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Review Article

A COMPREHENSIVE REVIEW ON HEAT TRANSFER AND FLUID FLOW IN ANNULUS

Dushyant Singh Chandel, Dr. S. K. Nagpure

Mechanical Engineering Department, Scope College of Engineering Bhopal, India

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Email: info@jusres.com

ABSTRACT

This paper focuses on extensive review on heat transfer and flow in Annulus. Conventionally, Heat transfer is categorized into three forms, namely, convection, conduction, and radiation respectively. Since convection is one of the chief modes of heat transfer which is qualified in terms of forced, natural, thermo-magnetic, gravitational and granular. In recent year enormous research has been carried out in the field of heat transfer via conventionally through annulus computationally, numerically, and experimentally.

Various factors have been investigated in order to examine the effect of eccentricity ratio, direction of flow, orientation of annulus i.e. horizontal, inclined or vertical. And on the basics of obtained results various empirical correlations has been reported and illustrated through meaningful graphs.

INDEX TERMS— Annulus, Convection, eccentricity, Heat transfer, CFD

INTRODUCTION

Convective heat transfer and fluid flow in annulus are imperative phenomenon in engineering systems since of their industrial applications in thermal storage system, heat exchangers, nuclear reactors, aircraft fuselage insulation to underground electrical transmission cables, solar energy systems, boilers, cooling of electronic devices, compact heat exchangers, cooling systems, cooling core of nuclear reactors, gas- thermal insulation, cooled electrical cables, & electrical gas-insulated transmission lines. In most of the work accounted on enclosure natural convection, the Boussinésq estimate has been raised. Though, for higher overheat ratios, compressibility effects require to be taken into consideration since Boussinésq approximation can become insufficient. [1-4].

In mathematics, an annulus (the Latin word for "little ring", with plural annuli) is a ring-shaped object, particularly a region bounded by two concentric circles. The adjectival form is annular (as in annular eclipse)

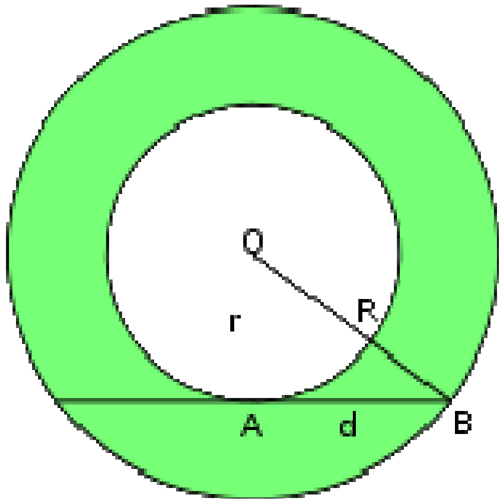


Fig. 1 Annulus

MATHEMATICAL MODELING

The governing equations in polar coordinate are described in dimensional form specifying boundary conditions for velocity and temperature as below:

$$\frac{\partial}{\partial r}(r^2 u \sin\theta) + \frac{\partial}{\partial \theta}(r^2 v \sin\theta) = 0 \tag{1}$$

$$u\frac{\partial u}{\partial r} + \frac{v\partial u}{r\partial\theta} - \frac{v^2}{r} = -\frac{1}{\rho_m}\frac{\partial p}{\partial r} + \mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial u}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial u}{\partial\theta}\right) - 2\frac{u + \frac{\partial v}{\partial\theta} + v\cot\theta}{r^2}\right] - \frac{1}{\rho_m}\rho g\cos\theta \tag{2}$$

$$u\frac{\partial u}{\partial r} + \frac{v\partial u}{r\partial\theta} + \frac{uv}{r} = -\frac{1}{r\rho_m}\frac{\partial p}{\partial\theta} + \mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial v}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial v}{\partial\theta}\right) + \frac{2}{r^2}\frac{\partial u}{\partial\theta} - \frac{v}{r^2(\sin\theta)^2}\right] + \frac{1}{\rho_m}\rho g\sin\theta \tag{3}$$

$$u\frac{\partial T}{\partial r} + \frac{v}{r}\frac{\partial T}{\partial\theta} = \alpha\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 T}{\partial\theta^2} + \frac{2\partial T}{r\partial r} + \frac{\cot\theta}{r^2}\frac{\partial T}{\partial\theta}\right)$$

