Contribution to the theoretical study of thermal transfers combined with fluid flows in a fixed and rotating annular pipe subject to a temperature gradient

Abstract :

This research work is a numerical simulation of forced and mixed convection (Gr=0, e3<Gr<e4) three-dimensional of a fluid (distilled water at Pr = 8.082) characterized by the thermo-dependence of physical properties (viscosity and thermal conductivity), confined between two rotating horizontal cylinders of the Rotor-Stator type submitted to a differential temperature gradient imposed on the side surfaces of the two lower and outer cylinders (T_i=200°, T_o=100°) respectively, this duct is closed at both ends by two fixed and adiabatic walls.

The finite volume method is used for the discretization of conservation equations which govern this flow as well as the initial and boundary conditions. Second order discretization schemes are used such as the Adams-Bashforth scheme, and the fully implicit centered difference scheme. The speed-pressure coupling is treated with the SIMPLER algorithm and the systems of algebraic equations obtained are solved iteratively by the TDMA method (Tri-Diagonal Matrix Algorithme) using Thomas' algorithm.

modeling governing equations (conservation of mass, conservation of momentum as well as the energy equation) non-dimensional numbers will appear which will be essential parameters controlling the solution of the problem, which are the Taylor number (Ta) which reflects the dynamic forces of rotation applied to the fluid within the air gap, the Prandtl number (Pr) which is a characteristic of the fluid and finally the Richardson number (Ri) which reflects the effect of thermal forces compared to dynamic forces of rotation applied to the fluid.

The results are carried out in three stages with a study on the geometric effect in the very last part of the results, the first part is the study of forced convection (Gr = 0) or the

effect of buoyancy is non-existent and a big dynamic dominance, the variation of the velocity of rotation of the inner cylinder (284.4 <Ta <2559.6) gave birth to different fluid regimes, which changes from the laminar regime to Ta = 284.4 with the presence of Ekman cells at the extremities those that are close to the inner cylinder are smaller and well structured than those that are next to the cylinder outer, the thermal lines are stratify from the inner cylinder to the outer cylinder except at both ends there is a waving due to the presence of the Ek, at this point there is the maximum heat transfer represented by the local nusselt (Nu = 2.42), in the laminar regime with a development of cells from the ends to the center with great symmetry along the axis (Z *) and between the two gaps of the cylinder, at this regime the dynamic or centrifugal forces become increasingly strong as the thermal or centripetal forces cannot prevent dynamic instability, the thermal lines are more and more wavy inside the gap the local heat transfer takes on the shape of counter-rotating cells and increases with their development, it goes from (Nu = 5.7345, Nu = 8.8246 to Nu = 11.2887), the same thing for the axial Nusselt the presence of the peaks represents the counter-rotating cells developing in the gap, with the increase of the speed of the inner cylinder the first instability is reached at Tac1 = 2024.4 where the contrarotating cells are well structured, well aligned, from wher the Name of (TVF), the thermal lines are well waved throughout the gap with the same length and width and the local heat transfer is at its maximum with the shape of the contrarotating cells Nu = 12.8460, , the same for the axial Nusselt where it is constituted of peaks which represent the heat exchange in all the axial direction (z *), until the second instability or the cells lean between them from the center to the ends creating waves where from the name (WVF), the thermal lines are still waving throughout the gap but they are no longer the same size those in the center are thinner than the rest and the local heat transfer is reduced compared to the previous one and it is at Nu = 12.4681,

The second part is the study of mixed convection (Gr ≠ 0) where there is the presence of both dynamic and thermal forces, the variation of these two forces (1 <Ri <6.25, 505.6 <Ta <2559.6) gives different regimes which are classified according to thermal dominance; at the two effects of buoyancy (weak and moderate) there is a weak development of counter-rotating cells at the level of the lower gap then a development of the cells from the extremities to the center until a great symmetry in the two planes (r *, θ) and (r *, z *) at the level of the upper gap of the cylinder and therefore a dynamic dominance the first instability is reached at (Ta = 2559.6, Ri = 0.1234), the thermal lines develop from the stratified case to the wave form, , while at the strong effect of buoyancy (4 <Ri <6.25, 505.6 <Ta <790) no cell development not even the presence of Ek cells at the ends , at this stage the fluid has a very weak almost fixed movement so there is a very high thermal dominance, the thermal lines have the stratified form separated by a vacuum for the upper gap, , while for the lower gap are stratify in the vicinity of the inner cylinder with a vacuum near the outer cylinder, the heat transfer at this point is dropped is equal to Nu = 12.7613.

the very last study was on the geometric effect, the first instability is reached more quickly with the decrease of the aspect ratio and at the same time there is a decrease in the pairs of counter-rotating cells (Γ = 37.361 a Tac = 2851.9 / Γ = 18.680 a Tac = 2559.6 / Γ = 4.670 a Tac = 2022.4), (28 pairs, 13 pairs and 3 pairs) respectively, whereas for the radius ratio case the first instability is reached more quickly with the increase in the radius ratio (η = 0.627 a Tac = 2851.9 / η = 0.727 a Tac = 2559.6 / η = 0.827 a Tac = 2022.4) respectively and with the same number of counter-rotating cells which is 19 pairs of counter-rotating cells.

Keywords :

Horizontal rotating cylinders, Rotor-Stator configuration, Counter-rotating cells, Mixed convection, Thermo-dependence of physical properties, Numerical simulation, symmetry in the two planes (r *, θ), (r *, z *), First instability Ta_{c1}, second instability Ta_{c2}.