New Blasch StaBlox^{TM} flue gas tunnel system

For decades, down-fired steam methane reformer furnaces have utilized flue gas tunnels (coffins) along the radiant section floor to collect and improve flue gas flow uniformity. These tunnels range from 1.2 to 3 m tall, 0.6 to 0.9 m wide, and 12.2 to 30.5 m long, depending on the unit design capacity. However, the conventional refractory firebrick or tongue-and-groove firebrick construction has always constrained the flue gas to non-uniform flow which has been correlated to non-uniform catalyst- tube temperatures and accelerated tube aging. Due to tunnel size and refractory volume, traditional brick design uses only basic shapes. Typical brick and mortar installations require several physical features including buttresses and large, periodic expansion joints which severely limit tunnel effectiveness, making uniform flue gas flow unachievable. The ability to design and construct tunnels using new highly-engineered refractory shapes, which eliminate these features, is new to this industry and could be the answer to

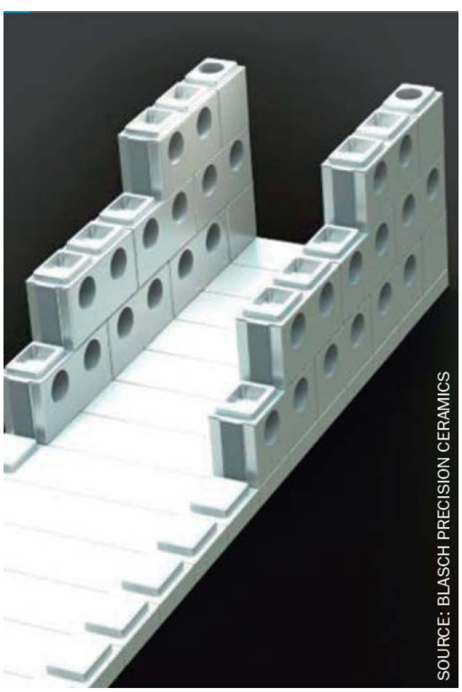

Figure 6: Blasch tunnel system

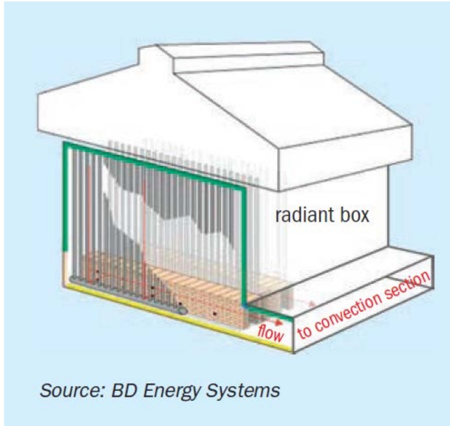

Figure 7: Radiant box flue gas flow

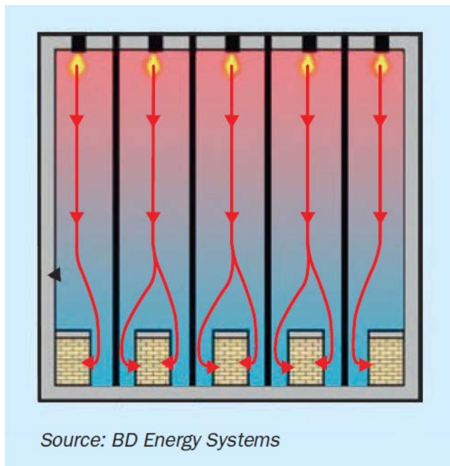

Figure 8: Flue gas flow into radiant box tunnels

improving flue gas tunnel effectiveness and improving catalyst tube reliability and longevity. In the July-August 2015 issue of *Nitrogen+Syngas* we featured an article by Blasch Precision Ceramics discussing how the reliability of primary reformer flue gas tunnels can be improved through the application of engineering design and improved material selection.

