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Spectroscopic techniques versus Pitot tube for the measurement of flow velocity in narrow ducts

Final Workshop

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Task 3.3: Introduction

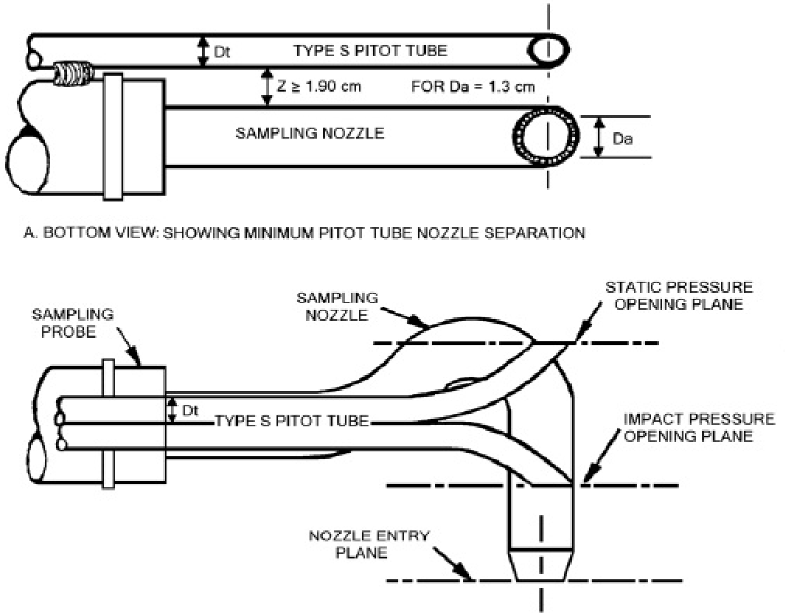
EN 16911-1:2013 Stationary Source Emissions–Manual and Automatic Determination of Velocity and Volume Flow Rate in Ducts—Part 1: Manual Reference Method

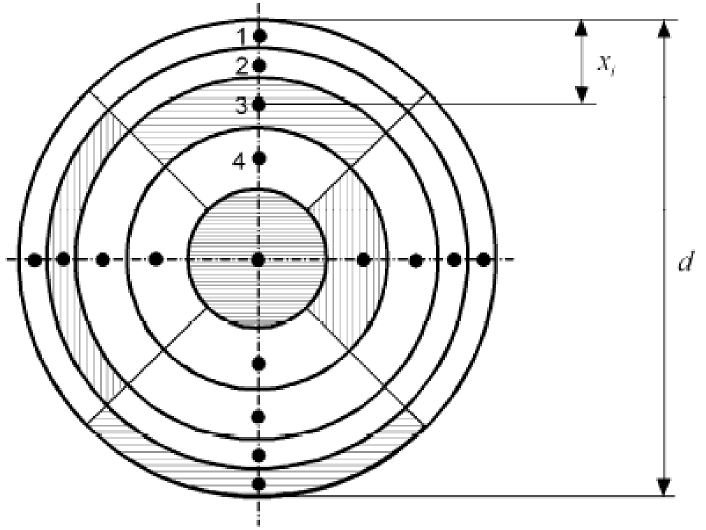
EN 16911-2:2013 Stationary Source Emissions–Manual and Automatic Determination of Velocity and Volume Flow Rate in Ducts—Part 2: Automated measuring systems

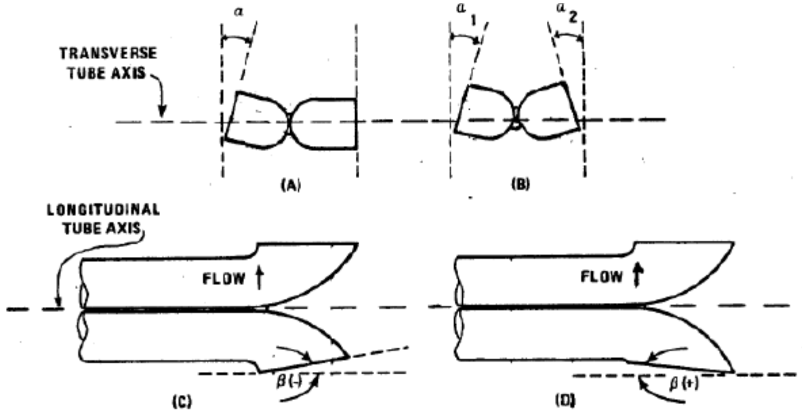
- Several methods and technologies are available to measure the velocity and flow rate of a gas flowing in a duct
- Differential pressure based techniques, using Pitot tubes, described in EN 16911-1:2013 Annex A are the most widely used for manual measurements as well as for the periodical calibration of the Automated Measuring Systems in industrial stacks
- These methods have been validated and are mainly applied in large industrial plants, on tall smokestack having a large section (> 1m)
- The others techniques, described in the Standards, are rarely used in practice and an extended set of validation data is not available for them

