Temporal Concentration Profiles in Steady and Unsteady Pipe Flow Dataset Read Me

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1 Introduction

This dataset describes experimental solute traces (upstream and downstream temporal concentration profiles) recorded at the University of Warwick from 2010-2013 in steady and unsteady pipe flow. It accompanies the journal articles entitled "Residence Time Distributions for Turbulent, Critical, and Laminar Pipe Flow" (Hart *et al.*, 2016) and "Longitudinal Dispersion in Unsteady Pipe Flows" (Hart *et al.*, 2021). This dataset was collected by Dr James Hart (Hart, 2013). Dr Fred Sonnenwald uploaded this archive under EPSRC grant EP/P012027/1.

Please visit https://www.sheffield.ac.uk/mixing-studies for more information.

2 File naming and data format

This dataset consists of two `ZIP` files, one `XLS` spreadsheet detailing flow conditions for each solute trace, and this `PDF` Read Me document. 57 `CSV` files with solute traces recorded in steady state flow conditions are located in the `SteadyState.zip` file and 265 `CSV` files with solute traces recorded in unsteady flow test programmes are located in sub-folders within the `Unsteady.zip` file. The sub-folders are named for each test programme. Each `CSV` file is named according to the type of flow, test programme, and ID within that test programme. For example, `Unsteady_Test4_R50.csv` resides in the `Test4` sub-folder of the `Unsteady` folder and is run 50 in test programme 4 under unsteady flow conditions.

2.1 Steady state concentration profiles

The first column of the steady state concentration `CSV` files provides the time, and the remaining columns give calibrated concentration in ppb at the specified instrument locations. To illustrate, the first part of `SteadyState_Test0_R23.csv` contains:

```
Time (s),x = 2.68 m (ppb),x = 4.89 m (ppb),x = 7.08 m (ppb),x = 8.92 m (ppb),x = 10.98 m (ppb),x = 13.06 m (ppb)
51.233,  0.0051787522,    0,               0,               0,               0,                0
51.267,  0,               0,               0,               0,               0,                0
51.3,    0,               0,               0,               0,               0,                0
...,     ...,             ...,             ...,             ...,             ...,              ...
```

The data from `SteadyState_Test0_R23.csv` are plotted in Figure 1.

