Seasonal Prevalence of Dengue Mosquitoes in Dhaka City

Shaila Nazneen*

Abstract : An investigation was carried out in Dhaka, one of the densest populated cities to study the dengue prevalence based on season and area. The Dengue viruses, borne by the *Aedes* mosquito can cause dengue fever in most tropical areas of the world. In this bionomics study of *Ae. aegypti* 85.85% eggs, larvae or pupae found in artificial containers. Whereas 14.15% *Ae. aegypti* larvae found in natural containers. Here higher number of mosquito population in artificial container than in natural container indicated recent creation and availability of huge breeding ground for *Aedes aegypti* in Dhaka city. Increased use of non-biodegradable plastics may have influenced higher mosquito densities by providing many more breeding sites. Larvae survey showed the Breteau Index around 20-40 from August to October, which was well above the risk level for dengue virus transmission. We found in our study that the post monsoon period is the most affected period for larval growth. The Indoor resting adult population start rising from August and the peak mosquito population and biting rate found from September to November, which also found consistent with the larvae survey. Though this bionomics study had done in small range and few selected areas of Dhaka city, it helped us to find the recent dengue prevalent season, dengue vector breeding sites and detect the peak season of vector population.

Keywords: *Aedes aegypti,* bionomic, mosquito population, Breteau Index, breeding site, larvae survey

Introduction

Dengue, a mosquito-borne viral infection is regarded as a major public health concern globally. The two main clinical manifestations of dengue, namely Dengue Hemorrhagic Fever (DHF) and Dengue Shock Syndrome (DSS), are responsible for exacting heavy morbidity and mortality every year and continue to be serious health problem[7,13] Dengue viruses are largely found in tropical and subtropical areas and outbreak of DHF occurs in definite seasons, is more common during the rainy season and tends to be recurrent. The disease maintains a definite seasonal and cyclical epidemic pattern in different areas[13].

Dengue virus is transmitted only by certain species of day biting *Aedes* mosquitoes, particularly *Aedes aegypti*[10,5,12]. The principal and efficient vector of dengue is *Aedes aegypti. Ae. aegypti* predominantly breeds indoors, in clean

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stored water and outdoors in natural and artificial containers, which trap rainwater. The female mosquito feeds during the day time with peak activity in the morning and late afternoon. After taking a blood meal on a viraemic individual, the mosquito may transmit virus directly by changing host or after 8-10 days extrinsic incubation period in the vector during which virus multiplies in their salivary glands. Once infected the vector is capable of transmitting viruses for rest of its life[5]. Viruses are usually introduced into a household by an index case and in the presence of vector mosquitoes may give rise to several secondary cases. As such, crowded urban areas provide ideal condition for increased dengue transmission in tropical urban cities[6].

Dhaka is a densely populated city where housing, sanitation and water supply system cannot keep pace with the rapid growth of the city. People have to store water in containers, which facilitate the breeding grounds of container breeding mosquitoes especially, *Aedes* species. As a result, in recent years both the population of vector and that of human have increased alarmingly in Dhaka city, thereby increasing the likelihood of epidemic DHF if and when dengue viruses with epidemic potentials are introduced.

In this study, the dengue prevalence in Dhaka city is observed through bionomic study based on season and area.

Method and Materials

Bionomics study of *Ae. aegypti* in Dhaka city

The Bionomics study component of this research was done in a small range which basically helped us for collection of mosquito samples for laboratory analysis. Our searches were focused on the Bionomics study of the principal dengue vector *Ae. aegypti.* Since *Ae. aegypti* is a highly domesticated mosquito which can complete its entire life cycle within the confines of a single human dwelling and can readily be adapted to laboratory colonization, we have chosen this vector for field collection. *Ae. aegypti* produces diapausing eggs making it easy to preserve for a long time. With a small number of volunteers, it was easy and convenient for us to collect the indoor resting adults and monitor the biting rates on regular basis.

Mosquito Surveys

The Dhaka region was chosen as the study area because of its relative high incidence of DF between years 2000-2009. Indoor resting adults and larval mosquito surveys were carried out in five representative dengue prevalent areas in Dhaka city from July, 2009- June, 2010. We used mosquito survey map by Ali, *et al.*[2] to select five high risk areas where the dengue cases and the vector population were comparatively high. The areas were: a) Dhaka University Campus; b) Shegunbagicha; c) Dhanmondi Residential Area; d) Rampura and e) Mirpur (Fig 1).

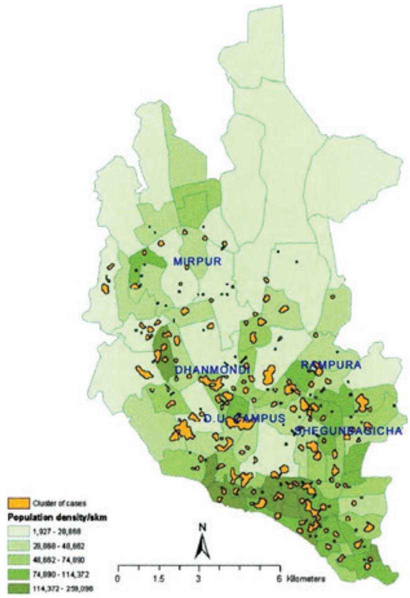

Fig 1: Disease-environment map showing Dengue prevalent areas in Dhaka City (Ali, Wagatsuma *et al.* 2003); five selected experimental areas marked by name.

Seasonal prevalence of larval and adult *Ae. aegypti* population is determined by observing Bretaeu Index, Container Index and Indoor resting adult mosquitoes biting rate and Probable relation to disease outbreak.

Larval Collection

For larval survey the entomological indices: House Index (HI); Container Index (CI) and Breteaue Index (BI) were used for measuring the larval population[9].

$$\text{House Index} = \frac{\text{No. of houses positive (larvae)} \times 100}{\text{No. of houses inspected}}$$

$$\text{Container Index} = \frac{\text{No. of containers positive} \times 100}{\text{No. of containers inspected}}$$

$$\text{Breteaue Index} = \frac{\text{No. of containers positive} \times 100}{\text{No. of house inspected}}$$

In each survey, all potential mosquito breeding containers were examined for mosquito breeding. Small containers were emptied into white pan and the contents were examined for larvae and pupae. Large containers which could not be emptied or aspirated were carefully examined, using flashlight necessary, and a sample of larvae and pupae was collected. Larvae were reared to adult stage for species identification. Routine collection and observation were made twice in each area per month from during study period. All five representative areas were visited at 15 days interval (twice a month), collection was made 10 houses per day in each area and a total of 250 houses in each study area were visited during one year study period for larvae collection.

Adult Collection

The biting activity of female mosquitoes had been monitored to observe the seasonal prevalence of Adult *Ae. aegypti.* The biting rate is expressed as the number of female mosquitoes caught per man per hour. Indoor resting *Aedes* adults were collected before sunset and after sunrise from the above-mentioned spots by the help of aspirator to analyses the mosquito's behavior, seasonal fluctuation, biting rates and to preserve them for further investigation.

