

Laminar flow pipe hydraulics of pseudoplastic-thixotropic sewage sludges

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Abstract

The flow properties of heterogeneous sewage sludges are dependent on solids concentration and sludge type. General pipe flow design methods for sewage sludge applications are therefore unreliable. The non-Newtonian (pseudoplastic) and time-dependent (thixotropic) influence on the rheological characteristics of raw sludge was determined experimentally. These characteristics were used as basis to develop an empirical method to determine the head losses in pressure pipes conveying these sludges under laminar flow conditions. The method is illustrated by means of a design example.

Introduction

Sewage sludges are heterogeneous fluids which make the direct use of Newtonian fluid hydraulics in the design of pressure pipelines unreliable. Some factors that may affect the hydraulics are the sludge characteristics such as settling properties and concentration of solids in the sludge.

To overcome these uncertainties, design engineers are inclined to use a critical flow velocity (usually 1.5 to 2.0 m/s) above which flow is assumed to be turbulent. It is then assumed that no settling of solids will occur under turbulent flow conditions. For friction losses, the design is then based on Newtonian fluid hydraulics, with a so-called "sludge factor", which is usually based on the solids concentration of the sludge.

Although the assumption is always true that no settling of solids will occur under turbulent flow conditions (Dodge and Metzner, 1959), there is a minimum velocity (V_{min}) above which no settling of solids will occur, even under laminar flow conditions. This minimum velocity is determined by the settling properties of the sludge (Newitt et al., 1955).

For Newtonian fluids the Reynolds number (Re) is used to determine whether the flow is laminar or turbulent. This number is not only dependent on velocity (V) but also on dynamic viscosity (μ), pipe diameter (D) and fluid density (ρ) (Webber, 1971). In contrast, most sewage sludges with a solids concentration above 3% (mass per volume) conform to non-Newtonian fluid models, viz. pseudoplastic or Bingham plastic fluids (Frost, 1982; Rose-Innes and Nossel, 1983). This indicates that the viscosity is dependent on the shear rate (dv/dr) and thus an alternative method is required for determining the Reynolds number and friction headloss. To complicate matters further, Rose-Innes and Nossel (1983) indicated that these sludges are time-dependent, namely thixotropic (shear stress reduces with duration to shear).

The purpose of this study was to determine concentrated activated sludge flow characteristics required for the design of a pressure pipeline which conveys a sewage sludge under laminar flow conditions.

Theoretical consideration

Four aspects of sludge hydraulics are of importance in the design of pressure pipelines, namely the minimum flow velocity, the type of fluid (Newtonian or non-Newtonian), the time behaviour of the sludge viscosity and the type of flow (laminar or turbulent).

Minimum flow velocity

Settling of solids inside a pipeline (and thus clogging) will be prevented if the flow velocity exceeds a minimum value (V_{min}) which is dependent on the relative densities of solids and liquids in the fluid (Newitt et al., 1955). Kapfer (1967) proposed the following relationship:

$$V_{min} = 1.9D^{0.2}[(\rho_p - \rho)/\rho]^{0.3} \quad (1)$$

where:

$$\begin{aligned} V_{min} &= \text{minimum flow velocity to prevent settling of solids} \\ \rho &= \text{fluid density} \\ \rho_p &= \text{particle density (kg/m}^3\text{)} \end{aligned}$$

Newtonian and non-Newtonian flow characteristics: Herschel-Bulkley flow model

The Herschel-Bulkley model (also called the generalised Bingham model) is the most suitable model to describe the flow of non-Newtonian fluids (Frost, 1982):

$$\tau = \tau_y + K(dv/dr)^n \quad (2)$$

where:

$$\begin{aligned} \tau &= \text{shear stress (N/m}^2\text{)} \\ \tau_y &= \text{yield stress (N/m}^2\text{)} \\ n &= \text{flow behaviour index (dimensionless)} \\ K &= \text{fluid consistency coefficient ((N}\cdot\text{s}^n\text{)/m}^2\text{)} \\ dv/dr &= \text{shear rate (s}^{-1}\text{)} \end{aligned}$$

This model is schematically shown in graphical form in Fig. 1.

Newtonian and non-Newtonian flow relationships for a fluid may be identified from the values of n , τ_y and K as shown in Fig. 1. Investigations by Frost (1982) and Rose-Innes and Nossel

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