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Research Article

Numerical Studies on Natural Convection Heat Losses from Open Cubical Cavities

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The natural convection heat losses occurring from cubical open cavities are analysed in this paper. Open cubical cavities of sides 0.1 m, 0.2 m, 0.25 m, 0.5 m, and 1 m with constant temperature back wall boundary conditions and opening ratio of 1 are studied. The Fluent CFD software is used to analyse the three-dimensional (3D) cavity models. The studies are carried out for cavities with back wall temperatures between 35°C and 100°C. The effect of cavity inclination on the convective loss is analysed for angles of 0° (cavity facing sideways), 30°, 45°, 60°, and 90° (cavity facing vertically downwards). The Rayleigh numbers involved in this study range between 4.5×10^5 and 1.5×10^9. The natural convection loss is found to increase with an increase in back wall temperature. The natural convection loss is observed to decrease with an increase in cavity inclination; the highest convective loss being at 0° and the lowest at 90° inclination. This is observed for all cavities analysed here. Nusselt number correlations involving the effect of Rayleigh number and the cavity inclination angle have been developed from the current studies. These correlations can be used for engineering applications such as electronic cooling, low- and medium-temperature solar thermal systems, passive architecture, and also refrigeration systems.

1. Introduction

Buoyancy-driven heat transfer is one of the most important heat loss mechanisms from open cavities and is now widely studied due to their applications in many engineering fields such as solar thermal conversion, refrigeration, passive architecture, fire research, and electronic equipment cooling. The heat loss due to natural convection from open cavities is dependent on various factors such as shape of cavity, cavity wall boundary conditions, cavity inclination, aspect ratio, and opening ratio. Therefore in open cavities, the natural convection heat transfer analysis is complicated when compared to the heat transfer due to radiation and conduction.

It is observed from the literature that experimental and numerical studies on natural convection in open cavities have been performed for different cavity shapes, namely, cubical [1–6], rectangular [7–17], and square [18–24]. Studies have also been reported on other cavity shapes used for specific applications like solar thermal receivers [25–31].

In the studies involving open cavity natural convection, two basic boundary wall conditions are observed: (a) all the walls of the open cavity were heat transfer surfaces at constant temperature [1, 2, 4, 6, 8, 9, 12, 18, 19, 21, 22, 25, 26, 30–32], henceforth referred to as isothermal wall boundary condition and (b) only one wall (wall opposite to the aperture) was at constant temperature and the remaining walls were kept adiabatic, henceforth referred to as constant temperature back wall boundary condition [3, 5, 10, 11, 13, 20, 23, 24, 33]. Other wall boundary conditions such as one wall having constant heat flux and other walls being adiabatic [14–16] and non-isothermal wall temperatures [7, 27–29] were also studied. Chakroun [17] studied the effect of different wall boundary conditions on the natural convection heat transfer from an open cavity.

It is noticed from the literature that there are studies related to natural convection loss from cavities at 0° (sideways facing cavity) inclination [2–4, 11–14, 20, 23]. The effects of more than one angle of cavity inclination (upward and downward facing) on the convective losses are also analysed [1, 5–9, 14–19, 21, 22, 24–33], and it is inferred from these studies that for a downward facing cavity, the convective loss decreases with an increase in inclination; the highest loss being at 0° inclination and the least at 90° (vertically downward facing cavity).

The ratio of cavity aperture dimension to the cavity dimension can be termed as opening ratio (a/H or d/D). Opening ratios of 1 [1–3, 5, 6, 9–13, 16–23, 25, 26], 0.5 [3, 8, 22, 30], 0.6 and 0.4 [7], and 0.25 [30] have been studied. Clausing et al. [4], Chakroun et al. [14], Elsayed and Chakroun [15], Bilgen and Oztop [24], Stine and McDonald [28], McDonald [29], and Sendhil Kumar and Reddy [31] have analysed different opening ratios ranging from 1 to about 0.1. The effect of this ratio on the convection loss is found to be significant as the loss decreased with a decrease in the opening ratio.

It can be observed from the literature that the determination of convective losses from cubical and rectangular open cavities are mainly carried out for isothermal wall boundary condition while studies related to the constant temperature back wall boundary condition are limited. The effect of inclination on the convective loss from open cavities with isothermal wall boundary condition is studied extensively, but the inclination effect on convective loss from cavities with a constant temperature back wall boundary condition is limited to a study by Hinojosa et al. [5]. Studies carried out by Bilgen and Oztop [24] mainly involve the upward facing cavity. Mohamad [34] and Polat and Bilgen [35] have also analysed upward facing cavities with constant heat flux back wall boundary condition. These studies [24, 34, 35] indicate a weak effect of the inclination angle on the convective losses. The effect of inclination on the convective loss needs to be analysed when the open cavity is used for specific applications such as solar thermal conversion systems, passive architecture, and electronic cooling.

