Operational and Safety Improvements in Foster Wheeler Terrace Wall™ Reformers

Foster Wheeler’s Terrace Wall™ reformer design was developed in the 1960s, and it has become a work-horse for the refining and petrochemical industry. Even today some of those reformers built in the 60s and 70s are still in operation.

This paper will discuss some observations in the older reformer design, and the resulting improvements that are incorporated in Foster Wheeler’s new steam reformers, or that can be retrofitted into existing reformers. This continuous improvement demonstrates that a steam methane reformer based on Foster Wheeler’s Terrace Wall™ design provides a cost-effective solution that satisfies high expectations in regards to operations, reliability and safety.

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Introduction

Foster Wheeler is one of the pioneers of the high-pressure Steam Methane Reforming (SMR) plant design and developed its patented Terrace Wall™ reformer furnace in the early 1960s. This design has been continuously updated and improved to ensure highest reliability while incorporating many features that improve plant safety, simplify operations, and enhance plant efficiency.

Many of today’s hydrogen, methanol and fertilizer producers utilize the Foster Wheeler Terrace Wall™ reformer (Figure 1) for the production of synthesis gas that is used for the production of hydrogen, methanol, or ammonia. More than 150 of these plants were built in the 60s, 70s and early 80s, and many more afterwards. While some plants have been shut down, others are still in operation and have seen modest upgrades in recent years. With the development of shale gas, particularly in North America, a significant reduction in the natural gas price has been realized, and operators are now implementing expansions, revamps, or even replacing existing reformers to take advantage of gas feedstock pricing and improve overall profitability.
This paper will discuss mechanical and safety improvements that are part of new steam reformers, or that can be implemented into existing ones, and it will illustrate that an SMR based on the Foster Wheeler Terrace Wall™ design provides a modern day solution that satisfies highest expectations in regards to safety, economy, and operations.

The Terrace Wall™ Reformer

Overview

Steam methane reforming of natural gas continues to be the leading technology for synthesis gas generation. The Foster Wheeler Terrace Wall™ design (Figure 2) incorporates unique features that provide controlled heat transfer to the reformer catalyst tubes, which translates to longer tube life, longer catalyst life, and better stability at turndown conditions.

The Terrace Wall™ reformer features a radiant section consisting of one or more cells with each cell containing a single row of catalyst tubes. The heat is supplied by upward firing burners on either side located at two terrace levels. The hot flue gases flow naturally upward into the convection section very much like a conventional fired heater.

The convection section, located on top of the heater and in between the radiant sections, has several coil sections, which recover much of the remaining heat from the flue gas for various process and steam duties. Depending on the application, a process gas boiler for high pressure steam generation may be close-coupled to the reformed gas outlet manifold.

Radiant Cell

The reformer radiant cell design gave the Terrace Wall™ reformer its name. The burners are located at two levels in the radiant section, the terraces, firing upwards adjacent to the sloped brick firing walls. Each terrace is capable of being independently fired to provide the particular heat flux desired in a given zone.
The sloped walls are uniformly heated along the length of the furnace as a result of the special burner design and provide a uniform vertical flux profile since the distance from the tube to the radiating wall decreases as the flue gas cools. Figure 3 illustrates the burner configuration and flow pattern of a radiant cell.

![Figure 3. Radiant cell](image)

The configuration, with burners firing upwards and the flue gases also flowing upwards counter-current to the down flowing process gas, significantly reduces the power demand for the flue gas induced-draft (ID) fans. This configuration even allows natural-draft operation in case of an ID fan failure.

By varying the upper terrace height, the Terrace Wall™ reformer design can be tuned to the customer’s specific heat recovery requirements while still maintaining maximum radiant fuel efficiency. As an example, lowering the upper terrace firing level from the original 50-50 split reduces the temperature at the furnace bridge wall, the transition zone between radiant and convection section. This reduction helps to reduce steam export to levels that are unachievable in top-fired designs, while still maintaining the required outlet conditions on the process side.

Catalyst Tubes With Inlet and Outlet Connections

Internally-machined centrifugally cast tubes are used for this type of heater. The material is typically 25-35 Cr-Ni Nb stabilized, which assure good creep-rupture properties and resistance to carburization and oxidation up to 1100 °C (2012 °F).

The catalyst tubes are top-supported by means of counterweights, so that the movement and secondary stresses at the most critical hot tube outlet are virtually eliminated (Figure 4).

