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A low-speed corona jet for internal spot cooling of tubes

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Introduction

• A high electric potential applied to a wire electrode at the centerline of a circular tube may cause gas ionization and corona discharge, leading to formation of secondary flows and a corona jet.

• A computational model was implemented to show that the corona jet appears only if the electrode is slightly off-center with respect to the tube.

• The computations indicate that the jet is oriented in the direction of electrode-tube offset and it may be suitable for target-cooling of thermal components mounted on the inner surface of the tube.

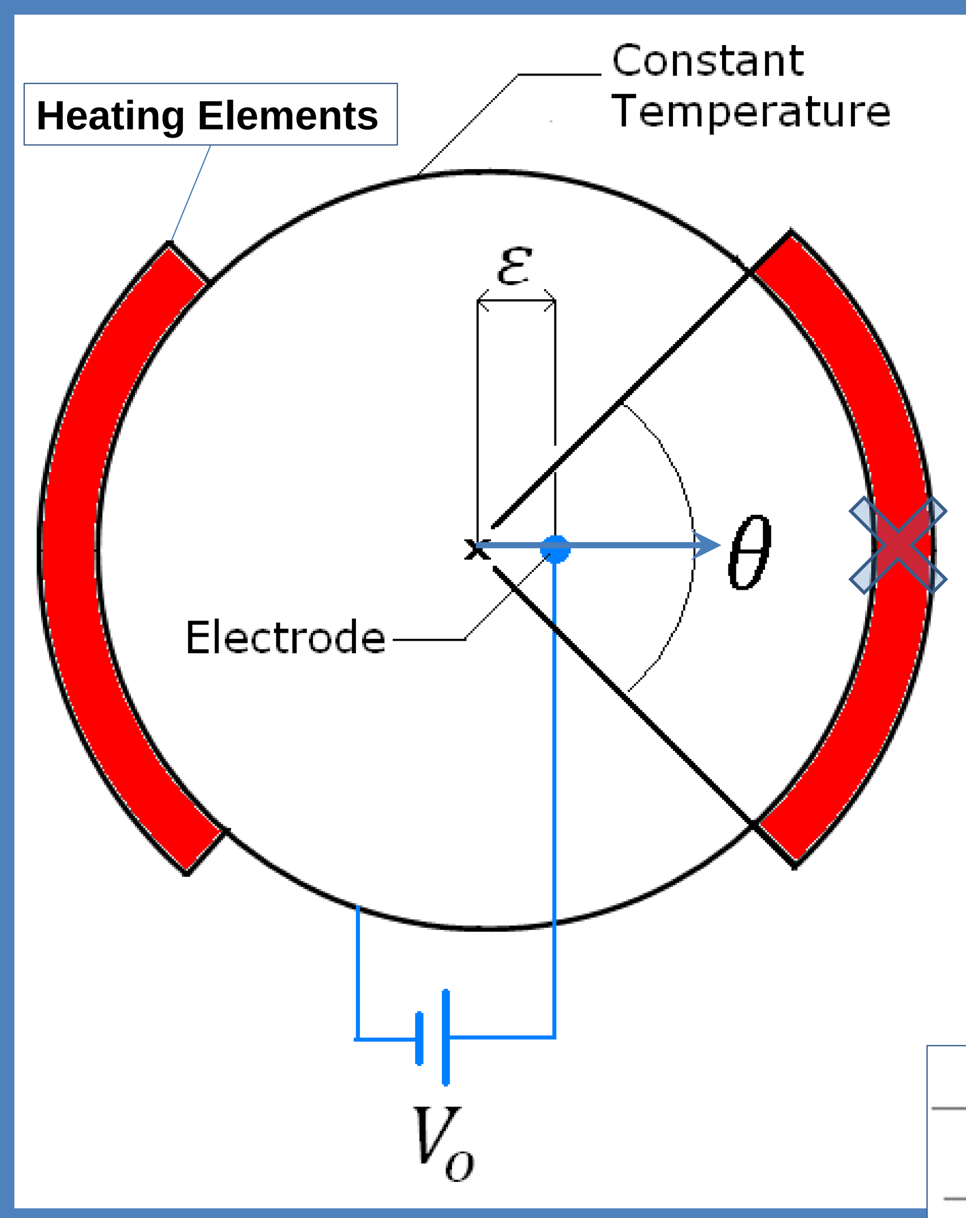
Description of the Problem

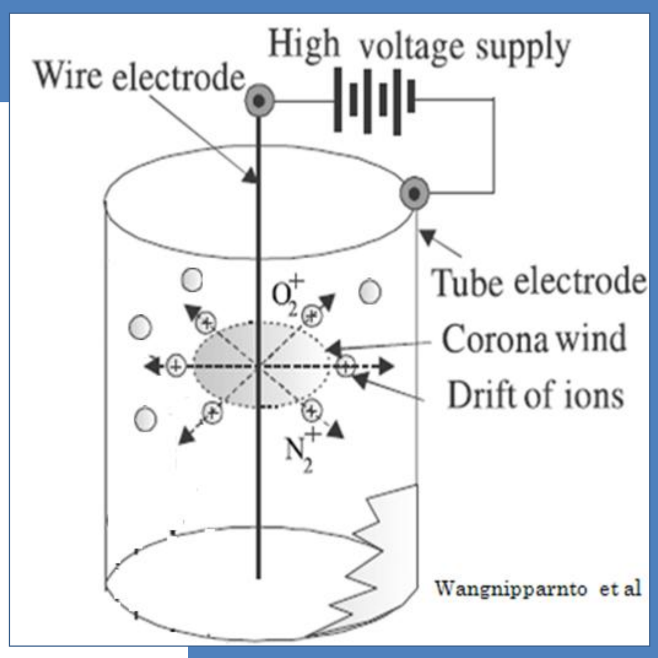
➢ Geometry

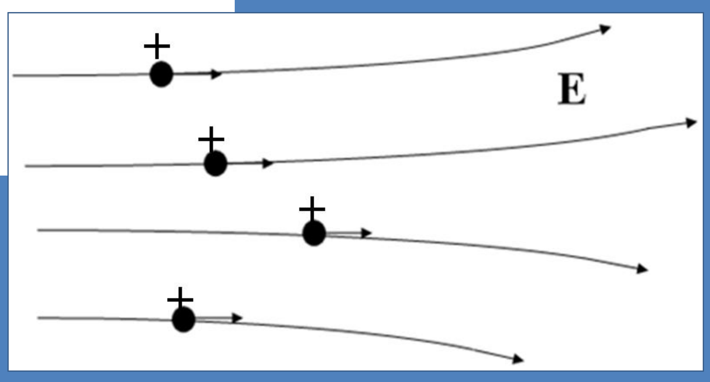
• The geometry is a circular tube and a tightly stretched wire electrode mounted at the tube center.

• The electrode is slightly off-center to allow for fluid disturbance and formation of the corona jet.

• The adopted geometries consist of a number of equivalent heating elements, attached to the perimeter of the tube and corresponding to different extension angles.







Characteristic Lines

Fig. 1 - Geometry of the problem; The eccentricity of the electrode is 1% of the tube radius. The angle θ represents the angular extension of the heating elements. The positive ions move in the direction of electric field and collide with

➢ Electrical Governing Equations

❑ Gauss's Law

$$\nabla\cdot(\epsilon\vec{E})=\rho_c \quad \text{where} \quad \vec{E}=-\nabla V$$

❑ Charge Continuity

$$\frac{\partial\rho_c}{\partial t}+\nabla\cdot\vec{J}=0 \quad \text{where} \quad \vec{J}=\rho_c\vec{u}_d+\rho_c\vec{u}+\sigma\vec{E}$$

