2016 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Numerical Simulation on Forced Convection Cooling of Horizontal Ionic Wind with Multi-electrodes

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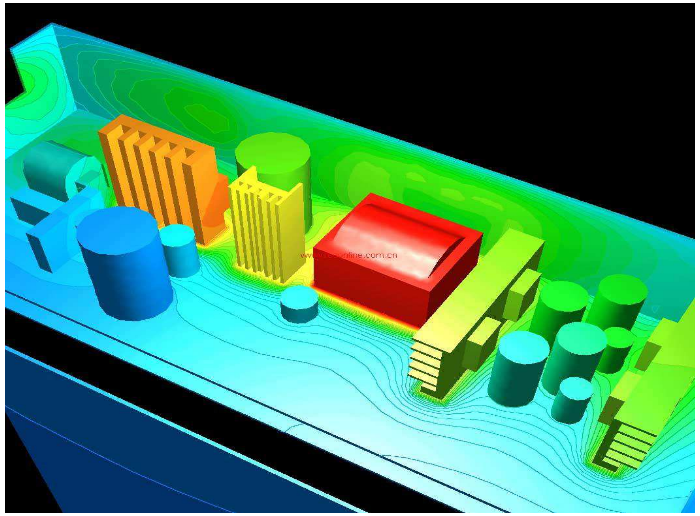
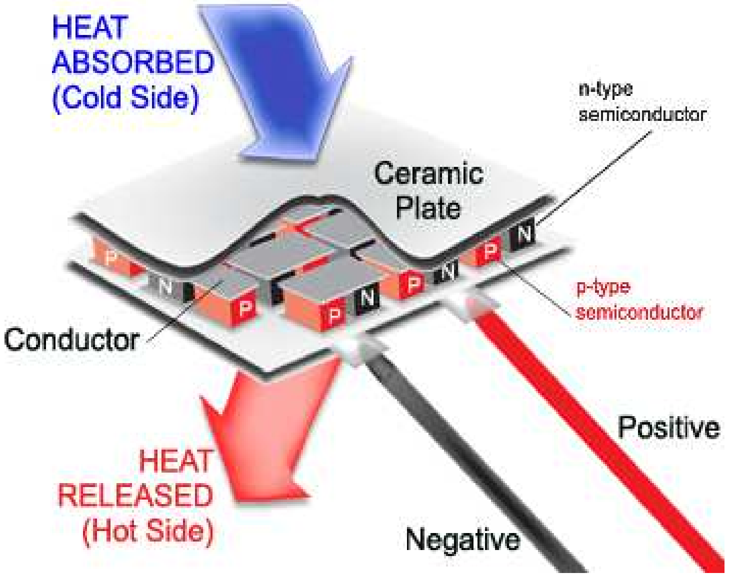
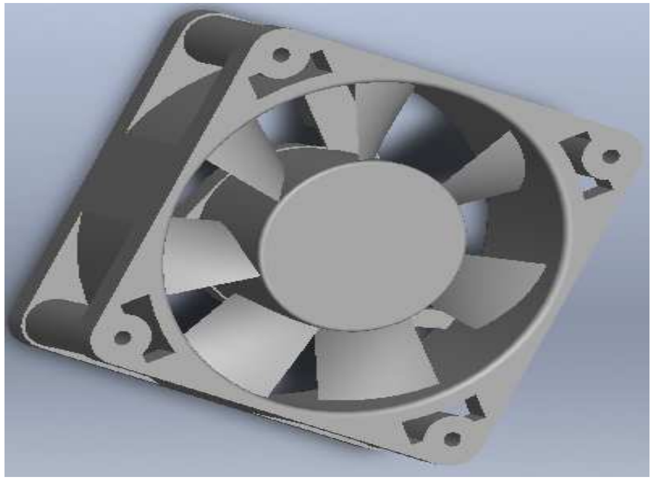
Outline

