CFD ANALYSIS OF HYPERSONIC NOZZLE THROAT ANALYSIS

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ABSTRACT

This paper presents conjugate heat transfer analysis for Mach 12 nozzle of hypersonic wind tunnel. For the analysis, ANSYS Fluent has been used for both flow and conduction analysis in coupled manner considering actual material properties. First, steady state simulation has been performed to obtain the settled flow with wall temperature of 300K. After achieving steady state solution, transient simulation has been performed get convergence. Flow simulation had done by cooling the throat regime by cool water (25kg/s) which is very normal flow rate in nozzle flow.

Keyword: - *ANSYS Fluent1, Mach number2, Temperature Distribution3, and Nozzle Throat4.*

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1. INTRODUCTION

A nozzle (from nose, meaning 'small spout') is a tube of varying cross-sectional area (usually axisymmetric) aiming at increasing the speed of an outflow, and controlling its direction and shape. It is 7m long nozzle; divided into 8 segments from ease of fabrication and inspection point of view.

Convergent portion (Subsonic portion) is 1772mm long and rest is divergent portion (supersonic portion). Throat is made of Beryllium Copper alloy with a thickness of 6mm. In order to cool the nozzle, a gap of 5mm is maintained by using a split throat made of SS304L and through this gap, water is circulated. Adjacent regions of split throat are made of 15-5PH. Outer shell in throat region is SS304L. The outer shell of subsonic section-2 is SA516 gr 70. To withstand the thermal profile of the flow, Inconel 617 and Cera blanket are used in the subsonic sections. Nozzle flow inlet diameter is 270 mm. Material for the divergent sections 2 to 6 has been selected as SS304L with maximum section length of 1150mm and minimum of 750mm. Physical nozzle exit diameter is 1000 mm.

