Cyclonic stack flow measurement uncertainties and impact on annualised mass emission measurements

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Introduction – **Emission limits are enforced by flow measurements, legally required to adhere EN ISO 16911-1 [1]. This standard also refers to EN 15259 [2] which sets requirements for measurement sections and sites, including requirements for the measurement plane when determining the average velocity from a grid of point flow measurements. One of these requirements is that the flow conditions should be homogenous. It is noted that this requirement is generally fulfilled in a section of duct with at least five hydraulic diameters of straight duct upstream of the sampling plane and two hydraulic diameters downstream. However, the field validation trials for EN ISO 16911-1 were carried out at plants with no significant cyclonic flow (turbulent flow with a significant amount of swirl) so that this part of the standard is poorly validated in stacks with cyclonic flow.**

Experimental

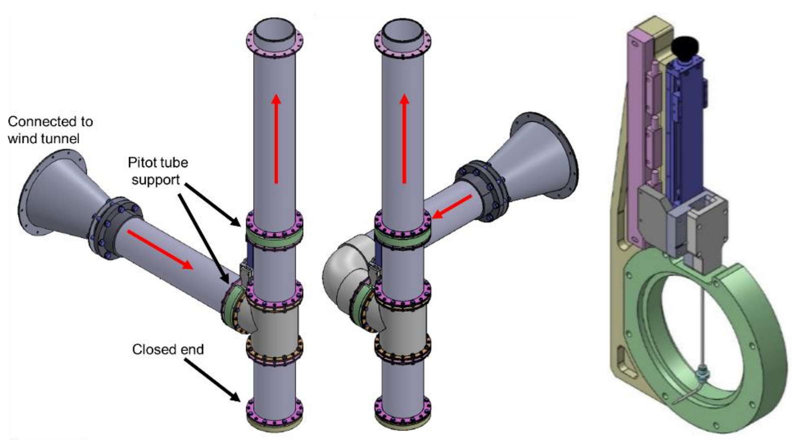

Figure 1: *Left: Stack simulator with straight entrance, and with an elbow before the entrance. Right: close-up of the Pitot tube support.*

We perform experiments in a stack simulator. The stack is a vertical pipe with a diameter of 0.20 m. The stack has a blunt closed bottom, and the flow enters the stack through a T-piece, of which the horizontal tube is connected to a calibrated wind tunnel. We use the stack simulator in two configurations: one with a straight stack entrance, the other with an elbow just before the stack entrance (Fig. 1).

We use an L-Pitot tube to perform the velocity measurements. The Pitot tube is held in place using a specially designed support with a linear stage, allowing to position the Pitot tube at various radial positions in the stack (Fig. 1+2).

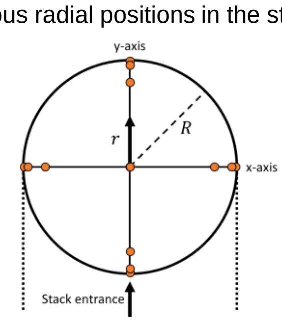

Figure 2: *Top view of the measurement plane. The y-axis is parallel to the axis of the stack entrance. The radial position of measurement point is denoted by r while the tube radius is given by R. Orange points denote the measurement positions.*

Results

We characterize the flow by measuring the non-dimensional axial velocity at measuring planes spaced 3 to 7 hydraulic diameters downstream of the stack entrance. At each plane, we measure the velocity as indicated in Figure 2. Results are plotted in Figure 3. Although for the stack with a straight entrance, at 7 hydraulic diameters downstream (Fig. 3c), the profile becomes somewhat symmetrical, deviations from the reference profile are significant. The deviations are considerably larger in the case of cyclonic flow (Fig. 3d-f), where the profile is still highly asymmetric at 7 diameters from the stack entrance.

