# Friction Factor for Perforated Pipes


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**Introduction**: Parametric studies are conducted computationally to show that the friction factor for perforate pipe is a linear function of the porosity. The study is confined to the perforated pipes in Concentric Tube Resonators (CTR) which are extensively used in automotive exhaust noise control.

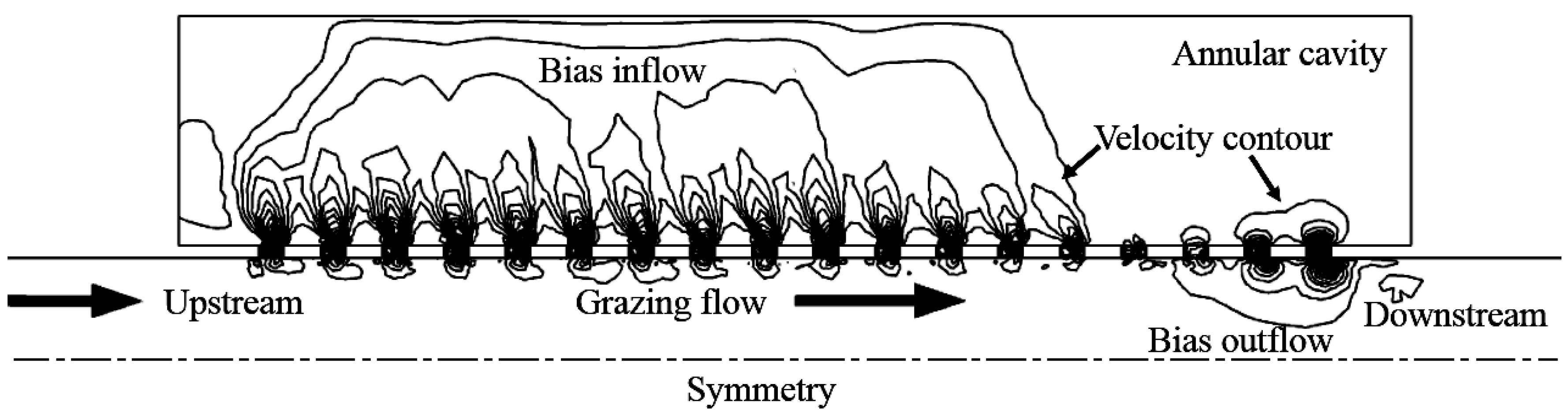


**Figure 1**. Flow dynamics in CTR

**Computational Methods**: The $\mathcal{k}-\varepsilon$ Turbulent interface model is used in the analysis. The transport equation of equation (1) for the turbulent kinetic energy, $\mathcal{k}$, and the transport equation of equation (2) for the turbulent dissipation rate, $\varepsilon$, are coupled by the production term given by equation (3). The turbulent viscosity is modeled as given in equation (4).

$$\rho\frac{\partial \mathcal{k}}{\partial t}+\rho\boldsymbol{u}.\nabla\mathcal{k}=\nabla.\left(\left(\mu+\frac{\mu_T}{\sigma_{\mathcal{k}}}\right)\nabla\mathcal{k}\right)+P_{\mathcal{k}}-\rho\varepsilon \quad (1)$$

$$\rho\frac{\partial \varepsilon}{\partial t}+\rho\boldsymbol{u}.\nabla\varepsilon=\nabla.\left(\left(\mu+\frac{\mu_T}{\varepsilon}\right)\nabla\varepsilon\right)+C_{\varepsilon 1}\frac{\varepsilon}{\mathcal{k}}-C_{\varepsilon 2}\rho\frac{\varepsilon^2}{\mathcal{k}} \quad (2)$$

$$P_{\mathcal{k}}=\mu_T\left(\nabla\boldsymbol{u}:(\nabla\boldsymbol{u}+(\nabla\boldsymbol{u})^T)-\frac{2}{3}(\nabla.\boldsymbol{u})^2\right)-\frac{2}{3}\rho\mathcal{k}\nabla.\boldsymbol{u} \quad (3)$$

$$\mu_T=\rho C_\mu\frac{\mathcal{k}^2}{\varepsilon} \quad (4)$$

The model is built using the model builder interface of COMSOL. A quarter or half geometric symmetric model is built depending on whether the number of holes along the circumference is even or odd (figure 2).

