KUWAIT 3RD FLOW MEASUREMENT TECHNOLOGY CONFERENCE

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A Subsidiary of Kuwait Petroleum Corporation

DEAN WADE

Principal Measurement Consultant

Dynamic Measurement Uncertainty

Kelton® Engineering Limited

What is Uncertainty?

Doubt

The "Give or take" or the "±"

Range of values in which the 'true' value lies

Parameter associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (ISO GUM 1995)

Uncertainty is always an estimate, the quality of which depends on the experience, detail and judgement which goes into constructing the model.

What is Uncertainty?

Important to note that uncertainty is by definition "±".

i.e. either party could gain or lose, but we can not know which is which.

There is often a mistaken belief that measurement uncertainty is random and will cancel out over time… **this is generally not the case**

Part of uncertainty (often a significant part) will not be random and will tend one way rather than the other.

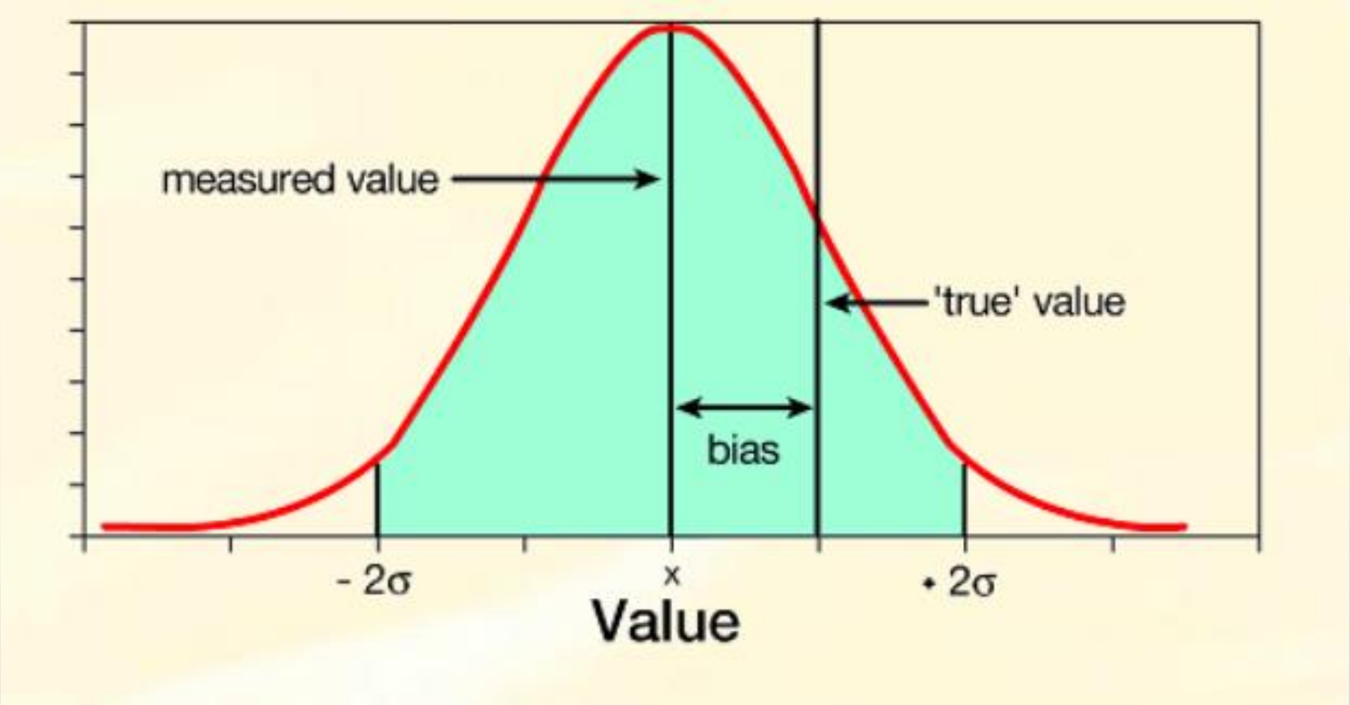
Not maintaining a suitable uncertainty budget can result in ***exposure to bias error***

This bias represents the **biggest financial risk** in measurement.