$$\rho = \rho_m\left[1 - \beta(T - T_m)\right] \tag{4}$$

Boundary Condition

u=0, v=0, T=Ti at r=ri for 0≤θ

u=0, v=0, T=Ti at r=ro for 0≤θ≤π

u=0, v=0, dt/dθ=0 at θ=0 for ri≤r≤ ro

u=0, v=0, dt/dθ=0 at θ=π for ri≤r≤ ro

Non Dimensional Parameters

$$U = \frac{u}{a/d} \qquad T^* = \frac{T - T_c}{T_h - T_c}$$

$$V == \frac{v}{a/d} \qquad P = \frac{\rho}{\mu\alpha / d^2}$$

$$R = r/d \qquad \bar{\rho} = \frac{\rho}{\rho_m} \qquad rr = \frac{r_o}{r_i}$$

Where rr (radius ratio)

$$rr = \frac{r_o}{r_i}$$

Pr (Prandlt Number)

$$\Pr = \frac{\mu}{\rho_m \alpha} = \frac{\vartheta}{\alpha}$$

Ra (Rayleigh Number)

$$Ra = \frac{g\beta \Delta T d^3}{\vartheta\alpha}$$

LITERATURE REVIEW

Abu-Nada and Oztop [1] numerically investigate consequences of inclination angle on natural convection in enclosures filled with Cu–water nanofluid. It is found that the effect of nano-particles concentration on Nusselt number is more pronounced at low volume fraction than at high volume fraction. Inclination angle can be a control parameter for nano-fluid filled enclosure. Percentage of heat transfer enhancement using nanoparticles decreases for higher Rayleigh numbers.

Reddy et al. [5] performed a numerical investigation of non-Boussinésq conjugate natural convection of air in a vertical annulus. The annulus was shaped by an inner solid heat-generating rod with a circular cross-section and an outer concentric cylinder. The top and bottom surfaces of the annulus were regard ed to be adiabatic, while the outer cylindrical surface was presumed to be isothermal. The results illustrate that the average Nu on the solid–fluid interface enhanced with Gr, in contrast to the dimensionless maximum temperature. The non-Boussinésq model calculated somewhat lower temperatures and to some extent higher Nu as contrasted with the Boussinésq model at a Gr of 10^{10}

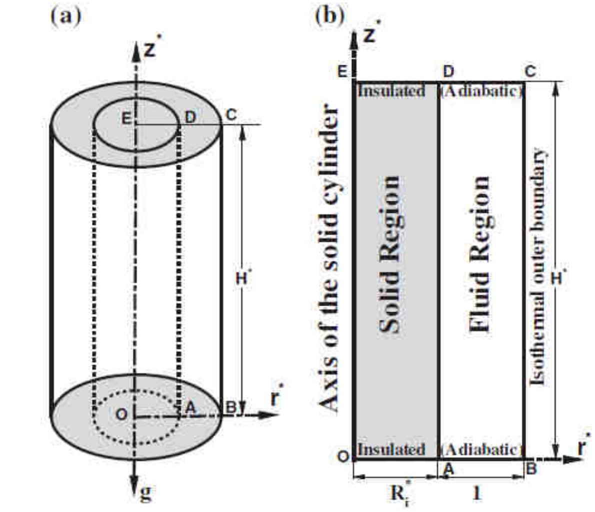


Fig. 2. Physical model and coordinate system [5]

Hussein [6] experimentally examines the laminar mixed convection heat transfer in a vertical circular tube under buoyancy assisted and opposed flows. The experimental setup was intended for influential the consequence of flow direction and the effect of tube inclination on the surface temperature, local and average Nusselt numbers with Reynolds number ranged from 400 to 1600 and Grash of number from $2.0x10^5$ to $6.2x10^6$. It was found that the circumferential surface temperature along the dimensionless tube length for opposed flow would be higher than that both of assisted flow and horizontal tube.

