Real-Time Respirable Crystalline Silica Detection

AB36-COMM-56-1

Contents

1.0 Background Information

The first section of this document provides a background to Trolex and includes information regarding current activities relating to the monitoring of airborne particulates with a focus on Respirable Crystalline Silica (hereafter referred to as RCS). The company has worked with academia for several years to patent technology that has the potential to detect RCS in real-time. Details of this work are given in this section including an overview of the sensor module prototype, how the technology works, lab and field trials results.

1.1 Trolex Introduction

Since 1959, Trolex has been at the forefront of the design and manufacture of safety instrumentation for some of the most hazardous and demanding industries. Its gas and environmental monitoring systems, strata monitoring, and particulate monitoring solutions are sold and serviced globally into the world's mining, tunnelling and process industries, giving it a market leading position in countries such as Australia, Russia, Chile, South Africa, India, Turkey and China.

The development of innovative new products and technology is at the core of Trolex's strategy and it has a strong track record of working with academia, industry bodies, funding partners, regulators and other stakeholders. The company has been the recipient of prestigious awards, such as SME Manufacturer of the Year Award in 2012 and the EEF Smart Product Award in 2013.

1.2 Particulates Background

For a number of years Trolex has seen a need to provide active monitoring of airborne particulates. With a background supplying environmental monitoring to the underground coal mining sector the company has been acutely aware of the serious health implications of long-term exposure to dust and silica. It has only been relatively recently however, that the technology underpinning particulate detection has improved to the point that it is suitably reliable, accurate and rugged for the demanding type of applications in which it is most needed.

Trolex has been working with UK Universities and technology partners over the last five years to bring the necessary technology to market and in 2017 released its first real-time dust monitoring suitable for use in a wide range of industries and applications. The first generation of the AIR XD focussed on highly accurate, real-time dust monitoring in demanding applications, significantly moving the technology forward to allow detailed analysis of particulate sizing that would typically only be available in lab-grade equipment. Instant access to detailed, continuous, accurate information regarding dust concentration and composition has allowed companies to adopt a proactive approach to managing the working environment with respect to airborne particulates and worker protection.

Trolex has just launched the second generation of the AIR XD dust monitor, improving this industry leading product to monitor a wider range of particle sizes and extend the life in environments with very high dust loading. Additionally, the product is currently being certified for use in potentially explosive atmospheres (IECEx/ATEX).

1.3 Respirable Crystalline Silica (RCS)

In the UK, RCS is responsible for the second highest number of cancer cases related to airborne particulates after Asbestos. Until recently it has not been possible to use the type of light scattering techniques found in typical real-time dust monitors to distinguish RCS from general dust populations or non-crystalline Silica. In collaboration with a leading UK University in the field of particulate detection (University of Hertfordshire), Trolex has achieved a significant breakthrough in this area. The technology underpinning this breakthrough allows for several unique properties of RCS to be accurately characterised enabling real-time statistical analysis of RCS content within the general airborne dust population.

The technical approach adopted involves a sophisticated algorithm that combines data collected using the following three techniques/properties:

- Mie Theory (property: particle sizing)
- Scatter asymmetry (property: particle shape)
- Light polarisation (property: particle birefringence)

Whilst it is not possible to positively identify RCS by analysing any of these properties in isolation, combining the data can determine the presence of RCS. The technology is patented (International WO2016198866, USA Patent Ref. 15/580.546) and has been proven in a lab environment to identify RCS from a general dust population as well as distinguishing it from particles of non-crystalline Silica. The technique has also been tested in several field trials.

It should be noted that at this stage this is not the same as being able to quantify the concentration of RCS within a dust population. The ability to determine the concentration is seen as critical to providing a useable sensor and it is suggested that this is the next significant step in realising a practical unit. It is proposed that this would form a significant element of Phase 1 of the funded project.

1.4 Academic Collaboration and Sensor Research

Trolex has collaborated on research projects with a number of leading UK Universities, including Durham University, Liverpool University, Manchester University and the University of Hertfordshire. In addition, Trolex is participating as one of a number of industry partners supporting the creation of 'The Centre for Doctoral Training in Aerosol Science'. This has been led by a consortium of leading Universities including The University of Bristol, The University of Hertfordshire, The University of Cambridge and Imperial College London. Trolex also maintains links with the University of Exeter via the Camborne School of Mines and offers summer internships to Mining Engineering students.

The Trolex AIR XD real-time dust monitor is based on technology developed in collaboration with the University of Hertfordshire. The company has been successful in securing government funding for advanced research projects and has so far undertaken two funded projects in relation to the real-time detection of RCS, partnering with the University of Hertfordshire.

