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EFFECT OF ASPECT RATIO AND INCLINATION ANGLE ON FLUID FLOW AND HEAT TRANSFER IN RECTANGULAR ENCLOSURES

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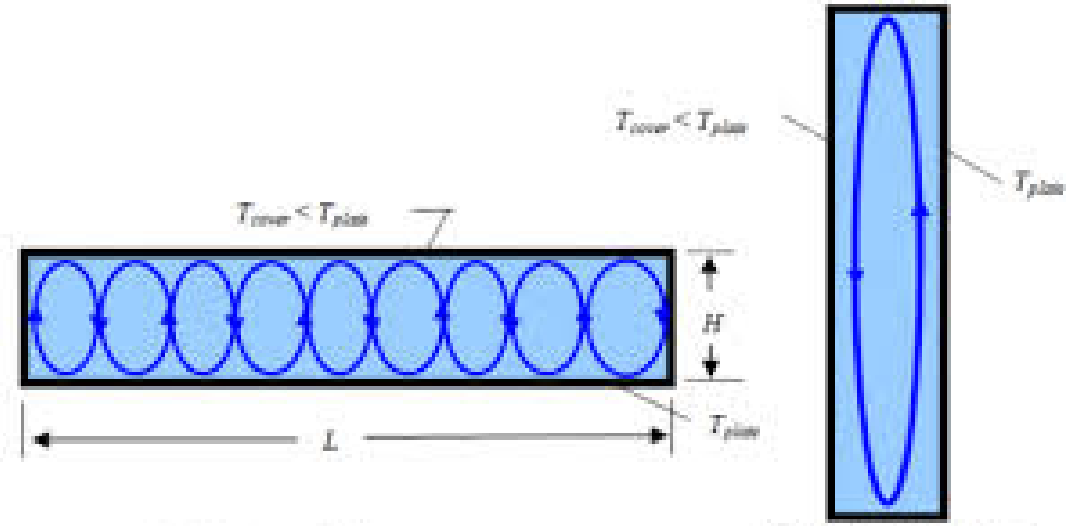
OUTLINE

- Problem Description
- Governing Equations
- Numerical Method
- Validation
- Results
- Conclusion

NATURAL CONVECTION

Natural convection in rectangular enclosures are encountered in many engineering applications such solar collectors, facades, multiple pane windows, hollow bricks.



(a) Horizontal collector with cover glass

(b) Vertical collector with cover glass

PROBLEM DESCRIPTION

Fluid :Air (Pr=0.71)

