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Numerical Comparative Study on Convective Heat Transfer Coefficient in a Combustor Liner of Gas Turbine with Coating

G Manoj Kumar[1*] and J Bruce Ralphin Rose[2]
[1*] PG Scholar, Department of Mechanical Engineering, Regional Centre of Anna University, Tirunelveli, Tamil Nadu, India.
[2] Assistant Professor, Department of Mechanical Engineering, Regional Centre of Anna University, Tirunelveli, Tamil Nadu, India.
[*]Email: manojkumargmech@gmail.com
Mobile: +91-8220207150

Abstract-**The combustion components of gas turbines (GT) are operating under high temperatures and stresses by reason of combustion instabilities. As a result, gas turbine combustion components need regular monitoring or condition assessment in order to avoid failures. The goal is to investigate the effects of changes in the convection heat transfer coefficient on the temperature profile distribution at the liner inner and outer interfaces. The effect of convection heat transfer coefficient on the combustor liner surface temperatures through the combined effect of convection and conduction at the surface is investigated. A transient thermal analysis of one gas turbine combustion liner with and without TBC is used to handle the heat transfer computations. The benefit of the application of the TBC layer on the liner surface is to assess the reduction of the thermal effects on the base material. The results were impressive, showing how the internal and external surface temperatures are affected by varying the convective heat transfer coefficient. The higher the coefficient, the higher the measure of heat transferred. Higher wall temperatures are attained with complex coefficients. But temperature variance between liner outer and inner wall surface temperatures gets larger with increased coefficients. Optimum engine performance is obtained by providing a kind of coating on the inner wall of the combustion chamber. By the coating material of combustion chamber liner, convection inside the combustor will be minimized so that cooling air consumption reduced which could be utilized for other components in the airplanes.**

***Keywords*: Gas turbine, Coatings, Thermal Analysis, Combustor.**

I INTRODUCTION

In gas turbine engine combustion chambers, the internal walls of the combustor liner are always subjected to heat. Thermally induced axial stresses occur in materials when they are heated or cooled. It affects the operations of gas turbine engines due to the large components subjected to stresses (E.Ufot et al., 2010). Today's gas turbine can influence thermal efficiencies in excess of 40% as result of the increased thermodynamic parameters like pressure ratio and inlet temperature of turbine. Accordingly, new material, Thermal Barrier Coating (TBC), and advanced combined cooling methods (B. Weigand et al., 2009), (K. H. Park et al., 2009) have been developed to improve reliability and durability of the hot components. Of late, the highest combustor exit temperatures are approximately 2000K and for the most widely used nickel or cobalt based alloys, the maximum temperature should not exceed 1200 K (A Schultz., 2002).

It is observed that different mass flow yielded different convection heat transfer coefficients. Researchers used for inner and outer liners, convective heat transfer coefficients extending from 140 to 1400 W/m^{2}K, depending on the engine functional condition. The current work used varying convective heat transfer coefficients on the inner walls of the combustion chamber liner, while retaining a constant coefficient on the external walls. The reason for these conditions was to observe distinctly the effects of the inner heat transfer coefficients on the wall temperatures as a result of exposure to intense radiation. The work used observation range of 100 to 2000W/m^{2}K.

II MATERIALS AND METHODS

A. *Base material*

The combustion chamber practices the maximum gas temperatures in a gas turbine and is subject to a combinationof creep, pressure loading, high cycle and thermal fatigue. The materials used presently titanium-based alloy. These provide noble thermomechanical fatigue, creep and oxidation resistance for stationary parts and are formable to fairly complex shapes such as combustor barrels and conversion ducts. The high thermal loadings executed often mean that largeportions of the combustor need to be sheltered using thermal barrier coatings.

B. *Coating materials*

The important requirements of a coating are to shield the components against erosion, oxidation, corrosion and cracking complications. Superalloys coating will be provided over base material of titanium alloy. Duplex layer has been created for the coating over the liner material. Coatings are there to avert the base metal from occurrence. Added benefits of coatings contain thermal fatigue from cyclic action, surface smoothness in combustor coatings and heat flux loading when one is considering thermal barriers.

C. *Thermal Analysis of the combustor liner wall*

During the combustion process, heat is transferred from the hot flame by radiation and convection of the combustion products. The radiative heat interchange depends on the distance between the flame and the walls and by the absorption of the colder combustion gases in between.

Fig.1, indicates the heat flux through the liner. It is excited by convection and radiation from the exhaust gas inside and it is cooled by radiation to the outer casing and by convection to the casing air passage.

