Effects of New Cooling Hole Arrays and Thermal Barrier Coating on Insert Ring in V94.2 Gas Turbine Combustor

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Abstract

In order to increase insert ring lifetime in V94.2 gas turbine combustor, new upgrades have been presented in the current study. Since this part of the combustor is in direct contact with propagating flames produced by burner, it is important to consider a state-of-the-art cooling strategy. Based on the working condition of the insert ring, on the hot side, thermal barrier coating (TBC) has been considered. For lowering the temperature of the insert ring's body, new sets of cooling holes have been taken into account. The results have indicated that by using TBC, heat flux rate dropped significantly. The maximum temperature happened to be less than 1110 K due to usage of TBC. But the temperature gradient remained unchanged. By increasing the cooling holes surface area through distortion of cooling holes, the temperature gradient in insert ring had dropped substantially. In addition, among the three presented cases, the best case for lowering the temperature gradient is the one with 48 oblique L-shaped cooling holes which dropped the maximum temperature by 15.7%.

Keywords: V94.2, Insert ring, TBC, Cooling holes, Combustion

Introduction

Upgrading the power of gas turbines by improving the combustor has always been one of the most serious concerns since it leads the combustor walls toward higher wall temperature. Thus, the lifetime of the combustor parts has to be considered as a limiting factor. V94.2 gas turbine has 2 vertical silo-type combustion chambers consisting of eight insert rings for each one. An insert ring is a part inside the combustion chamber on which the burner is located [1]. The main role of this part is to locate the burner for forming and guiding the flame into the combustion chamber. The location of these insert rings is above the flame tube, and divided by the combustion chamber's walls. In fact, this piece is a puzzle part of the flame tube dome plate. These rings are connected to the flame tube dome plate by 12 bolts [1]. The outer side of the insert ring is exposed to the air supplied by compressor that has a temperature of about 613 K. But the inner side of the insert ring is in contact with the hot gases produced by burner. Additionally, in order to cool down the insert ring, series of cooling holes have been designed. In the recent years, a lot of upgrades and researches have been done by different institutes. Kargarnejad and Abbasi-Chianeh [2] have investigated the sources of burner ring failure in V94.2 gas turbine. The result showed that the most destructive causes are the adverse working conditions and thermal stresses. Sheykhlari et al. [3] have studied failure of a heat-resistant stainless-steel ring in V94.2 gas turbine burner. Results indicated that cooling system and applying TBC decrease ring temperature, but the latter has significant effect on reducing ring temperature and cracking. Ansaldo company [4] has made a great effort to upgrade V94.2 combustor. Ansaldo has employed TBC and wear resistance coating for prolonging the overhaul intervals of V94.2 combustor including insert rings. Siemens Company [5] also had initiated a development in order to upgrade V94.2. Siemens has performed series of programs to improve the functionality of V94.2 gas turbine combustor which involved TBC and wear resistance coating, hiring new materials and new design for combustor elements. The main objective of this paper is to design a new version of insert ring as a part of Ultra-Extended-Life program (UEL) in Turbotec company in order to upgrade the V94.2 combustor.

Numerical models

In the present study, Ansys Fluent and Ansys Meshing are employed for simulating insert ring and grid generation, respectively. The SIMPLE algorithm [6] is applied for connecting the pressure and velocity terms.

Equations

The standard k-ε transport equations [7] are employed in order to simulate the turbulent flow over insert ring's wall. These equations are defined, as follows:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_i k)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k-\rho\varepsilon \qquad (1)$$

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \frac{\partial(\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\epsilon}{k}G_k - \rho C_{2\varepsilon}\frac{\varepsilon^2}{k} \quad (2)$$

Energy equation for thermal analysis has been considered which is in the following form:

$$\frac{\partial(\rho E)}{\partial t} + \nabla\cdot\left(\vec{v}(\rho E + p)\right) = \nabla\cdot\left(k_{eff}\nabla T - \sum_j h_j \vec{J}_j + \left(\bar{\bar{\tau}}_{eff}\cdot\vec{v}\right)\right) + S_h \quad (3)$$

Geometry and boundary conditions

The identical silo-type combustion chambers are shown in Figure 1. The current insert ring as used by OEM (Original equipment manufacturer) being used and its location has shown in Figure 1 as well. The orange holes represent current array of cooling holes, and the black ones are bolts.