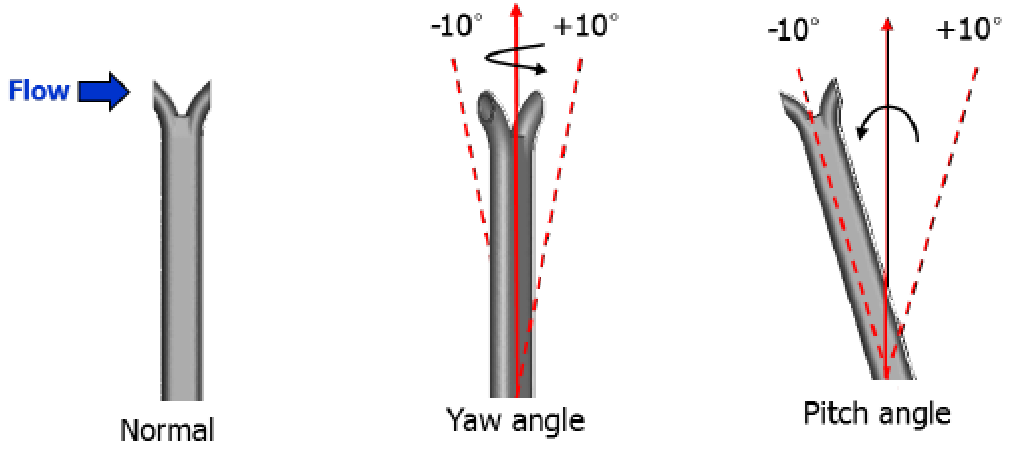
Task 3.3: Pitot tubes

- Pitot tubes, mainly S-type, are widely used and generally reliable devices for the measurement of point velocity
- The greatest limitation arises from the limit in the measurement of differential pressure (> 5Pa)
- Misalignment of the Pitot ends, due to either poor mechanical manufacturing or to the pitch and yaw angle, referred to the flow direction, may produce deviations and uncertainty of the reading



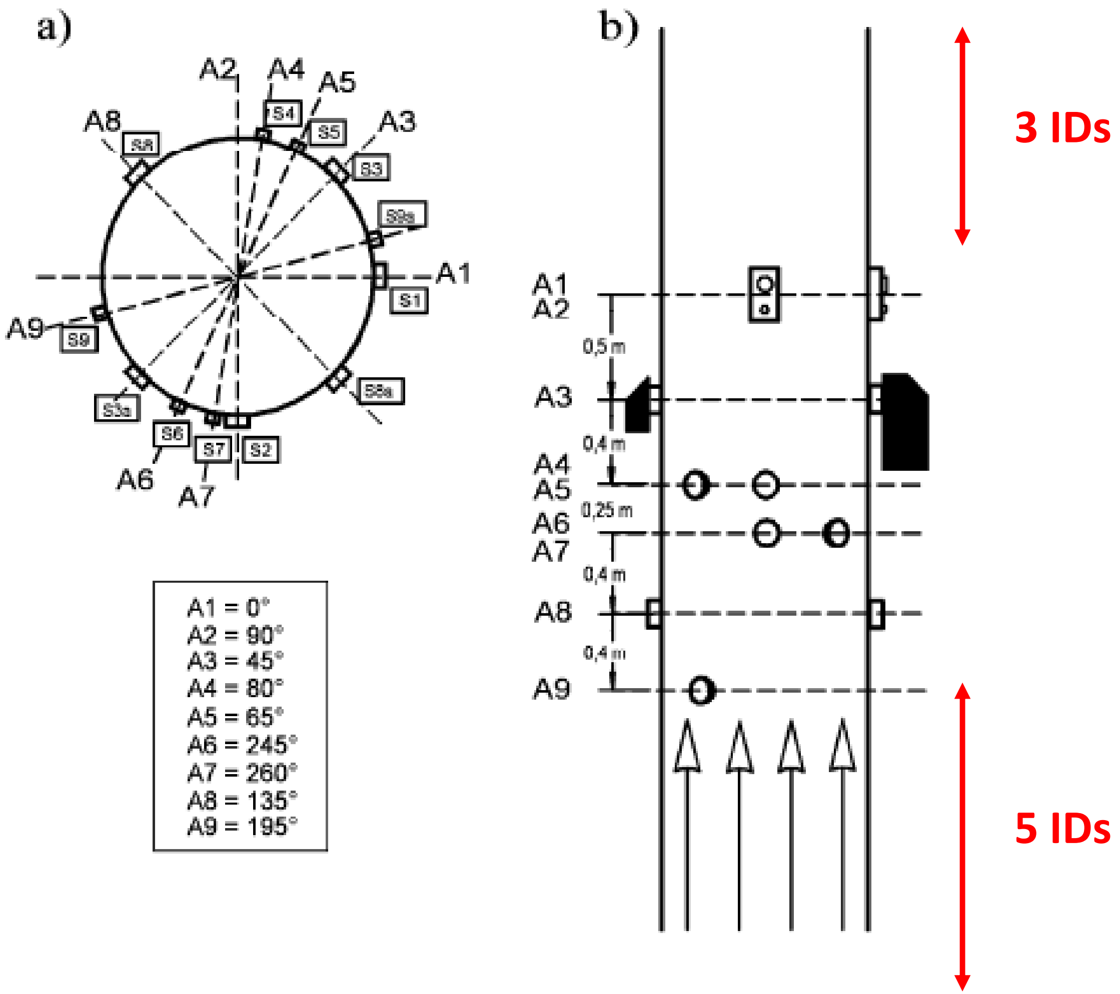






Task 3.3: General requirements

- In order to perform velocity measurement according to the Standard Methods specific requirement are prescribed
- The measuring section must be straight, constant area, far from obstructions, elbows and other flow disturbances
- The flow pattern must be regular, the swirl angle should be <15° (otherwise a correction is required), a wall effect correction coefficient must be applied