1. Introduction
2. Mathematical Model
3. Results
4. Conclusion

Introduction



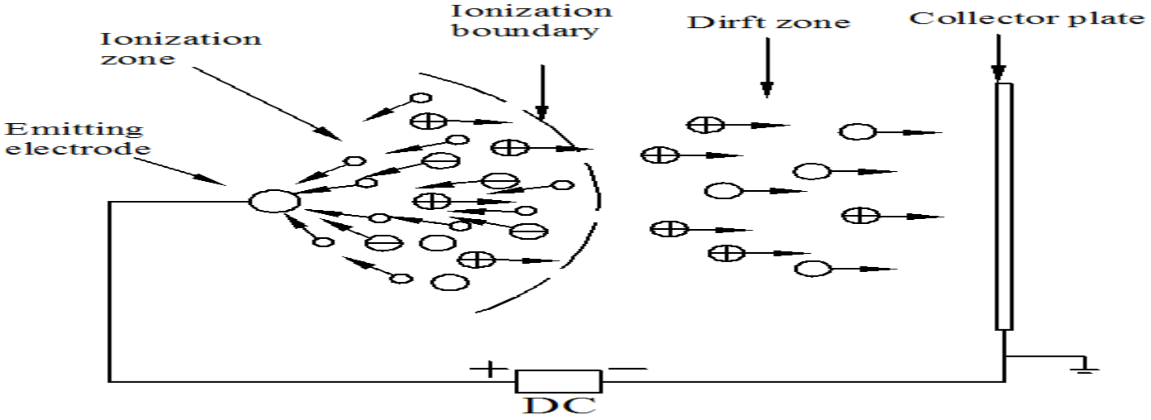




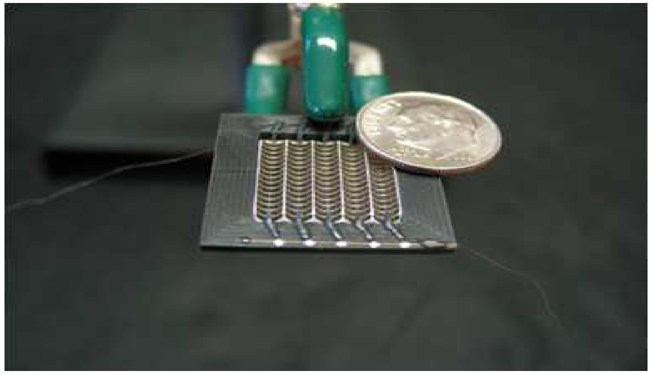
Vibration and Noise

Introduction

Principle of Ionic wind



- No moving part and silent
- Simple structure
- High heat transfer rate



RSD5 Solid-state Fan

u_{max}=2.4m/s

Mathematical Model

Assumption:

- Stable corona discharge process is obtained
- Ignore the influence of the dust
- Ignore the magnetic field generated by ionization
- Ignore the reactions during ionization process
- Flow is under steady condition
- Pressure of the environment is set at one atmosphere pressure

Mathematical Model

Governing Equations

1.Poisson's equation:

$$\nabla^2 \varphi = \frac{\rho_e}{\varepsilon}$$

$$\vec{E} = -\nabla \varphi$$

φ-- electrical potential，V
ρ_e-- space charge density, C/m^3
ε-- dielectric permittivity of vacuum
E-- electrical field density, V/m

2.Current continuity equation:

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

$$\vec{J} = \mu_e \rho_e \vec{E} - D \nabla \rho_e$$

J-- current density, A/m^2
μ_e-- ions mobility, m^2/(V·s)
D-- diffusivity coefficient of ions, m^2/(V·s)

Mathematical Model

3.Navier-Stokes equations and continuity equation:

$$\rho_a \vec{u} \cdot \nabla \vec{u} = \mu \nabla^2 \vec{u} - \nabla p + \overrightarrow{F_e}$$

$$\nabla \cdot (\rho_a \vec{u}) = 0$$

$$\overrightarrow{F_e} = \rho_e \vec{E}$$

ρ_a-- density of air, kg/m^3
u--velocity of air, m/s
μ-- dynamic viscosity of air, kg/(m·s)
p-- pressure, Pa
$\boldsymbol{F_e}$-- volume force, N

4.Energy equation:

