FLOW MEASUREMENT

For

Air Monitoring Users Group

NPL

3 December 2003

Why Are You Here? Why Am I Here?

- **To learn about NEL?**
- **To learn about air monitoring?**
- **To learn a bit about flow?**
- **To hear about measurement and traceability?**
- **How flow measurement relates to you?**

What is NEL ?   Who Am I ?

- **Established 1947**
- **Sister Laboratory to NPL specialising in mechanical engineering**
- **Privatised in 1995**
- **130 staff**
- **70% scientists and engineers**
- **A business of TUV Suddeutchland**
- **Most based in East Kilbride- Glasgow**
- **Some in Swindon**

What Do We Do ?

- **Largest interest is in Fluids measurement**
- **All aspects**
- **Flow**
- **Fluid property software**
- **Emmissions monitoring**
- **Power systems efficiency**
- **Consultancy and testing**

What Do We Do in Flow?

- **Custodian of UK national standards for flow and density measurement**
- **Consultancy in single and multiphase flows**
- **Calibration**
- **Testing and evaluation**
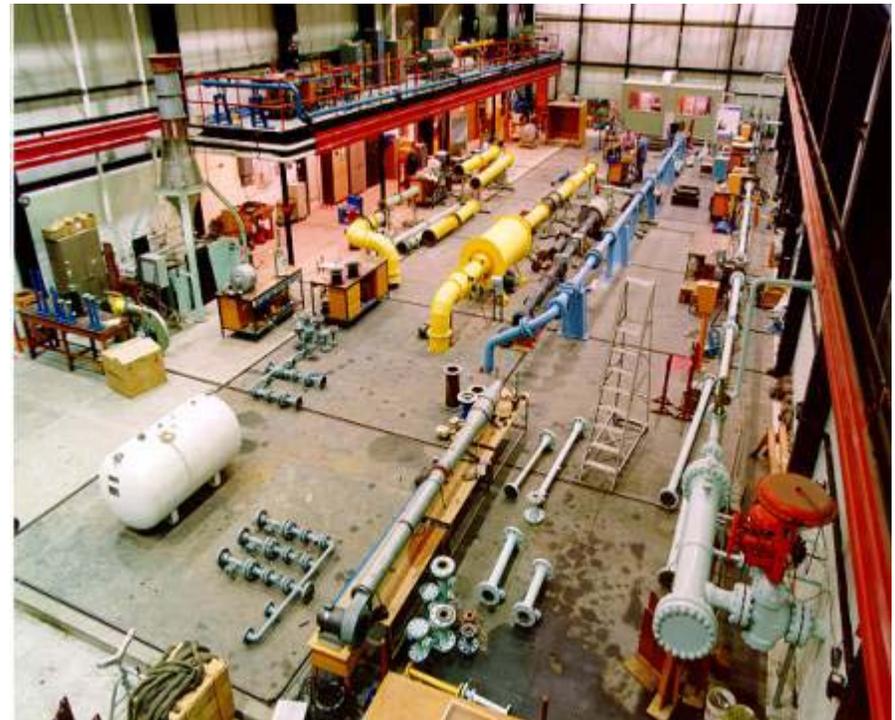- **Research**
- **CFD modelling**
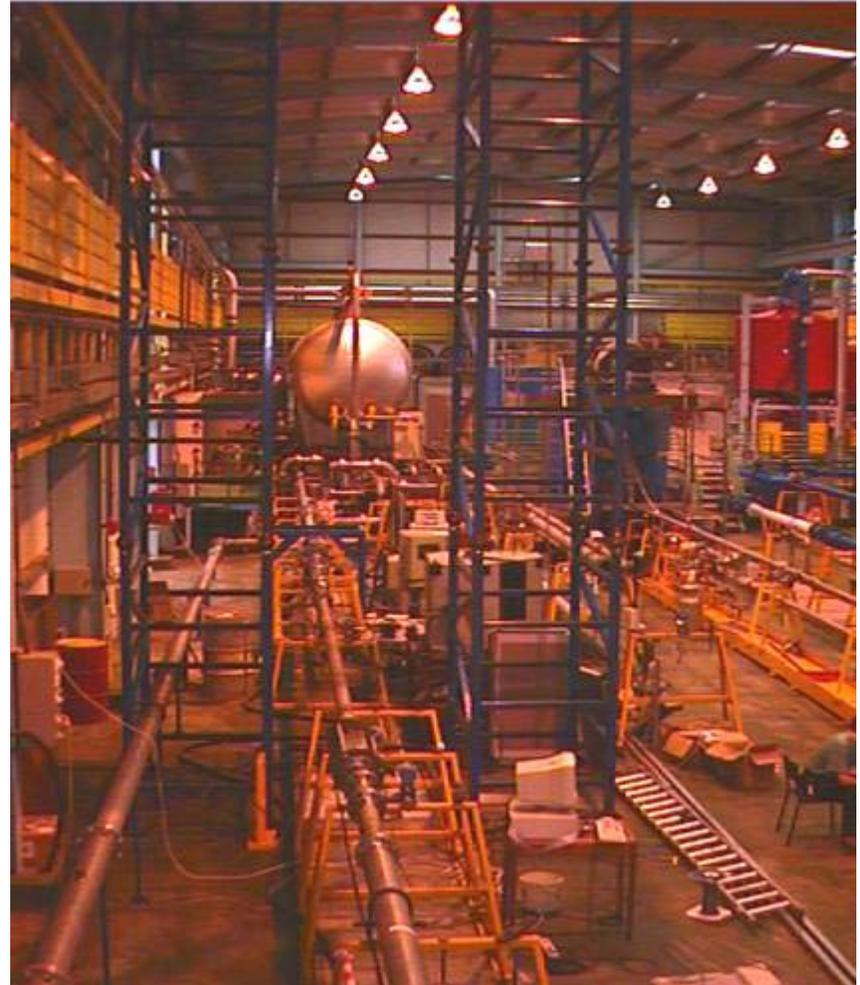
Water Flow Facilities

