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Analytical and numerical study of mass and heat transfer for gas and liquids in TCP flow

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Analytical and numerical study of mass and heat transfer for gas and liquids in TCP flow

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Abstract – *We present an analytical and numerical study on the influence of rotating cylinder on heat and mass transfer in an annular space between two coaxial cylinders with an imposed axial flow. The rotating inner cylinder has a constant wall temperature, greater than the fluid temperature. The resolution is based on the finite difference scheme. Two values of Schmidt number are considered; a small (Sc=0.7) number corresponding to gas and a large number (Sc=7) corresponding to liquids. The Taylor number varying from 0 to 140.*

Keywords: *Template, Science Research, publication*

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1. Problem formulation

This work is concerned to a numerical study of the heat and mass transfer of a TCP laminar flow of type in an annular space, Fig1.

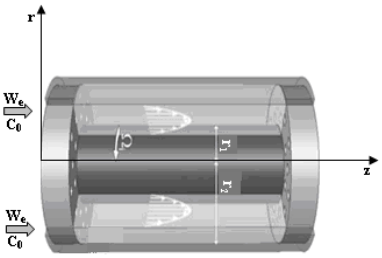


Figure. 1 geometry of the study

2. Mathematicals equations

The no dimensional equations are obtained used the no dimensional variables defined as follows:

$$u^*=\frac{u}{w_e};\ v^*=\frac{v}{w_e};\ C^*=\frac{C-C_0}{C_2-C_0}$$

$$\Theta^*=\frac{T-T_0}{T_0};\ r^*=\frac{r}{R_2};\ z^*=\frac{z}{R_2};\ t^*=\frac{tw_e}{R_2};\ \Pi^*=\frac{\Pi}{\rho w_e^2}$$

The no dimensional equations of mass, moment, concentration, temperature conservation are obtained used the no dimensional variables as follows:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}-\frac{v^2}{r}+w\frac{\partial u}{\partial z}=-\frac{\partial \Pi}{\partial r}+\frac{1-\eta}{Re_a}\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}+\frac{\partial^2 u}{\partial z^2}-\frac{u}{r^2}\right)+ \frac{1}{(1-\eta)R^2e_a}\left(Gr_T\Theta+Gr_C C\right) \quad (2.1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial r}+\frac{vu}{r}+w\frac{\partial v}{\partial z}=\frac{1-\eta}{Re_a}\left(\frac{\partial^2 v}{\partial r^2}+\frac{1}{r}\frac{\partial v}{\partial r}+\frac{\partial^2 v}{\partial z^2}-\frac{v}{r^2}\right) \quad (2.2)$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial r}+w\frac{\partial w}{\partial z}=-\frac{\partial \Pi}{\partial z}+\frac{1-\eta}{Re_a}\left(\frac{\partial^2 w}{\partial r^2}+\frac{1}{r}\frac{\partial w}{\partial r}+\frac{\partial^2 w}{\partial z^2}\right) \quad (2.3)$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial r}+w\frac{\partial C}{\partial z}=\frac{1-\eta}{Sc\,Re_a}\left(\frac{\partial^2 C}{\partial r^2}+\frac{1}{r}\frac{\partial C}{\partial r}+\frac{\partial^2 C}{\partial z^2}\right) \quad (2.4)$$

$$\frac{\partial \Theta}{\partial t}+u\frac{\partial \Theta}{\partial r}+w\frac{\partial \Theta}{\partial z}=\frac{1-\eta}{Pr\,Re_a}\left(\frac{\partial^2 \Theta}{\partial r^2}+\frac{1}{r}\frac{\partial \Theta}{\partial r}+\frac{\partial^2 \Theta}{\partial z^2}\right) \quad (2.5)$$

Where: d=R_2-R_1 is the gap of annular space,$\eta=\frac{R_1}{R_2}$: is the radius ratio.

The reference parameters are R_2 the outer cylinder radius for length, w_e the inlet velocity of the fluid injection for the velocity, C_0 the concentration, Θ_0 the initial fluid temperature.