Utilizing the StaBlox platform, BD Energy Systems developed a method for achieving near-perfect flue gas flow uniformity among and along the tunnels. This system combines BD Energy's vast steam methane reforming experience and Blasch's customized-precision-refractory-shapes design and manufacturing expertise. The result is unparalleled flue gas flow control using the patented Blasch StaBlox flue gas tunnel system and BD Energy System's TOP Program. The new StaBlox reformer tunnel system can be used in furnace revamps or for new furnaces and can reduce installation time by 70-80% compared to conventional tunnel systems.

Conventional tunnel systems

Catalyst tube failure

Top-fired reformer arch burners heat catalyst-filled tubes for steam methane reforming. The catalyst tubes are heated by both radiation and convection from the flue gas (exhaust), which flows downward through the radiant box. Catalyst tubes typically are designed for a service life of 100,000 hours. In reality, however, tube longevity varies. Some tubes remain in service for 20 years, while others age much more rapidly, failing far ahead of schedule. Typically, reformers develop regions where tubes degrade more quickly, seemingly without cause. Catalyst tube inspection reports indicate that excessively high catalyst tube temperatures are correlated positively to accelerated catalyst tube aging and premature tube failure. Even when the average tube temperature is within design limits, non-uniform flue gas velocities cause some tubes to be heated more than others. Higher than average tube temperatures have been correlated to radiant box regions with greater than average flue gas velocities.

Flue gas flow

Hot flue gas flows from the arch burners into tunnels on the floor directly below each burner row. Flue gas enters the tunnel through tunnel wall openings distributed along the tunnel length and exits the open end of the tunnel to the convection section for additional heat recovery (Figure 7). Ideally, radiant box flue gas flows vertically down- ward with uniform velocity throughout the box to achieve uniform catalyst tube heating and tube temperature and also to improve flame patterns. Consequently, the ideal total

Figure 9: Incremental flow per open-area column for conventional inner and outer tunnels

flow into each tunnel is proportional to the firing rate of their respective burner rows and the ideal flue gas flow rate into each tunnel is uniform along the length of that tunnel.

Typically, burner outer-row firing is lower than inner-row firing because the outer row of burners must heat only one row of tubes, whereas inner rows heat tubes on either side of these burner rows. As a result, outer-row burners produce less flue gas than inner-row burners (Figure 8). Therefore, proportionally less flue gas must be transported by the outer tunnels than by the inner tunnels. For example, if an outer burner row were designed to fire at 65% of the rate of an inner burner row, then the ideal outer tunnel flue gas load would be 65% of that of an inner tunnel. The ideal flow ratio between outer and inner tunnels is achieved by designing the outer tunnels with less tunnel-wall open-area and a smaller cross-section compared to inner tunnels. Uniform flow into a tunnel along the length of the tunnel requires less open area near the tunnel open end than near the tunnel closed end. Flue gas is drawn into the tunnel wall opening by the differential static pressure across the wall which is proportional to the flue gas velocity

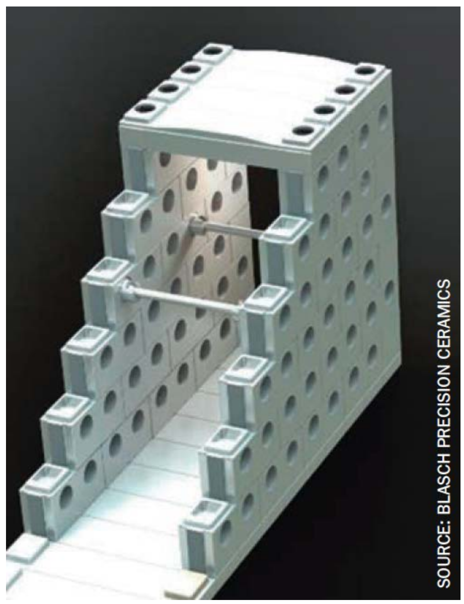

Figure 10: Tunnel system with support tie rod

inside the tunnel. Near the tunnel closed end where the in-tunnel flue gas velocity is very low the differential static pressure also is low, so more open area is required to draw in flue gas. Toward the tunnel open end, where the in tunnel flue gas flow rate and velocity is high, the differential static pressure also is high, so less open area is required to draw in flue gas. Ideal tunnel wall open area decreases gradually from the tunnel closed end to the tunnel open end. Due to certain physical constraints (see below), ideal open-area distribution is not achievable for the conventional tunnel system design.

