



Performance Evaluation of Inferential Devices

Adam Lomax, EffecTech Group
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Introduction

- A new generation instruments are being used for natural gas quality measurement.
- These instruments have complex algorithms which infer a set of gas properties by direct measurement of a set of other gas properties.
- Often these methods are proprietary and are not published by the manufacturers.

Introduction

This presentation will describe a new method to assess the performance of these instruments using a **black box** approach which does not require knowledge of the measurement equation.

Natural gas quality



- Metering
 - both the heating value and density of natural gas are critical for fiscal metering.
- Interchangeability / compatibility
 - ensures that gas will burn correctly in appliances.
- Environmental
 - for the monitoring of emissions
- Process control
 - ensures that plant and equipment operate as efficiently as possible.

Performance evaluation

- Gas quality measurements are vital for reducing the probability of long-term mismeasurements which can lead to extremely large financial discrepancies.
- Incorrect measurement could lead to
 - costing either the buyer or the supplier ££millions
 - loss of good will
 - possible legal consequences and knock-on effect for operations
- Undertaking a performance evaluation reduces the financial risks caused through mismeasurement of the gas passing through the metering point.

Gas quality measurement - current approach

- Typically the major components are measured using a process gas chromatograph using a simple response/amount fraction relationship.
- Major components typically
 - nitrogen (usually including trace amounts of oxygen and argon)
 - carbon dioxide
 - all alkane isomers with 5 or fewer carbon atoms
 - a composite peak of all hydrocarbons with more than 6 carbon atoms (C_6+)
- Properties are calculated from composition using an appropriate standard

Calorific Value Determination Devices (CVDD)



ISO 10723 performance evaluation - Current approach

- Collect data from reference gases (typically seven points for each specified component defined in the analytical method)
- Use the data to construct a model of the measurement
- Use the model to simulate the “measurement” of 1000s of hypothetical gases
- Compare the true composition to the actual simulated composition
- Use the simulated data to assess errors, mean error (bias) and uncertainties associated with the instrument
- 2nd step is not possible with inferential devices

Inferometers

- Use multiple sensors to measure properties of the gas such as
 - Speed of sound
 - Thermal conductivity
 - Infrared absorption
 - Density
- This sensor data along with directed measurement of certain components (typically carbon dioxide) are subjected to a correlative evaluation to provide the properties required

New approach – Dynamic method

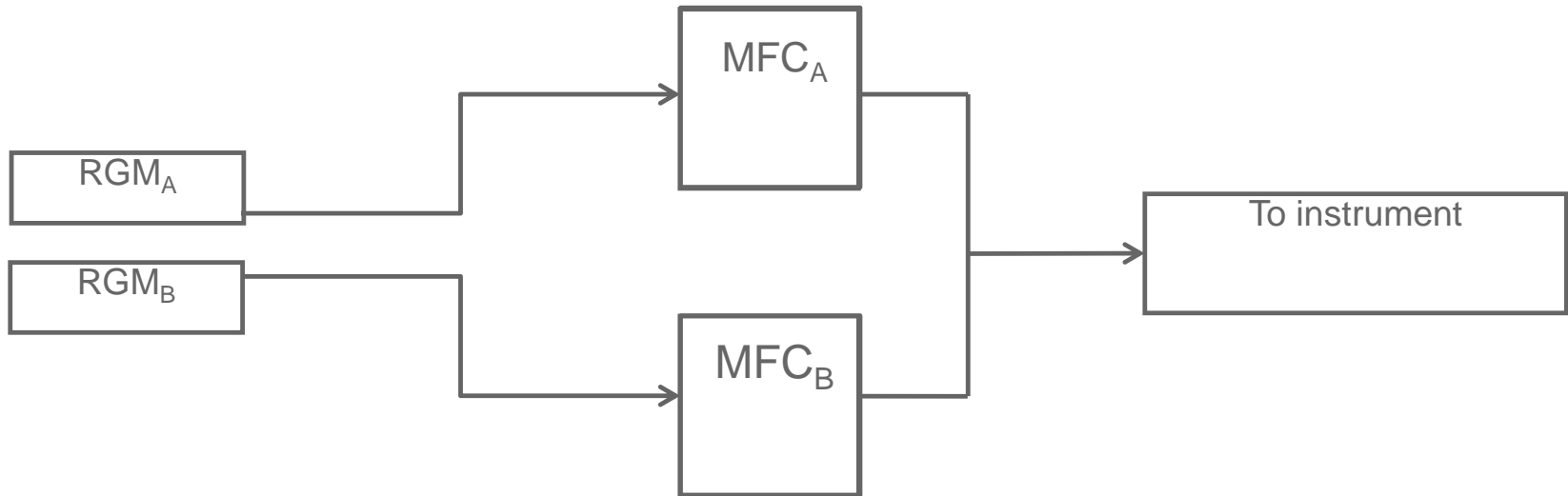
- Inferential devices have very rapid response times
 - so it is possible to directly measure a large number of reference gases in a short time.
- A large number of dynamic reference gases can be produced using dynamic blending of two (2) reference gas mixtures in cylinders.
 - it is possible to measure over 600 reference gases generated dynamically by this method in a day
- Compare properties/composition calculated for the dynamic gas to the properties/composition measured by the device
- This approach is currently under development as an ISO standard (ISO/AWI 23568 - Part 2) convened by Adam Lomax (EffecTech)