Ion's Drift Velocity $\vec{u}_d=b\vec{E}$ — Convection — Electrical Conduction

➢ Flow Field Governing Equations

$$\nabla\cdot\vec{u}=0$$

$$\rho\vec{u}\cdot\nabla\vec{u}=-\nabla P+\mu\nabla^2\vec{u}+\rho\vec{g}\beta(T-T_c)+\vec{F_e}$$

$$\vec{u}\cdot\nabla T=\alpha\nabla^2 T$$

Buoyancy Force — Electric Body Force $\vec{F_e}=\rho_c\vec{E}$

Results

➢ Flow Field

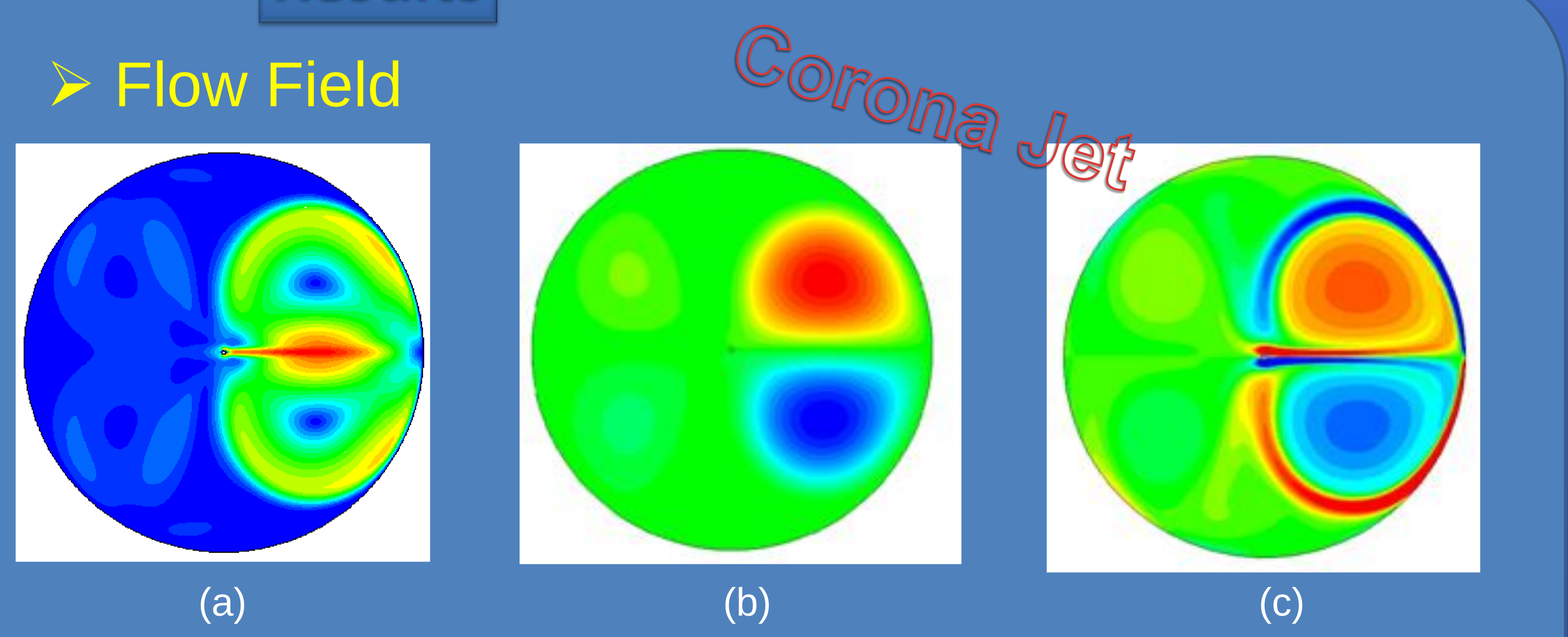


Fig. 2 - Flow Field Analysis; **a) Velocity b) Stream Function c) Vorticity**
The eccentric configuration of the corona electrode leads to a jet flow along the eccentricity direction.

