Are the Dynamics of Fluid Injection a Mechanism of Improving the Acoustic Characteristics of Performance Exhaust Mufflers?

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1. Abstract

Perforated tubes are used extensively in industry for various applications. Oil well completion and draining systems are examples of such applications. These applications involve the lateral injection of an incompressible fluid through the perforations. The injection of fluid alters the characteristics of the flow inside the tube. Hence, numerous investigations have been conducted in this field in order to gain insight on the dynamics of pressure drop when perforations and fluid injection are present. The trends seen from pressure drop fluctuations validated the acoustic damping effect of perforated tubes in the absence of injection. These results also encourage the use of perforated tubes in exhaust mufflers. In addition to the perforation effects, fluid injection has the potential to enhance the damping effect even further. Are the dynamics of fluid injection a mechanism of improving the acoustics characteristics of performance exhaust mufflers?

2. Introduction

A basic exhaust system performs multiple functions. This study focuses on the functions of conveying exhaust gases from the combustion chamber to the environment and the role of acoustic damping. Such an exhaust system can be modelled as a network of plain (smooth tubes) and perforated tubes [1]. The plain tubes are employed for the function of conveying exhaust gases between two points. Perforated tubes are housed inside mufflers, which are primarily responsible for acoustic damping.

An ordinary, exhaust muffler (top left corner of Fig. 1) provides damping by restricting the flow of exhaust gases. This process increases the pumping working done by the engine and reduces the efficiency of the engine in the process [1]. Performance exhaust mufflers are employed in performance applications to reduce pumping losses. These mufflers are usually constructed as straight and single pass perforated tubes (bottom right corner of Fig. 1). This configuration results in a reduction of pumping work but comes with the penalty of increased noise levels. Thus, performance mufflers are reserved for exotic or recreational vehicles.