3. Initial and boundary conditions.

a. 3.1 Initial conditions:

at t=0:

$$u(r,z,0)=v(r,z,0)=w(r,z,0)=0 \qquad (3.1)$$
$$p(r,z,0)=C(r,z,0)=\Theta(r,z,0)=0$$

b. 3.2 Boundary conditions :

3.2.1. Dynamics

$$\begin{array}{lll} r=\eta & z\geq 0 & u(\eta,z,t)=0,\ w(\eta,z,t)=0, v(\eta,z,t)=v_p \\ r=1 & z\geq 0 & u(1,z,t)=0,\ w(1,z,t)=0, \\ \eta\langle r\langle 1 & z=0 & u(r,0,t)=0, w(r,0,t)=1 \end{array} \qquad (3.2.a)$$

3.2.2. Thermal :

$$\begin{array}{lll} r=\eta & z\rangle 0 & \Theta=1/3 \\ r=1 & z\rangle 0 & \dfrac{\partial\Theta}{\partial r}=0 \\ \eta\langle r\langle 1 & z=0 & \Theta=0 \end{array} \qquad (3.2.b)$$

3.2.3. Solutal:

$$\begin{array}{lll} r=\eta & z\rangle 0 & C=0 \\ r=1 & z\rangle 0 & C=1 \\ \eta\langle r\langle 1 & z=0 & C=1 \end{array} \qquad (3.2.c)$$

c. 3.3 Exit condition

$$z=L \qquad \frac{\partial v}{\partial z}=\frac{\partial u}{\partial z}=\frac{\partial w}{\partial z}=\frac{\partial c}{\partial z}=\frac{\partial\Theta}{\partial z}=0 \qquad (3.2.d)$$

4. Numerical method

The finite deference scheme used is similar that given by Peyret.R [1], J.C. Loraud [2]. It is a Crank-Nicholson semi implicit scheme. The calculated domain is divided on the rectangular mes ($\Delta r=1/48, \Delta z=1/16$). The spatial discretisation is based on the Marker And Cell mesh (MAC) and indicated on Figure 2.

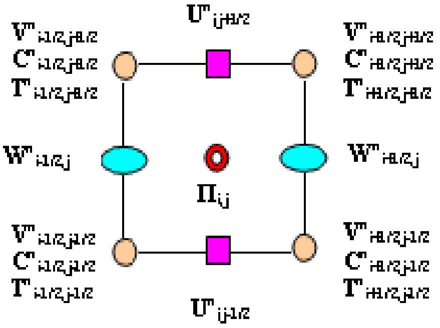


Figure 2. The M.A.C mesh

5. Analytical solution

The resolution of the system of equations (2.1) à (2.5) is based on the parallel flow concept used by different authors. On the flow of an induced gas layer by the combined action of a force of shearing and the Soret effect, also using the method of the approximation of the parallel flow. The concept of the parallel flow consists in supposing that in an annular space of great extension ($\Gamma\rangle\rangle 1$), the flow is parallel relative with the long walls of annular space. This makes it possible to neglect the perpendicular velocity component to the horizontal velocity, so that:

$$w\,(z,r)=w(r) \qquad (5.1.a)$$

$$u(z,r)=0 \qquad (5.1.b)$$

The temperature and of the concentration are then given by the sum of a term defining a linear longitudinal variation and of another term giving the transverse distribution:

$$C(z,r)=1+C_S.z+Sc.Re.C_S.\left[\frac{r^2-\eta^2}{4}-\frac{r^4-\eta^4}{16}-\frac{1-\eta^2}{\ln\eta}\left(\frac{r^2}{4}\ln r-\frac{\eta^2}{4}\ln\eta-\frac{3}{4}(r-\eta)\right)\right]-$$
$$\frac{\ln\left(\frac{r}{\eta}\right)}{\ln\left(\frac{1}{\eta}\right)}\left\{1+Sc.Re.C_S.\left[\frac{1-\eta^2}{4}-\frac{1-\eta^4}{16}+\frac{1-\eta^2}{\ln\eta}\left(\frac{\eta^2}{4}\ln\eta+\frac{3}{4}(1-\eta)\right)\right]\right\}$$

