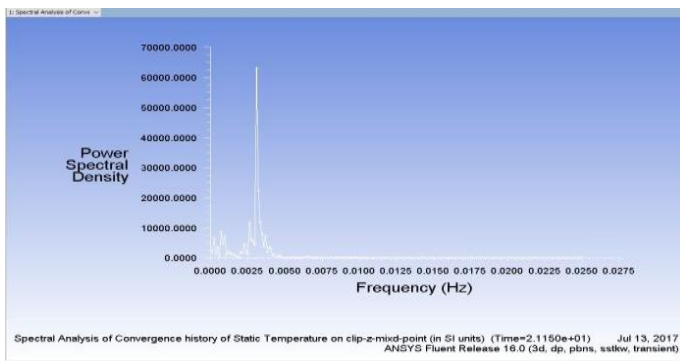
Fig 3.1.7 Power density factor for copper test plate specimen

- OUTPUT MAXIMUM FREQUENCY IS <u>0.0028 HZ</u>

- This frequency is other than (0.1-10)Hz

- This copper test plate is recommended for the using as inner core metal but the life of this copper is very less due to weak mechanical properties
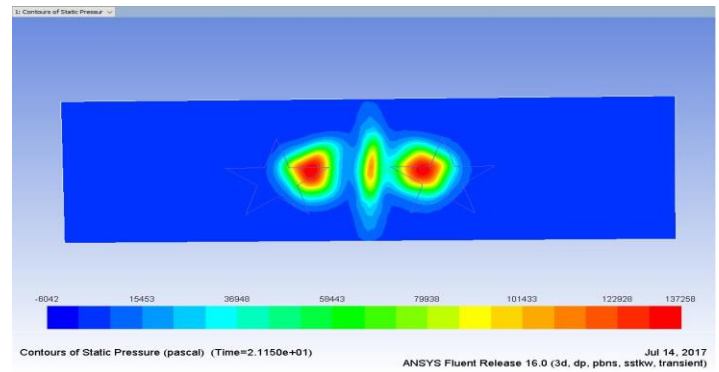
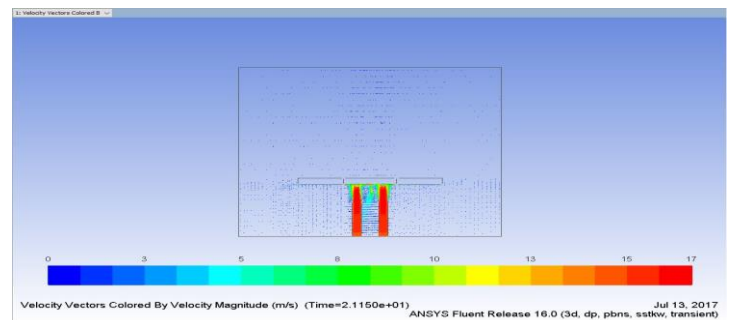## 3.2 CFD analysis on Copper test plate specimen with Star nozzle
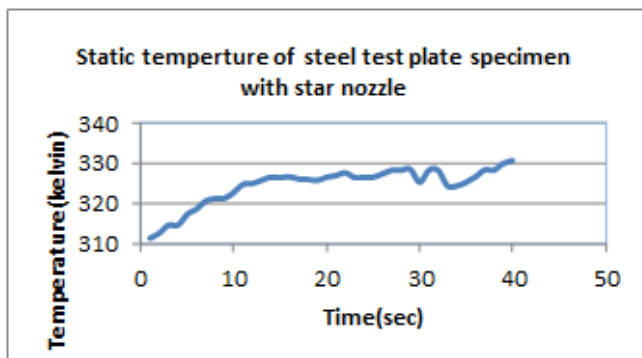
Fig3.1.8 Steel test plate specimen with star nozzle
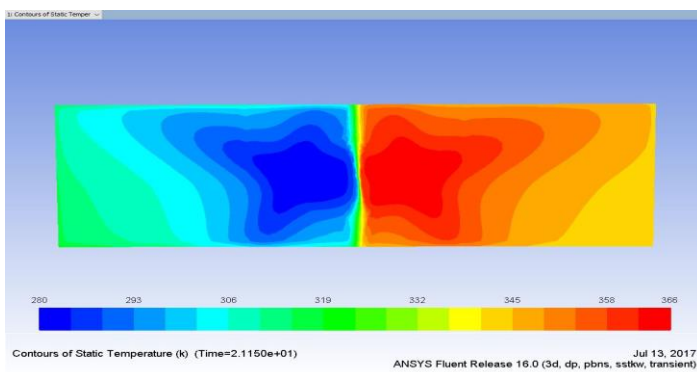
Fig.3.1.9 Bottom Static temperature of a steel Test plate specimen with star nozzle(310-332) kelvin