It was also observed that most of the studies from cubical and rectangular open cavities with a constant temperature back wall boundary condition are limited to Rayleigh numbers of about 10^7 except for studies such as Hess and Henze [3] and Chan and Tien [10], where Rayleigh numbers of about 10^{11} and 10^9 have been analysed, respectively. Nusselt number correlations have been proposed for open cavities with a constant temperature back wall boundary condition, but their use is limited to 0° inclination and low Rayleigh numbers.

In this communication, numerical studies of natural convection heat transfer from open cubical cavities of sides 0.1 m, 0.2 m, 0.25 m, 0.5 m, and 1 m are carried out. The cavities have a constant temperature back wall boundary condition. The cavities are fully open (opening ratio of 1) and are inclined at different inclinations (downward facing). Rayleigh numbers in the range of 4.5×10^5–1.5×10^9 are studied. Nusselt number correlations that involve Rayleigh numbers and the inclination effects are proposed. These correlations can be used for engineering applications such as electronic cooling, low- and medium-temperature solar thermal systems, passive architecture, and also refrigeration systems.

2. Problem Description

Open cubical cavities of sides 0.1 m, 0.2 m, 0.25 m, 0.5 m, and 1 m are used for the study. The numerical analysis is performed with a constant temperature back wall boundary condition. The convective loss from each open cubical cavity is analysed for different back wall temperatures between 35°C and 100°C. The inclination effect on the convective loss for each back wall temperature case is studied for five different cavity inclinations: 0° (sideways facing cavity), 30°, 45°, 60°, and 90° (vertically downward facing cavity). The ambient temperature is kept constant at 30°C. The Rayleigh number range is between 4.5×10^5 and 1.5×10^9. The aperture height of each cavity is equal to the cavity side, thus making them fully open cavities ($a/H = 1$). Figure 1 shows the schematic of the open cubical cavity with back wall temperature T_{bw} and inclined downwards at an angle θ.

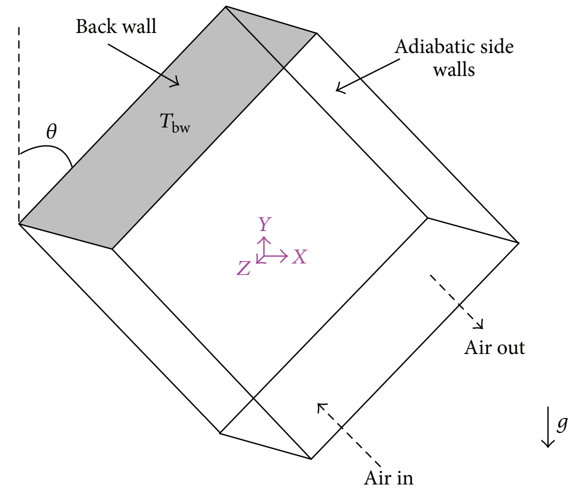
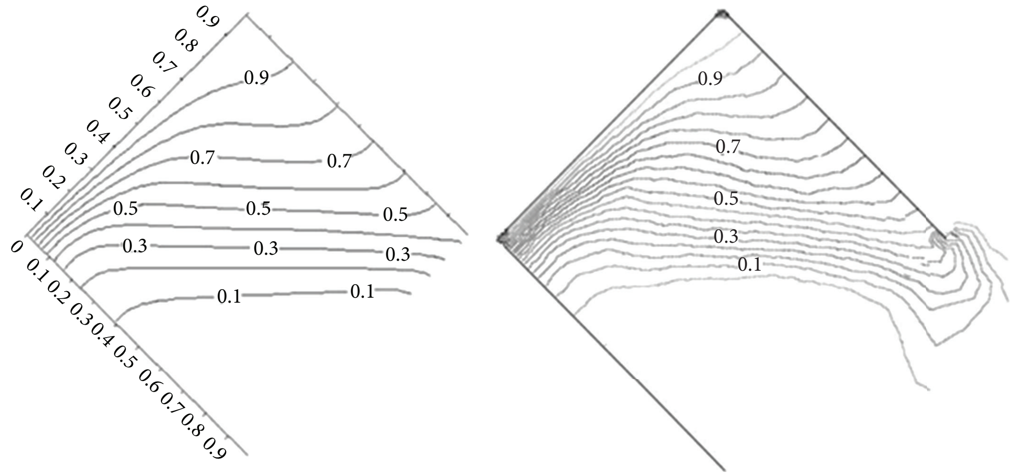


Figure 1: Schematic of the open cubical cavity inclined downwards at an angle θ.

It is seen from the literature that the numerical analyses of natural convection losses in solar cavity receiver [26, 27, 31] have been performed using the Fluent CFD [36] software. The appropriateness of using Fluent CFD software for the present numerical study, therefore, needs to be checked. In order to check this, a study from the literature (Hinojosa et al. [5]) is used. The work of Hinojosa et al. [5] refers to the three-dimensional (3D) numerical study of open cubical cavities with constant temperature back wall boundary condition. The analysis by Hinojosa et al. [5] was performed for Rayleigh numbers between 10^4 and 10^7 and for cavity inclinations between −90° (vertically upward facing cavity) and 90° (vertically downward facing cavity). Hinojosa et al. [5] performed numerical analysis using the finite-volume method, the SIMPLEC algorithm, the SMART scheme, and the central differencing scheme.