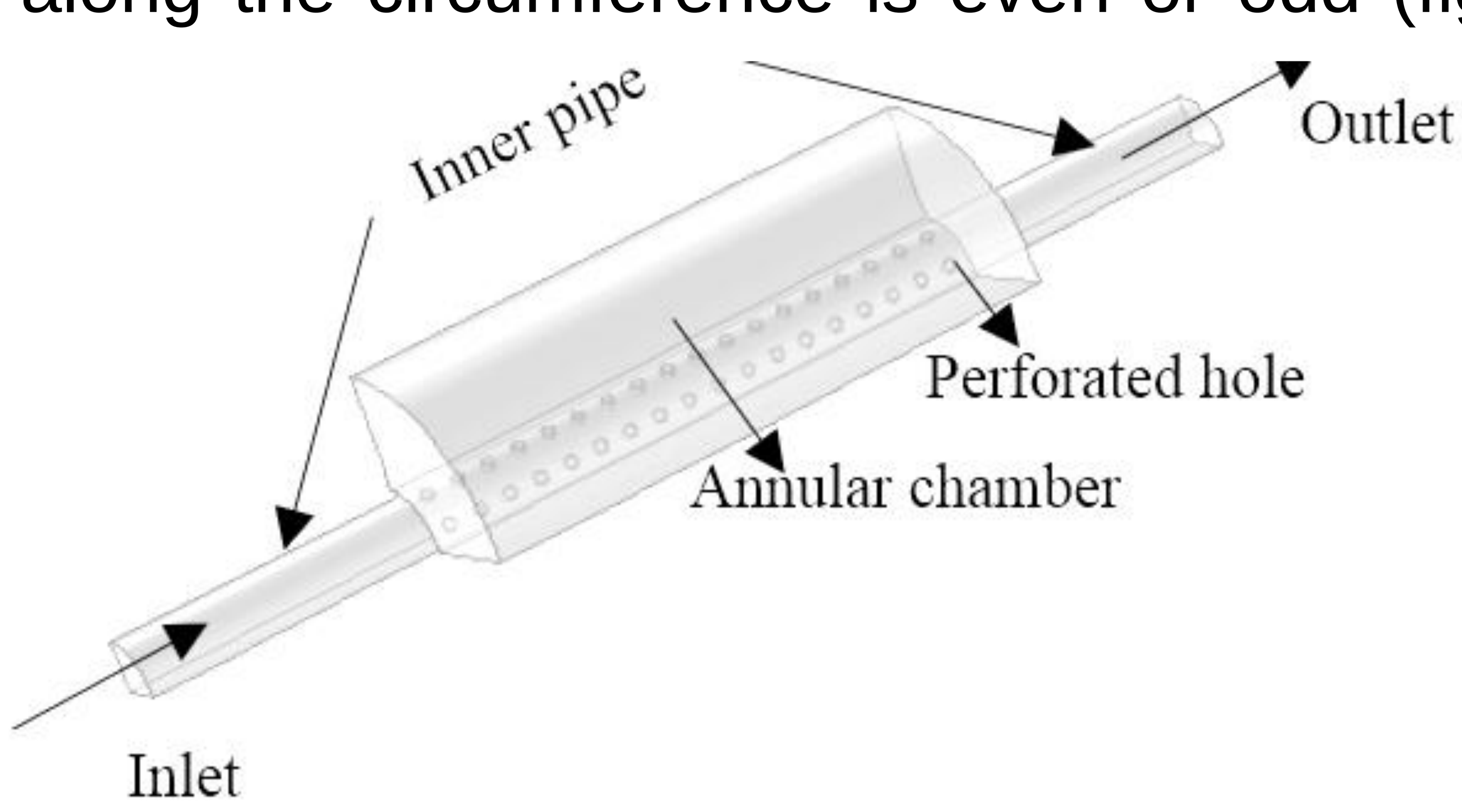


**Figure 2**. COMSOL model of a CTR

Turbulent intensity of 0.03 and turbulent length scale of 0.07 times the inner pipe diameter is applied at the inlet. The friction is assumed to be a function of the inner pipe thickness, perforated hole diameter, porosity and perforated length as $f=F(\sigma, d_h, t_w, l)$

**Results**: Within the limits of practical dimensions, the effect of pipe thickness, perforated length and perforated hole diameter is insignificant for automotive applications.

The normalized pressure drop varies linearly with the porosity (figure 5).

