Measurement Challenges in Harsh Environments: Workshop Report

May 2013

This report provides a summary of the discussions that took place at the workshop 'Measuring in harsh operating environments: Focus on oil & gas and power generation' held on 20 March 2013 at the National Physical Laboratory, Teddington.

Executive summary

The workshop identified the following areas as critical to the industry.

Oil and Gas:

- Verifiable data simulation and interpretation models
- Corrosion monitoring and models: Corrosion Under Insulation (CUI), wide area corrosion monitoring
- Measurement of pH at the actual temperature and pressure
- Developing techniques, standards and verifying traceability for built-in diagnostic and calibration systems
- Condition monitoring of coatings at high temperature and pressure

Power Generation:

- Methods to accelerate creep-fatigue tests and understanding the limitations of accelerated testing
- Sensors for direct temperature measurement in gas turbines (circa 1000 °C)
- Measuring or inspecting cracking of bricks at high temperature / pressure in irradiated environments

Applicable to both sectors:

- Understanding the performance of erosion-resistant materials
- Characterisation of thin films, coatings and engineered surfaces
- Lifetime prediction of materials
- Mechanical and corrosion characterisation to simulate real conditions

About Measurement Network

Measurement Network connects business with measurement knowledge. It is the UK’s network that supports businesses to improve, innovate and grow through facilitating the access to and adoption of measurement expertise, training, facilities, standards and good practice.

> *“The trouble with measurement is its seeming simplicity”* (Anon)

With a vibrant community of over 2000 businesses, the network is a place for the academic and business community to engage, interact and find solutions to current and future challenges in measurement. We focus on increasing the spread and access of measurement knowledge and expertise to businesses that will benefit from learning and adopting good practices in measurements.

Approach

To facilitate innovative growth, the network focuses on specific challenges, a key industrial issue where measurement interventions can add significant value. Our focus is to connect businesses with measurement knowledge and help them solve their measurement needs through knowledge transfer and technology brokerage. We create opportunities for the business community to network and engage through events, workshops, roadshows and seminars. We also focus on supporting small and medium sized companies to access facilities and expertise, as well as the NPL Technology Innovation Fund. The network provides a window to organisations to access free resources such as Good Practice Guides, Event Reports, Educational Videos, Event Podcasts, Posters and Case Studies.

To know more about the current focus areas and activities of the network, please visit: www.npl.co.uk/measurement-network.To join the online discussions, please visit our groups on: LinkedIn and _connect

If you have questions or comments about this report or would like to engage in discussions please contact Tiju Joseph: tiju.joseph@npl.co.uk

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Introduction

Many processes in the oil & gas and power generation industries are required to operate in extreme environments, often with high standards of safety and efficiency. These environments vary and could be corrosive, abrasive or subject to extreme temperatures, pressures, vibration or contamination, or any combinations of these factors. Measurement technologies and systems that will enable accuracy, repeatability and reliability are vital to meet the growing challenges in these sectors. New needs are emerging and businesses must ensure that they are ahead of the curve to maintain the competitive advantage, and allow exploitation of the available resources in an efficient and timely manner.

Better measurements will contribute to the design, development and characterisation of materials and allow businesses to understand how systems operate in extreme environments. Potential benefits include better understanding of the properties and behaviours of materials under harsh environmental conditions, improvements in corrosion monitoring and sensors that work reliably, allowing in situ monitoring of materials, components and processes. It is also important to understand the key challenges faced by the industry and find suitable models that will facilitate the development of applicable solutions.

With this focus, Measurement Network (MN) organised a workshop to understand the key challenges in harsh operating environments, current and future needs in tools, technologies and methods, and discuss how new models can be developed to enable innovation. The workshop was attended by a wider stakeholder group comprising energy companies, technology and engineering service providers, test houses and universities.

This report provides a summary of the presentations and discussions that took place at the event and the potential solutions highlighted by the attendees. MN would like to thank all the presenters (ITF, KBR, Alstom, and NPL) and participants for their contribution to the workshop and this report.

Challenges in Oil and Gas: Strategic level

The Oil and Gas sector is driven by requirements to find additional reserves and optimise production. In order to do this, one of the key things the sector should focus is better technology management and quick adoption of new technologies. However, there is a wide acceptance in the industry that the sector is a slow adopter of innovative technology, constrained by the high capital risk nature of the business and increasing regulatory requirements.

