Development and Validation of Nusselt Number Correlations for Mixed Convection in an Arc-Shape Cavity

R B Gurav, Mandar M Lele

Abstract: The analytical study has been performed to investigate the combined effects of lid movement and buoyancy force parameter on mixed convective flow in an arc-shape cavity. The dimensional analysis based on Buckingham π-Theorem is used in the present study. It results in correlations for Nusselt number in terms of non dimensionalized parameters, viz. Re, Pr, Gr, θ etc. The correlations developed are validated against the experimental data of horizontal arc- shape cavity and numerical data of inclined arc-shape cavity obtained from open literature. The correlation developed in the present study for horizontal arc-shape cavity is valid for wide ranges of Re varying from 30 to 1500 and Gr from 0 to 107. In inclined arc-shape cavity it is valid for Re varying from 30 to 1500, Gr from105 to 107 and inclination angle from 150to 600.The close agreement in the comparison between predicted results by correlation developed in the present study and reported Nu correlation shows the validity of the correlation.

Key words: Arc shape cavity, Buckingham π-theorem, Dimensionless correlation, Mixed convection, Nu.

I. INTRODUCTION

The mixed convection process in lid-driven cavities has developed substantial importance because of its congruence to heat transfer performance and variety of applications like nuclear reactors, solar ponds, dynamics of lake and heat exchangers, wet clutches and solar collectors [1,2]. In order to analyze the flow of physics and heat transfer, experimental and numerical studies of mixed convection effect in rectangular and non-rectangular cavities have been reported widely in the literature. Mei-Hsia Chang et al. [4] studied the flow pattern and heat transfer of lid-driven flow inside the cavity. High Re number is used for analysis. Prasad and Koseff [5] performed experimental investigation of combined convection in deep rectangular cavities for Re varies from 0 to 12000.They obtained correlation for Nusselt number as a function of Re, Gr/Re2 and depth aspect ratios. However, deep analysis the heat transfer characteristics and fluid flow in a complex-shape cavity with dimensional analysis is not studied .Chin-Lung Chen et al. [6] studied the mixed convection effect inside a lid-driven arc-shape cavity. Results show that the minimum Nu is found in the transition zone of buoyancy-dominated and the inertia-dominated situations. However the correlations for Nusselt number in terms of non dimensionalized parameters, viz. Re, Pr, Gr etc were not obtained in this paper which provides useful information for design applications. Chin-Lung Chen et al. [7] continued to study combined effects of natural and Forced convection effects in an inclined lid-driven arc-shape cavity with three physical parameters including Gr ranging from 105 to 107, Re varying from 30 to 1500 and θ from 150 to 600. Their results show that for all inclinations, average Nu increases as Gr increases. However the correlations for average Nusselt number related to inclination angles is not reported in this study.

The studies presented above are merely focused on numerical and experiential investigations of natural and mixed convection heat transfer inside the arc shape cavity. The objective of this study is to develop correlations using dimensional analysis to relate the variables of buoyancy effect and heat transfer characteristics of any flow undergoing mixed convection inside an arc-shape cavity. The set of dimensionless correlations relating average Nusselt number for mixed convection in a lid driven arc shaped cavity are developed using Buckingham π-theorem in the present study. Validation of the obtained Nu correlations for horizontal and inclined arc-shape cavity is also made to check their applicability for combined convection flows. The physical model of an arc shape cavity is subjected to moving lid is schematically shown in Fig.1. The profile of an arc shape wall is defined by the expression, $(x-p)^2 – (y-q)^2 = r^2$. In this analysis the ratio p/r, q/r and r/L are fixed at 1/2, 1/2√3 and 1/√3 respectively .An arc-shape cavity of height D and width L is placed horizontally. A lid maintained at lower temperature T_L is moving from left to right with constant speed v. The lid speed can be varied to produce Reynolds number up to 1500. The bottom arc-shape wall of cavity is kept at higher temperature T_H.