The collections were made in the morning after sunrise between 7-9 am and in the afternoon before sunset between 4-6 pm at an interval of 15 days. Each collection consisted of 30 min in each house. The collections were made 4 houses per day in each area. The specimens were taken to the laboratory and checked for sex and for species. The total number of female *Aedes* species counted in each morning or evening collection and biting rate per man per hour had been counted, recorded and preserved separately for each area.

Results

Breeding habitat of *Ae. aegypti*

In the Bionomics study container breeding habitat of *Ae. aegypti* has been observed from July, 2009-June, 2010 in five dengue prevalent areas of Dhaka city as mentioned. Total 85.85 % of *Ae. aegypti* eggs, larvae and pupae found in artificial containers and only 14.15% of *Ae. aegypti* larvae found in natural containers. The observation about types of containers found positive for *Ae. aegypti* larvae inside or outside the households are summarized in Table 1 and in Fig 2.

Table 1: Types of containers found positive (+ve) for *Ae. aegypti* larvae inside and outside the households from five sampling sites (Shegunbagicha-S, Rampura-R, Dhaka University Campus-DUC, Dhanmondi Residential Area-D and Mirpur-M) of Dhaka City.

Types of container	S (+ve)	R (+ve)	D.U.C (+ve)	D (+ve)	M (+ve)	Total (+ve)	% of (+ve)
1. Clay jar, pots and pitchers	3	2	0	2	3	10	7.1
2. Unused Bucket,Gallon, Jars, pots, cans	0	1	1	1	3	6	4.25
3. Bamboo stumps	1	0	14	0	0	15	10.6
4. AC/refrigerator drip pan	1	2	0	1	1	7	3.56
5. Flower -vase	2	2	0	3	3	10	7.09
6. Coconut shell	0	1	0	1	0	2	1.42
7. Drums	1	2	2	1	4	10	7.09
8. Discarded appliances	1	1	0	0	2	4	2.84
9. Tires	2	2	0	3	3	10	7.09
10. Tree holes/leafaxils	0	0	3	0	0	3	2.13
11. Glass jar with rooted plants	2	3	4	2	3	14	9.93
12. Flower pot saucers	6	5	4	3	3	21	14.89
13. Cemented water reservoir/t	3	4	4	6	5	22	15.60
14. Empty flower pots	1	2	2	1	3	9	6.38
Total	**23**	**27**	**34**	**24**	**33**	**141**	**100**

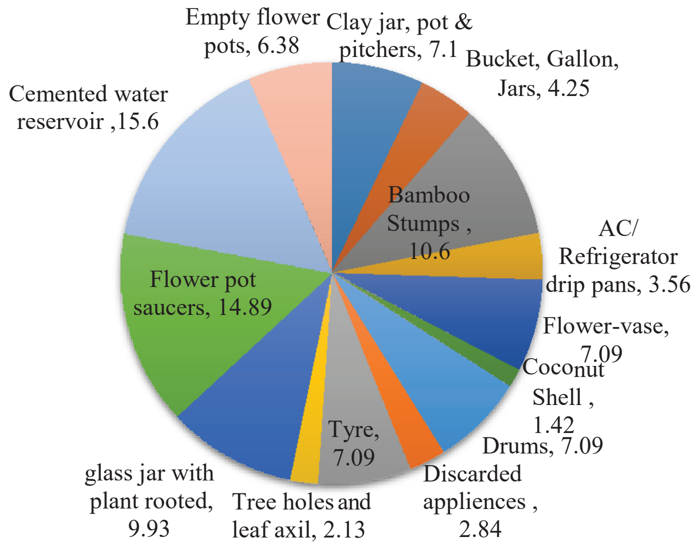

Fig 2: Pie diagram representing the types of containers and their percentages (%) found positive for presence of *Ae. aegypti* larvae from five sampling sites of Dhaka city

Prevalence of Larval and Adult *Ae. aegypti* population

Ae .aegypti population on the basis of container positivity (CI) for presence of larvae During the study period (July'2009-June'2010) total 1250 houses were visited for larvae collection.

Table 2: Percentages of mosquito population on the basis of positive containers for presence of *Ae.aegypti* larvae. TCC=Total Container Checked, TCP=Total Container Positive, CI=Container Index in %

Areas	TCC	TCP	CI
Rampura	793	28	3.53%
Shegunbagicha	746	25	3.35%
D.U Campus	728	26	3.57%
Dhanmondi R/A	632	26	4.11%
Mirpur	874	33	3.7%
Total	3773	138	3.658%

A total of 138 (Rampura =28, Shegunbagicha=25, D.U Campus=26, Dhanmondi R/A= 26, Mirpur=33) containers found positive for *Ae. aegypti* mosquito larvae out of total 3773 containers checked. In percentage there was 3.53%, 3.35%, 3.57%, 4.11% & 3.7% of the larvae positive containers found in Rampura, Shegunbagicha, D.U Campus, Dhanmondi R/A and Mirpur area, respectively. On an average 3.66% of containers were found as *Ae aegypti* larvae positive. Highest number of positive containers (4.11%) were found in Dhanmondi R/A as shown in Table 2.

Seasonal Prevalence of *Ae. aegypti* larvae on the basis of larval Breteau Index (BI)

In Fig 3, Bar diagram represents combined data of seasonal prevalence of *Ae. aegypti* larvae from five selected dengue prevalent areas. During the study period, total 1250 houses were visited and *Ae. aegypti* mosquito larvae were found from 138 containers.

Our overall BI result was 11.04(1205÷138×100). But in our yearly observation it varied season to season and also area to area. Highest number of positive containers found in the month of September.

There was heavy rain fall in the month of August, 2009. In our study we observed that post monsoon was the most suitable period for larval growth. The Breteau Index more than 20 considered as the risk level for transmission of Dengue. Our larva survey showed that the Breteau Index around 20-40 from August to October, in all the five selected areas of Dhaka city. That was well above the risk level for dengue virus transmission by the vector mosquitoes. BI became zero for almost 4 months (March-June, 2010). Cold wave passed all over the country by the mid of the December, 2009 to mid of the January, 2010 and no rainfall had seen until the end of June, 2010 in Dhaka. The scattered rainfall had seen at the end of June, 2010. BI 10 found again in all the five spots in the first week of July, 2010. In our observation we have seen winter and draught interrupted the mosquito's larval growth.

