ROBOTIC CONVECTION BANK CLEANING

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Abstract: Ethylene cracking heaters like other box fired heaters in the refining and petrochemical industry represent a significant investment in a plant. Proper maintenance of these assets assures their long term, safe and reliable operation. The convection section of a heater is subject to varying levels of external fouling from refractory dust and the combustion process. Maintenance of the convection banks is critical for optimum operation and longevity.

This paper presents the design and operation of equipment that addresses the issue of accessibility to the convection bank for proper cleaning. This is accomplished by using a self-propelled robotic cleaning vehicle that reaches deep between every row of finned or studded tube to remove the most tenacious fouling bringing the unit back to near new performance.
Introduction

The rise of US Shale gas and the increased supply of ethane has triggered a wave of investment in new ethylene plant capacity, with around 2.8 billion lb/year of US capacity expected to be added by four incremental projects in 2014 (1). The combination of new plant featuring the latest technology and using cheap feedstock means that the industry is under increasing pressure to boost margins through improving operational efficiency and without much in the way of capital investment.

Steam cracking furnaces account for roughly 58% of all energy consumption in US ethylene plants (2) and as a result their performance has a huge impact on a plant’s financial performance – around US$70.4/t ethylene (assuming a SEC of 15, $4.69/GJ).

Fired heaters cannot operate effectively when fouled with what would appear to be an insignificant amount of dust (both atmospheric and refractory), fuel system impurities and decoke effluent (in ethylene cracking furnaces that rout the decoke effluent to the firebox (3) ) and/or corroded under accumulated fouling due to the flue gas dewpoint. The decline in convection bank performance is dependent on the thickness of the deposit, as shown in Figure 1.

![Figure 1. Convection Bank effectiveness [%] versus Deposit Thickness (mm) (4)](image)

As the effectiveness of the convection bank drops, stack temperatures increase, leading to greater stack losses and greater energy consumption as shown in Figure 2, with every 20°C increase in stack temperatures resulting in roughly a 1% increase in stack losses at normal excess figures.
Typically, ethylene plant cracking furnaces are designed with convection section heat recovery using a BFW preheat economiser as the coldest service. This results in a stack gas temperature of about 150°C when the coils are clean, but heavy fouling can result in stack gas temperatures as high as 235°C (3).

In 2005, Foster Wheeler calculated that external fouling can reduce the efficiency of a fired heater with a duty of 60.5MW by 5.9%, increase the stack temperature by 100°C and result in incremental fuel costs of €944,000/p.a. or around €15,600/MW/pa (5).

The run-up in energy prices over the following years has increased the economic impact of convection bank fouling. 5mm outer dust or scale fouling in both the radiant and convection banks of a small-sized fired heater with 18MW fired duty, results in energy losses of 4.518GJ/h and annual losses of around €614,454/pa or €34,144/MW fired/pa (6). Although simulations are very design-specific, this gives a rough indication of the financial losses that can result from the external convection bank fouling of fired heaters.

While fouling in fired heaters occurs in both the hot and cold sides of fired heaters and on the hot side, it mostly occurs in the convective section (7). Modern designs such as the use of finned convection tubes mean that it is often possible to attain heat flux in the convection section that is comparable to the radiation section (8), putting greater emphasis on the need to ensure that convention banks are kept free from fouling.

Another issue is that elevated stack temperatures result in the Induced Draft Fan operating at a higher than intended volumetric flow. While such fans typically are designed with a capacity margin of 20-25%, when convection banks are extremely fouled, the fan may be operating at its limit, restricting throughput by around 1-2% (4).
The limitations of traditional cleaning methods

Unfortunately, traditional methods of cleaning tubes within convection banks, whether finned, bare or studded, leave a great deal to be desired. The majority, if not all, cleaning medium delivery mechanisms are by way of the cleaning contractor manually inserting a long hollow injection lance through each access door or via a static, in-built soot blowing lance whether the heater is on or off-line. They are restricted in that the area of the fouled convection bank that can be physically reached by the cleaning lance is invariably limited. An average sized finned convection bank has a surface area of around 2.5 square kilometres. As can be seen in Figure 3, traditional methods can only target “reachable” areas, of which they barely clean 2% of this, leaving 98% of the total surface area untouched and still fouled.

