An Improved Tube Plugging Technique for Ammonia and Urea Plant Heat Exchangers
Eliminates Welding, Reduces Downtime and Increases Reliability

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Abstract

The Pop-A-Plug® Tube Plugging System is a proven, safe and effective solution for plugging leaking and degraded heat exchanger tubes. Pop-A-Plugs® have been successfully used in critical applications in the nuclear power, fossil power and chemical industries for greater than 15 years. When recently approached with an ammonia plant Waste Heat Boiler plugging problem EST responded with a fast and simply installed mechanical tube plug with the same or better installed stability than the welded plugs they were replacing. This paper provides an update on the technical developments and advantages of the Pop-A-Plug in Ammonia and Urea Plant applications.

We will provide details documenting the development of Pop-A-Plugs specifically for this service and how this significantly reduces the shutdown time required to seal tubes in such service. Everybody knows that welded plugs in high pressure heat exchangers in urea plants are prone to leaking problems as the proper quality of the welds is difficult to assure. Pop-A-Plug® System plugs promise a much better reliability than welded plugs.

Figure 1. High Pressure Pop-A-Plug® II

Figure 2. Hydraulic Installation
Introduction

SKW Stickstoffwerke Piesteritz GmbH (SKW) is the largest producer of ammonia and urea in Germany. The company operates two Kellogg Ammonia Plants, each with an output of 1,650 mtpd (first name plate: 1,350 mtpd), three Stamicarbon CO2 Stripping Plants (all with a capacity of over 4,000 mtpd), one Uhde Nitric Acid Plant and other plants for the production of special products.

The ammonia plants of SKW are designed by M W Kellogg and engineered by Toyo Engineering. The plants were commissioned in 1973 and 1975 respectively. The process is a conventional steam reforming process. Both plant’s capacity was increased to 1,650 mtpd in 1989.

This Kellogg Ammonia Plant operates a secondary reformer 103-D followed by 2 primary waste heat boilers 101-CA/CB in parallel, followed by one secondary waste heat boiler 102-C.

Problem 1 – Secondary Waste Heat Boiler 102C

The 102-C waste heat boiler is a fixed tube vertical heat exchanger with 1,101 tubes 25.4 mm OD x 5.16 mm wall. Both the tubes and tube sheet are manufactured of hydrogen resistant 10CrMo910 (ASTM A182 F22) steel. The tube-to-tube sheet joint configuration is shown in Figure 3. The operating parameters are as follows:

- Tubeside Pressure: 35.5 BarG, Temperature (low) 340°C; (high) 450°C
- Medium: Process Gas
- Shellside Pressure: 118.0 BarG, Temperature 330°C;
- Medium: Steam Boiler feed water

Pitting corrosion due to caustic reaction results in tube leakage. Leaking and / or degraded tubes identified by eddy current examination require plugging so they may be taken out of service.

Historically the process used to seal the leaking tubes required fitting a tapered plug and seal welding it to the tube end and tube sheet face. Due to the material the process required both pre-heat and post weld heat treatment. This repair process is time consuming and the waste heat boiler had to be fully isolated and gas free. The repair process typically required a three day evolution. The welding is difficult and is prone to cracking failures in service, see Figure 4.

Problem 2 – Primary Waste Heat Boilers 123-C1/C2

Waste Heat Boilers 123-C1/C2 are heat exchangers with 19.05 mm OD x 3.10 mm wall tubes. The tube and tube sheet material is 10CrMo910 (ASTM A182 F22) hydrogen resistant steel. The tube to tube sheet joint configuration is shown in Figure 5. These are higher pressure units with operating conditions as follows:

- Tubeside Pressure: 320.0 BarG,
- Temperature 345°C
- Medium: Process Gas
- Shellside Pressure: 115.0 BarG,
- Temperature 330°C;
- Medium: Boiler feed water
Pitting corrosion due to caustic reaction results in tube leakage. Leaking and/or degraded tubes identified by eddy current examination require plugging so they may be taken out of service.