The smaller the uncertainty window, the less scope for any hidden bias

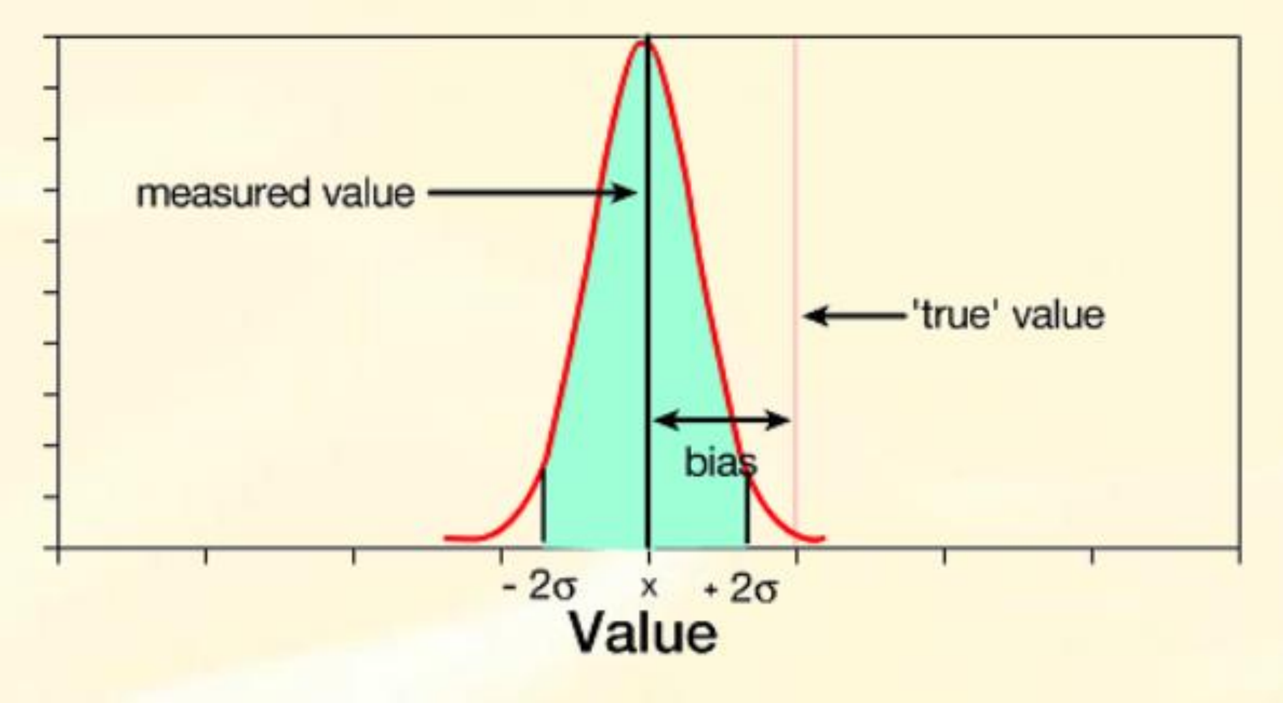
Uncertainty and Bias

Bias hidden within uncertainty range – difficult to detect



Uncertainty and Bias

Bias greater than uncertainty range – easier to identify and subsequently take steps to resolve



Uncertainty

Demonstrating uncertainty is a requirement

Typical limits

- Gas metering system ± 1%
- Liquid metering system ± 0.25%

Without knowledge of uncertainty in measurement a meaningful comparison cannot be achieved

It is important that uncertainty calculations are representative of the systems that they are associated

Products should be metered to a traceable and reputable standard with uncertainty similarly reported and estimated using traceable practices

Uncertainty statement

The result of any measurement should comprise 3 parts:

1. The result itself: 1,000 m3/hr
2. The uncertainty in this value: ±10 m3/hr
3. The confidence in this value: k = 2 (approx. 95%)

This means that the true value of the measured flowrate would be expected to lie between 990 and 1010 m3/hr on 95% (19 out of 20) occasions on average.