Figure 3. Limited access means that traditional cleaning methods only ever clean a small portion of the entire finned convection bank, as the remaining surface area cannot be reached from the available access points

Some fired heaters have zero access to the convection bank, while others have doors measuring less than 150mm x 200mm. This issue is compounded by the basic inability of traditional cleaning methods to access between tubes or remove even moderate fouling sitting between the fins or studs. One popular offline method, water jetting, congeals refractory dust and combustion deposits, turning it and soot into a paste which later dries into a concrete-like deposit between the tubes and finned areas. Similarly, lance applied abrasive blast media can erode and block fins, creating a “key way” increasing future fouling rates and making fouling impossible to remove. Soot blowers are as the name implies “soot” blowers – they cannot remove deposits that are harder than soot and are statically positioned, moving in and out but not between rows.
Foam cleaning can in theory make “surface contact” with the majority of the convection bank, but this only extends to the surface of the deposit and is not certain given that fouling characteristics deep inside the convection bank are unknown and foam, as well as chemicals, always takes the path of least resistance. Due to lack of shear force, foam cleaning relies on the dissolution of oil-based deposits with detergents and solvents and is appropriate for very light dust deposits. In addition, fouling is more prevalent on the underside of convection banks, but foam is administered from the top. While on-line cleaning methods do exist, they often struggle with hard, difficult to shift deposits and clean in only one direction using the updraft from the flue gasses and have the limitations associated with manual lance application.

Robotic fired heater convection section cleaning

Tube Tech International has developed a robotic fired heater convection bank cleaning technology (shown in Figure 4) to specifically address the issue of poor or limited access encountered when attempting to remove fouling from the convection banks of fired heaters.

The robot acts as a delivery vehicle for one or two lances, capable of delivering the range of cleaning media shown in Table 1. The choice of cleaning medium (see Table 1) is dependent on the nature of the deposit. The blast medium cleaning radius is delivered within a distance of one inch from the fouled surface. As a consequence, the robot can remove the hardest of deposits and can do so between every tube row while providing 360 degree tube surface contact, regardless of whether the design is square or triangular pitch. In contrast to the conventional cleaning methods detailed earlier, robotic fired heater convection section cleaning physically penetrates deep inside and between every row of finned or studded convection tubes.

Table 1. Appropriate cleaning media for a range of fouling deposits

<table>
<thead>
<tr>
<th>Nature of Deposit</th>
<th>Appropriate Cleaning Medium</th>
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<tbody>
<tr>
<td>Compacted dust, capable of being removed by finger pressure</td>
<td>Compressed Air</td>
</tr>
<tr>
<td>Compacted dust, other light deposits</td>
<td>Chemicals</td>
</tr>
<tr>
<td>Tenacious compacted dust</td>
<td>Steam</td>
</tr>
<tr>
<td>Deposit can be scratched with a coin on the tube surface</td>
<td>Dry ice @ 300 PSI</td>
</tr>
<tr>
<td>Resembles very hard mud – cannot be cleaned by other methods</td>
<td>High pressure water in excess of 500-15,000 PSI</td>
</tr>
<tr>
<td>Deposit can only be removed with pressure similar to a manual impact from a screwdriver</td>
<td>Super high pressure water</td>
</tr>
</tbody>
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The robotic fired heater convection section cleaner developed by Tube Tech International

The robot can either use one lance for cleaning and one for inspection—allowing inspection to follow immediately after to verify cleanliness without delay, conversely two lances can be used for cleaning, resulting in twice the productivity per robot. Productivity can be further enhanced and downtime reduced further by the simultaneous deployment of multiple robots, at multiple levels.

The robotic cleaning procedure begins with the placing of the robot on top of each convection bank via existing access doors. If new doors are required, they can be cut in whilst the furnace is running prior to shut down, thereby removing this element from the shutdown period, reducing down time further. The door size can be as little as 150 mm x 200 mm in dimension and as large as 24 in².

The robot is equipped with cameras allowing it to be remotely controlled from an operator external to the convection bank in which the robot has been placed. The lances are remotely activated and are preset to the technical drawings provided by the client, ensuring that each row of each convection bank is cleaned at every level (see Figure 5). The robot can negotiate a convection bank with as many as 20 rows from top to bottom. It can also operate vertically upwards.

Once cleaning has been completed, the robot inspects between each row with a flat, blade shaped camera and records the data for cleanliness, and integrity evaluation whereby images and video clips are recorded for archive purposes. The resulting archives can be used by clients to be used as a benchmark, for post contract evidence and for future cleaning and
inspection assessments which can be matched to overall fired heater performance before and after future cleaning exercises.

Robot is placed on top of each tube bank through existing or pre-installed access doors. Lance is used on triangular and square pitch studded, finned or bare tubes.

Robot cleans from the top of each convection bank with no tube or refractory damage. Lance can extend to any depth.

Any medium can be applied e.g. Brush, Air, Steam, Chemical, Water, Liquid Ice. Etc. Almost 100% of every convection bank can be cleaned no matter the level of fouling.