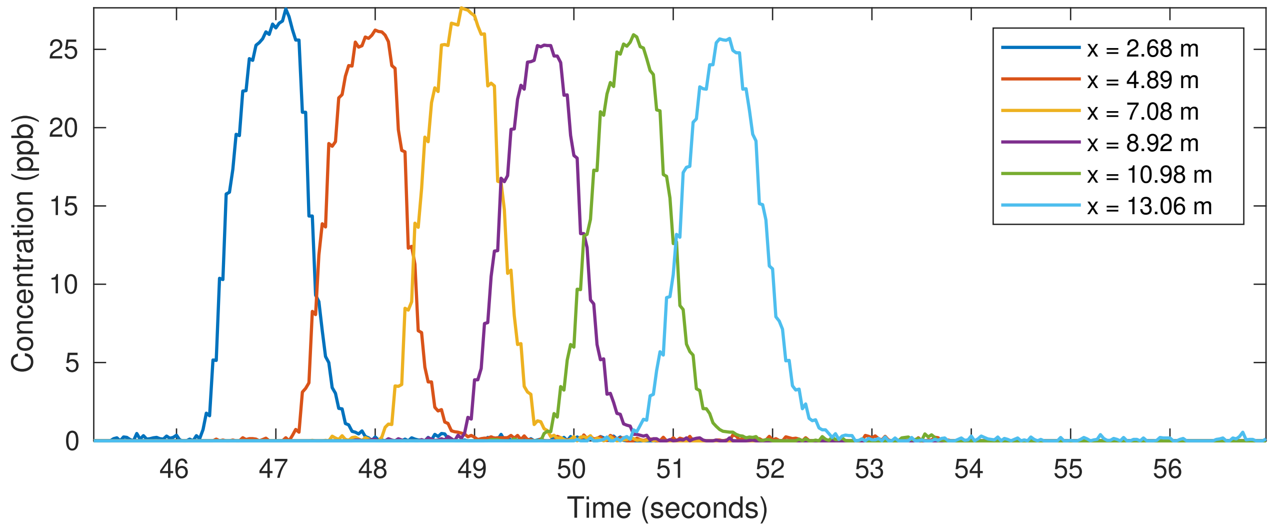

Figure 1: Example plot of steady state data, Test 0, R23

2.2 Unsteady concentration profiles

The unsteady `CSV` files also give the flow rate, velocity, Reynolds number, volume discharged during the time-step, and cumulative volume between the first column showing the time and the later columns showing concentration. The first part of `Unsteady_Test4_R50.csv` contains:

```
Time (s),Q (m^3/s),U (m/s),Re,    Volume (m^3), Cumulative volume (m^3),x = 0.50 m (ppb),  ...
0,       0.0010271,2.2704,  48220, 0,            0,                       0,                 ...
0.033333,0.0010271,2.2704,  48220, 3.4236e-05,   3.4236e-05,              0,                 ...
0.066667,0.0010271,2.2704,  48220, 3.4236e-05,   6.8473e-05,              0,                 ...
...,     ...,      ...,     ...,   ...,          ...,                     ...,               ...
```

```
...  x = 2.68 m (ppb),x = 4.89 m (ppb),x = 7.08 m (ppb),x = 8.92 m (ppb),x = 10.98 m (ppb),x = 13.06 m (ppb)
...  0,               0,               0,               0,               0,                0
...  0,               0,               0,               0,               0,                0
...  0,               0,               0,               0,               0,                0
...  ...,             ...,             ...,             ...,             ...,              ...,
```

The data from `Unsteady_Test4_R50.csv` are plotted in Figure 2.

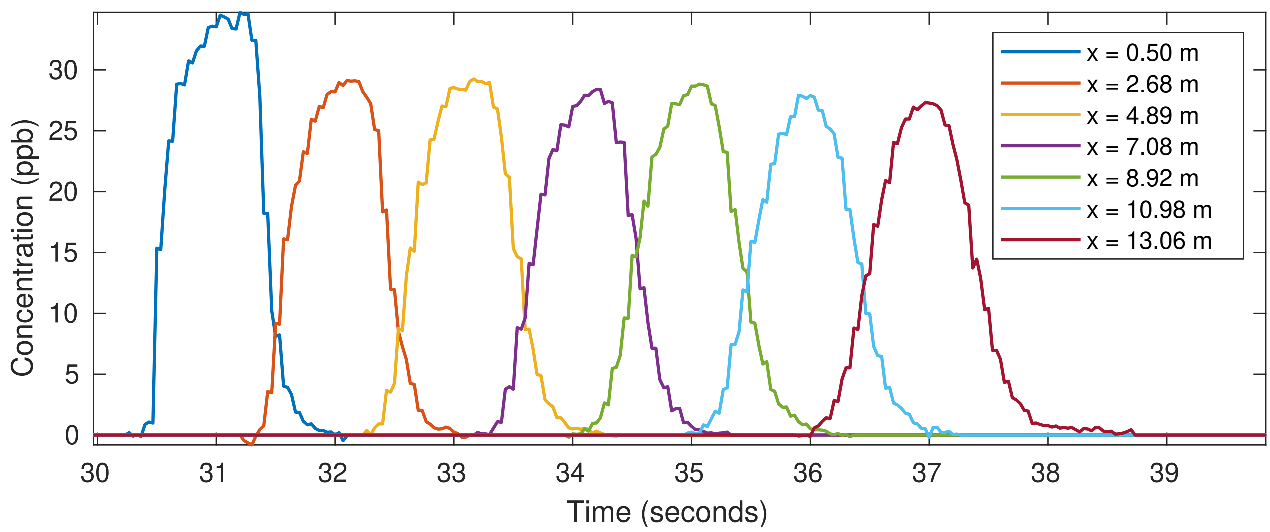

Figure 2: Example plot of unsteady data, Test 4, R50 (zoomed in)

2.3 Pre-processing

Background was subtracted as a constant mean of the first 30 seconds of the trace. Start and end of the profile were taken as 1% of peak concentration and the points before and after the 1% cut-off were set to 0. The steady-state traces were trimmed to this range, while the unsteady traces were not. In some cases, the instrument at $x = 10.98$ m did not record data and will report a concentration of 0. In some cases, the instrument at $x = 0.50$ m recorded off scale and thus the data at this location should be treated carefully.

3 Experimental setup

Hart (2013) conducted solute tracing in a 17.8 m long test section of perspex pipe with a nominal internal diameter of 24 mm. Concentrations of Rhodamine WT injected by peristaltic pump were recorded at 30 Hz using Turner Designs Series 10 fluorometers. The concentrations were measured at 6 locations in steady state flow conditions and 6 or 7 locations in unsteady flow conditions. Flow was measured using an electromagnetic Siemens Sitrans FM Magflo MAG 5100W flow meter. A schematic of the experimental setup is shown in Figure 3.