Swirl Correction

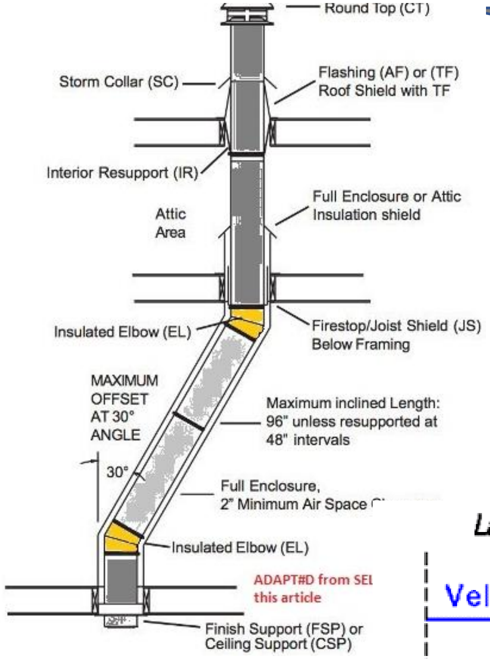
$$v_C = \cos\theta\, v_{meas}$$

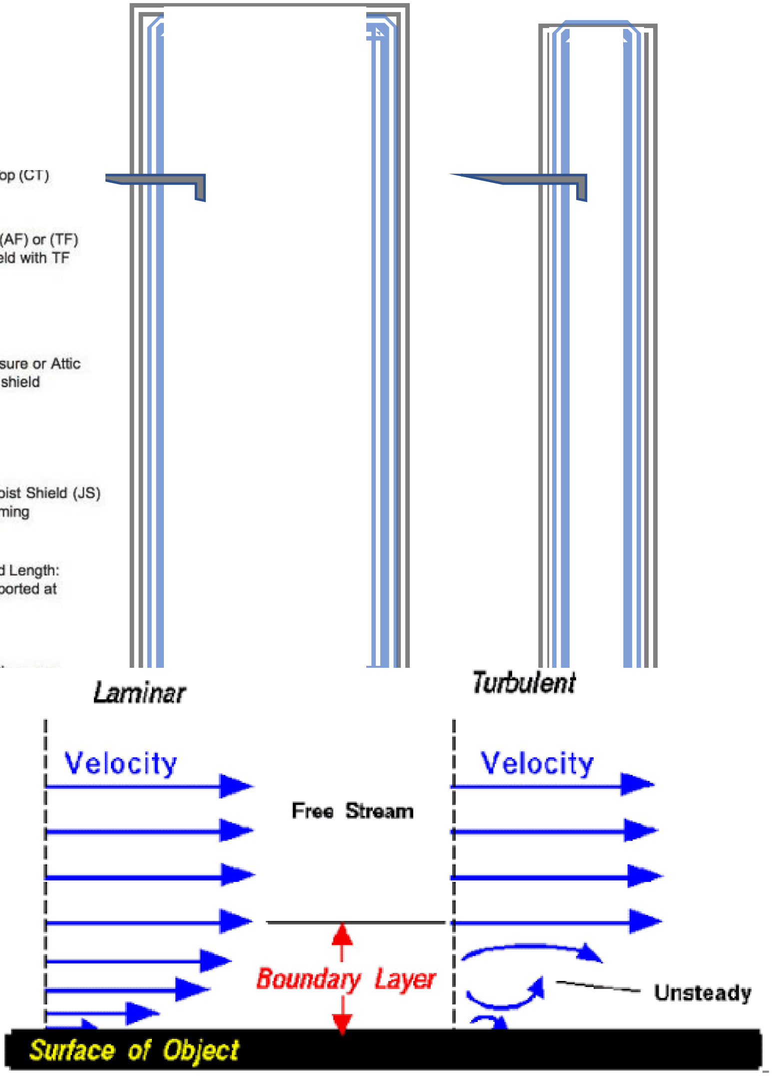
Wall Effects Correction

$$\bar{v}_C = \bar{v}\, f_{WA}$$

Task 3.3: Small ducts issues

- These requirements are relatively easily fulfilled in most large scale stacks
- In small ducts it is difficult to find a straight pipe long enough to get a smooth flow pattern
- Wall effects and disturbances are much more pronounced
- The probe itself may produced large hindrance to the flow

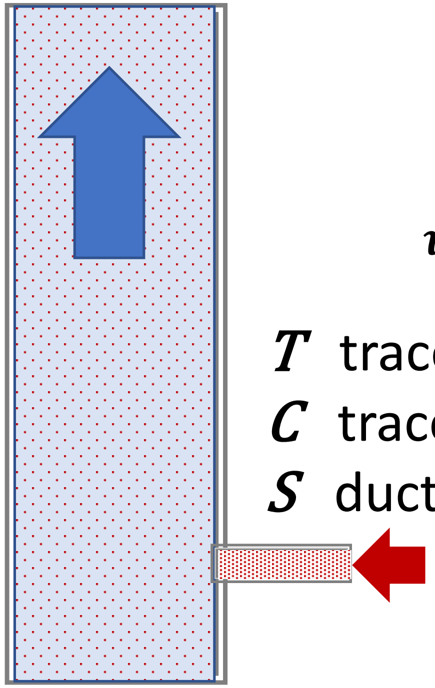




Task 3.3: Tracer Methods – Objectives

- Develop and validate tracer methods applicable in small ducts (Dilution Method and Transit Time Method)
- Inter-compare these methods with the conventional Pitot tube approach
- Find the possible sources of errors and uncertainty associated with these methods
- Find possible limitations to their applicability