Figure 5. Images showing the manner in which the robot can access deep between every tube row for the very first time regardless of depth
Regardless of whether the convection bank is square pitch or triangular pitch, the blast cleaning pressure emitted from the nozzles does not hit the refractory as the angle of the jets is such that they deflect off the tubes first where the pressure is dissipated quickly. There is therefore no danger of refractory damage, as witnessed by Shell Global Solutions, worldwide independent consultants. The refractory will only ever get damp and the moisture is easily evaporated during the normal run up procedures. A shroud can be easily attached to the lance to provide plant operators with extra confidence that the high pressure blast medium such as liquid ice, CO₂, water, etc., does not make contact with the refractory wall.

The robot delivers any cleaning medium e.g. air, steam or water at pressures ranging from 600 psi to 60,000 psi (4000 bar) with volumes as low as 2.5 litres per minute and can be collected below the last convection bank and removed to an awaiting tanker or straight to the plant’s interceptor tank.

The development of robotic cleaning systems means that fired heater operators now have the choice between either manual or static lancing (both of which in many cases struggle to remove the more tenacious and fused deposits) or robotic fired heater convection section cleaning which ensures removal of any form of deposit no matter how hard delivering a far superior clean combined with inspection within a window of just two days. This is made possible by the way the robot runs up, down and across every row and physically penetrates every deposit across every tube row.

As the rate of deposit formation is often dependent on surface roughness, with rough areas providing nucleation sites for new deposits (9), the better the finish on the finned convection bank tubes, the slower the fired heater’s performance will degrade, allowing the operator to delay the unit’s next clean for longer.

When selecting the cleaning method for a fired heater’s convection bank – it is crucial to consider the risk of cleaning failure, which is particularly high when the fouling is in the form of harder deposits. Should a standard lancing technique fail, the operator will be forced to take the unit offline sooner, adding lost production to the cost of cleaning. Robotic fired heater convection section cleaning is extremely cost effective considering the improvement from an average of 2% surface coverage to near 100% surface area coverage.

**Case study**

A 200,000bpd refinery in Germany was intending to change from oil to gas firing and sought to replace its fired heaters due to extreme fouling issues. It was faced with a decision: replace both fired heater sections or approach Tube Tech International to develop a new cleaning solution, as an alternative to replacement. It was important to have the fired heaters free from hydrocarbon fouling to ensure maximum heat transfer to reduce fuel consumption and increase asset life. The refinery operator opted for the latter, giving Tube Tech’s engineers only...
three weeks’ notice to build three multi-functional robots capable of achieving 80+% production standard clean or better, while not damaging the refractory.

The refinery had previously trialed many traditional lancing systems including dry ice, chemicals, water jetting and abrasive shot blasting, all of which were limited in their success as they could only clean what the operator could see. Access deep inside and between the furnace rows was never achieved and as a result, the units had never been cleaned properly for 20 years – as can be seen by the heavy fouling shown in Figure 6.

The cleaning robots (shown in situ in Figure 7) took just 48 hours to clean three levels on two fired heater containing six 15m long convection banks on three levels. This was despite expectations that 90% of all the furnace tubes had some fouling, with the deposits being 1-5mm thick and composed of hard scale and compact gummy residue between the finned tubes. Tube Tech used remote CCTV to inspect the units before, during and after cleaning. No refractory was damaged. The robots had no difficulty in obtaining access through 150 x 225mm doors.

![Figure 6. Images showing the extent of fouling on the refinery’s fired heater’s convection banks prior to robotic cleaning](image)
The robotic cleaning resulted in the inspection standard shown in Figure 8. The refinery recorded 50°C and 80°C reductions in HVU2 and CD2 stack temperatures, respectively and stated that the cleaning procedure had delivered several megawatts of energy savings. Assuming that the loss of 1MWhr costs US$33.60 at an oil price of US$56/barrel, then it can be assumed that the energy savings alone result in financial savings of at least $588,672/pa.
Conclusions

It is of critical importance to ethylene plant operators that their fired heaters are running optimally as even the lightest of fouling has a substantial impact on performance, given the high proportion of operating costs made up by energy consumption and heating requirements.

Traditional and often antiquated cleaning methods are limited in their ability to remove fouling from finned or studded convection banks within fired heaters. The majority can only clean ca. 2% of the entire tube bundle heat transfer surface area and fail to remove the more compact and tenacious deposits.

Robotic fired heater convection section cleaning as developed by Tube Tech International offers a unique and superior solution, delivering proven energy and financial savings in situations where conventional methods have struggled or failed and at a superior net present value.
References


4. Konijn, Martin (2015), consultancy correspondence, EPS / Triple EEE.