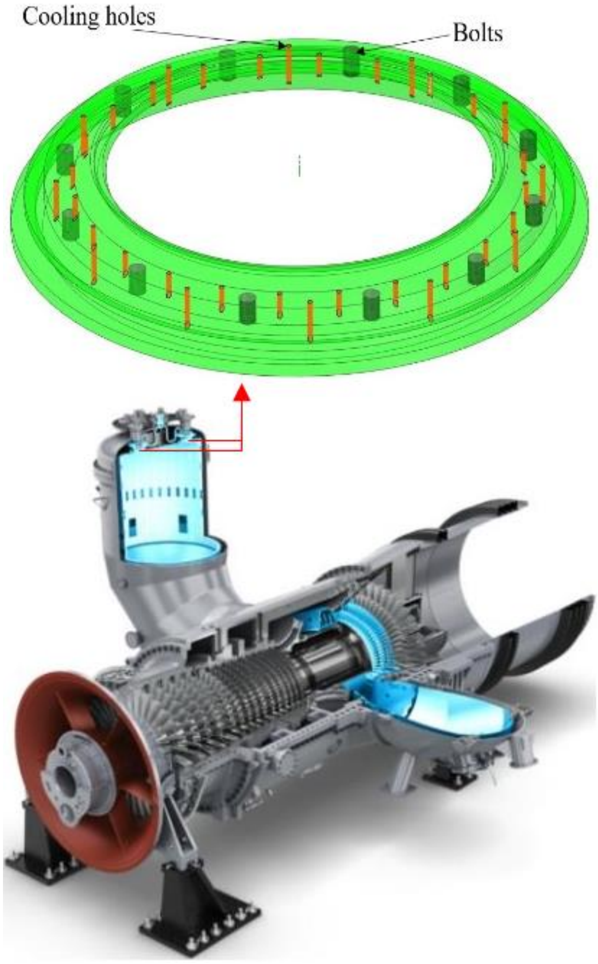
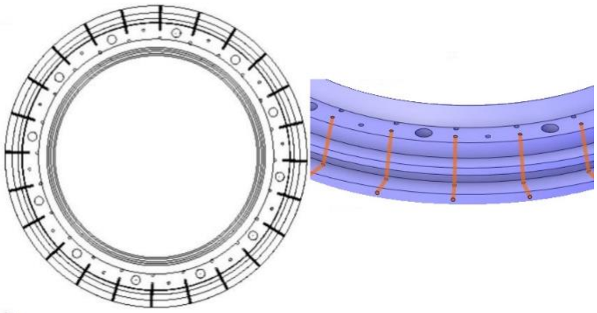
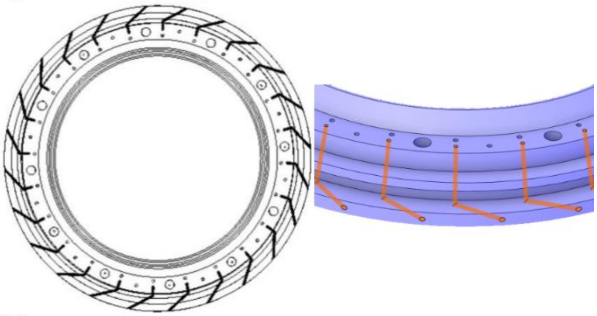


Figure 1. The current insert ring (OEM) geometry

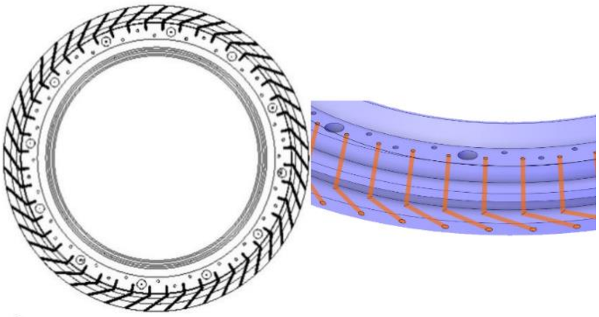
Figure 2 demonstrates new cooling holes arrays. Three sets of designs have been regarded in order to detect the optimal case for lowering the temperature. In all cases the old cooling holes has remained at the same location and new holes have been patterned symmetrically. Case A includes 24 new straight L-shaped cooling holes (Figure 2-a). Case B equipped with 24 new oblique L-shaped cooling holes (Figure 2-b). Case C consists of 48 new oblique L-shaped cooling holes (Figure 2-c).



a) 24 straight L-shaped cooling holes



b) 24 oblique L-shaped cooling holes



c) 48 oblique L-shaped cooling holes

Figure 2. New cooling hole arrays

For all cases, the hot side of the insert ring is TBC coated for lowering the body's temperature (Figure 3). The insert ring is made of Incoloy 800 and for TBC, thermal conductivity is considered as a function of temperature (polynomial type).