A cubical open cavity is modelled using the Gambit tool of the Fluent CFD software [36]. The model is analysed using the Fluent CFD software for Rayleigh numbers equal to 10^5 and three inclination angles (0, 45, and 90 degrees). The temperature profiles obtained from the Fluent CFD model are compared with those reported by Hinojosa et al. [5] at Ra = 10^5 and cavity inclinations of 0, 45, and 90 degrees. Figure 2 shows the temperature profiles obtained from Hinojosa et al. [5] and the Fluent CFD model for the cubical cavity (cavity



Hinojosa et al. [5]

(a)

Fluent CFD model

(b)

Figure 2: Comparison of temperature profiles at the midplane of the cavities at 45° inclination and Rayleigh number of 10^5.

midplane) inclined at 45°. A good agreement is observed. The maximum variation between the Nusselt numbers obtained from the Fluent CFD model and Hinojosa et al. [5] is about 7%. It can, therefore, be concluded from this preliminary study that the Fluent CFD software can be used to analyse natural convection heat transfer in cubical open cavities with constant temperature back wall boundary condition and different cavity inclinations.

3. Numerical Scheme

3D numerical models of the open cubical cavities of sides 0.1 m, 0.2 m, 0.25 m, 0.5 m, and 1 m are created using the Gambit tool [36]. The initial boundary condition at the aperture is unknown; hence, an enclosure, cubical in shape, representing the ambient is also modelled for each cavity in Gambit. An initial study is performed to determine the optimal dimensions of the enclosure. It is observed that an enclosure dimension ten times the cavity side affects the convection occurring within the cavity while this is not observed for enclosures having dimensions equal to and above 15 times the cavity side. Hence, an enclosure with sides having dimensions equal to fifteen times the cavity side dimension is chosen for the analysis. The mesh chosen for the analysis is nonuniform with the areas close to the cavity having a smooth mesh (mesh interval size of about 10) while the mesh is coarse at the enclosure walls (mesh interval size of about 300). These mesh sizes are chosen from a grid independence study performed on a 0.25 m cubic cavity with Ra of 2.4×10^7. The number of cells used for the simulations is of the order of 2×10^5. Figure 3 shows a sample of the internal and external mesh used for the numerical analysis. It can be seen from the figure that the mesh is made to progressively coarsen from the cavity to the enclosure walls.

The transition from laminar to turbulent flow in natural convection heat transfer from heated plates is reported in the literature and is dependent on the orientation of the plate (vertical, upward and downward facing horizontal, and inclined). In an open cavity, the heated wall is surrounded by other walls and the heated wall position changes with the cavity inclination (at 0° cavity inclination, the heated wall is vertical while it is horizontal at 90° inclination). It is, therefore, observed that the Rayleigh number at which flow transition occurs from laminar flow to turbulent flow in open cavities is not well defined. Therefore in this paper, a laminar model is assumed for Rayleigh numbers below 1×10^9 and the k-ε turbulence model for higher Rayleigh numbers.

The cavity wall material is chosen as copper while air ($\mathrm{Pr} = 0.7$) is the fluid within the cavity and the enclosure. Kothandaraman and Subramanyan [37] have been referred for the material properties used in this study. The Boussinesq approximation for air properties is used. The gravity vector is adjusted so as to perform the analysis at different inclinations.

The general equations describing the conservation of mass, momentum, and energy are given as (Kakac et al. [38])

$$\nabla \cdot V = 0,$$

$$V \cdot \nabla V = f - \frac{\nabla P}{\rho} + \nu \nabla^2 V, \tag{1}$$

$$\nabla \cdot (k \nabla T) = 0.$$

The numerical simulations are based on the simultaneous solutions of the above-mentioned equation (1).

The boundary conditions used for the numerical analysis are as follows:

(1) cavity back wall temperature is specified,

(2) other four cavity walls are adiabatic,

(3) the cavity walls are insulated from the outside, and

(4) enclosure walls are maintained at ambient temperature ($T_a = 30°\mathrm{C}$).

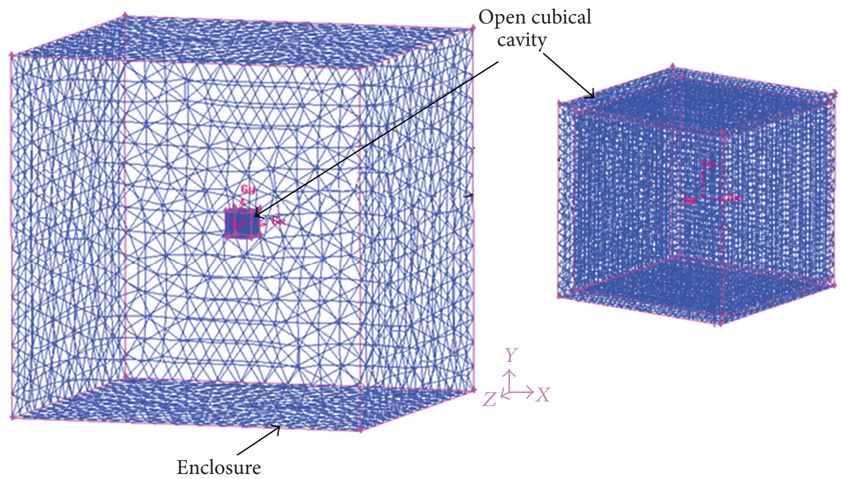


Figure 3: The mesh used for the open cubical cavity at 0° inclination along with the enclosure.