Fig.3.1.10 Bottom Static pressure of a steel Test plate with star (36978-101488) Kelvin
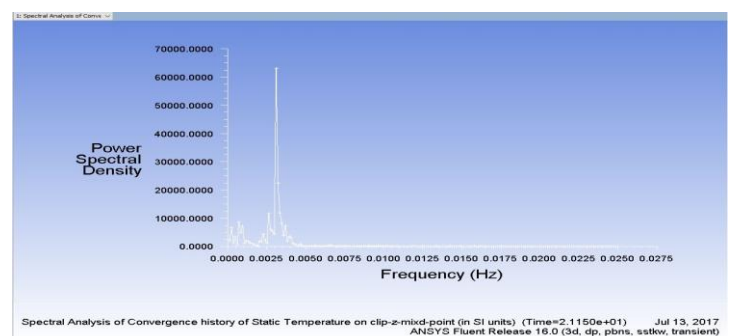

Fig3.1.11 Fluid flowing with velocity inside water jet box for steel test plate specimen with star nozzle (4- 15) m/s

Above analysis, values are stated below for Steel test plate specimen with star nozzle
AT   Max static temp   = 352 Kelvin
Max static pressure   = 105095 Pascal's
Max velocity of flow of water   = 15 m/s

Above Max static temp, Max static pressure, Max velocity is converted into Power Spectral density and the graph is drawn

Fig.3.1.12 Steel plate specimen power spectral density

- OUTPUT MAXIMUM FREQUENCY IS <u>0.0025 HZ</u>

- This frequency is other than (0.1-10)Hz

This Steel test plate is recommended for the using as inner core metal but the life of this Steel is very less due to weak mechanical properties

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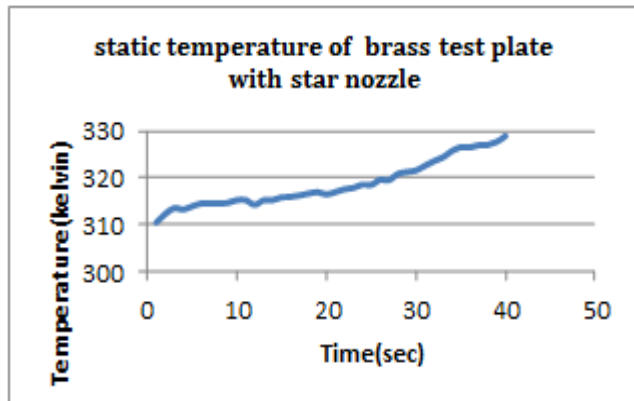## 3.3 CFD analysis on steel test plate specimen with Star nozzle

Fig.3.1.13 Brass test plate specimen with star nozzle
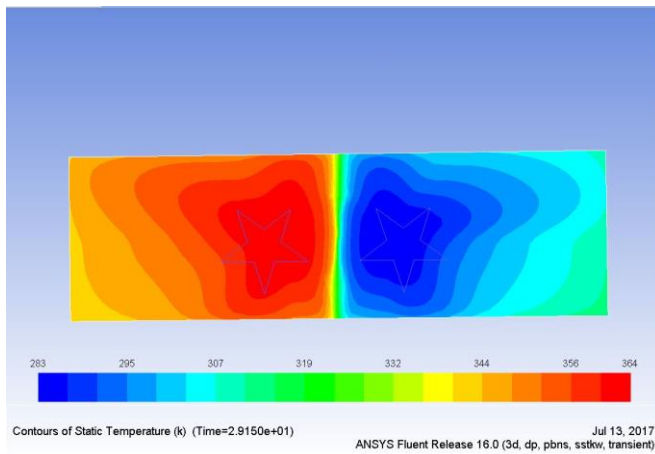