Implementation

- EffecTech has been using a dynamic gas dilution system within its accredited laboratory
- This system uses thermal mass controllers to generate the dynamic reference gases.
- Thermal mass controllers are typically calibrated based on a single gas, so experimentally derived gas correction factors are needed to correct the flows.
- EffecTech has now constructed a portable version of this system.



Dynamic blending - schematic



Portable dynamic blending system



Dynamic reference gases

- Reference gases can be generated by blending two different reference gases.
- ISO 6145 - Part 7 - *Preparation of calibration gas mixtures using dynamic volumetric methods* describes how to generate dynamic reference gases and calculate the amount fraction of components when blending two reference gases

Dynamic reference gases

- A dynamic reference is generated by setting the flow of each reference gas, or a reference gas and pure methane.
- The gas is measured using the instrument and the measured values recorded.
- The flows are then corrected using gas correction factors and a linearisation model. The corrected flows then allow the amount fraction of each component in the dynamic reference gas to be calculated.

Dynamic reference gases

$$\varphi_A = \frac{\varphi'_A q_{V,M} + \varphi''_A q_{V,B}}{q_{V,M} + q_{V,B}}$$

where:

φ'_A and φ''_A is the amount fraction of component A in RGM M and RGM B

φ_A is the amount fraction of component A in the DRGM

$q_{V,M}$ and $q_{V,B}$ are the flow rates of RGM M and RGM B

Note: Volume and mole fraction will be used interchangeably as the variability of compressibility at atmospheric pressure is very small and any systematic error introduced will be insignificant.