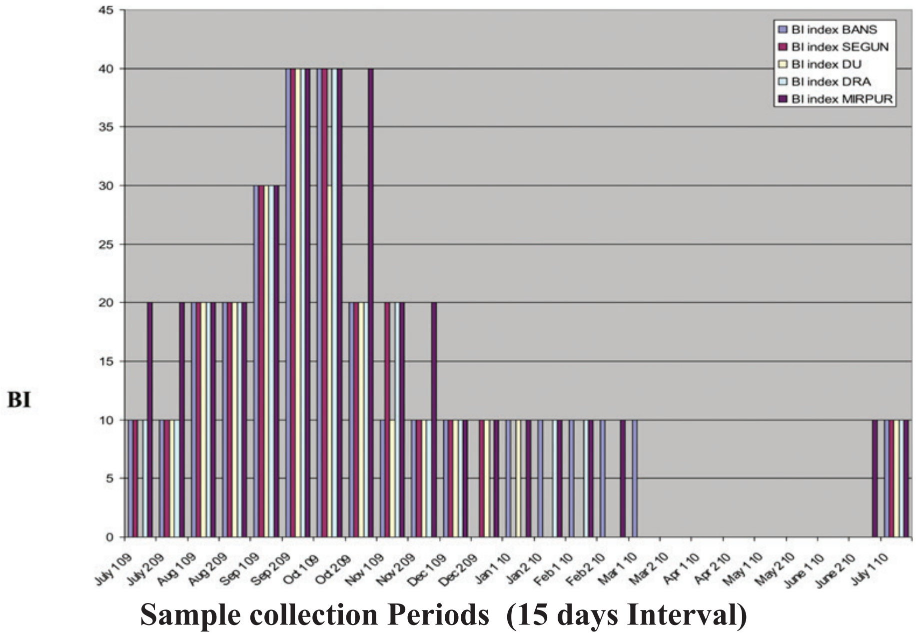

Fig 3: Seasonal prevalence of *Ae. aegypti* larvae from five sampling sites of Dhaka city

Seasonal prevalence of adult *Ae. aegypti*

In Fig 4 the line diagram represents combined data of seasonal prevalence of adult *Ae. aegypti* from five selected dengue prevalent area on basis of adult biting rate. The Indoor resting adult population start rising from August and the peak mosquito population found from September to November, which found consistent with the larvae survey. Adult population dropped from the starting of December, and few mosquitoes found until the next monsoon. Last week of December, 2009 to second week of January 2010 the mean temperature of Dhaka city was around 10-12°C. Interruption of transmission occurred during winter but transmission may have occurred throughout the year in some areas, peaking in the monsoon season.

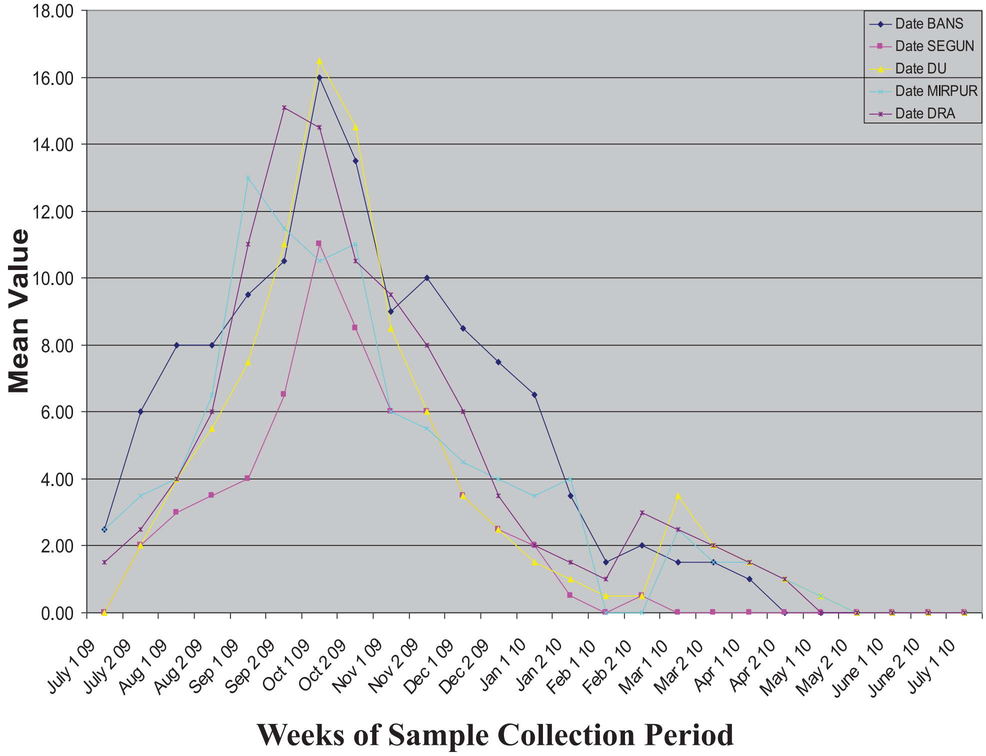

Fig 4: Seasonal prevalence of adult *Ae. aegypti* in five sampling sites of Dhaka city from July, 2009-June, 2010

Discussion

Bionomics of mosquito *Aedes aegypti* were studied to understand breeding sites and seasonal prevalence of larvae and adult mosquitoes and to determine their probable relation to disease outbreak. To study the bionomics of field caught *Ae. aegypti*, the indoor resting adults and larval mosquito surveys were carried out in five selected high-risk dengue prevalent areas in Dhaka city during July, 2009-June, 2010.

It was observed that empty flower pots, flower pot's saucers, flower-vases and glass jars with rooted plants, cemented water reservoirs in under constructed residences, bucket, jars, tin, pot, plastic bowls, bottles, jerry cans, discarded appliance were good sources for dengue mosquitoes breeding. Man-made earthen containers like clay jars & pitchers were also preferable sites to breed. Dumped tires containing rain water were good place for *Aedes* breeding. Water storage drums became ideal breeding ground of *Aedes* mosquitoes. In our survey total 85.85 %of *Ae. aegypti* eggs, larvae and pupae were found in artificial container that mentioned. 10.60% of larvae were found inside cut bamboo stumps which are manmade natural containers. The cut stumps were used to make the finch of garden or field in many places of surveyed area and many of which contained water. Thrown away coconut shells and leaf axils or tree holes were also the natural water container and found good place for *Aedes* breeding (3.55%). So, total14.15% of *Ae. aegypti* were found in natural containers. Our seasonal larvae occurrence survey showed that the post monsoon period (August – September 2009) was the most affected period for *Aedes* growth and transmission and winter has interrupted growth and biting activity.

In yearly observation BI varied season to season and also area to area. Highest number of positive containers found in the month of September. We have seen that winter and draught interrupted the mosquito's larval growth. In March, 2010 rainfall was very low and the population of *Aedes* was the lowest. Our observation supports the observation of Ahmed *et al*., 2007[1], where both the *Aedes* species were active in dry and wet seasons with peak during highest rainfall. The reduction of larvae population during the winter months was related to the low rainfall.

The Indoor resting adult mosquito population started rising from August with the peak mosquito population found during September to November and which is consistent with the larvae survey. Adult population dropped from early December and few dengue mosquitoes were found until the next monsoon came. From last week of December, 2009 to second week of January, 2010 the mean temperature of Dhaka city was around 10-12°C. Successful hatching temperature for *Ae. aegypti* is above 17°C[4,3,8]. The interruption of transmission occurred during winter but transmission may have occurred throughout the year in some areas, peaking in the monsoon season.

The peak for hospitalized cases was found in the month of November and December, 2009 which was in consistent with the adult peak biting period. Therefore, it can be concluded that increased biting rate had probable relation to disease outbreak. Adult mosquito collection just after the monsoon has better chance of getting dengue infected mosquitoes from nature. Though this bionomics study was done in small scale and in few selected areas of Dhaka city, it helped us to find the dengue prevalent season, dengue vector breeding sites and detect the peak season of vector population. These findings had increased the chance of getting more dengue infected mosquitoes from field. Findings of this study has also supported the findings of Ahmed & their team[1].