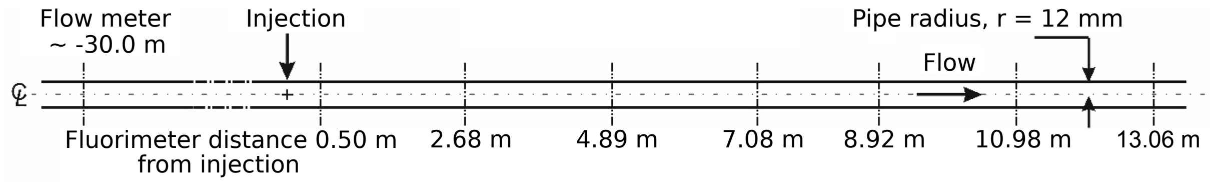

Figure 3: Laboratory configuration

Friction factor f for the pipe was calculated from measured head loss. Equations 1 to 5 were fit to the experimental measurements and may be used to calculate f as a function of Reynolds number Re (Hart, 2013).

$$P_1 = \frac{50.1}{Re} \tag{1}$$

$$P_2 = \frac{2.132 \times 10^{-9}}{Re^{-1.927}} \tag{2}$$

$$P_3 = \frac{0.2636}{Re^{0.2442}} \tag{3}$$

$$F_1 = P_1 + \frac{P_2 - P_1}{\sqrt{1 + (Re/4020)^{-16}}} \tag{4}$$

$$f = F_1 + \frac{P_3 - F_1}{\sqrt{1 + (Re/5000)^{-60}}} \tag{5}$$

Five solute tracing test programmes were carried out, one in steady flow conditions, and four in unsteady flow conditions. Test programme 0 investigated mixing in steady-state conditions. Test programmes 1 and 2 investigated mixing in turbulent-turbulent accelerating and decelerating conditions respectively. Test programmes 3 and 4 investigated mixing in laminar-turbulent accelerating and turbulent-laminar decelerating conditions respectively. Table 1 summarises the test programmes.

Test programme 0 consisted of 3 repeat injections at Reynolds numbers ranging from 1,800 to 51,000. Injection occurred at approximately 45 seconds.

Test programme 1 consisted of flows accelerating from Reynolds number 6,500 to 47,000, test programme 2 from 47,000 to 6,500, test programme 3 from 2,900 to 48,000, and test programme 4 from 48,000 to 3,300. Acceleration occurred at approximately 130 seconds for test programme 1 and 2, and 205 seconds for test programme 3, and 80 seconds for test programme 4.

Test programmes 1 to 4 each have three different acceleration durations of 5, 10, and 60 seconds. Dye was injected at the start of the acceleration. The 60 second duration also had a second injection halfway through the acceleration. Additional steady state injections were carried out before and after flow acceleration in the unsteady test programmes to verify steady state conditions before and after acceleration. In test programmes 1, 2, and 4, additional steady state injections were carried out immediately after the flow acceleration ended.

Additional detail on the experimental setup is available in Hart (2013).

Test Programme	Initial Reynolds Number	Final Reynolds Number	Acceleration duration (s)	Number of Injections
0	1,800–51,000	1,800–51,000	-	3 per Reynolds number
1	6,500	6,500	-	5 per transient time
	6,500	47,000	5, 10, 60	5, 5, 10
	47,000	47,000	-	10 or 15 per transient time
2	47,000	47,000	-	5 per transient time
	47,000	6,500	5, 10, 60	5, 5, 10
	6,500	6,500	-	10 or 15 per transient time
3	2,900	2,900	-	5 per transient time
	2,900	48,000	5, 10, 60	5, 5, 10
	48,000	48,000	-	5 per transient time
4	48,000	48,000	-	5 per transient time
	48,000	3,300	5, 10, 60	5, 5, 10
	3,300	3,300	-	10 per transient time

Table 1: Summary of test programmes

References

Hart, J. (2013). *Longitudinal Dispersion in Steady and Unsteady Pipe Flow*. PhD thesis, The University of Warwick. http://wrap.warwick.ac.uk/57725/

Hart, J., Sonnenwald, F., Stovin, V., & Guymer, I. (2021). Longitudinal dispersion in unsteady pipe flows. *Journal of Hydraulic Engineering*, 147(9), 04021033. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001918

Hart, J. R., Guymer, I., Sonnenwald, F., & Stovin, V. R. (2016). Residence time distributions for turbulent, critical, and laminar pipe flow. *Journal of Hydraulic Engineering*, 142(9), 04016024. https://doi.org/https://doi.org/10.1061/(ASCE)HY.1943-7900.0001146