International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

Effect of Aspect Ratio of Active Cooling Panel on Cracking of the Fuel/coolant used Supersonic Vehicle Combustion Chamber

Pavani Sreekireddy, T. Kishen Kumar Reddy

Abstract— In the present paper numerical and computational analysis is carried out to design an optimal cooling channel for active cooling system of a scramjet engine. For improving the engine performance the design of the cooling channel is very important. Maximum fuel cracking and weight minimization of the panel are objectives of the present study. 1D numerical and 3D CFD models are used for structural analysis and Chemkin package is used for fuel cracking. Role of geometry of the cooling channel on panel weight and fuel cracking are analyzed for different aspect ratios (ξ) of the channel. The selection of geometric parameters is controlled by allowable temperature of the channel wall and fuel coking temperature. The approximated channel dimensions obtained from 1D analysis are analyzed in 3D CFD model for optimal design of the channel. In the present study channels with aspect ratio variation from 2.0 to 0.5 are considered. Study for optimization is carried out for a heat load of 160W/cm^2 and fuel mass floe rate of 0.013kg/s. The temperature gradient in the channel is decreased and fuel cracking fraction is increased with decrease in aspect ratio of the channel. However, for cases of low aspect ratio, the structural stresses are increased the safe limit and the fuel exit temperature is increases above the fuel cocking temperature. Reduced aspect ratio increases the width of the channel, results number of channels per meter width are reduced. Hence the weight of the panel reduces with decreased aspect ratio. By increasing the channel width and pyrolysis the weight of the panel is reduced by 16.02%. Fuel temperatures, structural stress distribution and weight of the panel are analyzed and presented in the paper.

Index Terms— Fuel Cracking, Channel Aspect Ratio, Fins, High Heat Flux Combustion Chamber, High Temperature Materials, Heat and Structural Analysis. Fuel Cocking

1. Introduction

Combustion chamber of Supersonic vehicle experiences most severe aerodynamic heating and pressure gradients at high altitude. Due to this thermo mechanical stresses are generated. Hence, liners (or heat fins or active panels) are required to cool the combustion chamber for such extreme temperature and stress conditions. Without appropriate cooling of the body, most of the materials cannot withstand these extreme loadings for a long time. Along with the effectiveness, the adequacy of the thermal protection system is very important.

Many options such as active cooling and passive cooling are available to cool the structure. The passive system technique does not affect the flow and also does not impact the areas which contain the high thermal loads. Active cooling, on the other hand, is a viable option for effective cooling, since the fuel serves as the coolant by flowing through channels fitted around the periphery of the combustion chamber. Even though direct cooling is possible, the amount of fuel residing onboard is limited since it adds weight to the vehicle, thereby maximisation of the cooling is required. When Mach number increases, the amount of fuel consumed increases due to addition of external heat load (because the ram air heat increased). This means the fuel heat sink is insufficient, and hence, more fuel than required must be carried and the excess fuel has to be abandoned [1,2]. Extra fuel will increase the size, weight and complexity of the vehicle, which, in return, will significantly degrade the performance of the vehicle [3]. In addition, the lack of necessary heat sink confines the hypersonic vehicle to a relatively low flight speed. Many fuels are available for hypersonic vehicles among those hydrocarbon fuels will give extra benefit by absorbing the heat as endothermic energy. The absorbed heat preheats the fuels, which helps in improving the combustion efficiency due to better atomisation of fuel with reduces the ignition delay (termed as physical delay). This apart, due to the high temperature, the fuel molecules crack and break into smaller fragments resulting in absorption of the heat from the combustion chamber (termed as chemical delay) due to the endothermic heat absorption, resulting in better combustion.

• Pavani Sreekireddy is a Research Scholar in Mechanical Engineering Department, Jawaharlal Nehru Technological University, Hyderabad, India. E-mail: pavanisreekireddy@gmail.com
• T. Kishen Kumar Reddy, Professor Mechanical Engineering Department, Jawaharlal Nehru Technological University, Hyderabad, India.

The cooling efficiency depends on many parameters such as geometric parameters of the active panel, thermo physical properties of the channel (Fin) material. Design of the channel with endothermic (pyrolysis) reaction is a major challenge. When the length of the channel increases the heat gain of the

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

fuel increases. The extended length of the channel causes the fuel to reach coking temperature limit. The increased residence time of the fuel in the channel increases the pyrolysis. The heat flux on the combustion side plays a crucial role on the fuel temperature and pyrolysis of the fuel in the channel by considering above criticalities, design of the panel with reduced weight of the vehicle is predominant challenge. The influence of panel materials and optimal shape of the channel on fuel cracking while maintaining the stress in the safe limit is not addressed extensively in the literature.

Valdevit et.al.[4] showed that the heat transfer characteristics of the coolant is affected by the geometric parameters, thermo physical properties of the channel and also the authors observed that the rectangular channel with hydrocarbon fuel used as coolant shows adequate cooling while keeping the thermo-mechanical properties of the active channel material in safe limits. From the perspective of the geometric parameters of the active panel, the channel aspect ratio improves the efficiency of the cooling channel. Pizzarelli et.al [5, 6] observed that higher the aspect ratio (l/b) lower is the wall temperature while keeping the area of the cross section of the channel to be a constant. However in another related work, Pizzarelli et.al [7] did not consider the effect of change of fin thickness and the effect of fuel pyrolysis on cooling efficiency. Zhang et.al [8, 9] undertook similar studies but considered the channel aspect ratio without taking into account the fin thickness.