The bionomics study has found that all favorable environmental conditions conducive for maintaining *Ae. aegypti* were present in Dhaka during study period .Dhaka city dwellers life style and uncontrolled population makes *Ae. aegypti* very much domestic and principal dengue transmission vector.

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Numerical Analysis of Natural Convective Heat Transfer of Cu-water Nanofluid in Square Cavity with a Circular Disk

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Abstract : The convective heat transfer enhancement of Cu-water nanofluid in a differentially heated square cavity with a circular disk was investigated. A finite element model consisting of Navier-Stokes, continuity and energy equations was developed. Thermophysical properties of Cu-water nanofluid were taken from literature data. The model was validated against established solutions for natural convection of air and nanofluid inside a differentially heated square cavity. Average Nusselt numbers were calculated for various flow conditions obtained by varying solid volume fraction of the nanoparticles and different Rayleigh numbers.

Keywords: Nanofluid, Natural convection, Finite Element Method, Nusselt number

1. Introduction

Natural convection fluid flow and heat transfer are encountered in a number of engineering and industrial applications such as cooling of electronic equipment, solar energy, and geophysics. There are a number of very recent studies, using conventional numerical methods, on the free convection heat transfer in cavities filled with nanofluids. Nanofluid has been under extensive analysis in the last decade due to its potential in heat transfer enhancement related application. Nanometer sized particles finely dispersed in a base fluid is known as nanofluid which exhibits higher heat transfer coefficient than that of base fluid[1]. This phenomenon profoundly opens up doors for application of nanofluid in micro-cooling, nano-scale drug delivery and energy conversion. An extensive review on recent works on nanofluid can be found very helpful for the researchers working in this subject [2]. Both numerical and analytical many experimental studies[3] have been conducted as well as many theoretical studies[4]. Abu-nada and Oztop[5] conducted a numerical investigation on the effect of inclination angle of a square cavity on the free convection of the Cu-water nanofluid inside it. Numerical results for free convectionin a square cavity cooled from its two vertical and the top hori zontal walls and

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heated by a constant flux heaters on its horizontal bottom wall filled with a nanofluid were reported by Aminossadati and Ghasemi [6]. In the present paper, a finite element model has been developed to analyze the heat transfer enhancement of Cu-water nanofluid in differentially heated square cavity with a circular disk. The effect of heat transfer enhancement of Cu-water nanofluid has also been addressed. The model has been validated against established results for natural convection of air and nanofluid in a differentially heated square cavity.

2. Theoretical Formulation

2.1 Properties of nanofluid

A schematic view of a square cavity with a circular disk considered in the present study is shown in Fig. 1, side of the square cavity and diameter of the circular disk are denoted by h and d respectively. The problem is formulated in two-dimensional Cartesian coordinate system. The cavity is filled with Cu-water nanofluids which is considered to be Newtonian, laminar and incompressible. Nanoparticles and base fluid are in thermal equilibrium and there is no slip between them.

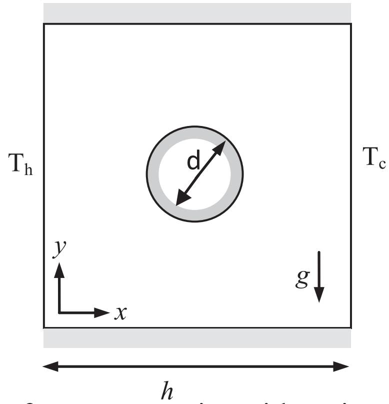

Fig.1. Schematic view of a square cavity with a circular disk The properties of nanofluid are obtained as following:

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s$$

$$C_{p,nf} = \left[(1-\varphi)\rho_f C_{p,f} + \varphi\rho_s C_{p,s}\right]/\rho_{nf} \tag{1}$$

$$\rho_{nf}\beta_{nf} = (1-\varphi)\rho_f\beta_f + \varphi\rho_s\beta_s$$

$$\alpha_{nf} = \frac{k_{nf}}{\left(\rho C_p\right)_{nf}}$$

where φ is the solid volume fraction, ρ is the density, Cp is the specific heat capacity, β is the thermal expansion coefficient, α is the thermal diffusivity, and k is the thermal conductivity. Here, subscript s, f and nf indicate physical properties of solid nanoparticle, base fluid, and nanofluid, respectively. The effective dynamic viscosity, μnf, of the Cu-water nanofluid is calculated from according to the Brinkman model using fluid viscosity μf [9]

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}} \tag{2}$$

The effective thermal conductivity of the nanofluid is determined using the Maxwell model [10]

$$\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\varphi(k_f - k_s)}{(k_f + 2k_s) + \varphi(k_f - k_s)} \tag{3}$$

Physical property of the Cu-water nanofluid is determined following in the Table 1.

Table 1. Thermo-physical properties of water and Cu nanoparticle

Physical properties	Water	Cu
C (J/kg K)	4179	385
ρ (kg/m^3)	997.1	8933
k (W/m K)	0.613	400
β (K^{-1})	21x 10^{-5}	1.67 x 10^{-5}
α (m^2 s^{-1})	1.471 x 10^{-7}	-

2.2 Theoretical description:

The set of equations that governs the thermo-fluid flow is given as:

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho_{nf}}\frac{\partial p}{\partial x} + \frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{4}$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho_{nf}}\frac{\partial p}{\partial y} + \frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{(\rho_{nf}\beta_{nf})}{\rho_{nf}} g(T - T_c)$$

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

where u and v are the fluid velocity in x-direction and y-direction respectively, p is the pressure, and T is the temperature.

Governing equations of the convective heat transfer are non-dimensionalized with the following dimensionless parameters defined as:

$$X = \frac{x}{h}; \quad Y = \frac{y}{h}; \quad U = \frac{uh}{\alpha_f}; \quad V = \frac{vh}{\alpha_f}; \quad P = \frac{ph^2}{\rho_{nf}{\alpha_f}^2}; \ \theta = \frac{T - T_c}{T_h - T_c}$$

The dimensionless forms of the governing equations are:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0$$

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \frac{\mu_{nf}}{\rho_{nf}\alpha_f}\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right)$$

$$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + \frac{\mu_{nf}}{\rho_{nf}\alpha_f}\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) + \frac{(\rho\beta)_{nf}}{\rho_{nf}\beta_f}RaPr\theta \tag{4}$$

$$U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y} = \frac{\alpha_{nf}}{\alpha_f}\left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right)$$

where U and V are the scaled fluid velocity in X-direction and Y-direction, respectively, P is the scaled pressure, θ is the scaled temperature. Rayleigh number Ra and Prandtl number Pr are defined as

$$Ra = \frac{g\beta_f(T - T_c)h^3}{\alpha_f v_f}; \quad Pr = \frac{v_f}{\alpha_f}$$

In order to evaluate the heat transfer enhancement in the cavity, the local Nusselt number on the walls is defined as:

$$Nu_l = -\frac{k_{nf}}{k_f}\frac{\partial \theta}{\partial n}\bigg|_{wall}$$

Average Nusselt number along the hot walls of the cavity is considered to evaluate the overall heat transfer rate and is defined as:

$$Nu_{avg} = \int_0^1 Nu_l dY|_{X=0}$$

3. Results and Discussion

3.1 Model Validation

The model is solved by using commercial finite element package COMSOL Multiphysics. It has been validated against benchmark solutions obtained in the literature as shown in Table 2. Natural convection of air inside a square cavity whose two sides are set to differential temperatures while keeping the top and bottom surfaces at adiabatic condition is a classic case for validation. Average Nusselt number for the hot wall calculated from the present model is compared with the data available in the literature and found very accurate for various high Rayleigh numbers.