![Figure 4. Catalyst tubes with hangers](image)

The pipe connections between the catalyst tubes and the inlet manifold, the inlet pigtails, provide sufficient flexibility to compensate for the thermal growth of the catalyst tubes. The short pigtails of the vertical outlet pigtail design are contained in an insulated box together with the outlet manifold (Figure 5). The elimination of penetrations at the bottom of the reformer is very significant, as it drastically reduces air infiltration and maintenance.
Footprint

The design of a Terrace Wall™ reformer, including a process gas boiler and convection bank, is very compact. The convection section and stack are placed at the top of the radiant section. The process gas boiler is located at grade, close-coupled between the radiant cells. This layout helps to reduce the footprint, which is 20% to 30% less compared to a top-fired or side-fired design. Figure 6 shows a plan view of a top-fired and a Terrace Wall™ reformer of comparable capacity, both equipped with an air preheat system.

Modularization

The geometry of the heater allows for the radiant section of the Terrace Wall™ reformer to be supplied in modules, complete with casing, structure, refractory, burners, inlet and outlet manifold, catalyst tubes, and pigtails. Such modules can be shipped easily and reduce the required site activities significantly, especially the high alloy welding for the pigtail to manifold connection. This high degree of modularization results in substantial savings in the overall construction costs and schedule.

The convection bank and stack can also be modularized, similar to any other conventional fired heater project. Smaller reformers can even be shipped in one piece (Figure 7).
Access

The Terrace Wall™ design allows the operating personnel easy access to all important parts of the steam reformer.

Catalyst tubes can be easily accessed from the top as the burners with fuel and combustion air piping are located on the side. This access enables the personnel to change the catalyst, replace catalyst tubes or isolate a single catalyst tube without working in a congested area, such as in a top-fired reformer penthouse.

The convection bank is also freely accessible as there are no other structures or piping around.

The burners are located on two levels of the side walls of the radiant cells. From platforms at each burner level, the operators can reach each burner easily, observe the operation of the burners, and ensure the correct heating of the catalyst tubes, through sight doors located on these levels.

Operational Experience

The Terrace Wall™ reformer has been in operation for over 50 years and has been a work horse for the refining and petrochemical industry. Many reformers built during the 60s are still in operation, which is evidence of its robust design and high reliability.

Even so, each design allows for improvements. This section will discuss some observations in older reformer design that have led to design changes in today’s reformers and revamp opportunities in older reformers.

Air Leakage

The flue gas side of the reformer is operating under a slight vacuum. It is important to keep the reformer as gas-tight as possible for the following reasons:

- To maintain the flue gas flow pattern.
- To provide sufficient air to the burners.
- To control air infiltration for proper operation of low-NOₓ burners.
- To avoid tramp air entering the reformer which would influence the oxygen analyser and reduce the heat efficiency.
- To avoid uncontrolled after-burning (see Figure 8, which shows blue flames in arch section).

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From years of operational experience, the following points were identified as the main causes of air leakage:

- Bottom penetration of catalyst tubes through reformer floor;
- Sight and observation doors; and
- Top tube penetrations through arch seals.
Outlet Pigtails

The outlet pigtails are a critical part of the reformer and most of the old Terrace Wall™ catalyst tube failures are attributable to outlet pigtail issues. The catalyst tube outlet experiences high temperature, high pressure, and mechanical stress due to thermal expansion.

The old Terrace Wall™ reformers were designed with a horizontal outlet pigtail (Figure 9). The pigtail was connected horizontally from the bottom outlet of the catalyst tube to the outlet manifold. The outlet manifold was located laterally adjacent to the catalyst tube row resulting in the pigtail giving a momentum to the catalyst tube and causing additional mechanical stress.

![Figure 9. Horizontal pigtail design](image)

Each catalyst tube had its own outlet through the reformer floor. Even with proper sealing, these openings in the reformer floor were subject to uncontrolled air infiltration.

Dissimilar Weld in Catalyst Tubes

There were two dissimilar welds for the old catalyst tube design. One dissimilar weld connected the top flange to the inlet of the catalyst tube. This weld sometimes showed fatigue and cracks after ten or more years of operation, but it has not caused any safety concerns.

The other dissimilar weld was at the cold bottom of the catalyst tube below the horizontal outlet pigtail. This bottom part below the connection of the horizontal pigtail was a dead leg, had an insulation plug, and ended with a blind flange. Since this area was cold, the metallurgy was changed to carbon steel. In a cold climate such as Canada, condensation has been observed which caused corrosion of the weld. Also the gasket of the blind flange was prone to leaking.

Coil Arrangement in Convection Bank

The hip section of the reformer - that is the channel (tunnel) between radiant and convection section - was sometimes used to install a mixed-feed preheater coil. The high flue gas temperature was utilized to preheat the feed/steam mixture to the maximum possible extent prior to introducing it to the catalyst tubes. The operational risk was that, with low flow rates, the material could be heated above the design temperature and cause tube failure.