Fig.3.1.14 Bottom Static temperature of a copper Test plate with star nozzle(305-351) Kelvin
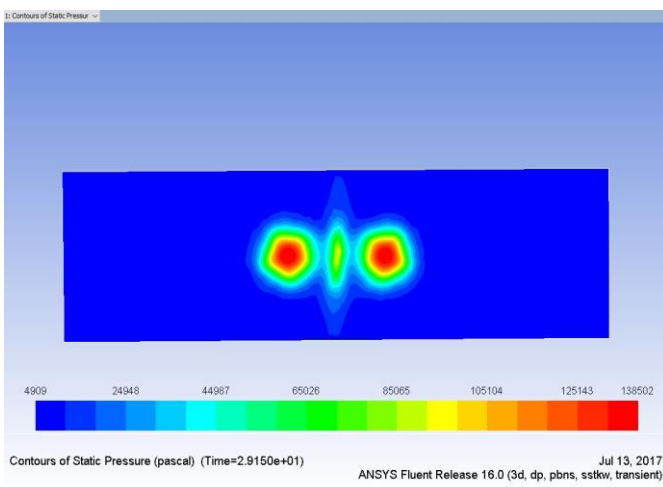

Fig.3.1.15 Bottom Static pressure of a copper Test plate with star nozzle (44984-105104) Pascal
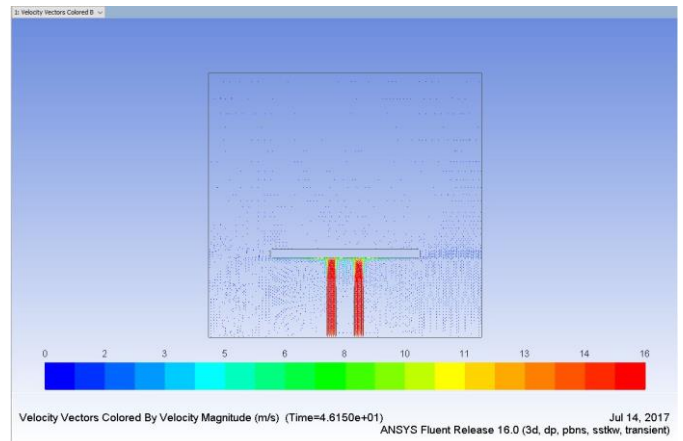

Fig.3.1.16 Fluid flowing with velocity inside water jet box for steel test plate specimen with star nozzle (5-11) m/s

Above analysis, values are stated below for Brass test plate specimen with star nozzle

AT   Max static temp   = 352 Kelvin
     Max static pressure   = 105095 Pascal's
     Max velocity of flow of water = 15 m/s

Above Max static temp, Max static pressure, Max velocity is converted into Power Spectral density and the graph is drawn
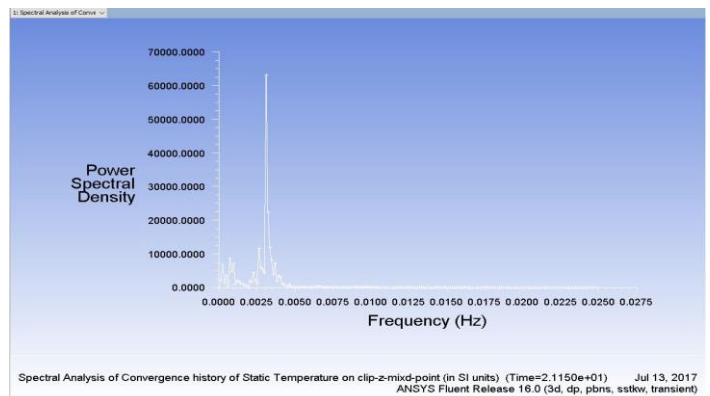