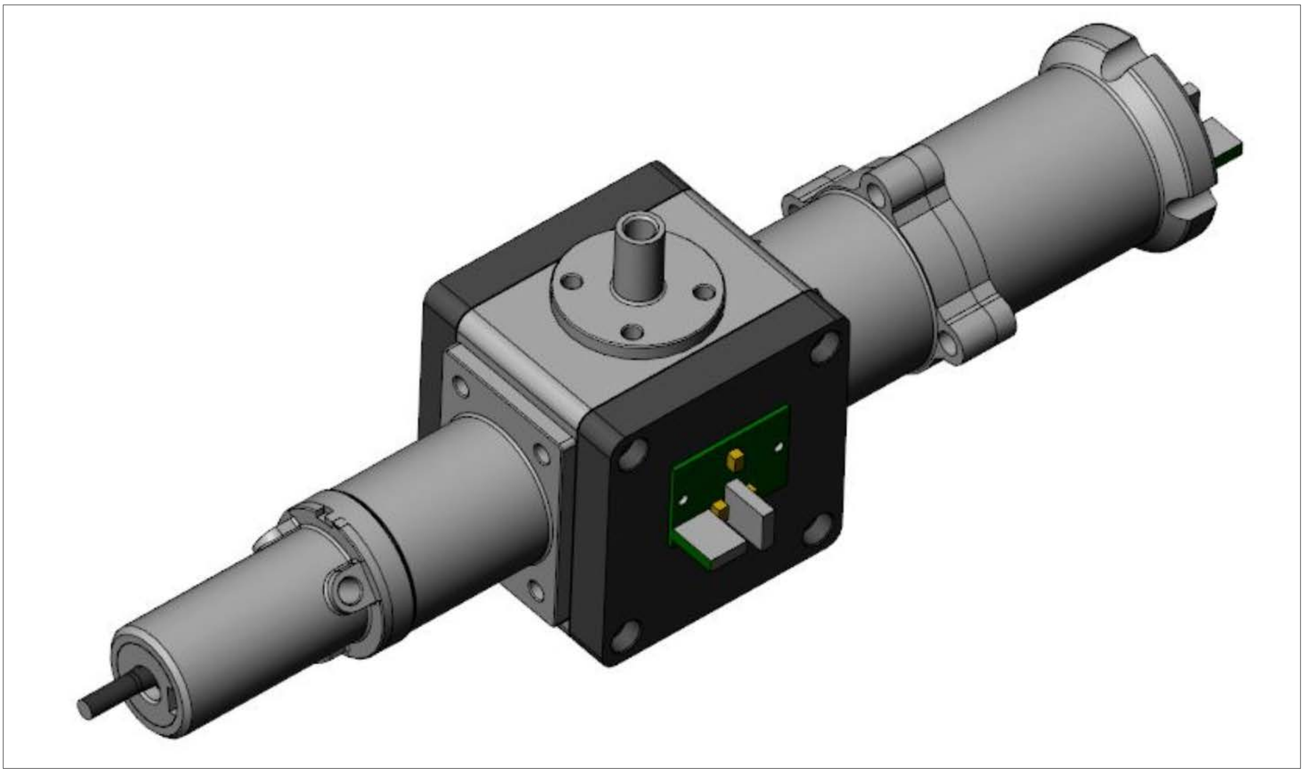
The first RCS project was proof of concept research that included the development of a lab prototype and collection of an initial dataset. The second recent RCS project built upon the findings of the first project in order to develop a prototype algorithm and expand the dataset. In parallel, Trolex has conducted its own inhouse research, mirroring the work conducted by the University whilst developing the sensor for use in field trials. A dedicated laser and optics laboratory was constructed at the Trolex facility in early 2018 to support advanced sensor research.

Trolex has a strong relationship with the UK's Health and Safety Executive (HSE) and collaborates closely in the sphere of occupational health hazards related to airborne particulates.

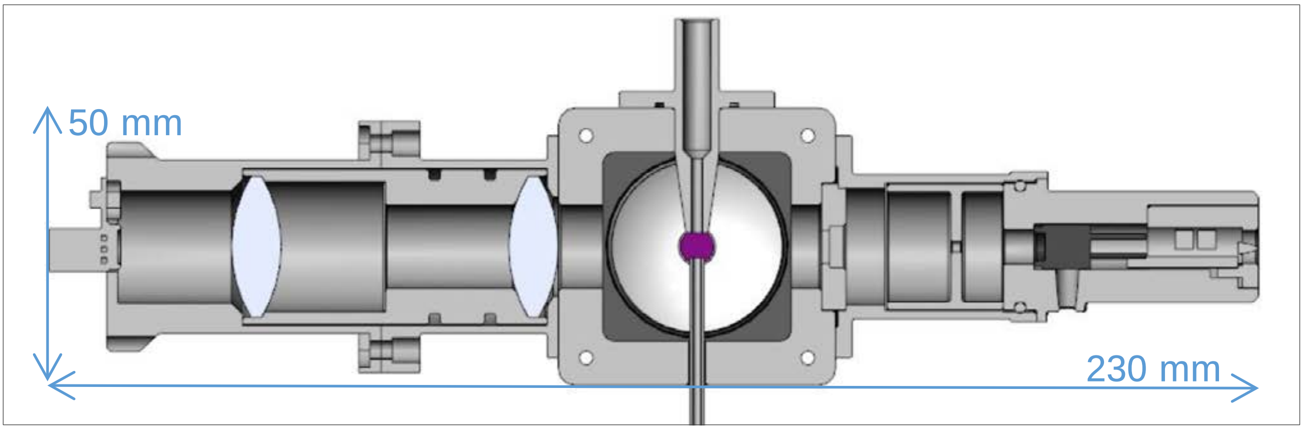
1.5 Prototype RCS Light Scatter Chamber

The picture below shows a 3D CAD model of the current Trolex prototype RCS sensor module. The sensor was developed firstly as a lab-based prototype located at the University of Hertfordshire and then subsequently as a field prototype that has been trialled in several locations where high levels of RCS are known to be present. The prototype has undergone several iterations with a focus on improving:

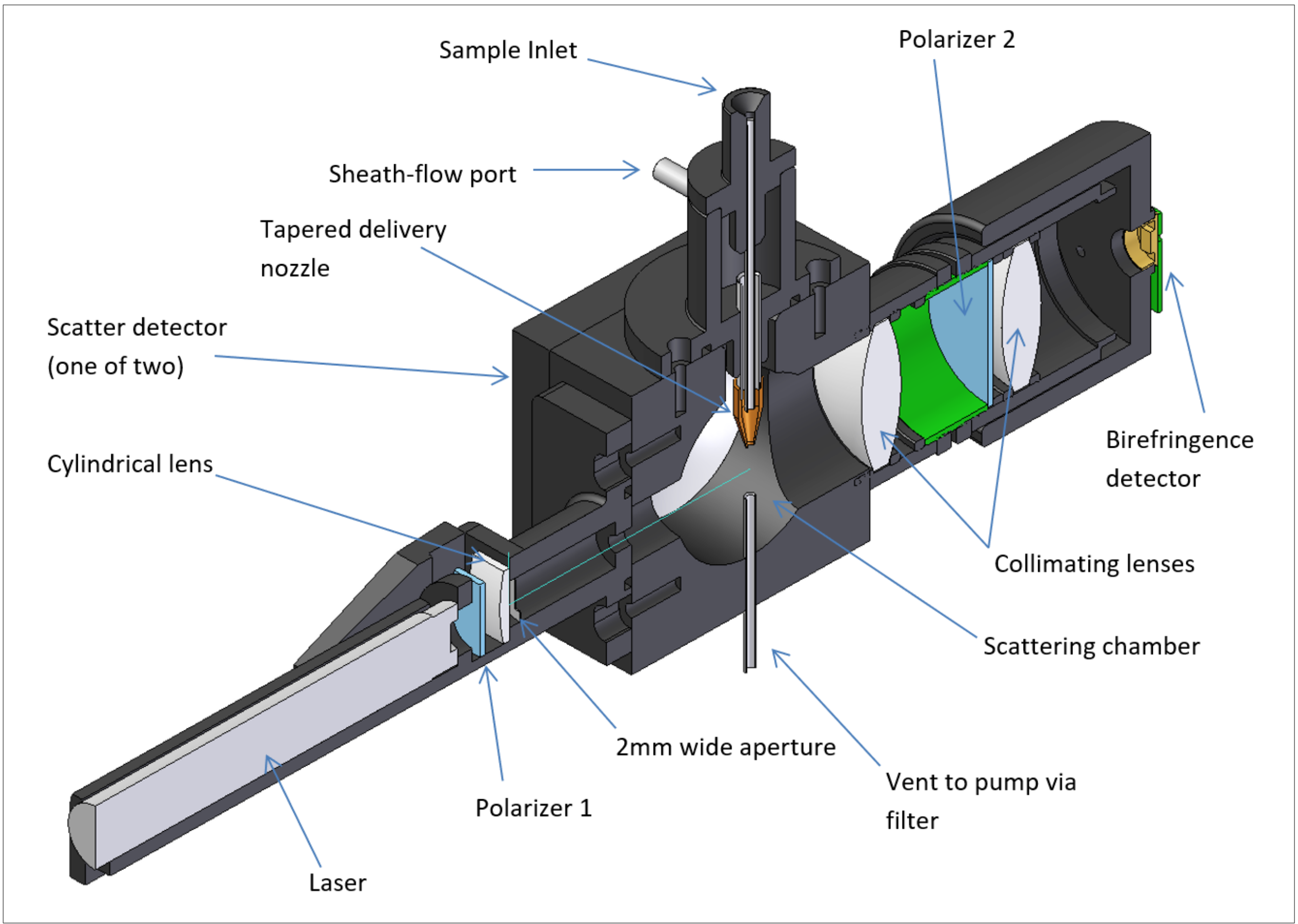
- Signal to noise ratio (especially the birefringence signal)
- Airflow
- Positioning of key components
- Reliability and lifetime
- Ease of calibration
- Design for Manufacture (DfM)
- Cost of components

