Opacity & Dust Concentration Measurement
BASICS
Dust Measurement

Humidity
- Dry Stack
  - T > Dew Point
- Wet Stack
  - T ≤ Dew Point

Gas Temperature (Stack)
- normally < 450°C
- (max. 1000°C)

Stack Size
- (Ø ≤ 18 m)

Particulate Measurement
- Triboelectric Particle Counter
- Transmission
- Scattered Light
- β-Absorption

Particle Conditions
- Concentration
- Color
- Shape
- Size

Ambient Situations
- Temp. (-20 ...+60°C)
- Hazardous?

In-Situ Extractive

DURAG VEREWA

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## Methods of Particulate Measurement

<table>
<thead>
<tr>
<th>Type</th>
<th>Procedure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>extractive</td>
<td>discontinuous</td>
<td>Gravimetric metering with filter head (Reference method VDI 2066)</td>
</tr>
<tr>
<td>extractive</td>
<td>discontinuous</td>
<td>Radiometric metering</td>
</tr>
<tr>
<td>extractive</td>
<td>continuous</td>
<td>Stray light metering in bypass systems</td>
</tr>
<tr>
<td>in-situ</td>
<td>continuous</td>
<td>Transmission metering</td>
</tr>
<tr>
<td>in-situ</td>
<td>continuous</td>
<td>Stray light metering</td>
</tr>
<tr>
<td>in-situ</td>
<td>continuous</td>
<td>Triboelectric method</td>
</tr>
<tr>
<td>in-situ</td>
<td>continuous</td>
<td>Particle counter (Transmission)</td>
</tr>
</tbody>
</table>
Filter Head Unit to VDI 2066 as Reference Procedure

1. Nozzle
2. Filter head (2-stage)
3. Elbow measuring
4a. Suction pipe
4b. Heated suction pipe with temperature measuring in the gas flow and regulation of the selected temperature
5. Stop valve
6. Condensate separator
7. Drying tower
8. Volume flow meter
9. Gas volume meter with temperature and pressure
   Regulator for suction and air feed
11. Suction pump
12. Temperature measuring
13. Pressure
14. Exhaust gas composition
15. Flow speed indicator (Prandtl pipe)
16. Filter preheating device
Calibration of Dust Meters (regarding VDI 2066)

Irregular Dust Distribution in the Cross Section for Metering

Arrangement of Measuring Spots of a Grid Metering in the Flue Gas Channel:

- in a rectangular cross section
- in a round cross section
Calibration of Dust Meters (regarding VDI 2066)

Influence of the Suction Speed on Concentration, Mass Flow and Granulation

<table>
<thead>
<tr>
<th>Suction speed</th>
<th>Concentration</th>
<th>Granulation</th>
<th>Dust mass flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>correct</td>
<td>correct</td>
<td>correct</td>
<td>correct</td>
</tr>
<tr>
<td>too low</td>
<td>too dense</td>
<td>too coarse</td>
<td>too small</td>
</tr>
<tr>
<td>too fast</td>
<td>too low</td>
<td>too fine</td>
<td>too big</td>
</tr>
</tbody>
</table>
Dust Monitoring using Tribo Electrical Principle
Measuring Principle

\[ i = f(s, v, k, l) \]

- \( s \) = Dust Concentration
- \( v \) = Gas Velocity
- \( k \) = Electrostatic Charge
- \( l \) = Length of Probe
D-RX 250

Combined Sensor

for

Dust Concentration
Volume Flow
Temperature
Pressure

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combustion and environment
Measuring Principles

- Dust monitoring according to the tribo electric measuring principle
- Volume flow Monitoring according to the differential pressure principle
- Temperature monitoring with a Pt100 resistance thermometer
- Absolute pressure transducer
# Flow-corrected Tribo

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive, low LDL</td>
<td>Only useful up to 500 mg/m³</td>
</tr>
<tr>
<td>Single flange, simple installation</td>
<td>Max. 1 m Measurement Probe: representative measurement in larger stacks?</td>
</tr>
<tr>
<td>4 signals from one probe:</td>
<td>Interferences from:</td>
</tr>
<tr>
<td>- Dust Concentration</td>
<td>- Particle Size</td>
</tr>
<tr>
<td>- Volume / Flow</td>
<td>- Particle Specific Weight</td>
</tr>
<tr>
<td>- Temperature</td>
<td></td>
</tr>
<tr>
<td>- Pressure</td>
<td></td>
</tr>
<tr>
<td>Low maintenance (only at low concentration)</td>
<td>High maintenance (at medium to high concentration)</td>
</tr>
<tr>
<td>Reports dust measurement signal on normalized basis, wet</td>
<td>Cannot be used:</td>
</tr>
<tr>
<td></td>
<td>- in stack gases at or below dew point</td>
</tr>
<tr>
<td></td>
<td>- after Electrostatic Precipitators</td>
</tr>
<tr>
<td></td>
<td>Requires stack gas velocity of min. 5-6 m/sec.</td>
</tr>
<tr>
<td></td>
<td>Complex reference calibration based on two variables</td>
</tr>
</tbody>
</table>
Dust Monitoring using Optical Principles
LIGHT TRANSMISSION
Transmission System