- **UK Primary Standard**
- **Flowrates from 7.2 l/h to 400l/s**
- **Up to 250mm pipe**
- **Heat meter and pattern approval facilities**

Gas Flow Facilities

- **UK Primary Standard**
- **Volumetric flowrates from 0.0003 l/s up to 4500 l/s**
- **Mass flowrates from 0.01 g/s up to 3.5 kg/s**
- **Pressures from ambient to 70 bar**
- **Wet gas flow facility operating up to 70 bar**

Oil Flow Facilities

- **Kerosene, gas oil, mineral oils**

- **Flowrates from 7.2 l/h to 200 l/s**

- **Ambient pressure to 5 bar gauge**

- **Temperature 5 to 40°C controllable to 1°C**

- **Viscosity 2.2 to 50 cSt**

Multiphase Flow Facilities

- **Multiphase flow of oil, water and gas**

- **Kerosene and crude oils**

- **Variable salinity of water**

- **Consultancy in multiphase flow and separation**

What Do We Do With Flowmeters

- **Flowmeter performance investigation**
- **Calibrations and test for industry**
- **Flowmeter type testing**
- **Basic device investigation**
- **Testing in support of pattern approval**

What Else

- **Erosion and valve testing**
- **Heat transfer**
- **Emissions monitoring**
- **Power station efficiency auditing**
- **Safety studies**
- **Fluid property database/software**
- **Rope and ambilical testing**
- **PPE bags and other testing**

What Flows?

- **A Fluid !**
- **What is a fluid?**
- **Liquid**
  - Incompressible (almost)
  - Keeps its own volume (and a free surface)
- **Gas**
  - volume kept by container
  - no free surface

Two Characteristics

- **Density = mass/volume**

$$\rho = \frac{m}{V}$$

  – Densities of gases and liquids are very different
  – Density varies with pressure and temperature

What Else? - Expansion

The thermal expansion is the change in volume caused by a change in temperature.

Compressibility is the decrease in volume caused by a unit change in pressure

- Oils must be considered if accuracy is needed
  - Relate volumes to one temperature
- Gases   must always be considered

Continuity of Mass

- **Conservation of mass requires that the mass flowrate is the same at all sections of a pipe**

- **For incompressible flow volume flowrate is constant**

- **If area changes the velocity must change**

- **Good basis to think about gas flows**

What Measurement is Required?

- **Point velocity**

- **Mean velocity**

- **Flowrate**

- **Total Quantity**

- **Mass**

- **Volume**

Point Velocity Measurement

- **To estimate total flow in a large system**
- **To measure variations within a duct or channel.**

  – In free gas - anemometer

  – In river or open channel - current meter

  – In pipes and ducts - insertion meter

How Do We Do Iit?