References:

1. ISO 16911-1: *Stationary source emissions – Manual and automatic determination of velocity and volume flow rate in ducts – Part 1: Manual reference method*, 2013.
2. EN 15259: *Air quality – Measurement of stationary source emissions – Requirements for measurement sections and sites and for the measurement objective, plan and report*, 2007.
3. Dimopoulos C, Robinson R A, Coleman M D, "Mass emissions and carbon trading: a critical review of available reference methods for industrial stack flow measurements", *Accreditation and Quality Assurance*, **22**, pp. 161-165, 2017.

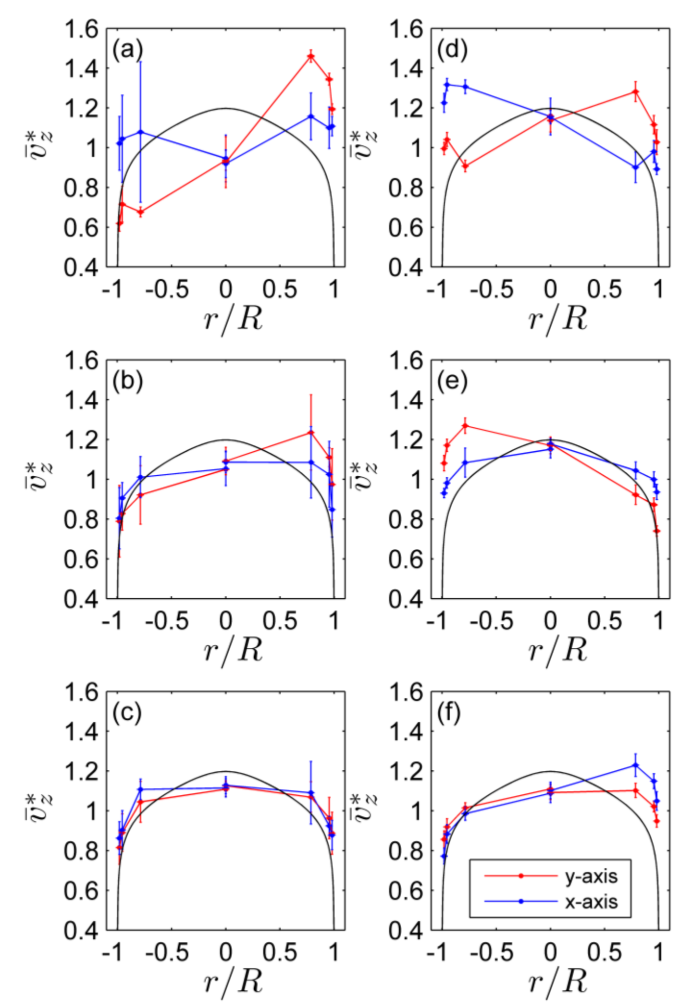

Figure 3: *Average non-dimensional axial velocity $\bar{v}_z^*$ as a function of r/R, for a stack with a straight entrance (a-c) and a stack with an elbow before the entrance (d-f) at 3 (a+d), 5 (b+e) and 7 (c+f) diameters downstream of the T-junction. All data shown was recorded at v_{bulk} = 10.0 m/s. Legend in (f) applies to all panels. Solid black lines represent the Gersten-Herwig reference profile for fully developed turbulent pipe flow [3].*

Conclusions

We present results of stack simulator measurements in two configurations: one with a straight stack entrance and one with an elbow. We show that for our narrow stack simulator, the flow profile deviates significantly from the reference profile for fully developed pipe flow, even at 7 hydraulic diameters downstream of the flow disturbance. The deviations are larger for the configuration with the elbow before the stack entrance, which generates cyclonic flow. These findings suggest that cyclonic flow not only increases the error of the flow rate measurement according to [1, 2] by presence of transversal velocity components and their impact on measurement error of a Pitot tube, but also by slower decrease with downstream pipe length of flow asymmetry introduced by the T-junction of the supply pipe.

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For more information about the project: empir.npl.co.uk/impress/