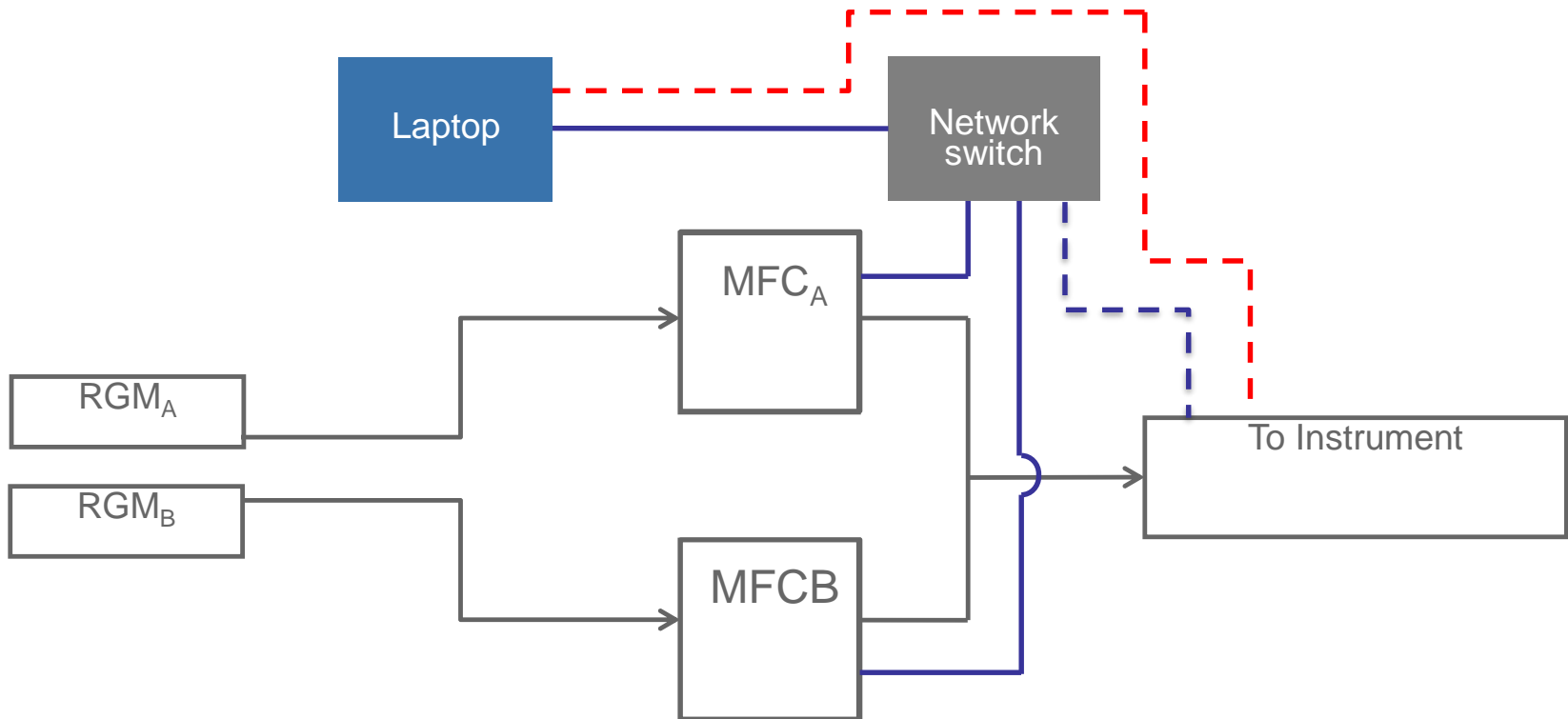
Dynamic reference gases

- Physical properties can be calculated from blended mixture composition using an appropriate standard
- This allows the errors inherent in the system to be assessed

Software design

- This process must be automated, so that data collection and flow control are synchronised.
- This can only be achieved if the software controlling the flows can also collect the data, so bespoke software must be written for each instrument.
- Data typically is collected via Modbus.

Control and instrumentation



Reference gas design

- Must produce sensible “natural gas” analogues so that amount fraction decreases with carbon number
- Must provide a range component ratios
- Must cover range of possible compositions through the measurement point
- Hydrocarbon dewpoint must also be taken into consideration.