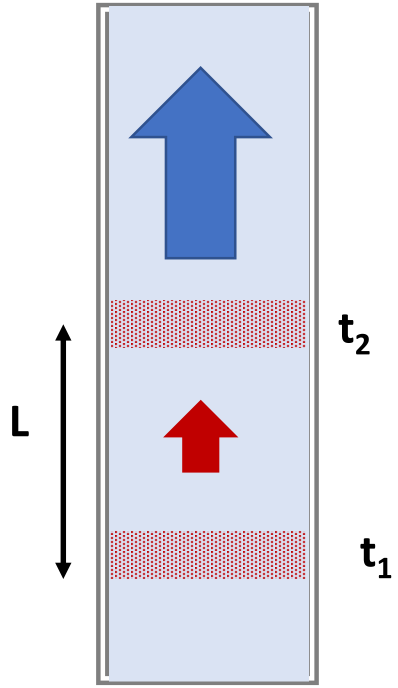
DILUTION METHOD
(EN 16911-1:2013 Annex C)



$$v = \frac{T}{CS}$$

T tracer flow
C tracer concentration
S duct section

$$v = \frac{L}{(t_2 - t_2)}$$

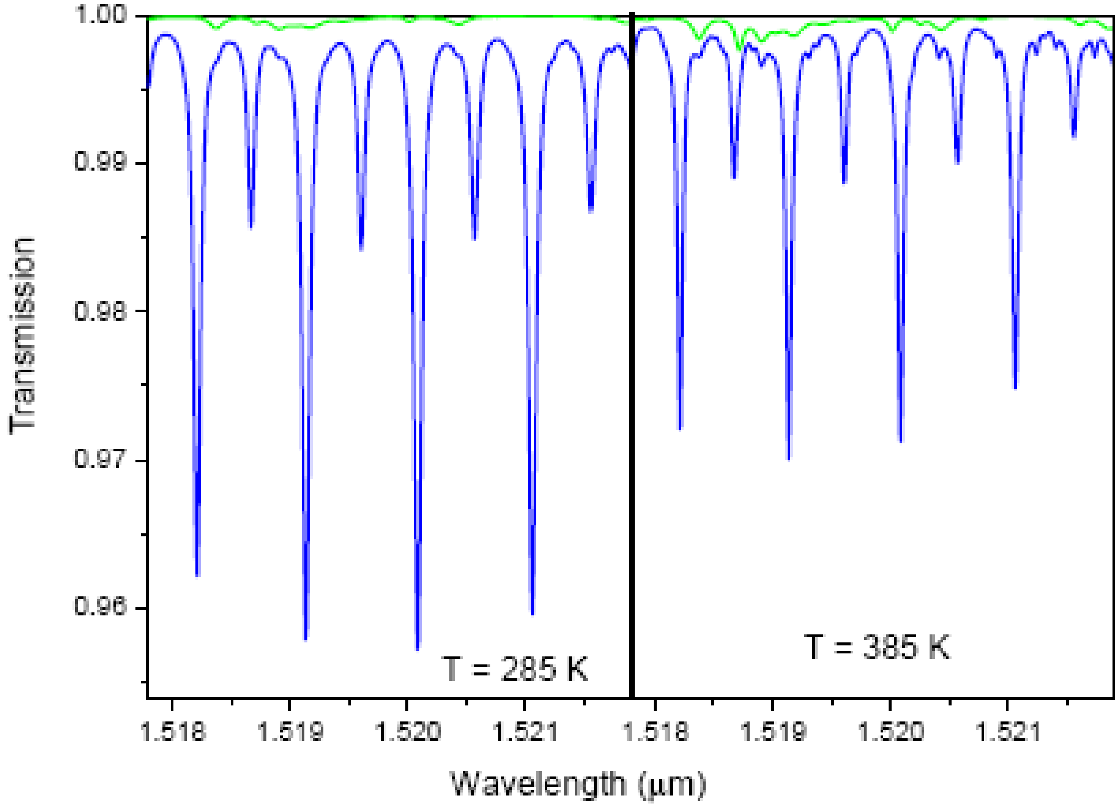


TRANSIT TIME METHOD
(EN 16911-1:2013 Annex D)

Task 3.3: Tracer Methods – Tracer selection

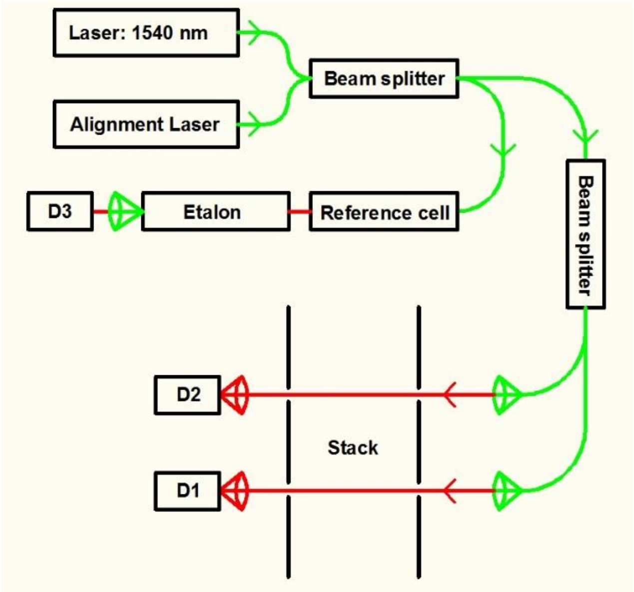
- The tracer should not be naturally present in the atmosphere, should not interfere with the normal operation of the plant, should be neither poisonous or toxic, nor environmentally detrimental, It should not be a byproduct of the plant itself.
- The maximum response time of the detection technique must be 10 - 100 ms, to be negligible compared to the rise time of the concentration of the tracer
- The tracer should feature optical absorptions in wavelength regions where user-friendly laser sources are available, and these absorptions should be sufficiently strong to reduce the tracer concentration to very low levels (1‰).

