# Innovative TDS Control System (ITCS)


## Summary

Detecting and controlling total dissolved solids (TDS) in steam boilers is important to the efficient and safe operation of the boiler. An innovative TDS control system (ITCS) based on a novel microwave TDS sensor was developed and demonstrated under the Industrial Energy Efficiency Accelerator programme. Under the programme, an industrial prototype of the ITCS was successfully developed and demonstrated on a 2,500kg/h steam boiler at Bakkavor Wigan UK. It showed significant improvement in boiler blowdown efficiency and subsequent energy savings and reductions in the boiler's carbon emissions in comparison to blowdown control systems that are based on conventional electrical conductivity TDS sensors. A longer testing period and full evaluation of the ITCS is planned in the near future. After encountering some challenges during the development of the microwave TDS sensor, the initial demonstration phase had to be shortened.


### The Industrial Energy Efficiency Accelerator (IEEA)

The IEEA programme supports the development of innovative technologies that will help industry reduce energy consumption and cut carbon emissions. It focuses on innovations with large potential cross-sector energy and carbon reduction impact - either new technologies or established technologies applied to new sectors. Over £15 million in public and private funding has been committed to develop solutions through partnerships between technology developers and industrial companies willing to test technologies on-site. The programme is funded by the UK government (BEIS) and managed by the Carbon Trust, with support from Jacobs.

## Introduction

When a steam boiler generates steam, impurities dissolved in the boiler's feedwater accumulate or concentrate in the steam boiler. Over time, the dissolved solids, known as total dissolved solids (TDS), become more concentrated, causing bubbles and foam to enter the steam line. This ultimately results in low quality, excessively wet steam and the contamination of control valves, heat exchangers and steam traps. Furthermore, highly concentrated levels of TDS can cause a build-up of scale on the fire tube, reducing the heat transfer from the fire to water side of the boiler. These potential impacts can ultimately reduce the capacity and efficiency of steam generation. The severity of the problem increases with boiler size, pressure and steam load.

When the TDS rises above a maximum allowable value and allows fresh water into the boiler to reduce TDS levels, TDS control systems automatically action a side blowdown (discharge) of boiler water. Since the action of a blowdown is a loss of energy and mass from the boiler water, it is important not to excessively discharge the boiler in a bid to main acceptable TDS levels in the boiler. Electrical conductivity probes used for detecting TDS levels in steam boilers are prone to scale build-up and measurement drifts and therefore need frequent probe recalibration. This can be a major drawback and cause user dissatisfaction. The severity of this problem increases with boiler pressure, which is why many high-pressure boiler operators stay away from automatic TDS control systems based on electrical conductivity sensors.

Through the IEEA programme grant, Spirax Sarco was able to gather further funding and accelerate the development of the ITCS.