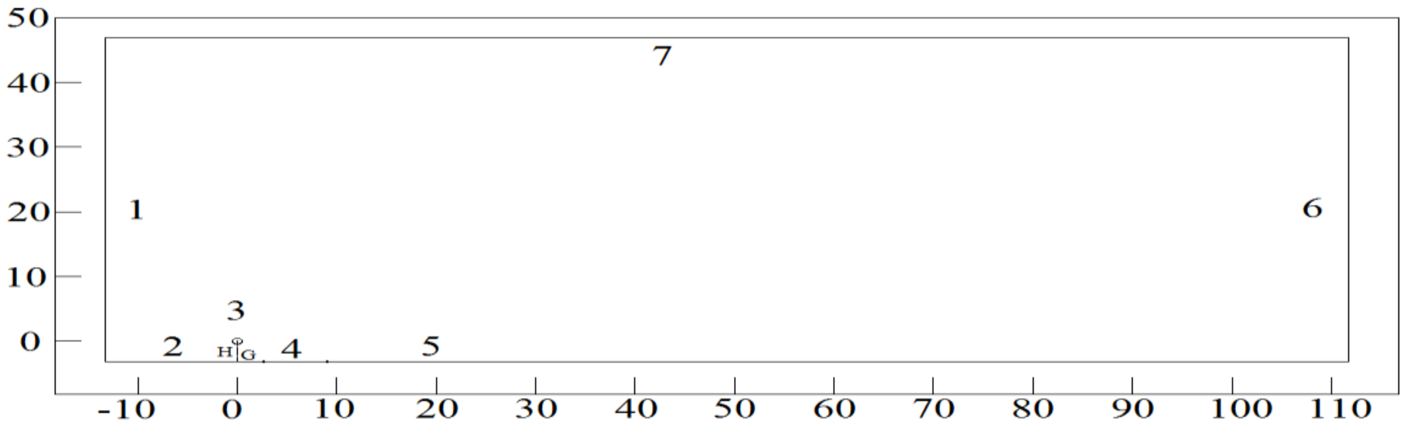
$$\rho_a C_p \vec{u} \cdot \nabla T = k \nabla^2 T + \mu_e \rho_e E^2$$

Joule heating

C_p-- isobaric specific heat capacity of air, J/(kg·K)
k-- thermal conductivity of air, W/(m·K)
T-- temperature of the air, K

Mathematical Model

Simulation domain of the ionic wind



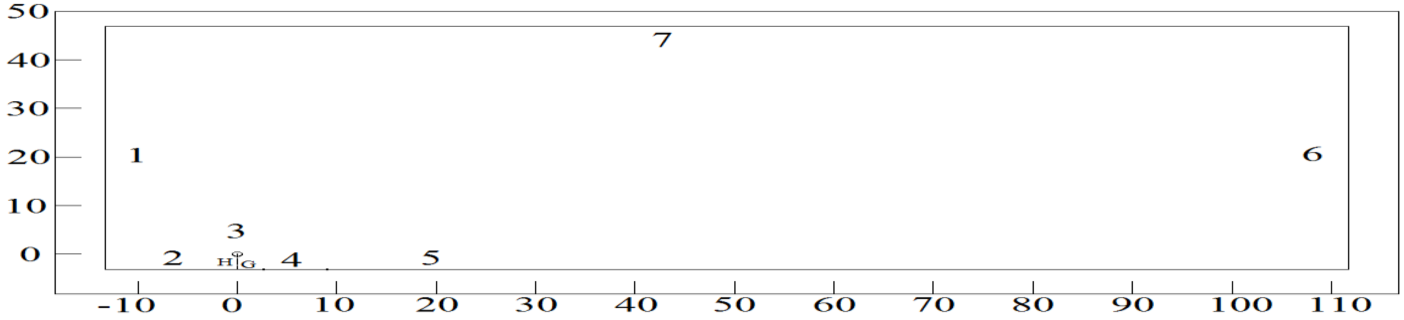
1-- flow inlet; 2,4,5-- heated plate; 3-- emitter electrode;4-- collector plate; 6-- flow outlet.