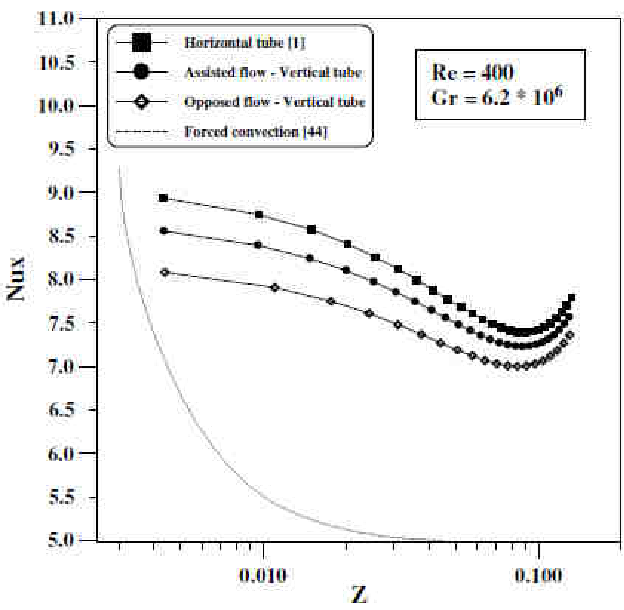
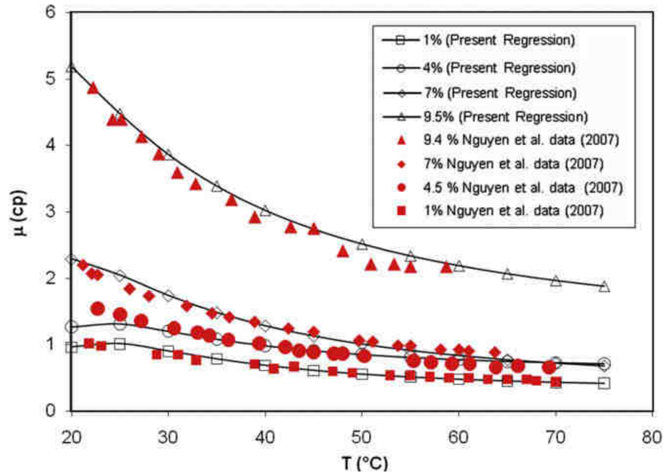


Fig. 3 Variation of Nusselt number [6]

Abu-Nada and Oztop [7] conducted a numerical study to examine the effects of inclination angle on natural-convection heat transfer and 380 fluid flow in a 2D enclosure filled with Cu-nanofluid. Inclination angle 381 was used as a flow and heat-transfer control parameter and varied from 0° to 120° for Ra numbers ranging from 103 to 105.



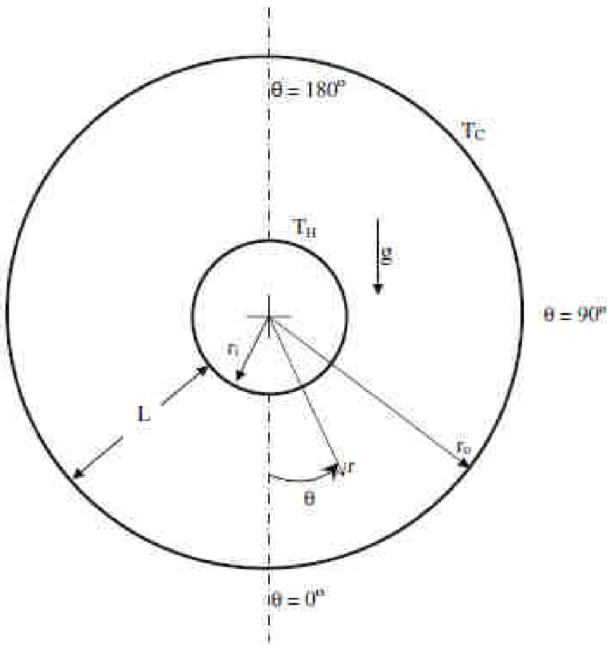


Fig. 4. Sketch of problem geometry and Comparison between viscosities with respect to temperature [7]

They reported that the effect of nanoparticle concentration on Nu number is more pronounced at a low particle volume fraction than at a high volume fraction. Thus, the inclination angle can be a control parameter for a nanofluid-filled enclosure. They also revealed that nano particle enhanced heat transfer decreases with high Ra numbers.

Akbari et al. [8] numerically examined the fully developed laminar mixed convection of Al_2O_3/water nano-fluid in inclined and horizontal tubes. They conclude that nano-particle concentration does not have major effects on hydrodynamics parameters. The heat transfer coefficient enhances by 15% at 0.04 nano-particle volume. The skin friction coefficient continually amplifies with tube inclination, while the heat transfer coefficient attains its maximum at the 45° inclination angle.