C_2H_2



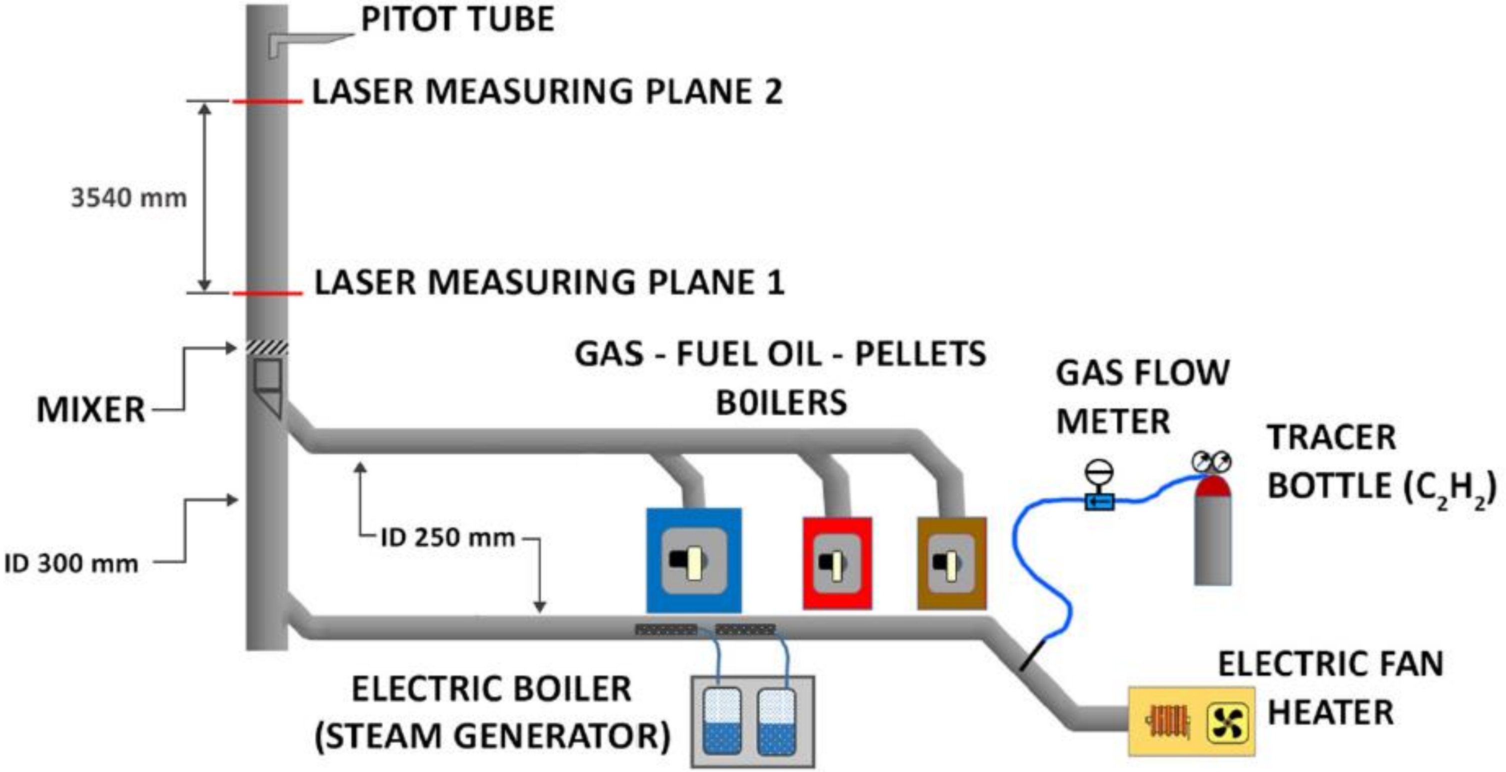
Task 3.3: Tracer Methods – Techniques

- The laser source is a DFB fiber laser with an emission wavelength at 1521 nm
- The laser beam is shot across the stack, onto a mirror reflecting the beam onto the detector, for a total of two passes
- The dilution measurements consist of a repeated laser wavelength scan across the selected absorption line
- In the TT method, the laser is set at the peak of the absorption and the time profile is acquired at two measuring points



Task 3.3: Tracer Methods – Test rig

- The tracer methods were tested in a small stack simulation facility (ID 300 mm)
- Simulated flue gases have been produced using a fan an electric heater and a steam generator (v= 1-8 m/s; T= 15-110°C; steam= 18-60 kg/h)
- C2H2 tracer was injected as far as possible from the stack using a TMFC
- 2 measuring planes for optical measurements (12 IDs apart) and 1 fixed point S-type Pitot tube for comparison



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Task 3.3: Tracer Methods – Flow pattern