- **Differential pressure**
  - Orifice plate; Nozzle; Venturi
- **A bucket and watch?**
  - Positive displacement meter
- **Turbine meter.**
- **Vortex meter**
- **Coriolis meter**
- **Ultrasonic meter**

Take a Case Study

Flare Gas Measurement

Measurement of Flare Gas

- **Velocity range (cm/s up to > 100 m/s)**
- **Process Temperatures: -70 to 150°C**
- **Low Pressure drop required**
- **Line sizes: 8" - 72" up to 3m possible**
- **'Dirty gas' (Oil, H_2O, scale, salt…etc.)**
- **Installation restraints (esp. retrofitting)**
- **Calibration:**
  - No traceability chain
  - Laboratory calibrations - type testing
  - In-situ (e.g. gas tracer, pitot traverse)

Flare Gas Metering Methods

- **Thermal Mass meters**
- **Differential pressure meters ('Pitots')**
- **Ultrasonic meter**
- **Insertion meters (Turbines, Vortex)**
- **Tracer techniques**

- **Estimation techniques (no dedicated meter):**
  - 'Flare Spectacles' (flame height 'measure' of flow rate)
  - Modelling packages utilising p & T meas.
  - Mass Balance (still most commonly used)
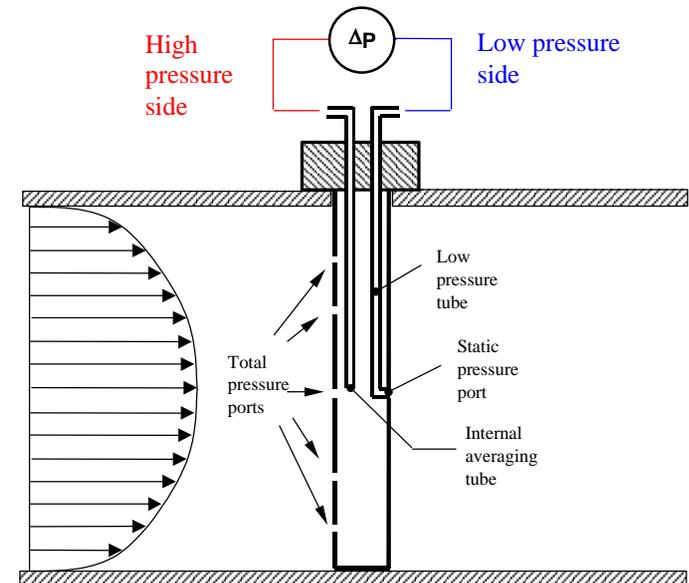 - High uncertainty in these techniques

Thermal Mass Probes

- **Work on Heat Transfer principle**
  - $\rho U \propto$ Electrical power input
- **Advantages:**
  - Direct output of mass flux (kg/m²s)
  - High turndown (> 100:1)
  - Low pressure drop
  - Sensitive to low flows (mm/s)
  - Relatively Cheap
- **Disadvantages:**
  - Very sensitive to Gas composition and Line conditions
  - Prone to fouling
  - Sensitive to liquid droplets
  - Multi-point measurements decrease uncertainty, but add to cost

$$Power = \Delta Tk \left[C + D \left(\frac{\rho U d}{\mu} \right)^n Pr^{0.33} \right]$$

Differential Pressure Meters

- **Differential pressure meter**
  - Volume flow $\propto$ dp
  - Multi-point measurement system
- **Advantages:**
  - Takes an 'average' of flow
  - Low system pressure losses
  - Relatively cheap
- **Disadvantages:**
  - Not practical for low flow rates (low dp)
  - Small turndown (typically 10:1 of flow)
  - Clogging in dirty gases
  - Doesn't measure true average

$$\sqrt{dp_{annubar}} \neq \frac{\left(\sqrt{dp_1} + \sqrt{dp_2} \ldots \sqrt{dp_n}\right)}{n}$$