## About the innovation

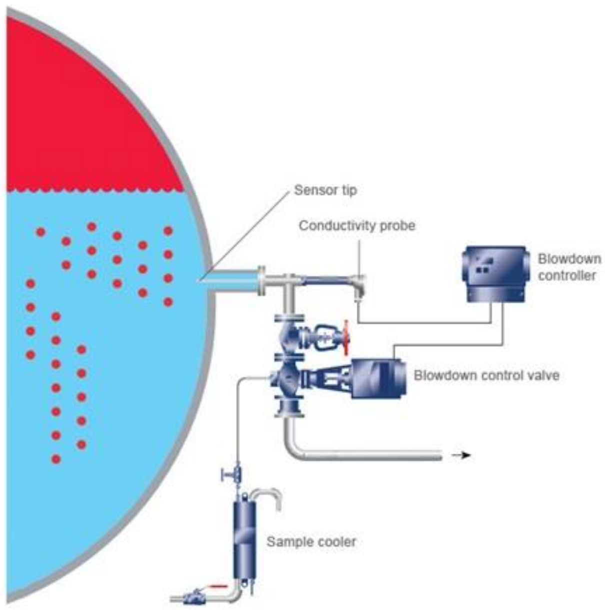


**Figure 1: A closed loop TDS control system based on an electrical conductivity probe**

In-line TDS measurement and control is crucial to efficient and safe industrial steam boilers. A typical automatic TDS control system tends to use electrical conductivity sensors to detect TDS levels in a boiler (see Figure 1). Then, with the aid of a blowdown controller and a control valve, it discharges highly concentrated water from the boiler and replaces it with clean water, keeping TDS levels within acceptable limits. Yet, commercially available TDS sensors are susceptible to measurement errors caused by scale deposition and measurement drifts, limiting the reliability of TDS control in boilers.

Spirax Sarco developed the microwave TDS sensor to overcome the traditional limitations of electrical conductivity-based TDS sensors. Its technology relies on electromagnetic interactions between electromagnetic waves which are propagated into the boiler water via the microwave TDS probe. A complex relationship between the intensity and phase of the electromagnetic interaction is proportional to TDS concentrations in boiler water.

The microwave TDS probe was designed and manufactured to fit an existing industrial boiler as well as on-head sensor electronics (see Figure 2).

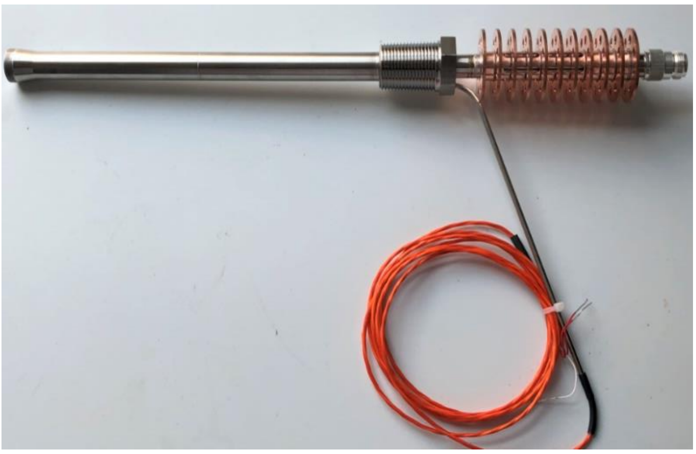

**Figure 2: Microwave TDS probe**

The microwave TDS prototype probe can operate in boilers with pressures and temperatures up to 100 Barg and 300°C respectively. On-head electronics are connected directly at the end of the probe. A temperature probe, which can be found within the microwave TDS probe, compensates for the effects of boiler temperature on the probe measurements. The TDS sensor processes measurements from the TDS probe before feeding them back in real-time to a blowdown controller. Here, the blowdown controller compares current TDS measurement to a setpoint value. Once that’s complete, it sends a control signal to open or close the control valve accordingly.

## The demonstration

The ITCS was trialled on a steam boiler in the plant room at Bakkavor Meals Wigan as part of the IEEA project. The goal was to demonstrate the energy savings and potential greenhouse gas reductions of the blowdown control. This was carried out by comparing the performance of the microwave TDS sensor with the installed electrical conductivity TDS probes. Bakkavor Meals Wigan is part of the Bakkavor Group, a leading provider of fresh prepared food. The ITCS was trialled on their 2,500 kg/h steam boiler, which uses natural gas fuel. The ITCS demonstration project included the following activities:

1. Design and development of boiler energy monitoring
2. Boiler monitoring and energy benchmark
3. ITCS design and development

4. ITCS installation and commissioning

5. ITCS system monitoring and evaluation

## Energy benchmark

A boiler energy monitoring system highlights the sensors and instruments that monitor various parameters within the boiler (see Figure 3). This is done to benchmark the boiler's energy performance. It includes a gas flow meter, steam flow meter, feedwater flow meter and blowdown flowmeter developed by Spirax Sarco.