Reference Gas selection

- Reference gases should be selected to cover the range required

typical range used		
component	min	max
nitrogen	0.01	12
carbon dioxide	0.01	8
methane	63.6	100
ethane	0.0	14
propane	0.0	8
iso-butane	0.0	1.2
n-butane	0.0	1.2
neo-pentane	0.0	0.15
iso-pentane	0.0	0.35
n-pentane	0.0	0.35
n-hexane	0.0	0.35

Set up considerations

- A number of dilution steps should be selected
 - EffecTech's trial, 100 dilution steps were used
- The time required for the instrument to settle must be checked
 - this can be achieved by measuring the time taken to reach a stable reading after changing flows
- The operating range of the MFC should also be taken into consideration

Software interface

MFC control

MFC Set up

Connect

MFC A

☒ Monitor/control

IP: 192.168.1.106

Connected 192.168.1.106

Mode : Digital (Modbus)

Current flow : 14.8 SCCM

Current set point: 14.8 SCCM

New set point : 10

Set flows

Set flows to Zero

Temperature : 37.72 °C

MFC B

☒ Monitor/control

IP: 192.168.1.107

Connected 192.168.1.107

Mode : Digital (Modbus)

Current flow : 485.1 SCCM

Current set point: 485.2 SCCM

New set point : 490

Set flow 1

Set flow 2

Temperature : 38.28 °C

Instrument Set up

MFC A Gas : Ref Gas A

MFC B Gas : Ref Gas B

Filename : A vs B 100 steps 60 sec

Path : C:\PRG data

Browse

Steps : 100

Measurement time (min 30s) : 60 seconds

Instrument :

Coms : Ethernet

Ethernet RS-232

Instrument IP : 192.168.1.99

Connect

Instrument Data - Running

Current step time elapsed: 6/60 seconds | Steps completed : 1/100 (1.10%)

Reg#	Value	Description
1	871.334	Upper Heating Value kJ/mol
2	36.9531	Upper Heating Value MJ.m3
3	41.8354	Upper Heating Value MJ.kg
4	788.047	Lower Heating Value kJ/mol
5	33.4209	Lower Heating Value MJ.m3
6	37.1131	Lower Heating Value MJ.kg
7	0.99723	Compressibility
8	43.1868	Upper Wobbe index MJ.m3
9	38.9864	Lower index MJ.m3
10	0.73487	Density ratio
11	0.98052	Density base conditions
12	21.2337	Molar mass g/mol
13	85.137	Methane number
14	7.54071	Amount fraction CO2 %mol/mol
15	74.1458	Amount fraction CH4 %mol/mol
16	6.81332	Amount fraction N2 %mol/mol
17	8.1419	Amount fraction C2H6 %mol/mol
18	2.35175	Amount fraction C3H8 %mol/mol
19	0.48312	Amount fraction nC4H10 %mol/mol

Tx:04593 Rx:04593 Com errors:00000

Start Stop Close

Data

- Data is saved every 5 seconds
- The average of the last 6 data points are used as the measurement for each dynamic reference gas
- The flows for each dynamic reference gas are then corrected and the composition and its uncertainty are calculated
- For each composition, the physical properties are calculated in accordance with ISO 6976
- Errors are then calculated by comparing the actual properties to the measured properties