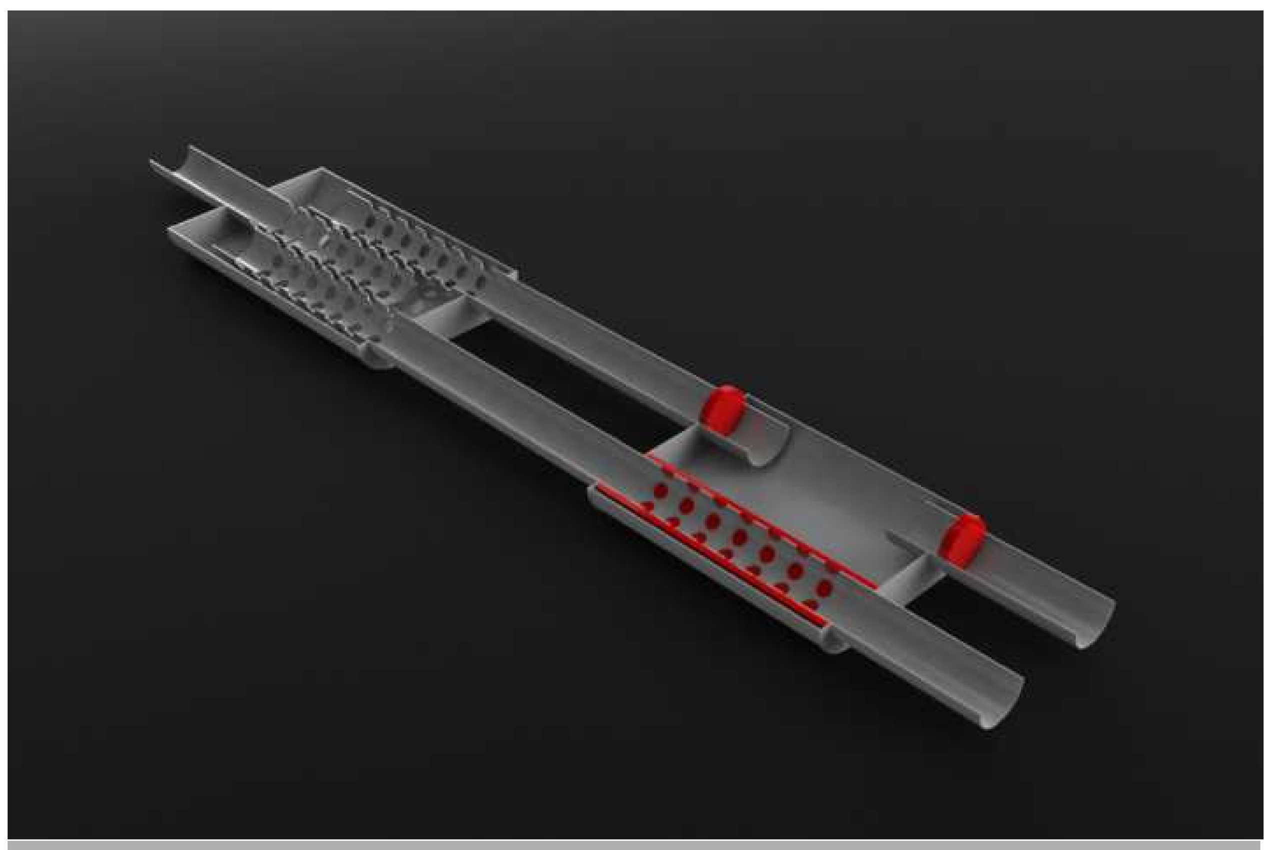

Fig 1: Application of fluid injection for adaptive muffling using a performance exhaust muffler (bottom right) in contrast with ordinary muffler (top left)

There are other applications [2][3][4][5], which employ perforated tubes in a similar configuration to the one used in performance exhaust mufflers. The research conducted in these fields confirm that fluid flow through perforated tubes have different characteristics when compared to the flow in smooth tubes [6]. Fluid injection alters the characteristics of flow even further [7]. There have been few attempts in literature, which investigate the propagation of pressure fluctuations and, possibly acoustic characteristics of perforated tubes when fluid injection is present. Hence, the purpose of this study is to discuss the fluctuation of pressure drop measurements when fluid injection is present for perforated tubes with a suitable perforation pattern.

3. Sources of pressure fluctuations (propagation of sound waves)

Turbulence is characterised by the fluctuation of flow rate and pressure drop measurements [8]. Thus, turbulence is the first source of pressure or pressure drop fluctuations. Researchers suppress turbulent fluctuations by obtaining multiple measurements, which are averaged to describe the state of the flow under steady conditions [9]. Pumps [7][9] also generate pressure pulses, which are observed in measurements. The percentage fluctuation, *pf*, is described by equation (1) and Fig. 2 depicts the fluctuation levels observed in smooth tubes (clear circles) and perforated tube (solid triangles). The moving average trendlines for the data is shown with dashed and solid lines for the smooth and perforated tubes respectively. These results are aligned with commercial practice [1].

$$pf_i = \left|\frac{\Delta P_i - \Delta\bar{P}}{\Delta\bar{P}}\right| \times 100\% \qquad (1)$$