(5.2.a)

$$\theta(z,r)=\frac{1}{3}+C_s.z+C_s.Pr.Re.\left[\frac{r^2-\eta^2}{4}-\frac{r^4-\eta^4}{16}-\frac{1-\eta^2}{\ln\eta}\left(\frac{r^2}{4}\ln r-\frac{\eta^2}{4}\ln\eta-\frac{3}{4}(r-\eta)\right)\right]$$
$$-\frac{1}{2}C_s S\,Pr.Re.\ln\left(\frac{r}{\eta}\right).\left(\frac{1}{2}+\frac{1-\eta^2}{\ln\eta}\right)$$

(5.2.b)

6. Results and discussion

We expose the results corresponding to the cases of the thermal and solutale forces act in two opposite directions and for a N=-5 (where the flow is dominated by the solutal effect), and for CI=1, Ta=200, Re=50, Pr=0.7, η=0.5 and with a range of: $0.7\leq Sc\leq 7$. This choice is justified by the fact that the majority of experimental work use primarily gases or aqueous solutions because of the important difference between thermal and solutal diffusivity.

a. 6.1 Influence of Schmidt number

6.1.1. Comparison of the analytical and numerical results.

The analytical solution is found for the case of the cylinder interior activated, predicted by the theory of the parallel flow in the case without rotation, it is indicated on by lines in feature, whereas the results numerical are represented by symbols (Figure.3). This for low values of Schmidt (≤2.8) corresponding to the cases of gases and the relatively large values correspondent to the cases of the liquids. One note that it concentration decrease almost linearly according to R for the low numbers of Sc, what shows `there is a stratification of the fluid layers in the case of the gases. Then that for the great Sc values the curves present an asymptotic limit towards the value of concentration of the activated wall. It is noted that the values of the concentration are increasingly large that the number of Sc increases. In addition one notes a good agreement between the numerical and analytical results.

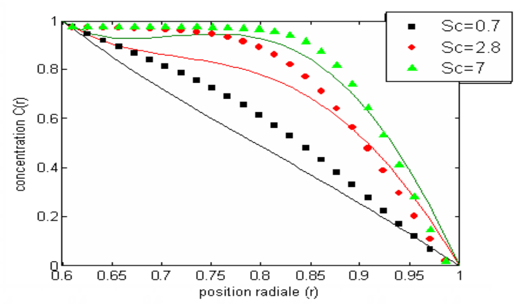
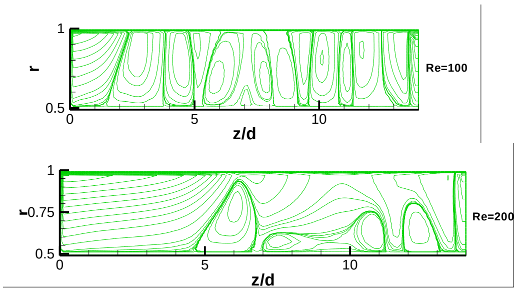


Figure 3 : influence of Sc on the concentration profil for Ta=0, Re=100, Pr=0.7, N=-5 et η=0.5

6.1.2. On the structure of the flow

The figure 4, illustrate numerical results obtained for the case: Ta=200, Pr=0.7, Sc=0.7 and η=0.5 for various Re values. The figure (4.a) shows that the flow is characterized by the presence of the swirls being able to turn clockwise or anti-clockwise. The convection is relatively intense, giving place to an important deformation of the isotherms and lines of Iso concentrations. By increasing the number of Re, the figure (4.b) indicates that the swirls start to move towards the downstream of annular space until a final disappearance, this for a value of Re=600. It is also noted that when the convection becomes intense, it transfer of heat and mass becomes more important. This tendency is in conformity with the results already found by various authors relating to the diffusive double convection in enclosures, Béjan [3] .