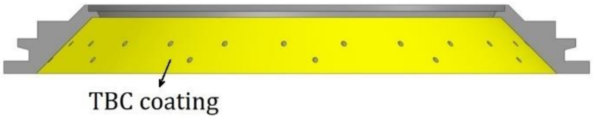


Figure 3. TBC for insert ring

Boundary conditions for each case involves temperature and heat transfer coefficient over the insert ring surface on both sides which extracted from aerothermal solution [8]. These data are in profile type which obtained from Ansys Fluent software (Table 1).

Table 1. Boundary conditions

Boundary condition	Cold side	Hot side
h (w/m^2.K)	Profile	Profile
Temperature	Profile	Profile
TBC	-	included

In order to perform the computations, the geometry is discretized by the unstructured grid. Unstructured grids for all cases are illustrated in Figure 4.

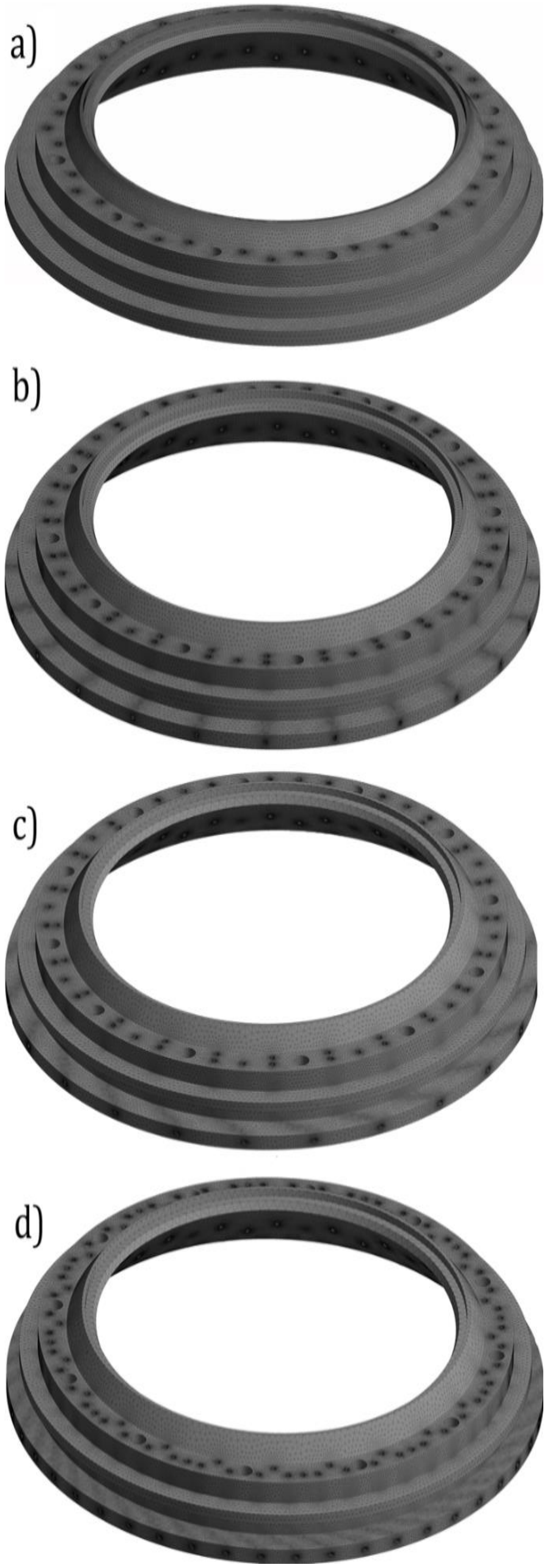


Figure 4. Unstructured grids for a) OEM, b) Case A, c) Case B, d) Case C

The grid size of each case is shown in Table 2. As it can be seen, a rise in number of cooling holes or using oblique holes will increase the grid size. The grid size for “OEM” and “OEM with TBC” cases are the same.