The industry faces a number of unique and specific challenges related to the harsh operating environment. Typical bottom-hole temperature in a High Pressure High Temperature (HPHT) well is above 149 °C and has a pore pressure of at least 0.8 psi/ft (~15.3 lbm/gal)[1]. In some cases this can go up to the 'ultra' scale of 260 °C and 30 kpsi.

At the current level, it is possible to achieve a production capacity of 40% of the available oil. However, 40% may never get extracted due to economics, leaving the industry to focus on the remaining 20%. The table below shows some of the key technological advances that will help the sector to achieve this, as highlighted during the workshop.

Need	**Areas for improvement**
Reliable sensors	Cost-effective and reliable sensors, distributed sensors, inadequate standards and test methods, monitor system components, shock and vibration, pH at the actual temperature and pressure
Wireless communication	Reliable communication mechanisms, wireless protocols, remote power generation
Data acquisition and interpretation	New models and techniques that will allow full integration of the data from multiple sources, better prediction of material life, data mining diagnostics and analysis
Multiphase meters	Non-intrusive downhole meters that can measure the amount of oil, gas and water, as well as the flow of crude; thermal noise measurement; measurement at point of interest
Detection and monitoring of material degradation	Monitoring of coating breakdowns, detection of stress corrosion cracking, erosion induced by sand

[1] http://www.glossary.oilfield.slb.com/en/Terms.aspx?LookIn=term%20name&filter=HPHT

Corrosion monitoring and models	Measure the effect of H_2S , range of temperature and pressure at which pH can be measured with accuracy, wide area corrosion monitoring
Corrosion under insulation (CUI)	NDT/NDE technologies for the early detection of CUI in onshore, offshore, subsea and pipelines
Standardisation of testing for reliability and integrity	Interoperability of test methods, model validation, materials testing, industry-wide maintenance standard systems
Upscaling issues of samples	Linking measurement at nanometre scale to bulk values
Simulating in real time conditions	Relationship models, transient analysis and interpretation, understanding well characteristics, density profiling, measuring across the field, need for traceability, data acquisition systems, new improved translation models
Power electronics	High temperature capacitors and circuits
Self-diagnosis / In-situ calibration of instruments	Traceability and standards, stability of built-in calibration devices

Key reasons why we need better measurements:

- Extraction from deeper wells in remote locations will lead to higher stresses on equipment and structures

- Higher temperatures and pressures will affect flowlines and front end processing

- High CO_2 and H_2S levels will lead to increased corrosion potential and damage the systems

- Increasing use of more novel methods of extraction, e.g. EOR using water, polymer and dense phase CO_2 injection

- Lack of robust and reliable models will lead to misinterpretation of the data

- Stretching our understanding of how materials behave: are our material test methods keeping pace?

- Are we using the right measurement techniques?

Needs, Challenges and Opportunities: Technical level

Reliable sensors

The importance of cost-effective and reliable sensors cannot be overstated. At a strategic level, these sensors should enable efficiency in extraction and the discovery of new oil. At a very technical level, sensors that can monitor strain, measure behind casing, in annulus, in tubing, measure the pore pressure or non-intrusive downhole meters and measure the amount of oil, gas and water, as well as the flow of crude etc. are of high importance to the sector.

New technologies like fibre optics allow distributed sensing and the monitoring of pressure, temperature and acoustics. Such sensors can also be applied to monitor well stimulation at the actual point in the formation where injection takes place and for in situ control for gas fracking. They can also be used in CO_2 sequestration where dense phase CO_2 is transported via pipeline and must be kept dry and above the triple point. However, it is doubtful that the specifications and test methods for producing these sensors are up to the requirements for the harsh environment. There is a wider agreement that the standards and test methods for manufacture and use of fibre optic sensors are currently inadequate.

Measurement devices that will monitor changes in pressure, temperature, flow rate, water, multiphase differentials and gas cut are required for multilateral well management. The ideal scenario in the area of sensing is the availability of sensor systems that can take continuous bottomhole measurements including water, oil and gas flowrates at all points in the well with continual feed to the surface and complete reliability. Three key areas highlighted during the workshop are highlighted below:

Multiphase metering: Since the 1980s, the industry has been trying to develop multiphase meters. Success has been reported when these have been used to measure oil, gas and water flow rates close to the well head. They can also be installed on individual flow lines to remove the need for test separators and test lines. The ultimate vision is to have a 'plug & play' multiphase meter on every well head (Busaidi & Bhaskaran, 2003)[2]. However, the accuracy levels of multi-phase metering are low and will be further affected by high temperature and pressure.

