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CHAM Case Study – Non-Newtonian Flow

PHOENICS [2009] applied to Axisymmetric Flow of a Pseudoplastic Fluid in Annual Passages

The case considered is the steady, laminar, isothermal, axisymmetric flow of a pseudoplastic fluid in an annulus. The shear-thinning behaviour of the non-Newtonian viscous fluid is described by the power-law model. The main input parameters specified by the client are:

- Outer diameter D_i = 0.065m
- Inner diameter D_o = 0.048m.
- Volumetric flow rate Q = 3000 *l*/hr
- Apparent dynamic viscosity, $\mu = K\,\gamma^{(n-1)}$ where the consistency K=11.09 $Pa.s^n$, the power-law index n =0.265, and γ is the mean rate of strain.

The pipe length has been chosen arbitrarily as 0.25m, which corresponds to a length L≈15d. Here, d is the hydraulic diameter, which is given by $d=D_o-D_i$=0.017m.

The fluid density ϱ was not specified by the client, and so in the present computations, the density of water has been presumed, i.e. ϱ =1000 kg/m^3. The working fluid is believed to be some sort of fluid food, and so the density of water is likely to be a good first approximation. The value of the power-law parameters K and n, correspond to a temperature of 50.6°C, as specified by the Client.

The inlet velocity w=Q/A=0.5523 m/s, where $Q=8.3333.10^{-4} m^3/s$ and the flow area $A=\pi(D_o+D_i)(D_o-D_i)/4 = 1.50875.10^{-3} m^2$. The flow regime can be determined from the Generalised Reynolds number, Re*, which is given by:

$$\mathrm{Re}* = \frac{\rho w d}{\mu_e} \qquad (1)$$

where the effective viscosity μ_e is given by:

$$\mu_e = K\left(b+\frac{a}{n}\right)^n \left(\frac{8w}{d}\right)^{n-1} \qquad (2)$$

For circular pipe flow, the values of constants a and b in equation (2) are given as a=0.25 and b=0.75; whereas for flow in concentric annuli, these values depend on the value of $\kappa = D_i/D_o$. For the present case, with κ=0.7385, a=0.4986 and b=0.999. Therefore, equations (2) and (1) yield μ_e=0.24649 Pa.s and Re*=38.09, which corresponds to laminar flow of the shear-thinning fluid.

Two computations are made with PHOENICS-2009. The first considers purely annular flow, whereas the second considers flow in an annulus with a double-cone obstruction located on the inner surface. The results of these computations are discussed very briefly in the following two sections.

Purely Annular Flow

The PHOENICS CFD computation is made on an axisymmetric, cylindrical-polar mesh of 50 radial by 100 axial cells. No attempt is made to assess the mesh-sensitivity of the solution. The computation converges in less than a minute on a Dell Precision T7400 Intel Xeon 2.5GHz pc with 16GB RAM.

The predicted pressure drop is Δp=3.848 kPa, which is within 2% of the analytical value. The analytic pressure drop of the power-law fluid is given by:

$$\Delta p = \frac{1}{2} \rho w^2 f \frac{L}{D} \qquad (3)$$

where the friction factor f=64/Re*. For the present case, the expected pressure drop is Δp=3.769 kPa.

Flow in an Annulus with a Double-Cone Obstruction

PHOENICS computations are made for this case on an axisymmetric, cylindrical-polar mesh of 61 radial by 165 axial cells. This calculation converges in less than 2 minutes on the Dell pc. Again, no attempt is made to assess the mesh-sensitivity of the solution. The double-cone geometry is represented by means of PARSOL, the cut-cell algorithm in PHOENICS. PARSOL captures complex geometries automatically on a background polar mesh by using cut cells at the fluid-solid interface. These cells are partially filled with solid and fluid.

The flow geometry and predicted pressure drop for this case are shown in Figure 1 below:

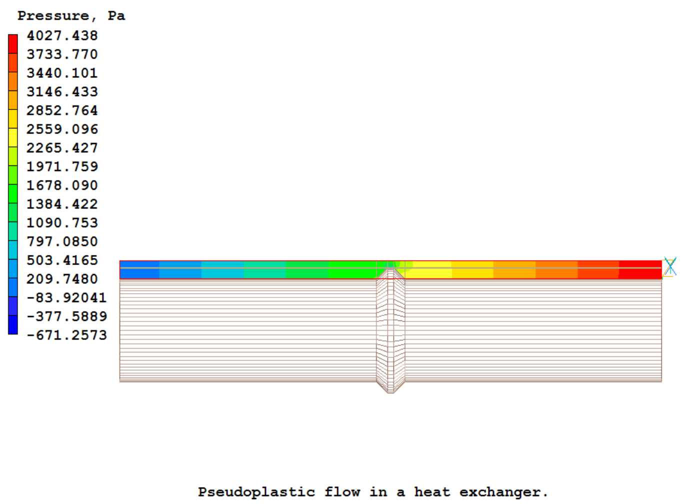

Figure 1: Annulus with Double-Cone Obstruction: Predicted Pressure Drop.