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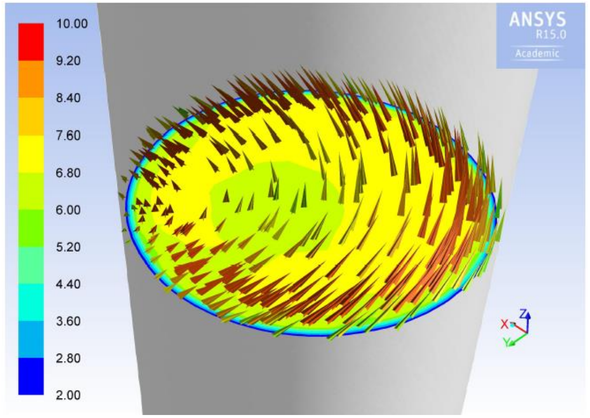
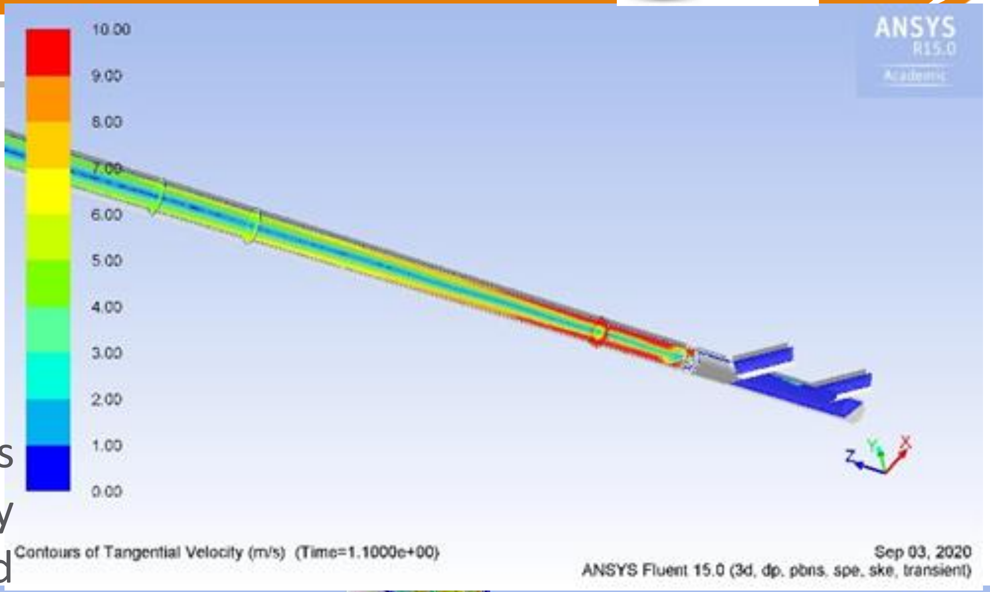
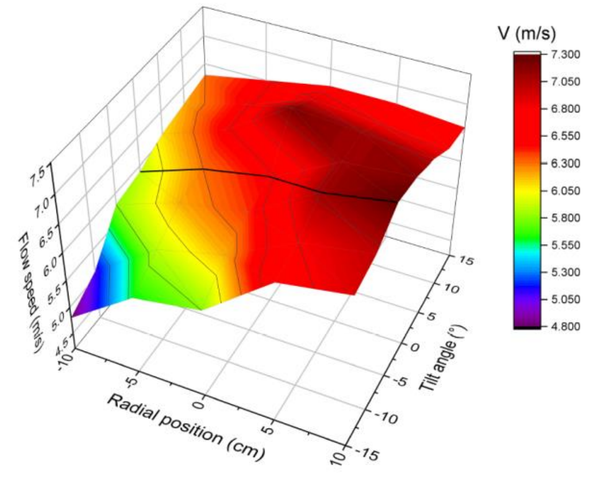
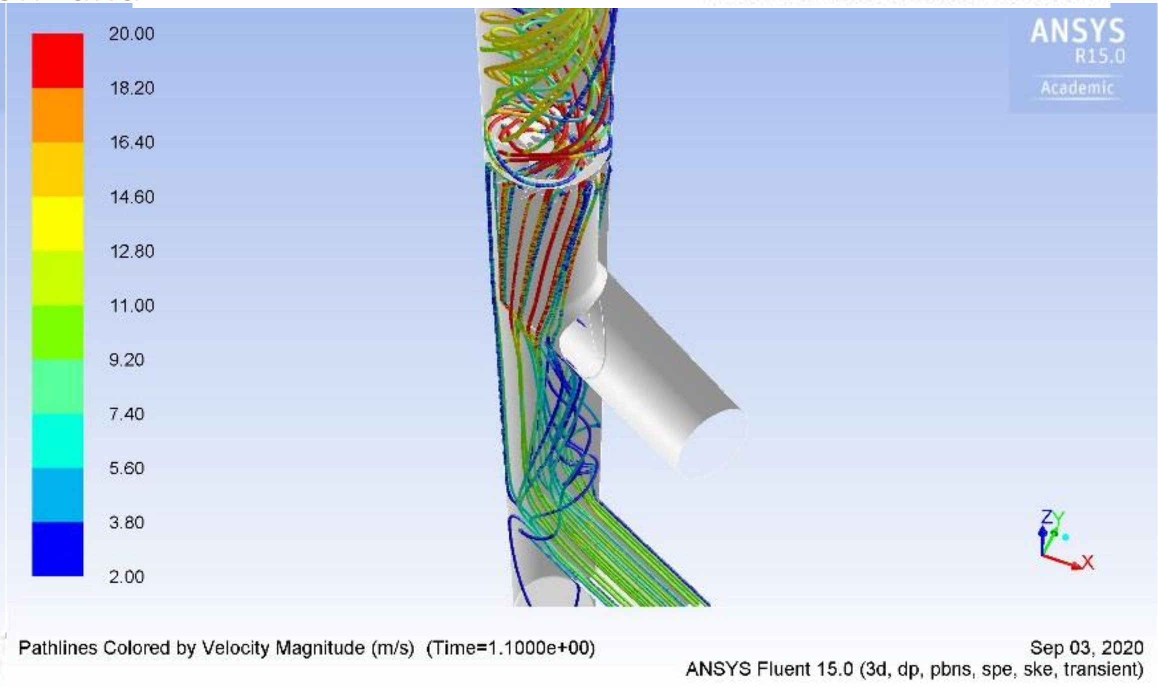


- The coil mixer produced a cyclonic flow whose effects extend well beyond 5 IDs from it (18 IDs)
- The measuring plane where the Pitot tube is installed is affected by its disturbance
- CFD and accurate Pitot measurements show that the measured velocity strongly depends on the position and angle