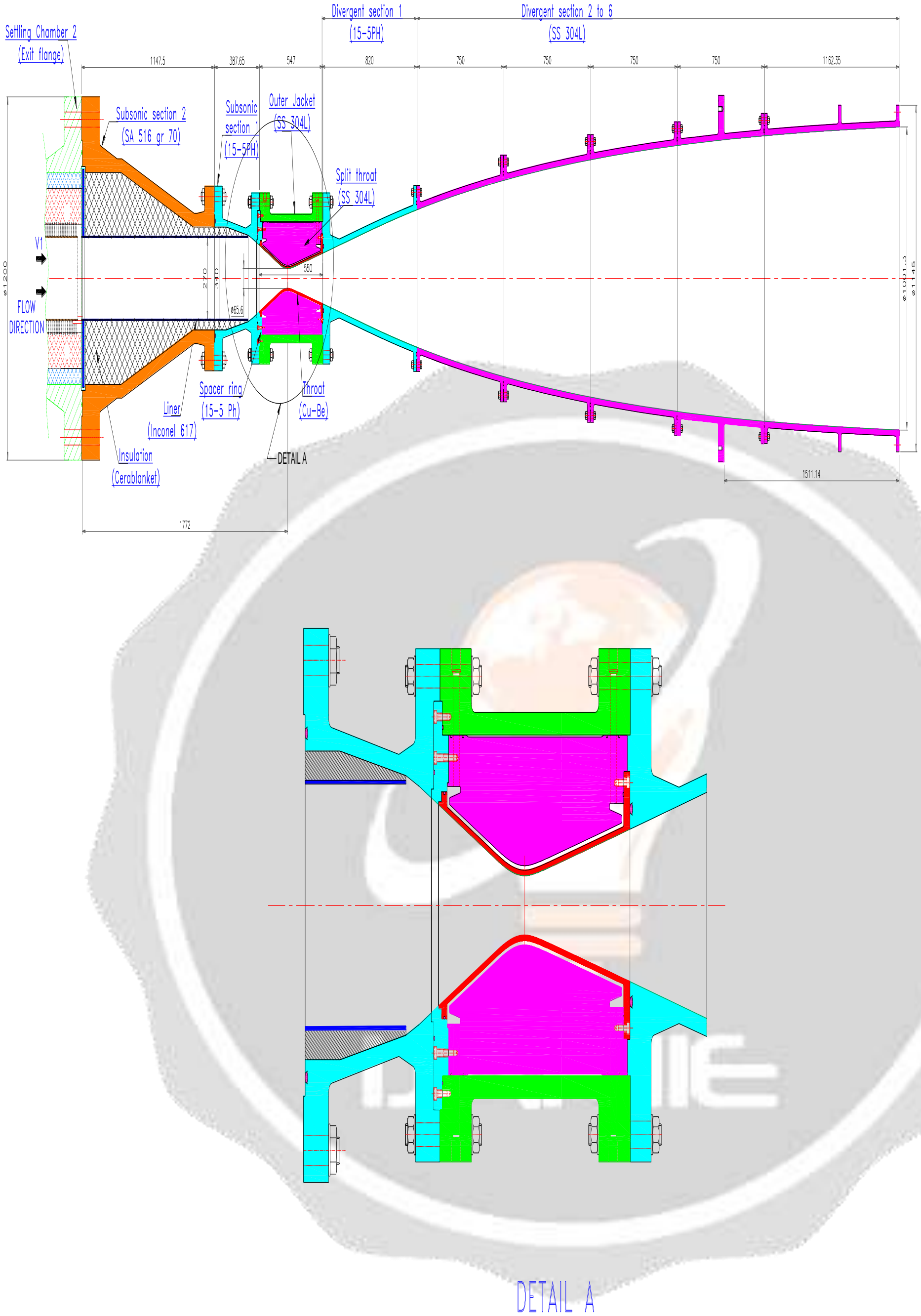

Fig. 1 Geometrical details of the nozzle

2. RESULTS AND DISCUSSIONS

2.1 Steady State Simulation

The results from steady state simulations are shown in Fig. 2 below. The Mach number, static pressure, and static temperature distribution along the length of the nozzle axis are plotted in Fig. 2a and Fig. 2b respectively.