The present paper studies the influence of Fuel cracking and the consequent effect of the geometric parameters of the fin on weight of the panel. The fuel considered was n-decane which served as the coolant in the channel. The objective is to identify suitable aspect ratio which increases the cooling efficiency and minimizes the weight of the panel. The effect of fuel endothermicity along with channel geometry is studied. The heat transfer 1D fin equations to evaluate the active panel temperatures and also the resulting stresses equations employed by Valdevit et al [4] were used in this study. 1D MATLAB programming was employed to solve the equations. This programme does not accurately capture the transient response of the structure to the thermal loads. The approximate optimised channel dimensions were obtained from the 1D program for various panel aspect ratios under steady state conditions. The program used the range of design parameters of the coolant channel, properties of the material (NbCb-752). Once the optimal material and aspect ratios are selected, rigorous 3D CFD analysis is performed for precise results of the channel. The structure of the paper is as follows:

a) An overview of the Python program written for 1D analysis for various aspect ratios of the channel
b) 3D CFD analysis is carried out to validate the Python results using ANSYS-CFD
c) The Fuel pyrolysis was included by adding the CHEMKIN output to the 3D CFD analyses.
d) The ability of the material to withstand the thermo-mechanical stresses were examined by using ANSYS structural analysis.
e) The above analysis is followed by the conclusion and discussion

2. METHODOLOGY

Initially 1D model is used to predict the approximate channel dimensions for range of operating conditions. The fuel inlet temperature, pressure range of geometric parameters and coolant mass flow rate and heat transfer coefficients are provided as initial inputs. The heat transfer coefficients at inside and outside of the cooling channel are calculated by using Gnielinski [10] correlation and Eckert's enthalpy methods respectively. Fuel allowable (cocking) temperatures and material strength are given as constraints in the initial approximation of channel dimensions. 1D analysis is carried in two set of channels. In one set the area of the channel and mass flow Rate of the fuel are maintained constant and the channel aspect ratio is changed. For the second set the mass flow rate varied appropriately for safe structure. In the next step 3D CFD is carried out with the optimal channel dimensions obtained from 1D analytical model.

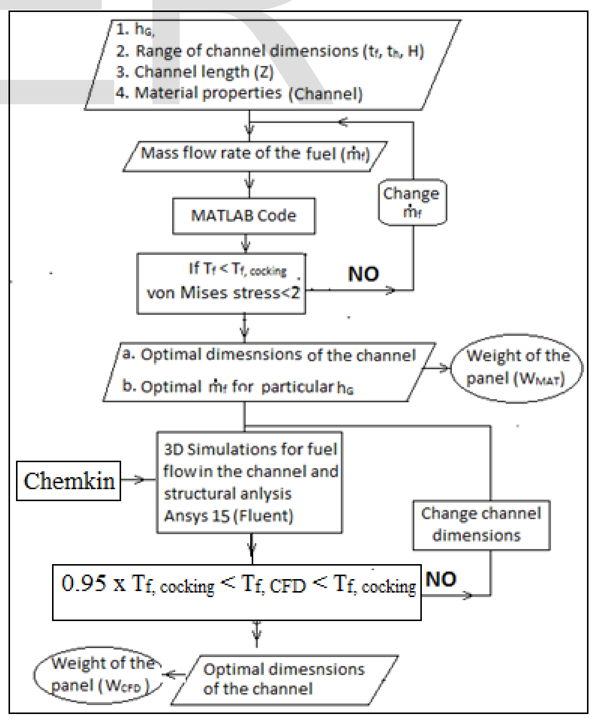

Figure 1 Flowchart for methodology

The first step of 3D analysis is focused on redesign the channel geometry by maintaining the fuel exit temperature and pyrolysis within safe limits. In the final step the material strength is

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

checked using von-Mises criteria. The entire process is repeated for different materials and operating conditions to obtain the optimal channel geometry with safe fuel and structural temperatures along with enhanced cracking. The methodology followed in this study is shown in flow chart, Fig. 1

Table 1 Material properties of Nb-cb 752 [4]

Property	Quantity
Yield strength of material, σ_y (MPa)	382
Density, ρ_m (Kg/m^3)	9030
Coefficient of thermal expansion, α (10e -6)(K^{-1})	7.4
Thermal conductivity, k_m (W/m-K)	50
Specific heat, $C_{P,m}$ (J/kg. K)	250

1D model: 1D analysis gives the crucial step for the entire process. MACH 7 conditions are used for these calculations. The initial range of dimensions of the panel (channel width b ≥ 2 mm, channel height l ≥ 2.5 mm, face and core wall thicknesses t_c and t_f ≥ 0.4 mm) are taken. The panel considered as fin, one face is exposed to heat flux from combustor and another face is insulated. Python is used for the different aspect ratios ξ (l/b) of the channel starting from 0.5 to 2. The analysis is done for the single channel with the length of 1.85 m; the width of the channel varies from 0.0025 m to 0.005 m. Apart from the range of the channel sizes thermal inputs such as inlet temperature, inlet pressure, h_G, h_c and combustion wall temperature. Different high temperature materials are considered in this study for optimizing the channel dimensions and minimize the panel weight. Material properties are listed in Table 1.

CFD model: For numerical simulation finite volume method is used. For the present simulation we choose SST k-ω model for the turbulent flow and heat transfer calculations. In this paper SIMPLEC model was adopted to get the accurate solution. The channel operating pressure is 3 MPa, mass flow rate set to be 0.013 kg/s. The inlet temperature and pressures are 300 K and 3 MPa respectively. The length of the channel considered as 1.85 m. The fin thickness varies from 1.25 mm to 1.3 mm. For all aspect ratios (ξ) varying from 2 to 0.5, the area set to be constant. Pressure drop considered as negligible.

