# Effect of Slotted Hole on Film Cooling using OpenFOAM

**Jishnu Handique**

National Institute of Technology Manipur, Department of Mechanical Engineering, Imphal, India

## Abstract

***A film cooling process was numerically investigated on flat plate with a secondary slotted hole. Velocities at main stream and secondary stream were kept at 1 m/sec and 0.6 m/sec respectively for blowing ratio, M = 1.***

***Keywords: Film cooling, Slotted hole, Blowing ratio***

### Nomenclature

| | |
|---|---|
| K | Turbulence kinetic energy |
| D | Diameter |
| s | Slot height |
| $q^{//}$ | Heat flux |
| U | Velocity |
| T | Temperature |
| S | Source |
| M | Blowing ratio |
| $C_p$ | Specific heat capacity |
| h | Heat transfer coefficient |
| SIMPLE | Semi Implicit Method for Pressure Linked Equation |

*Greek Symbols*

| | |
|---|---|
| ρ | Density |
| μ | Dynamic viscosity |
| $\overline{\Omega_{ij}}$ | Mean rate of rotation tensor |
| $\epsilon$ | Turbulence energy dissipation rate |

## 1. Introduction

Film cooling is mainly used in gas-turbine operation. A low-temperature secondary fluid is injected to the surface exposed to high temperature gas. The coolant fluid forms a film over the surface and protects it from the hot gas [3].

In this investigation heat transfer coefficient along the surface was computed for blowing ratio, M=1 and secondary slotted hole geometry. Heat flux, $q^{//}$ was kept constant for $T_{fluid} = T_{\alpha}$. Distribution in heat transfer coefficients is compared to the results obtained in Ansys simulation that was run for the same parameters. Again, the outcomes are plotted with experimental data of a film cooling process for circular secondary hole to show the heat transfer variations for different hole geometries.

## 2. Numerical Description

**Table 1. Geometry and Computational Details**

| ***Parameter*** | ***Detail*** |
|---|---|
| Model | 2 Dimensional |
| Geometry-Mesh creating software | ICEM CFD |
| Number of cells | 14,686 |
| Post-processing tool | Paraview, Sigma Plot |
| Solver | buoyantSimpleFoam |
| Pressure-velocity coupling | SIMPLE algorithm [5] |
| Convective term solving scheme | bounded Gauss upwind [5] |
| Turbulent term solving scheme | bounded Gauss upwind [5] |

**Table 2. Fluid properties and initial conditions**

| ***Parameter*** | ***Value/Condition*** |
|---|---|
| $\rho_{fluid}$ | 1.225 kg/m$^3$ |
| μ | 1.831e-05 Pa.sec |
| $C_p$ | 1004.4 J/kgK |
| M | 1 |
| s | 0.1 m |
| Secondary Injection Angle | $35^0$ |
| $q^{//}$ | 1000 W/m$^2$ |
| $T_{fluid}$ | 300 K |
| $T_{\alpha}$ | 300 K |
| $U_{Main}$ | 1 m/sec |
| $U_{Secondary}$ | 0.6 m/sec |

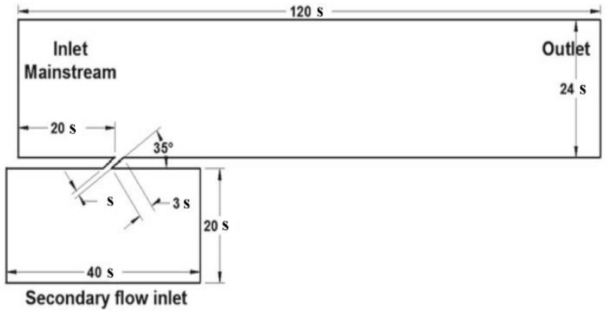


**Fig. 1. 2D domain for numerical analysis** [1]

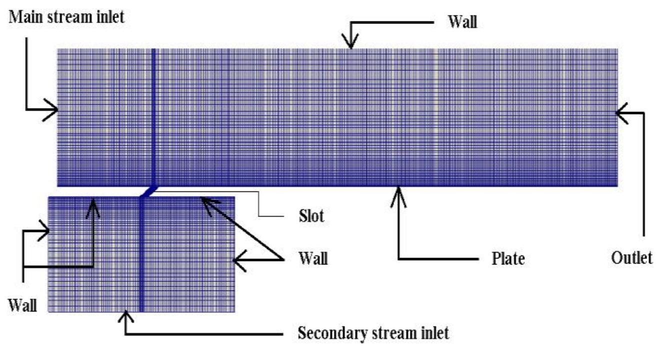


**Fig. 2. Domain with mesh**

## 3. Equations

### *3.1. Heat Transfer Coefficient*

$$h = \frac{q''}{T_{wall} - T_{\alpha}}$$

### *3.2. Realizable k- ϵ* [4]

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial xj}(\rho k u_j) = \frac{\partial}{\partial xj}[(\mu + \frac{\mu_T}{\sigma_k})\frac{\partial k}{\partial xj}] + G_k + G_b - \rho\varepsilon - Y_M + S_k$$

And,

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial xj}(\rho\varepsilon u_j) = \frac{\partial}{\partial xj}[(\mu + \frac{\mu_T}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial xj}]$$

Where,

$$C_1 = \max(0.43, \frac{\eta}{\eta + 5}), \eta = s\frac{k}{\varepsilon}, S = \sqrt{2S_{ij}S_{ij}}$$

$\sigma_k$ and $\sigma_\varepsilon$ are turbulence Prandtl numbers for k and ϵ respectively.