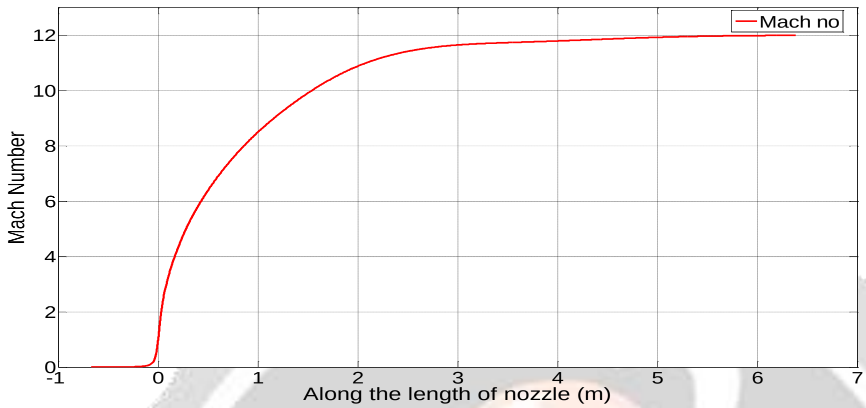

Fig- 2 a : Mach number distribution

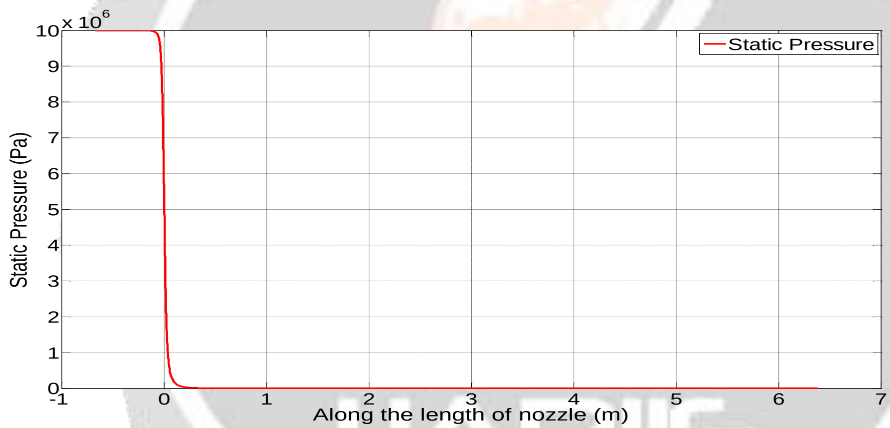

Fig-2b: Static Pressure & temperature distribution

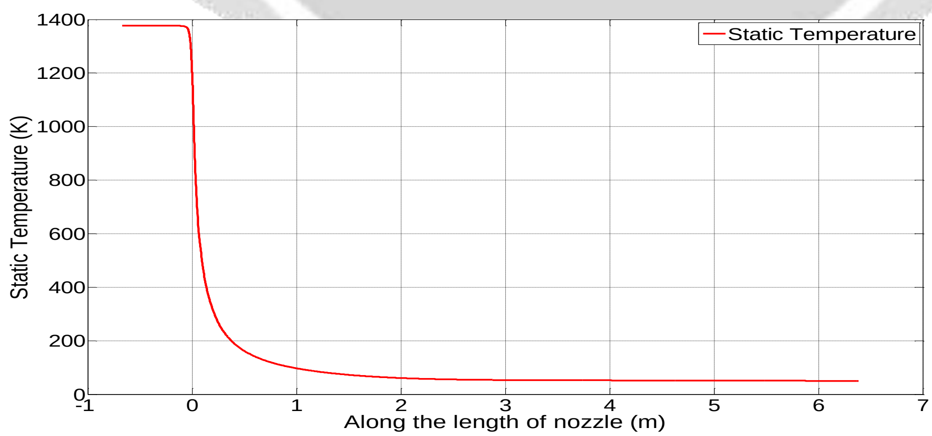

Fig- 2c: Static Pressure & temperature distribution

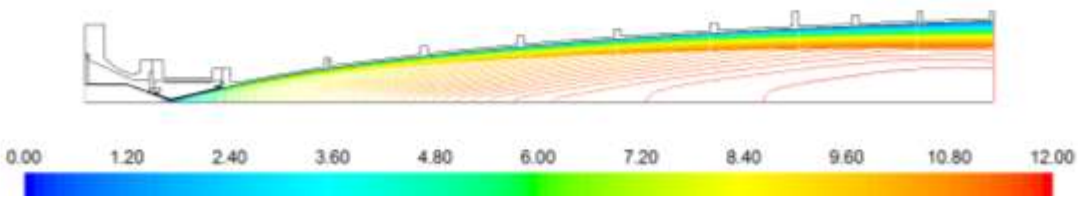

Fig-2 d: Mach contour

Case-1: Throat thickness is 6mm

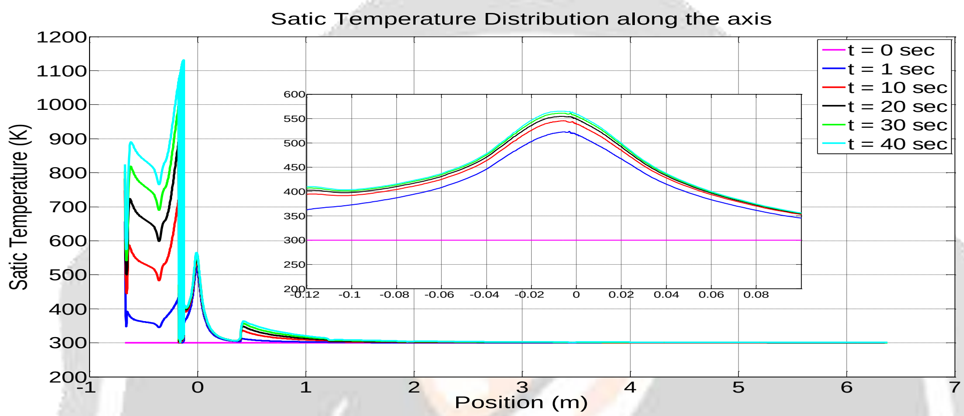

Fig-8a: Static temperature distribution along the axis

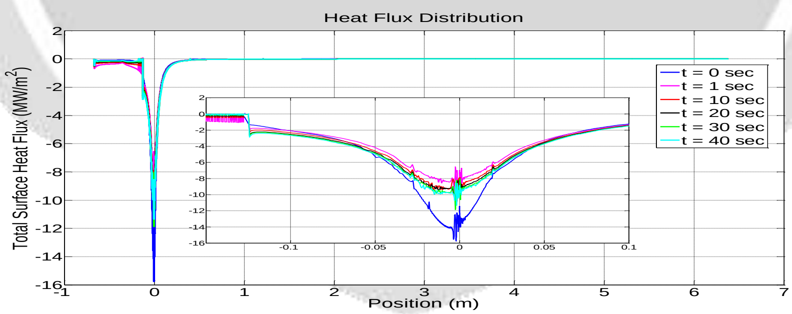

Fig. 8b Heat Flux distribution along the Length of the nozzle

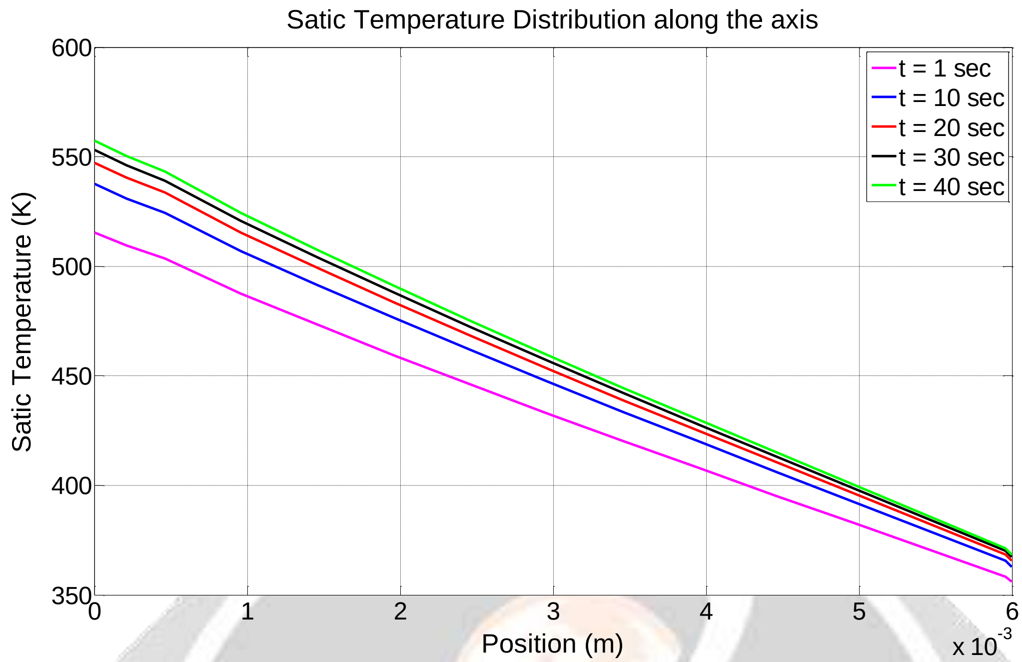

Fig-3 c : Static temperature distribution along the thickness of the nozzle

The temperature in the subsonic region of the nozzle reaches a maximum temperature of about 1120 K. At the interface of the subsonic section and throat, the temperature falls down to 410 K. Along the axis, the throat temperature increases, and there is drop in temperature at two locations of throat and this is due to axial gap provided for thermal expansion. In the throat section of the nozzle, the temperature picks up with duration and reaches a maximum of 560 K and then starts falling. As it approaches the throat end region, the temperature picks up and drops again. This increase in temperature is due to change of material from Beryllium copper to 15-5 PH. Further the temperature falls down to minimum of 420 K at the exit of the nozzle.