Chemical Model: In the present analysis, plug flow reactor (CHEMKIN) is considered to analyse the cracked products of the fuel. In the plug flow reactor, the complete mixing is assumed in the radial direction and no back mixing is presumed in the flow direction. In plug flow reactor one inlet stream and one outlet stream is constructed. The 3D numerical analysis temperature profile is set in as input as well. The axial length of reactor used is 1.85 m and hydraulic mean diameter is varying from 0.0033m to 0.0035m.Surface area of the fluid per unit length is set to be 1.25×10^{-5} m and heating surface area per meter length is varying from 7.5×10^{-6} m to 11.25×10^{-6} m. Channel operating pressure is 3MPa.

3. PHYSICAL MODEL AND BOUNDARY CONDITIONS

The Scramjet combustion chamber surrounded with number of active cooling channels, as shown in Fig. 2. The numbers of rectangular channels are calculated based on the width of the panel and thickness of the panel. Number of channels $N_c = \left(Z/(b+t_c) \right)$ where Z is the length of the panel, b is the width of the panel and t_c is the core thickness. Single rectangular channel is designed in the present study. Heat transfer coefficients (h_G) in combustion side and in the channel (h_c) are calculated by using Gnielinski correlation Eckert's enthalpy method respectively. Based on these conditions the heat flux considered as 160W/cm^2. Mass flow inlet $\dot{m}_f$ is calculated based on the following equations.

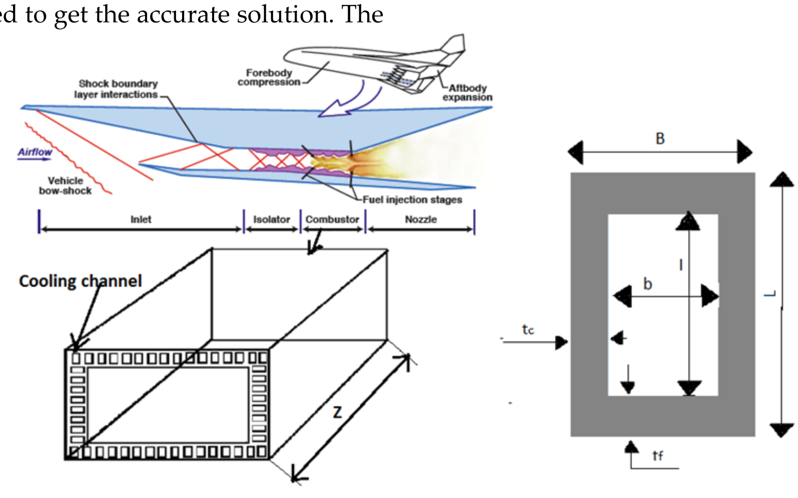

Figure 2 Combustion chamber with active cooling channel

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

$$\dot{m}_f = \frac{\rho A \dot{v}_f (b+t_c)}{l \times b} \quad (1)$$

$$D_h = \frac{2bl}{(b+l)} \quad (2)$$

Inlet temperature T_o and inlet pressure p_o are given as Mach 7 conditions. The heat flux applied on top of the channel and the three remaining sides set as adiabatic. Boundary conditions of the channel are shown in Fig. 3. For the simulation of flowing hydrocarbon fluid mass conservation, momentum conservation and energy conservation equations are used [11]. In the present study Species model is enabled and Finite rate/Eddy-dissipation model is used for reaction modeling and we choose SST $k-\omega$model was used. SIMPLEC method is used for the simulation for the accurate results.

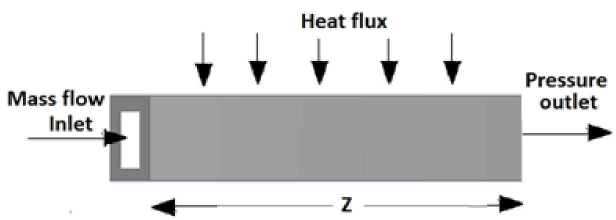

Figure 3 Boundary conditions for the active cooling panel

Fluid properties: For the present study n-decane is used as a fuel, since it is a liquid hydrocarbon and it is a main component of the jet fuels which are commonly used in aerospace applications. In this study the working fluid is taken under super critical condition, since the variation of fluid properties is accountable at super critical condition. Also to get the accuracy of the model predicted thermo physical properties of the fluid and species are used. Real properties of the fluid and species along the temperature are considered. The properties of the fluid along with the species are obtained from NIST chemistry web book [12], listed in Table 2.

Table 2 Fuel (n-decane) properties

Property	Quantity
Thermal conductivity, k_f(W/mK)	382
Density, ρ_f (Kg/m^3)	727
Viscosity, μ (Pa.s)	0.0008548
Cocking temperature, T_c (K)	975
Specific heat, $C_{P,m}$ (J/kg. K)	2196

4. TEST CASES

To get the better performance of the cooling channel different aspect ratios (ξ) are considered. To capture the real working conditions fuel cracking is considered in the present analysis. For the present analysis ξ values are considered from 2 to 0.5. For ξ is 2, channel parameters are obtained from 1D mathematical code. In the present analysis mass flow rate set to be constant. The fin thickness varied from 1.25 mm to 1.3 mm for some (ξ value 0.78 to ξ value 0.615) cases to target the strength criteria. The geometric parameters of the channels are listed in Table 3.