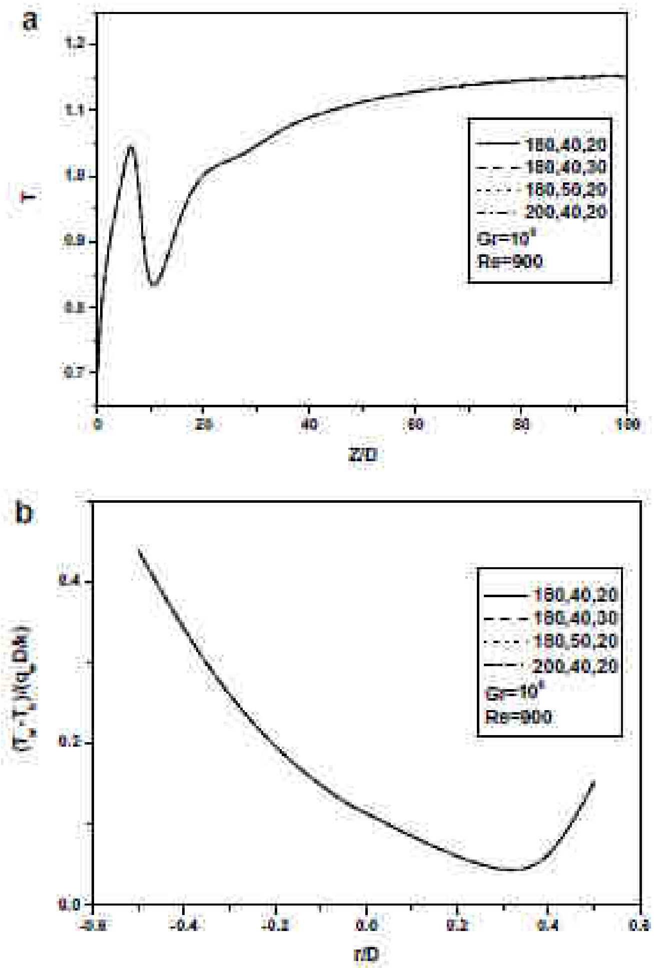


Fig. 5. Grid independence tests (a) axial profile of centerline axial velocity (b) fully developed temperature profile [8]

Lu and Wang [9] experimentally to investigate the convection heat transfer characteristics of water flow in a narrow annulus. The experiment involves three flow directions, specifically, upward, horizontal, and downward flows. The experimental results reveals that the heat transfer characteristics of single-phase water flow in a narrow annulus are dissimilar from those in circular tubes.

Convection heat transfer experiments were conducted in vertical and horizontal narrow annuli when the Re number ranges from10 to 30,000. The transition from laminar to turbulent heat transfer in the narrow annulus is earlier than that in circular tubes. Fig. 6 demonstrates the relationship between convection heat transfer and outer-wall temperature.

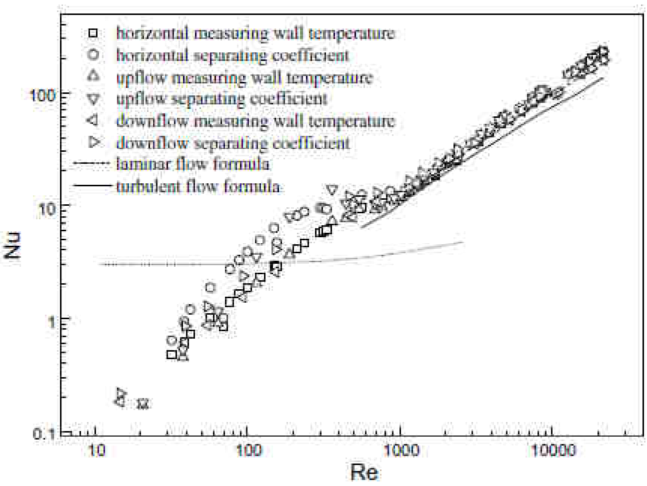


Fig 6. Convection heat transfer for the three flow directions [9]

Asan [10] focused on steady-state, laminar, two-dimensional natural convection in an annulus between two isothermal concentric square ducts. Solutions are obtained up to Rayleigh number of 106. Three different dimension ratios, L∗, namely 15, 310, and 35, are considered. The effects of dimension ratio and Rayleigh number on the flow structure and heat transfer are investigated. The results show that dimension ratio and Rayleigh number have a profound influence on the temperature and flow field.

