

Thermodynamic Analysis of Turbine Blade Cooling on the Performance of Gas Turbine Cycle

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Abstract

Turbine inlet temperature strongly affects gas turbine performance. Today blade cooling technologies facilitate the use of higher inlet temperatures. Of course blade cooling causes some thermodynamic penalties that destroys to some extent the positive effect of higher inlet temperatures. This research aims to model and evaluate the performance of gas turbine cycle with air cooled turbine. In this study internal and transpiration cooling methods has been investigated and the penalties as the result of gas flow friction, cooling air throttling, mixing of cooling air flow with hot gas flow, and irreversible heat transfer have been considered. In addition, it is attempted to consider any factor influencing actual conditions of system in the analysis. It is concluded that penalties due to blade cooling decrease as permissible temperature of the blade surface increases. Also it is observed that transpiration method leads to better performance of gas turbine comparing to internal cooling method.

Key words: Gas turbine performance, Internal cooling, Transpiration cooling, Thermodynamic penalties.

(Impingement cooling)
 (convection cooling)
 (film cooling)

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 (GASCAN)

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(The Free Vortex Design)

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(Semi-Emperical)

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EL-Masri

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($Bi = hl / k$)

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(Slot

– (Transpiration Cooling)

(Hole

– film Cooling)

– Injection film cooling)

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(Impingement Cooling)

$$h = St \cdot \left(\frac{\dot{m}}{A_g} \right) \cdot C_{Pg} \quad (1)$$

(ε)

$$\frac{d\dot{Q}}{d\dot{W}} = \sigma \cdot C_{Pg} \cdot (T - T_w) \quad (2)$$

$$\sigma = St \cdot \left(\frac{A_w}{A_g} \right) \cdot \frac{1}{C \cdot U^2 \cdot \varepsilon} \quad (3)$$

$$\varepsilon = \frac{T_{a2} - T_a}{T_w - T_a} \quad (4)$$

(Continuous Expansion Path)

(EL-Masri)

$$\frac{d\dot{W}}{dA_w} = \frac{\dot{W}_{stage}}{A_{w,stage}} \quad (5)$$

(St = 0.005)

$$\left(\frac{A_w}{A_g} = 8 \right)$$

$$\dot{W}_{stage} = \dot{m} \cdot C \cdot U^2 \quad (6)$$

(200 < U < 300)

C

(1 < C < 1.5)

0.5 0.3

(ε = .5)

(ε = .3)

0.0003

(σ)

$$\frac{d\dot{Q}}{dA_w} = h \cdot (T - T_w) \quad (7)$$

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0.0006

(h)

(Internal cooling)

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$$\dots \quad (-A) \quad ($$

$$St = \frac{St_0}{1 + n \cdot \frac{C_{pg} \cdot (T - T_w)}{\int_{T_a}^{T_w} C_{pair} dT}} \quad ()$$

$$d\dot{Q} = \varepsilon \cdot d\dot{m} \cdot \int_{T_a}^{T_w} C_{pair} dT \quad ()$$

(Transpiration cooling)

$$d\dot{W} = -\dot{m} \cdot C_{pg} dT - d\dot{m} \cdot \int_{T_a}^T C_{pair} dT \quad ()$$

$$(d\dot{m}) \quad (-B)$$

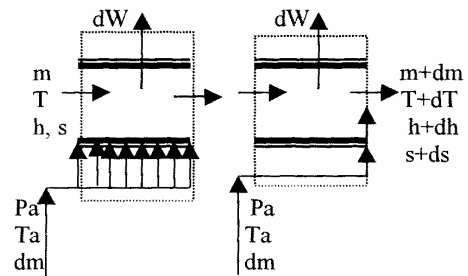
$$(h / h_0 = St / St_0)$$

:[] (b)

$$\frac{d\dot{m}}{\dot{m}} = \frac{-\sigma \cdot C_{pg} \cdot (T - T_w) dT}{\frac{\int_{T_a}^{T_w} C_{pair} dT}{C_{pg}} + \left(n + \sigma \cdot \int_{T_a}^T C_{pair} dT \right) (T - T_w)} \quad ()$$

$$St = St_0 - n \cdot b \quad ; \quad 1/8 < n < 1/2 \quad ()$$

$$b = \frac{d\dot{m} / d A_w}{\dot{m} / A_g} \quad ()$$



خنک کاری نفوذی -B

خنک کاری داخلی -A

$$\dot{W}_{cooled.tur.} = \int_{TIT}^{T_w} \left[-C_{pg} - \left(\frac{d\dot{m}}{\dot{m}} \right) \cdot \int_{T_a}^T C_{pair} dT \right] dT \quad ()$$