Historically the process used to seal the leaking tubes required fitting a tapered plug and seal welding it to the tube end and tube sheet face. Due to the material the process required both pre-heat and post weld heat treatment. This repair process is time consuming and the waste heat boiler had to be fully isolated and gas free. The repair process typically required a three day evolution. The welding is difficult and is prone to cracking failures in service, see Figure 6.

Pop-A-Plug® Features

The Pop-A-Plug System is a comprised of Pop-A-Plug tube plugs, tube preparation, plug installation and removal hardware. Pop-A-Plugs are a simple mechanical tube plug consisting of three metallic components: a conical shaped Pin, a sealing Ring with both internal and external serrations, and a tensile component called a Breakaway, shown in Figure 7. During installation the conical pin is drawn through the Sealing ring, expanding the Ring radially outward. As the Ring contacts the tube wall the pulling force compresses the ring between the tube and the conical ring crushing the serrations and forming a leak tight seal. The pulling force is precisely controlled by the Breakaway which breaks or “pops” when the plug is set. Pop-A-Plugs can be installed in minutes, including simple tube preparation steps. The Pop-A-Plug design is a proven performer with long term reliability in high and low pressure critical heat exchanger applications in a number of industries including the nuclear and fossil power generation, refining and petrochemical. Pop-A-Plugs eliminate the need for welding in plugs and provide considerable time savings. The Pop-A-Plug heat exchanger tube plugs are the only plugs featuring the patented internally serrated ring design which increases plug performance and pressure holding capability under extreme thermal and pressure cycling.

The precision Breakaway controls the installation force. This protects against damage to tube, tube sheet ligaments and the adjacent tube sheet joints, extending the life of your heat exchanger and reducing costs when you need to re-tube. Pop-A-Plugs are available in over twenty-five different materials. Matching the plug to the tube material eliminates concern over galvanic corrosion or differences in the rate of thermal expansion further insuring long term reliability during temperature and pressure cycling.
Solution

SKW approached EST to find a better solution for plugging their waste heat boilers – improving plug reliability, eliminating welding and speeding up the process.

The first step was for EST Group to investigate the suitability of ASTM A182 F22 Class 3 alloy for suitability as a Pop-A-Plug. Adequate tube preparation is a critical step in the success of any plugging operation. EST has found that a combination of reaming to remove excess weld material or tube end damage, then brushing with a special tube preparation brush which sizes the tube end, eliminates the effects of pitting and erosion, reduces tube end ovality and improves plug holding capability. Plug size selection for the 102-C unit called for tube preparation using a combination of reaming and brushing to an inside tube diameter of Ø 16.0 mm. Using a similar combination of preparation steps, the plug size was determined for the 123-C1/C2 units with an inside diameter to Ø 20.0 mm.

EST Group designed, manufactured and qualified an appropriate Pop-A-Plug made from ASTM A182 F22 Class 3 for each heat exchanger.

Table 1. Pop-A-Plug Operating Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>102-C Unit</th>
<th>123-C1/C2 Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug Model</td>
<td>Pop-A-Plug II (P2)</td>
<td>Pop-A-Plug II (P2)</td>
</tr>
<tr>
<td>Part Number</td>
<td>P2-630-CR-SP0611</td>
<td>P2-790-CR-SP0611</td>
</tr>
<tr>
<td>Size Range, Tube ID</td>
<td>16.03-16.51mm</td>
<td>20.09 to 21.57 mm</td>
</tr>
<tr>
<td></td>
<td>0.631-0.660 inches</td>
<td>0.791 to 0.810 inches</td>
</tr>
<tr>
<td>Operating Pressure</td>
<td>423.8 BarG / 6,000 psig</td>
<td>344.8 BarG / 5,000 psig</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>537.8C / 1,000F</td>
<td>537.8C / 1,000F</td>
</tr>
</tbody>
</table>

Qualification Testing

SKW provided 10CrMo9 10 bar stock material from which EST manufactured test coupons. EST manufactured plugs, prepared the test coupons and installed plugs per the installation instructions and procedures supplied with the plugs. Installed plugs were subjected to various tests including pneumatic and hydrostatic pressure tests, thermal cycling and hardness to ensure suitability for service.