Fig.3.1.17 Brass test plate power spectral density

- OUTPUT MAXIMUM FREQUENCY IS <u>0.0026 Hz</u>

- This frequency is other than (0.1-10)Hz

This Brass test plate is recommended for the using as inner core metal but the life of this Brass is very less due to weak mechanical properties

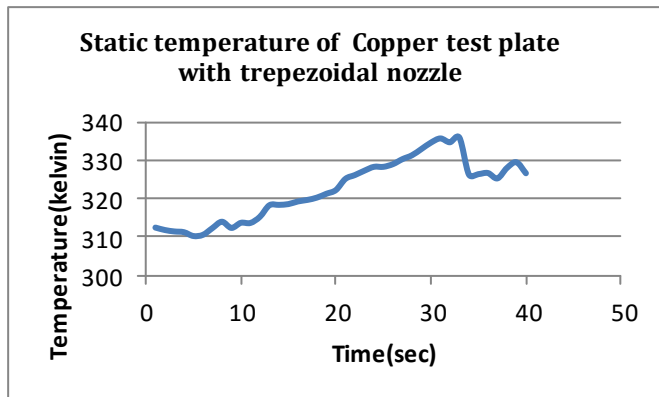## 3.4 CFD analysis on Brass test plate specimen with Star nozzle

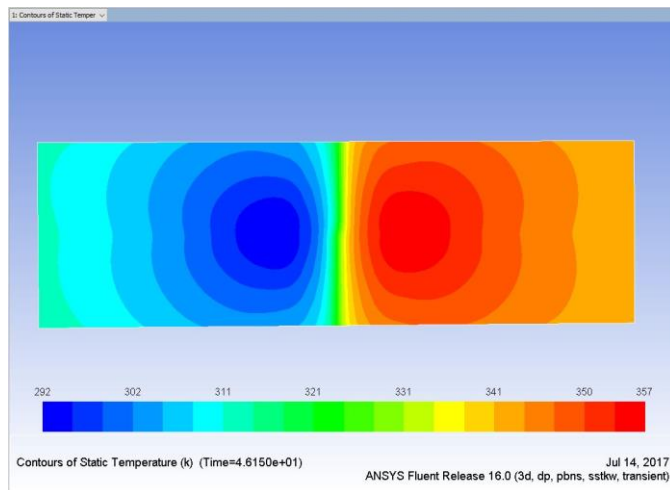**Fig3.1.18** Copper test plate with trapezoidal nozzle

Fig.3.1.19 Bottom Static temperature of a Copper Test plate with trapezoidal nozzle(309-351) kelvin
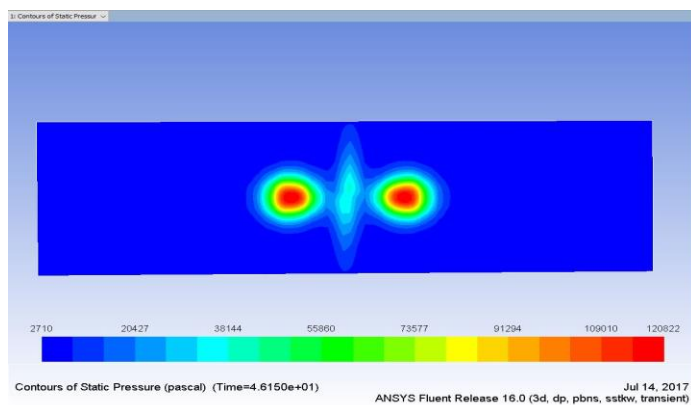