Table 3 Details of all cases

Case	ξ	*b* (mm)	*l* (mm)	t_f (mm)	t_c (mm)
1	2	2.5	5	1.5	1.25
2	1.38	3	4.16	1.5	1.25
3	1.02	3.5	3.57	1.5	1.25
4	0.78	4	3.12	1.5	1.25
					1.3
5	0.615	4.5	2.77	1.5	1.25
					1.3
6	0.5	5	2.5	1.5	1.25
					1.3

5. RESULTS AND DISCUSSIONS

The present study is aimed to satisfy the minimum weight and maximum utilization of heat sink for different channel dimensions with constant cross-sectional area. The aspect ratio (ξ) is changed accordingly from 2 to 0.5. The mass flow rate of the fuel is considered constant, resulting in the velocity of fuel in the channel to be also constant.

5.1 Effect of AR on fluid and solid temperature

The variations of temperature across the channel for different channels of ξ = 2 to 0.5 is shown in Fig. 4. For this analysis the velocity is taken as constant and the applied heat flux on combustion side is 160 W/cm^2. From 1D analysis the acceptable range of channel widths and heights are 2 mm to 7 mm and 3 mm to 5 mm respectively. It is observed from the Fig.4 that temperature gradients between top and bottom point of the fuel flow decrease when aspect ratio is decreased. The heat flux is given at the top of the channel. The height and width of the channel are respectively decreased and increased with decreased aspect ratio (ξ). Results, the wetting area of the fuel in the heat flux side increase and heat absorption of the fuel increases. It is shown in the Fig. 4 that the contours of temperature of fuel in the channel become more uniform. Temperature variation of the fuel at bottom and top planes of the channel are analyzed along the length of the channel for channels with different aspect ratios (ξ) and shown in Fig. 5. For case of higher ξ, large temperature difference is observed between top and bottom plane of the fuel and this gradient increases along the length of the channel. With decreased aspect ratio, the temperature gradient of the fuel between top and bottom planes of the channel is decreased and the average temperature of the fuel in the channel is increased. For instance at the axial length of 1.0 m, fuel temperatures at top and

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

bottom of the channel respectively, are 597 and 724 K for the case of ξ = 2.0 and 745 and 756 K for case of ξ = 0.5. The temperature gradient for ξ = 2.0 and 0.5 are 127 K and 11 K respectively. The cases ξ = 0.615 and 0.5, the fuel exit temperature is above the coke formation limit of the fuel. Hence these two channels with aspect ratios (ξ) 0.615 and 0.5 are not suitable to consider for active panel with endothermic fuel cracking.

