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Research article

Numerical study of natural convection in a horizontal annular channel with a rotating inner cylinder

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This paper presents a numerical study of the natural convection of a viscous incompressible fluid that completely fills a horizontal annular channel. The temperature difference at the outer boundary produces convection, which can cause the rotation of the inner cylinder around its axis. The cylinder is assumed to rotate without friction. The Boussinesq approximation is used as a mathematical model. The problem is solved numerically by the algorithm SIMPLER. The equation of motion of the inner cylinder is derived from the law of conservation of angular momentum. The choice of a numerical integration method for the equation of motion of the inner cylinder does not affect the result. The influence of the dimensionless parameters on the flow structure and the angular velocity of the inner cylinder was studied. Dimensionless parameters vary within the ranges: Grashof number $10^3...2{\cdot}10^5$, Prandtl number 0.5...15, the dimensionless thermal conductivity of the cylinder $0...\infty$, and the cylinder inner radius 0.05...0.9. Numerical simulations have shown that the flow structure affects the angular velocity of the inner cylinder, which reaches its maximum in the case of a single-cell flow and at a minimum internal radius. As the Grashof number increases, the maximum possible angular velocity of the inner cylinder increases monotonically and is realized at large inner radius values. The Prandtl number has an opposite effect on the cylinder rotation velocity. If it decreases, then the angular velocity becomes extremely high at smaller inner radius values. An increase in the dimensionless thermal conductivity leads to the growth of the angular velocity, but it reaches a maximum at a smaller inner radius. The influence of the considered parameters on the angular velocity is determined by the change in the structure of the flow in the annular channel. The research results may be useful in the development of technical devices with an annular channel and a rotating inner cylinder.

Keywords: natural convection, annular channel, numerical modeling, rotation, Boussinesq approximation, Grashof number, Prandtl number, SIMPLER algorithm, finite volume method

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References

1. *Kuznetsov G.V.*, *Maksimov V.I.*, *Sheremet M.A.* Natural convection in a closed parallelepiped with a local energy source. Journal of Applied Mechanics and Technical Physics. 2013. Vol. 54. P. 588–595. DOI: 10.1134/S0021894413040093
2. *Sorokin A.P.*, *Kuzina Y.A.*, *Ivanov E.F.* Characteristics of heat transfer during boiling of liquid metal in the fuel assemblies of fast reactors in emergency regimes. Atomic Energy. 2019. Vol. 126, no. 2. P. 73–82. DOI: 10.1007/s10512-019-00518-0
3. *Kokorev L.S.*, *Kharitonov V.V.*, *Bol'shakov V.I.*, *Sysoev Y.M.*, *Plakseev A.A.* Natural Convection in Fibrous Thermal Insulation. High Temperature. 1980. Vol. 18, no. 2. P. 341–346.
4. *Gorelikov A.V.*, *Ryakhovsky A.V.*, *Fokin A.S.* Numerical investigation of some unsteady regimes of natural convection in a rotating spherical shell. Computational Continuum Mechanics. 2012. Vol. 5, no. 2. P. 184–192. DOI: 10.7242/1999-6691/2012.5.2.22
5. *Goncharova O.N.* Modeling of microconvection in a fluid between heat conducting solids. Journal of Applied Mechanics and Technical Physics. 2011. Vol. 52. P. 67–73. DOI: 10.1134/S002189441101010X
6. *Bautin S.P.*, *Obukhov A.G.*, *Barannikova D.D.* Numerical simulation of fire vortices with consideration of gravity and Coriolis forces. High Temperature. 2018. Vol. 56. P. 229–233. DOI: 10.1134/S0018151X18020025
7. *Kuehn T.H.*, *Goldstein R.J.* An experimental and theoretical study of natural convection in the annulus between horizontal concentric cylinders. Journal of Fluid Mechanics. 1976. Vol. 74. P. 695–719. DOI: 10.1017/S0022112076002012
8. *Cherkasov S.G.* Teoreticheskiy analiz balansa energii pri statsionarnoy teplovoy gravitatsionnoy konvektsii. 4th Russian National Conference on Heat Transfer. Vol. 3. Moscow, 23-27 October/2006. P. 168–171.
9. *Fallah K.*, *Ghaderi A.*, *Sedaghatizadeh N.*, *Borghei M.* Simulation of natural convection heat transfer using nanofluid in a concentric annulus. Thermal Science. 2017. Vol. 21, no. 3. P. 1275–1286. DOI: 10.2298/TSCI150118078F
10. *Shaija A.*, *Narasimham G.S.V.L.* Effect of surface radiation on conjugate natural convection in a horizontal annulus driven by inner heat generating solid cylinder. International Journal of Heat and Mass Transfer. 2009. Vol. 52. P. 5759–5769. DOI: 10.1016/j.ijheatmasstransfer.2009.05.033

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11. *Al-Ansary H.*, *Zeitoun O.* Numerical study of conduction and convection heat losses from a half-insulated air-filled annulus of the receiver of a parabolic trough collector. Solar Energy. 2011. Vol. 85, no. 11. P. 3036–3045. DOI: 10.1016/j.solener.2011.09.002

12. *Narygin E.I.*, *Zubkov P.T.* A model of natural convection in an annular channel with movable internal border. Vestnik Bashkirskogo universiteta. 2023. Vol. 28, no. 2. P. 131–136. DOI: 10.33184/bulletin-bsu-2023.2.1

13. *Patankar S.V.* Numerical Heat Transfer and Fluid Flow. Hemisphere Publishing Corporation, 1980. 197 p.

14. *Patankar S.V.* Computation of conduction and duct flow heat transfer. CRC press, 2017. 370 p.