Non-Newtonian Fluids Flow in a Closed Conduit

Name

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Date

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Research methodology

Non-Newtonian fluid flow in a closed conduit is characterized by energy loss caused by friction in the flowing fluid. This is influenced by the flow velocity, fluid type, and surface nature of the static pipe wall. The flow's characterization helps determine the friction loss, classified as turbulent flow and laminar flow.

Laminar flow

It is a steady and smooth flow that has less proof of interacting with the stream's different parts. It happens because the fluid appears to flow within continuous compartments.

Figure 1: Laminar flow in closed conduit

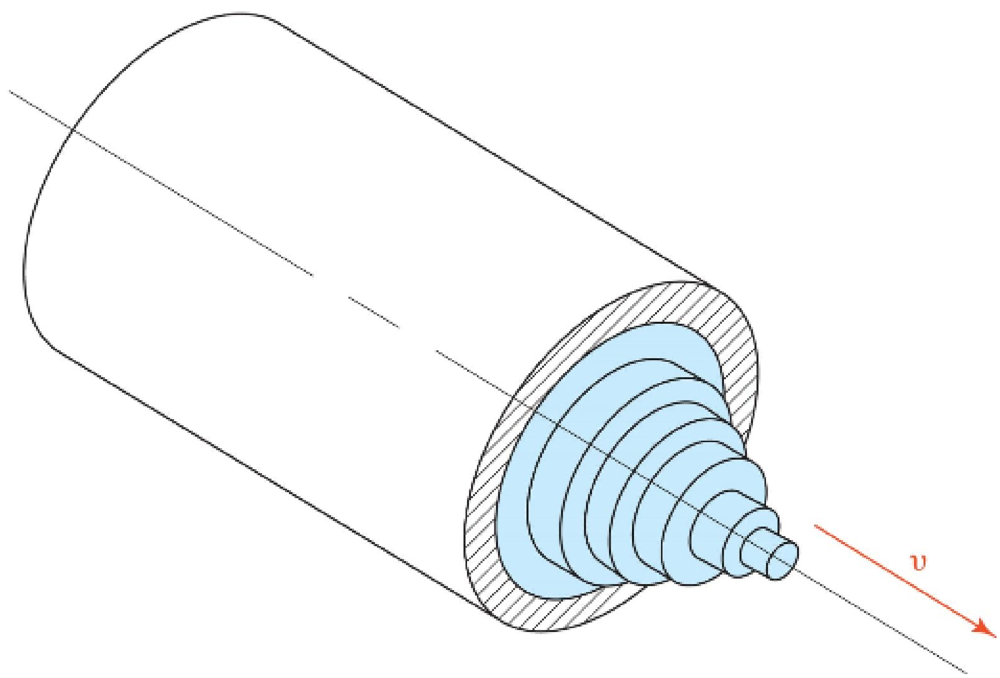
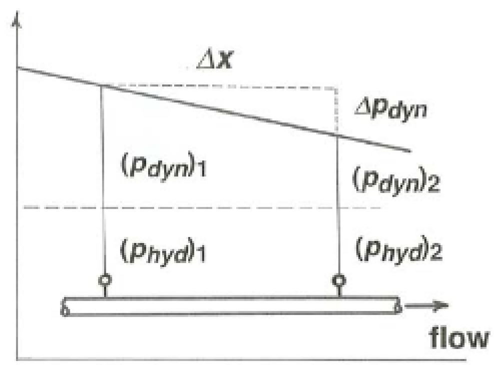


Figure 2: Closed conduit flow



Turbulent flow

The flow seems rough and chaotic, with several fluid intermixtures. There are often transitions between fluids in the turbulent and laminar flows. This movement between the two types of flows may be affected by several variables.

Shear stress

In closed conduits, various pressure forces act on the direction of flow on both the downstream and upstream free body segments in a directly proportional way (Tamburrino and Cristobal 2020). However, due to the uniformity of these pressure forces' vertical distribution, the phenomenon becomes similar to each cross-section. This balance cancels each of these pressures out and results in no net force upon the free body.

Thus, γsinα BLd is equal to τoBL and

When solving for τo, → τo = γ dsinα

The boundary shear stress is adjacent to the flow depth product, the liquid's specific weight, and the slope angle’s sine.

Reynolds' Experiment

Reynolds number is dependent on the diameter of a pipe in the transition from laminar to turbulent flow in the same tube (Chapter 11 Flow in Closed Conduits, 2020). For the Non-Newtonian fluid in motion, the Re was continuously adjusted by increasing the velocity.