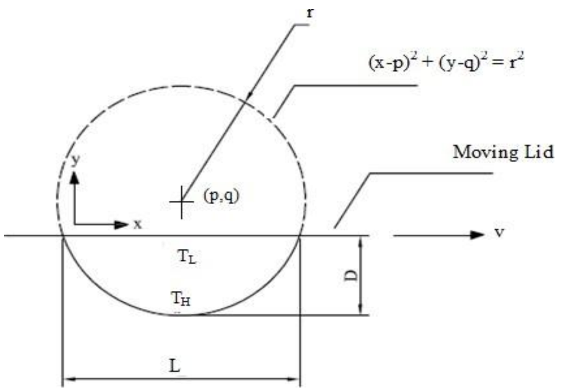

Fig.1 An arc shape cavity with moving lid

II. DIMENSIONAL ANALYSIS AND DATA REDUCTION FOR MIXED CONVECTION IN ARC-SHAPE CAVITY

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To determine the non-dimensionalized groups proper for this problem, the Buckingham π-theorem and method of indices were used to develop new empirical correlations. The heat transfer coefficient in mixed convection of arc shape cavity depends on following dimensional variables: The density of air, specific heat, thermal conductivity and dynamic viscosity of air with which cavity is exchanging heat, buoyancy force parameter, width and height of cavity, velocity of lid. In dimensional form the heat transfer coefficient is given by

$$h = f\,(D, \rho, k, \mu, v, L, h, Cp,\ g\beta\Delta T, \theta) \qquad (1)$$

Which can be written as,

$$f\,(h, D, \rho, k, \mu, v, L, h, Cp, g\beta\Delta T, \theta) = 0$$

- Total variables, n = D, ρ, k, μ, v, L, h, cp, gβΔT =10
- Number of fundamental dimensions, m = L, M, T, ϴ = 4 Number of repeating variables =Number of fundamental dimensions= 4
- Number of dimensionless parameters or groups, π- Terms = n-m = 10–4=6

The methodology used to obtain Nusselt number correlations is as shown in fig.2. The theory of dimensional analysis indicates that the non-dimensionalized variables are formed by the products of powers of certain of the original dimensional variables. So generalized dimension less variables are often termed dimensionless products and are denoted by the symbol π. The six dimensionless variables or groups required in the present study will be denoted by$\pi 1$, $\pi 2$, $\pi 3$, $\pi 4$, $\pi 5$ and $\pi 6$.The theory of dimensional analysis shows that each of these π- terms must contain one prime dimensional variable which does not occur in any of the other π- terms, together with other dimensional variables which occur in all other π- terms. In the present study, there are ten dimensional variables and six π-terms so six prime variables must be selected and there will be also four other dimensional variables which occur in all the π-terms.

The prime variable in each dimensionless product characterizes some distinct feature of flow in cavity. The buoyancy variable (gβΔT) and velocity (v) are used as a prime variable since they determines the importance of free and forced convective effects. Similarly Cp will determine the thermal capacity of fluid and will, therefore influence the relation between the velocity and temperature fields. For gases, Cp is used because it is the change of enthalpy of fluid.The direction in which the boundary layer grows in the fluid flow field is the characteristic dimension. Width of cavity (L) is used as a characteristic dimension in the present study.Analysis of Nu, Re and Gr is based on cavity width (only one length scale because of constant aspect ratio) in this work. Also, since h is the variable whose value is required, it should be used as a prime variable.

Fig.2 Flow chart for present analysis for mixed convection in arc-shape cavity

Eq.(1) can be transformed into dimensionless form as

$$F(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6) = 0 \qquad (2)$$

$$\pi_1 = F(\pi_2, \pi_3, \pi_4, \pi_5, \pi_6) \qquad (3)$$

$$\pi_1 = D^{a_1}\rho^{b_1}\mu^{c_1}k^{d_1}\ h \qquad (4)$$

$$\pi_2 = D^{a_2}\rho^{b_2}\mu^{c_2}k^{d_2}\ v \qquad (5)$$

$$\pi_3 = D^{a_3}\rho^{b_3}\mu^{c_3}k^{d_3}\ L \qquad (6)$$

$$\pi_4 = D^{a_4}\rho^{b_4}\mu^{c_4}k^{d_4}\ c_p \qquad (7)$$

$$\pi_5 = D^{a_5}\rho^{b_5}\mu^{c_5}k^{d_5}\ g\,\beta\,\Delta T \qquad (8)$$

$$\pi_6 = \theta \qquad (9)$$

In terms of Eq. (4), substituting the physical variables with the basic dimension units would lead to ,