The Semi-Implicit Pressure-Linked Equation (SIMPLE) scheme of Fluent software is used for the numerical analysis. The SIMPLE scheme is found to be more suited for complicated problems involving laminar, transitional, and turbulent flow. The scheme involves a pressure-velocity coupling and is stable than other pressure-velocity coupling schemes. It is used along with a segregated solver for steady-state problems. First-order upwind momentum and energy solution controls are used in order to reduce the convergence time. The convergence criterion set for the residuals is of the order of 10^{-3} for the continuity and the velocity equations while for the energy equation it is 10^{-6}. The simulations are complete once the convergence criteria are satisfied. The convective loss values are then obtained from the simulations.

In the present study, the numerical analysis is performed on 3D cubical cavity models with constant temperature back wall boundary condition. The back wall temperatures range between 35°C and 100°C and the ambient temperature is 30°C. For each constant temperature back wall case, the cavity is inclined at five angles (0, 30, 45, 60, and 90°). The steady-state convective losses are then obtained from the numerical simulations.

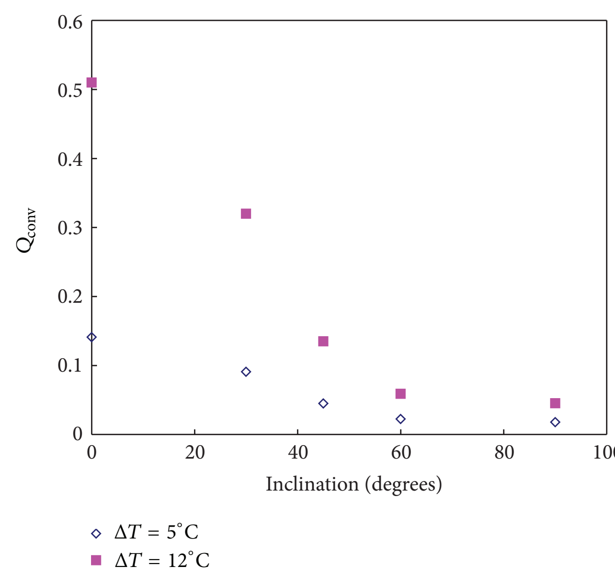


Figure 4: Variation of the convective loss (in Watts) with ΔT and inclination for open cubical cavity of side 0.1 m.

4. Results and Discussion

The convective loss due to buoyancy from open cubical cavities of side 0.1 m is shown in Figure 4. It is observed that the convective losses increases with an increase in ΔT ($\Delta T = T_{bw} - T_a$) value. This is valid for all cavity sizes. It is also seen that the convective losses decrease with an increase in cavity inclination; the highest loss at 0° and the least at 90°. The relation between the convective loss and inclination is nonlinear. This is similar to the findings by Hinojosa et al. [5]. Figure 5 shows the convective loss trends for the cavity with side 0.5 m and ΔT of 20°C and 70°C. Similar trends are observed for all cubical cavities analysed here.

The decrease in convective loss with an increase in cavity inclination is due to the presence of stagnation and convective zones within the cavity. The convective losses occur from the convective zone. It is observed from the temperature profiles that there is a stagnation zone at the topmost part of the cavity and this zone area increases with cavity inclination. The convective zone area on the other hand decreases with cavity inclination leading to a decrease in convective loss. This can be observed from Figure 6 where the temperature profiles along with the nondimensional air temperature values $((T_{air,i} - T_a)/(T_{bw} - T_a))$ are shown for a cubical cavity of 0.5 m side, $T_{bw} = 100$°C and inclined at different angles. The temperature profiles obtained from other cubical cavities analysed here also show similar trends.

The average heat transfer coefficient (h) is calculated for each case:

$$h = \frac{Q_{conv}}{A_{bw}\left(T_{bw} - T_a\right)}, \tag{2}$$

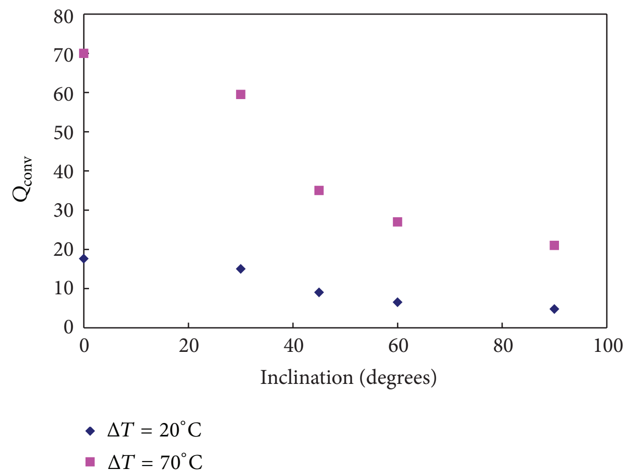


Figure 5: Variation of the convective loss (in Watts) with ΔT and inclination for open cubical cavity of side 0.5 m.

where Q_{conv} is the natural convection loss, A_{bw} is the area of the cavity back wall, T_{bw} is the back wall temperature, and T_a is the ambient temperature.