Fig.3.1.20 Bottom Static pressure of a Copper Test plate with trapezoidal nozzle (38144-109010) Pascal's
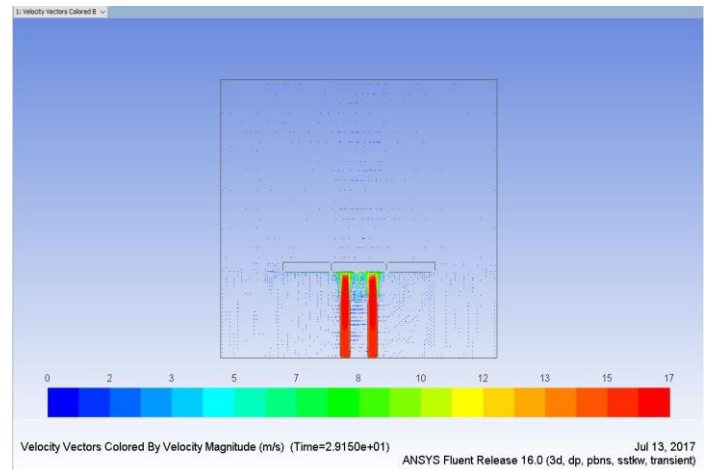

Fig.3.1.21 Fluid flowing with velocity inside water jet box for copper test plate specimen with Trapezoidal nozzle (3-13) m/s

Above analysis, values are stated below for Copper test plate specimen with star nozzle

AT   Max static temp   = 352 Kelvin
        Max static pressure   = 105095 Pascal's
        Max velocity of flow of water = 15 m/s

Above Max static temp, Max static pressure, Max velocity is converted into Power Spectral density and the graph is drawn

Fig.3.1.22 Copper plate specimen power spectral density

- OUTPUT MAXIMUM FREQUENCY IS 0.0001 Hz

- This frequency is other than (0.1-10)Hz

This copper test plate is recommended for the using as inner core metal but the life of this copper is very less due to weak mechanical properties

3.5 CFD analysis on Copper test plate specimen with Trapezoidal nozzle
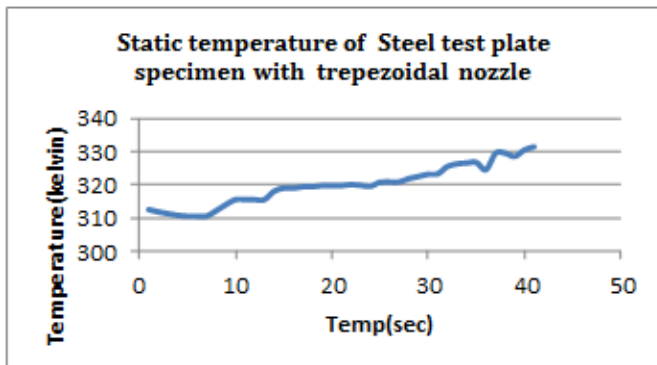
Fig.3.1.23 Steel test plate specimen with trapezoidal nozzle

Fig.3.1.24 Bottom Static temperature of a Steel Test plate with trapezoidal nozzle(303-353) Kelvin

Fig3.1.25 Bottom Static pressure of a Steel Test Plate with trapezoidal nozzle (37710-1086259) Pascal's

Fig3.1.26 Fluid flowing with velocity inside water jet box for Steel test plate specimen with Trapezoidal nozzle (3-14) m/s

Above analysis, values are stated below for Copper test plate specimen with star nozzle

AT   Max static temp   = 352 Kelvin
      Max static pressure   = 105095 Pascal's
      Max velocity of flow of water   = 15 m/s