L=125 mm H=3.15 mm
G=2 mm $R_{emitter}$=50 um

Table 1: Boundary conditions for simulation

Mathematical Model

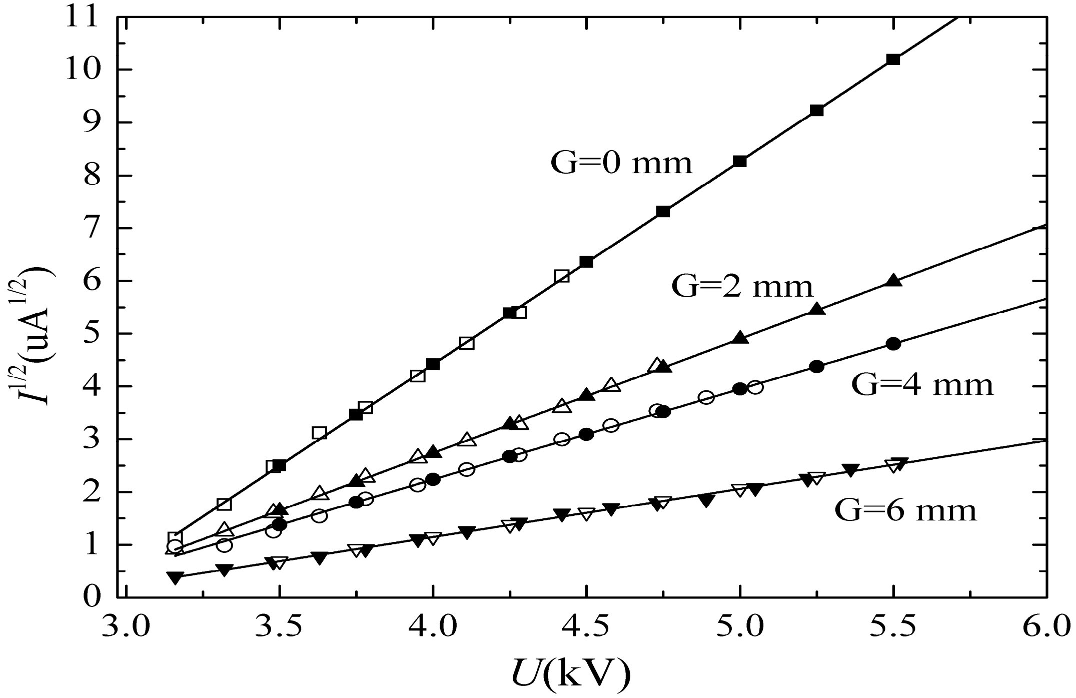
Boundary condition



Boundary	Electric field	Charge Transport	Fluid dynamics	Heat transfer
1	Absorbing boundary condition	Zero flux	$u=u_0$	$T=T_{amb}$
2	Absorbing boundary condition	Zero flux	Wall, no slip	$T=T_{plate}$
3	$\varphi=U_0$	$\rho_e=\rho_0$	Wall, no slip	Adiabatic
4	$\varphi=0$	Zero flux	Wall, no slip	$T=T_{plate}$
5	Absorbing boundary condition	Zero flux	Wall, no slip	$T=T_{plate}$
6	Absorbing boundary condition	Zero flux	$P_{out}=0$	
7	Absorbing boundary condition	Zero flux	Symmetric	