The turbulent viscosity is, $\mu_T = \rho C_\mu \frac{k^2}{\varepsilon}$

$$C_\mu = \frac{1}{A_0 + A_S \frac{kU*}{\varepsilon}}$$

$$\overset{*}{U} = \sqrt{S_{ij}S_{ij} + \Omega_{ij}\hat{\Omega}_{ij}}$$

$$\Omega ij = \overline{\Omega ij} - \varepsilon_{ijk}\omega_k$$

$$\hat{\Omega} ij = \Omega ij - 2\varepsilon_{ijk}\omega_k$$

$$A_0 = 4.04, A_S = \sqrt{6}\cos\varphi$$

$$\varphi = \frac{1}{3}\cos^{-1}(\sqrt{6}W)$$

$$W = \frac{S_{ij}S_{jk}S_{ki}}{S^3}$$

$$S_{ij} = \frac{1}{2}(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j})$$

The constants are, C1 ϵ = 1.44, C2 = 1.9, σk = 1 and σ ϵ = 1.2

The model transport equations used in OpenFOAM,

$$\frac{D}{Dt}(\rho k) = \nabla \bullet (\rho D_k \nabla k) + \rho G - \frac{2}{3}\rho(\nabla u)k - \rho\varepsilon + S_k$$

And,

$$\frac{D}{Dt}(\rho\varepsilon) = \nabla \bullet (\rho D_\varepsilon \nabla\varepsilon) + C_1\rho|S|\varepsilon - C_2\rho\frac{\varepsilon^2}{k + (\vartheta\varepsilon)^{0.5}} + S_\varepsilon$$

## 4. Results

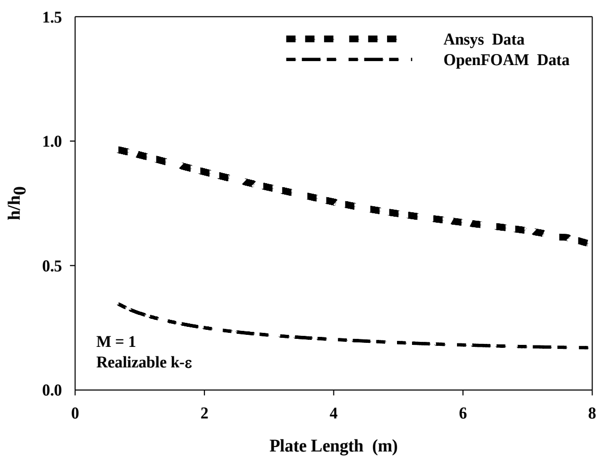


**Fig. 3. Heat transfer coefficient along the plate from the secondary hole showing for slotted hole geometry**

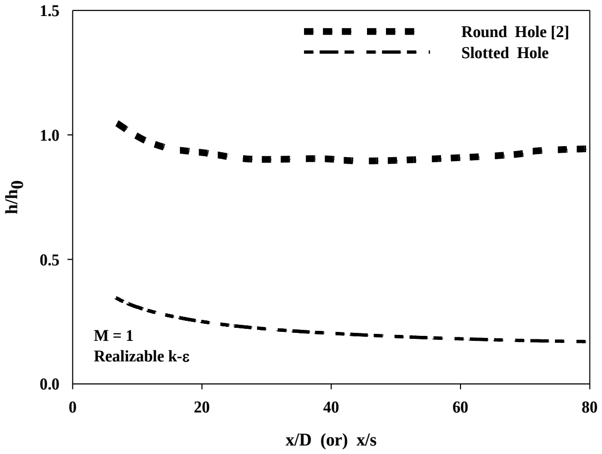


**Fig. 4. Heat transfer coefficient along the plate from the secondary hole showing for different hole geometries**

From the Fig. 3. it can be concluded that OpenFOAM predicts lower values of heat transfer coefficient compared to Ansys Fluent for this case.

And, Fig. 4. shows that heat transfer coefficient for slotted hole is significantly lower than the heat transfer coefficient for round hole [2].

## 5. Contour

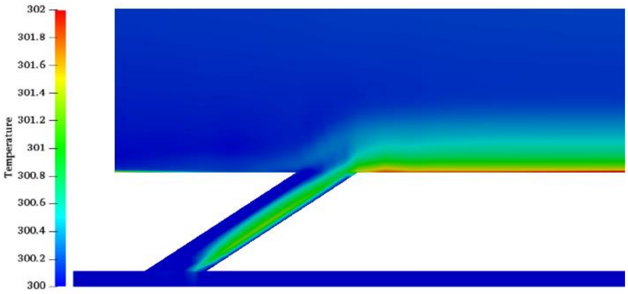


**Fig. 5. Temperature above the plate surface**

## References


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