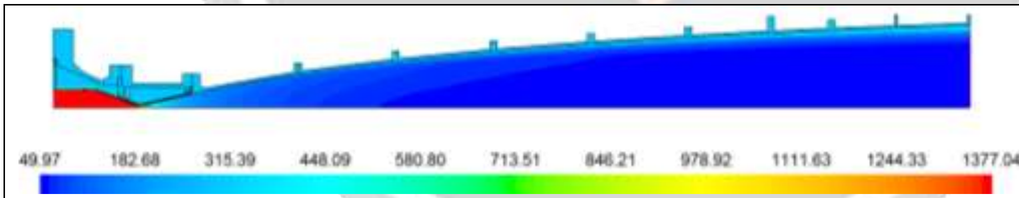

Fig.4a: Wall static temperature distribution at different time instants

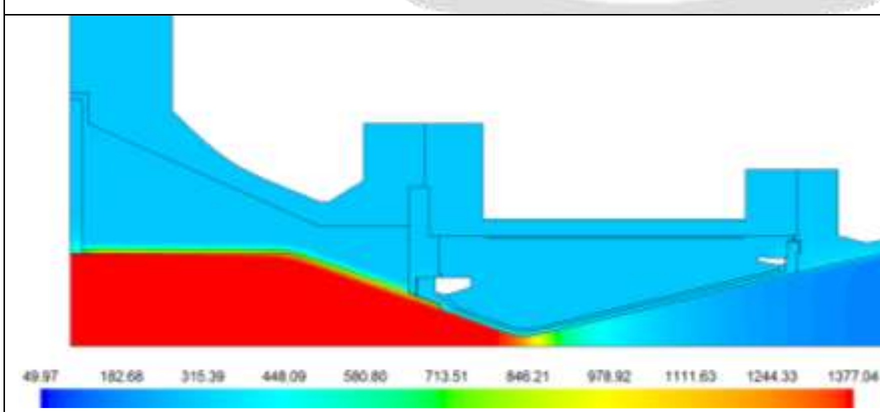

Fig. 4 b. Wall static temperature distribution at different time instants

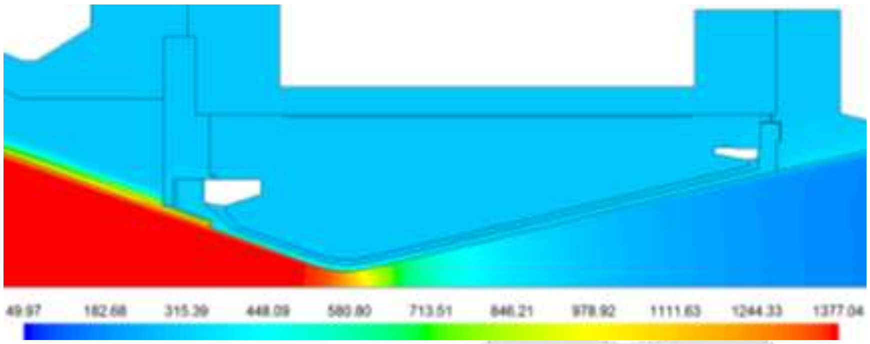

Fig. 4c: Wall static temperature distribution at different time instants

In this boundary condition of the nozzle, the coolant flow is maintained at 25 Kg/s. The wall static temperature distribution and wall heat flux distribution along the nozzle profile is plotted in Fig. 3a and Fig. 3b respectively.

It can be inferred from Fig. 3a, the steady state is reached at 20 sec duration, after that the rise in temperature is negligible. The maximum temperature experienced in the throat region is 560 K and in the divergent sections, it is about 360 K. At the exit of the nozzle, the temperature is 420 K. The maximum heat flux is 10.2 MW/m2.

The static temperature distribution along the thickness of the nozzle is plotted in Fig. 3c. At the end of blow down of 40 sec, the temperature on the inner wall is 560 K and on the outer wall is 370 K.