5% chance (1 in 20) that the true value will lie outside this range.

UNCERTAINTY AS A DECISION MAKING TOOL

Fit for Purpose

When designing a system it is important to consider the level of uncertainty that is appropriate

- Fiscal requirements
- Contractual agreements

Impact of uncertainty should be evaluated at the earliest possible stage.

With live uncertainty measurement ongoing maintenance procedures can be evaluated against actual production data.

Demonstrates operation within necessary uncertainty limit

Uncertainty based decisions

Uncertainty evaluations should not just be for compliance but also for decision making:

- Identifying the important (largest) uncertainties and working to reduce them.
- Purchase of new replacement equipment
- Calibration and maintenance levels
- Stream Online/Offline requirements
  - Determining Low flow cut off values

Incorrect uncertainty can lead to problems with:

- Operation within agreed uncertainty limits
- Level of financial exposure for operator/stakeholders
- Ability to identify and act on measurement bias

Uncertainty over life cycle

Uncertainty analysis is sometimes performed at the design stage and never seen again.

This approach loses significant potential benefits. Operators should consider changes that could occur:

- Production rates.
- Value of products.
- Operating costs of system.
- Equity interests in system.
- Composition / quality of produced fluids
- Fiscal regime

Uncertainty over life cycle

Many of these changes can affect the system uncertainty.

Uncertainty analysis should therefore be a continuous process.

On-going assessment of balance between cost and exposure.

The availability of live uncertainty data provides a useful tool for an operator to demonstrate that the system uncertainty is being maintained within the contractual Uncertainty limits.

Uncertainty analysis should be viewed as a valuable business tool, not just a technical document

Uncertainty in financial terms

Metering Uncertainty is more than just an esoteric concept amongst engineers… it translates into financial exposure

High measurement uncertainty can lead to high financial exposure.

Once this exposure has been clearly identified, a decision can be made as to how much to spend on measurement to reduce the exposure.

Uncertainty in financial terms

Uncertainty is normally expressed as a percentage.

e.g. Flowrate = 50,000 bpd ± 0.25%.

Very useful; however, consider the uncertainty in financial terms:

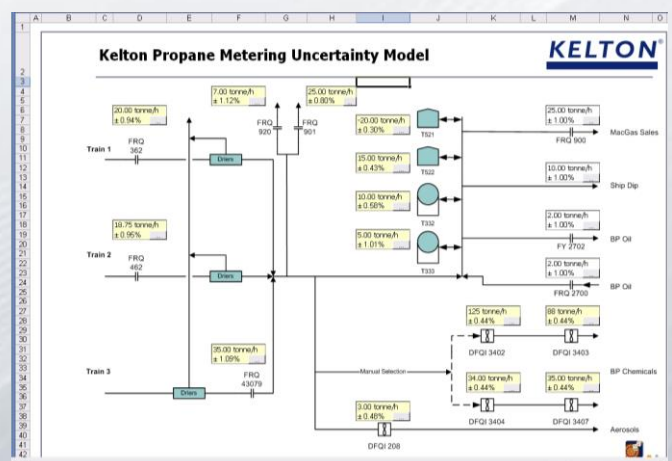
e.g. $/day or $m/year

Following example illustrates:

• Average flowrate (oil)	=	50,000 bpd
• Measurement uncertainty (relative)	=	0.25%
• Measurement uncertainty (absolute)	=	125 bpd
• Price of oil:	=	$60/bbl
• Exposure per annum (95% level)	=	$2.74m (yes, million!)

Key Features

- Fully traceable uncertainty analysis
- Uncertainty recalculated as process conditions change
- Uncertainty written back to Flow or Supervisory computer system
- Uncertainty visible across entire organisation
- Full report available for every saved result
- Uncertainty based alarms
- User configurable



Benefits

- Calibration intervals can be optimised and uncertainty based
- Compliance is demonstrated through uncertainty archive
- Meaningful comparisons between measurements can be made
- Calculated values *[Fiscal Measurement]* have values expressed with Uncertainty margin
- Business Risk associated with Measurement Uncertainty is immediately apparent;
  The effect of high uncertainty excursions

QUESTIONS?