Flow : Laminar

: Steady

: 2D

: Incompressible

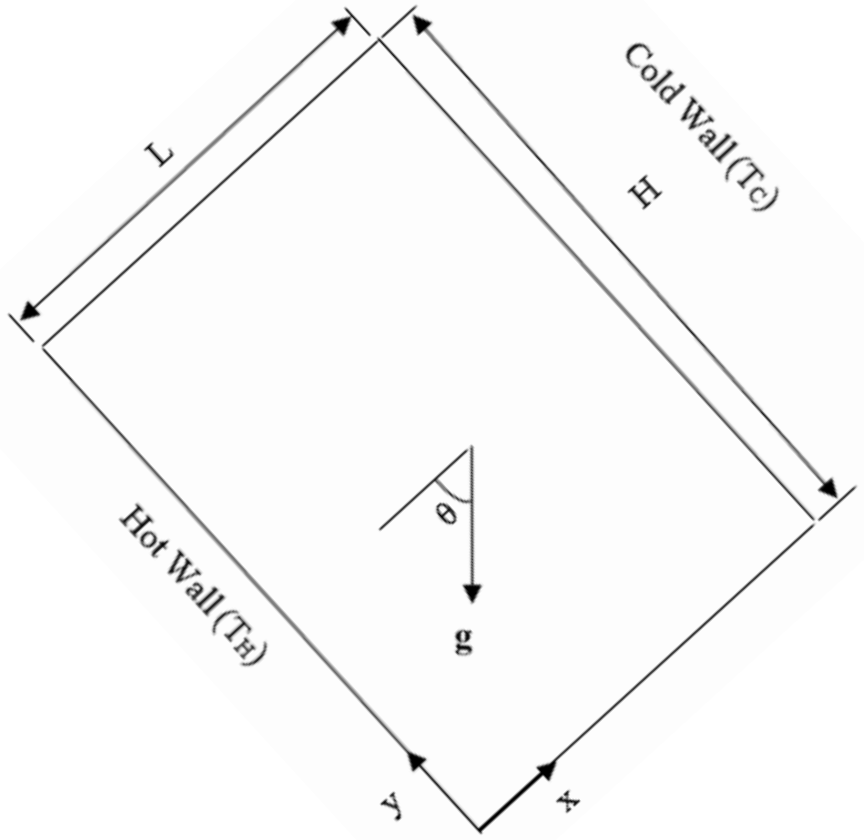
: Boussinessq approximation

T_C = 293 K

T_H = 303 K

T_O = 298 K

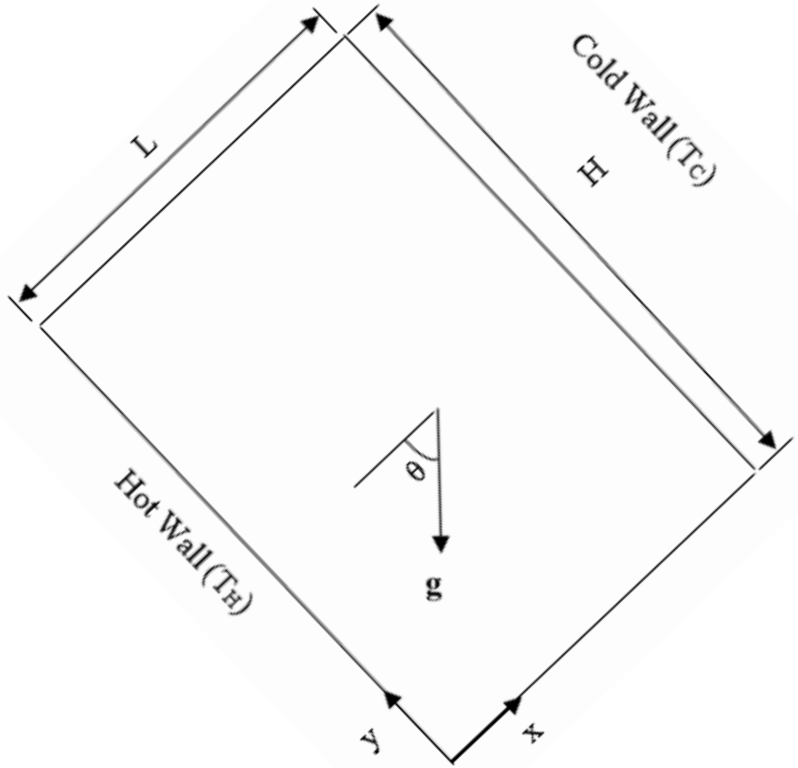
Not participating medium



PARAMETERS OF INTEREST

Rayleigh Number (Ra) $Ra_L = \frac{g\beta\Delta T L^3}{v^2} Pr$	$10^3 – 10^4 – 10^5$
Inclination Angle (θ)	$0^o – 30^o – 60^o – 90^o – 120^o – 150^o – 180^o$
Aspect Ratio (AR) (H/L)	1 – 5 – 20
Emissivity (e)	0 - 1
Radiation Number (Nr) $N_r = \frac{\sigma\varepsilon {T_o}^4}{\frac{k(T_H - T_C)}{L}}$	17.40 – 37.48 – 80.75

Pr=0.71 constant



GOVERNING EQUATIONS

Continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0$$

x-momentum:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+g\beta(T-T_\infty)\sin\theta$$

y-momentum:

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+g\beta(T-T_\infty)\cos\theta$$

Energy:

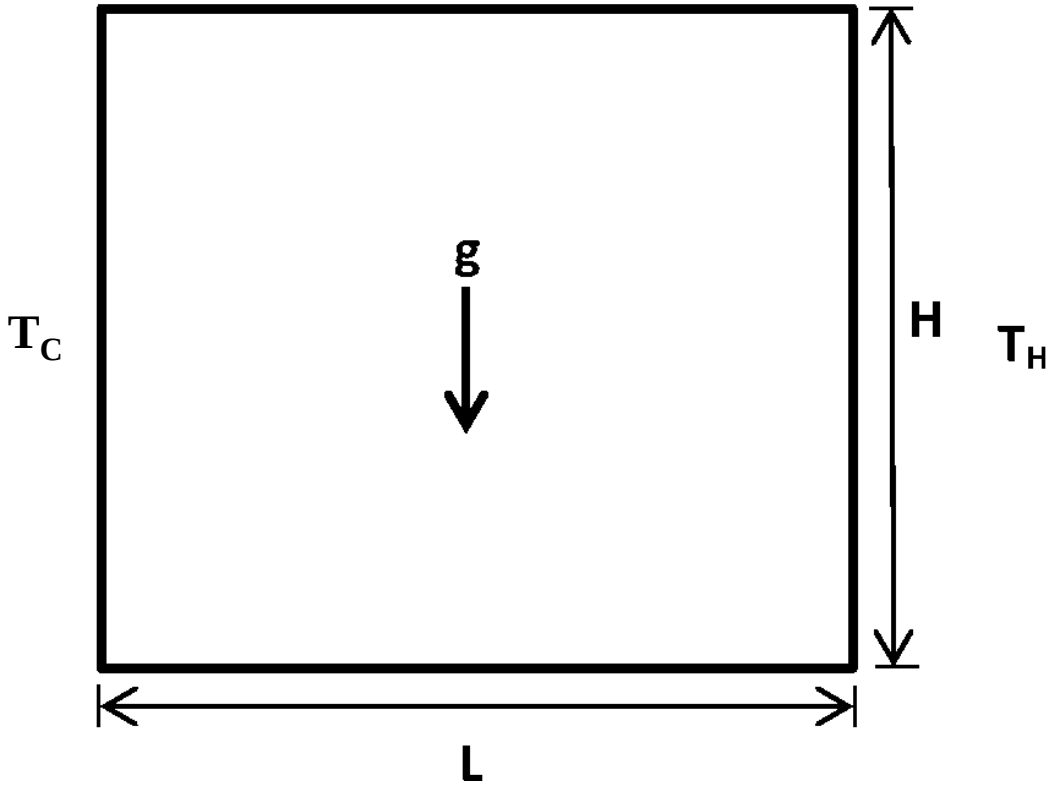
$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)$$

NUMERICAL METHOD

- Governing equations are solved by ANSYS FLUENT.
- Second Order Upwind differencing is used to discretisize momentum and energy equations
- SIMPLE algorithm is used to couple Pressure-Velocity.
- S2S model is used for radiation.
- Residuals are set to 10^{-5}.

VALIDATION (excluding radiation)

Rayleigh Number	10^3	10^4	10^5
De Vahl Davis *	1.116	2.234	4.487
Present study	1.115	2.240	4.528
Difference (%)	0.06	0.27	0.91



*G. De Vahl Davis, Natural convection of air in a square cavity a bench mark numerical solution, International Journal for Numerical Methods in Fluids 3 (1983) 249 – 264.

VALIDATION (including radiation)

	$Nu_{convection}$			$Nu_{radiation}$		
Rayleigh Number	10^4	10^5	10^6	10^4	10^5	10^6
Akiyama and Chong*	2.1	4.3	8.8	3.2	7.0	15.1
Present study	2.2	4.5	8.9	3.1	6.9	14.9
Difference (%)	4.8	4.7	1.1	2.72	1.67	1.27

*M. Akiyama and Q. P. Chong, Numerical Analysis of Natural Convection with Surface Radiation in a Square Enclosure, Numerical Heat Transfer, Part A: Applications 32 (1997) 419-433.