Table 2. Average Nusselt number for the hot wall of the air filled square cavity obtained by various studies are shown and compared with present study for different Rayleigh numbers

Rayleigh number (Ra)	Present study	Vahl Davis (1983) [11]	Fusegi et al.(1991) [12]	Comini et al.(1995) [13]	Khanafer et al.(2003) [3]	Bilgen (2005) [14]
10^4	2.2448	2.243	2.302	-	2.245	2.245
10^5	4.5216	4.519	4.646	4.503	4.522	4.521
10^6	8.8262	8.799	9.012	8.825	8.826	8.800
10^7	16.5301	-	16.543	16.533	-	16.629

A second degree of validation has been done for Cu-water nanofluid. Calculated average Nusselt number of the present study was compared against that of a Cu-water nanofluid filled square cavity for various Grashof number and found satisfactory.

Table 3. Comparison of average Nusselt number calculated on hot wall in Cu-water nanofluid filled square cavity with Khanafer et al.(2003):

Grashof number (Gr)	Present study	Khanefer et al (2003) [3]
10^3	2.5662	2.835
10^4	5.4050	5.895
10^5	10.6669	11.245

3.2 Adiabatic circular disk

The first problem was defined as differentially heated square cavity with an adiabatic circular disk at the centre of the cavity. The ratio of diameter of the disk *(d)* to sides of the square cavity *(h)* is taken as $\lambda=d/h=0.2$. Thermal boundary conditions are taken as $T=T_h$ for the hot left wall, $T=T_c$ for the cold right wall and adiabatic condition $\partial T/\partial n=0$ for the top, bottom and disk walls. No-slip condition is imposed on all surfaces.

Using the dimensionless parameters in Eq. (4) the following boundary conditions are obtained.

On the left wall: $U=V=0; \quad \theta=1$

On the right wall: $U=V=0; \quad \theta=0$

On the top and bottom walls and disk: $U=V=0; \quad \partial\theta/\partial n=0$

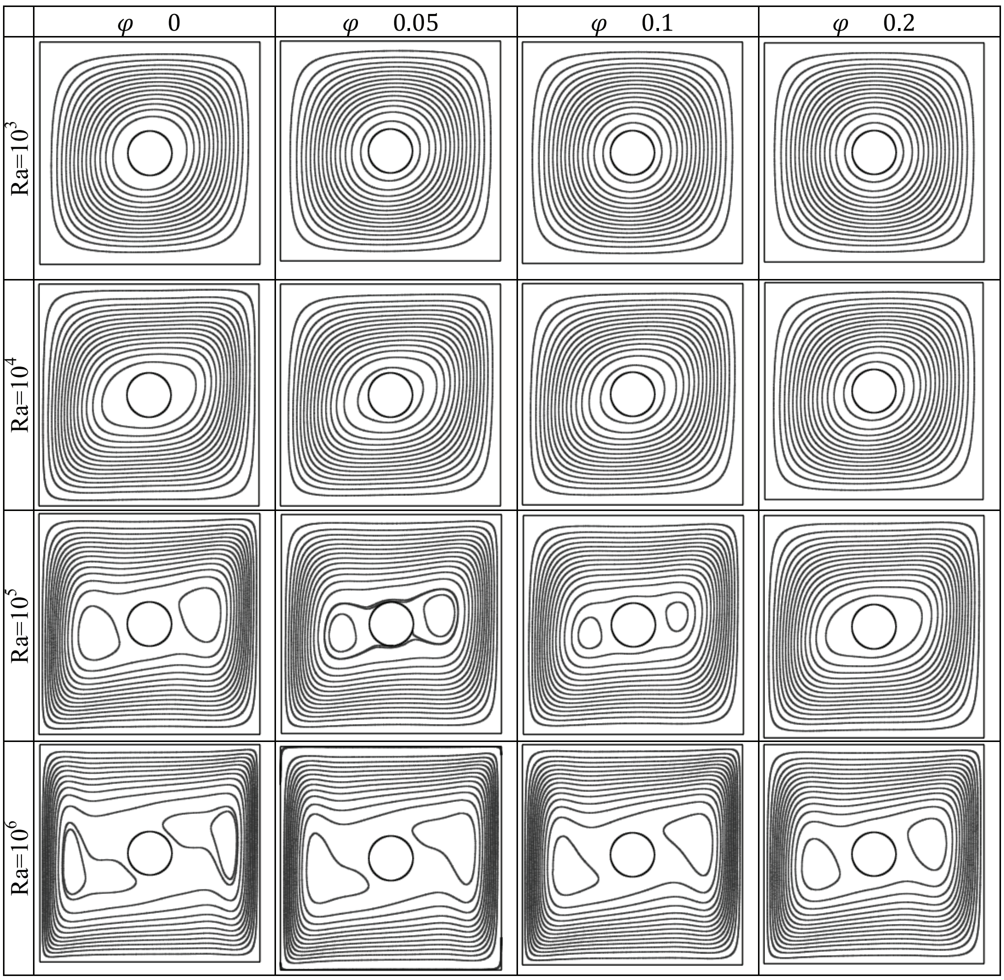

Fig.2. Streamlines for Cu–water nanofluid in a differentially heated square cavity with an adiabatic circular disk for different volume fractions and Rayleigh numbers