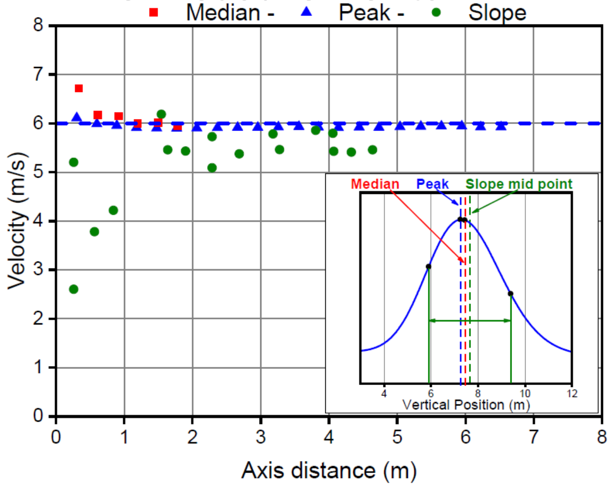


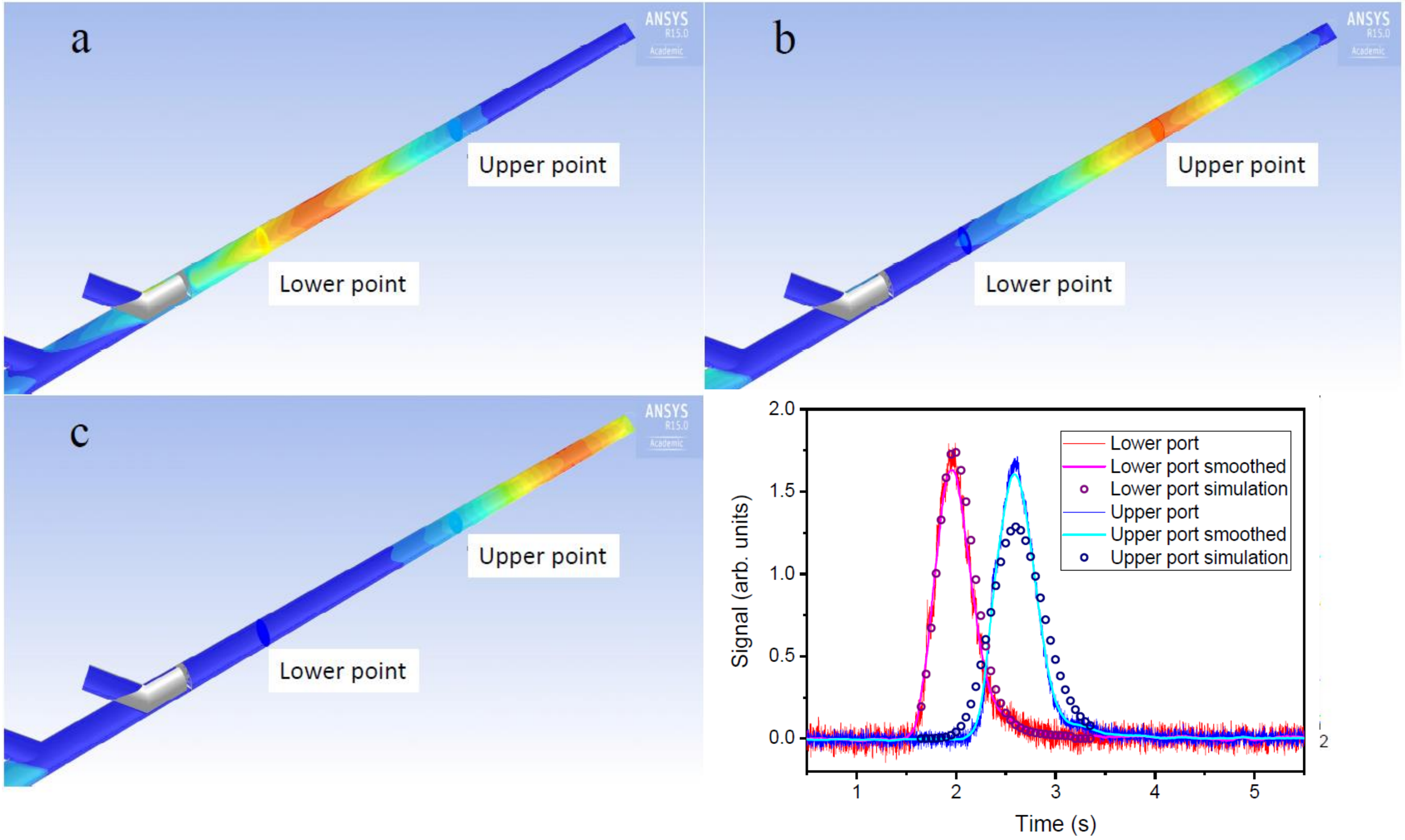




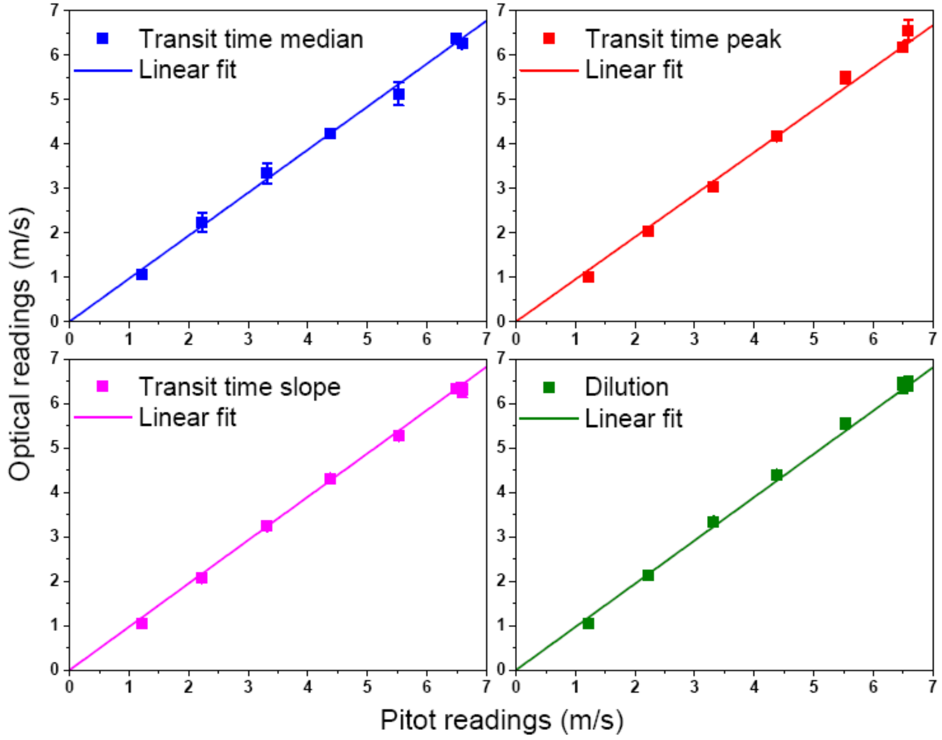
Task 3.3: Tracer Methods – CFD simulated results