It is possible to substantially reduce the equipment inventory and vessel size if a single meter could be used, e.g. on normally unmanned well head platform. It has also been suggested that meters that could measure the viscosity of oils and thermal noise and allow measurement at the point of interest would be of enormous interest to the industry. An ideal scenario will be the availability of a cheap and reliable, wireless, self-powered, non-intrusive, wireline retrievable, downhole Pump&Treat (P&T) multiphase flow measurement system.

[2] Multiphase Flow Meters: Experience and Assessment in PDO, SPE Annual Technical Conference and Exhibition,(Busaidi, Khamis & Bhaskaran, Haridas), 2003

Sensing and Monitoring Challenges

Workshop attendees highlighted the following areas to demonstrate why we need better sensors:

- monitor the reliability of equipment
- enable measurement at point of interest
- monitor down-hole conditions to improve reliability and uptime
- measure shock and vibration
- identify and quantify gauge drift (data can tune wellbore models)
- allow distributed sensing capabilities
- monitor system components
- conduct in-situ self-diagnosis
- measure reservoir overburden (Formation monitoring)
- non-intrusive downhole meters
- monitor well annuli pressure
- monitor mooring chain fatigue
- continuous subsea oil-in-water measurement
- reliability of subsea P&T transducers
- standardisation of testing for reliability & integrity
- cost effective subsea monitoring (scale, asphaltene and wax; downhole chemical monitoring and real-time measurement of fluid chemistry)

Measurement of actual pH at the actual temperature and pressure: pH probes are delicate and only a limited number of types exist that are robust enough to be placed in a full flow pipe under pressure and at temperature. The equations, and thus graphs, used to account for pressure and temperature only allow for up to ~10 bar and ~100 °C. Down hole pressures can be 300 bar and temperatures can be 180 °C, or even higher in some fields. The current methods only enable calculations, not reliable measurements. It is also not uncommon for the pH meter to become polluted with chloride or ions, giving false data. pH probes that can operate above 100 °C are required.

Transient analysis and interpretation: A major requirement for the industry in the wake of previous disasters is the development of a better transient flow analysis model which can accurately predict potential blow outs. National Measurement Institutes, like NEL and NPL, have been highlighted as the key organisations to play an important part in providing credibility and validity to the number of models currently on the market.

Wireless communication

There are a number of challenges related to the use of wireless communications systems. Such systems have the advantage of real time data transfer and better management of the assets. They can also significantly reduce the cost of materials, labour, wiring systems and have an impact on the schedule, e.g. on an FPSO (Floating Production, Storage and Offloading). However, a key question to answer is whether the current standards are suitable for harsh environments.

Some of the key issues that need resolving in this area include:

- Reliability and robustness of the protocols
- Energy efficient batteries
- New ways of generating power for the devices to operate remotely
- Data connectivity – communications of measurement in various mediums

Data acquisition and interpretation

Collecting data from multiple sources and developing new models to enable accurate interpretation of these data are key challenges which require collective industrial action. A number of third party suppliers can provide such solutions in the market, however many oil majors consider the ability to simulate as a competitive advantage.

Fracture modelling is critical to predicting PWRI (produced water reinjection) behaviour in subsea conditions. A key objective is to maintain injectivity while increasing production and reducing costs. Systems that allow better validation and simulation have been highlighted as a key requirement by the attendees. The benefits include the ability to interpret pore pressure in well cementations, carry out density profiling, improve user interpretation and allow better understanding of well characteristics. This area has a number of measurement challenges, both qualitative and quantitative, as highlighted in the next page.