UNCERTAINTYLIVE™.net

DYNAMIC UNCERTAINTY MODELS

GAS ORIFICE EXAMPLE

Influences on uncertainty

Flow rate

In use streams

Differential pressure

Temperature

Pressure

Composition

Drift/calibration interval

Test tolerances

Underlying models e.g ISO 5167, AGA 8

Evaluating inputs

Calibration data

Manufacturers' specifications

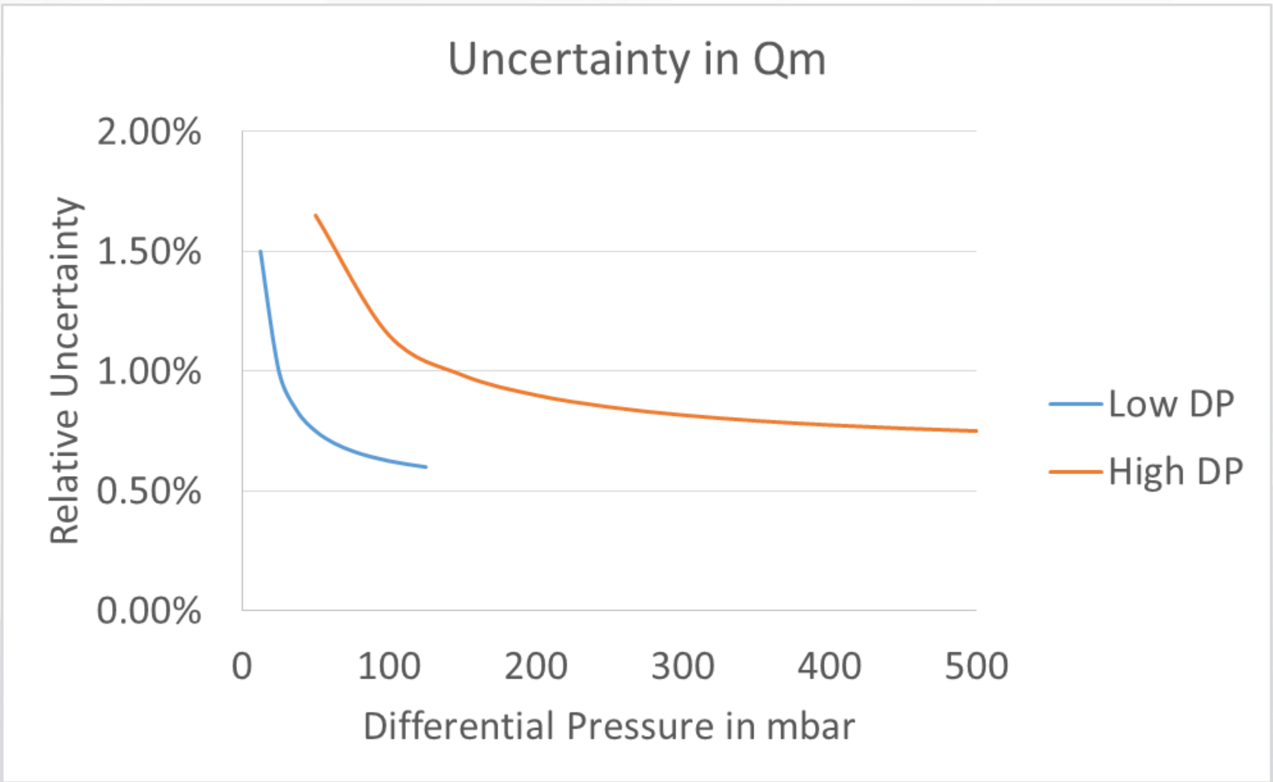
Calibration tolerances

Non compliance with standards

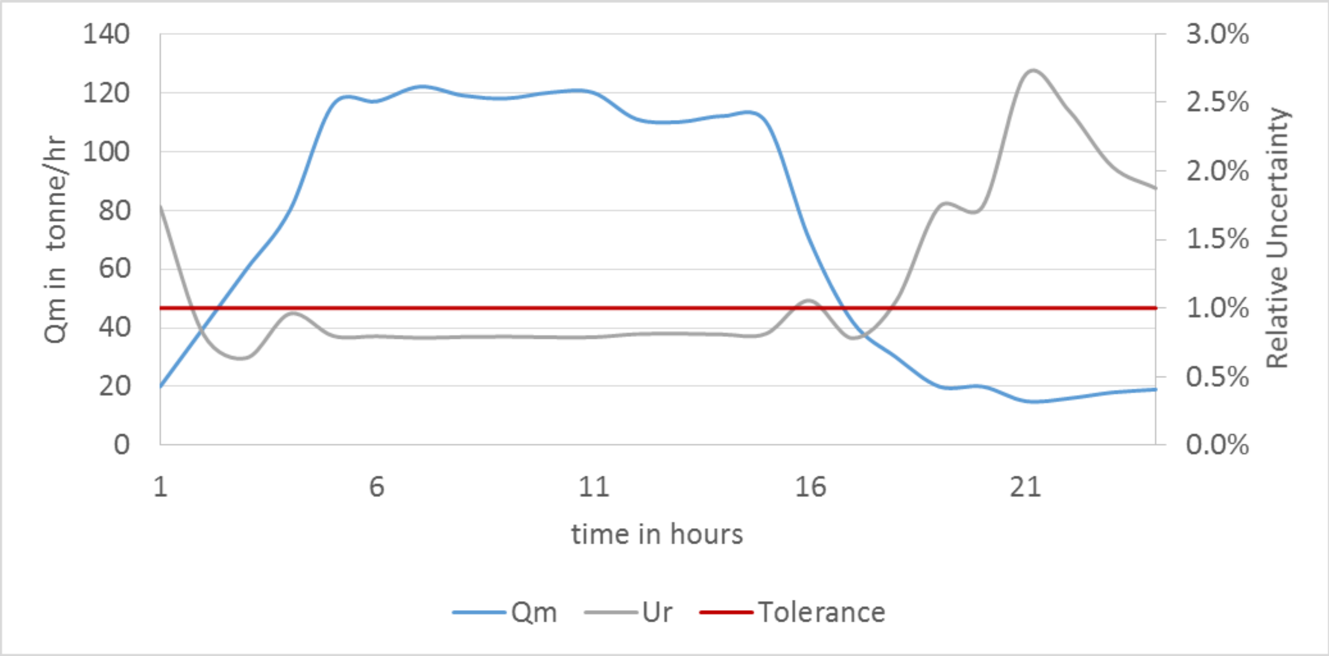
Resolution

Drift between calibrations

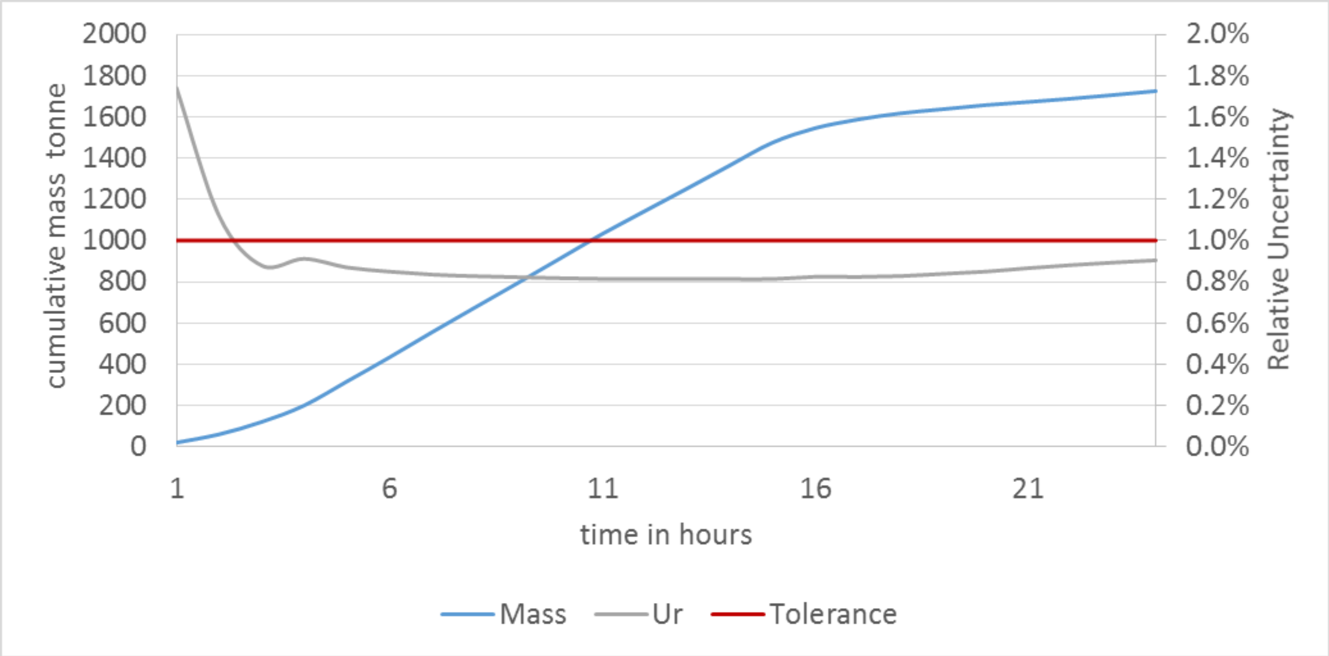
Typical orifice meter uncertainty profile



Instantaneous uncertainty – mass flow