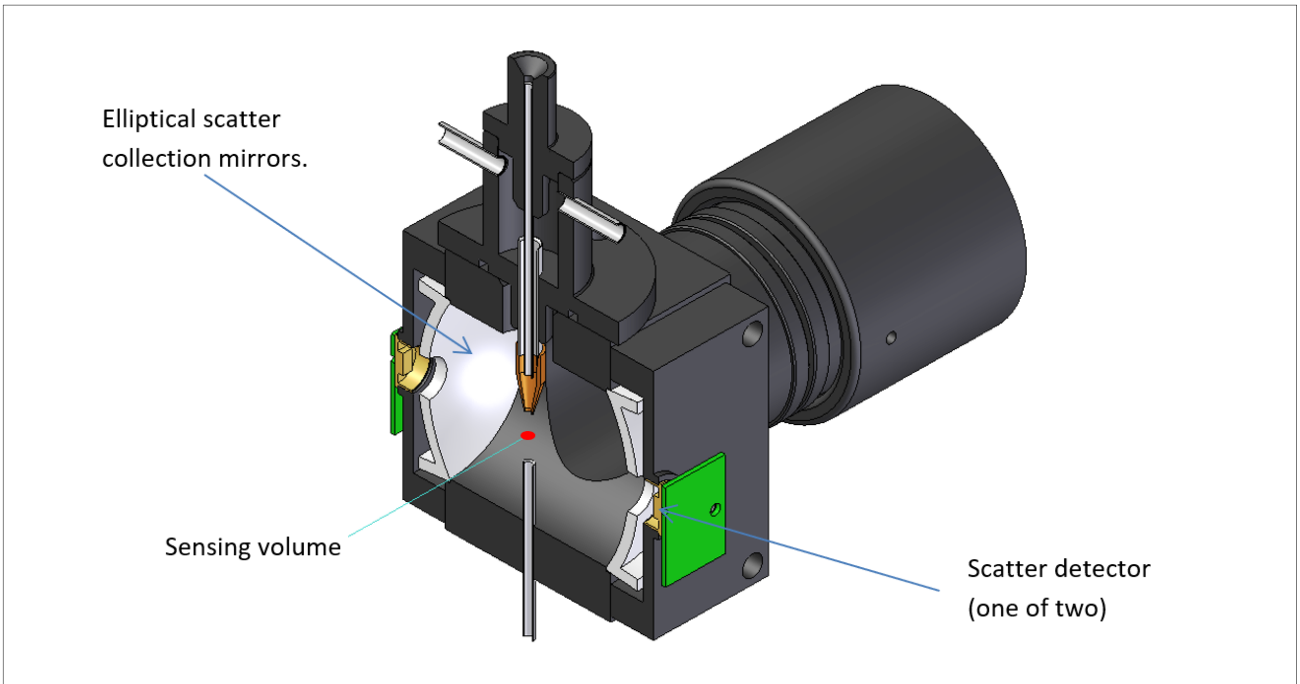


The picture below shows a two-dimensional cross-section of the RCS sensor module.



The pictures below show annotated sectional views of the sensor module (based on the first generation of prototype).


Sample Inlet
Polarizer 2
Sheath-flow port
Tapered delivery
nozzle
Scatter detector
(one of two)
Cylindrical lens
Birefringence
detector
Collimating lenses
Scattering chamber
2mm wide aperture
Vent to pump via
filter
Polarizer 1
Laser

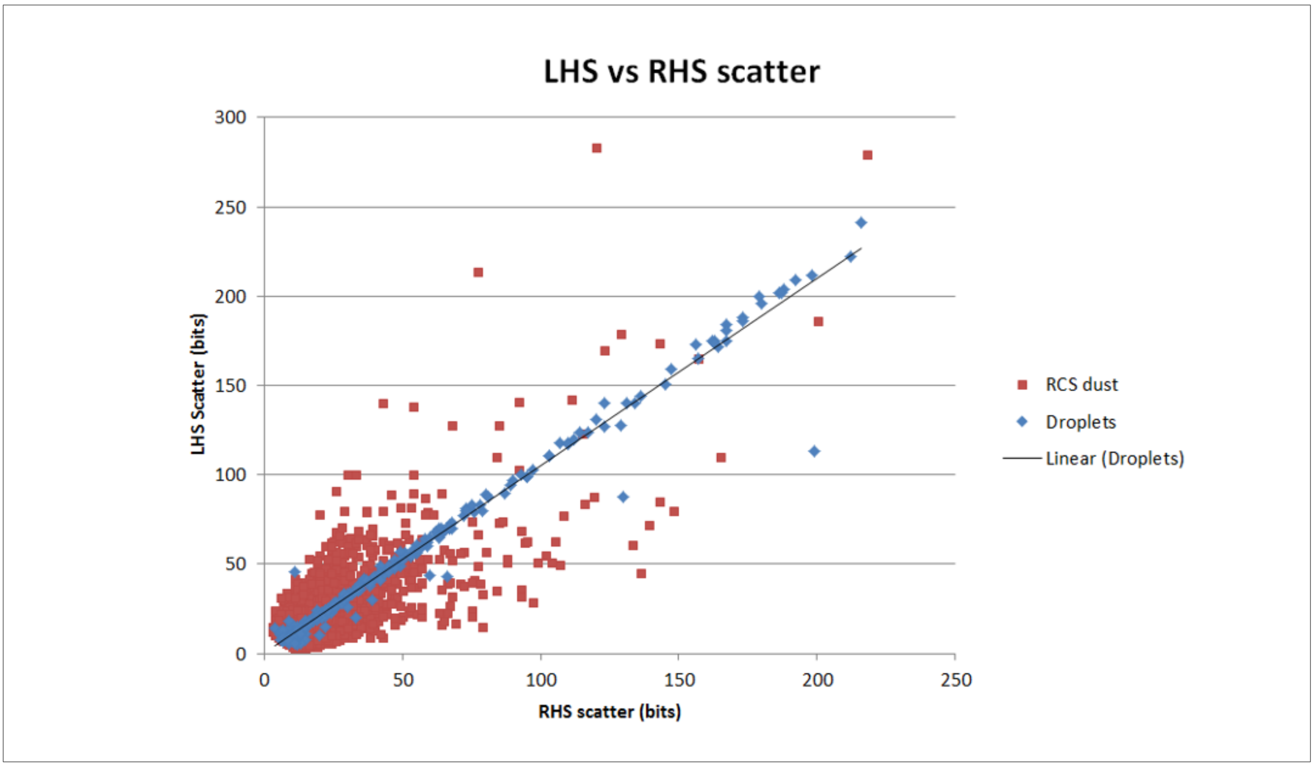

Elliptical scatter
collection mirrors.
Sensing volume
Scatter detector
(one of two)