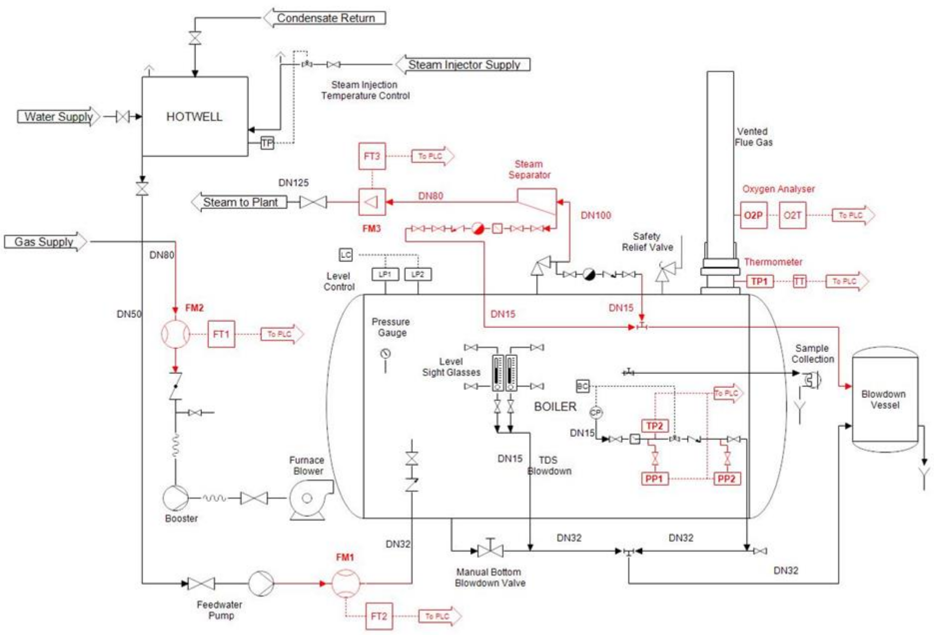


**Figure 3: PI&D diagram of the demonstration boiler showing metering systems (in red) under the project**

An instrumentation panel collects, displays and stores data signals from the meters and sensors. It is also a gateway to remotely monitor the installed sensors and collect data from devices via a Strata energy management cloud-based dashboard. After monitoring the demonstration boiler for ten months, a baseline energy performance report was produced.

## ITCS development

**Figure 4: Panoramic view of simulation steam boiler test rig**

As the boiler benchmarking was being monitored, Spirax Sarco designed and developed an industrial prototype of the microwave TDS probe and sensor. During this stage, various iterations of the probe were simulated, manufactured and tested to meet the desired technology requirement and performance. The final probe design was optimised to ensure a safe and efficient operation of the probe. An advanced microwave TDS probe calibration and sensor algorithm helped to overcome challenges associated with calibrating the probe in a boiler. Finally, the team integrated the various components of the ITCS at the Spirax Sarco steam testing laboratoryFigure 4 under relevant operating conditions (see Figure 4).

## ITCS delivery and installation

The existing electrical conductivity TDS probe and its associated control system was replaced with the ITCS including the microwave TDS probe (see Figure 5). Shortly after commissioning the system, the boiler's burner failed, causing significant delays across the monitoring phase. In addition, probe failures caused by chemical attack on the probe material meant the team had to uninstall the probe for safety reasons.


**Figure 5: Picture showing the ITCS and instrumentation panels installed on the steam boiler at Bakkavor Wigan**

After addressing the issue, the probe was successfully remanufactured, installed and commissioned ready for the project's monitoring stage.

## ITCS monitoring

The ITCS was installed and commissioned on the Bakkavor 2,500 kg/h boiler, automatically controlled the TDS blowdown based on continuous TDS measurement. The energy monitoring system enabled real-time monitoring of the boiler onsite via HMI touch screen and online via a Strata energy management cloud-based platform. During this stage, the operator mirrored the conditions of the project's benchmark stage. In doing so Spirax Sarco could evaluate the energy and greenhouse gases emission performances of the boiler, comparing data from the ICTS and benchmark stages. Originally, the monitoring period was scheduled to last seven months. However, due to delays from producing a replacement probe, the monitoring period was reduced to nine weeks. After completing the IEEA programme, Spirax Sarco plans to test and evaluate the ITCS at Bakkavor for a longer period.