Integrated uncertainty – mass total



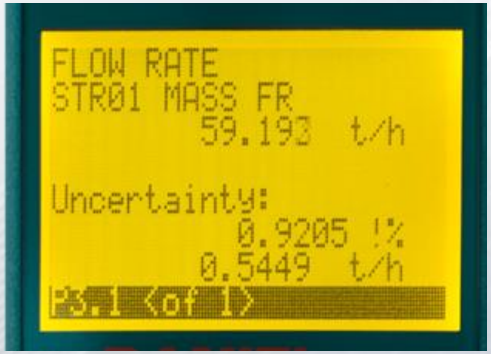
Dynamic Online Uncertainty

Use of dynamic computer-based uncertainty models such as UNCERTAINTYLIVE™.net can be used for this

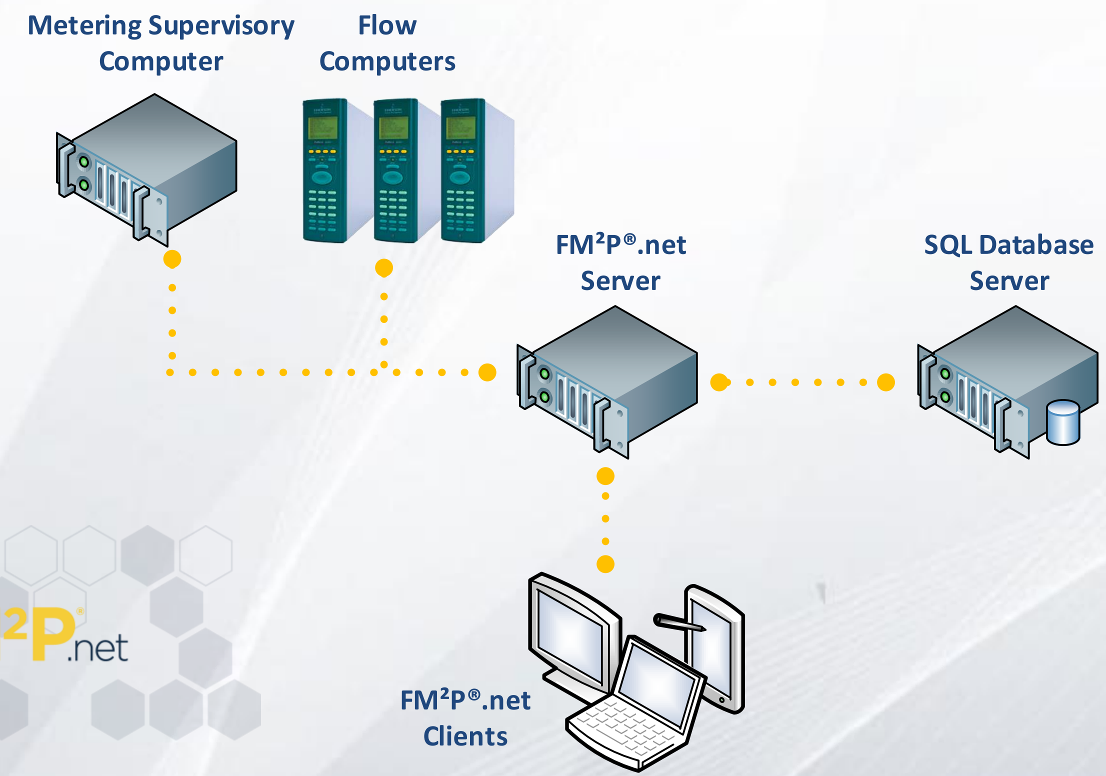
Allows operators to track uncertainty over time – better informed decisions.