Results

Validation



Solid-- experiment
Hollow-- simulation

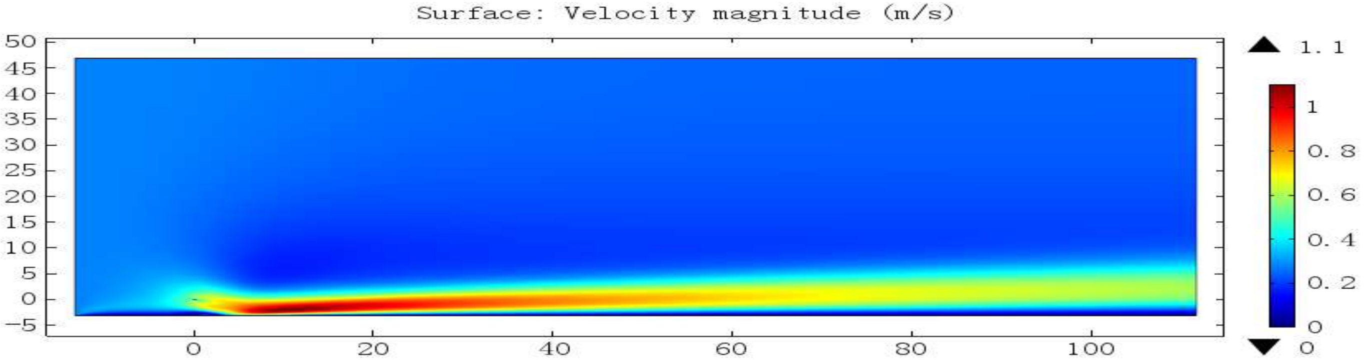
V-I characteristics of ionic wind

Go D.B., *et al.* Enhancement of external forced convection by ionic wind. *International Journal of Heat & Mass Transfer*, *51*(25–26) , 6047-6053.

Results

Horizon ionic wind with single emitter electrode

G=2 mm, U_0=4.50 kV, T_{plate}=343.15 K, u_0=0.28m/s



Flow field of the single electrode ionic wind

$$h = \frac{Q}{A(T_{plate} - T_{amb})}$$

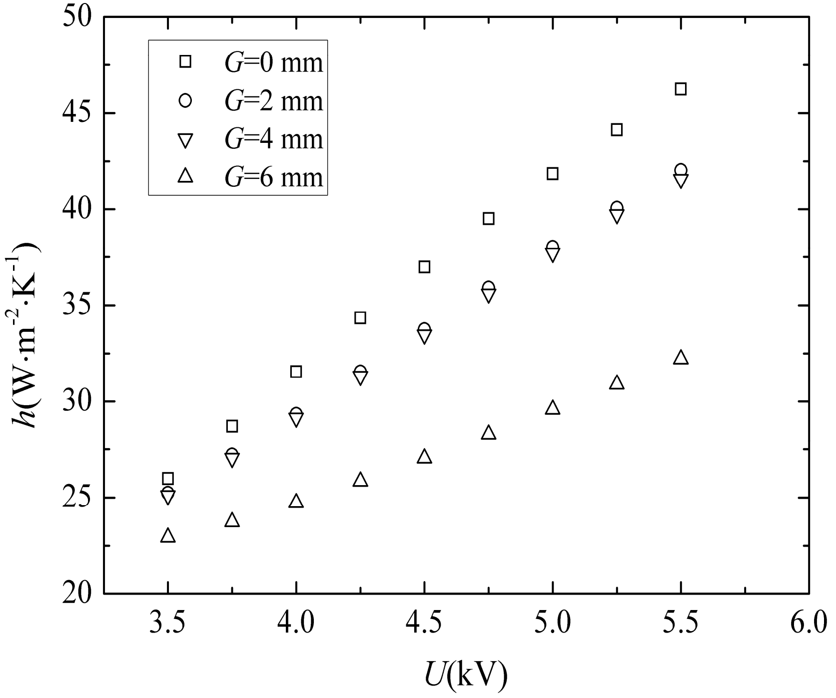
$$\Gamma = \frac{(h_{bulk+ionic} - h_{bulk})}{h_{bulk}} \times 100$$

h= 33.74 W/(m^2·K)