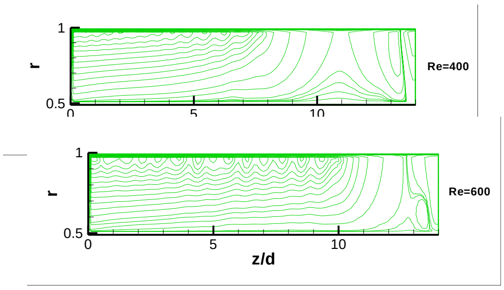


Figure. 4a Stream line for, Ta=200, Sc=0.7, Pr=0.7, N=-5 et η=0.5 (a) Re=100; (b) Re=600.

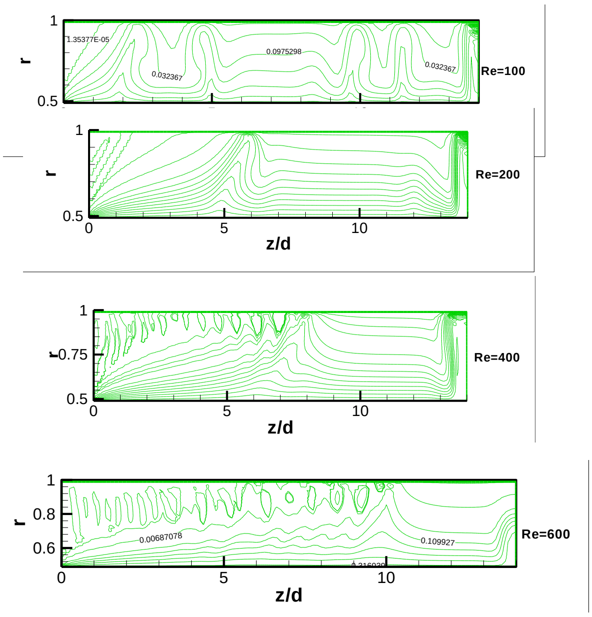


Figure. 4b isotherms for, Ta=200, Sc=0.7, Pr=0.7, N=-5 et η=0.5 (a) Re=100; (b) Re=600.

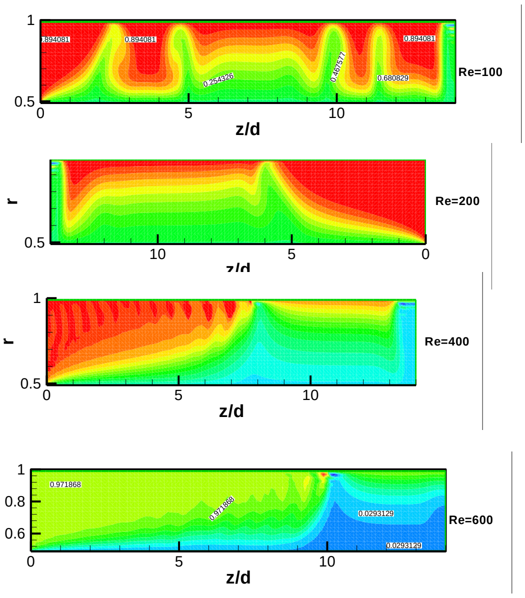


Figure 4c. Concentrations lines for, Ta=200, Sc=0.7, Pr=0.7, N=-5 et η=0.5 (a) Re=100; (b) Re=600.

7. CONCLUSION

One studied the heat and mass transfer by mixed convection thermosolutale of a Newtonian fluid in an annular space between two horizontal coaxial cylinders, when the forces of volume (thermal and solutal) are opposite. A numerical method based at a finite differences was used for solving the complete Navier-stokes equations. Resultes showe the influence of the Reynolds number on the heat and mass transfer between the wall and the fluid. The increase in the axial flow contributes to an increase in the heat and the mass transfer, this for a range of Sc = [0.7-7] and for aN=-5 (the solutal volume forces is very large compared to the thermal volume forces). An analytical result is compared with numerical in the case without rotation.

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