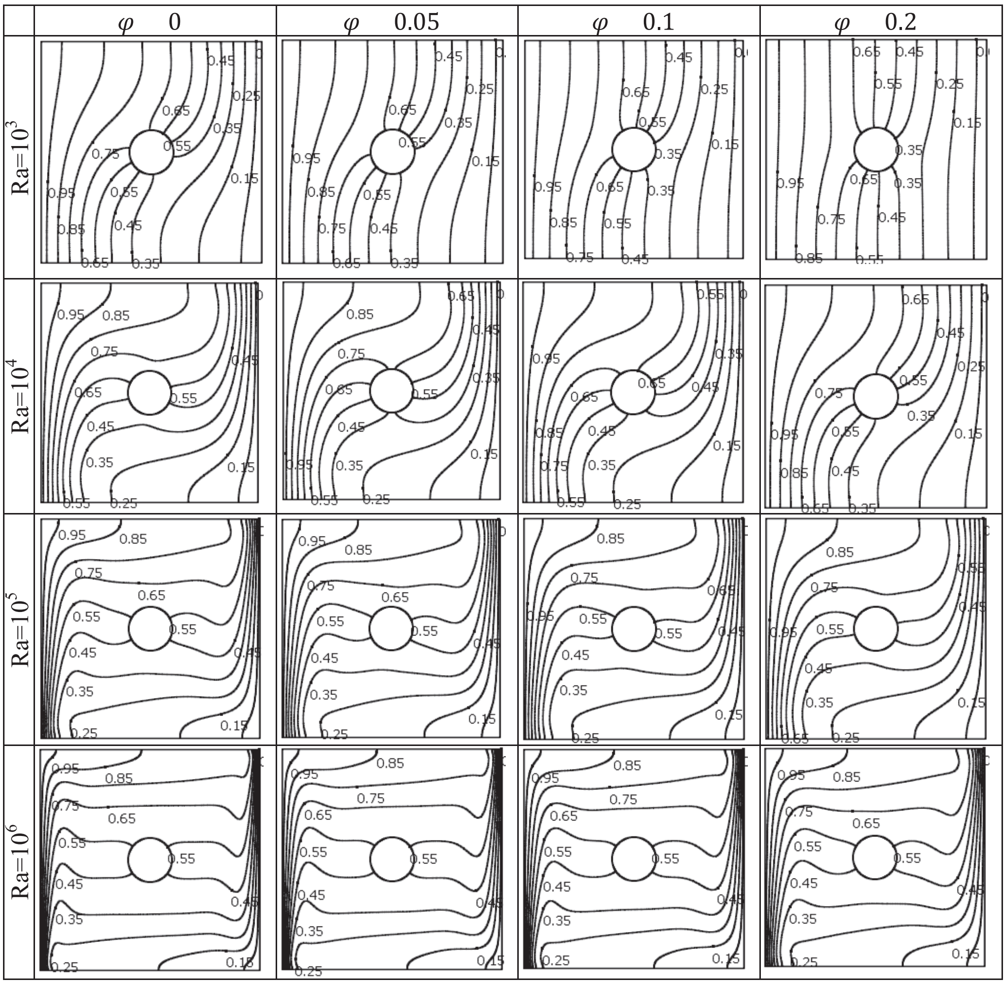

Fig.3. Isotherms for Cu–water nanofluid in a differentially heated square cavity with an adiabatic circular disk for different volume fractions and Rayleigh numbers

3.3 Cold circular disk

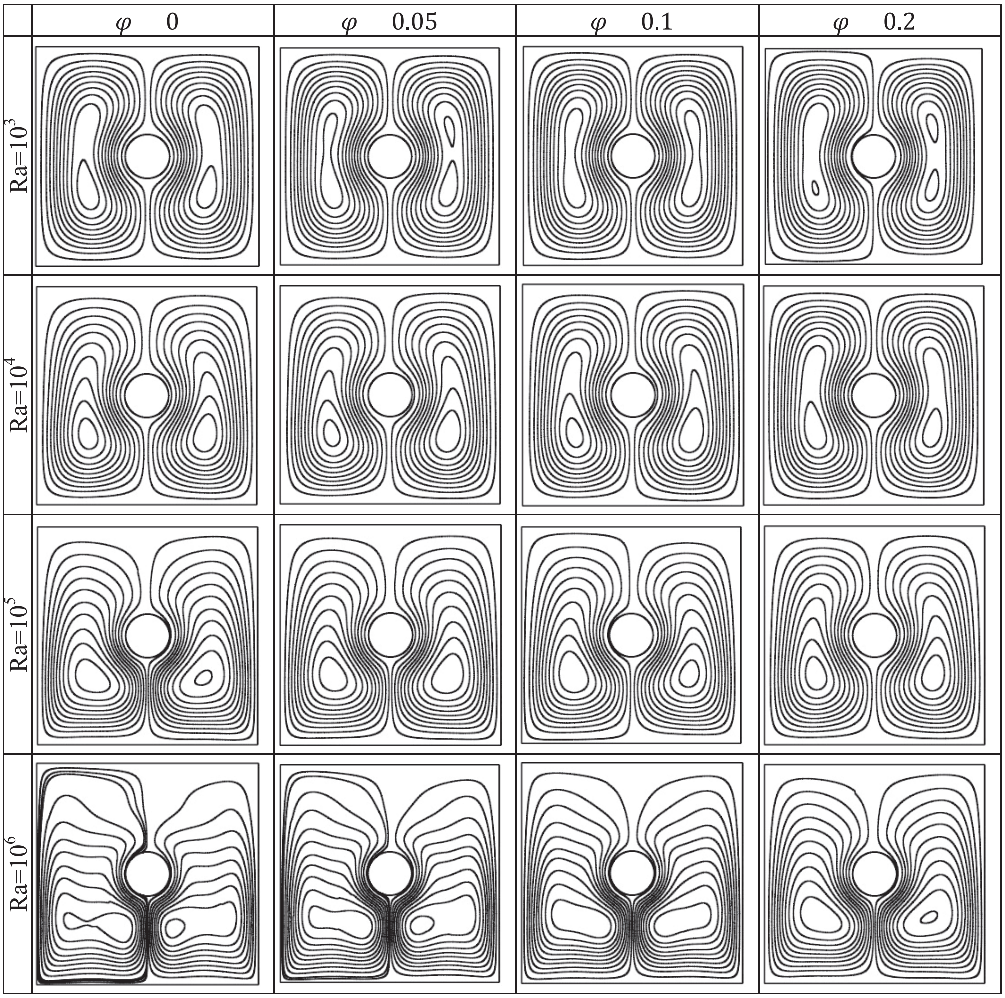

Fig.4. Streamlines for Cu–water nanofluid in a square cavity with a cold circular disk at different volume fractions and Rayleigh numbers

Eq. (4) the following boundary conditions are obtained for cold circular disk.