Transmission

Beer-Lambert Equation

Transmission

Opacity %

$O = 1 - T$

$O[\%] = (1 - T) \times 100\%$

Extinction (Optical Density)

$E = \lg \left( \frac{1}{T} \right) = \frac{k}{2.3} \times c \times l$

$c = \frac{1}{l} \times \frac{2.3}{k} \times \lg \left( \frac{1}{T} \right)$

$c = \frac{1}{l} \times \frac{2.3}{k} \times E$

Dust Concentration in mg/m³

(Calibration reg. VDI 2066 or other standard method)

$I_0$ - Source Intensity (emitted light)

$I$ - Received Intensity (received light)

$K$ - Extinction Constant

$c$ - Concentration

$l$ - Path Length

with temperature compensation in the measuring head:

mg/Nm³

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Light source

- High energy solid-state green LED with a wavelength of 530nm.
- Automatic aging and temperature compensation. Emitted light intensity is continuously stabilized.
- Insensitive to ambient light due to 2kHz light modulation.
- Homogenous light spot allows thermal duct movement.
Spectral Distribution of Light Sources

Spectral Sensitivity of DURAG Super Wide Band Diode vs. narrow-band LED’s

- White light LED
- Blue Gallium Nitrite diode in connection with a fluorescent layer
- Spectral response 400-700 nm
- Life time >5 years
- No temperature shift

- green LED
- red LED

Intensity 100%
max. 10%

400 700 Wave Length [nm]

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## Optical Transmission

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measures large stacks representative</td>
<td>LDL based on stack diameter, questionable accuracy in smaller stacks</td>
</tr>
<tr>
<td>Lowest cost alternative for continuous dust monitoring in stacks</td>
<td>Two flange installation, optical alignment</td>
</tr>
<tr>
<td>2 signals from one instrument:</td>
<td>Interferences from:</td>
</tr>
<tr>
<td>- Dust Concentration</td>
<td>- Particle Size (strongly)</td>
</tr>
<tr>
<td>- Opacity</td>
<td>- Particle Color (some)</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>- Particle Specific Weight</td>
</tr>
<tr>
<td>Useful for very high temperature stack gas</td>
<td>Reports measurement signal on actual basis, no normalization or correction</td>
</tr>
</tbody>
</table>
LIGHT SCATTERING
Light Forward Scattering, Optical Principle

- Light trap
- Emitted light
- Stray light
- Measuring volume
- Fail safe shutter (optional)
- D-R 300-40
- Control display
- Purge air fan
- Waste gas
- Line recorder

A second light trap is required for smoke spot number (soot) measuring.
Light Backward Scattering, Optical Principle

- The collimated and modulated light beam of a laser Emitting Diode (1) crosses the Measuring Volume (2); the dust particles are scattering light mostly in the forward direction.

- This “stray light” is proportional to the dust concentration and is collected by an Objective (3) and transferred via a Fiber Optic (4) to the Receiver Diode (5).

- The signal is processed by a highly sensitive circuit which calculates the final measurement value. The result can be calibrated according to the German regulation VDI 2066 (or any other standard method) into dust concentration [mg / m³].
# Light Scattering

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measures in small to very small stacks</td>
<td>Not useful for concentrations &gt;300 mg/m³</td>
</tr>
<tr>
<td>Extremely low LDL: 50 µg/m³</td>
<td>Interferences from:</td>
</tr>
<tr>
<td></td>
<td>• Particle Size (some)</td>
</tr>
<tr>
<td></td>
<td>• Particle Color (very strong: factor 20 between white and black)</td>
</tr>
<tr>
<td></td>
<td>• Particle Specific Weight</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>Not useful in stack gases at or below dew point</td>
</tr>
<tr>
<td>Simple installation at stack gas temperature</td>
<td>Complicated installation at stack gas temperatures &gt;400°C</td>
</tr>
<tr>
<td>&lt;300°C</td>
<td>Area of measurement only 80 to 280 mm inside from the stack wall: representative measurement?</td>
</tr>
<tr>
<td></td>
<td>Reports measurement signal on actual basis, no normalization or correction</td>
</tr>
</tbody>
</table>
WET STACK MONITORING