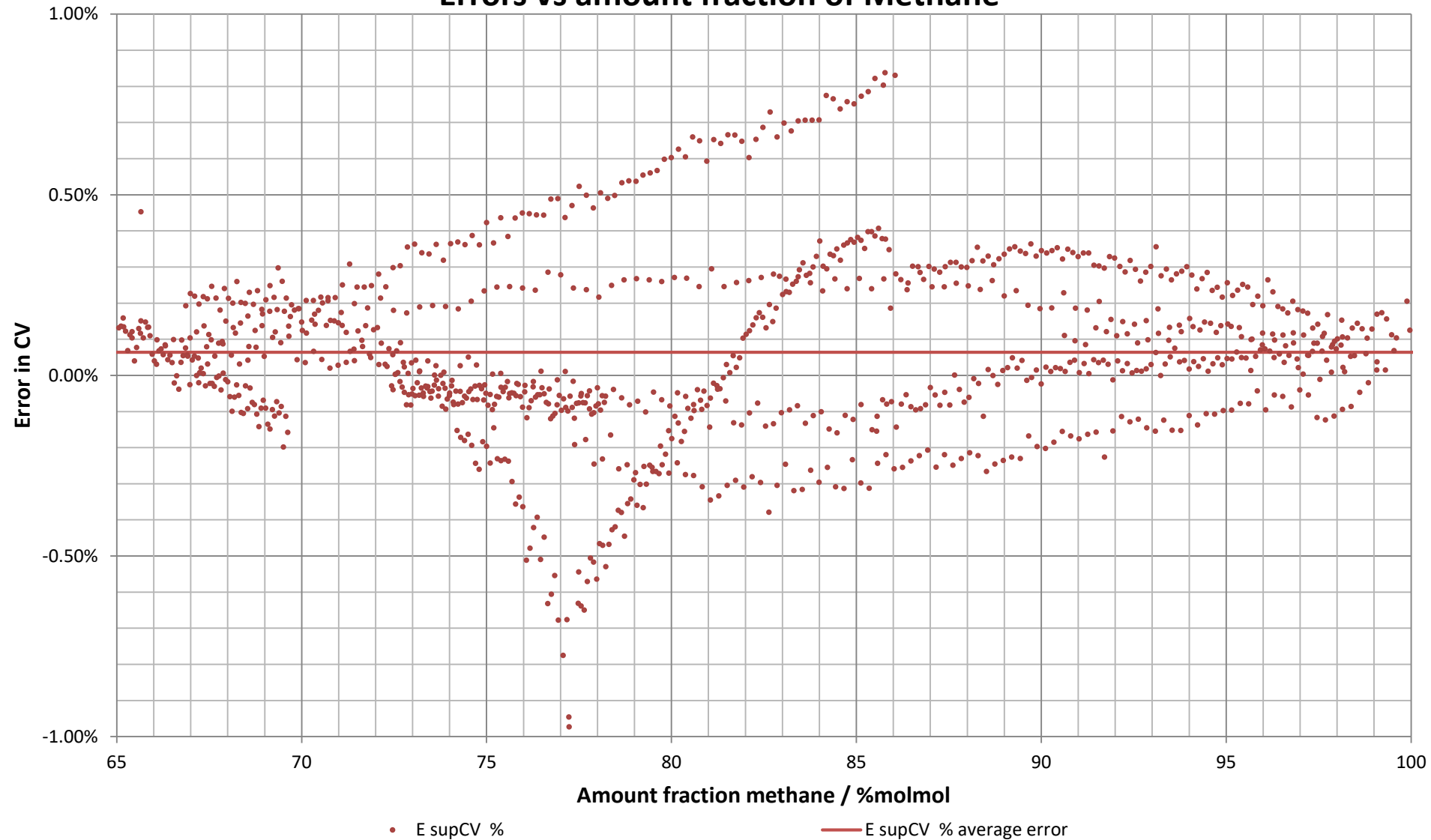
Carbon dioxide emission factors

- None of the instruments we have applied this new method to, report on carbon dioxide emissions
- Carbon dioxide emission factors calculated from the inferred compositions were compared to those calculated for the actual composition.