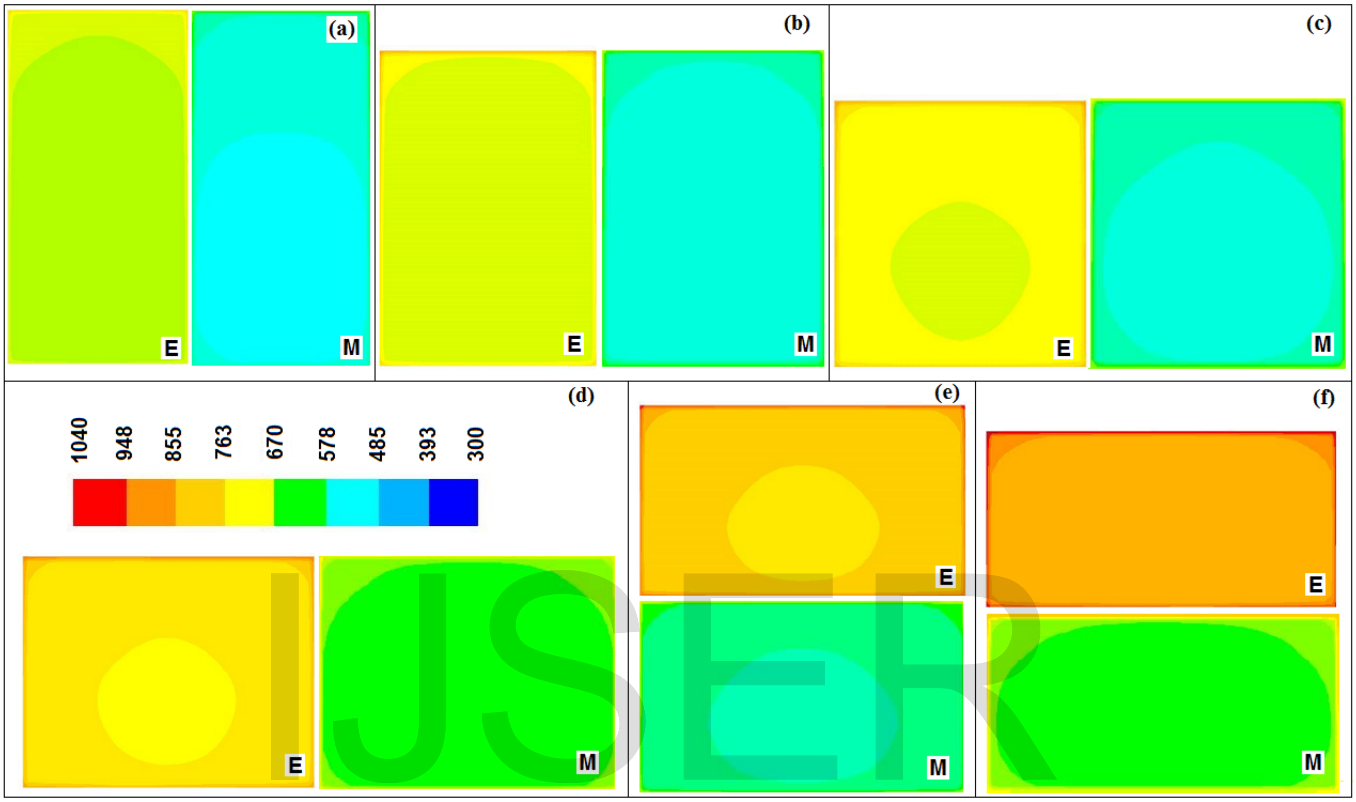

Figure 4 Temperature contours of fuel pattern at the middle and exit of the channel for different aspect ratios (a) ξ _2 (b) ξ _1.38 (c) ξ _1 (d) ξ _0.78 (e) ξ _0.615 (f) ξ _0.5

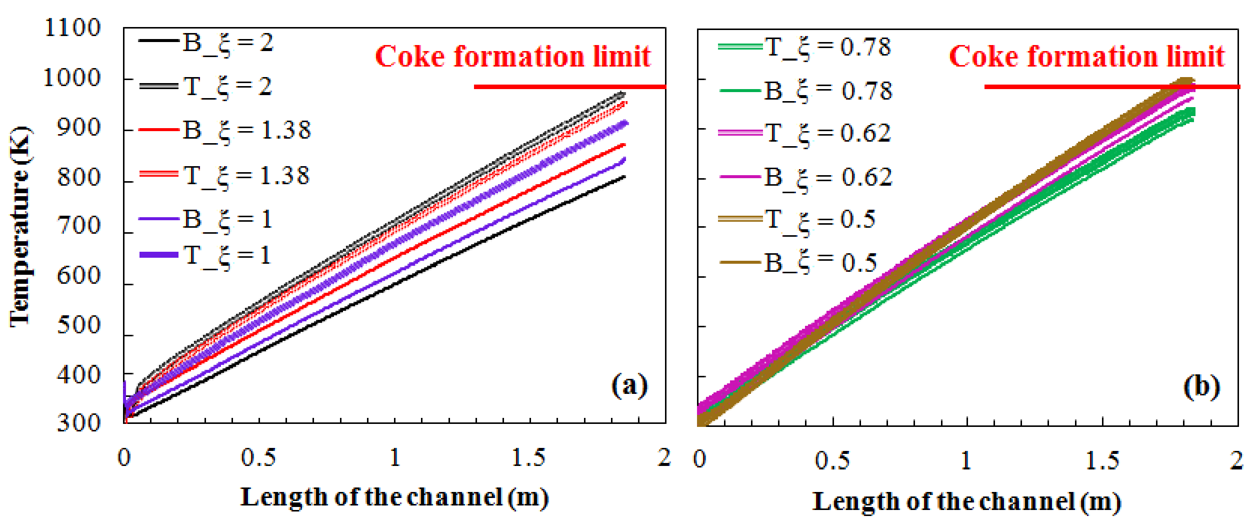

Figure 5 Variation of temperature at top and bottom along the channel for pyrolysis for different aspect ratios

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

5.2. FUEL CRACKING AND HEAT ABSORPTION

Cracking of fuel in the channel is proportanally related to heat absorption rate of the fuel for a constant heat flux at the top surface. The effective cracking starts when the fuel temperature reaches 725 K to 850 K. The height of the channel reduced with decrease in aspect ratio and the width is increased. The heat absorption of the fuel increased for lower aspect ratios. The quantity of cracking conversion is directly proportional with heat availability of the fuel and residence in the channel. The variation of heat absorption of fuel in the channel for different channel geometries is shown in Fig. 6. The width of the channel increases with decreased aspect ratio, results the fuel wetting area to heat source increases. Fuel in the lower aspect ratio channels attains to cracking initiation temperature faster than higher aspect ratio channels. Hence the residence time of the fuel after cracking initiation increases. Therefore the yield of further conversion increases for lower aspect ratio channels. Quantity of the cracking conversion is proportional with further residence time of the fuel after cracking initiation. Therefore the quantity of cracked products increases with the decrease in aspect ratio of the channel. The variation of fuel cracking and production of cracked products for different aspect ratios for a constant heat flux of 160 W/cm^2 are shown in Fig. 7.

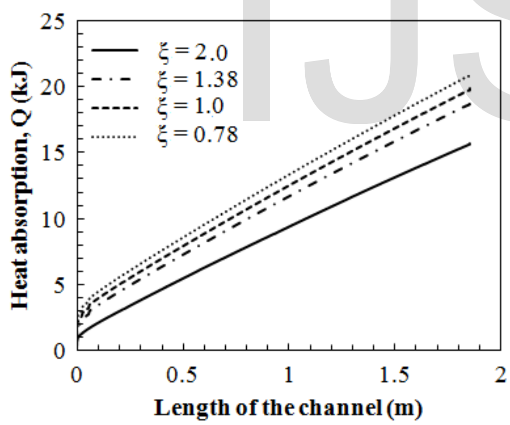

Figure 6 Variation of heat absorption of the fuel for different aspect ratios

For case of ξ =2, the cracking initiation temperature attained at the channel length of 1.44 m. The amount of fuel (n-dodecane) cracking is limited to 25 % only and maximum amount of resultant products (C_2H_4 and C_2H_6) are 0.1 and 0.048 mole fractions respectively. Whereas, for ξ = 0.78, the cracking temperature attained at 1.09 m and cracked percentage of the fuel is 64% and higher quantity of products 0.38 and 0.29 mole fractions respectively are observed for C_2H_4 and C_2H_6. At an instance, the heat flux of 160 W/cm^2 for ξ = 0.78 and mass flow rate of the fuel 0.014 kg/s, the fractions of cracked products at the exit of the panel is shown in Eq. 3.