$$\pi_1 = M^0L^0T^0\theta^0 = (L)^{a_1}(ML^{-3})^{b_1}(ML^{-1}T^{-1})^{c_1}(MLT^{-3}\theta^{-1})^{d_1}(MT^{-3}\theta^{-1})$$

Since π_1 is a combination dimensionless group, thus the exponents a_1, b_1, c_1, d_1 must satisfy the following simultaneous equations.

$M, 0 = b_1 + c_1 + d_1 + 1$

$L, 0 = a_1 - 3b_1 - c_1 + d_1$

$T, 0 = -c_1 - 3d_1 - 3$

$\theta, 0 = -d_1 - 1$

Thus a_1, b_1, c_1, d_1 were solved:

$d_1 = -1$, $b_1 = 3c_1 = 0$, $a_1 = 1$

Therefore,

$$\pi_1 = \frac{h\,D}{k}$$

Similarly, π_2, π_3, π_4, $\pi_5$were obtained respectively

$$\pi_2 = \left(\frac{\rho v D}{\mu}\right),\quad \pi_3 = \frac{L}{D},\quad \pi_4 = \left(\frac{\mu . C_p}{k}\right),$$

$$\pi_5 = \left(\frac{g\,\beta\,\Delta T\,D^3}{v^2}\right)$$

By rearranging all π-terms, final π -terms obtained as

$$\pi_1 = \frac{h\,L}{k} = Nu \qquad (10)$$

$$\pi_2 = \left(\frac{\rho v L}{\mu}\right) = Re \qquad (11)$$

$$\pi_3 = \left(\frac{\mu . C_p}{k}\right) = Pr \qquad (12)$$

$$\pi_4 = \left(\frac{D}{L}\right) = A \qquad (13)$$

$$\pi_5 = \left(\frac{g\,\beta\,\Delta T\,L^3}{v^2}\right) . \left(\frac{\mu}{\rho v L}\right)^2 = \frac{Gr}{Re^2} = G \qquad (14)$$

$$\pi_6 = \theta \qquad (15)$$

Substituting Eq.(10) to (15) into Eq.(3),

$$Nu = f(\,Re, Pr, Gr, A\,, \theta) \qquad (16)$$

Based on general form of dimensionless group equation, Eq. (16) could be rewritten as,

$$Nu = C\ \ Re^m Pr^n (G)^x (A)^y (\theta)^z \qquad (17)$$

A. Correlation for horizontal arc-shape Cavity

The dimensionless parameters used to develop correlation for horizontal arc-shape cavity in present study are listed in Table 1.

Values of constant C,

exponent's m and x in Eq. (17) were fitted using experimental data. Due to constant aspect ratio, heat transfer coefficient for a cavity is influenced by width of cavity only and not depth in the present study. Hence neglecting the effect of π_3 and π_4 terms, Eq.(16) and (17) could be rewritten as,

$$Nu = f(Re, G)$$

$$Nu = C\ Re^{m} (G)^{x}$$

Table 1 Dimensionless π groups used for present study on horizontal arc-shape cavity

Groups	Definition	Effect	Range
π_1	h L / k	Average Nusselt number	-
π_2	ρ v L/ μ	Reynolds number	30 to 1500
π_3	$\mu C_p / k$	Prandtl number	0.71 (air)
π_4	D/L	Aspect Ratio	0.29
π_5	Gr/Re^2	Buoyancy force parameter	4.4×10^{-7} to 1.1×10^{4}