Evaluation of conventional design

A conventional 12 m long tunnel system is evaluated (Figure 9). Calculated total flow through each outer-tunnel is approximately 77% of the inner-tunnel flow, but this ratio is not constant along the tunnel length. For example, at each open-area column, the ratio of one outer-tunnel flow to one inner tunnel flow (the 'flow ratio') is calculated. The resulting average flow ratio is 77.4% +/-55.1%, with a standard deviation of 21.3%. Additionally, the 'high-flow' columns tend to be grouped together. For the 6 columns closest to the closed end, for example, the average outer-tunnel incremental flow is 110% that of the inner tunnels. For the 6 columns closest to the open end, however, the average outer-tunnel incremental flow is 56% that of the inner tunnels. Also, incremental flow is non-uniform along the length of each inner or outer tunnel. Following any open-area step change, the incremental flow increases with each successive open- area column. As in-tunnel velocity increases along the tunnel length, incremental flow through each successive column increases until an open-area-per column step-change reduces the open area and, consequently, the incremental flow. After the step change, incremental flow increases, again. The areas near buttresses and/or expansion joints are 'no flow' regions. Therefore, at the tunnel closed end, some flue gas generated above the inner tunnels moves laterally toward the outer tunnels and toward the radiant-box center. At the tunnel open end, however, some flue gas generated above the outer tunnels moves laterally toward the inner tunnels and toward the middle of the outer tunnel. Half-way between the tunnel ends, flue gas generated above the outer tunnels moves toward the radiant-box center.

StaBlox interlocking tunnel system

Physical characteristics

The patented StaBlox system utilizes five unique core tunnel construction components. The construction begins with a base component that spans the bottom of the tunnel and mates to the side wall blocks. The side wall blocks each contain two openings for conveyance of flue gas. These openings are readily field configurable for a variety of sizes facilitating even the most complicated flow balancing efforts. A tie rod system is employed if supplemental stability is required replacing the traditional buttresses that typically serve as a support structure (Figure 10). These tie-rods easily can be removed and replaced during outages to allow easy access down the tunnel interior for inspection or repairs. At the top of the tunnel is a light weight lid that mates to the side walls. The sidewalls and lids each have provisions to seal against bypassing flue gas while accommodating differential thermal expansion of the overall structure.

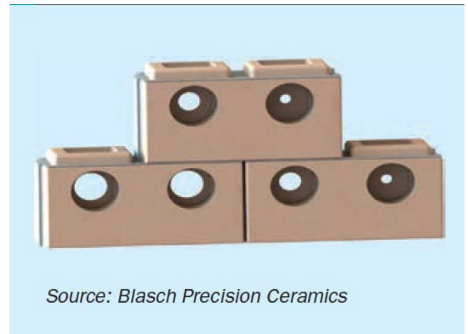

Figure 11: StaBlox interlocking blocks with varied orifice insert diameters

Mass

Temperature differential stresses across a body can result in thermal shock failure. The most direct way to reduce the thermal stresses to below the refractory component yield strength is to decrease the refractory component wall thickness to allow the wall temperature to equilibrate more quickly and eliminate temperature differential stresses. The wall thickness should be as thin as possible without sacrificing the overall stability of the tunnel system. Because the tunnel