When considering a closed conduit pipe flow, there is no need to worry about the cross-section, since no free surface exists. The pipe setup is on a horizontal plane. Thus, only the fluid flow velocity (v), the fluid density (ρ), (-gcΔP), the viscosity of the fluid (μ), the pipe's pressure drop, the pipe's roughness (e) and the pipe's length (L) are considered.

Reynolds Eu is parallel to L / D (in situations where the pipe is longer, the pressure drop will be extensive, the size of the pipe will be minimized, and there will be a greater drop in pressure) (Chapter 11 Flow in Closed Conduits, 2020). Therefore, the term can be separated from the (eq.2), Eu = L / Df' (Re, e / D) (eq.3). Contrastingly, the Reynolds f' (Re, e / D) function is termed a dimensionless expression, highlighted as friction factor φ. Thus, φ can be expressed as,

- Darcy friction factor: Eu = φD/ 2 (L / D) (eq.5)
- Fanning friction factor: Eu = 2 φf(L / D) (eq.4)
- Ti friction factor: Eu = φT(L / D) (eq.6); this can be used in discerning the φD= 2 φT= 4 φf.

Dimensional analysis

This applies force, time, and length (F, L, and T) as the variables (and dimensions) featuring the fluid. The density ρ (FL−4T2), with an index flow (F0L0T0=1), flow index *n*, and a consistency coefficient *K* (FL−2T*n*).

Secondly, the closed conduit sediment diameter (L), (*ρS*−*ρ*) *g* (FL−3) submerged weight, and repose angle *α* (F0L0T0=1) are expressed as shown. The non-Newtonian motion of fluid is considered critical shear stress result acting on it, *τc* (FL−2), while the bottom's inclination is expressed as angle θ (F0L0T0=1) (Tamburrino and Cristobal 2020). According to Buckingham's theorem, a problem is solved by using five dimensionless aspects. Selecting (ρ, K,d) as the repeat variables yields the following dimensionless perspective:

$$\Pi_1 = n$$

$$\Pi_2 = \theta$$

$$\Pi_3 = \alpha$$

$$\Pi_4 = \frac{(\rho_S - \rho)\, g\rho^{n/(2-n)}\, d^{(2+n)/(2-n)}}{K^{2/(2-n)}}$$

$$\Pi_5 = \tau_0 \left(\frac{\rho^n d^{2n}}{K^2} \right)^{1/(2-n)}$$

The functional correlation within various dimensionless aspects and the shear stress are expressed as:

$$\tau_0 \left(\frac{\rho^n d^{2n}}{K^2} \right)^{1/(2-n)} = \Phi\,(n,\ \theta, \alpha, \Pi_4)$$

Results and Discussion

The formula and various expressions were used to generate the non-Newtonian fluids flow within closed conduits. The first flow regime was defined and a procedure was used to determine the phenomenon. Secondly, shear stress within the horizontal closed conduit was highlighted and shown. The last aspect involved the Reynolds number, which expressed the criteria for the transition from turbulent to turbulent flow within a pipe, and this number was determined based on the pipe’s diameter.

Conclusion

The non-Newtonian flow motion of molecules within a closed conduit fluid can be determined using the flow regime, shear stress, and dimensionless parameters, all adequately modified to consider the Reynolds number (*Re**). Reynolds number considers a pipe's slope via the friction velocity, recorded from the sufficient shear exerted on the particle or molecules. The dimensional analysis effectively refers to the ratio between the buoyancy of the particle and the shearing, as well as the non-Newtonian viscous force that was exerted on the particle. Even though the dimensional analysis shows that the motion status should also rely on the *GaK and Re***p*, index flow, *n*, it was impossible to conclude its impact from the experimental data acquired in this study. Thus, this work's foundation was how the Reynolds number affects the flow and the non-Newtonian fluid.

References

Chapter 11 Flow in closed conduits. (n.d.). In *CN2122 / TCN2122E*. http://courses.nus.edu.sg/course/chetihc/nuscampus/fluid/PowerPoint/Chapt11.PDF.

Tamburrino, A., & Traslaviña, C. (2020). Condition for the incipient motion of non-cohesive particles due to laminar flows of power-law fluids in closed conduits. *Water*, *12*(5), 1295. https://doi.org/10.3390/w12051295