Above Max static temp, Max static pressure, Max velocity is converted into Power Spectral density and the graph is drawn
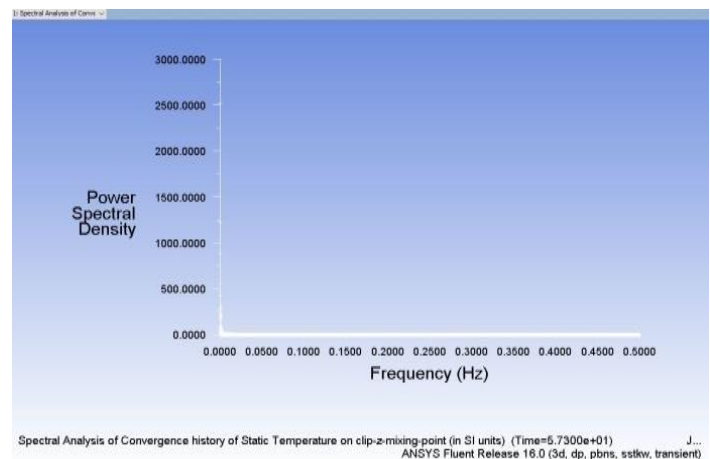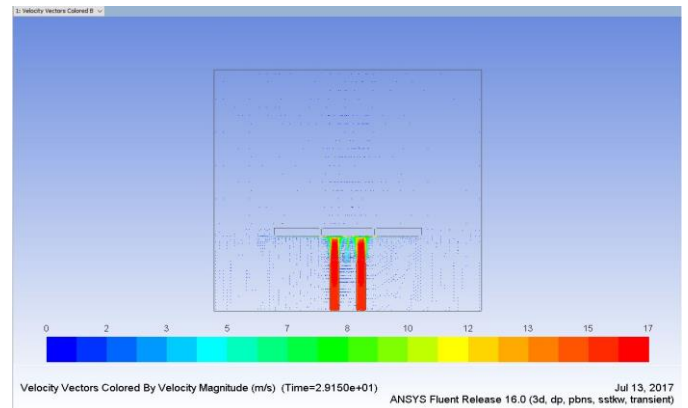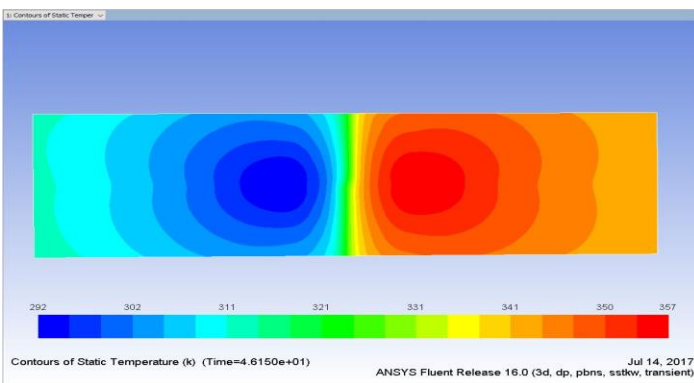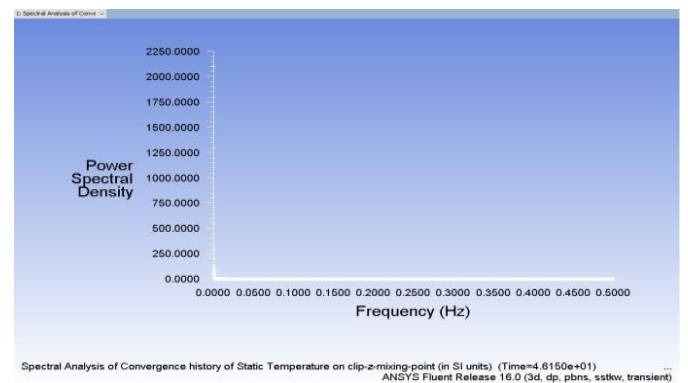

Fig.3.1.27 Steel plate specimen power spectral density

- OUTPUT MAXIMUM FREQUENCY IS 0.0025 HZ

- This frequency is other than (0.1-10)Hz

This Steel test plate is recommended for the using as inner core metal but the life of this Steel is very less due to weak mechanical properties

3.6 CFD analysis on Steel test plate specimen with Trapezoidal nozzle

Fig3.1.28 Brass test plate specimen with trapezoidal nozzle

Fig3.1.29 Bottom Static temperature of a brass Test plate with trapezoidal nozzle(301-347) kelvin

Fig3.1.30 Bottom Static pressure of a brass Test plate with trapezoidal nozzle(3741-102816) Pascal

Fig.3.1.31 Fluid flowing with velocity inside water jet box for Brass test plate specimen with trapezoidal nozzle (5-13)m/s

Above analysis, values are stated below for Copper test plate specimen with star nozzle

    AT   Max static temp   = 347 Kelvin
         Max static pressure   = 102816 Pascal's
         Max velocity of flow of water = 13 m/s