The average Nusselt number based on the cavity height (Nu_H) is then calculated:

$$\text{Nu}_H = \frac{hH}{k}, \quad (3)$$

where H is the height (side) of the cubical cavity and k is the thermal conductivity of air. All air properties are obtained at the film temperature T_f (Clausing et al. [4]), where $T_f = 0.5(T_{\text{bw}} + T_a)$.

The Rayleigh number is calculated based on the cavity height (H):

$$\text{Ra}_H = \frac{g\beta\Delta T H^3}{\nu^2}\,\text{Pr}, \quad (4)$$

where g is the gravitation acceleration, β is the volume coefficient of expansion, ν is the kinematic viscosity, and Pr is the Prandtl number (0.7 for air). The range of Rayleigh number is between 4.5×10^5 and 1.5×10^9.

A comparison of the Nusselt number values obtained from the present simulation and those reported by Hinojosa et al. [5] for $\text{Ra}_H = 1 \times 10^6$ is shown in Table 1. The maximum variation is about 10%. It is also observed that there are convective currents at the cavity aperture at 90° inclination, and hence the cavity is not fully in the stagnation zone. This leads to very low convective loss values and hence the lowest average Nusselt numbers when compared to other inclinations.

It is realized that correlations between the calculated Nusselt number and the Rayleigh number are important for determining or predicting the convective loss from open cubical cavities with constant temperature back wall conditions. The inclination effect on the convective loss also needs to be incorporated in the correlations so that the convective losses at different inclinations (for downward facing cavities)

Table 1: Comparison of the Nusselt number values obtained from the present simulation and those reported by Hinojosa et al. [5] for $\text{Ra}_H = 1 \times 10^6$ at different inclinations.

Inclination	Nusselt number from present simulation	Nusselt number from Hinojosa et al. [5]	Variation (%)
0°	15.74	14.33	9.83
30°	9.88	9.55	3.45
45°	4.17	4.32	3.47
60°	1.82	1.86	2.15
90°	1.39	1.45	4.13

can be determined accurately. In this study, Nusselt number correlations are developed by regression analysis. The correlations take into account the Rayleigh numbers and the inclination effect. The correlations will be relevant for open cubical cavities used in solar thermal conversion systems, passive architecture and electronic cooling applications.

The Rayleigh numbers involved in these studies range between 4.5×10^5 and 1.5×10^9, and a single correlation between the Nusselt number, the Rayleigh number, and all the inclination angles for this entire range is not possible. Therefore, two correlations involving the Nusselt number, the Rayleigh number, and the inclination angles are proposed for two ranges of Rayleigh numbers: (i) $4.5 \times 10^5 \le \text{Ra}_H \le 1 \times 10^7$ and (ii) $2.5 \times 10^7 \le \text{Ra}_H \le 1.5 \times 10^9$. A correlation for the entire range of Rayleigh numbers (4.5×10^5–1.5×10^9) is only possible for the 0° inclination case.

The variation of Nusselt numbers with Rayleigh numbers for different inclination values can be seen from Figure 7. It is observed that the Nusselt numbers in the lower Rayleigh number range ($4.5 \times 10^5 \le \text{Ra}_H \le 1 \times 10^7$) for the 90° inclination cases are negligible when compared to the Nusselt numbers for other inclination angles. This could be due the fact that at these Rayleigh numbers, the heat transfer at 90° inclination is predominantly conducted based on minimal convective currents at the cavity aperture and is the least when compared to the other inclinations, where heat transfer is due to convective currents within the cavity. The coefficient of determination is very low (about 0.8) when a Nusselt number correlation is developed for all the inclination angles. Therefore, the Nusselt number correlation for this range of Rayleigh number (4.5×10^5–1×10^7) is limited to inclination angles (θ) between 0° and 60° and is given by

$$\text{Nu}_H = 0.143\text{Ra}_H^{(1/3)}(\cos\theta)^{3.0}. \quad (5)$$

The Nusselt numbers at 90° inclination in the higher Rayleigh number range (2.5×10^7–1.5×10^9) are the least when compared to other inclination angles. The values though low are significant as there are convective currents near the cavity aperture leading to heat transfer by convection. The Nusselt number correlation in this Rayleigh number range is proposed for all inclinations between 0° and 90° and is given by