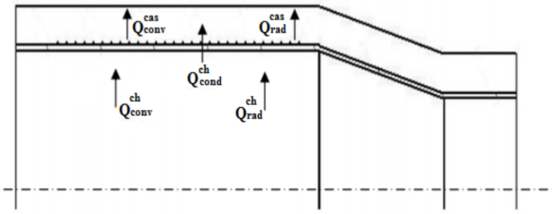


Fig. 1. Heat fluxes through the liner walls

Under transient condition, the heat transfer into the wall domain is composed by the heat transfer out of it.

$$Q^{ch}_{conv} + Q^{ch}_{rad} + Q^{w}_{cond} = Q^{cas}_{conv} + Q^{cas}_{rad} \quad (1)$$

For flame temperatures up to about 1700 K, forced convection is the prevailing mechanism in flame heat transfer (E.G. Jackson et al., 1956). Loss of heat by conduction along the liner wall is very small compared to the further terms. The convective, radiative and conductive heat are calculated using the equations sotto:

Suggesting the CFD calculated wall adjacent gas temperature and heat transfer coefficient atthe inner wall of the liner (Q_{conv}, convective boundary condition)

$$Q_{conv} = h(T_{gas} - T_{wall}) \quad (2)$$

Prescribing a radiative heat input at the inner wall using the CFD calculated maximum gas temperature (T_{max}) privileged the liner. The radiative heat response is distinct as

$$Q_{rad} = \sigma_{SB}\varepsilon(T^{4}_{\max} - T^{4}_{wall}) \quad (3)$$

$$Q^{1-2}_{cond} = \frac{k_w}{t_w}(T_{w1} - T_{w2}) \quad (4)$$

The convective coefficient *h* is the quantity of heat energy voyage a unit area per unit time per unit temperature.

D. *Description of the combustor model*

Considering a designed combustion liner (cross-section) dimensions that is so thermally loaded as in Fig.2, at transient state, it can be eminent that a measure of heat, q is transferred to outer space, in the direction offered.

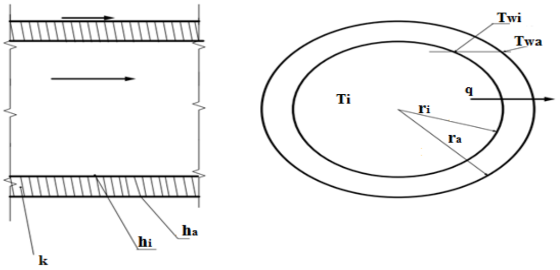


Fig. 2. Cross section of Combustion liner

E. *Geometry*

The domain in the shell combustion liner is modeled as rectangular Fig.3, ranges from the assembly of nozzle cap to the combustion liner end (approximately 100*50*3mm).

As can be further illustrate from Fig.2, the bulk stream temperature persistent the liner, temperature of surrounding, Tsurr = 620K.

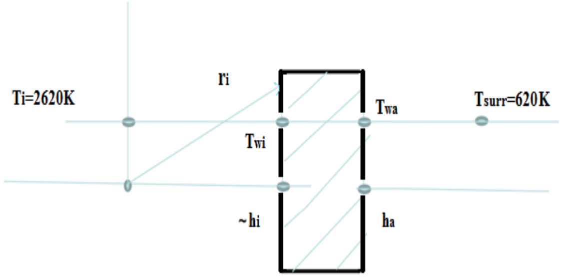


Fig. 3. Schematic presentation of the cross-section of combustor liner

The overall temperature distributions can be analyzed using the heat transfer coefficients and the wall adjacent temperature inside and outside the combustion liner. However, the combustion liner has very complex structures. Therefore, calculated the wall adjacent temperature throughthermal analysis for a part inside the combustion liner.

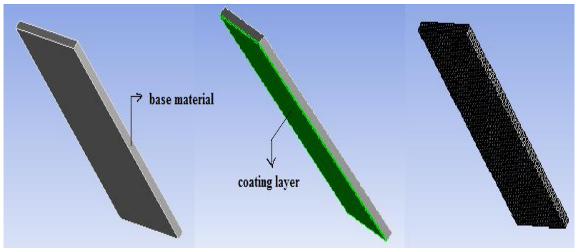
To analyze the heat transfer characteristics outside the objective combustion liner, three dimensional analysis was performed using Ansys numerical package.