On the disk wall: $U=V=0; \quad \theta=0$

On the left and right walls: $U=V=0; \quad \theta=1$

On the top and bottom walls: $U=V=0; \quad \partial\theta/\partial n=0$

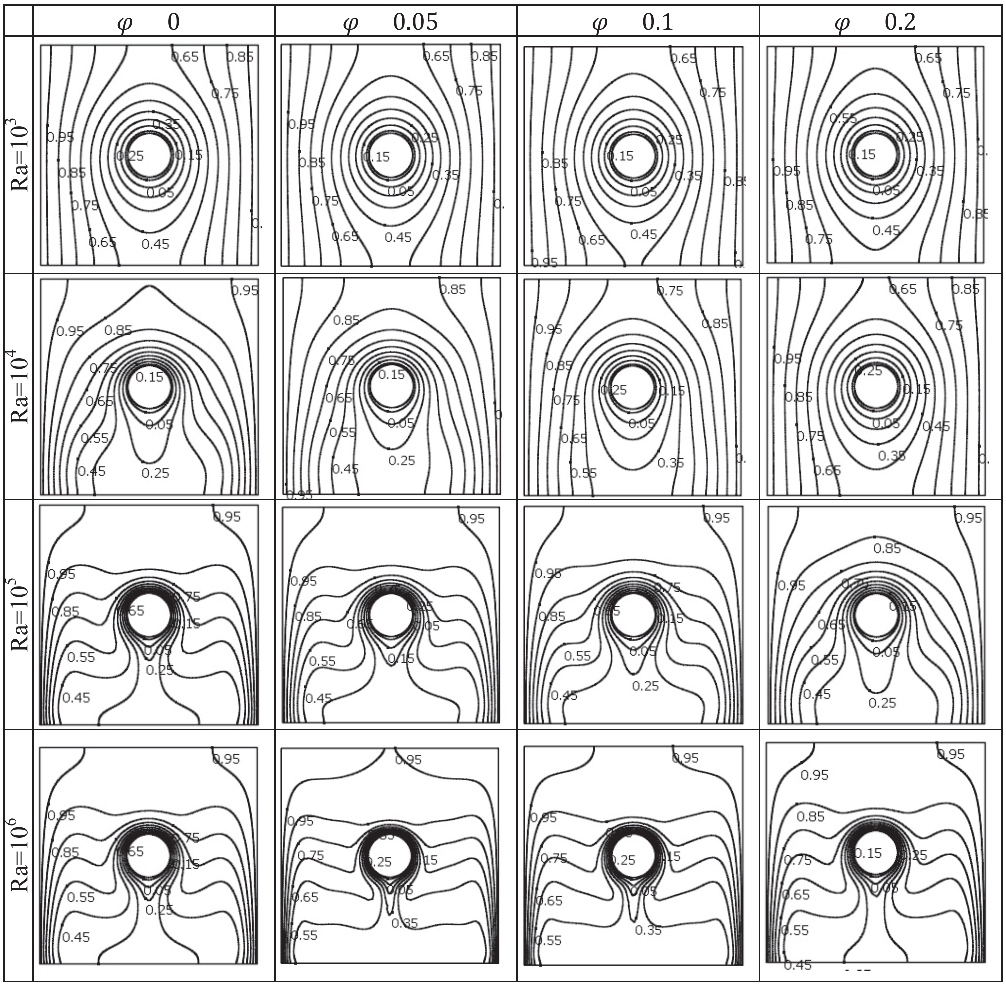

Fig.5. Isotherms for Cu–water nanofluid in a square cavity with a cold circular disk for different volume fractions and Rayleigh numbers

3.4 Heated circular disk

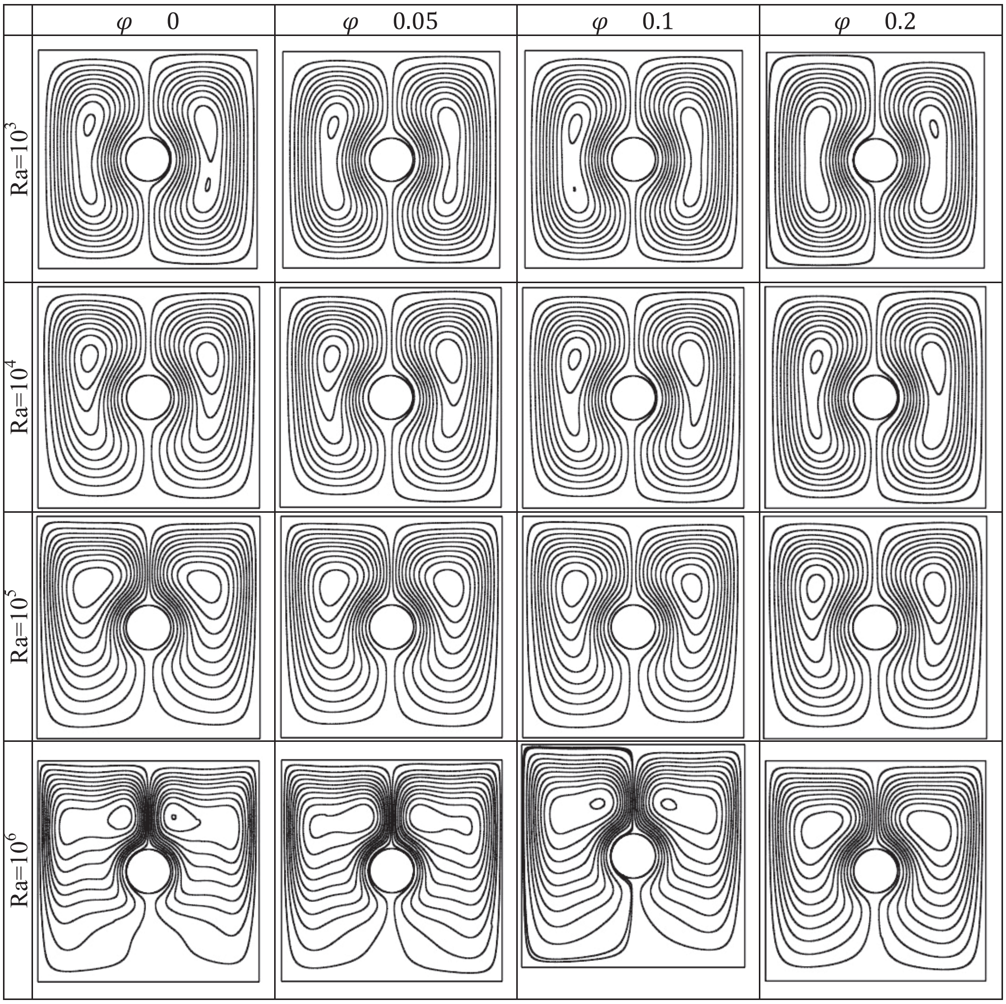

Fig.6. Streamlines for Cu–water nanofluid in a square cavity with a heated circular disk for different volume fractions and Rayleigh numbers

Eq. (4) the following boundary conditions are obtained for heated circular disk.

On the disk wall: $U=V=0; \quad \theta=1$

On the left and right walls: $U=V=0; \quad \theta=0$

On the top and bottom walls: $U=V=0; \quad \partial\theta/\partial n=0$

In the present investigation, the influences of Rayleigh number Ra and solid volume fraction of nanoparticles φ on the streamlines and isotherms were assumed while Prandtl number is kept constant at $(Pr = 6.2)$. The values of Rayleigh numbers and solid volume fraction of nanoparticles considered are $Ra = 10^3, 10^4, 10^5, 10^6$ and $\varphi = 0, 0.05, 0.1, 0.15, 0.2$. Beside these, the average Nusselt numbers in the enclosure have been calculated in the Fig. 2, which is related to streamlines and temperature lines of the Cu-water nanofluid at lower values of Ra isotherms formed in the cavity and especially in the vicinity of the lids which shows the dominance of conduction heat transfer. The effects of Rayleigh number Ra upon the streamline patterns have been presented in Fig.2. while $\mathrm{Pr} = 6.2$ and $\mathrm{Ra} = 10^3, 10^4, 10^5, 10^6$ and $\varphi = 0, 0.05, 0.1, 0.15, 0.2$. Two primary recirculation cells are found in the streamlines at high Rayleigh number. The shapes of these vortices change from circular to triangular with the increasing of Ra . This happens as a result of getting higher buoyancy force. When volume fraction of nanoparticles increases from 0.1 to 0.2, length of the circulation cell becomes smaller

Fig.3 shows the temperature distribution for different Ra and φ . In this figure the isotherms become parallel with the increase of the suggesting inner circulation around the disk, outer circulation zone formed close to the wall.