$$
\begin{aligned}
nC_{10}H_{22} \rightarrow\ & 0.0408H_2 + 0.0840CH_4 + 0.1148C_2H_6 + 0.2843C_2H_4 \\
& + 0.05558C_3H_6\ \ 0.00129C_3H_8 + 0.009C_4H_6 \\
& + 0.00895C_4H_{10} + 0.00023nC_4H_8 \\
& + 0.03572nC_6H_{12} + 0.0129nC_7H_{14} \\
& + 0.00797nC_9H_{18} \\
& + 0.0296nC_8H_{16} \qquad (3)
\end{aligned}
$$

However, the fraction constants of cracked products are function of heat source available and residence time of the fuel in the channel.

5.3 STRUCTURAL ANALYSIS

The structural analysis is verified for channel with different ξ values. Temperature distribution for channels with different aspect ratio is shown in Fig. 8. The height of the channel decreased and with of the channel increased for low aspect ratio channels. Results the channel maximum material is exposed to heat sources. The maximum temperature in the channel increased with decrease in aspect ratio.

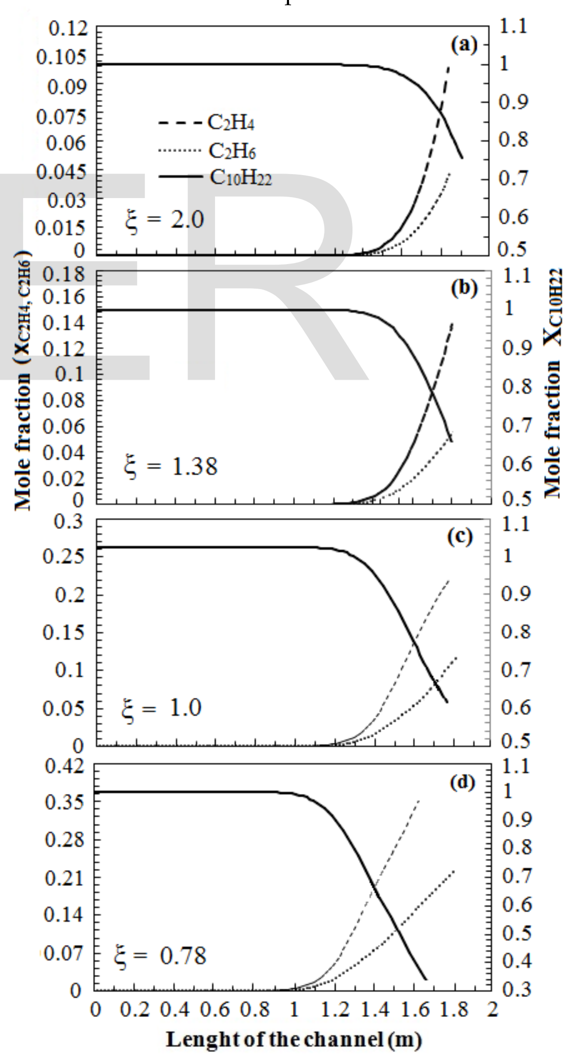

Figure 7 Conversion rates of dodecane and products along the length of channel for different aspect ratios

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

For cases of ξ = 0.62 and 0.5, the maximum temperature of 1136 K is observed at the top of the channel. However, the fuel exit temperature of these two channels are exceeded the cocking temperature limit of the fuel. Based on the structure and fuel exit temperature limitations, the channels with aspect ratio of 0.62 and 0.5 are considered as not capable for the applied loads. Structural analysis is carried out for four channels with aspect ratio of 2 to 0.78. It is observed from structural analysis that the gradient in temperature and stresses reduced with decreased aspect ratio of the channel.