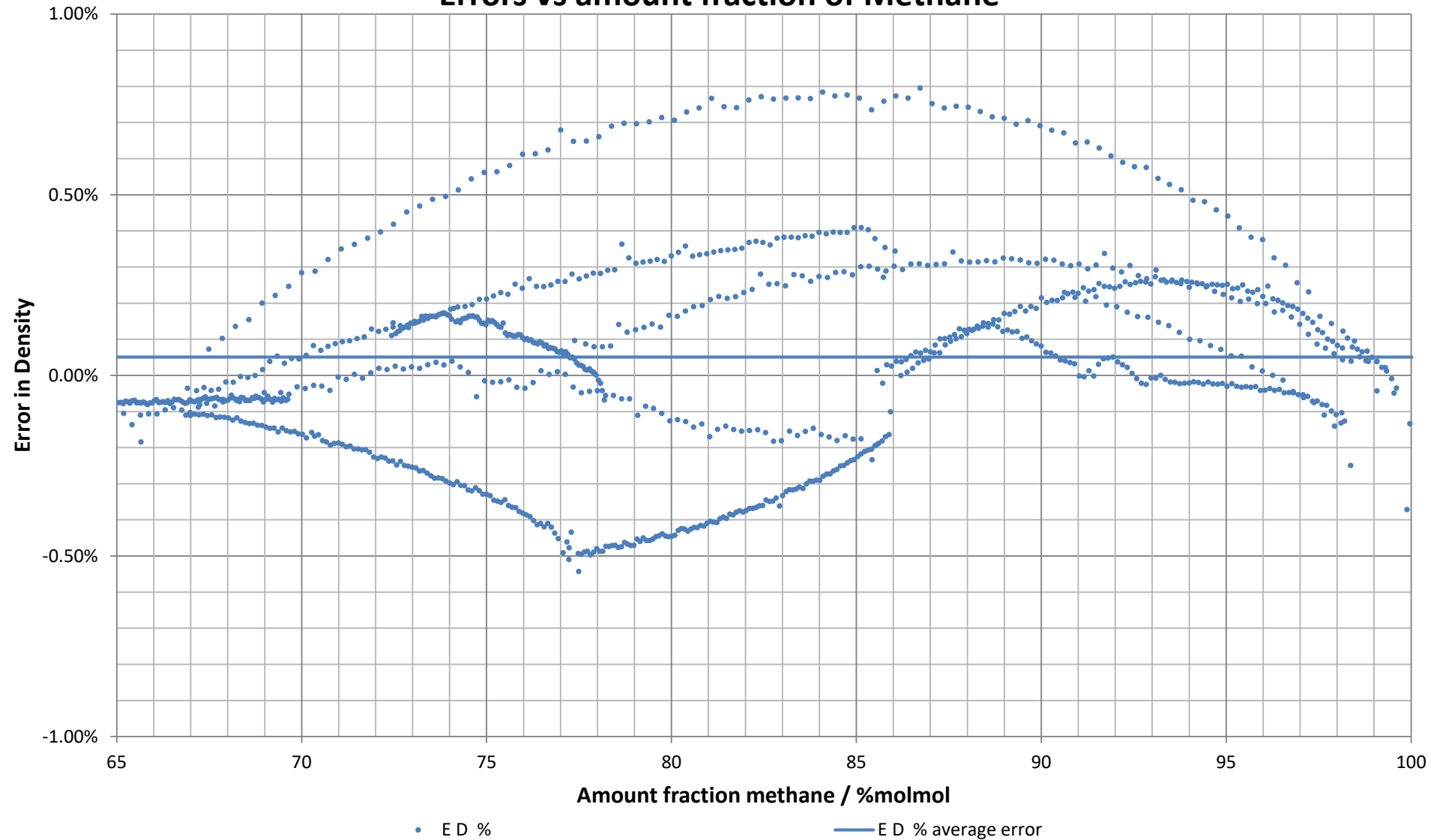
Results

- Once all the data for the 600 dynamic reference gases have been collected, an error distribution similar to that produced by an ISO 10723 calibration can be generated
- The average of the errors will give the bias of the measurement system.