(n)

()

1/2

:[] 1/8

$$ms + d\dot{m} \cdot s_a + dS_{gen.} = (\dot{m} + d\dot{m}) (s + ds) \quad ()$$

$$(\varepsilon = 1 \text{ و } n = 0.25)$$

$$(\varepsilon = 0.5 \text{ و } n = 0)$$

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$$r_t^* = \frac{P_3}{P_3^*} = EXP \left[\left(\frac{-1}{R} \right) \left(s_3 - s_{3^*} \right) - \int_{3^*}^3 C_{pg} \frac{dT}{T} \right] \quad ()$$

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$$dS_{gen,fric.} = \frac{1 - \eta_{act.}}{\eta_{act.}} \cdot \frac{dW_{act.}}{T} \quad ()$$

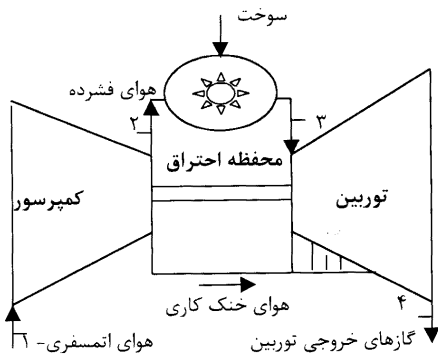
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$$r_t^{**} = \frac{P_{3^*}}{P_4} = \frac{r_t}{r_t^*} \quad ()$$

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$$dS_{gen,thr.} = dm \cdot R \cdot Ln \left(\frac{P_a}{P_{local}} \right) \quad ()$$

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$$dS_{gen,mix.} = dm \left[\int_{T_a}^T \frac{C_{pair} dT}{T} + C_{pair} \left(\frac{T_a}{T} - 1 \right) + \gamma \cdot R \cdot M^2 \right] \quad ()$$

DP_c

$$ds = \frac{\eta_{act.} - 1}{\eta_{act.}} \left[C_{pg} \frac{dT}{T} + \frac{dm}{m} \int_{T_a}^T C_{pair} \frac{dT}{T} \right] +$$

$$\frac{dm}{m} \left[\left(\frac{T_a}{T} - 1 \right) + (\gamma - 1) M^2 \right] C_{pair} \quad ()$$

(η_{oc})

[] (C_{pair})

(dm/m)

(-)

$$f_{act} = \frac{(12n+m)(1+\omega)/(A\eta_{cc})}{(n+m/4)(4.76+\omega_1)(2897+1805\omega_1)} \quad (T_2)$$

$$\int_{T_1}^{T_2} C_{pair} \frac{dT}{T} = \int_{p_1}^{p_2} \frac{R}{\eta_{\infty c}} \cdot \frac{dP}{p} = \frac{R}{\eta_{\infty c}} \ln \frac{P_2}{P_1} \quad ()$$

$$w_{comp.} = \frac{\int_{T_1}^{T_2} (C_{pair} + \omega_1 C_{p,vap}) dT}{28.97 + 18.05\omega_1} \quad ()$$

$$\left(\begin{matrix} C_{pg} \\ r_t^{**} \end{matrix} \right)$$

$$(\omega_1)$$

$$\int_{P_3^*}^{P_4} \eta_{\infty t} \cdot R \cdot (dP/P) = \int_{T_w}^{T_4} C_{pg} (dT/T) \quad ()$$

$$w_{uncooled} = \frac{1 + \omega_1}{28.97 + 18.05\omega_1} \int_{T_w}^{T_4} C_{pg} dT \quad ()$$

$$\begin{aligned} & C_n H_m + A(n+m/4)[O_2 + 3.76N_2 + \omega_1 H_2O] \\ & \Rightarrow nCO_2 + 3.76(n+m/4)N_2 + (A\omega_1(n+m/4) \\ & + m/2)H_2O + (A-1)(n+m/4)O_2 \end{aligned} \quad ()$$

$$w_{net} = (1 + f_{act.})(w_{cooled} + w_{uncooled}) - w_{comp.} \quad ()$$

$$\eta_{th.} = \frac{w_{net}}{f_{act.} \cdot LHV} \quad ()$$

$$\sum_{i=Re\ act.} n_i \cdot h_i = \sum_{j=Pr\ od.} n_j \cdot h_j \quad ()$$

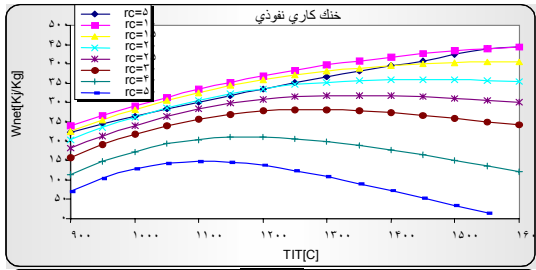
$$h = h_{form.} + \int_{T_1}^T C_{pg} dT \quad ()$$

$$C_{pg} = \frac{\sum_{j=Pr\ od.} n_j \cdot C_{pj}}{\sum_{j=Pr\ od.} n_j} \quad ()$$