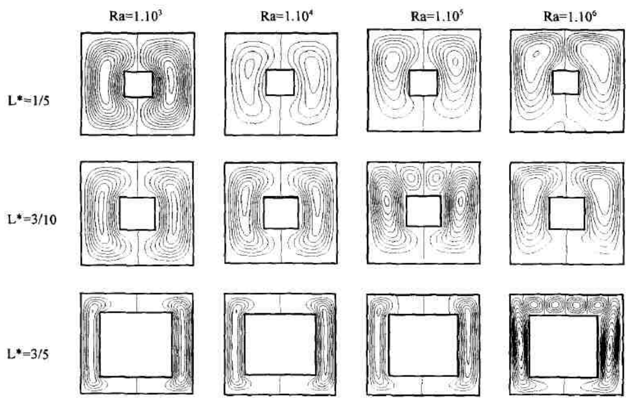


Fig .7 Streamlines for different dimension ratios and Ra numbers [10]

Vadim and rath [11] discuss the energy stability problem with respect to axisymmetric disturbances of the natural convection in the narrow gap between two spherical shells under the earth gravity. The results are evaluated with the results of the linear stability investigation for the similar problem. The problem is resolved for different fluids with Pr=0–100 and different radius ratios η=0.9,0.925,0.95.

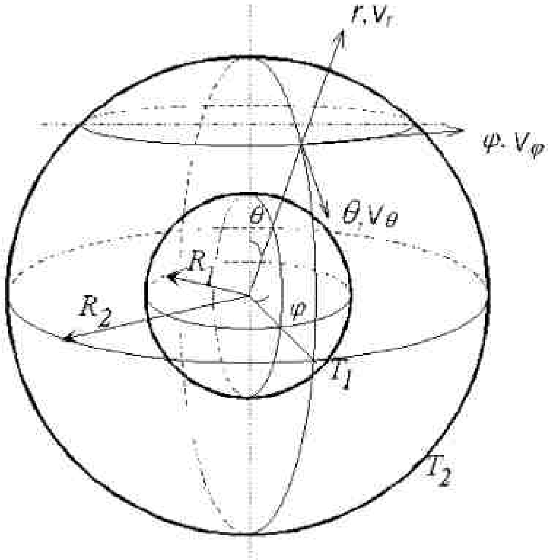


Fig. 8. Spherical geometry [11]

Shekholeslami and ganji [12] studied, natural convection in a concentric annulus between a cold outer square and heated inner circular cylinders in presence of static radial magnetic field using the lattice Boltzmann method. The results reveal that the average Nusselt number is an increasing function of nanoparticle volume fraction as well as the Rayleigh number, while it is a decreasing function of the Hartmann number.

Sangita [13] reports results of a numerical investigation of natural convection in a spherical porous annulus. The inner and outer surfaces are subjected to constant temperatures. The Brinkman extended Darcy flowmodel is considered in her study.

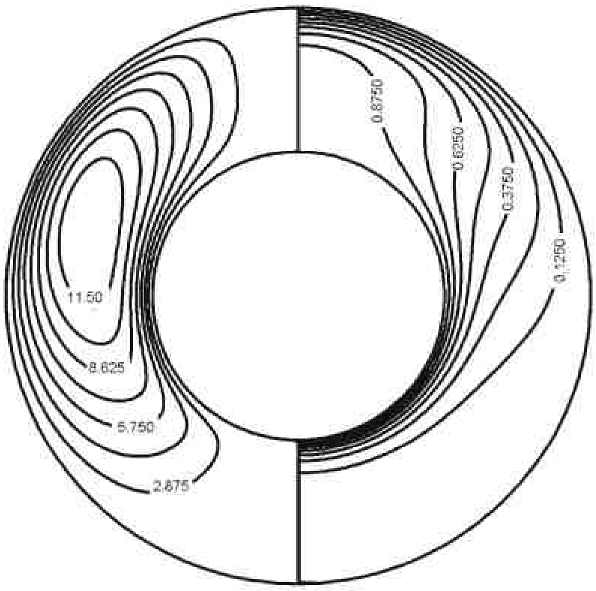


Fig. 9 Streamlines (left) and isotherms (right) for Ra=100, rr=2 and Da = 10^{-4} [13]