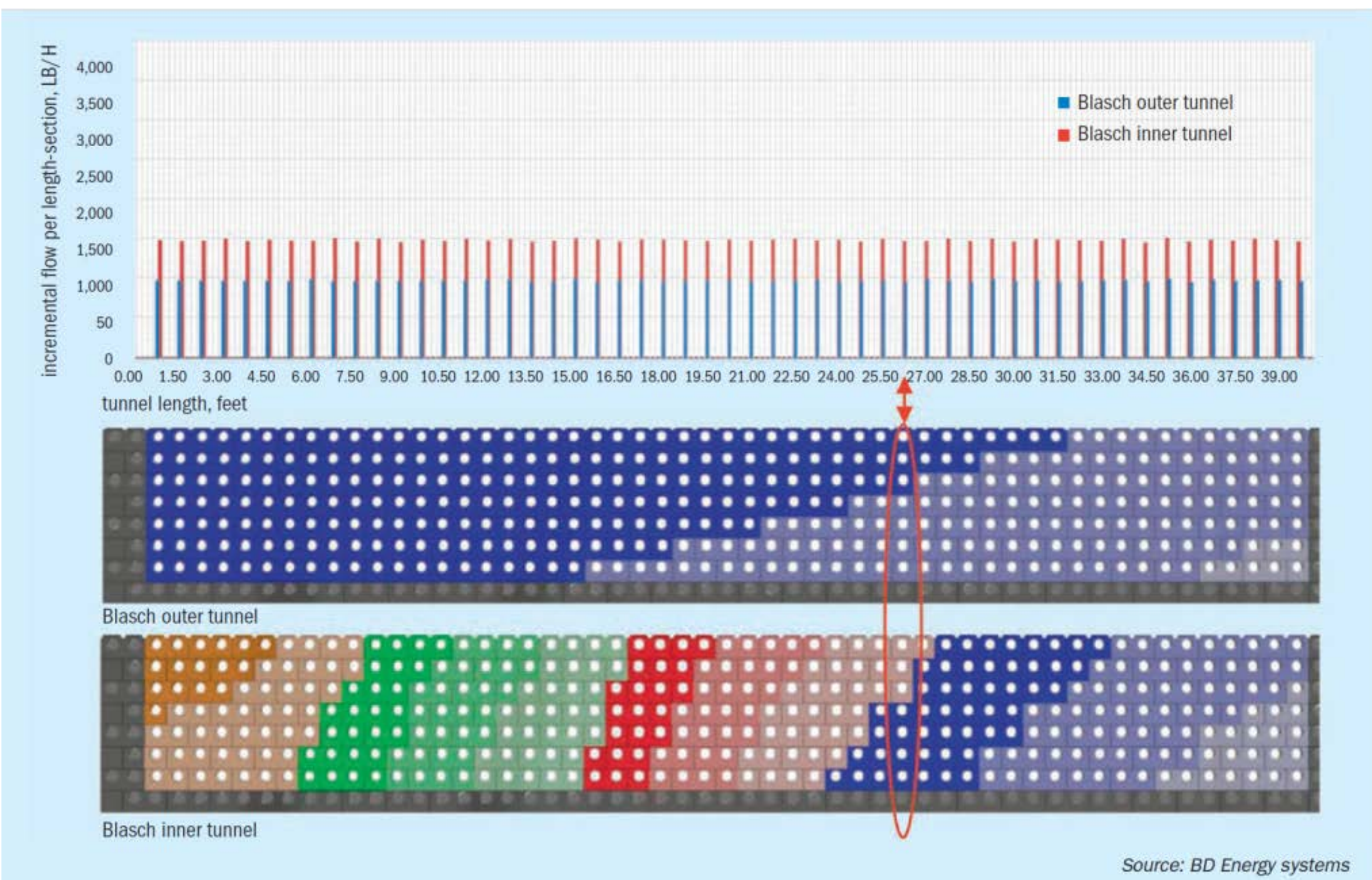

Figure 12: Blasch tunnel evaluation

system is self-supporting, component wall thickness reduction decreases the overall system weight. With the StaBlox design, tunnel system weight can be reduced by up to 60%. A light weight design coupled with a larger base component makes possible the use of highly insulating materials which would improve structural furnace support reliability and, therefore, improve overall system reliability.