## Results

The aim of the ITCS project under the IEEA programme was to demonstrate ITCS's potential to reduce boiler blowdown and subsequent energy savings and greenhouse gases emission reduction in comparison to boilers with conventional blowdown control systems. In addition, the system demonstrates improved reliability by reducing the frequency of probe recalibration.

Spirax Sarco collected data over a period of two months, before analysing and comparing it to the baseline data from the project's energy baseline phase. The demonstration phase was originally scheduled to run for seven months but had to be shortened due to delays. Nonetheless, initial data gives good indication of the benefits which will be further validated from longer term testing after the completion of the IEEA programme.

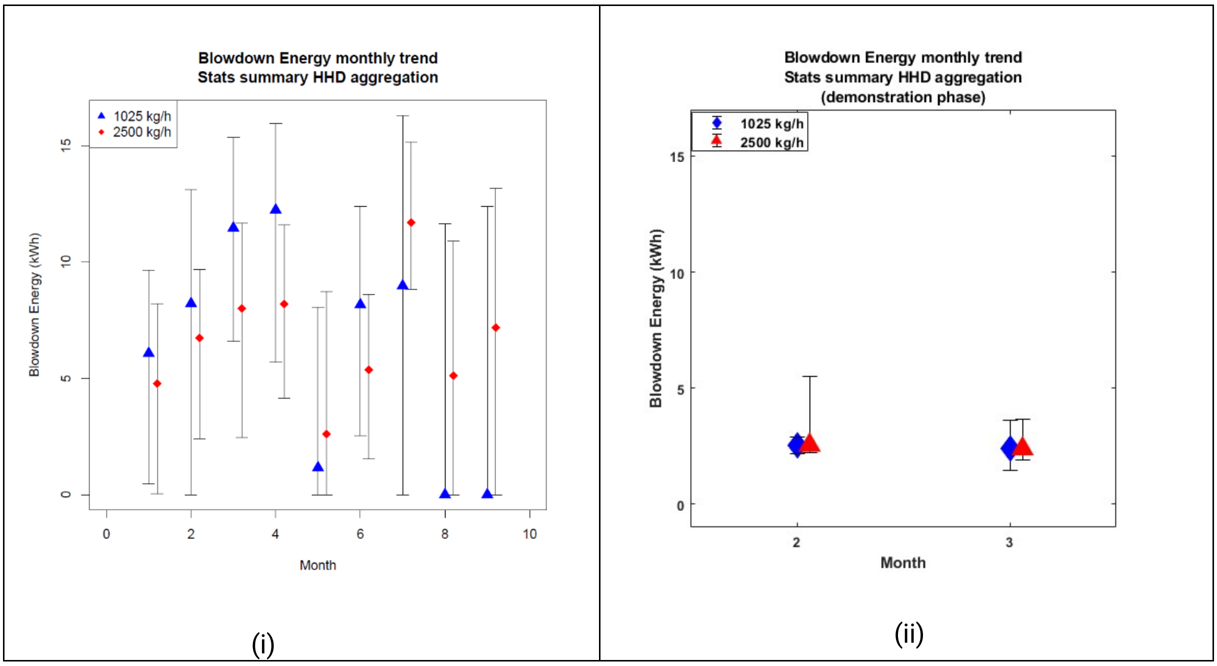


**Figure 6: Monthly HHD Boiler blowdown energy over the (i) benchmark and (ii) demonstration stages.**

As shown in Figure 6, the blowdown energy for the demonstration stage is significantly lower in comparison to that of the benchmark stage. It is worth noting that during the summer, the median blowdown energy reduced in comparison to the winter and spring months. This shows a correlation between the blowdown energy and the boiler efficiency. With lower boiler losses, heat is conserved in the boiler, consuming less gas to generate steam. This ultimately leads to higher boiler efficiencies.