The above equation indicated that Nusselt number for mixed convection in arc-shape cavity depended on Reynolds number and buoyancy force parameter. To find out the relation between Nusselt number and its influencing dimensionless factors, experimental results are taken from open literature to determine the exponents of above equation. Therefore final correlation could be expressed as,

$$Nu = 9.29\ Re^{0.121} G^{0.0347} \qquad 0 \le Gr \le 10^{7} \qquad (18)$$

B. Correlation for inclined arc-shape cavity

The dimensionless parameters used to develop correlation for inclined arc-shape cavity in present study are listed in Table 2

Table 2 Dimensionless Parameters used for present study on an inclined arc-shape cavity

Groups	Definition	Effect	Range
π_1	h L/ k	Average Nusselt number	-
π_2	ρ v L /μ	Reynolds number	100 to 1500
π_3	$\mu C_p / k$	Prandtl number	0.71 (air)
π_5	Gr/Re^2	Buoyancy force parameter	4.4×10^{-2} to 10^{2}
π_6	θ	Inclination angle	15^0 to 60^0

Values of constant C, exponents n, x and z in Eq.(17) were fitted using numerical data. So final correlation could be expressed as,

$$Nu = 7.75\ Re^{0.125}\ G^{0.0841} \theta^{0.0516} \qquad (19)$$

The main purpose of current investigation is to develop correlation using dimensional analysis to relate the variables of buoyancy effect and heat transfer characteristics of the flow undergoing mixed convection inside an arc shape cavity. To provide relevant information for design applications, Nu correlation have been obtained in the present study for horizontal arc shape cavity using experimental data and for inclined arc-shape cavity using numerical data. In order to make comparison and check the validity of predicted results with experimental, regression analysis was performed. The relative error (ξ) and coefficient of determination (ϕ) were employed for analysis.

The coefficient of determination or goodness Fit index, ϕ indicate relative comparison criterion between the measured and the predicted data. It can be elucidated as the proportion of total variability in the response variable Y (on y-axis) that is deemed for the predictor variable X (on x-axis). If ϕ is near 1, then X accounts for a large part of the variation in Y, hence ϕ is known as coefficient of determination. It is a key output of regression analysis. It is interpreted as the proportion of the variance in the dependent variable that is foreseeable from the independent variable. It is a evaluation that allows determining how accurate one can be in making predictions from a model/graph. The relative error, ξ specify the maximum deviation of the measured data from the predicted values. As ϕ reaches a value of 1, the predicted data converge to measured data. The mathematic definition of ϕ and ξ are given here.

$$\frac{\sum \left(\pi_{1,pred.} - \overline{\pi_{1,expt.}}\right)^2}{\sum \left(\pi_{1,expt.} - \overline{\pi_{1,expt.}}\right)^2} \qquad (20)$$

$$\xi = \frac{\left(\pi_{1,expt.} - \pi_{1,pred.}\right)}{\pi_{1,pred.}} \qquad (21)$$

Where $\pi_{1,\ expt.}$ is the experimental data of π_1, $\pi_{1,\ pred.}$ is the predicted data and $\overline{\pi_{1,expt.}}$ is the average value of the experimental data of π_1.

The present study is related to the flow driven by shear and buoyancy in a cavity. Basically, the strength of buoyancy is given by Gr and the strength of inertia-driven motion is given by Re. The buoyancy parameter G is used conventionally to show the relative strengths of the free and forced convection in a mixed convective regime. For G«1, the forced convection component (shear) controls the heat transfer process, while for G »1, buoyancy effects predominate. Unfortunately, G cannot be applied invariably to every flow configuration. Researchers have frequently revised the exponent of Re and range of G in order to interpret their data based on geometry and engineering applications. So the mixed convection limits for heat transfer from a plate, cavity or channels were found to be different in an open literature.

III. RESULTS AND DISCUSSION

A. Variation in ϕ with small change in exponent of buoyancy force parameter

The exponent m has a value of 0.121 and 0.125 of π_2 , is higher than the other exponent in Eq.(18) and (19) . It shows Nu increases with increasing Re and hence the effect of Re on Nu is more noteworthy than that of any other parameter present in the correlation.

