Internal Pitting Corrosion

Background

Cokeusters Ltd were requested by a reputable global group of refining companies to carry out a Merlin™ in-line inspection of three separate sections of 6-inch furnace tube. The three sections of tubing had been removed from the furnace due to the presence of severe internal pitting corrosion. The aim of the investigation was to observe the geometric data acquired from the Merlin intelligent pig within these corroded areas. The three sections of tubing were sent to the Cokebusters Technology Centre (UK), where the tests were conducted. The inspection was carried out using the patented Merlin™ Intelligent In-line inspection, or intelligent pigging system for accurate geometric assessment of the tube sections.

Merlin Inspection System

The **Merlin™ Mark IV Smartpig** is a carbon fibre, single bodied un-tethered device, which employs a series of ultrasonic transducers to measure tube wall thickness and internal radius at equally spaced circumferential locations along the full length of the heater coil, effectively scanning the process tubes for geometric abnormalities or defects. The intelligent pig records and stores the received data to its on- board memory, which is later uploaded via USB to a computer. The data is then automatically interpreted and analyzed by the Merlin™ software, which can then output various graphical images and C-scans of the process tubes.

The intelligent pig itself is constructed from a neutrally buoyant, moulded carbon fibre body, the interior of which contains the electronic circuitry, and lithium-ion battery back. The microprocessor manages the operation of the whole device, including data acquisition, sorting and storage. The battery pack is capable of achieving a run time of up to 8- hours before a recharge is necessary.

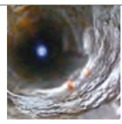
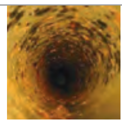
The scanner unit employs a series of custom built piezo-composite transducers, each constantly firing and receiving a complexity of rapid-fire ultrasonic pulses. The moulded body is encased in a separate Carbon Fibre/HDPE/Kevlar framework for protection and propulsion through the furnace tubes. This complete unit is able to be driven bi-directionally through tight radius tube coils under water pressure supplied by the same pumping unit as used for mechanical decoking.

Figure 1: Merlin Mark IV Intelligent Pig

Testing

The three tube sections to be tested were classified as described in **Table 1**. Clear evidence of severe internal pitting was visually observable within each tube. This pitting was seemingly more obvious on Section C29, where the pitting at the either end of the tube was more severe. Internal visual examination was hampered by the length of the tubes, making it impossible to visually locate defective areas towards the center of the sections.

Table 1: Classification of Tube Sections

Tube Reference	Composition	Visual Defects	
C28	A-106, TNOM 11.0mm		Severe Internal Pitting
C29	A-106, TNOM 11.0mm		Severe Internal Pitting (More observable at end)
A27	A-106, TNOM 11.0mm		Severe Internal Pitting

The three tube sections were fitted with removable (temporary) flanges at either end to accommodate pig launchers/receivers. Each tube was then connected to a Cokebusters S21 pumping unit to create a "closed loop", whereby the Merlin intelligent pig was able to be maneuvered bi-directionally along each tube section.

A series of four separate inspection runs were carried out bi-directionally on each test section for validation of data. Additionally, two further inspections were carried out on each tube using a different Merlin Intelligent Pig for comparison purposes. The data obtained from each inspection was collated and analyzed using standard Merlin procedures.