$$\text{Nu}_H = 0.024\text{Ra}_H^{(1/3)}(1 + \cos\theta)^{1.96}. \quad (6)$$

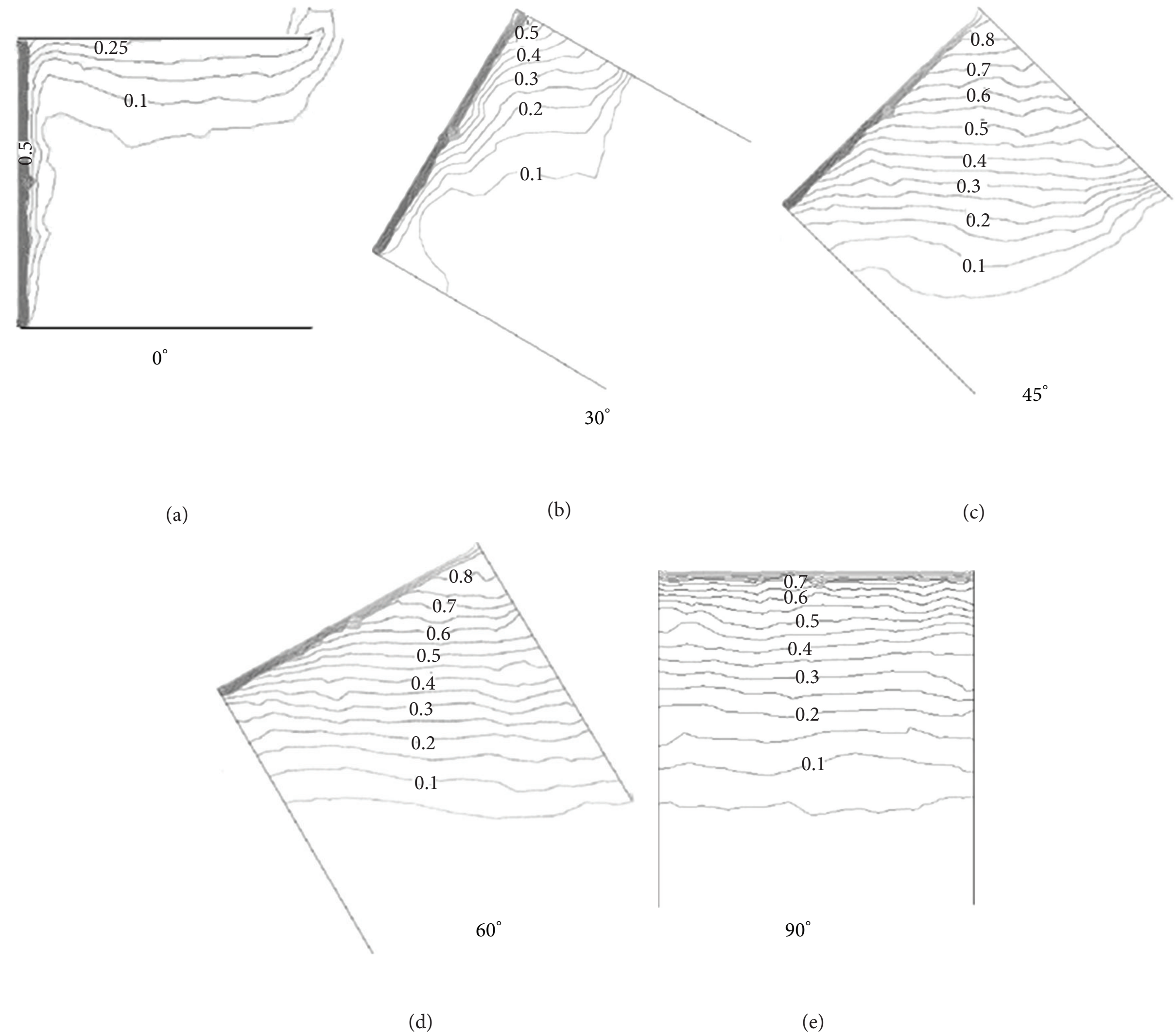


Figure 6: Temperature profiles at different inclinations for open cubical cavity of side 0.5 m and $T_{\text{bw}} = 100^{\circ}$C.