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$$(\sigma = .00045, T_w = 900C) \quad ()$$



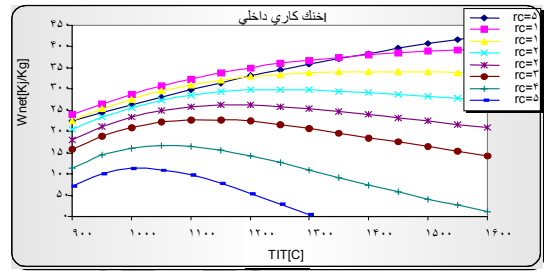
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(c)

(KJ/kg)

(c)



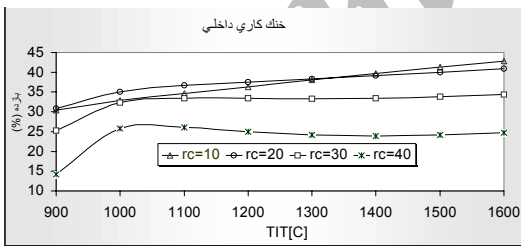
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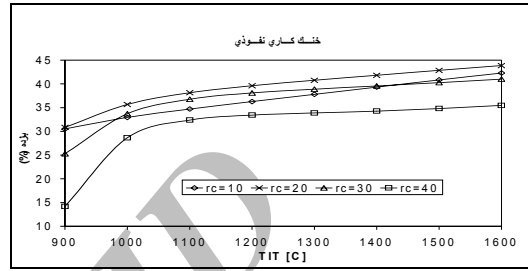
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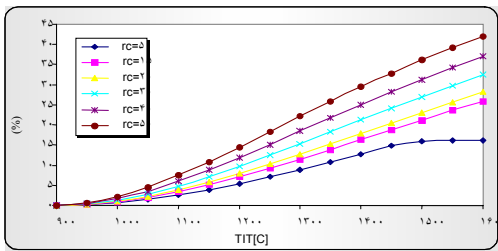
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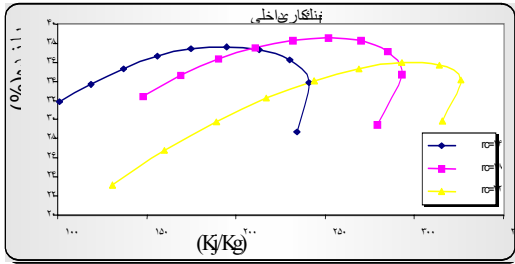
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$$(T_0 dS_{gen.} / dW)$$

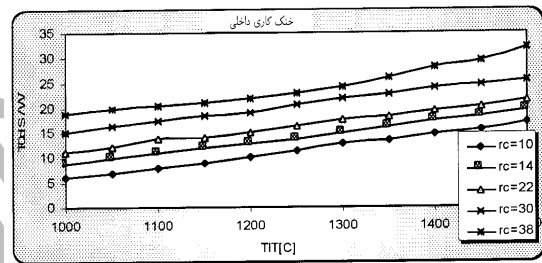
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(KJ/kg) % /

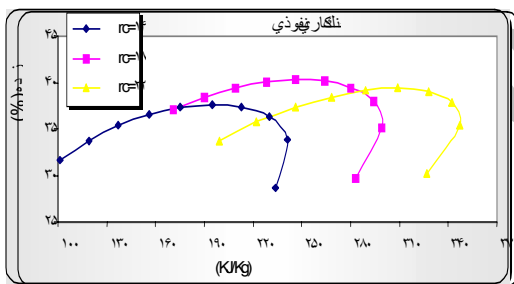
(KJ/kg) (% /



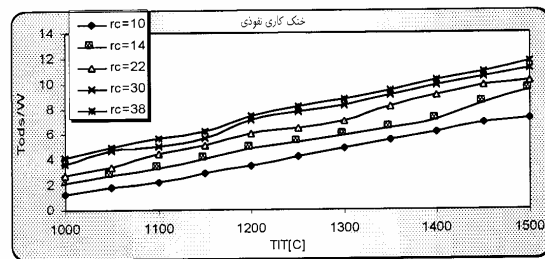
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