Material selection

Selected materials for tunnel system components should have the highest creep resistance reasonably available, because a reduced creep will prolong tunnel system life and prevent premature failures. ASTM tests on super duty brick have published results of a 7.86% deflection at 1,427°C. An ideal candidate to replace super duty brick is mullite bonded alumina refractory material, which has published results of 1.11% deflection at 1,649°C.

In addition to creep resistance, a high HMOR (High Temperature Modulus of Rupture) also is critical for these tunnels. Com- paring the same mullite bonded alumina to super duty fire brick results in a similar difference in material strength properties. Super duty brick has a <600 psi HMOR, high grade castable can have up to an almost 500 psi HMOR, and mullite bonded alumina has a 1700 psi HMOR. A fully characterized CTE (coefficient of thermal expansion), higher HMOR, and increased creep resistance will improve the overall tunnel system reliability.

Design technique

Open-area distribution design

The patented StaBlox design method is to segment the tunnel length into half block sections, one column of openings per section. For example, a 23 m tunnel-wall length is segmented into 100 sections with openings in every course (row). Utilizing BD Energy Systems' TOP Program, the open area is distributed along the tunnel length by specifying the orifice-insert internal diameter for each opening, rather than by specifying the per-section opening quantity (Figure 11). Evaluation of BD Energy Systems' TOP Program The conventional tunnel system in Fig. 9 is redesigned using Blasch StaBlox technology in conjunction with BD Energy Systems' TOP Program (Figure 12). The goal is to achieve 65% flow through each outer tunnel compared to the flow through each inner tunnel and to achieve near uniform incremental flow along each tunnel length. The inner and outer walls are segmented into 9 inch sections, one opening-column per section. Buttresses are not included and expansion gaps are evenly distributed among the blocks. Required open area per column is calculated and appropriate ori- fice insert diameters are selected for each opening. Each orifice size is illustrated with a unique colour. For each column, more than one orifice size may be specified, so the average orifice diameter per column gradually decreases closer to the tunnel open end. The outer tunnel requires very little orifice diameter change compared to the inner tunnel because the outer tunnel closed end flue gas velocity is very low. So, the outer-tunnel closed end acts somewhat like a manifold, whereas the inner-tunnel closed end develops high-velocity flow almost immediately. To be conservative, the minimum orifice-size step-change is arbitrarily specified well above manufacturing limitations. More finely tuned diameters are feasible. Calculated total flow through each outer-tunnel is approximately 65.64% of per-inner-tunnel flow, and this ratio is approximately constant along the tunnel length. At each open-area column, for example, the ratio of one outer-tunnel flow to one inner-tunnel flow (the 'flow ratio') is calculated. The resulting average flow ratio is 65.64% +/- 1.8%, with a standard deviation of 0.7%. Also, neither high-flow nor low-flow regions are grouped together. For the six columns closest to the closed end, for example, the average outer-tunnel incremental flow is 65.62% that of the inner tunnels. For the six columns closest to the open end, the average outer-tunnel incremental flow is 65.60% that of the inner tunnels.

Additional advantages

Reduced pressure drop

Because StaBlox tunnels do not require buttresses, the tunnel-wall footprint is narrower – typically half the conventional width. Therefore, the StaBlox interior tunnel-width can be increased without increasing the tunnel footprint. This increased interior width results in approximately one third greater cross-sectional flow area and significantly reduces pressure drop across the tunnel system.

Process flexibility

Often, operating conditions change after tunnel-system construction. A capacity increase may be desired, for example. Typically, in such cases, the existing tunnel-wall open-area distribution no longer performs optimally. For a conventional tunnel, open-area distribution redesign may require partial or complete reconstruction, incurring material costs and possibly lengthening the turnaround schedule. For a StaBlox tunnel system, however, open area redesign requires only the reconfiguring of the openings in each block impacted in situe (a relatively quick and inexpensive procedure), re-using the wall tunnel structure in its entirety. Reduced heat storage During heat up or cool down it is important

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