F. Liner solid domain

Liner Solid Domain Ansys enables to create, through the heat transfer model, solid regions in which the equations for heat transfer are deciphered, but with no stream. Within the solid fields, the conservation of energy equation can description for heat conveyance due to solid gesture, conduction, and volumetric heat sources:

$$\frac{\partial(\rho H)}{\partial t}+\nabla(\rho U_s \mathrm{H})=\nabla(\mathrm{k}\nabla T)+S_E \qquad (5)$$

The solid motion advection term is also optional and is added only when a solid motion velocity is fixed. In the circumstance considered, no solid velocity is set and the term is therefore neglected.



(a) (b) (c)

(a) Combustor liner (b) Combustor liner with coating (c) Liner meshed model

Fig. 4. Model of Combustor liner

The combustion chamber liner is modeled and Nickel based alloys are generally used for combustion liners because of their high resistance to oxidation and corrosion and high temperature strength. The base material is internally covered by a thin layer of TBC (≈500 μm) which aims to reduce the metal surface temperature and protects the base material. The TBC material is characterized by very low emissivity and low thermal conductivity. It is divided into two different layers: Titanium-nickel alloy bound coating (at the base material interface) and the super alloy which provide the highest resistance to the heat flux from the chamber wall to the GT casing. Structured grids are generated using Ansys Workbench. The three-dimensional grid independent study was carried out with number of nodes varying from 145000 to 234000 nodes. The grid spacing selected is finest at the inner of combustor liner and becomes gradually coarser away from the inner surface.

III NUMERICAL CONDITION

For a cylindrical cross-section of a combustor of gas turbine, such as shown in Fig.2, having a wall width of 0.3 cm:

Table 1. Basic assumptions and boundary condition

Parameter	**Value**	
The compressor discharged air temperature	620	K
The adiabatic temperature within the combustor liner	2,620	K
A convection heat transfer coefficient, ha (external wall influence)	20	W/m^{2}K
A convection heat transfer coefficient on internal walls, hi (varying)	100	W/m^{2}K
A heat conduction coefficient in the material of the liner wall, k	22	W/mK
And a wall thickness of	0.3	cm

With an Ansys numerical tool, heat transfer and the wall surface temperatures, at transient-state for 10seconds, can be computed, as Fig.6, 7. A constant convective heat transfer coefficient, h_a is conserved on the peripheral walls, whereas diverse values of h_i are applied on the internal walls, for other alternates.

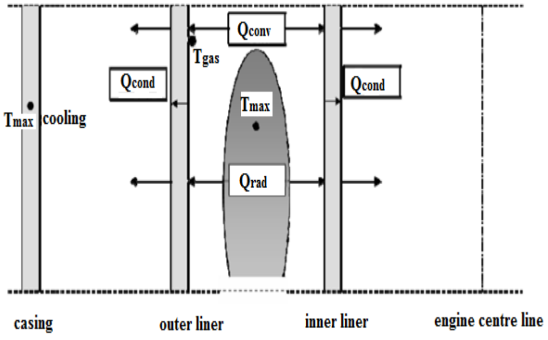
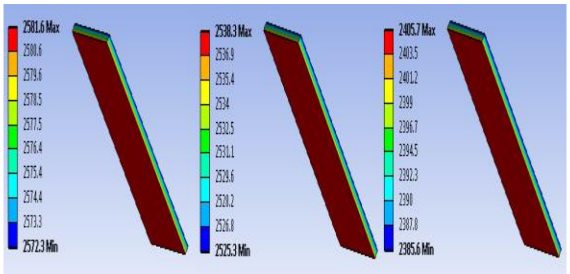


Fig. 5. Boundary Conditions

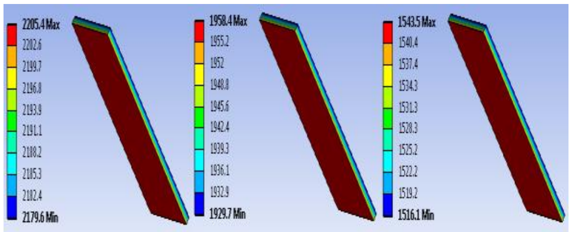
IV RESULTS AND DISCUSSION

Fig.6, shows distributions of heat transfer coefficient and wall adjacent temperature from the internal passage of the combustor liner.The combustion liner in the present study is divided into two parts such as liner without coating and liner with coating section as shown below.