The buoyancy force parameter G employed in dimensional analysis ranges from 4.4 $\times 10^{-7}$ to 1.1 x 10^{4}. Due to wide range of G, the rapid change in ϕ occurs which creates difficulty to fit predicted results with measured results. The buoyancy force parameter G decides the range of mixed convection regime. The exponent of buoyancy parameter obtained in a correlation has a value of 0.0343 is very small. Very small change in exponent affects the regression analysis of arc-shape cavity as shown in Table 3. So G is important parameter and cannot be omitted this term (due to very small value) from correlation obtained from dimensional analysis. Table 3 shows the variation of ϕ with small change in exponent of G.

Table 3 Variation of ϕ with small change in exponent of G

Exponent	Deviation in exponent	ϕ
0.0340	-	0.969
0.0330	0.001	0.945
0.0320	0.001	0.922
0.0310	0.001	0.900

B. Validation of the present Nu correlation

The Nusselt number correlation developed using dimensional analysis for mixed convection inside the arc-shape cavity. The correlation with their applicable conditions and evaluation indicator obtained from regression analysis is listed in Table 4.

Table 4 Correlation with their applicable conditions and evaluation indicators

Present Nu Correlations	ξ	ϕ
1) Horizontal arc-shape cavity		
$Nu = 9.29\ Re^{0.121}\ G^{0.0347}$	-32 % ~ +25%	0.987
2) Inclined arc-shape cavity		
$Nu = 7.75\ Re^{0.125}\ G^{0.0841}\ \theta^{0.0513}$	-31 % ~ +25%	0.98

For horizontal arc-shape cavity, Gr varies from 0 to 10^{7} and Re varies from 30 to 1500 in the present study. Pure force convection data is obtained when Gr =0 and Re varies from 30 to 1500. Mixed convection effect is possible when the impact of forced convection and natural convection are of comparable magnitude occur inside the cavity.Fig.3 compares the measured Nu, with those predicted using Eq.(18).From inspection, ϕ is found to be 0.987 and the range of ξ varies from -32% to 25%. The value of ϕ=0.987 indicates that nearly 99% of total variability in the response variable Y (on y-axis) is responsible for the predictor variable X (on x-axis). The regression analysis shows the close agreement in the comparison between experimental and correlated results.

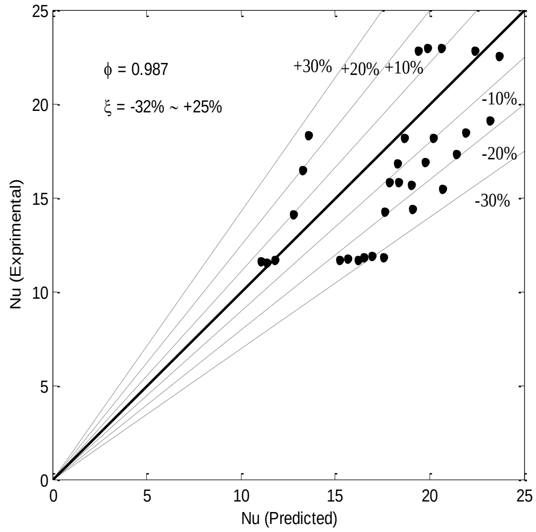

Fig.3 Comparison between Nu (experimental) by Chin-Lung Chen et al.[6] and Nu (predicted) using Eq.(18)

For inclined arc-shape cavity the correlation obtained for range of G given in Table 3. Fig. 4 compares the measured Nu (numerically), with those predicted using Eq.(19). From inspection, ϕ is found to be 0.98 and the range of ξ varies from -31% to 25%. The value of ϕ=0.98 indicates that nearly 98% of total variability in the response variable Y (on y-axis) is responsible for the predictor variable X (on x-axis) The regression analysis shows the close agreement in the comparison between numerical and correlated results.