- CFD simulations allowed to analyze the profiles of tracer concentration along the axis
- Model data have been compared with experiments
- Model data have been used to find the best estimator of the centroid of the tracer concentration for the Transit Time measurements

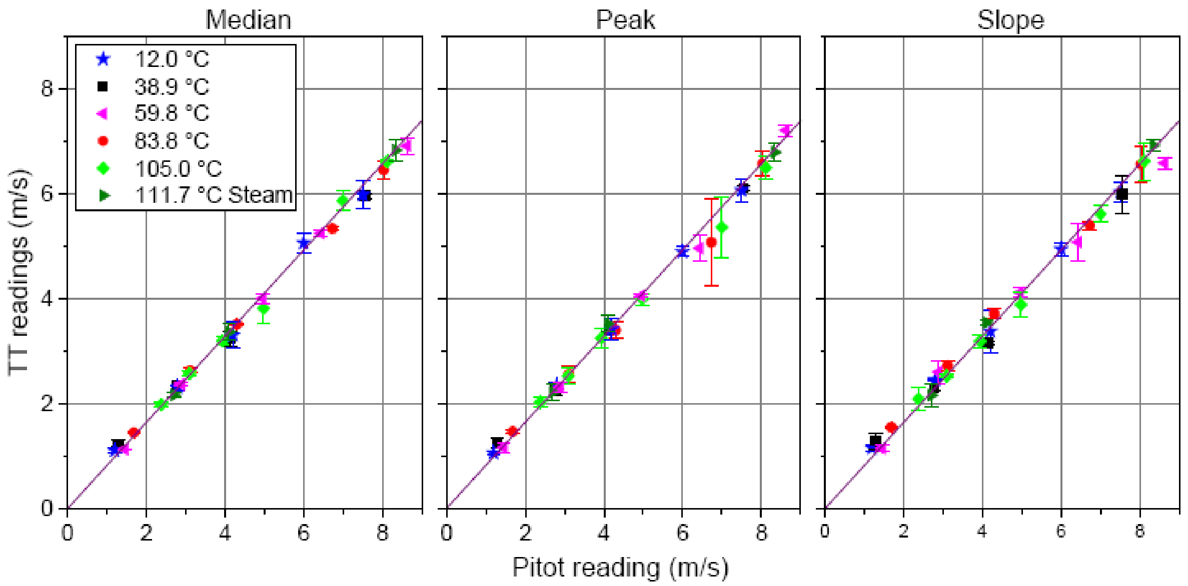




Task 3.3: Tracer Methods – Results



- Velocity measurements resulting from tracer TT and Dilution techniques are extremely similar to each other and well corresponding to the values read with a Pitot type S accurately positioned in the center
- The different time stamp options give comparable results



- TT results on a wider range of flow conditions are highly linear and reproducible
- A larger mismatch is observed with Pitot tube data due the manual alignment procedure

Task 3.3: Conclusions

1. The conditions of 5 internal diameters of straight duct upstream and 3 downstream of the measuring section, without elements disturbing the flow, may not be a sufficient guarantee to provide a regular velocity profile at the measuring plane;
2. Single point measurements may be non-representative of the average velocity, a multipoint technique should be required even for ducts having an internal diameter smaller than 0,35 m;
3. Manual alignment of a Pitot tube is not accurate and stable enough, large deviations of the measured values may be produced by very small variations in the placement of the probe;
4. Techniques relying on the bulk properties of the flow, such as the concentration of a tracer injected in the gas stream, are largely insensitive to the flow pattern and the local disturbances, producing linear and accurate results and can be considered reliable tools for the in situ periodic calibration of automated measuring systems

Task 3.3: Publications

sensors

MDPI

Article

Spectroscopic Techniques versus Pitot Tube for the Measurement of Flow Velocity in Narrow Ducts

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Abstract: In order to assess the limits and applicability of Pitot tubes for the measurement of flow velocity in narrow ducts, e.g., biomass burning plants, an optical, dual function device was implemented. This sensor, based on spectroscopic techniques, targets a trace gas, injected inside the stack either in bursts, or continuously, so performing transit time or dilution measurements. A comparison of the two optical techniques with respect to Pitot readings was carried out in different flow conditions (speed, temperature, gas composition). The results of the two optical measurements are in agreement with each other and fit quite well the theoretical simulation of the flow field, while the results of the Pitot measurements show a remarkable dependence on position and inclination of the Pitot tube with respect to the duct axis. The implications for the metrology of small combustors' emissions are outlined.

Keywords: laser flow meter; Pitot tube; flow speed; time of flight; dilution method; flow simulation; flow turbulence; gas sensing applications

Thank you for your attention

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