(STACK GAS BELOW DEW POINT)
EXTRACTIVE METHOD

Heated By-Pass
### Advantages
- Measures in every stack gas, wet or dry (at, below, or above dew point)
- Single flange installation
- Includes Dilution System for high humidity content
- Instantaneous values

### Disadvantages
- Single sampling point, installation at laminar flow area
- Requires automatic isokinetic adjustment, if stack gas velocity varies $>\pm 15\text{m/sec.}$
- Second highest investment for continuous dust monitoring
Extractive Method
BETA ABSORPTION
VEREWA F-904 Emission / Process Dust Monitor

The Smart Solution for Wet Stacks, BFG monitoring, and varying Fuels.
Extractive Beta Absorption, Operating Principle

Stack

Sample Probe Nozzle

Valve

Pressurized Air

Cover Foil (option)

Tape Printer (option)

Filter Advance Stepping Motor

Take-up Reel

C-14 Source

C-14 Source (option)

Filter-Adapter

Counter Tubes

PLC

4-20mA STATI

Sample Cooler with Automatic Drain

Supply Reel

Total Flow Venturi Nozzle

Total Flow Vacuum Pump with Bypass Controller

4-20mA STATI

Exhaust

Dilution Flow Venturi Nozzle

Smart Solutions for Combustion and Environment DURAG GROUP
## Extractive Beta-Gauge

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measures in every stack gas, wet or dry (at, below, or above dew point)</td>
<td>Single sampling point, installation at laminar flow area</td>
</tr>
<tr>
<td>LDL and range easily variable through adaptation of sampling cycle</td>
<td>Requires automatic isokinetic adjustment, if stack gas velocity varies &gt;±15m/sec.</td>
</tr>
<tr>
<td>No interferences by any particle condition</td>
<td>Frequent maintenance required</td>
</tr>
<tr>
<td>Single flange installation</td>
<td>Frequent use of consumables (filter tape)</td>
</tr>
<tr>
<td>Sample line length up to 50 m, instrument can be installed in analyzer shelter</td>
<td>Highest investment for continuous dust monitoring</td>
</tr>
<tr>
<td>Collects sample, heavy metal analysis possible</td>
<td></td>
</tr>
<tr>
<td>Low emission, long-life radioactive emitter, no license required</td>
<td></td>
</tr>
<tr>
<td>Reports concentration signal normalized, dry basis</td>
<td></td>
</tr>
</tbody>
</table>
## Comparison of Emission Particulate Monitoring Methods

<table>
<thead>
<tr>
<th>Condition</th>
<th>Heated Bypass</th>
<th>β-GAUGE</th>
<th>Transmission</th>
<th>Scattered Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration High (&gt; 200 mg/m³)</td>
<td>ok</td>
<td>good</td>
<td>good</td>
<td>ok</td>
</tr>
<tr>
<td>Concentration Low (&lt; 100 mg/m³)</td>
<td>good</td>
<td>good</td>
<td>bad</td>
<td>good</td>
</tr>
<tr>
<td>Dry Stack (above dew point)</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Wet Stack (below dew point)</td>
<td>excellent</td>
<td>excellent</td>
<td>very bad</td>
<td>very bad</td>
</tr>
<tr>
<td>Humidity (non-condensing) constant</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Humidity (non-condensing) varying</td>
<td>good</td>
<td>good</td>
<td>bad</td>
<td>very bad</td>
</tr>
<tr>
<td>Stack Diameter Large (&gt; 3 m)</td>
<td>ok</td>
<td>ok</td>
<td>good</td>
<td>bad</td>
</tr>
<tr>
<td>Stack Diameter Small (&lt; 3 m)</td>
<td>good</td>
<td>good</td>
<td>ok</td>
<td>good</td>
</tr>
<tr>
<td>Particle Size constant</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Particle Size varying</td>
<td>bad</td>
<td>good</td>
<td>not ok</td>
<td>bad</td>
</tr>
<tr>
<td>Particle Color constant</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Particle Color varying</td>
<td>very bad</td>
<td>good</td>
<td>not ok</td>
<td>very bad</td>
</tr>
<tr>
<td>Particle Density constant</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Particle Density varying</td>
<td>bad</td>
<td>good</td>
<td>not ok</td>
<td>bad</td>
</tr>
<tr>
<td>Gas Velocity constant</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Gas Velocity varying (&lt; ± 10-15 m/s)</td>
<td>bad</td>
<td>acceptable</td>
<td>good</td>
<td>good</td>
</tr>
</tbody>
</table>
TOTAL MERCURY ANALYZER
for Stack Monitoring
# Basic Features