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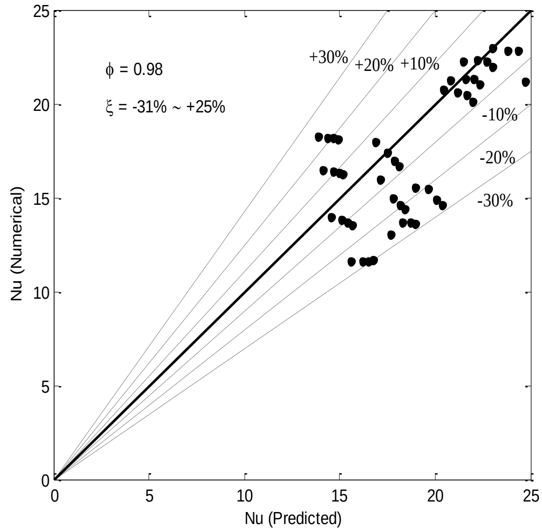

Fig.4 Comparison between Nu (Numerical) by Chin-Lung Chen et al.[7] and Nu (predicted) using Eq. (19)

C. Comparison of Nu correlation of the present study with reported correlations

In the literature, several Nu correlations have been proposed to provide useful information for design applications. Balaji et al.[8] used asymptotic computational fluid dynamics (ACFD) technique, to first perturb the limiting solutions of natural and forced convection, to obtain Nusselt number correlation. To elucidate the technique, the problem of mixed convection in a lid driven square cavity has been used. The Nu correlation obtained as,

$$Nu = \widehat{Nu}\left(a\, Gr^{0.25} + b\, Re^{0.5}\right) \qquad (22)$$

Where a and b are constants and weighted Nusselt number $\widehat{Nu}$, is calculated through Eq.(23)

$$\widehat{Nu} = 1.0 - 0.54Ri^{-0.25}\left[1 + \left(\frac{0.559^{0.8}}{Ri}\right)\right]^{\frac{-1}{16}} \qquad (23)$$

Where Ri is the Richardson number and its value is calculated by taking the ratio of Gr and Re^2. As long as the flow is laminar Eq.(23) is valid for any value of Gr, Re and Ri.

Moallemi and Jang [2] carried out numerical simulations and correlated the average heat transfer in the cavity as,

$$Nu = A\; Re^{0.5}\, Pr^{n}\left[1 + B\left(\frac{Ri}{Pr^{q}}\right)^{s}\right] \qquad (24)$$

Where A and B are constants, the exponents n and q are 0.4 and 0 for Pr<1, and s is a constant in the range of 0.20 to 0.25.This correlation was obtained for a range of Re varying from 100 to 2200, Pr from 0.01 to 50 and Gr from 10^4 to 10^7. Comparison of the experimental results of horizontal arc-shape cavity with those predicted by Balaji et al.[8] is shown in Fig.5 for a range of Re varying from 30 to 1500 and Gr from 0 to 10^7. Fig.5 shows the excellent agreement between the experimental results and predicted results when the constants a=0.41 and b=9.59 are used in Eq.(22). From inspection, ϕ is found to be 0.987 and the range of ξ varies from -24% to 19%. Fig.6 compares the predicted results using Eq.(18) with those predicted by Balaji et al.[8]. From inspection, ξ varies between -24% and 19%.

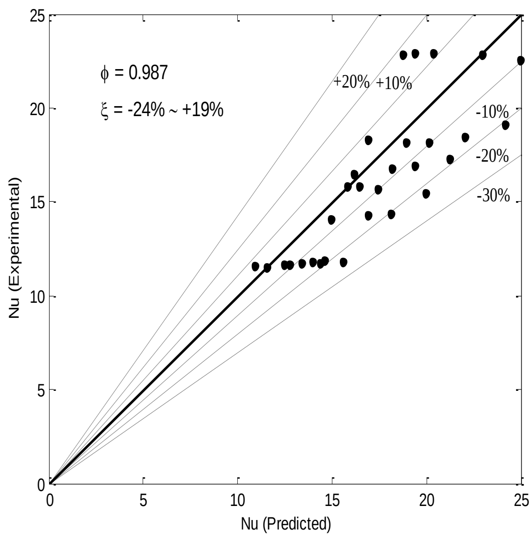

Fig.5 Comparison between Nu (experimental) by Chin-Lung Chen et al.[6] and Nu (predicted) by Balaji et.al.[8]