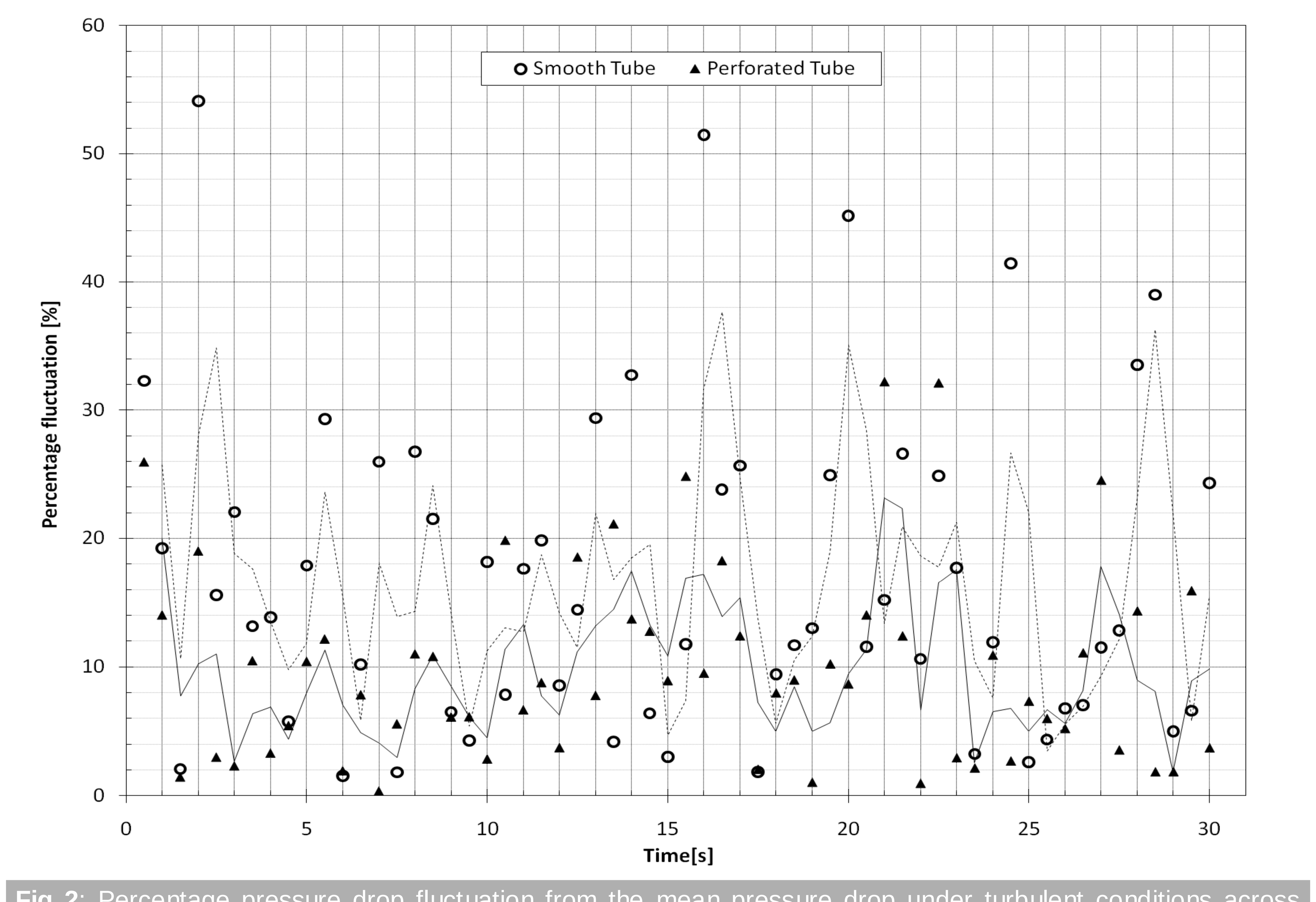

Fig 2: Percentage pressure drop fluctuation from the mean pressure drop under turbulent conditions across smooth and perforated tubes using a centrifugal pump to drive the flow

4. Perforated tube and fluid injection

The perforated tube used for this study has seven 1.5 mm diameter perforations, which were equi-spaced around the circumference of the tube. The second row and subsequent even numbered rows were staggered to the odd numbered rows. This pattern formed an isosceles triangle with a pitch of 15.6 mm. The tube had an inner and outer diameter of 20.8 mm and 22 mm respectively. The perforated length of the tube was 800 mm and there was 450 mm lengths at both the entrance and exit of the tube.

Figure 3 depicts average (solid triangles) and peak (clear circles) percentage pressure drop fluctuation as a function of fluid injection ratio. Average percentage fluctuation remained fairly constant with an increase in fluid injection. Significant drops in fluctuations were observed for injection rates between 2% and 3%. This effect was more pronounced when analysing peak percentage fluctuation values. Injection caused a sharp decrease in peak fluctuation levels for these injection ratios. The results encourage the use of injection for adaptive damping applications by simply installing valves (red discs in Fig. 1), which regulate the injection rate.

5. Conclusion

This study described the propagation of sounds waves in an exhaust system as pressure drop fluctuations. The trend of the results were aligned with the results obtained in commercial practice. A perforated tube with a pitch-diameter ratio of 0.75 was used. The peak percentage pressure drop fluctuations for this configuration was extremely sensitive to changes in injection ratio. The results open door for adaptive damping. Are the dynamics of fluid injection a mechanism of improving the characteristics of performance exhaust mufflers?