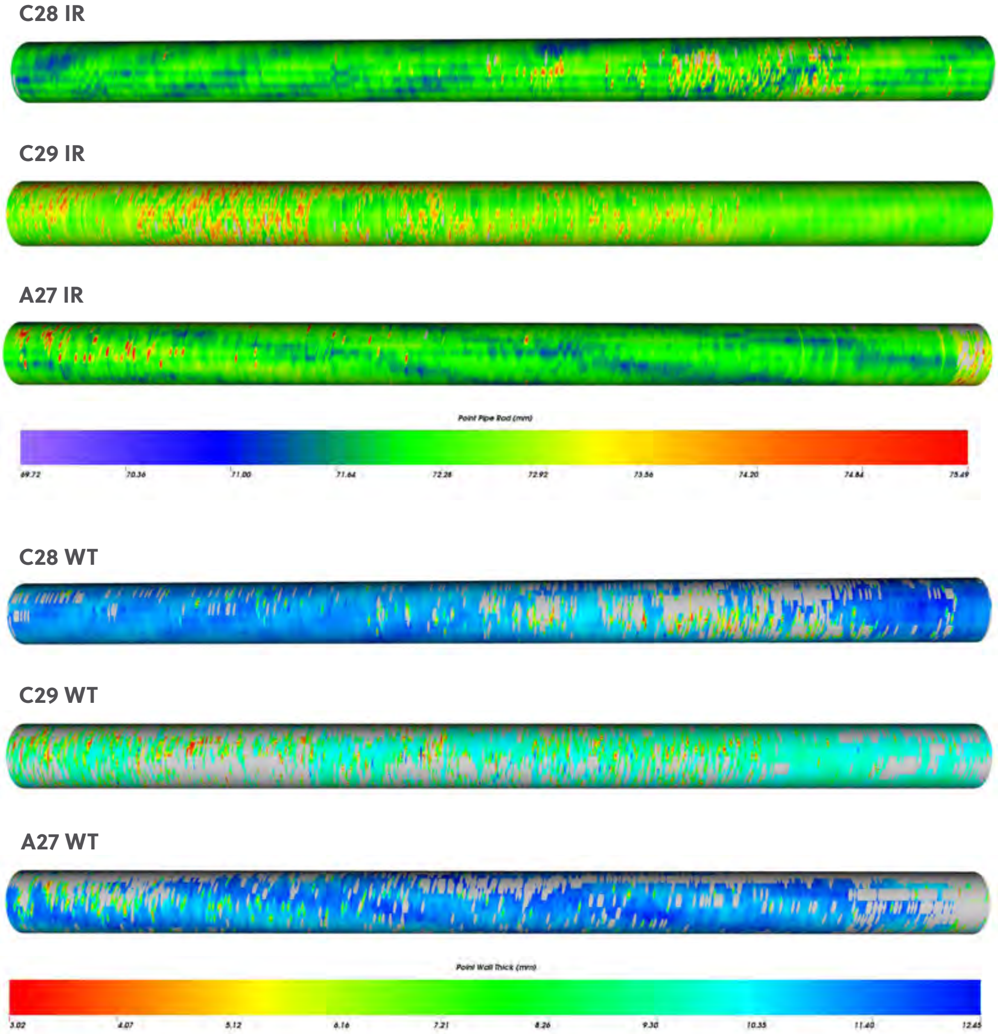


Figure 2: C-Scan images displaying internal radius (top) and wall thickness measurements (bottom)

Results

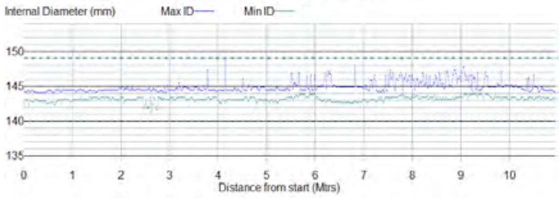
Evidence of wall loss through internal pitting corrosion was clearly apparent from the geometric tube data obtained from the inspection operations. Where an internal pit is present, a reduction in tube wall thickness corresponding to an increase in internal diameter would be expected. **Figure 2** shows the resulting wall thickness and internal radius C-scans obtained.

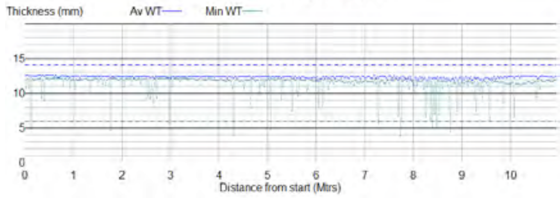
The corresponding linear graphical plots displayed an obvious pattern, consistent with internal pitting. The wall thickness and internal diameter data obtained within the areas of pitting showed a high standard deviation from the nominal values, indicating a variety of pit depths. **Figure 3** shows the typical graphical plots obtained from the three tube sections.

Section C29 showed the most severe pitting of the three sections tested. The damage was distributed throughout the full length of tubing, with a minimum wall thickness of 3.0mm measured. Data tables summarizing the wall thickness and internal diameter measurements obtained can be seen in **Tables 2** and **3**.

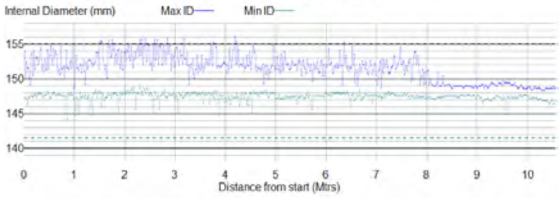
In areas where the pitting was dense, i.e. high amount of pits per internal surface area, significant amounts of ultrasonic scatter were observed. The result of the scattering effect was a loss in wall thickness data at these locations. This can be seen as the grey shaded areas in the C-scans shown in **Figure 2**.