1.6 Technology Explanation

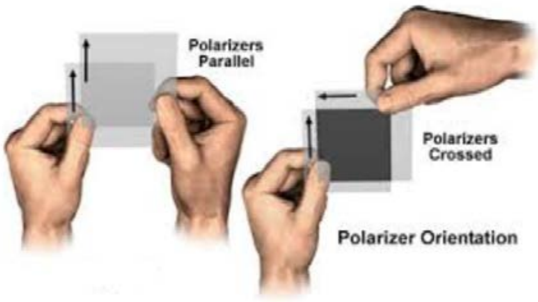
At the heart of the RCS detector is an Optical Particle Counter (OPC) sensor module that draws a volume of air (and particulates) through a scatter chamber and uses a laser in combination with several optical detectors to gather data on the stream of particulates passing through the chamber. As introduced in section 1.3, the RCS sensor module primarily relies on data gathered in relation to three distinct properties of RCS. These properties are size, shape, and birefringence. The techniques used to assess these properties are Mie Theory, scatter asymmetry and light polarisation. An advanced algorithm then combines the resulting data to determine whether a volume of particulates contains RCS. It is only when these data are combined that it is possible to accurately distinguish RCS from other types of airborne particulates.

Mie Theory (Size): Mie Theory is used to determine particle size. The intensity of the flash from the scatter of light as a particle passes through the laser beam can be used to approximate the size of the particle. The intensity of the flash typically increases as the size of particle increases. Whilst the size property is a very important in determining the presence of RCS, only a very basic description of Mie Theory is given as this technique is well known and often utilised in general particulate monitors incorporating OPC technology. Further details can be provided on request.

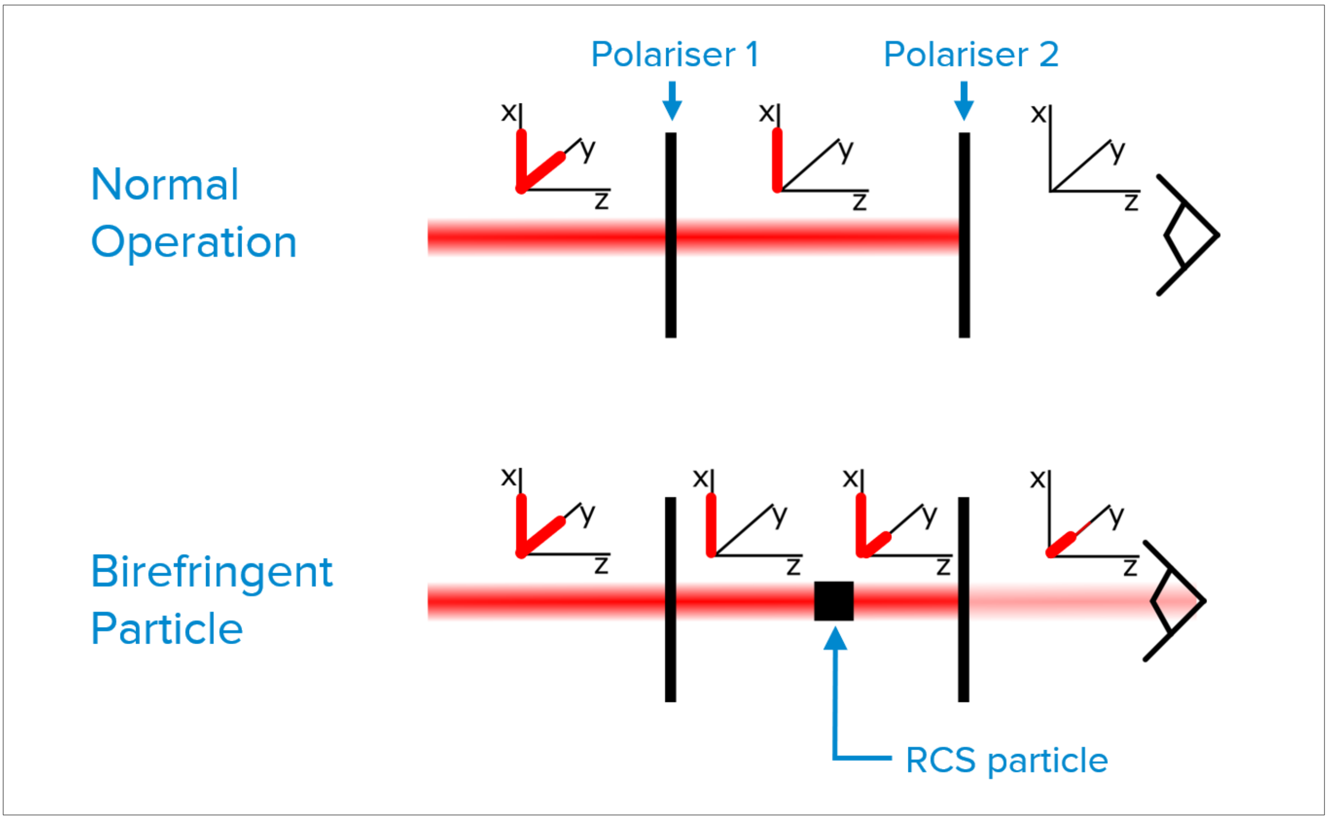
Scatter Asymmetry (Shape): By using two scatter detectors on opposite sides of the scatter chamber (see section 1.5), the scatter intensity seen at each detector can be compared to give a scatter ratio. This ratio is then used to determine a level of particle asymmetry. In the plot below, RCS is compared to spherical droplets. Left-Hand Side (LHS) and Right-Hand Side (RHS) refer to the scatter detectors on either side of the detector. RCS occurs in a range of shapes and size, hence the variation in the level of asymmetry. The line fitted to the droplet data shows that when particulates can be approximated as spheres, the LHS and RHS detectors see similar levels of light scatter.