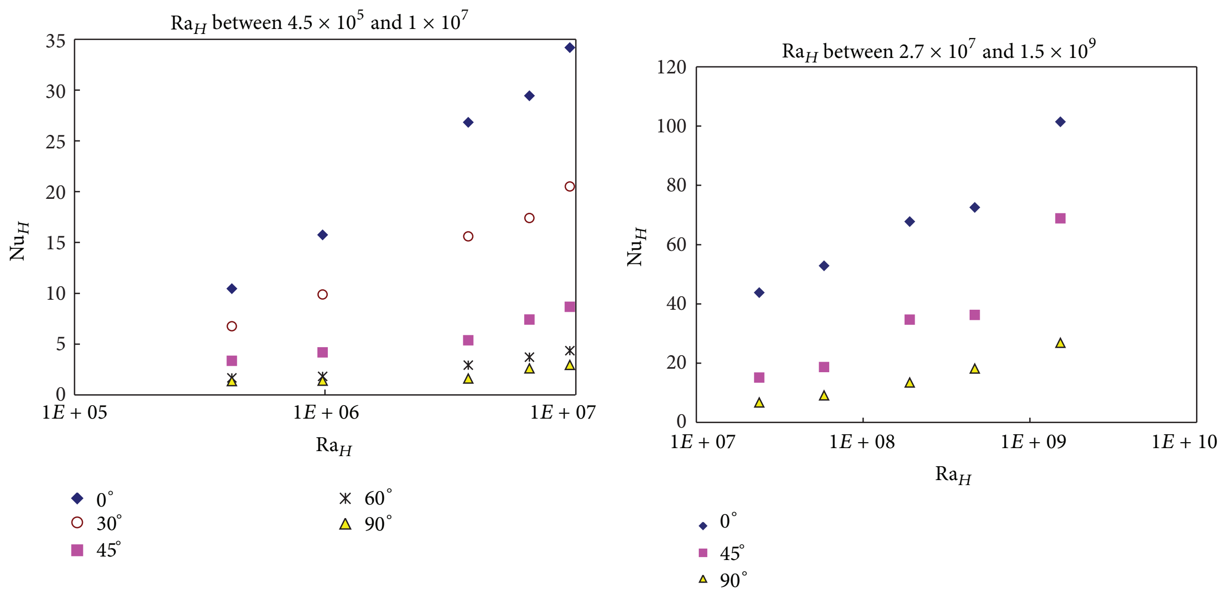
The parity plots for both the correlations are shown in Figure 8. The coefficient of determination is about 0.93. It is noticed that a Nusselt number correlation is possible for the entire range of Rayleigh numbers (4.5×10^5–1.5×10^9) for the 0° inclination cases. This correlation is only suitable to predict the convective losses from the sideways facing open cubical cavity with constant temperature back wall boundary condition. The correlation proposed is

$$\mathrm{Nu}_H = 0.513\mathrm{Ra}_H^{0.252}. \quad (7)$$

All the correlations are developed for (T_{bw}/T_a) range between 1.03 and 1.23, where the temperature values are in Kelvin.

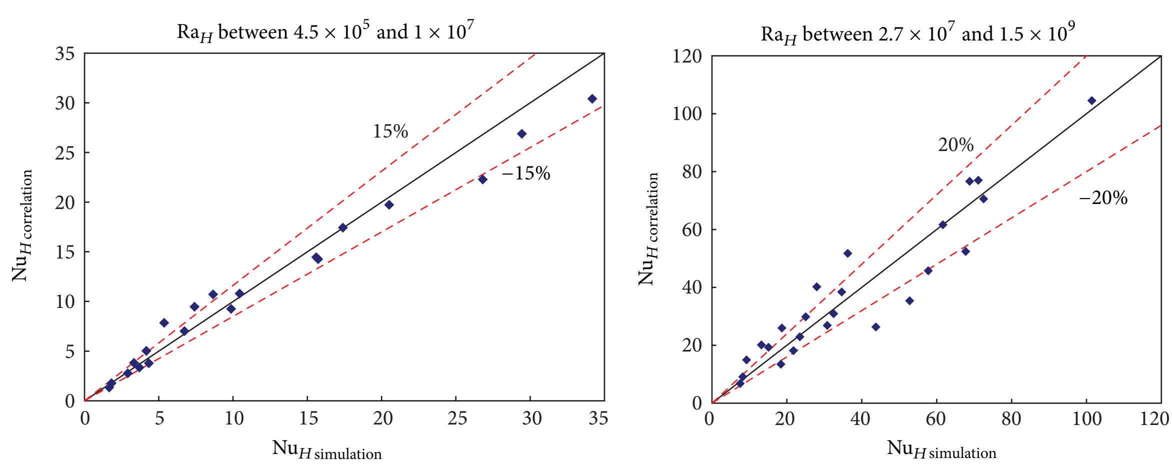
The applicability of the correlations proposed in this study is checked by comparing the Nusselt number from the correlations with the results already available in the literature. The Nusselt numbers predicted by (5) for Rayleigh numbers of 10^6 and 10^7 and inclinations between 0° and 60° are compared with those reported by Hinojosa et al. [5]. It is observed that the maximum variation between the predicted Nusselt numbers and those obtained numerically by Hinojosa et al. [5] for Rayleigh number of 10^6 is about 15%. At Rayleigh number 10^7, the agreement is good for lower inclination values but the variation is high for angles of 45° and 60°. A better agreement is observed when the predicted Nusselt number values for 45° and 60° inclinations are compared with those obtained from the correlation suggested by Hinojosa et al. [5].

The predicted Nusselt number values obtained from (5) for Rayleigh number of 10^6 at 0° inclination is compared with those reported in the literature [13, 20]. The studies by Comini et al. [13] and Chan and Tien [20] are for open rectangular and square cavities with constant temperature back wall boundary condition. A Nusselt number value of 14.3 is obtained from (5), while the values from Comini et al. [13] and Chan and Tien [20] are 14.7 and 15, respectively. The Nusselt number value calculated using (5) for Rayleigh number of 10^7 and inclination of 0° is 30.8 while the values reported by Chan and Tien [20] are 28.6 and 30.7 by Polat and Bilgen [35]. The Nusselt number value reported by Chakroun et al. [14] for a sideway facing rectangular open cavity at



(a) (b)

Figure 7: Variation of the Nu_H with Ra_H for different inclinations.