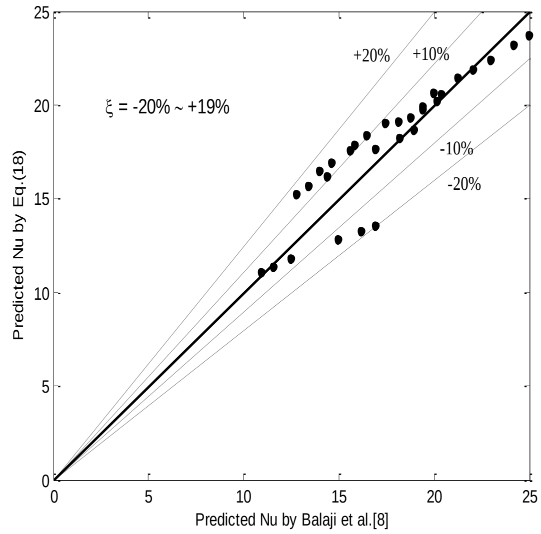

Fig.6 Comparison between Nu predicted by Eq.(18) and Nu predicted by Balaji et al.[8]

Similar Comparison of the experimental results of horizontal arc-shape cavity with those predicted by Moallemi et al.[9] is shown in Fig.7 for a range of Re varying from 30 to 1500 and Gr from 10^4 to 10^7. Fig.7 shows the excellent agreement between the experimental results and predicted results when the constants A=3.52, b=0.11 and exponent of Re is 0.23 instead of 0.5 are used in Eq. (24). From inspection, ϕ is found to be 0.98 and the range of ξ varies from -11% to 30%. Fig.8 compares the predicted results using Eq.(18) with those predicted by Moallemi et al.[9]. From inspection, ξ varies between -40% and 4%.

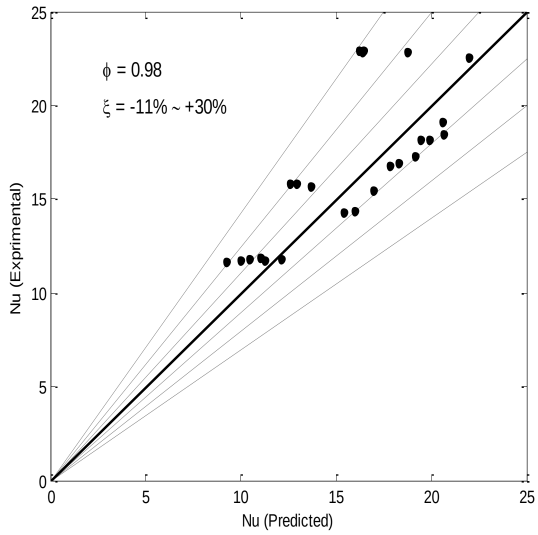

Fig.7 Comparison between Nu (experimental) by Chin-Lung Chen et al.[6]and Nu (predicted) by Moallemi et al.[9]

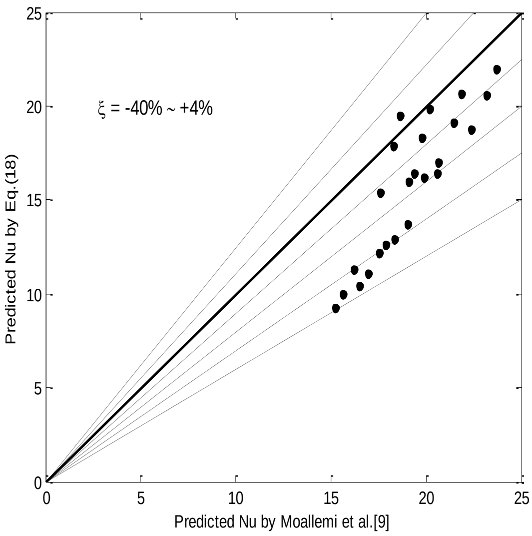

Fig.8 Comparison between Nu predicted by Eq.(18) and Nu predicted by Moallemi et al.[9]

IV. CONCLUSIONS

This study has developed generalized dimensionless correlation for analyzing the buoyancy effect and heat transfer characteristics in a horizontal and inclined arc-shape cavity. The investigations on present study can be summarized as follows.