EFFECT OF INCLINATION ANGLE and ASPECT RATIO ($Ra=10^5$, $\varepsilon=0$)

AR=1

Streamlines

Isotherms

AR=5

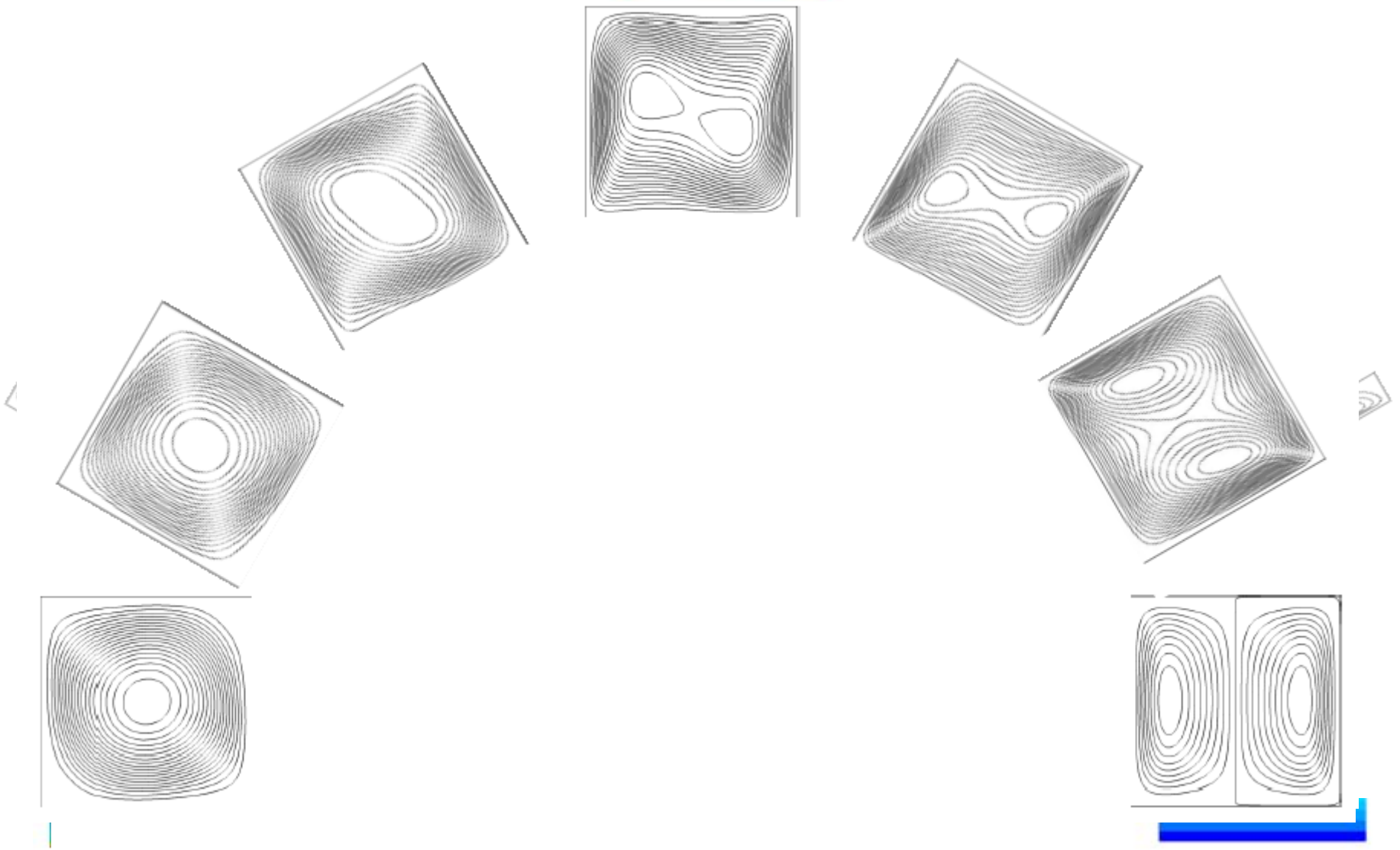
Streamlines

Isotherms

AR=20

Streamlines

Isotherms



EFFECT OF INCLINATION ANGLE and ASPECT RATIO ($Ra=10^5$, $\varepsilon=1$)

