Problems with Pitots Measurement Issues in Industrial Emissions Flow Monitoring

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Overview

- Project Background
- Flow measurement theory
- Potential issues in emission monitoring
- Survey results
- Proposed future work
Project Background

- Project in the UK Department of Trade and Industry funded programme to underpin flow measurement
- Aim of the project is to review potential measurement issues relating to air flow measurement in industrial emissions monitoring
- Develop and propose future work programmes to address key measurement issues
Potential Issues in Emissions Monitoring

- The project was initiated because of concerns over the measurements of flow carried out in stacks.
- In particular there were concerns over the performance of Pitot Tubes at high temperatures.
- Flow measurement often considered a solved problem, Pitots are readily available, and they work – don’t they?
Importance of Flow Measurement for Emissions Monitoring

- Stack gas flow
  - Emissions fluxes
  - Possibly emissions trading
  - Stack flow characterisation – meeting the monitoring requirements of sampling methods
  - Enabling and demonstrating isokinetic sampling

- Sample flow – gas meters
  - Concentration measurement
Pitot-Static Tubes

- Pitot tubes are still routinely used for flow measurements
- Based on differential pressure measurement
- Provide the reference for flow measurements
- Two general types
  - L type (also the ellipsoidal tipped NPL or E-Type)
  - S type
L Type

- Defined standard
- Criteria on its construction

Diagram:

- Flow
- Impact pressure port
- Static pressure ports
- Differential Manometer
S Type

- Larger bore pressure orifices
- Less susceptible to clogging by moisture/dust
- Calibrated against the standard tube
- Easier to fit into stack

Differential Manometer

Flow
Standards

- Standard withdrawn, though national versions still exist (eg BS1042 part 2.1)
  - references ISO 3966-1977 to provide the standard or reference L Type tube - but hold on this has been withdrawn!
- CEN TC264 WG 23 are developing new flow standard
  - Automatic and manual
  - Currently on hold due to funding issues
- US EPA method 2 – multiple parts, recently updated to account for issues encountered in some situations
- CEN low dust standard references ISO 3966
A Little Theory

- First described by Daniel Bernoulli in the 18th Century
- Bernoulli equation states that, given certain conditions, there is conservation of energy along a flow line
- There are different forms of Bernoulli’s equation depending on the conditions (and assumptions) made
- One of the simplest forms, and that most often used in emissions monitoring, is

\[
\frac{V^2}{2g} + \frac{p}{\rho g} = \text{Const}
\]

In effect two terms, one due to the kinematic energy and one due to the potential energy
Differential Pressure Equation

- P1 is a flow line, brought to a halt at P2
- Conservation of energy between point P1 and P2
- We actually measure the differential pressure $\Delta p$ between P1 and P3, taking P3 to be representative of P1

$$V = \sqrt{\frac{2\Delta p}{\rho}}$$
Why Go Back to Basics?

Because there are a number of assumptions implicit in this derivation

- Flow is brought to a halt at the stagnation point
- Two pressures are representative of the same flow line – need tube in correct orientation, with no swirl or turbulence
- Conditions on the stack flow, (Reynolds number)
- may be met theoretically, based on stack diameter and average flow.
- Actual conditions in the stack, such as obstructions, complex flow conditions, pulsed flow from fans, and the sample probe itself, may well cause the flow to become highly unstable and non-laminar.
- Remember the standard Pitot was developed for nice clean duct flows, not stack conditions
Further Conditions Required

- **Negligible air viscosity and compressibility**
  - There are corrections in the standard, but are they used, and are they valid for stacks?

- **Steady state conditions**
  - The tube must be in thermal equilibrium, temperature differentials will have an effect
  - Steady state flow – not always true

- **The ISO standards provide a large number of conditions that have to be met to enable measurements to be carried out**
  - How many of these are met in real conditions?
Calibration and Traceability

- Measurement methods require flow measurements to be traceable to standard L-Type Pitot
- The S Type Pitots require calibration to the standard Pitot
- Single point calibration, carried out in a laboratory, in a dry, clean well characterised duct.
- ISO 10780 states that tubes calibrated according to the procedure given will have an accuracy of 3% for velocities in the region 5 m/s to 50 m/s
  - Based on US studies
- No quantification of the effect of conditions that were not covered by the calibration, eg temperature
Review of Previous Studies

- There have been a number of studies on differential pressure tube performance
  - US EPA development of Method 2, F,G and H
    - Issues with wall effects, yaw, and highlighted calibration issues
    - S-type and 3D flow measurement
    - EPRI study- mainly on misalignment and flow direction
    - EPA collected papers – includes work which supports the single calibration point for S type tubes
  - Various studies in Europe
    - Swedish study
    - Dutch study on performance of ISO10780
    - Repeatability and reproducibility
  - Early work, including the original NPL paper on the ‘new’ ellipsoidal tip tube
    - Air ducts not stacks
The review of published research highlighted the following issues inter-alia:

- Wall effects
- Manual pressure reading bias
- Effects of pulsating pressure readings
- Use of assumed calibration factors for S Type Pitot tubes
- Calibration being performed at unrepresentative Reynolds numbers
- Displacement effect – transverse flow across tube
- Experimentally determined repeatability and reproducibility range from few percent to factors of four.
Potential Problems

- Pitot tubes are capable of giving adequate flow measurements, under certain stack conditions, provided care is taken in their use.
- Early papers, even when discussing measurements in clean ducts, stress the need for good quality control to ensure reliable results.
- Correct positioning, angle into stack, closeness to wall.
- Instrument condition, no blocked holes, undamaged and a note to certain test teams, don’t put it in stack gas so hot that it melts!
Pressure reading

- In general either an inclined manometer or digital meter are used to measure the differential pressure.
- Nearly all digital pressure meters used in the UK are used at the extreme low end of their range, leading to the potential for large uncertainties.
- Manometers are often calibrated under very different conditions from those found in use, and there are potential issues with user bias.
UK Survey

- Carried out a survey of STA members
- 29 organisations replied
- 360 Pitot Tubes, 41% L type, 56% S type (3% other types)
- 59% were routinely measuring stacks that have flows lower than stated in ISO 10780, and 38% made measurements in ducts smaller than covered in ISO10780
- All respondents who used digital pressure sensors were using them at the extreme low end, with many using them below 0.1% of their full scale range
**Summary of Key Issues**

- There are very defined limitations on the range of conditions in which differential pressure devices may be used with confidence – real conditions often exceed these.
- There is very little research work quantifying effects outside these conditions.
- How representative are calibrations of S-Type tubes for real stack conditions?
- A further area not covered in this talk are the newer technologies such as Laser Doppler Anemometry, and continuous systems.
Future Work?

Work programmes are proposed to
- Assess performance under stack conditions. Quantify the effects of non-standard conditions.
- Provide training and workshops on the issues related to the measurement of flow in stacks
- Improve the calibration and traceability of flow measurement, including use of new technologies
“It is regrettably an inescapable conclusion that in the present state of knowledge calibration factors of pitot-static tubes once conditions depart appreciably from such as may be called very good are by no means well defined or are easily determined” – original NPL paper describing the development of the L-Type ellipsoidal tube, 1962

‘they are rarely used in process streams but are used occasionally in utility streams where high accuracy is not necessary’

Applied Instrumentation in the Process industries, 1980