Can be used to test future scenarios.

Implemented in real-time and linked back to the metering supervisory system.



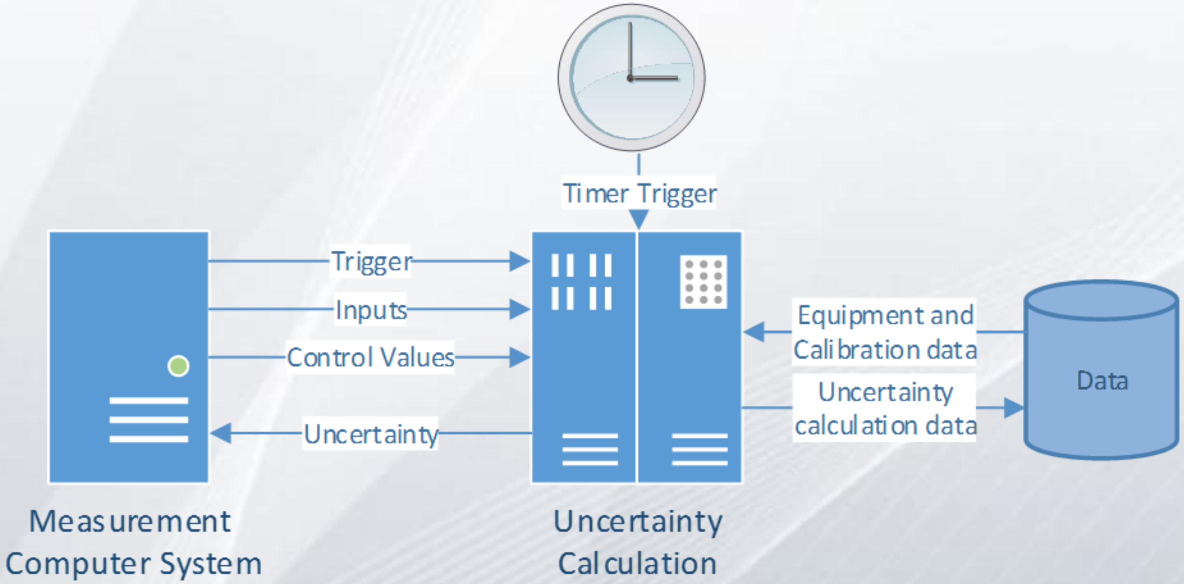
Dynamic Online Uncertainty



Dynamic Online Uncertainty

KELTON® uses a modular system to develop uncertainty models for different metering configurations using a common block library.

Uncertainty calculations are integrated with common metering calculations as per international standards



Gas Orifice Plate

Each module has an Input/Output tab where the module's global inputs are entered and the outputs are displayed. Here OPC inputs and outputs can be set.