(a) (b)

Figure 8: Parity plots of $Nu_{H\,\mathrm{simulation}}$ and $Nu_{H\,\mathrm{correlation}}$.

Rayleigh number of 0.63×10^7 is 24 while from (5), the value obtained is 26.4.

It was reported earlier in this paper that studies involving the inclination effect on convective losses from downward facing open cavities with constant temperature back wall boundary condition are limited to Rayleigh numbers of 1×10^7. Therefore, the Nusselt number values obtained from the correlation developed for the higher Rayleigh number ranges (6) are compared with those reported in the literature only for 0° inclination. At Rayleigh number of 10^8, the Nusselt number value from (6) is 43.4 while the values from literature are 56.8 [20] and about 40 [23]. The Nusselt number value from (6) at Rayleigh number of 10^9 is 93.3 while from the literature the value is 105 [20]. The comparison between the Nusselt numbers obtained from (7) and Chan and Tien [20] for open cavities at 0° inclination, constant temperature back wall boundary condition, and Rayleigh numbers between 1×10^6 and 1×10^9 is shown in Table 2.

It is, therefore, observed that the Nusselt numbers predicted by the correlations proposed in this paper have a fairly good agreement to those reported in the literature. The variations between the Nusselt numbers obtained from the correlations proposed in this study and the literature may be due to the difference in the numerical schemes used for the analysis and also due to the difference in the modelling itself (present study is 3D while Chan and Tien [20] analyses a 2D model). It is also seen that the correlations can be used for other shapes like square and rectangular cavities inclined

Table 2: Comparison of predicted Nusselt numbers with those reported by Chan and Tien [20].

Rayleigh number	Nusselt number (7)	Nusselt number [20]
1×10^6	16.6	15.0
1×10^7	29.8	28.6
1×10^8	53.2	56.8
1×10^9	95	105

at 0° for Rayleigh numbers between 1×10^6 and 1×10^9 with fairly good accuracy.

5. Conclusions

In this paper, numerical studies on the natural convection loss from open cubical cavities having constant temperature back wall boundary condition are carried out. The effect of the different back wall temperatures and cavity inclinations (between 0° and 90°) on the convection loss is studied. The following conclusions can be drawn from this study.

(i) It is observed that the convective loss increases with an increase in ΔT value. This is observed for all cavity sizes and inclination angles. The convective loss values for all inclinations can increase by a factor between 5 and 8 (based on the cavity size) when ΔT increases by about 50°C.

(ii) It is also seen that the convective losses decrease with an increase in cavity inclination; the highest loss at 0° and the least at 90°. This is due to the increase in stagnation zone area and decrease in convective zone area with an increase in cavity inclination. It is observed that the convective loss values at 90° inclination for different cavity sizes and temperature values can vary between 8 and 30% of the convective loss at 0° inclination.

(iii) Nusselt number correlations involving Rayleigh numbers and cavity inclinations are developed. Correlations are proposed for a low Rayleigh number range (4.5×10^5–1×10^7) and higher range of Rayleigh number (2.5×10^7–1.5×10^9). A correlation for the 0° inclination angle (sideways facing cavity) is also proposed for the entire range of Rayleigh numbers analysed here (4.5×10^5–1.5×10^9).

(iv) The Nusselt numbers predicted by the correlations are compared with the limited data available in the literature. A good agreement is observed with maximum variation of about 20%.

Nomenclature

A_{bw}: Area of the back wall (m^2)
a: Height of cavity aperture opening (cubical, rectangular, and square cavities) (m)
D: Diameter of open cavity (cylindrical, spherical, and hemispherical cavities) (m)
d: Diameter of the cavity aperture opening (cylindrical, spherical, and hemispherical cavities) (m)
a/H, d/D: Opening ratio
f: Body force per unit mass
g: Gravitational acceleration (m/s^2)
H: Height of cavity (cubical, rectangular, and square cavities) (m)
h: Convective heat transfer coefficient (W/m^2-K)
k: Thermal conductivity (W/m-K)
Nu_H: Nusselt number based on cavity height
P: Pressure (N/m^2)
Pr: Prandtl number
Q_{conv}: Convective loss (W)
Ra_H: Rayleigh number based on cavity height
T_a: Ambient temperature (°C)
$T_{\text{air},i}$: Air temperature at a point "i" within the cavity (°C)
T_f: Film temperature (°C)
T_{bw}: Cavity back wall temperature (°C)
V: Velocity vector.

Greek Symbols

β: Volume coefficient of expansion (1/K)
ΔT: Temperature difference ($T_{\text{bw}} - T_a$)
ν: Kinematic viscosity (m^2/s)
θ: Cavity inclination (degrees).

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