Figure 8. P2-630-CR-SP0611 Plug Installed in Test Coupon

Figure 9. P2-790-CR-SP0611 Plug Installed in Test Coupon

Thermal Cycling

A 10CrMo9.10 Test Coupon with a P2-630-CR-SP0611 installed was subjected to ten (10) thermal cycles as follows. The temperature limits were selected by SKW and were based upon the process gas entry temperature.

- Increase from 22°C to 400°C in 4 Hours (rate of change ~100C/hour)
- Holding Time at 400°C: 2 Hours
- Cool down from 400°C to 22°C: Overnight

A 10CrMo9.10 Test Coupon with a P2-790-CR-SP0611 plug installed was subjected to ten (10) thermal cycles as follows. The temperature limits were selected by SKW.

- Increase from 22°C to 350°C in 4 Hours (rate of change ~100C/hour)
- Holding Time at 350°C: 2 Hours
- Cool down from 350°C to 22°C: Overnight
Pressure Testing

Pressure testing was performed and witnessed by representatives of SKW, EST and TÜV-Nord. A summary of the testing performed is included in Table 2; the original signed datasheet is attached as Appendix 1.

Table 2. Pressure Testing Results

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Installed Plug Size</th>
<th>Test Criteria</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P2-630-CR-SP-0611</td>
<td>Bubble Leak Test with Air 0,5 BarG (7.3 psig)</td>
<td>Passed</td>
</tr>
<tr>
<td>2</td>
<td>P2-760-CR-SP-0611</td>
<td>Bubble Leak Test with Air 0,6 BarG (7.3 psig)</td>
<td>Passed</td>
</tr>
<tr>
<td>3</td>
<td>P2-330-CR-SP-0611</td>
<td>Pressure Test with Air, 1,1 x Tube Side Operating Pressure = 126,5 BarG (1,843,1 psig)</td>
<td>Passed</td>
</tr>
<tr>
<td>4</td>
<td>P2-700-CR-SP-0611</td>
<td>Pressure Test with Air, 1,1 x Tube Side Operating Pressure = 302,0 BarG (4,524,8 psig)</td>
<td>Passed</td>
</tr>
<tr>
<td>5</td>
<td>P2-630-CR-SP-0611</td>
<td>1,5:1 Safety Ratio Pressure Test with Water, 1,5 x Maximum Pop-A-Plug Rated Pressure = 1,5 x 413,6 = 620,4 BarG (9,092,2 psig)</td>
<td>Passed</td>
</tr>
<tr>
<td>6</td>
<td>P2-700-CR-SP-0611</td>
<td>1,5:1 Safety Ratio Pressure Test with Water, 1,5 x Maximum Pop-A-Plug Rated Pressure = 1,5 x 544,8 = 517,2 BarG (7,558,6 psig)</td>
<td>Passed</td>
</tr>
</tbody>
</table>

(*) Max Working Pressure Rating for Pop-A-Plug Type, Size and Material.

Hardness measurement

Following the successful completion of the pressure tests the coupons of both plug sizes were sectioned and etched to review sealing characteristics and perform a hardness test.
Conclusion:
The Pop-A-Plug successfully passed all qualification tests. Based upon the successful testing, SKW approved the use of and has installed Pop-A-Plugs in alloy ASTM A182 F22 Class 3 material in the Ammonia plant heat exchangers with 10CrMo910 tubes.

During a recent shut down SKW installed Pop-A-Plugs in a Waste Heat Boiler Application. The technicians were able to perform the work using standard Conditional Environment PPE and Forced Air Breathing equipment. Additional cost savings by avoiding pre-heating and post weld stress relieving were realized. The installation of Pop-A-Plugs and tube plugging evolution was successfully accomplished in a matter of hours compared to 3 days for the previous method.

EST Group reviews every application of Pop-A-Plugs in detail prior to order and installation.

EST provides Service Technicians, Certified Trainers and has a network experienced and Certified Pop-A-Plug installation companies Worldwide.

Upcoming Developments
Based on the above outcomes, the next phase of this program has started. SKW, in coordination with Stamicarbon, Sandvik and EST have begun developing Pop-A-Plugs in Safurex® material for Urea Plant heat exchanger applications.

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