Burners

The original design allowed burners to be maintained and replaced only by accessing them from the bottom, i.e. through the terrace floor. This design has the risk of hot insulation material or other debris falling out of the burner opening when removing a burner during operation.

Design Changes and Other Safety Improvements

General

Over the last five decades the design of the Terrace Wall™ reformer has undergone continuous improvement. Fortunately many of these changes, which increase safety and
enhance operations, will not only apply to new reformers, but can also be retrofitted into existing ones.

Outlet Pigtails

The modifications of the outlet pigtails have been key to solving several issues observed during operations.

The new vertical pigtail design has the outlet manifold located directly under the catalyst tube. Instead of having the pigtail connected to the catalyst tube horizontally, the outlet pigtail is a straight pipe vertically connecting the catalyst tube and outlet manifold (Figure 10). This vertical outlet pigtail is welded to the outlet manifold. There is no dissimilar weld, and there is no dead end where condensation and corrosion could occur.

The catalyst tube outlet, the outlet pigtail, and the manifold are completely enclosed in an insulated environment. This design avoids any thermal bridge with the risk of condensation at the critical outlet pigtail or any critical weld. It also reduces the temperature loss in the process outlet to the process gas boiler, and it keeps the whole outlet system gas tighter resulting in a significantly lower air leakage into the reformer box.

The outlet manifold is the fixed point. All the thermal expansion of the catalyst tube is directed upwards and will be compensated by the inlet pigtail. As the inlet temperature is less severe than the outlet, the stress on the inlet pigtail is not a critical design issue. The weight of the catalyst tube, including catalyst, is borne by adjustable counterweights. As the outlet pigtail is a straight tube in the centerline of the catalyst tube, there is no torque. Counterweights and the straight vertical design keep the outlet pigtail virtually free of any mechanical load or secondary stresses.

The vertical outlet pigtail has been in trouble-free operation for many years now and this design modification is proven to have significantly improved the already excellent reliability of the Terrace Wall™ reformer.

Sight Doors

The previous sight door design allowed for gaps between the doors and the reformer wall. These gaps led to an uncontrolled air flow into the reformer. A modified design (Figure 11) ensures that the doors close tight and seal without the use of costly and high-maintenance glass covers.

Figure 11. Bottom hinged sight door

A second improvement is the sight door refractory surround in the radiant wall. For better monitoring of the tube metal temperature, the refractory surround was newly designed to
increase the viewing angle into the fire box (Figure 12).

**Figure 12.** Sight door ceramic formed surround, viewed from inside

**Burners**

The burner design has been modified so that the burners can be taken out of the radiant cell like a drawer, i.e. they are slid out to the side instead of lowering them out from the bottom (Figure 13). This design allows maintenance or a complete burner replacement during operation without risk to personnel from hot particles falling through the burner opening.

**Metallurgy**

Improvements in the metallurgy and in the manufacturing process of the catalyst tubes have significantly reduced the risk of tube failures. Micro alloys such as 25-35 Cr-Ni Nb stabilized, instead of HK 40, allow the wall thickness and total weight of these tubes to be reduced. For an additional increase in reliability and tube life, Foster Wheeler applies their own standards regarding chemistry, microstructure, and grain size of the catalyst tubes. These standards are more stringent than typical tube manufacturer standards.

**Modularization**

Larger sections of the reformer cell and the convection bank can be manufactured and shipped in modules (refer to Figure 7 above). A significant improvement is the ability to also preassemble larger sections of catalyst tubes (Figure 14). The single row design of the reformer cell allows multiple tubes to be completely preassembled in a shop with inlet and outlet manifolds, and to be hydrotested before shipment to site. This prefabrication significantly reduces the number of high-alloy field welds and the need for x-ray testing, resulting in shorter erection times and higher overall quality.
Terrace Levels

Client specifications regarding energy consumption and steam production can be better met by varying the height of the two burner levels. Newer reformers often show a lowered upper level, resulting in a reduction of the bridge temperature of more than 100 °C (180 °F). While the heat for the reforming reaction is still provided, the flue gas temperature to the convection section can be reduced to less than 1000 °C (1832 °F). This relatively low temperature results in a lower export steam production and allows the design temperature of the first convection bank coil to be reduced.

Summary

Foster Wheeler’s Terrace Wall™ reformer has been in operation for over 50 years. Continuous development of the Terrace Wall™ reformer - which has taken into consideration the availability of new materials, improvements in design and manufacturing, and the feedback from plant operators - has resulted in today’s state-of-the-art design. This design has excellent reliability and satisfies the highest safety requirements.

Most of the improvements can also be implemented in existing reformers, allowing operators to significantly extend the reformer lifetime and improve the safety and operability of existing plants.

References