Light Polarisation (Birefringence): Birefringence is an optical property of RCS and has the effect of changing the polarisation of light passing through the material. To detect this property, light from the laser first passes through a polariser before passing through the measurement volume and then a second polariser oriented at 90° to the first polariser. In standard operation the first polariser will block the horizontal component of the light beam from the laser and the second polariser blocks the vertical component i.e. all light is blocked. The image below shows a simple example of this (and can be easily demonstrated by removing the lenses from polarised sunglasses and overlaying them on top of each other).



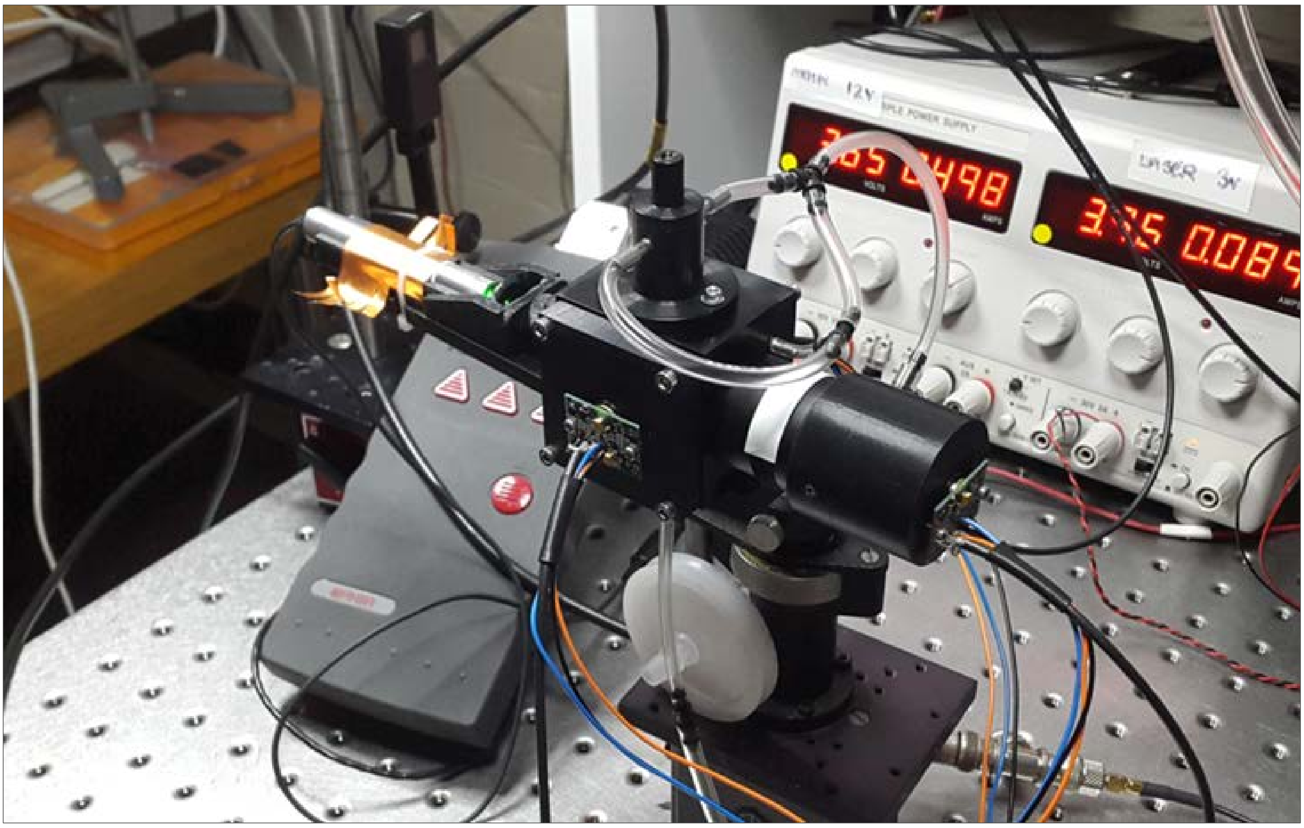
If, however, the light beam strikes an RCS particle with the birefringence property, the polarisation of the light will be changed marginally, thus allowing a small portion of the light through the second polariser. This signal is then picked up by the birefringence detector (see section 1.5). The diagram below further illustrates the technique.



As can be seen in the lower diagram, the beam strikes an RCS particle and changes the polarisation of the light, re-introducing a small horizontal component. As the second polariser is oriented to block the vertical element, this horizontal component passes through and is picked up by the detector. Birefringence can also vary dependent on particle size, so it is essential to combine this data with the size data.