(a) (b) (c)

(a) h_i=2000W/m^2K (b) h_i =1500W/m^2K
(c) h_i =1000W/m^2K



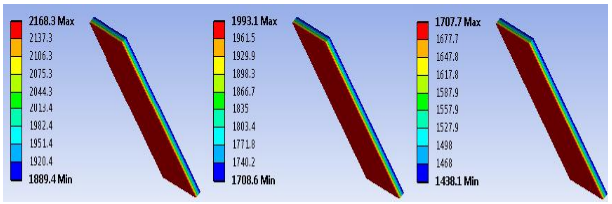
(a) (e) (f)

(d) h_i=700W/m^2K (e) h_i =500W/m^2K
(f) h_i =300W/m^2K

Fig. 6. Temperature distribution of Titanium alloy on liner model

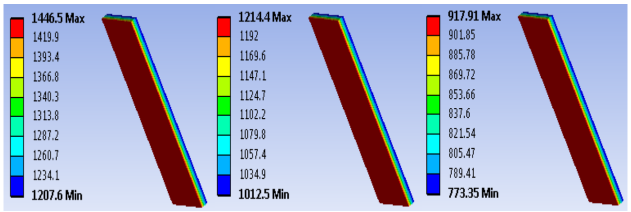
The results of the thermal analysis performed for the two casesare accessible in this section. The temperature profile perceived from numerical investigation, while Fig.8, 9 compare the output parameters. The transient-condition results of the model show the different distribution of temperature along the liner cross section. Differences in the temperature are noticed because of the reduced combustion convection concentration for the liner. Combustor analysis without coating hot regions of the liner is highlighted in the Fig.6.

The transient thermal analysis of titanium alloy material liner is reached the maximum temperature level upto 2581.6K. On account of differences in thermal expansion temperature distress the material layers elasto-plastically. It is observed a decent consistency between the temperatures when the convective heat transfer coefficient is increased.The temperature level is at maximum at the inner of combustor liner and becomes gradually reduced away from the inner surface.



(a) (b) (c)

(a) h_i=2000W/m^2K (b) h_i =1500W/m^2K
(c) h_i =1000W/m^2K



(d) (e) (f)

(d) h_i=700W/m^2K (e) h_i =500W/m^2K
(f) h_i =300W/m^2K

Fig. 7. Temperature distribution of super alloy coating on liner model

In primary zone the wall heat load is caused by a very hot flame with high radiation and by convection of the combustion gases. This heat exchange with the walls however, is reduced due to the long distance between flame and the wall absorption by the combustion gases in between. Nevertheless, these flame tube areas had to be cooled intensively by establishing thick cooling parallel to the high temperature of primary zone where reduced to turbine entry level by adding TBC layers on the combustor liner. In the mixing zone and in the transition zone to the turbine the flame tube temperature could be kept at an acceptable level by minimizing convection to the outer surface.

When the coating material is introduced in the liner, temperature distribution between inner and outer layer of combustor is reduced. This coating material resist heat flux generation between the layers and the thermal analysis maximum temperature distribution level upto 2168.3K. Besides increased temperature differences on the hot gas side and the decreased temperature differences available on the coolant side, the introduction of coating on the combustor liner. By reason of the coating material convection classified the combustion chamber is condensed across the liner.

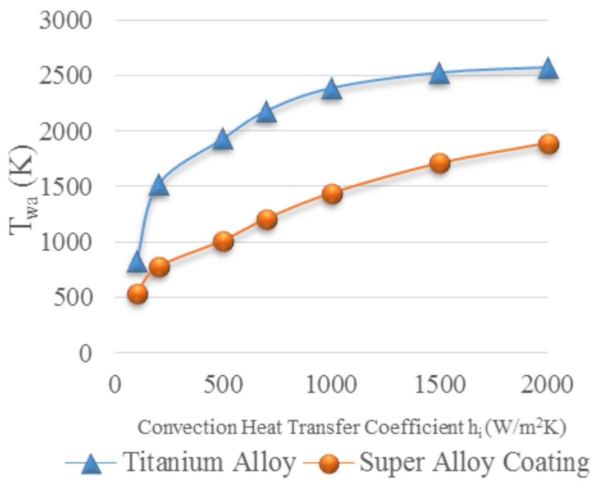


Fig.8. Comparison of outer surface temperatures against convection coefficient

Fig.8, 9, shows the comparison of temperature distribution between inner liner and the wall surface of the combustion chamber for the constant heat transfer coefficient on external wall surface and varying convective coefficient on the inner walls. When the base material is coated with super alloys heat flux is altered according to the variation of convective coefficient.