As can be seen from the figure, the predicted pressure drop is about 4KPa, which represents a 4% increase over that found for flow in a simple annulus.

The computed absolute velocity contours and velocity vectors are shown in Figures 2 and 3, respectively. For clarity, the velocity vectors are plotted on a mesh actually coarser than that used in the computations.

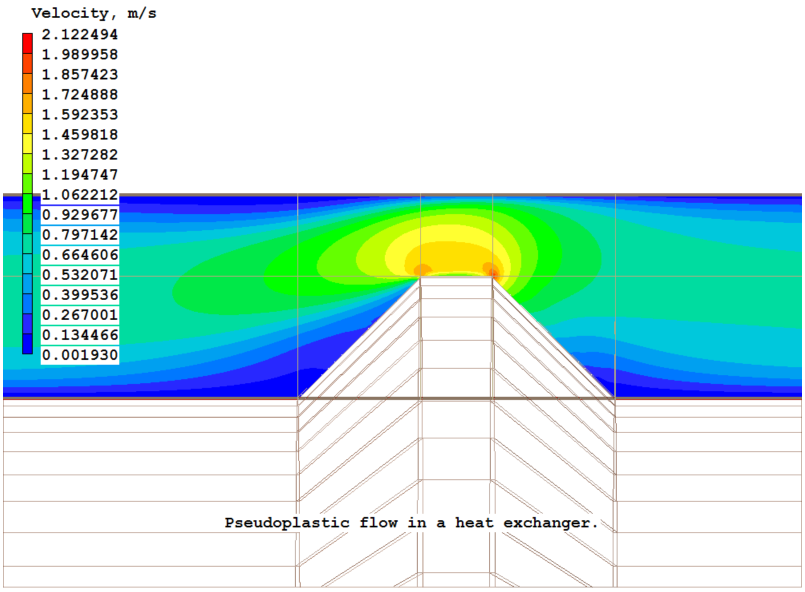

Figure 2: Double-Cone Obstruction: Predicted Absolute Velocity Contours.

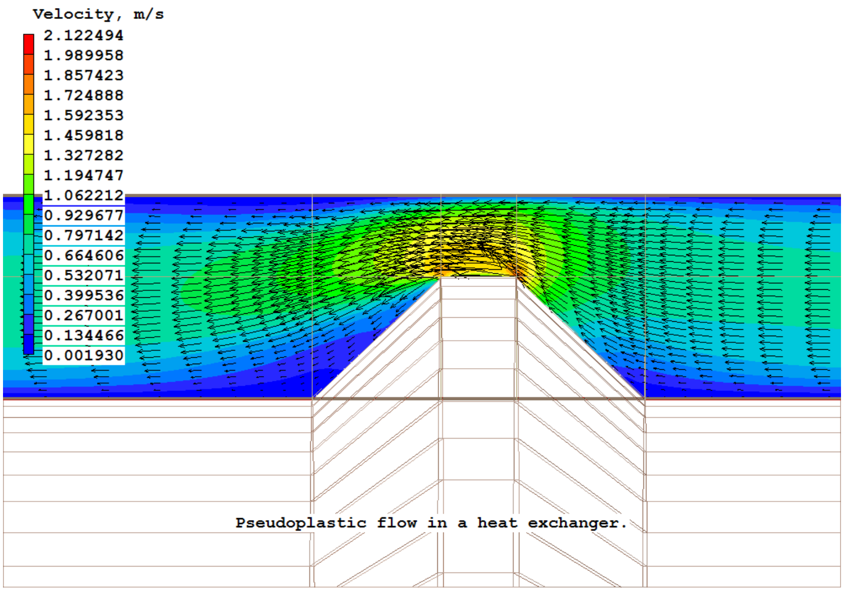

Figure 3: Double-Cone Obstruction: Predicted Velocity Vectors.