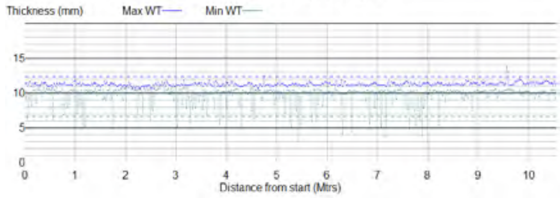
C28



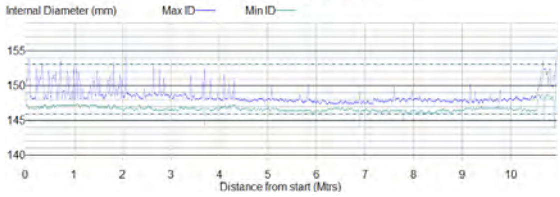


C29





A27



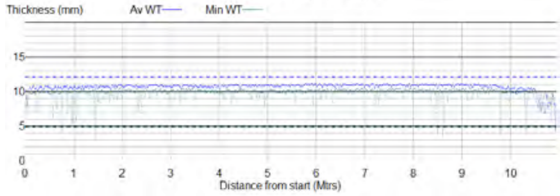


Figure 3: Linear graphical plots showing average/minimum wall thickness & maximum ID with respect to tube length

Table 2: Wall thickness data table for sections C28, C29 & A27

Tube Reference	Average Wall Thickness	Minimum Wall Thickness	Minimum WT Axial Location	Maximum Wall Loss
	mm	mm	mm	mm
C28	**12.4**	**3.8**	**7.6**	**7.2**
C29	**10.4**	**3.0**	**5.4**	**7.9**
A27	**10.7**	**3.1**	**1.4**	**7.9**

Table 3: Internal diameter data table for sections C28, C29 & A27

Tube Reference	Average Internal Diameter	Minimum Internal Diameter	Minimum ID Axial Location	Maximum Internal Diameter	Maximum ID Axial Location
	mm	mm	mm	mm	mm
C28	**144.1**	**141.3**	**2.6**	**149.1**	**4.1**
C29	**147.2**	**142.7**	**10.5**	**155.0**	**1.5**
A27	**147.6**	**143.9**	**10.9**	**155.6**	**10.9**

Discussion

It has been proven that the Merlin Mark IV inspection system is able to detect areas of internal pitting corrosion, found within the three tube samples supplied by the client. The areas of the pitting were accurately located both along the tube length and circumferentially around the tube. **Figure 4** shows an example of the pitting detail observed in Section C29.

ULTRASONIC SCATTER

The wall thickness measurements obtained by the intelligent pig are reliant on a solid, even surface from which the reflected ultrasound signal can penetrate. When the morphology is uneven, the transmitted ultrasound signal can be deflected, causing a loss in the reflected signal. This will result in a zero reading at this point. This loss in wall thickness data is therefore proportional to the pit density within the tube.

RESOLUTION

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Discussion (continued)

LIMITATIONS

The Merlin system employs ultrasonic immersion transducers, centered around a frequency of 5MHz. This design frequency was chosen during the design stage to provide a good response to wall thickness measurements in the range of 3 – 20mm. Consequently, at areas where the wall thickness falls below 3mm, the reliability of the measurements also decreases. This phenomenon is well documented in NDT literature and inherent of any ultrasonic based measuring system using this frequency of single element immersion transducer. The key objective to using an intelligent pigging system for furnace tube assessment is to accurately locate anomalies and flaws. The identified anomalies can then be further investigated/assessed using alternative methodologies such as handheld UT measurement and other corrosion mapping techniques.

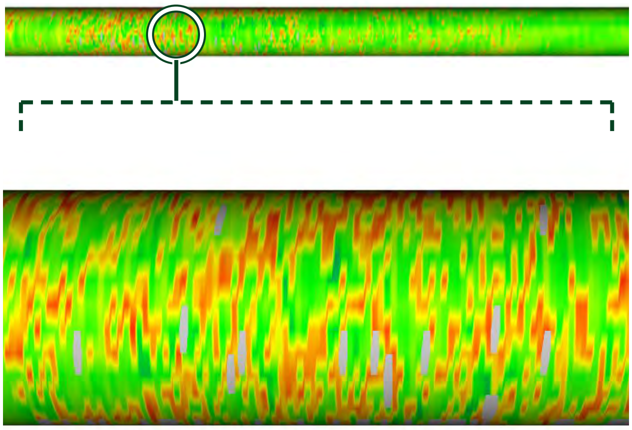

Figure 4: C-Scan identifying an area of dense internal pitting in Section C29

Conclusions

- Inspection of three separate tube sections was carried out using standard operating procedures with the **Merlin Mark IV intelligent pig**.
- The as-obtained wall thickness and internal radius data highlighted problematic areas within each of the three tube sections.
- Each data measurement was accurately mapped to its correct axial and circumferential location within the tube.
- The wall thickness and internal radius data gathered was consistent with internal pitting corrosion.
- The minimum measured wall thickness was 3.0mm (Section C29), relating to a maximum pit depth in the region of 8mm. Wall thickness measurements below 3mm are limited by the centre frequency of the immersion transducers used within the Merlin intelligent pig.
- Internal pitting was clearly identified within each of the three tube sections provided by the client.

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