Input / Output | Composition | Pressure | Differential Pressure (Lo) | Differential Pressure (Hi) | Temperature | Density | Standard Density

Options

DP Transmitters: 2

Station Uncertainty: Single stream

Pressure units: Absolute

Inputs

Parameter	Value	Unit	Data Source
Absolute pressure	38.87199	bar	FQI.S1_PV.UPSTR_PRESS
Atmospheric pressure	1.01325	bar	Fixed Value
Differential pressure	142.604	mbar	FQI.S1_DP.DP_STACK
DP Transmitter Switch Point	95	%	Fixed Value
Temperature	15.04414	°C	FQI.S1_PV.UPSTR_TEMP

Outputs

Name	Value		Absolute Uncertainty (k=2)		Relative Uncertainty (k=2)		Destination	Trend
Mass flow	58.1862	tonne/hr	0.513173	tonne/hr	0.88195	%	OPC Set	✓
Standard volume flow	74744.7	Sm^3/hr	684.328	Sm^3/hr	0.915554	%	OPC Set	
Energy flow	3022.21	GJ/hr	28.5566	GJ/hr	0.94489	%	OPC Set	

OPC Connectivity

UNCERTAINTYLIVE™.net can communicate with supervisory system via OPC. This is done through KELTON® K-LINK.net application.

The uncertainty can be made to calculate depending on the value of an OPC tag or it can be set to calculate at a defined time interval.

When relevant criterion is met UNCERTAINTYLIVE™.net will calculate the stream uncertainty, write this to the SQL database and send the outputs to supervisory system via OPC

Dynamic Online Uncertainty

UNCERTAINTYLIVE™.net is part of FM²P®.net software suite

Installed on the server and accessed across your organisation by the FM²P®.net Client application

Dynamically updated as process conditions change

Live Uncertainty written to supervisory computer systems

Historical Uncertainty written to SQL database for future evaluation, trending and review

Alarms raised when target uncertainty is exceeded

Uncertainty based decisions such as shutting streams can be made

Benefits

Uncertainty is representative of current conditions

An integrated uncertainty for a measured quantity is produced

Demonstrate compliance with regulatory and contractual agreements

Exposure to bias is reduced

Informed decisions can be made

Financial exposure can be managed more efficiently

Risk based calibration routines can be established

The functional relationship

Flow calculations defined in standards such as ISO 5167

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \rho_1}$$

Sensitivity coefficients

The sensitivity refers to the change in output, y, caused by a change in input, x_i, for $y = f(x_i)$.

Sensitivity coefficients are gained from the partial differentiation of the measurand with respect to each parameter.

The finite difference method is a practical numeric method of estimating the sensitivity of each component.

$$\frac{\partial y}{\partial x} \approx \frac{f\left(x_i + \delta_i\right) - f\left(x_i - \delta_i\right)}{2\delta_i}$$

δ_i = a finite increment

x_i = an independent input

Partial differentiation

Where a symbolic solution can be found $\partial y/\partial x_i$

Such as the basic ISO 5167 equation

$$q_m = \frac{C_d}{\sqrt{1-\beta^4}} \cdot \frac{\pi \cdot \varepsilon \cdot d^2}{4} \cdot \sqrt{2\Delta p \cdot \rho_1}$$

$$c_{\Delta p} = \frac{\partial q_m}{\partial \Delta p} = \frac{C_d}{\sqrt{1-\beta^4}} \cdot \frac{\pi \cdot \varepsilon \cdot d^2}{\sqrt{32}} \cdot \sqrt{\frac{\rho_1}{\Delta p}}$$

Practical working formulae

Some standards such as ISO 5167 suggest practical methods of combining uncertainty

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\delta C}{C}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(2 \cdot \frac{\beta^4}{1-\beta^4}\right)^2 \cdot \left(\frac{\delta D}{D}\right)^2 + \left(\frac{2}{1-\beta^4}\right)^2 \cdot \left(\frac{\delta d}{d}\right)^2 + \frac{1}{4} \cdot \left(\frac{\delta \Delta p}{\Delta p}\right)^2 + \frac{1}{4} \cdot \left(\frac{\delta \rho_1}{\rho_1}\right)^2}$$

Potential discrepancy can occur when the source is not verified

THANK YOU
FOR
YOUR ATTENTION