Above Max static temp, Max static pressure, Max velocity is converted into Power Spectral density and the graph is drawn
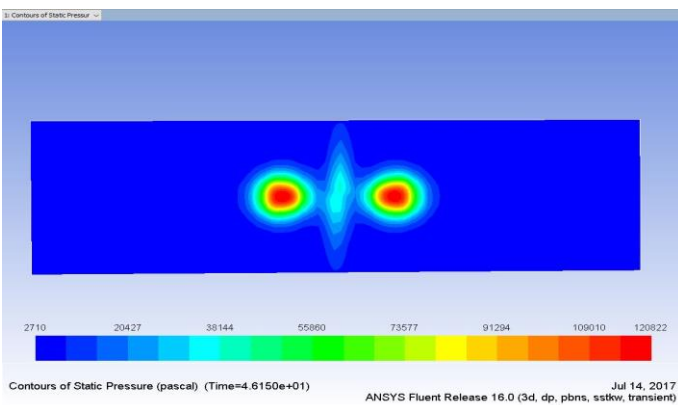

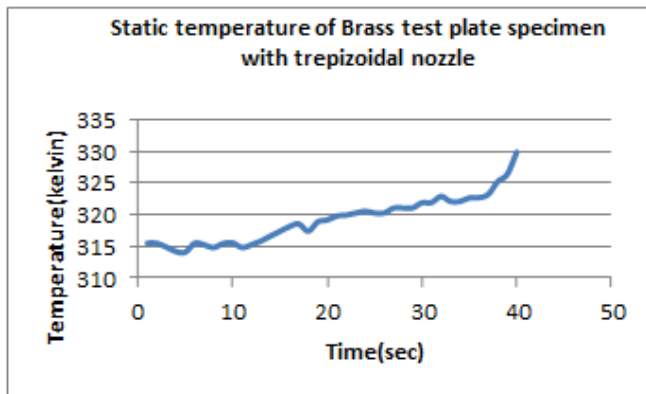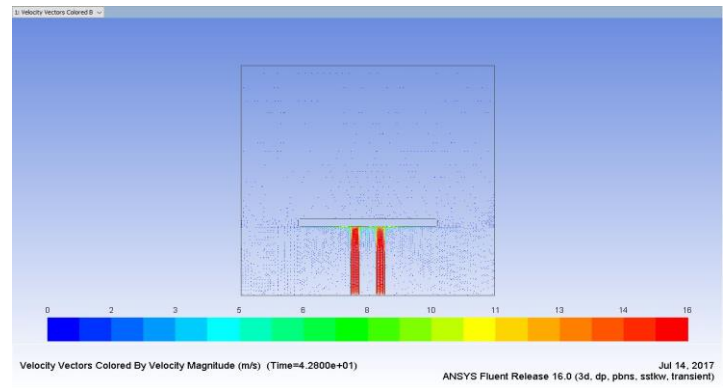**Fig3.1.32** Brass plate specimen power spectral density

- OUTPUT MAXIMUM FREQUENCY IS <u>0.0001 HZ</u>

- This frequency is other than (0.1-10)Hz

This Brass test plate is recommended for the using as inner core metal but the life of this copper is very less due to weak mechanical properties