Dimensionless correlation for Nu has been developed for horizontal arc-shape cavity, based on experimental results and Buckingham π-theorem. The value of coefficient of determination (ɸ) is 0.987, calculated from regression analysis. Hence the accuracies of the dimensionless correlation are found to be acceptable compared with the experimental results taken from open literature.

Correlation for Nu has been developed for inclined arc-shape cavity, based on numerical results. The calculated value of coefficient of determination (ɸ) is 0.98. Hence the accuracy of correlation is found to be acceptable compared with the numerical data taken from open literature.

The value of Nu is determined by dimensionless numbers Re and Gr. A rapid change in value of coefficient of determination(ɸ) occurs at a smallest increment or decrement of exponent of buoyancy parameter G. Thus G is an important parameter and cannot be omitted (due to very small value of exponent) from correlation.

The close agreement in the comparison between predicted results by correlation developed in the present study and reported Nu correlations show the validity of correlation.

Nomenclature:

A	Aspect ratio, D/L
C_p	Specific heat, $kJkg^{-1}K^{-1}$
D	Height of cavity, m
Re	Reynolds Number
Gr	Grashof Number
Pr	Prandtl Number
G	Buoyancy force parameter, $\frac{Gr}{Re^2}$
h	Heat transfer coefficient, $Wm^{-1}K^{-1}$
L	Width of cavity, m
Nu	Average Nusselt number
T_H	Temperature on arc shape bottom wall, K
T_L	Temperature of moving lid, K

Greek Symbols:

ρ	Density of air, kg m^{-3}
ν	Kinematic viscosity of fluid, m^2 s^{-1}
ɸ	Coefficient of determination
ξ	Relative error
θ	Inclination angle

Superscripts

a, b ,c ,d	Exponents in π- term

REFERENCES

1. P.Payver, Y.N. Lee, W.J. Minkowycz (1994),Simulation of heat transfer to flow in radial grooves of friction pairs, International Journal of Heat and Mass Transfer, 37, 313–319.
2. A.F. Kothdiwala, B.Norton, P.C.Eames (1995), The effect of variation of angle of inclination on the performance of low concentration ratio compound parabolic concentration solar collections, Solar Energy, 55 , 301–309.
3. Chin-Lung Chen, Chin-Hsiang Cheng, Buoyancy-induced flow and convective heat transfer in an inclined arc-shape enclosure (2002), International Journal of Heat and Fluid flow, 23, 823-830.
4. Mei-Hsia Chang and Chin-Hsiang Cheng, Predictions of lid driven flow and heat convection in an Arc shaped cavity (1999), International Communication in Heat and Mass Transfer, 26, 829-838.
5. Ajay K. Prasad, Jeffrey R. Koseff, Combined forced and natural convection heat transfer in a deep lid driven cavity flow(1996), International Journal of Heat and Fluid Flow ,17 ,460-467.
6. Chin-Lung Chen, Chin-Hsiang Cheng, Experimental and numerical study of mixed convection and flow pattern in a lid-driven arc-shape cavity (2004), Heat and Mass Transfer, 41, 58–66.
7. Chin-Lung Chen, Yun-Chi Chung, Parametric study on mixed convection heat transfer in an inclined arc-shape cavity (2012), International Communication in Heat and Mass Transfer, 39,610-616.
8. C. Balaji, M Holling and H. Herwig, A general methodology for treating mixed convection problems using asymptotic computational fluid dynamics (2007), International Communication in Heat and Mass Transfer, 34, 682-691.
9. M. K. Moallemi and K.S. Jang, Prandtl number effects on laminar mixed convection heat transfer in a lid-driven cavity (1992), International Journal of Heat and Mass Transfer 35 1881-1892.

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Width of cavity, m