As shown in Figure 7, the thermal efficiency of the boiler is higher during the demonstration stage. This improvement in the boiler's thermal efficiency is mainly due to a reduction in blowdown, i.e., reduction in blowdown energy (see

Figure 6). These gains were achieved by optimising the controller's blowdown dead band from 10% to 2%. Unlike conventional electrical conductivity TDS probes, this improved accuracy and stability of the microwave TDS probe enables a tight control dead band. It is expected that a 1% reduction in blowdown could lead to about 0.2-0.8% in energy savings.

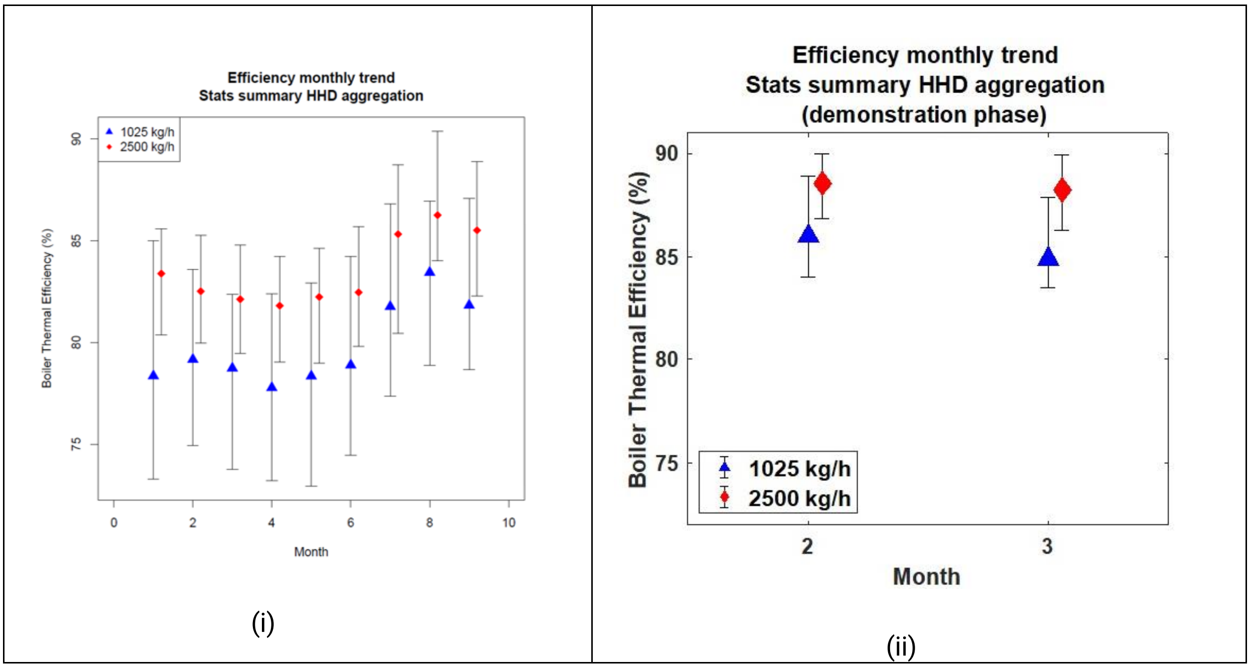


**Figure 7: Monthly HHD Boiler efficiency over the (i) benchmark and (ii) demonstration stages at medium and high steaming rate conditions.**

Table 1 shows a summary of the boiler's performance over the period of demonstration compared to that of the baseline. The energy performance of the boiler with the ITCS showed a:

- 6% thermal efficiency of savings
- 30% reduction in percentage blowdown
- 76% reduction in the frequency of TDS probe recalibration