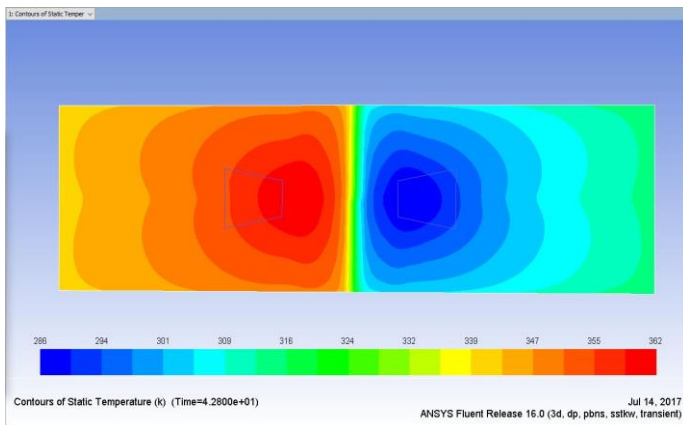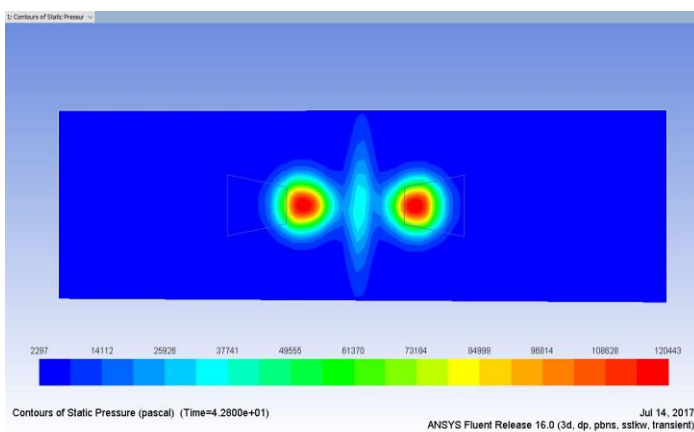| Nozzle	Test plate	Max temp, Max pressure, Max velocity	Power spectral density factor
Star	Copper	341 K,105095 Pascal's,12m/s	0.0028(REC)
	Steel	350 K,101488 Pascal's,15 m/s	0.0025(REC)
	Brass	344 K,105104 Pascal's,11 m/s	0.0026(REC)
Trapezoidal	Copper	351 K,109010 Pascal's,13 m/s	0.0001(REC)
	Steel	353 K,108625 Pascal's,14 m/s	0.0001(REC)
	Brass	347 K,102816 Pascal's,13 m/s	0.0001(REC)

Table 3.2.1 Comparison of power spectral density factor for different nozzles with different test plate specimens

*(REC)=RECOMMENDED FOR USING TEST PLATE SPECIMEN AS INNER CORE MATERIAL IN LMFBR REACTORS

4. CONCLUSION

The major results are summarized as follows

1. Copper test plate specimen with star nozzle at Maximum static temperature

    AT

    Max static temp   = 352 Kelvin

    Max static pressure   = 105095 Pascal's

    Max velocity flow of water   = 15 m/s

    For this given input values in CFD analysis we got

    Power spectral density= 0.0001(Recommended)

2. Steel test plate specimen with star nozzle at Maximum static temperature

    AT

    Max static temp   = 350 Kelvin

    Max static pressure   = 101488 Pascal's

    Max velocity flow of water = 15 m/s

    For this given input values in CFD analysis we got

    Power spectral density factor   = 0.0001 (REC)

3. Brass test plate with star nozzle at Maximum static temperature

    AT

    Max static temp   = 344 Kelvin

    Max static pressure   = 105104 Pascal's

    Max velocity flow of water   = 11 m/s

    For this given Input values in CFD analysis we got

    Power spectral density value   = 0.0001 (REC)

4. Copper test plate specimen with Trapezoidal nozzle at Maximum static temperature

    AT

    Max static temp   = 352 Kelvin

    Max static pressure   = 105095 Pascal's

    Max velocity flow of water   = 15 m/s

    For this given input values in CFD analysis we go

    Power spectral density value   = 0.0028(REC)

5. Steel test plate specimen with trapezoidal nozzle at Maximum static temperature

    AT

    Max static temp   = 351 Kelvin

    Max static pressure   = 109010 Pascal's

    Max velocity flow of water   = 13m/s

    For this given input values in CFD analysis we got

    Power spectral density value   = 0.0025 (REC)

6. Steel test plate specimen with trapezoidal nozzle at Maximum static temperature

    AT

    Max static temp   = 353 Kelvin

    Max static pressure   = 1086259 Pascal's

    Max velocity flow of water   = 14 m/s

    For this given input values in CFD analysis we got

    Power spectral density value   = 0.0026(REC)

*(REC)=RECOMMENDED FOR USING TEST PLATE SPECIMEN AS INNER CORE MATERIAL IN LMFBR REACTORS

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