Fig.8, shows the comparison of wall surface temperature between titanium alloy and super alloy coating on the liner of combustor. The combustion chamber witnessed temperature on the coolant side wall is lower than that on the hot side wall. The super alloy coating resists the convection from inner line of combustor which gives the minimum temperature distribution on the outer wall surface where the convection coefficient is constant.

Fig.9, shows the comparison of inner liner surface temperature between titanium alloy and super alloy coating on the combustor liner. Transient condition thermal analysis of temperature diffusion super alloy coating inner liner surface is low compared to the base material of combustor. Hence the appropriate super alloy coating resist the convection from combustor which gives the minimum temperature distribution on the inner liner surface where the convection coefficient is not constant.

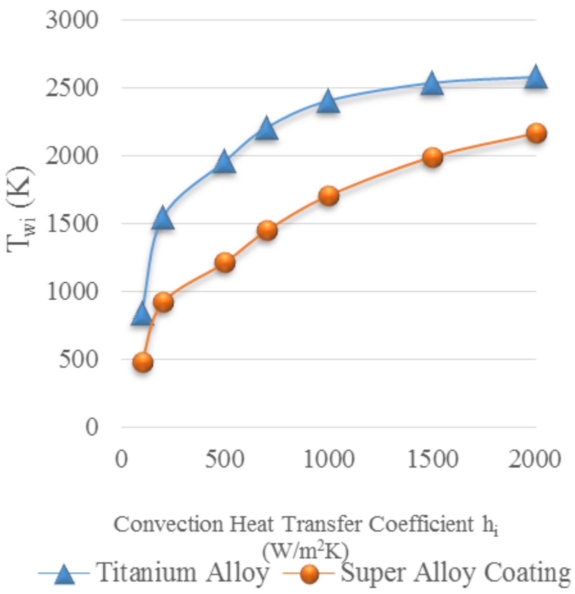


Fig. 9. Comparison of Internal surface temperatures against convection coefficient

The heat transfer coefficient at the liner interface for both the cases highlights the importance of the distribution of the temperature inside the chamber.

V CONCLUSIONS

The energy released by the combustion reaction process inside the combustion chamber is transferred to the surroundings causing temperature gradients and heat flux undulations in the liner solid domain that depletes the base material and damages the chamber walls. Degradation of the material properties, crack development and release of damaged pieces downstream are some of the most common failures of the combustion liners. This study is to define the Convective heat transfer coefficients which influence the quantity of heat transfer in the combustor liner of gas turbine engines. The higher the coefficient, the higher the measure of heat transferred. Higher wall temperatures are accomplished with higher coefficients. But temperature modification between combustor liner outer and inner wall surface temperatures gets larger with increased coefficients.The work is very adequate in computing the thermal dissemination in combustorsof rectangular shellsections at the instance of known wall surface temperatures. By appropriate coating, convection inside the liner of combustion chamber is concentrated. When the convection inside the combustor is abridged, cooling air requirement is reduced which may perhaps exploited for the supplementary workings of plane locomotives.

Imminent developments are aimed at applying thicker coatings to enable higher flame temperatures and/or reduce metal temperatures further. Other programmes are pointed at growing the phase stability and to the inclusion of diagnostic sensor layers within the coating that enable the plant and component condition to be actively monitored.

Nomenclature

h	The heat transfer coefficient
H	Enthalpy of the solid
$\mathrm{h_a}$	Convective heat transfer coefficient for external wall surface
$\mathrm{h_i}$	Convective heat transfer coefficient for internal wall surface
k	Conductive heat transfer coefficient in the material
k_w	The thermal conductivity of the liner wall (for the base material and TBC)
$\mathrm{r_i}$	Radius to inner wall surface from center of cylinder
$\mathrm{r_a}$	Radius to outer wall surface
q	Transferred heat from the inner bulk fluid stream through thewall to annular space.
S_E	Optional volumetric heat source.
t_w	The thickness of the liner wall
$\mathrm{T_a}$	Constant outer surrounding temperature ($\mathrm{T_a = T_{surr}}$)
$\mathrm{T_i}$	Internal bulk stream temperature
T_{gas}	The temperature of the exhaust gas near the wall (wall adjacenttemperature)
$\mathrm{T_{max}}$	The maximum flame temperature
$\mathrm{T_{wa}}$	Outer wall surface temperature
T_{wall}	The temperature at the liner wall
$\mathrm{T_{wi}}$	Internal wall surface temperature
$\mathrm{T_{surr}}$	The surrounding temperature
Us	The solid velocity

Greek letters

ε	Emissivity of the wall
σ_{SB}	Stefan-Boltzman constant.
ρ	Density of the solid

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