Table 2. Different grid sizes

Name	Size
OEM	2.2×10^6
OEM with TBC	2.2×10^6
Case A	4.9×10^6
Case B	5.5×10^6
Case C	9.1×10^6

Results and discussion

The normalized temperature of the insert ring for OEM with TBC is illustrated in Figure 5. To state the obvious, for all cases with TBC, the temperature beneath the TBC layer is reported. As it can be seen, TBC has a significant effect on lowering the insert ring’s temperature. The maximum temperature happened to be less than 1110 K due to usage of TBC. But the temperature gradient remained unchanged.

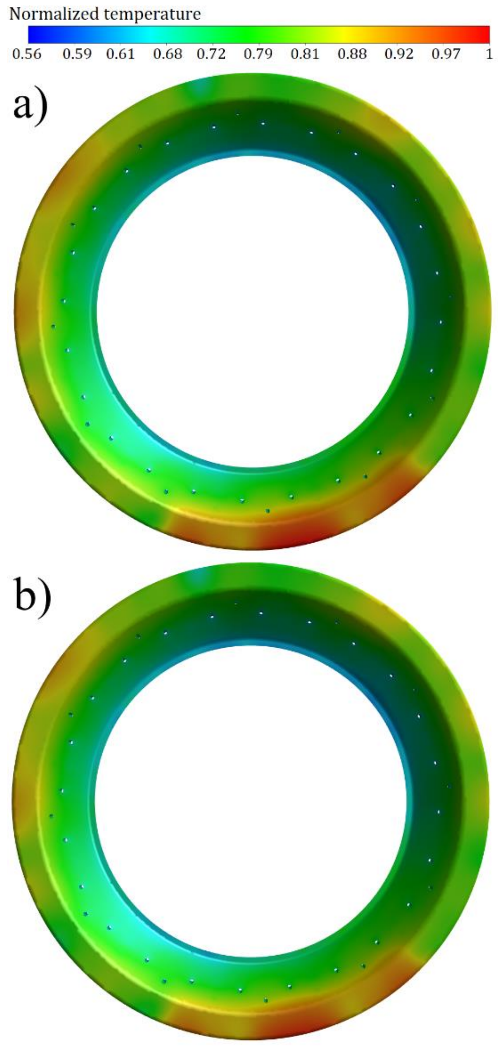


Figure 5. Normalized temperature of the insert ring for a) OEM, b) OEM with TBC

In Figure 6, the normalized maximum temperature for each case has been drawn. By employing TBC and increasing the number of cooling holes the maximum temperature drops significantly. Two dramatic drops in maximum temperature are observed. The first one is between B and C cases and the second one is between D and E cases. According to the A and B cases, an increase in surface area almost will have the same result as increasing the number of cooling holes. Thus, the main focusing point in regard to lowering the body temperature is the growth of cooling surface area.

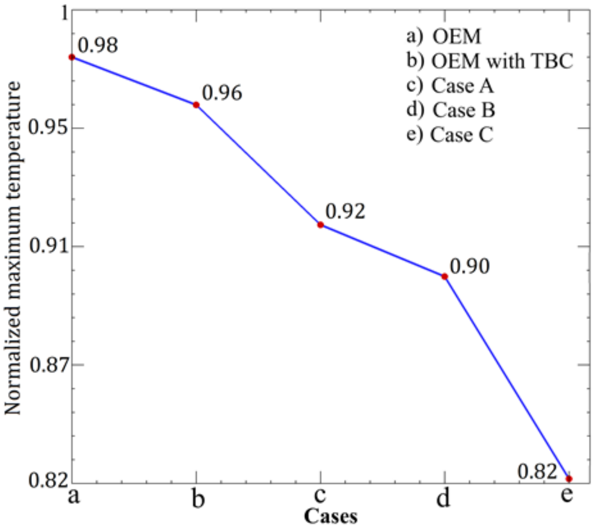


Figure 6. Normalized maximum temperature of the insert ring for a) OEM, b) OEM with TBC, c) Case A, d) Case B, e) Case C

The normalized temperature of the insert ring for each case is demonstrated in Figure 7. In all cases, TBC and cooling holes dropped the insert ring's temperature. In B and C cases, the insert ring's temperature has decreased far more than case A due to the growth of cooling holes surface area. For case A, the temperature gradient almost remained unchanged. In case B, with usage of oblique cooling holes, the temperature gradient seemed to be more uniform than case A. The same deal goes for case C but far better than case B which led to the best temperature gradient among all current cases because of an increase in oblique cooling holes. The critical strength of the solid must be regarded since an increase in the number of cooling holes will challenge the mentioned concern.