Averaging Pitot

Ultrasonic Meters

- **Works on time-of-flight principle**
  - Velocity $\propto$ time
- **Advantages:**
  - Widest turndown (2500:1 quoted)
  - U (hence q_{vol}) insensitive to P & T
  - Can determine q_m from measurement of c using correlation
- **Disadvantages:**
  - Relatively high cost
  - Less accurate at low velocity (< 0.2m/s)
  - Doesn't measure mean flow - must correct for velocity profile (calibration, ideally)
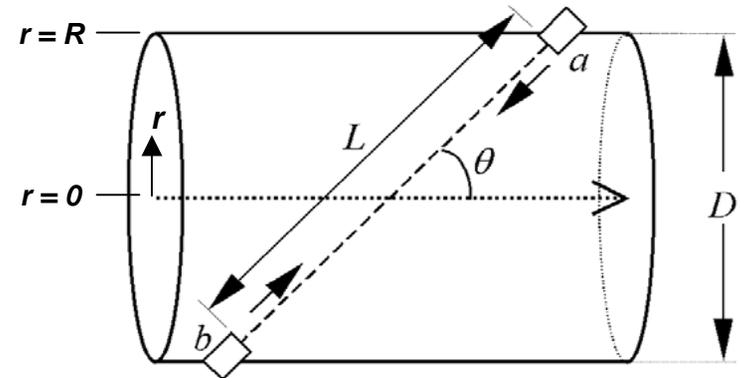
$$\overline{U}_p = \frac{L}{2\cos\theta}\left[\frac{t_{ab} - t_{ba}}{t_{ab}t_{ba}}\right]$$

$$c = \sqrt{\gamma R_0 T / M_w} \qquad \gamma = f(T, p)$$

$$\overline{U}_m = k\left[\frac{t_{ab} - t_{ba}}{t_{ab}t_{ba}}\right]$$

Hybrid Acoustic/dp Method

- **Used in USA (Acid Rain program)**
- **Same theory as Ultrasonic: $U_p = f(t)$**
- **Signal - air blast (10kHz)**
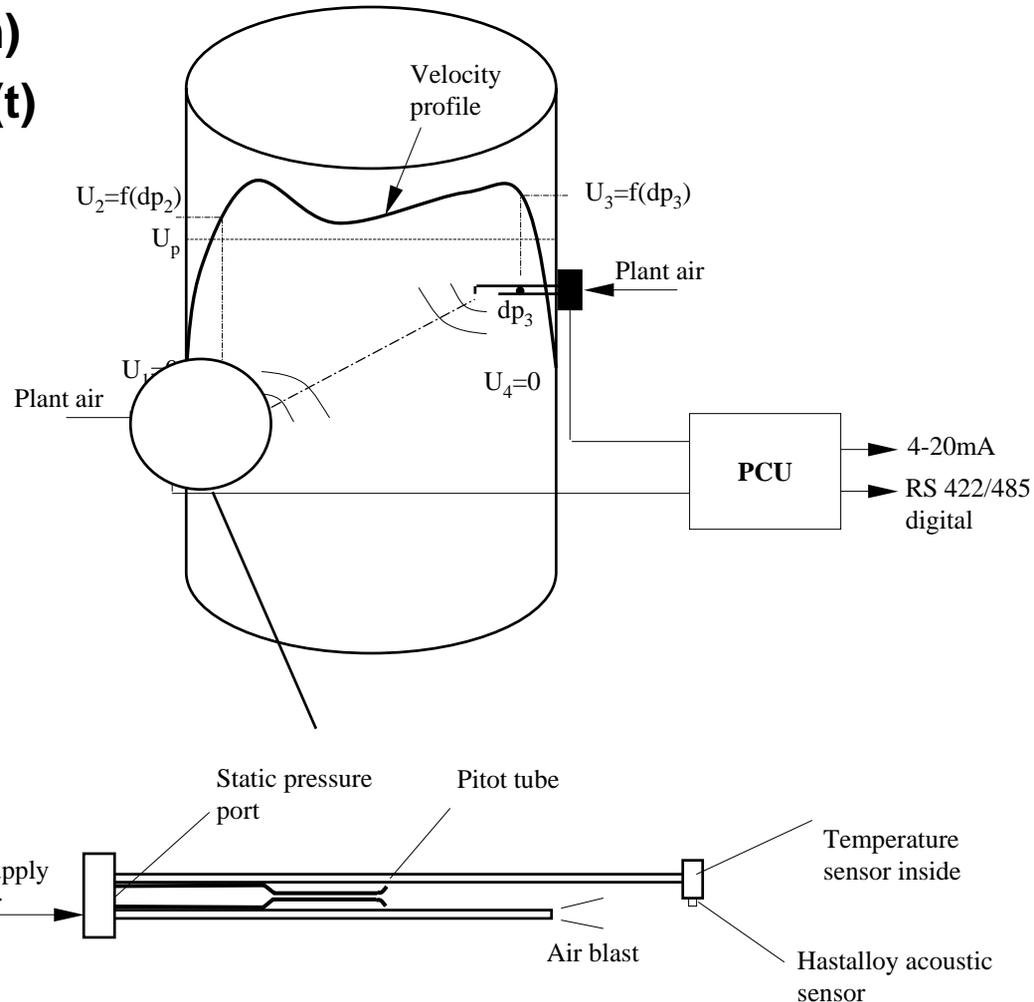- **Pitot tubes (one on each probe)**
  - Determine k-factor
  - But only 2 dp measurements
- **Advantages:**
  - Larger ducts
  - No beam produced
 - Inherent purge system
  - Already being used in CEMS
- **Disadvantages:**
  - Limited top end ?
  - Noise effects
  - Robust enough ?