Case-2: Throat thickness is 5mm

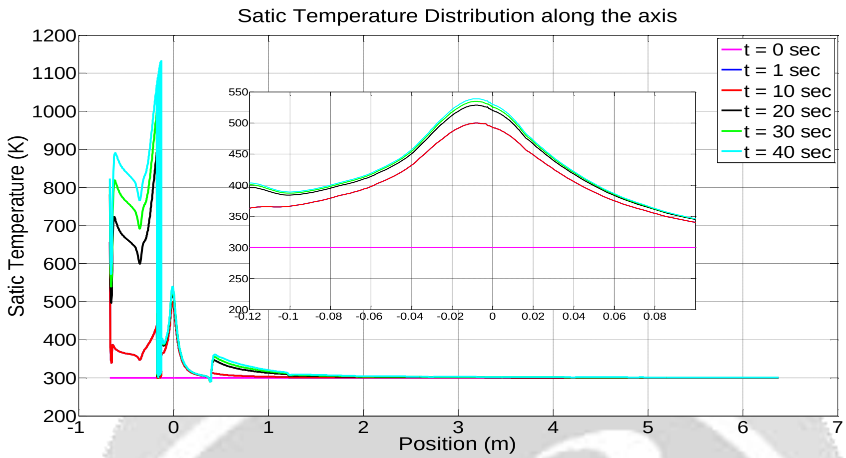

Fig- 5a Static Temperature distribution along the Length of the nozzle

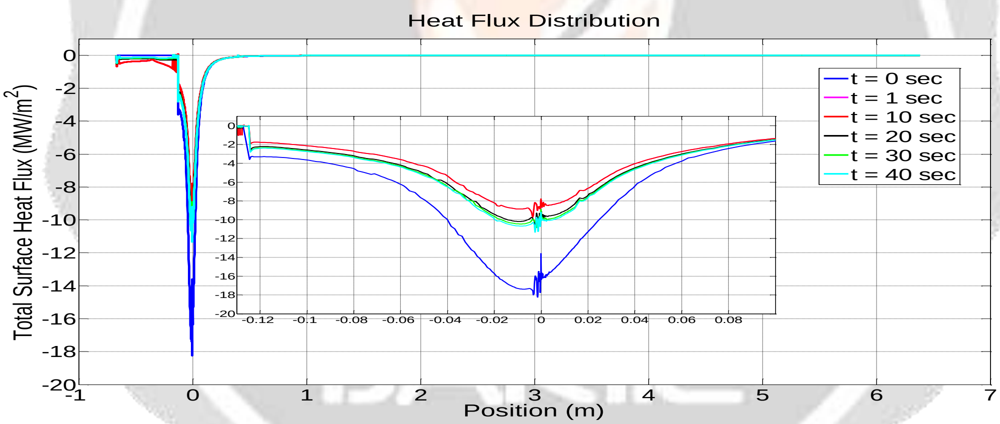

Fig-5b Heat Flux distribution along the Length of the nozzle

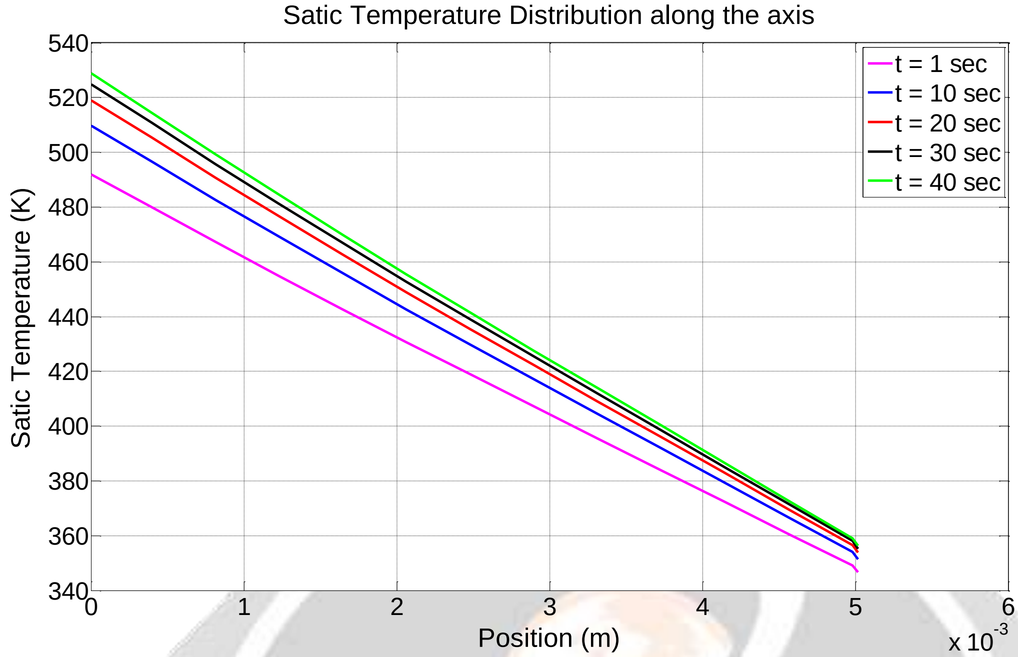

Fig-5c: Static temperature distribution along the thickness of the nozzle

The temperature in the subsonic region of the nozzle reaches a maximum temperature of about 1120 K. At the interface of the subsonic section and throat, the temperature falls down to 410 K. Along the axis, the throat temperature increases, and there is drop in temperature at two locations of throat and this is due to axial gap provided for thermal expansion. In the throat section of the nozzle, the temperature picks up with duration and reaches a maximum of 530 K and then starts falling. As it approaches the throat end region, the temperature picks up and drops again. This increase in temperature is due to change of material from Berylium copper to 15-5 PH. Further the temperature falls down to minimum of 400 K at the exit of the nozzle.

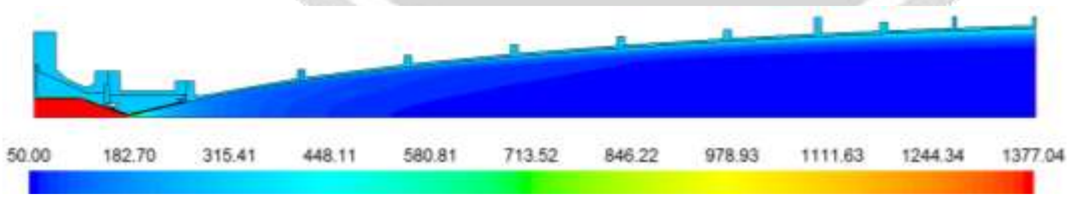

Fig. 6. Wall static temperature distribution at different time instants

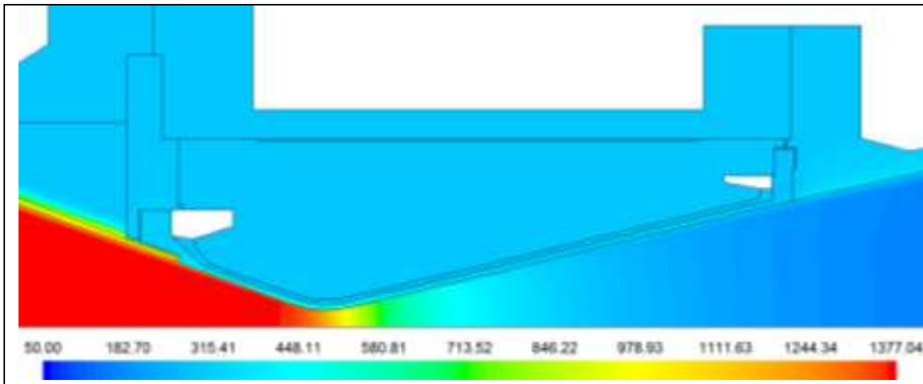

Fig. 7. Wall static temperature distribution at different time instants

In this boundary condition of the nozzle, the coolant flow is maintained at 25 Kg/s. The wall static temperature distribution and wall heat flux distribution along the nozzle profile is plotted in Fig. 5a and Fig. 5b respectively.

It can be inferred from Fig. 5a, the steady state is reached at 20 sec duration, after that the rise in temperature is negligible. The maximum temperature experienced in the throat region is 530 K and in the divergent sections, it is about 370 K. At the exit of the nozzle, the temperature is 420 K. The maximum heat flux is 10.8 MW/m2.

The static temperature distribution along the thickness of the nozzle is plotted in Fig. 5c. At the end of blow down of 40 sec, the temperature on the inner wall is 530 K and on the outer wall is 360 K.

CONCLUSION:

In presented work the CHT simulations have been carried for Mach 12 nozzle at operating stagnation pressure of 100 bar and stagnation temperature of 1377 K using ANSYS Fluent. The analysis has been carried out for two-inlet case with two different throat 6mm & 5mm thicknesses, Maximum material temperature of 550K has been observed in subsonic portion and throat regime. It has also indicated that maximum temperature of wall is about 500K.

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