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Investigation of viscoelastic effects on transient flow in a relatively long PE100 pipe

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HIGHLIGHTS

- Two mathematical models are developed to study transient flow in viscoelastic pipe.
- The evolution of pressure wave velocities is discussed using a viscoelastic model.
- The viscoelastic model is necessary to study the water hammer in viscoelastic pipe.

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ABSTRACT

In this paper, the dynamic effect of the viscoelastic behavior of PE100 material, on the transient flow in a relatively long pipe, has been studied. At first, to study the transient flow in pipes with fluid structure interaction (FSI), two mathematical models, i.e., fully coupled four equation model and simplified two equation model, have been developed. The method of characteristics has been used to solve the model. Then, we have demonstrated that the viscoelastic behavior of PE100 plays a primordial role in the damping of the water hammer phenomenon. It has a dynamic effect to cause the decrease of pressure wave velocity with increase of pressure along the wave front. At the end of the paper, It has been shown that the coupled model with FSI does not introduce many changes from the simplified viscoelastic model.

1. Introduction

When a change occurs in a piping system, such as starting or stopping a pump, closing or opening a valve, or changes in tank levels, a transient flow in pipe networks will be generated. The sudden change in fluid velocity causes a pressure wave to propagate within the pipe. If the fluid is incompressible, this results in a tremendous increase in pressure. Compared to the steady state, the pressures can reach excessive values. Due to the inertia of the fluid, the flow velocity of the fluid in its entirety can no longer adapt to the new situation. The volume of fluid deforms and this deformation is accompanied by dynamic changes in the pressure. If we take the example of water hammer in a metal pipe, the pressure waves propagation velocity is close to 1250 m/s. On the other hand, the low rigidity of the material, such as polyethylene, limits the effect of the water hammer. The pressure wave propagation velocity is of the order of 400 m/s.

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Notations

D	Inside diameter of the pipe
E_0	Pipe-wall Young's modulus
H_0	Initial pressure head
H_{Ve}	Pressure head in the final equilibrium state
H_{v0}	Initial pressure head at valve
$J(t)$	Creep function
$\bar{J}(s)$	Complex compliance
J_i	Creep compliance of the *i*th solid of Kelvin–Voigt
K	Bulk modulus of compressibility
L	Length of the pipe
N_{kv}	Number of the Kelvin–Voigt solids
Q_0	Initial flow rate
Q_e	Flow rate in the final equilibrium state
R	Inside radius of the pipe
V	Average velocity of the fluid
cc	Non-dimensional parameter calculated for different anchored conditions
c_f, C_F	Classical pressure wave velocity
$\widetilde{c}_F$	Pressure waves velocity
c_p	Speed of sound in the bar or in the elastic pipe wall
$\widetilde{c}_P$	Stress wave velocity
e	Pipe-wall thickness
g	Gravitational acceleration
k	Roughness
p_0	Initial pressure
$\widetilde{p}(t)$	Dynamic pressure
s	Laplace variable
t	Time
$\bar{\dot{u}}_x$	Average axial displacement rate
x	Space dimension
Δt	Time step
T_0	Shear stress fluid-pipe
ε	Strain
ε_r	Radial strain
ε_x	Axial strain
ε_ϕ	Circumferential strain
γ	Angle between pipe and horizontal direction
λ_f	Friction coefficient
μ_i	Viscosity of the *i*th solid of Kelvin–Voigt
ν	Poisson's coefficient
ρ_f	Density of the fluid
ρ_p	Density of the pipe material
σ	Pipe wall stress
$\widetilde{\sigma}_h(t);\ h = x,\ r,\ \phi$	Dynamic stress
$\overline{\sigma}_{h,0};\ h = x,\ r,\ \phi$	Initial average stress
σ_r	Radial stress
$\overline{\sigma}_r$	Average radial stress
σ_x	Axial stress
$\overline{\sigma}_x$	Average axial stress
σ_ϕ	Circumferential stress
$\overline{\sigma}_\phi$	Average circumferential stress
$\tau = 2L/C_f$	Wave period
τ_i	Delay time of the *i*th solid of Kelvin–Voigt
$(x,\ r,\ \phi)$	Cylindrical coordinate system

The mechanical behavior of pipe has an important effect on the response of the system during dynamic loading. Rheological behavior of viscoelastic pipe walls causes much damping in waterhammer pressures. The effects of the