<table>
<thead>
<tr>
<th>Principal</th>
<th>CVAAS (Cold Vapor Atomic Absorption Spectroscopy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalyst</td>
<td>The HM 1400 TRX is equipped with a solid catalyst which converts ionic Mercury into elemental.</td>
</tr>
<tr>
<td>Range</td>
<td>0-45…0-500 µg/Nm³</td>
</tr>
<tr>
<td>Benefits</td>
<td>No Preconcentration,</td>
</tr>
<tr>
<td></td>
<td>Real Continuous Measurement,</td>
</tr>
<tr>
<td></td>
<td>Maintenance Interval, 6 Months,</td>
</tr>
<tr>
<td></td>
<td>low costs of operation</td>
</tr>
</tbody>
</table>
UV Detector – SO$_2$ Interference

Issue: SO$_2$ Interference

- 50 mg/m$^3$ SO$_2$
- 30 mg/m$^3$ SO$_2$
- 10 mg/m$^3$ SO$_2$

SO$_2$, Sulfurdioxide
Hg, Mercury

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UV Detector – Dual Beam

- Signal Output: 3.25µg/m³
- PLC
- Differential Signal
- Photodiodes (6yrs Lifetime)
- Mercury Trap (1yr Lifetime)
- Measuring Cell
- Reference Cell
- GAS IN
- LP UV Lamp (6yrs Lifetime)
- GAS OUT

Evaluating the differential signal eliminates SO₂ interference!
Calibration/Span check, Total Mercury

- Sample Probe
- Heated Sample Line
- Vapouriser
- Carrier Gas
- HM1400 Certified Mercury Calibration Gas to the CEM
- Peristaltic Pump
- Calibration Solution
- Mass Flow Controller
- MFC

Certified ionic Mercury standardsolution

Calibration of complete system
Installation incl. Calibrator
SUMMARY - HM 1400 TRX

1: Total Mercury Measurement (Ionic + Elemental)
2: Optional Ionic + Elemental Speciation
3: No wet chemicals for normal operation
4: True Continuous Measurement – no concentration steps
5: Designed as a CEM from the outset
6: Elimination of interferences
7: Lower maintenance & running costs – direct aim of design
GAS FLOW MONITORING
D – FL 100

Differential Pressure Probe

MULTI-PITOT
Overview

- Flow rate measurement with a probe by the principle of differential pressure method
- Evaluation with the Microprocessor Unit D-FL 100-10 (optional)
- Adjustable parameters
- Load-independent current for line recorder and indicator instrument
Measuring Principle

Cross Section of the Differential Pressure Bar

\[ V = A \cdot k \sqrt{\frac{2 \Delta P}{\rho}} \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V )</td>
<td>volume flow</td>
<td></td>
</tr>
<tr>
<td>( A )</td>
<td>cross section</td>
<td></td>
</tr>
<tr>
<td>( k )</td>
<td>correction factor</td>
<td>0.5 ... 0.7</td>
</tr>
</tbody>
</table>

**Impact Pressure**

**Reference Pressure**

**Shedding Point**
D – FL 200 / 220

Ultrasonic Flow Monitor
D-FL 200 Flow Meter

- Ultrasonic measuring system
- Principle of differential propagation time
- In-situ measuring directly in the flue gas flow
- Continuous measurement
- No interference with the medium
- Automatic zero-point and reference-point control
- Programmable via the evaluation unit’s keys or via PC
- Load-independent current for line recorder and indicating instrument
Principle of Ultrasonic Flow Measurement I

Sensor (mit Strömung)
Downstream Sensor

Impulsgeber
Tracker Unit

Steuer und Messelektronik
Control and Measuring Electronics

Mustererkennung
Pattern Recognition

Auswerteinheit
Evaluation Unit

Sensor (gegen Strömung)
Upstream Sensor

\[ c + u \cdot \cos \alpha \]

\[ c - u \cdot \cos \alpha \]
Applications of D-FL 100 and D-FL 200

Ultrasonic
- cold stacks (below dew point)
- aggressive gases
- wet stacks
- very low velocity

Multi-Pitot
- extremely hot stacks
- very small stacks
- extremely high absolute pressure
- medium sized stacks
- high velocity
- medium sized stacks
- high dust load
- medium velocity
- aggressive gases
- hot gases
- big stacks

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THANK YOU FOR YOUR INTEREST

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