1.7 Lab Results – Identification of RCS

The picture below shows the first generation of sensor module prototype undergoing bench testing at the University of Hertfordshire. The prototype was created as a proof of concept and has been used to gather data and validate the proposed techniques (see section 1.6).

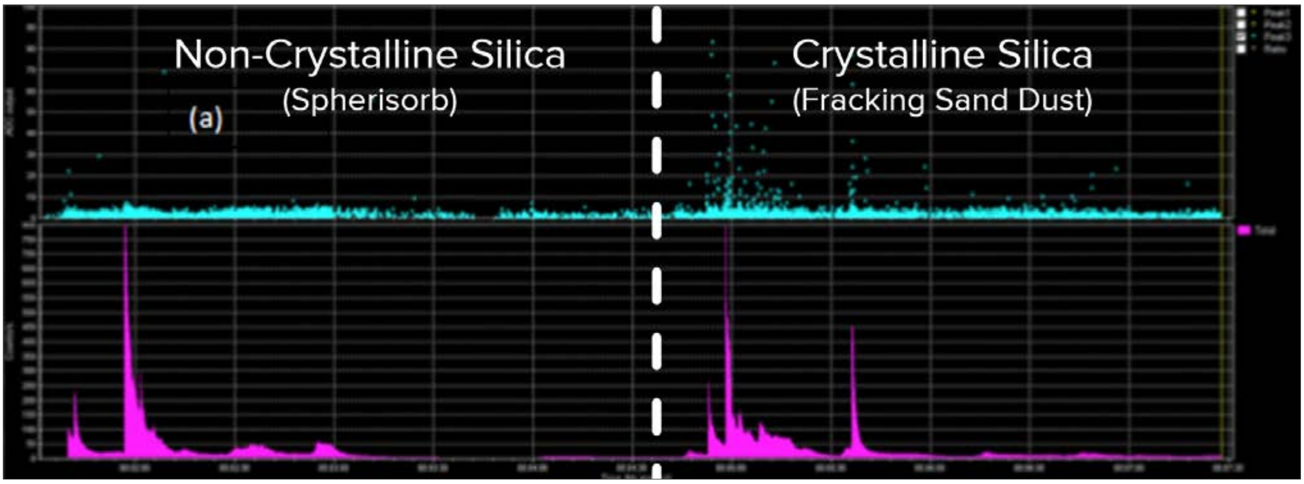


Initial results from this early prototype have been used to inform numerous prototype improvements and aid development of the critical algorithm. The prototype shown above requires additional electronics to aid high speed data acquisition. All processing of data during the trials to date has been completed ‘offline’ i.e. not in real-time.

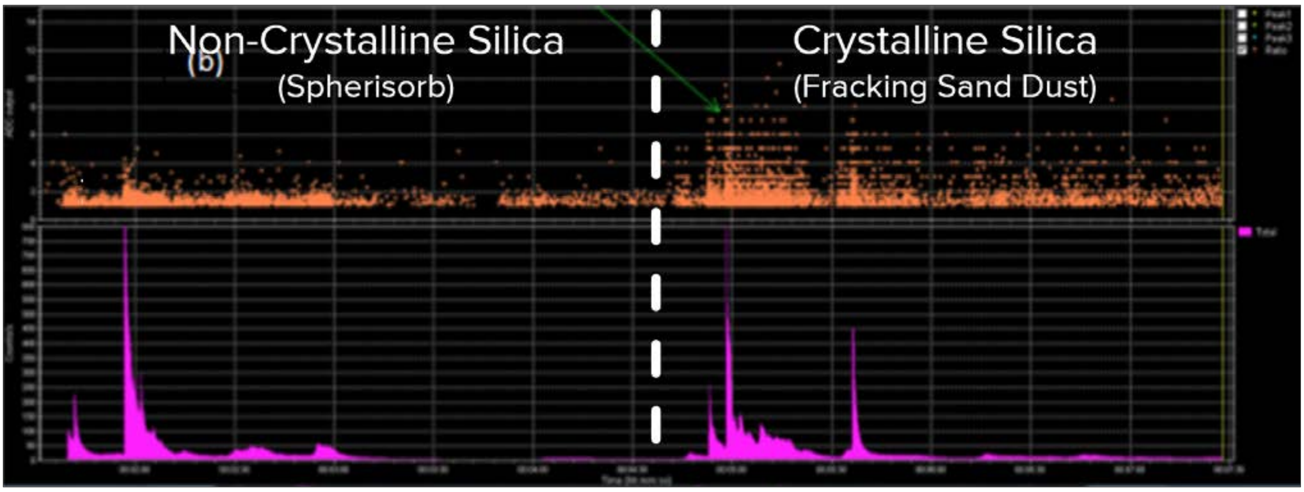
The majority of the initial research and prototype development work focussed on the birefringence signal and scatter ratio relating to RCS. Many parameters were investigated and adjusted in order to acquire high quality data sets. Sample laboratory results are shown on the next page.

Focussing on the scatter ratio and the birefringence signal (see section 1.6), the graphs below show the results when comparing non-crystalline Silica to Crystalline Silica.