In Fig.4 and Fig.5, the results are presented in terms of streamlines and isotherms for different choice of solid volume fractions φ and different Rayleigh numbers Ra in the square cavity containing cold circular disk. The shape of streamlines changes slightly with the increasing of the solid volume fraction because of higher concentration of nanoparticles. As the volume fraction of nanoparticles enhances from 0 to 0.2, the isotherm contours tend to get affected considerably.

In Fig.6 and Fig.7, the results are presented in terms of streamlines and isotherms for different choice of solid volume fractions φ and different Rayleigh numbers Ra in the square cavity containing heated circular disk. The flow rate exists with maximum value in the centre of the circulation. As the parameter Ra increases, the flow rates at the centers of circulation increase.

In Fig.7. for increment of Ra, the isothermal lines become more condensed near the heat source and a thermal plume formed based on the heated body due to convection are is dominated across the enclosure. Due to rising values of Ra, the temperature distributions become deformed ensuing in an augmentation in the whole heat transport process. This effect may be accredited to the control of the buoyant convection. Moreover, it is observed that raising the Rayleigh numbers cause the higher depth of the thermal boundary layer near the heated surface that point towards a steep temperature gradient and consequently, an enhancement on the whole heat transfer inside the cavity. In addition, these lines corresponding to $\varphi = 0.2$ become more bended. The isotherms are packed out about the vigorous part of the heated surface in the cavity for clear water ($\varphi = 0$). It is seen that, clear water moves more rapidly than the solid concentrated nanofluids. Rising of φ shows a deformation at the isothermal lines near the upper part of the top portion of the heated circular disk.

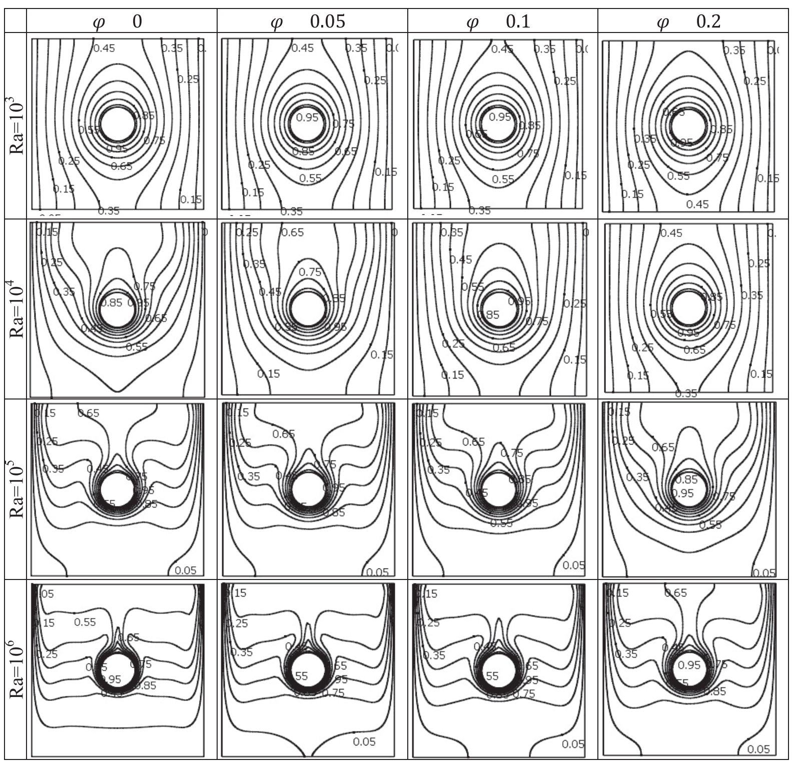

Fig.7. Isotherms for Cu–water nanofluid in a square cavity with a hot circular disk at different volume fractions and Rayleigh numbers

Figure 8(a), displays the average Nusselt number Nu_{avg} due to the Rayleigh number (Ra) as well as solid volume fractions(φ) effect. It is seen from figures Nu_{avg} increases for greater values of φ because nanofluid has greater thermal conductivity in comparison to pure water.

Figure 8(b), presents the variation of average Nusselt number Nu_{avg} with volume fraction (φ) using different values of Rayleigh number. The figure shows that the heat transfer increases almost monotonically with increasing the volume fraction for all Rayleigh numbers .

Figure 8(c), displays the average Nusselt number Nu_{avg} due to the Rayleigh numbers (Ra) as well as solid volume fractions(φ) effect. It is seen from figures that Nu_{avg} enhances sharply upto $Ra = 10^4$ and beyond this region it rises gradually.

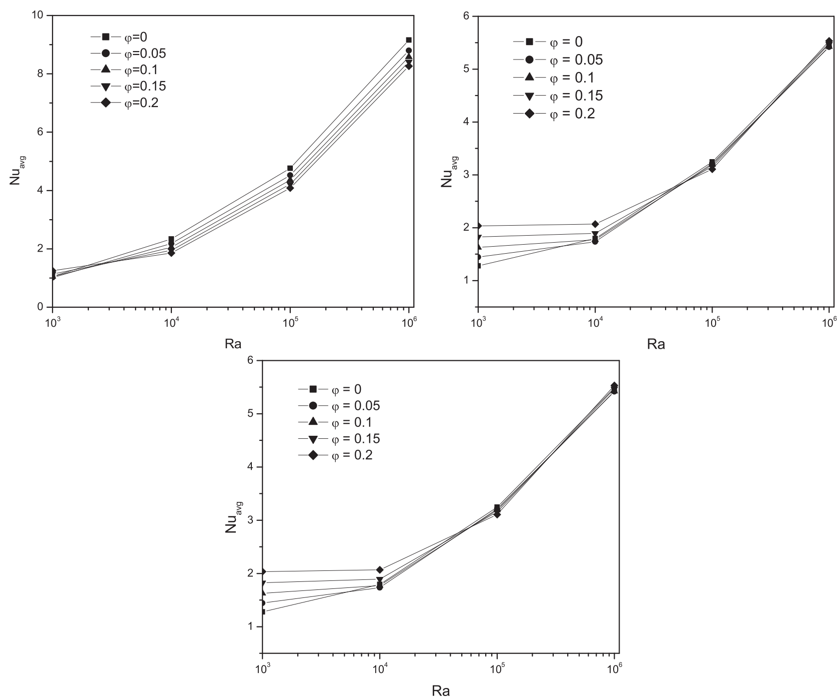

Fig.8 Average Nusselt number for different volume fraction of (a) adiabatic circular disc (b) cold circular disk, and (c) heated circular disk.

4. Conclusion

A numerical investigation concerning the effects of nanoparticles concentration and natural convection parameter Ra on velocity and temperature field around an adiabatic circular disk, cold circular disk and heated circular disk placed in an enclosure filled with Cu-water nanofluids is accounted. The focal point of the present investigation is to calculate the average heat transfer rate and entropy generation of the Cu-water nanofluids with a wide choice of Rayleigh number along with solid volume fraction while Pr is fixed at 6.2. The subsequent findings can be seen from the current numerical analysis:

- Ra and φ significantly affect the configuration of the streamlines and isotherms within the square cavity containing different circular disk.
- Greater variation is observed in velocities at a particular point for the changes of Ra than φ .

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