➢ Temperature Field

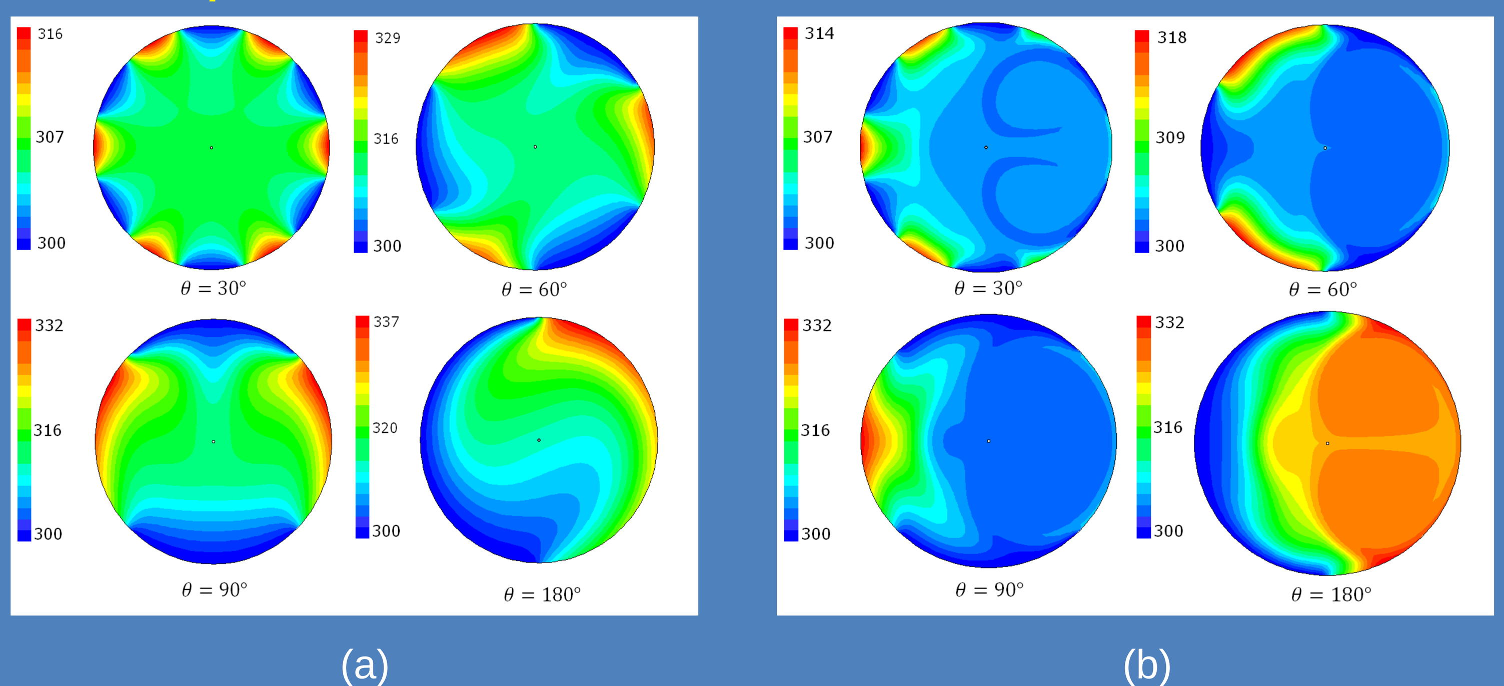


Fig. 3 - Temperature contour plots of tube cross section for different extension angles **a) Natural Convection b) Corona Cooling;** The presence of the corona-induced jet flow changes the temperature distribution dramatically. The direction of impinging corona jet is identical to the electrode eccentricity. The eccentricity direction is utilized to adjust the orientation of the jet flow to impinge exactly at the center of the target heating element.