**Table 1: Summary table of the HHD boiler's energy performance during the baseline and benchmark stages**

| TDS level control system | Boiler thermal efficiency [%] | Boiler blowdown losses [%] | TDS probe calibration frequency (per week) |
|---|---|---|---|
| **Baseline (old system)** | 83 | 0.66 | 1.58 |
| **ITCS** | 88 | 0.39 | 0.375 |
| **Change** | 5 | $-0.2$ | $-1.21$ |
| **% Change** | 6% | -30% | -76% |

A typical boiler, such as the demonstration boiler, with a baseline using 8.9MWh per annum with an average annual gas price of 2.91 pence/kWh and 6% energy savings will save customers about £15,613. At launch, the ITCS is expected to be sold for about £8,000 with a six-month payback period. These savings do not include savings from reduced chemical and water use.

The annual greenhouse emission savings just for the demonstration boiler were determined to be 120 tonnes of $CO_2e$. That is the same as removing 26 passenger cars from the road. This reduction does not include equivalent savings associated with reducing water and chemical use.

## Future impact

### Market potential in target sector

The ITCS adds value to all steam boiler and boiler house control systems, and is therefore not limited to any industrial sector. Currently, industrial boilers must have at least two level sensors and one electrical conductivity sensor for level and TDS detection respectively. There is a total addressable potential of about 500k units of industrial steam boilers worldwide. Spirax Sarco and its subsidiaries have a presence in all regions and industrial sectors and will look to address this gap.

### Potential future energy and carbon savings

The energy savings and corresponding greenhouse gas emissions of a boiler deploying the ITCS will depend on the method of TDS control. Steam boilers with manual or fixed blowdown control will see the highest savings. Boilers with modulating control for feedwater, burner, gas and load can take advantage of the ability to reduce the TDS control band to as low as 1.5%. This will optimise control and minimise blowdown, ultimately leading to significant savings.

## Innovation lessons

### Lessons for other innovators

Developing novel technologies is challenging. It requires periodic reviews to leverage insights from stakeholders and partners. The key learning from this programme was the need to adopt agile processes that will allow effective design changes. This strategy encouraged the development of an advanced microwave probe calibration technique. For this, Spirax Sarco has already filed a patent application to overcome any barriers to the probe calibration post-installation without having to change the probe calibration procedure for conventional TDS probe calibration. This promotes end-user adoption of the technology.

This strategy will resolve the challenges of having to substitute the probe's construction material, which is prone to chemical attacks. By partnering with material science experts and engineers within the project, Spirax Sarco will be able to identify and evaluate the material for the optimised prototype of the microwave TDS probe.

## Barriers needed to be overcome for successful replication of ITCS

The probe failure experienced after the first installation of the microwave TDS probe, highlighted the need to change one of the probe's materials so it can survive the boiler's harsh conditions without falling under a chemical attack. Following successful demonstration, this will be the top priority for Spirax Sarco's design team.

The international boiler market is very conservative. For the past six decades, the market has seen electrical conductivity TDS probes as the sole solution for measuring TDS content. As such, the sales campaign must emphasise effective customer benefits, such as fuel and system maintenance cost savings. The potential to reduce the carbon footprint and improve steam quality of steam boilers will also be emphasised.

## Future developments for ITCS

The microwave TDS probe will undergo further product development processes under a strategic new-to-the-world, new-to-Spirax product service or solution offering. The team is currently working on an advanced self-calibration technique which will allow the probes to become fit and forget. This technique will no longer require operators to manually recalibrate the probe. Additionally, Spirax Sarco will complete a commercial design of the ITCS system with the support of industrial development partners such as Martec UK Ltd, SGA Technologies UK Ltd, and LA Techniques UK. A hybrid manufacturing approach will be applied as some elements of the system will be contracted with final assembly and testing in-house at Spirax Sarco. Finally, the commercial prototype will be optimised for quality, reliability and compliance with various standards by relevant regulatory bodies—local and international—such as the American Society of Mechanical Engineers (ASME), the American ANSI and the European standardising body.

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