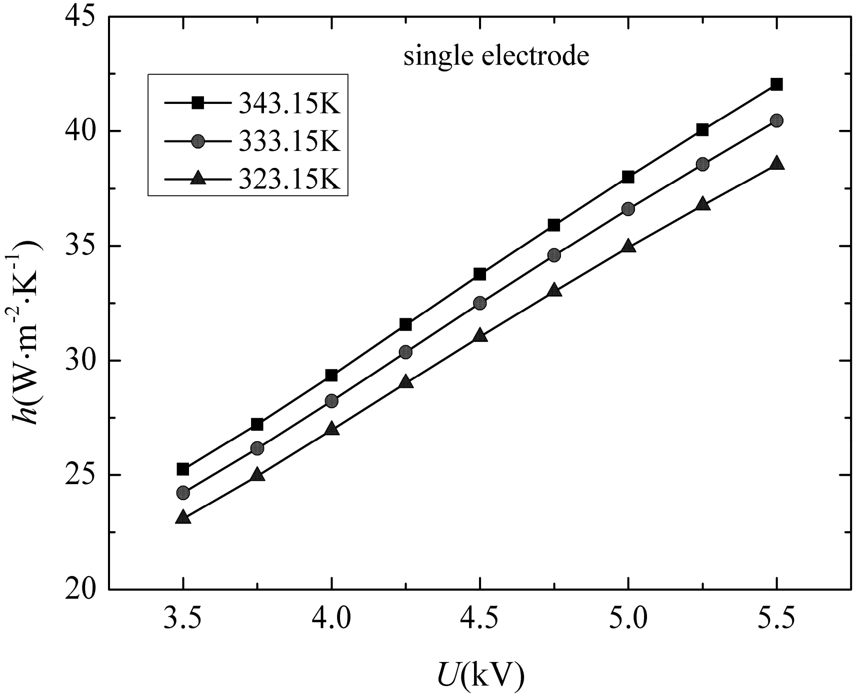
Γ= *50 %*

Results

Horizon ionic wind with single emitter electrode



Heat transfer coefficient at different *G*

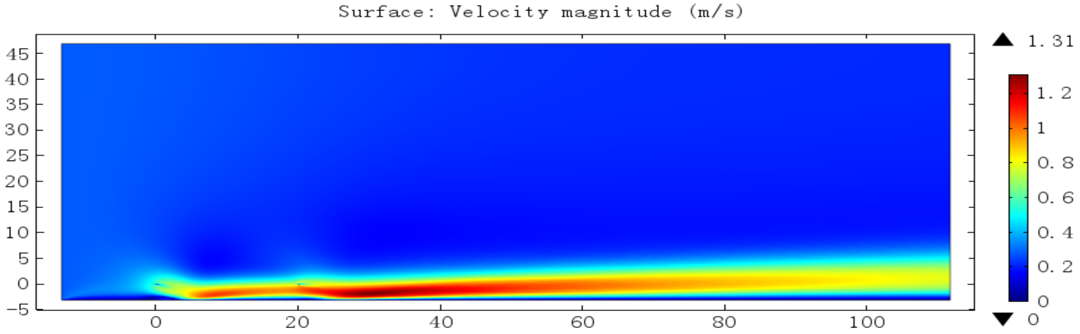


Heat transfer coefficient at different T_{plate}

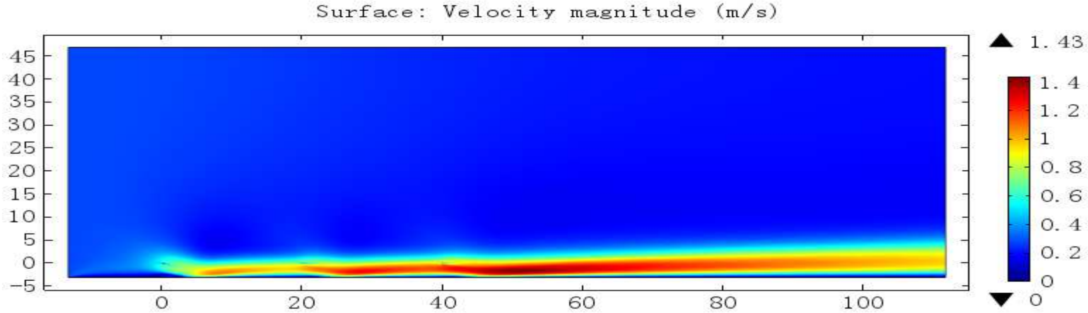
Results

Horizon ionic wind with multi-emitter electrode