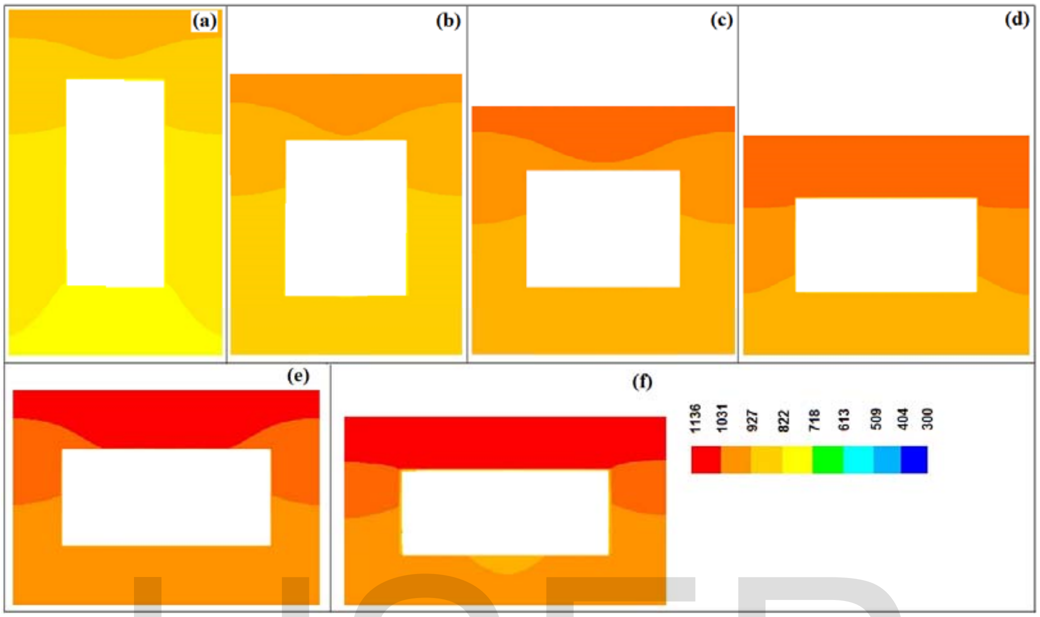

Figure 8 Temperature contours of the channel at the exit for different aspect ratios (a) ξ _2 (b) ξ _1.38 (c) ξ _1 (d) ξ _0.78 (e) ξ _0.615 (f) ξ _0.5

Stresses in the channel are within the limits for ξ = 2, 1.38 and 1.0 cases. Stresses in the channel with ξ = 0.78 are exceeded the safe limit of the structure. Yield stress for Nb-Cb 752 is 382 MPa. The maximum stress for observed for this case is 4.63×10^{9} Pa, shown in Fig. 9a. Therefore, structural analysis is not satisfied for the channel with ξ = 0.78 Bending stress at the bottom web is increased since the width of the channel increased. For ξ =1.0 channel, the von-Mises stress is less than the yield stress of the material, as shown in Fig. 9b. Maximum and minimum stresses for ξ _1 channel are 255 MPa and 169 MPa respectively. From this structural analysis it is inferred that the channel with the aspect ratio range of ξ = 2 to 1.0 are structurally safe.

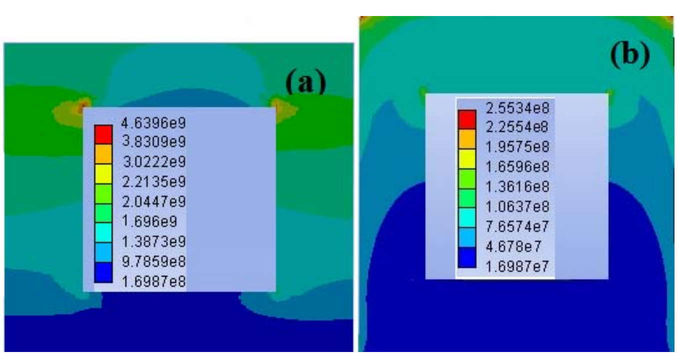

Figure 9 Stress distribution (Pa) for (a) ξ = 0.78 and (b) ξ = 1.0

5.4 WEIGHT ANALYSIS

The effect of endothermicity and geometric parameters on weight of the panel is summarized in Table 3. Based on fuel exit temperature and stress distribution in the channel material, three channels with aspect ratio of 0.78, 0.62 and 0.5 are eliminated. Number of channels for ξ = 2.0 and 1.0 are 266 and 210 respectively. Weight of the channel for ξ = 2.0 and 1.0 are are 45.6 and 38.3 kg respectively. The channel weight of the case ξ = 1.0 is 16.02% less than the channel of ξ = 2. Fuel cracking is increased with decreased aspect ratio of the channel. Hence the channel with ξ = 1.0 is considered as optimal geometry with maximum yield of cracking and less material.

Table 3 Weight analysis of different channels based on pyrolysis

ξ	N_C	m_f (Kg/m)	$m_p + m_f$ (Kg/m)
2.0	267	3.47	45.6
1.38	235	3.05	41.2
1.0	210	2.74	38.3

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

6. CONCLUSIONS

The present paper is to study the influence of Fuel cracking and geometric parameters of the fin on weight of the panel. The objective is to identify suitable aspect ratio which increase the cooling efficiency and minimize the weight of the panel. The effect of fuel edothermicity along with channel geometry is studied. Different channel dimensions with constant cross-sectional area are considered. The aspect ratio (ξ) is changed accordingly from 2 to 0.5.

The temperature gradients between top and bottom point of the fuel flow are decreased when aspect ratio is decreased. With decreased aspect ratio (ξ), the wetting area of the fuel in the heat flux side increase and heat absorption of the fuel increases. For higher ξ, large temperature difference is observed between top and bottom plane of the fuel. With decreased aspect ratio, the temperature gradient of the channel is decreased and the average temperature of the fuel in the channel is increased. At the axial length of 1.0 m, the temperature gradient for ξ = 2.0 and 0.5 are 127 K and 11 K respectively. The cases ξ = 0.615 and 0.5, the fuel exit temperature is above the coke formation limit of the fuel. Hence these two channels are not suitable for active panel with endothermic fuel cracking.

The heat absorption of the fuel increased for lower aspect ratios. The quantity of cracking conversion is directly proportional with heat availability of the fuel and residence in the channel. Fuel in the lower aspect ratio channels attains to cracking initiation temperature faster than higher aspect ratio channels. Hence the residence time of the fuel after cracking initiation increases. Quantity of the cracking conversion is proportional with further residence time of the fuel after cracking initiation. Therefore the quantity of cracked products increases with the decrease in aspect ratio of the channel. For case of ξ =2, the cracking initiation temperature attained at the channel length of 1.44 m. The amount of fuel (n-dodecane) cracking is limited to 25 % only. Whereas, for ξ = 0.78, the cracking temperature attained at 1.09 m and cracked percentage of the fuel is 64%.