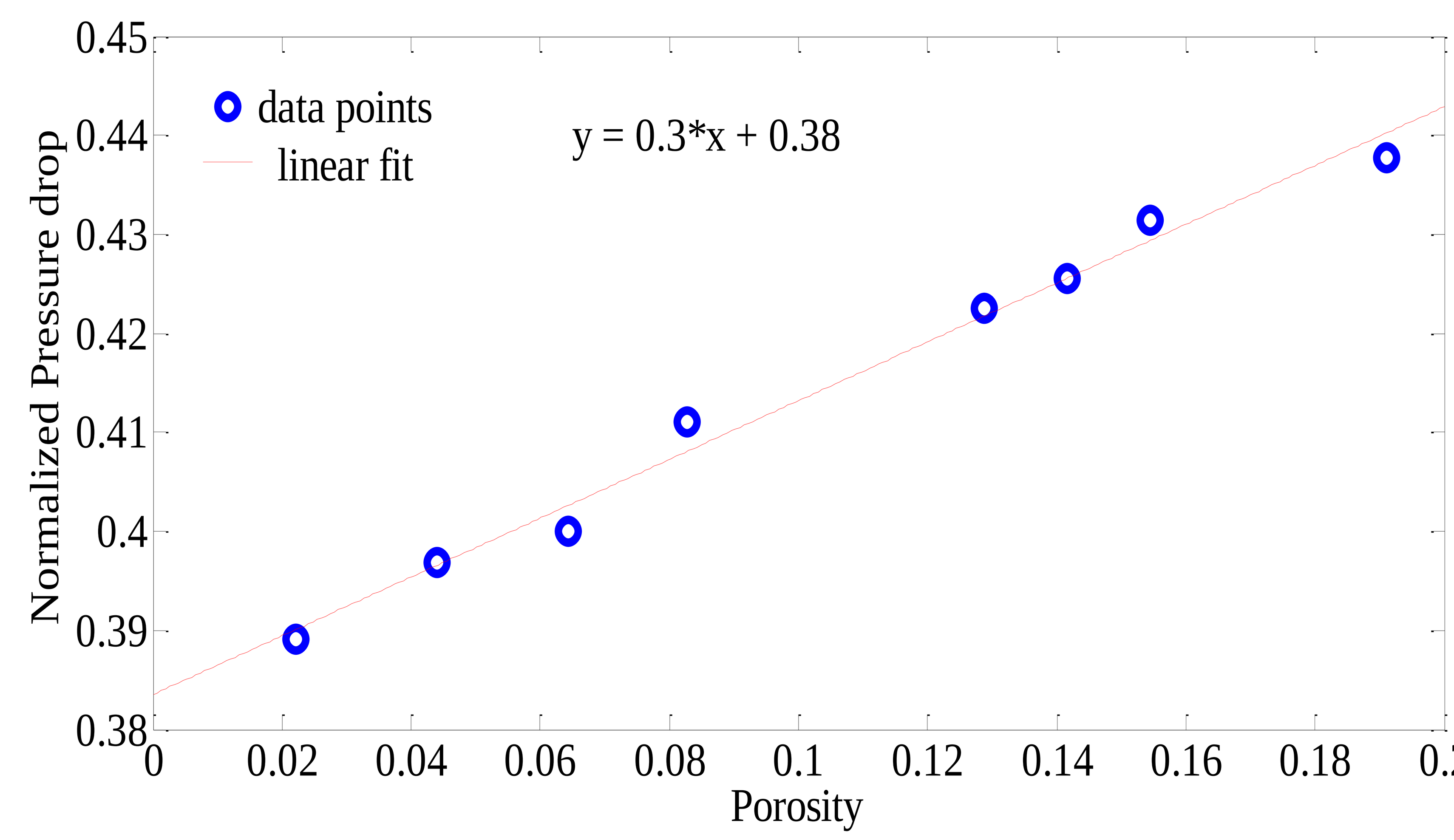


**Figure 3**. Normalized pressure drop Vs porosity

An additional term **'a'** is added to the Darcy-Weisbach equation to account for the contributions of the porosity. Using the default geometry from Table 1, the resulting equation (5) is obtained.

$$\frac{\Delta p}{H}=12.5\,f_0+2a\sigma \quad (5)$$

| Parameters | Value | Units |
|---|---|---|
| Total length | 400 | mm |
| Inner diameter, d | 32 | mm |
| Perforated length | 2d | mm |

**Table 1**. Default values of CTR

By comparing the coefficients of equation (5) and the linear fit given in figure (3), the desired friction factor for perforated pipe is obtained as

$$f=0.0304+0.15\sigma \quad (6)$$

**Conclusions**: The friction factor for perforated pipe is found to be a linear function of the porosity. The formula is easy to use in finding the back pressure of mufflers with perforated pipes.

**References**:


1. Neihguk, D., Munjal, M. L, and Prasad, A., Pressure Drop Characteristics of Perforated Pipes with Particular Application to the Concentric Tube Resonator. No. 2015-01-2309, *SAE Technical Paper*, doi:10.4271/2015-01-2309 (2015)