➢ Surface Temperature

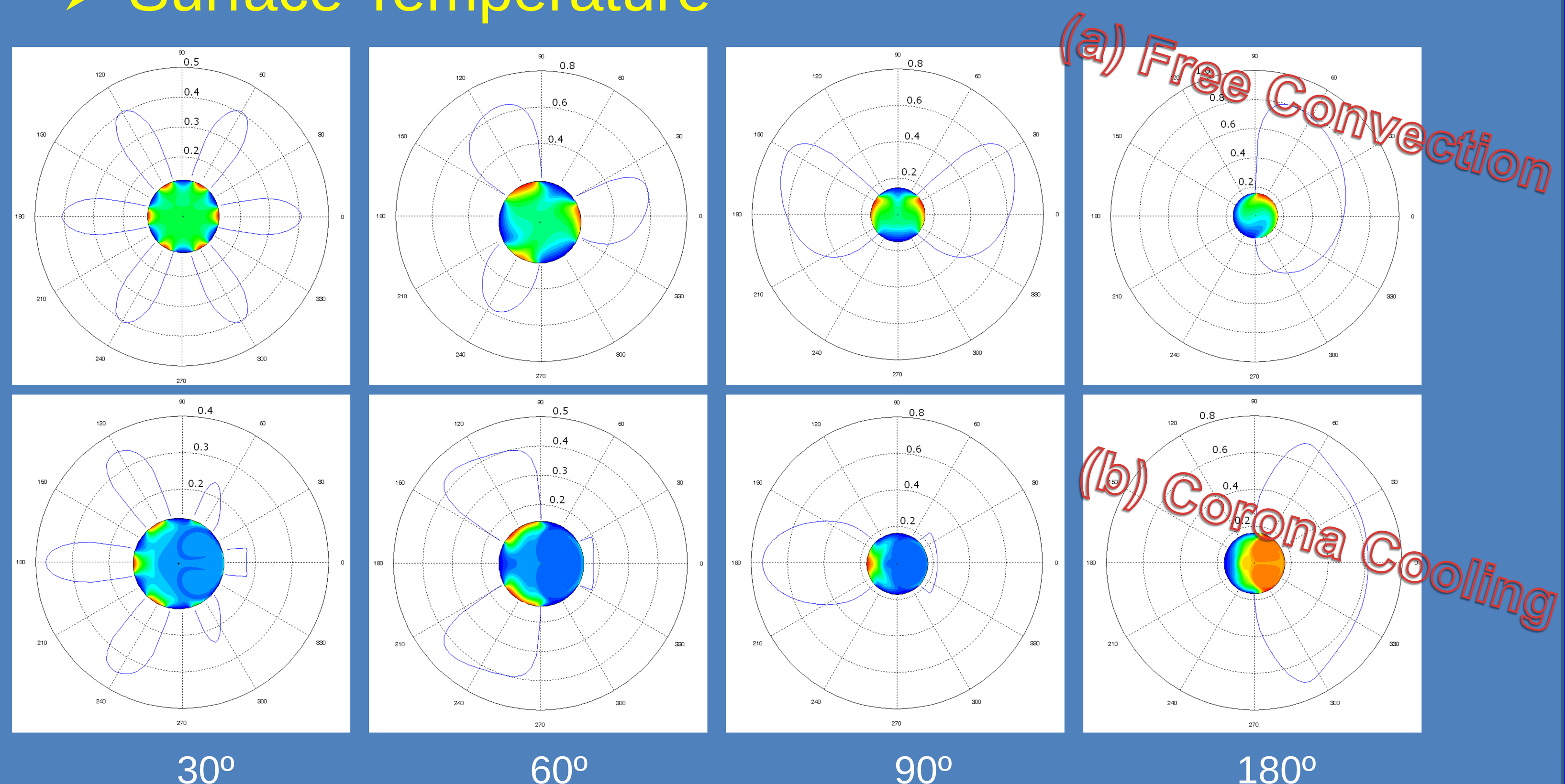


Fig. 4 – Dimensionless Surface temperature polar plots for different extension angles of heating elements **a) Natural Convection b) Corona Cooling;** The surface temperature of the target element reduced noticeably compared with natural convection. The effectiveness of corona cooling is a function of the extension angle. Although the surface temperature of the target element reduces compared with the free convection in all cases, the efficiency of the cooling method decreases in higher extension angles.