The structural analysis is verified for channel with different ξ values. The maximum temperature in the channel increased with decrease in aspect ratio. For cases of ξ = 0.62 and 0.5, the maximum temperature of 1136 K is observed at the top of the channel. Stresses in the channel are within the limits for ξ = 2, 1.38 and 1.0 cases. However, for case of ξ = 0.78 stress exceeded the safe limit of the structure. Yield stress for Nb-Cb 752 is 382 MPa. The maximum stress for observed for this case is 4.63×10^9 Pa. Therefore, structural analysis is not satisfied for the channel with ξ = 0.78 bending stress at the bottom web is increased since the width of the channel increased. For ξ =1.0 channel, the von-Mises stress is less than the yield stress of the material. Maximum and minimum stresses for ξ _1 channel are 255 MPa and 169 MPa respectively. Number of channels for ξ = 2.0 and 1.0 are 266 and 210 respectively. Weight of the channel for ξ = 2.0 and 1.0 are 45.6 and 38.3 kg respectively. The channel weight of the case ξ = 1.0 is 16.02% less than the channel of ξ = 2. The channel with ξ = 1.0 is considered as optimal geometry with maximum yield of cracking and less material.

NOMENCLATURE:

h_G – Heat Transfer coefficient of the hot gases (W/cm^2)

h_C – Heat Transfer Coefficient of the coolant inside the channel (W/cm^2)

t_f -face thickness (mm)

tc – core thickness (mm)

Z – Length of the channel (m)

$\dot{m}_f$-Coolant flow rate (Kg/s)

m_f - Mass of fuel in the channel per unit width (kg/m)

m_P - Mass of the panel per unit widthe (kg/m)

T_f - Coolant temperature (K)

l– Height of the channel (mm)

b – Width of the channel (mm)

ξ – Chanel aspect ratio

σ_y -Yield strength of material(Pa)

ρ_m-Density of the material (Kg/m_3)

α - Coefficient of thermal expansion (K^{-1})

k_m- Thermal Conductivity of the metal (Kg/m^3)

$C_{P,m}$-Specific heat of the metal (J/Kg.K)

N_c- Number of channels

A- Area of the fluid

$\dot{v}_f$- Volumetric flow rate of the fluid (m^2/s)

kf – Thermal Conductivity of the fuel / coolant (K)

T_c-Coolant coke temperature (K)

D_h – Hydraulic Diameter

vf – Coolant dynamic viscosity

P – Pressure (Pa)

T – Temperature (K)

q – Heat flux W/m^2

$C_{p,f}$– Specific heat of the fuel (J/kg K)

ρ_f- Density of the fluid (Kg/m^3)

REFERENCES

[1] B. Youn, A.F. Millst, "Cooling panel optimization for the active cooling system of a hypersonic aircraft" J Thermophys Heat Transfer, Vol 9, No 1, pp. 136-143, 1995.

International Journal of Scientific & Engineering Research, Volume 9, Issue 1, January-2018
ISSN 2229-5518

[2] F. F. Chen, W. F. Tam, N. R. Shimp, R. B. Norris, “An innovative thermal management system for a Mach 4 to Mach 8 hypersonic scramjet engine” AIAA-1998-3734, 1998.

[3] T. Edwards, “Liquid Fuels and Propellants for Aerospace Propulsion: 1903-2003,” J. Propul. Power, Vol 19, pp 1089–1107, 2003.

[4] V. Lorenzo, V. Natasha, W.Z. Frank, G.E. Anthony, “A materials selection protocol for light weight actively cooled panels” J. Appl. Mech. Vol 75, No 6, pp 061022-1 – 061022-15, 2008.

[5] M. Pizzarelli, F. Nasuti, M. Onofri,”Trade-off analysis of high-aspect-ratio-cooling-channels for rocket engines” Int. J. Heat Fluid Flow, 44, pp. 458-467, 2013.

[6] M. Pizzarelli, F. Nasuti, M. Onofri, “Effect of channel aspect ratio on rocket thermal behaviour,” J. Thermophys. Heat Transf., Vol 28, No 3, pp. 410-416, 2014.

[7] H. Huang, L.J. Spadaccini, D.R. Sobel, “Fuel-cooled thermal management for advanced aeroengines,” J. Eng. Gas Turb. Power, Vol 126, pp 284–293, 2004.

[8] S. Zhang, J. Qin, K. Xie, Y. Feng, W. Bao. "Thermal Behavior Inside Scramjet Cooling Channels at Different Channel Aspect Ratios", J. Prop. Power, Vol. 32, No. 1, pp. 57-70, 2016.

[9] S. Zhang, Y. Feng, Y. Jiang, J. Qin, W. Bao, J. Han, O.J. Haidn, “Thermal behavior in the cracking reaction zone of scramjet cooling channels at different channel aspect ratios,” Acta Astronaut Vol 127, pp 41-56, 2016.

[10] V. Gnielinski, “New Equations for Heat and Mass-Transfer in Turbulent Pipe and Channel Flow,” Int. Chem. Eng., Vol 162, pp 359–368, 1976.

[11] ANSYS FLUENT User's guide, 13.0, Nov 2010.

[12] E.W. Lemmon, A.P. Peskin, D.G. Friend, “NIST 12: thermodynamic and transport properties of pure fluids,” NIST Standard Reference Database Number 12, Version 5.0. NIST; 2000.