References

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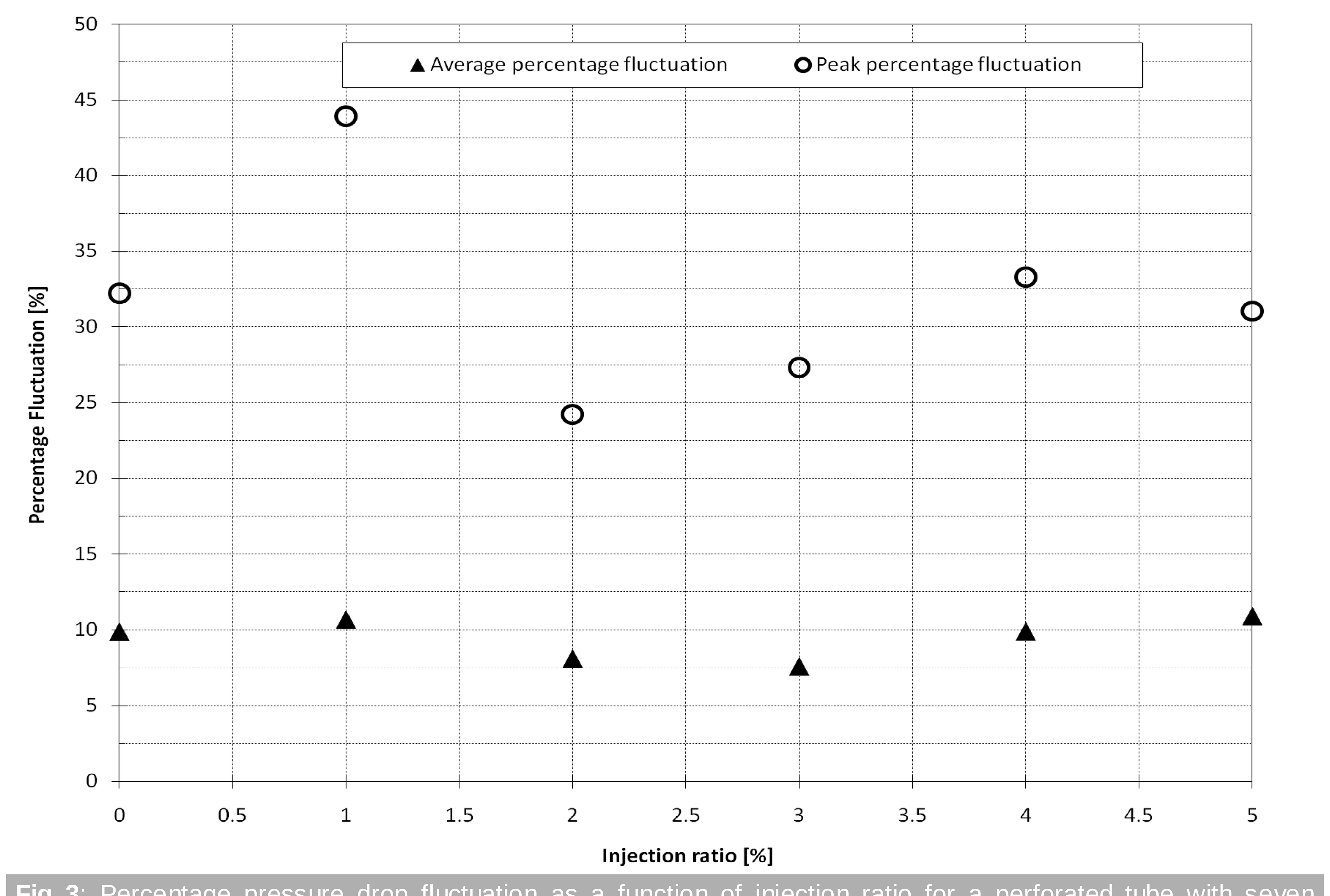

Fig 3: Percentage pressure drop fluctuation as a function of injection ratio for a perforated tube with seven perforation holes, which are equi-spaced around the circumference of a tube and a pitch-diameter ratio of 0.75