Data acquisition and interpretation challenges

Some of the key issues discussed at the workshop are highlighted below:

- Lack of long term data
- Lack of availability of comparable data
- Availability of reliable data acquisition systems and translational models
- Challenges in measuring across the field
- Traceability of measurements
- Data comes from multiple sources and the difficulty in knowing where they are coming from (localisation data)
- Difficulty in correlating the data and validating the model
- Challenges in measuring what is needed to be measured – identification of data points
- Lack of a coordinated effort between oil majors and suppliers of data simulation systems
- Integration of old systems with new ones
- Handling or visualisation of large data sets

Measuring material integrity

Integrity of the materials is of foremost importance to the sector. The ageing infrastructure and the need to prolong the life of existing wells require the industry to pay more attention to the integrity of the materials to avoid any disasters. A number of technology challenges exist which need to be addressed by the industry. The key areas are highlighted below.

Detection and monitoring of material degradation: Key challenges include understanding the coating mechanism, monitoring of coating breakdowns, detecting coating disbandment prior to the onset of corrosion, detecting stress corrosion cracking as well as creating high level guidelines to manage the impact of process changes on existing materials.

Better prediction of material life: Key things to consider are techniques that can provide increased accuracy of fatigue status, better qualification and application of repair methodologies leading to accurate lifespan predictions and full life cycle designs resulting in fewer unplanned shutdowns. It is also important to understand and predict the long term viability of material performance to select the most cost-effective material to facilitate the affordable sour gas field developments.

Corrosion detection challenges

- **Corrosion under insulation:** Key challenges include the development of NDT/NDE technologies and new measuring techniques for the early detection of CUI in onshore, offshore, subsea and pipelines. It is also important to develop new prediction models and techniques to improve current NDT methods.

- **Corrosion monitoring and models:** There is no consensus on a model which can accurately account for the effect of H_2S and there are restrictions on the range of temperature and pressure at which pH can be measured with accuracy. Measuring pH at high temperature and pressure in real time is important to increase the confidence in existing models to ensure that we are using safe materials, but also to allow us to make better techno-economic judgements. Hydrogen tends to penetrate alloys. Techniques which are used to measure the amount of hydrogen in nickel alloys will not give the right results and are not reliable if used in carbon steel or standard steel. New methodologies that will allow the measurement of hydrogen in metals and alloys are important.

- **Wide area corrosion monitoring:** Currently, most of the corrosion monitoring is restricted to single point measurements, which is not representative of the wider area of interest. Attempts made to use arrays that circle a pipe have met with varying degrees of success and they are not widely adopted. Corrosion in piping and pressure vessels is rarely uniform and can be underestimated or missed when using localised detection methods (e.g. coupons, inserted probes, or manual ultrasonic). There is no open protocol for how the data is manipulated in order to display results and it is not possible to cross check.

Power Electronics: At high temperatures the junctions of silicon-based microelectronic devices may not function properly. Capacitors that deliver high energy density and temperature stability are important for pulsed power applications. Recently, NPL has announced the development of a new ceramic capacitor dielectric material that operates with a stable capacitance up to 200 °C, or above.

Sand Erosion: Material loss due to sand erosion can cause severe damage to oil and gas production facilities and lead to leaks and ruptures if left undetected. There is demand for a reliable erosion prediction tool which will model the erosion resistances of the exposed material and its impact resistance[3]. The existing models may not be accurate as new materials and coatings are used by the industry to improve material integrity. Expensive materials such as CVD Diamond and low cost materials such as Silicene, a two-dimensional form of silicon, could be used to increase the wear resistance.

[3] GE Oil and Gas: http://www.onepetro.org/mslib/servlet/onepetropreview?id=OTC-23356-MS

Standardisation of testing for reliability and integrity

Interoperability of test methods: One of the key questions industry should address is the development of cheaper transferable tests. This should be the case whether the requirement is in sub surface, subsea or onshore. For example, certain test methods devised for carbon steels are not necessarily suitable for CRAs. Standardisation of certain aspects of 4 point bend tests for stress corrosion cracking that were not covered by other standards in relation to pre conditioning of specimens of certain types of material are required. It is important to challenge the assumptions that were used to develop tests. Are protocols that were used in the past still valid, and can they be used with a different material (of all types, metals and polymers) or in a different environment?

Infrastructural maintenance reliability: There is a lack of industry wide maintenance standards to ensure infrastructural maintenance reliability. Such standards are required to predict and manage equipment lifetime. Reliable sensors are going to play an important role in detecting, treating, monitoring and managing assets as well as equipment. Some of the key requirements are listed in the box below.