G=2 mm, U_0=4.50 kV, T_{plate}=343.15 K, u_0=0.28m/s. d=20 mm



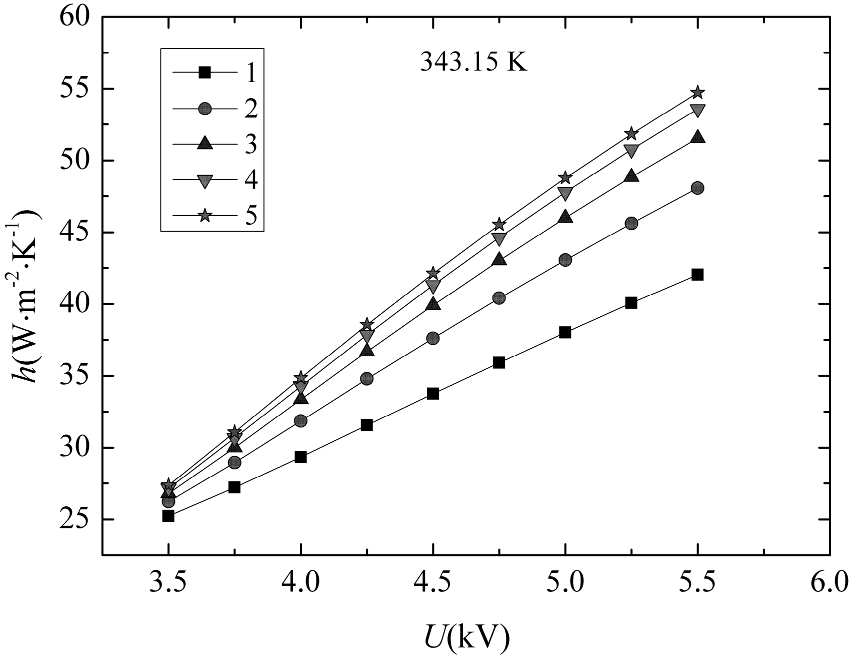
Velocity magnitude of ionic wind with two emitters



Velocity magnitude of ionic wind with three emitters

Results

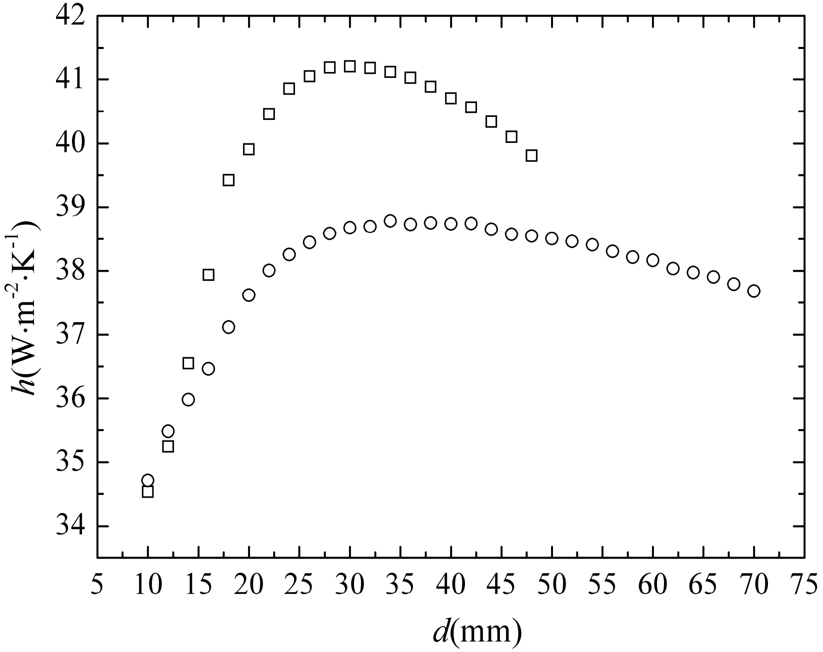
Horizon ionic wind with multi-emitter electrode