➢ Local Nusselt Number

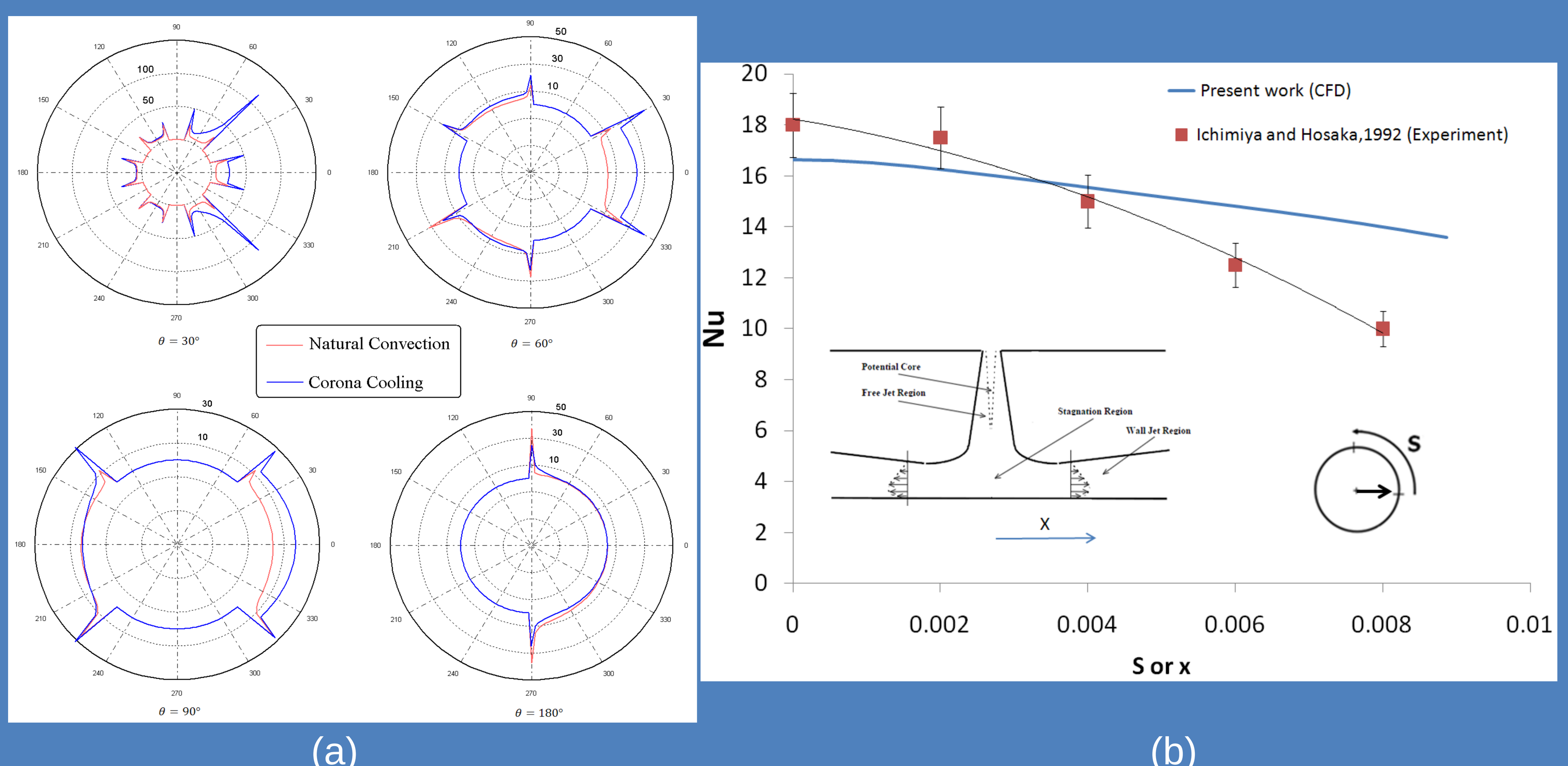


Fig. 5 – a) Surface Nusselt Number for **Natural Convection & Corona Cooling**; The values of Nusselt number are increased compared with the corresponding configuration of natural convection. Smaller heating elements provide a higher Nusselt number and a more efficient targeted cooling. b) Nusselt Number distribution for 90º compared with an experimental work on slot air jet impingement.

$$h=\frac{q''}{T-T_c} \qquad Nu=\frac{hD}{k}$$

Conclusion

➢ The corona-induced jet flow can significantly enhance the local heat transfer from the target heating element and cool the surface of the tube.

➢ The surface temperature of the hot components was decreased 10 K to 16 K degrees, while the local Nusselt number was enhanced 2 to 6 times in different extension angles compared to natural convection.