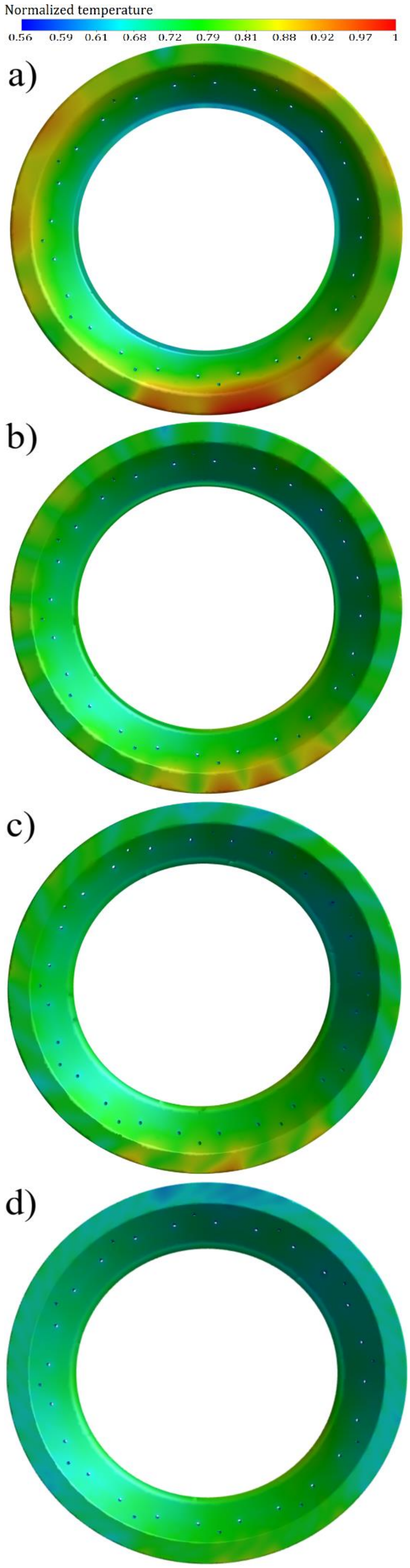


Figure 7. Normalized temperature of the insert ring for a) OEM, b) Case A, c) Case B, d) Case C

Conclusions

In the present study, the effects of new cooling Holes arrays and TBC on insert ring in V94.2 gas turbine combustor is investigated by employing the standard k-ε transport equation for simulating the fluid flow over the insert ring. The main conclusions may be drawn, as follows:

1. TBC has a significant effect on lowering the insert ring's temperature.
2. An increase in cooling holes number has a substantial impact on decreasing the insert ring's temperature.
3. Growth of cooling holes surface area by distorting them, made the temperature gradient more uniform
4. The best uniform temperature gradient is observed in case C which consist of 48 distorted cooling holes.
5. The critical strength of the solid must be regarded since an increase in the number of cooling holes will challenge the mentioned concern.
6. The main focusing point in regard to lowering the body temperature is the growth of cooling surface area.

List of Symbols

$C_{1\varepsilon}, C_{2\varepsilon}$	Constant number in standard k-ε equation
E	Energy
G_k	Source generation of turbulence kinetic energy
h_j	Sensible enthalpy
J_j	Diffusion flux of species j
k	Turbulence kinetic energy
k_{eff}	Effective conductivity
P	Pressure
S_h	Source of heat of chemical reaction
t	Time
u_j	Velocity component (m/s)
x_j	Cartesian coordinates
ρ	Density (kg/m^3)
σ	Turbulent Prandtl number
τ	Viscous stress (N/m^2)
ε	Dissipation rate of turbulence kinetic energy
μ	Dynamic viscosity (Ns/m^2)
υ	Velocity vector

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