CONCLUSION

A broad review of prior studies on forced, natural and mixed-convection heat transfer and fluid flow through annuli was addressed in this paper. The effects of several parameters, such as, aspect ratio, Ra number, geometrical parameters, Re number, & heat flux, were also widely examined. Besides, wide reviews for preparation, mechanisms, parameters, characteristic, and heat transfer enhancement with applications for annulus were accounted. Literature on forced, natural and mixed convection comprised the preparation of these fluids, discussion on heat transfer properties and characteristics, and numerical and experimental results. Several remarks has been given below on the basis of review

- At fixed radius ratio the average Nusselt number increase with increase in Rayleigh number.
- At fixed Rayleigh number the Nusselt number first increases with increase in radius ratio, but after a critical radius ratio value Nusselt number stars decreasing.
- The centre of main vortex, where stream function is maximum, moves upward with increase in both Rayleigh number and radius ratio.
- Prandlt number has very slight effect upon Nusselt number if radius ratio has kept constant.
- Increasing the surface area or ratio the rate of heat transfer increases
- At high temperature the rate of heat transfer is significantly more as compared to low.
- Higher pressure drop enhances the heat transfer rate but it leads to an increase in the power consumption.
- Heat transfer and pressure drop increase by increasing nanoparticle concentration.

REFERENCES

[1] E. Abu-Nada, H.F. Oztop, Effects of inclination angle on natural convection in enclosures filled with Cu-water nanofluid, Int. J. Heat Fluid Flow 30 (4) (2009) 669–678.

[2] B. Duka, C. Ferrario, A. Passerini, S. Piva, Non-linear approximations for natural con vection in a horizontal annulus, Int. J. Nonlinear Mech. 42 (9) (2007) 1055–1061.

[3] A. Passerini, C. Ferrario, G. Thäter, Natural convection in horizontal annuli: a lower bound for the energy, J. Eng. Math. 62 (3) (2007) 247–259.

[4] N. Sambamurthy, A. Shaija, G. Narasimham, M. Murthy, Laminar conjugate natural convection in horizontal annuli, Int. J. Heat Fluid Flow 29 (5) (2008) 1347–1359

[5] P .V. Reddy, G.S.V.L. Narasimham, S.V. Raghurama Rao, T. Johny, K.V.

Kasiviswanathan, Non-Boussinésq conjugate natural convection in a vertical annulus, Int. Commun. Heat Mass Transfer 37 (9) (2010) 1230–1237

[6] E. Abu-Nada, Effects of variable viscosity and thermal conductivity of Al2O3–water nanofluid on heat transfer enhancement in natural convection, Int. J. Heat Fluid Flow 30 (4) (2009) 679–690

[7] H.A. Mohammed, Laminar mixed convection heat transfer in a vertical circular tube under buoyancy-assisted and opposed flows, Energy Convers. Manag. 49 (8) (2008) 2006–2015.

[8] M. Akbari, A. Behzadmehr, F. Shahraki, Fully developed mixed convection in horizontal and inclined tubes with uniform heat flux using nanofluid, Int. J. Heat Fluid Flow 29 (2) (2008) 545–556

[9] G. Lu, J. Wang, Experimental investigation on heat transfer characteristics of water flow in a narrow annulus, Appl. Therm. Eng. 28 (1) (2008) 8–13.

[10] H Asan ,"Natural convection in an annulus between two isothermal concentric square ducts", International Communications in Heat and Mass Transfer, Volume 27, Issue 3, April 2000, Pages 367-376

[11] Vadim V. Travnikov, Hans J. Rath, Christoph Egbers "Stability of natural convection between spherical shells: energy theory", International Journal of Heat and Mass Transfer, Volume 45, Issue 20, September 2002, Pages 4227-4235

[12] M. Sheikholeslami, M. Gorji-Bandpay, D.D. Ganji "Magnetic field effects on natural convection around a horizontal circular cylinder inside a square enclosure filled with nanofluid", International Communications in Heat and Mass Transfer, Volume 39, Issue 7, August 2012, Pages 978-986

[13] Sangita, M. K. Sinha, R. V. Sharma, "Natural Convection in a Spherical Porous Annulus: The Brinkman Extended Darcy Flow Model", Transp Porous Med (2013) 100:321–335)E. Abu-Nada, H.F. Oztop, Effects of inclination angle on natural convection in enclosures filled with Cu-water nanofluid, Int. J. Heat Fluid Flow 30 (4) (2009) 669–678.