AR=1

Streamlines

Isotherms

AR=5

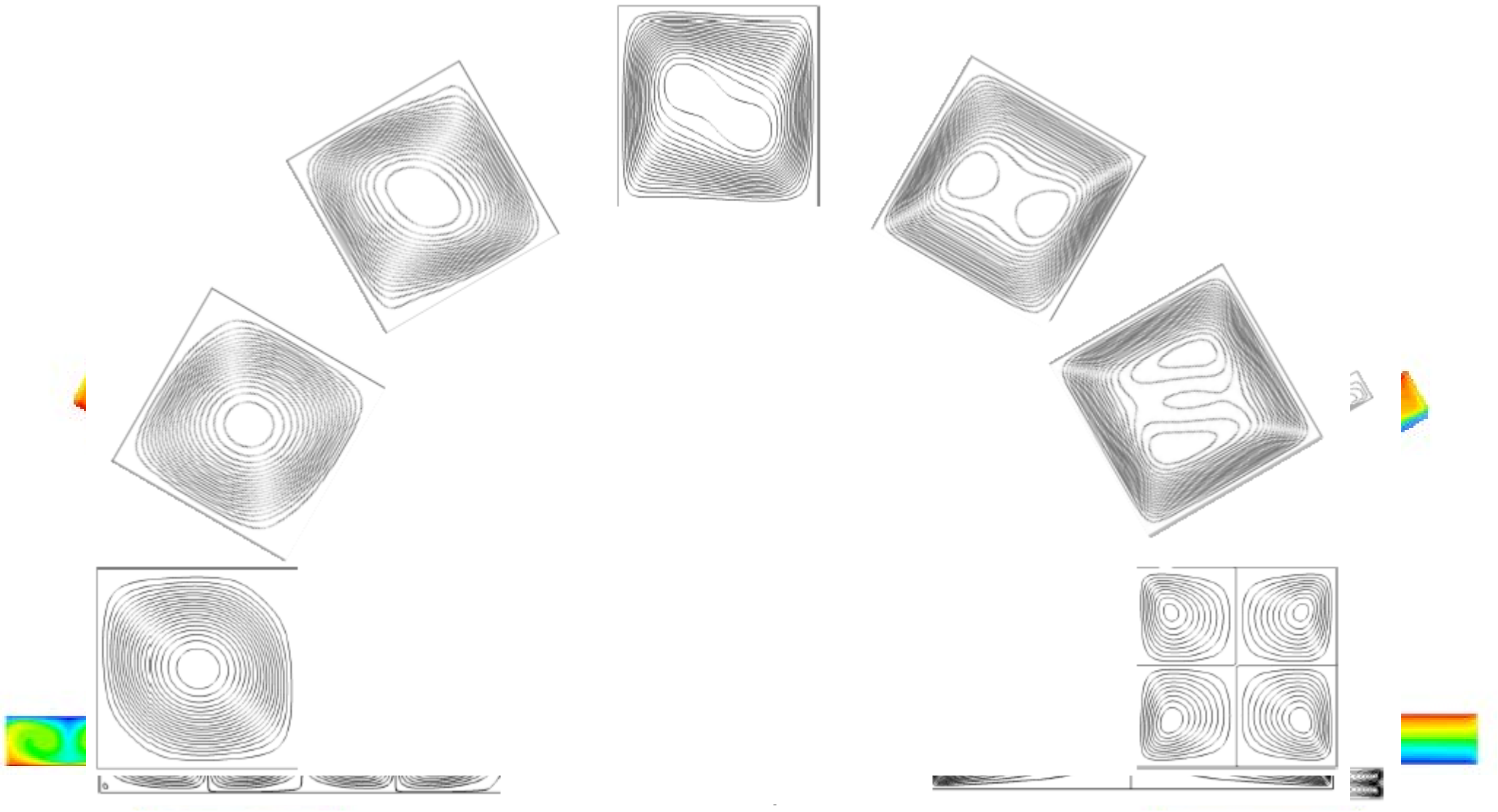
Streamlines

Isotherms

AR=20

Streamlines

Isotherms

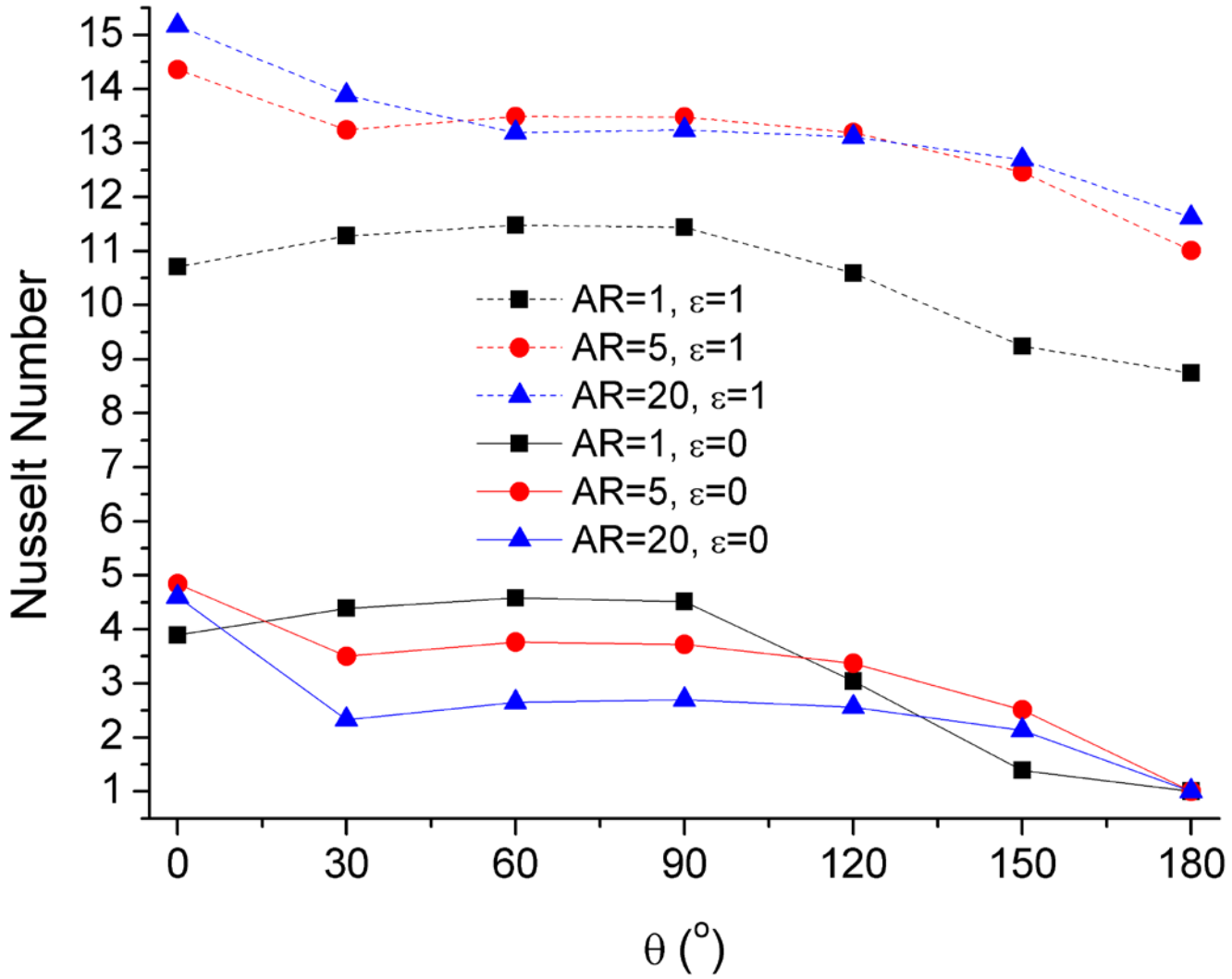


MEAN NUSSELT NUMBER

Ra=10^3

Ra=10^4

Ra=10^5



CONCLUSIONS

- When Rayleigh number or aspect ratio increases, Nusselt number increases.
- Aspect ratio has a significant effect on the flow structure particularly for high inclination angles.
- When radiation is not considered, Nu number decreases as AR increases.
- When radiation is considered, Nu number increases as AR is increased from 1 to 5. Nu number decreases slightly as AR is increased from 5 to 20.
- Effect of radiation is more profound in cases where convective heat transfer is not initiated.
- When radiation is taken into account, Nu number increases 2-11 times depending on aspect ratio and inclination angle.

THANK YOU FOR YOUR ATTENTION