Birefringence signal:



Scatter ratio:

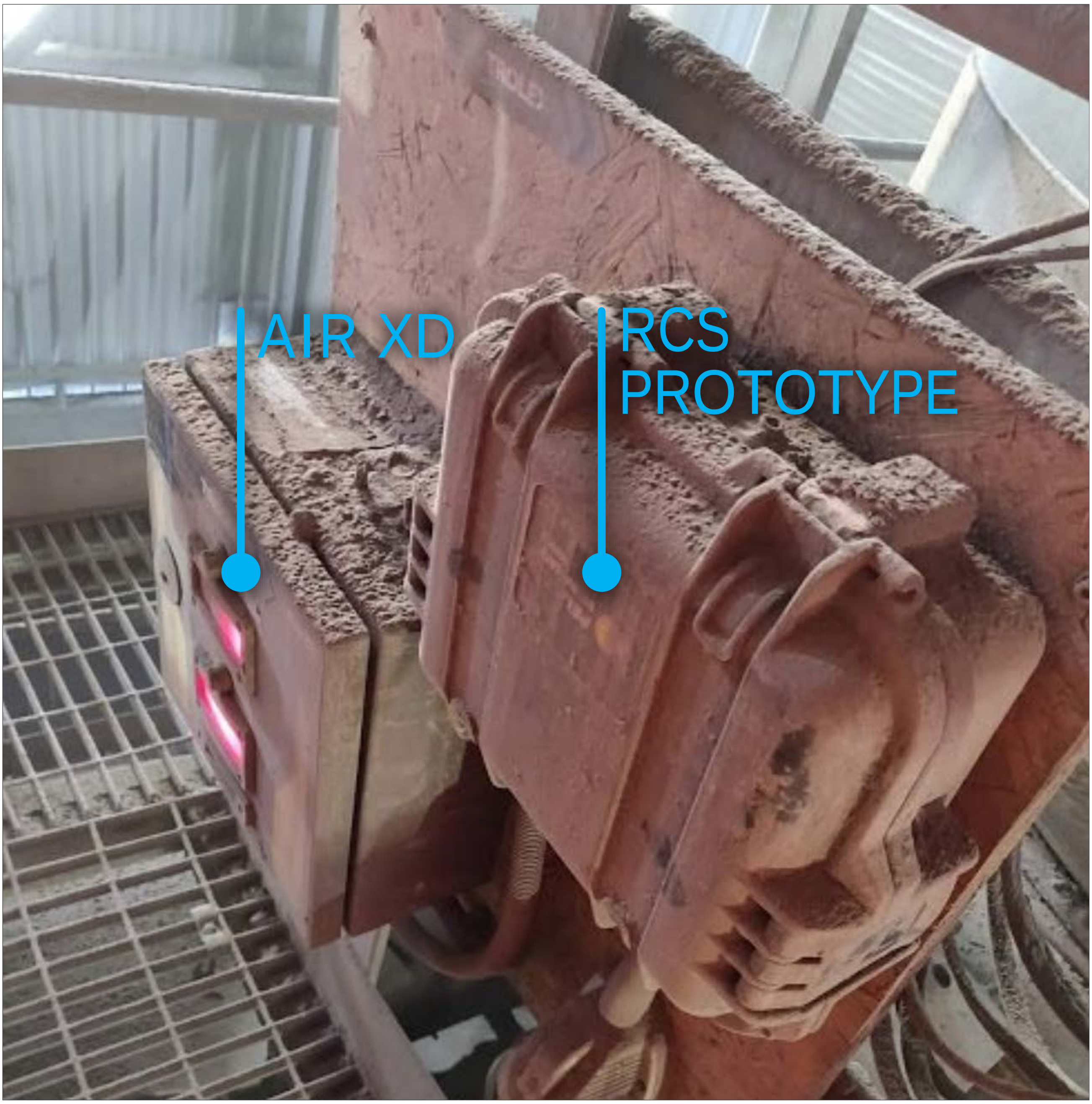


As can be seen in the graphs, both the birefringence signal and the scatter ratio show an identifiable difference between non-Crystalline Silica and Crystalline Silica. By statistically analysing both signals in combination with size data it is possible to identify Crystalline Silica from non-Crystalline Silica.

It is noted that lab experiments were carried out in a very tightly controlled manner with highly uniform samples. Further work has since been successfully carried out to verify operation with a wider range of samples.

1.8 Completed Field Trials – UK Quarry

The picture below shows a prototype RCS sensor housed in a Peli Case, mounted alongside an AIR XD general dust monitor, situated close to a crushing machine. This was one of the first field trials for the prototype RCS unit and was aimed at assessing performance in a real-world application situated in an extremely harsh environment. The unit performed exceptionally well both from the perspective of detecting particulates as well as operation under extremely high dust loading. The AIR XD was included in the trial to provide a benchmark dataset. Correlation between the two units was extremely good.



TROLEX

1.9 Current Position

As illustrated in the previous sections, Trolex has successfully demonstrated a technique for detecting RCS. Current successes have been achieved via two government-funded projects in collaboration with the University of Hertfordshire, combined with research conducted within Trolex.

The current focus of Trolex research and internal development activities are directed towards the following tasks with regards to the monitoring of RCS and the ultimate launch of the world's first Real-Time RCS Monitor:

- Algorithm development (ongoing)
- Generation of high-quality data sets for the current target applications (ongoing)
- Development of a fixed monitoring unit (ongoing)