Velocity profile

$U_2 = f(dp_2)$ $U_3 = f(dp_3)$

U_p

Plant air

dp_3

$U_4 = 0$

Plant air

PCU   4-20mA   RS 422/485 digital

Static pressure port   Pitot tube

Supply air

Air blast

Temperature sensor inside

Hastalloy acoustic sensor

Tracer Techniques

- **Inject 'Tracer' into flow**
- **Time of flight**
  - Inject Chemical , Radioactive or Thermal tracer as a short pulse
  - Detect passing two detectors
  - Time passage between detectors
  - Measure distance between detectors.
- **Problems**
  - Need ID of pipe
  - Need length
  - Need mixing and good flow profile
  - Acceptance of tracer
- **Alternative: Dilution**
  - Constant measured injection
  - Sample from downstream
  - Concentration = flow
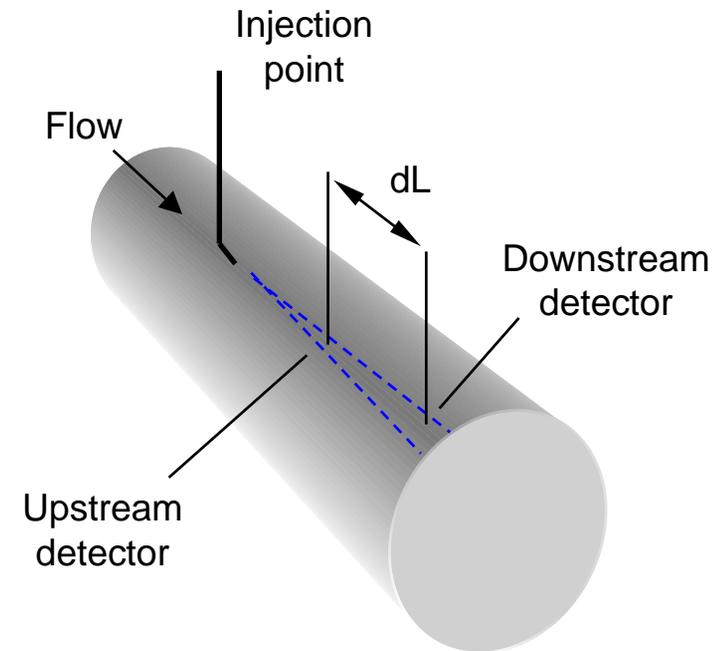
$$\overline{U} = \frac{dL}{dt}$$

The NMS

- National Measurement system
- Co-ordinated / funded by DTI
- Within UK the NMS is operated by different suppliers
- NPL is by far the largest with many programmes
- LGC and NWML also have one programme each
- NEL operates the 'FLOW Programme'

What Do We Want From You?

- **We need the programme relevant to UK industry**
- **We want to broaden the R&D base**
- **What are your problems**
  - Instruments
  - Traceability
  - Standards
- **Let us know**
  - Directly
  - Or through this club
- **Ideas Needed now!**

Discussion?

- Let us have your ideas
- Contact through:
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- rpaton@tuvnel.com
- jsattary@tuvnel.com