Infrastructural maintenance and reliability challenges

- Measurement at the point of interest
- Monitoring downhole conditions to improve reliability and uptime
- Measurement becomes an integral part of the pipeline integrity strategy and full lifecycle planning
- Sensors to monitor system components
- Distributed sensing for in-situ real time monitoring
- Self-checking mechanisms to monitor the failure of components, sensors and unreliable analysis
- Availability of open access information for better modelling

Sampling problem: There is also a need to address the sampling issue. Fine samples require measurement at the nanometre scale and linking to bulk values. The key question is whether we can upscale this.

Self-diagnosis / In-situ calibration of instruments: One of the important technological needs identified through this workshop is the need for self-calibrating instruments. The immediate needs include the development of pressure and temperature transducers that self-calibrate. However, there are a number of challenges to meet before these will be accepted, even if the community manages to build such devices. The industry should be provided confidence on the measured numbers, robustness and traceability referred to a global standard.

NPL has made significant advances in the area of temperature measurement and one of the presentations highlighted the availability of a remote calibrating thermocouple. They demonstrated performance of miniature high-temperature fixed points (HTFPs) for in-situ validation of W-Re thermocouples up to 2300 °C. Implementation of self-validating thermocouples in-situ has been shown to be essential for user confidence when employing Type C thermocouples above 1300 °C. The HTFPs have been shown to provide suitable immersion for clear observation of the melting and freezing transitions and to be reliable under the conditions of these tests. HTFP containing two fixed-point materials was also shown to perform excellently - providing the opportunity for validation of the thermocouple output over an increased temperature range. NPL has also developed a direct replacement for a four-wire PT100 thermometer; Self-Validating Temperature Sensor (SVTS) System, a simple and robust technology that would indicate when its calibration has shifted. This would eliminate the need for pre-emptive or annual calibrations, and so reduce the cost of recalibrations and downtime in your process.

Challenges in Power Generation

The workshop had a relatively low number of participants from the power generation sector compared to the oil and gas. Therefore, the following section has its own limitations on the number of key issues raised.

Challenges in Power Generation:

- Fireside corrosion testing beyond material ranking
- Characterisation of thin films, coatings and engineered surfaces
- Lifting and condition monitoring of coatings
- Understanding the morphological features from processing to degradation to manage in-service performance
- Complex mechanical and corrosion characterisation to simulate real service conditions
- High pressure testing capability for steam-side oxidation
- Methods to understand location-specific properties
- Methods to accelerate creep-fatigue tests and understanding the limitations to accelerated testing
- Models that allow lifetime prediction of materials in power plants
- Measuring and inspecting at high temperature/pressure in irradiated environments
- Understanding and characterising the performance of erosion-resistant materials
- Characterisation of thin films, coatings and engineered surfaces
- Lifetime prediction of materials

Needs, Challenges and Opportunities

Managing erosion

The models currently in use to measure the initial sift of erosion resistant materials are not always based on the correct mechanism and so are not always appropriate to use. There is a lack of understanding between the relationship of erosion performance to other properties like hardness and toughness. The two key gaps are:

- Lack of research capability
- Fundamental lack of understanding of the erosion process

Improved solutions can be achieved if customers are made aware of the cost of efficiency loss and replacement costs due to erosion. Universities and research institutes are ideally placed to develop new solutions and provide training programmes to increase the awareness of the erosion process and to improve current measurement and test capability and understanding.

Temperature measurement in gas turbines

Currently, no reliable sensors exist for the direct measurement of temperatures above 1000 °C. The efficiency of the engine increases with an increase in gas temperature, which can go beyond 1700 °C. Understanding this temperature is critical for controlling and managing the engine. Similarly an increase in temperature above 600°C can adversely affect the health of the turbine blade and coatings. The current models are wrong and often unreliable as they are based on inaccurate temperature measurements and estimations. The major barrier is the availability of cost-effective solutions for temperature sensing and the restricted environment that delays the evolution of new engines.

Displacement management

Measuring or inspecting the cracking of bricks at high temperature / pressure in irradiated environments has been highlighted as a major issue, particularly in nuclear environments, resulting in shortened life of reactors. Some of the key issues include:

- How to take a measurement without shutdown
- Limited access in old/existing reactors
- Camera/Eddi current technique does not work in high temperatures
- Regulator will be taking more invasive action

Developments of technologies that will provide more in-situ images at very high temperatures are vital.

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