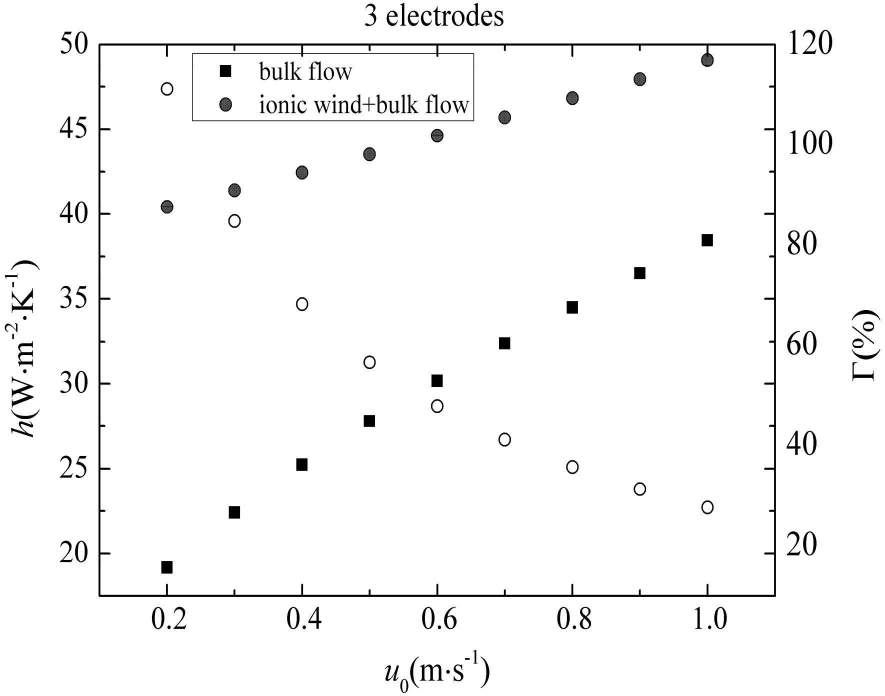
Influences of the electrode numbers on force convection

Results

Horizon ionic wind with multi-emitter electrode



Heat transfer coefficient at different *d*



Effect of the inlet velocity of bulk flow u_0

Cooling effectiveness

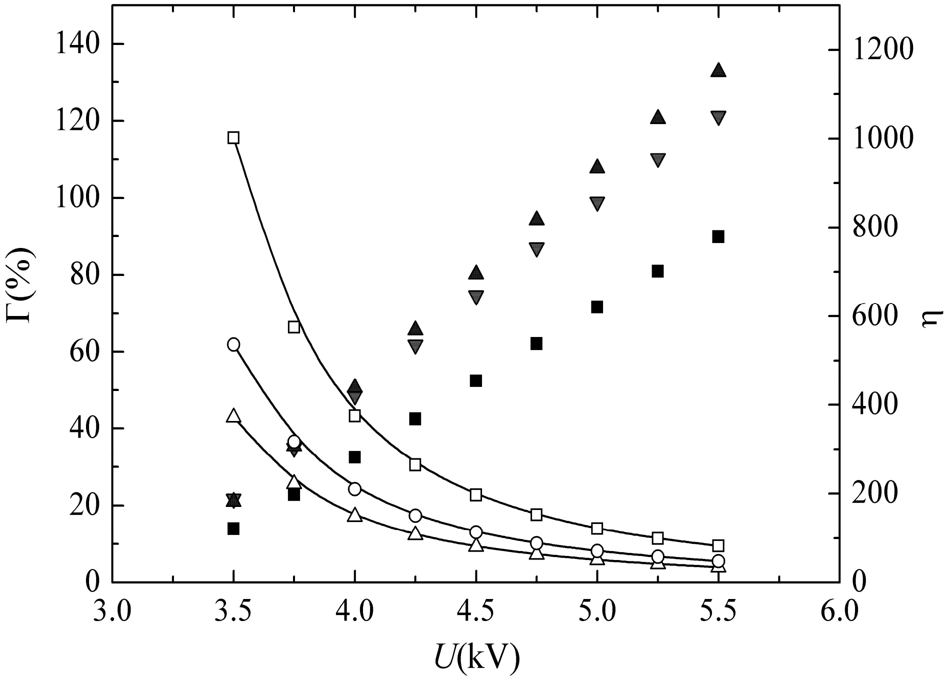
$$\eta = \frac{Q}{IU}$$

I-- total current of ionic wind, A

U-- input voltage, V

Q-- heat, W

η-- cooling Effectiveness



Percentage improvement and cooling effectiveness of the horizon ionic wind

Conclusion

- Heat transfer increases with the increase of the applied voltage and the decrease of the horizon gap *G*.
- Multiple emitter electrodes configuration predicts higher performance in terms of heat transfer coefficient than that of the single emitter electrode, and an maximum enhancement of average heat transfer coefficient around 140 % is obtained
- Better enhancement in heat transfer is happen at low bulk flow.
- An optimal distance between the emitter electrodes may existed to obtained the highest heat transfer coefficient
- Cooling effectiveness of the multiple emitter electrodes is relatively low

Thank you for your attention.
Questions?