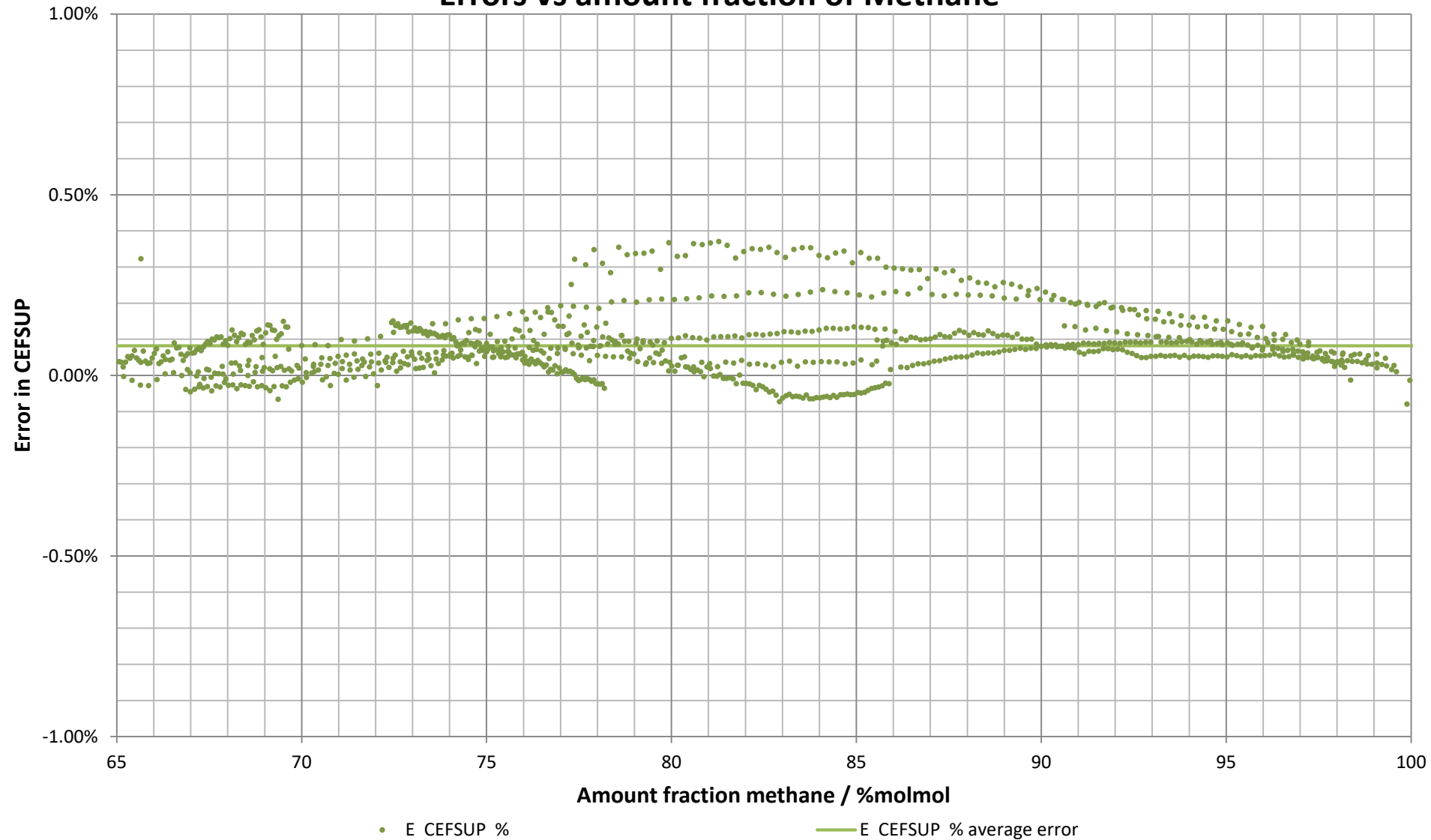
Errors vs amount fraction of Methane



Errors vs amount fraction of Methane



Errors vs amount fraction of Methane



Ongoing work

- Development of a formal validation procedure for the gas blending system
- Development of a method for assessing uncertainties
- Carry out the procedure on a wider selection of instruments with different measurement principles
- Look at ways of improving the performance of the instruments using the data collected during the validation
- Publication of this method as part of ISO 23568

Conclusion

- Existing standardisation is not applicable to interferometers.
- Interferometers are being installed, and knowing their performance is critical.
- Their rapid response time makes measuring many reference gases practical.
- The use of a dynamic gas blending makes producing a large amount of reference gases possible.

Thank you for your attention.

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