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New burner structure targets significant NO_x reduction

Delek US comprises both refining and logistic segments. The refining segment operates four moderate complexity refineries—El Dorado, AK; Krotz Springs, LA; Big Spring, TX; and Tyler, TX—representing a combined production capacity of more than 300 Mbpd. Delek's logistics segment gathers, transports and stores crude oil. It also distributes, stores and transports refined products to West Texas and the Southeastern US. The Tyler facility processes local light sweet crude (West Texas Intermediate and similar) and produces a complete range of refined products. These products include LPG, NGL, gasoline, jet and diesel fuels, with the largest volume being light, high-value products, such as gasoline and diesel. Delek has historically been forward-leaning with respect to technology and the environment. For example, the El Dorado facility produces low-sulfur gasoline and ultra-low sulfur diesel fuel that meet or exceed current clean-fuel standards. To date, Delek has invested nearly $1 B in technology, operational and environmental spending.

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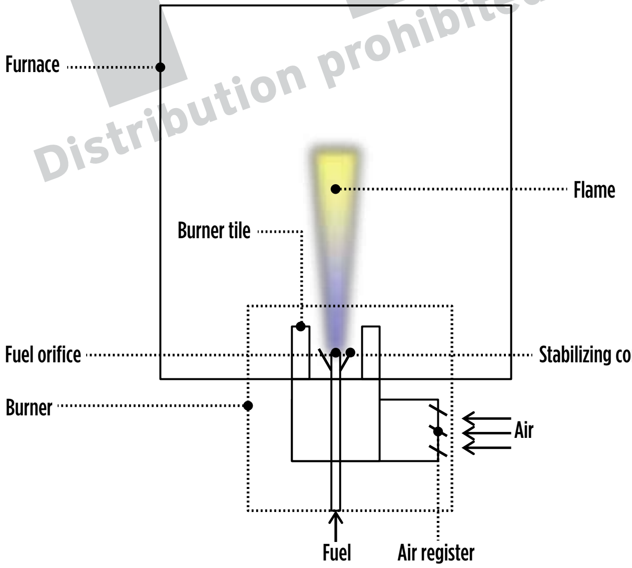

FIG. 1. Elements of a typical burner, including fuel orifices, an air register, a pilot (not shown) and a means of flame stabilization.

In its continued search for new technology to improve operational and environmental excellence, Delek began a program to improve the flame profile in key heaters. One heater of particular interest was a fluid catalytic cracking (FCC) preheater at its Tyler facility. The heater was originally sized for 15 MMBtu/hr in 1978, but it was operating at a reduced firing rate due to flame impingement issues. Flame impingement occurs when wayward flames impact process tubes. The high heat causes the process fluid to lay down, insulating sediment or forming oligomers known as coke. Over time, these layers thicken, further insulating the tube wall from the cooling effect of the process fluid. If coking continues unabated, the tube wall may become so hot that it loses critical strength and ruptures. In a refinery, this issue is of particular concern because the process fluid is flammable.

In some instances, emissions reduction techniques can impede heater operation. For example, low-nitrogen oxide (NO_x) burners generally reduce NO_x by elongating flames to allow more time for the flame to exchange radiant heat with the cooler process tubes in the furnace. Such radiative cooling lowers the flame temperature and reduces NO_x since NO_x is strongly affected by three factors: temperature, time at temperature and available oxygen (O_2) concentration. To understand why this happens, an overview of NO_x formation mechanisms is needed.

NO_x formation. NO_x can be formed in three ways: 1) by the oxidation of nitrogen (N_2) in a parent fuel molecule, termed *fuel-bound NO_x*; 2) by the fusion of N_2 and O_2 in the combustion air to create NO_x, termed *thermal NO_x*[1]; and 3) by the fusion of N_2 from the combustion air with partially decomposed fuel early in the combustion process, termed *prompt NO_x*.[2] Nitric oxide (NO) is the majority form[a] of NO_x in heaters and boilers; the discussion focuses on that species of NO_x. For gaseous refinery fuels, N_2 is generally not present as part of the fuel molecule. Moreover, prompt NO_x makes a small contribution to the total NO_x budget. That leaves thermal NO_x, which is represented in Eq. 1.

$$[NO]=A\left[N_2\right]\int e^{\frac{b}{T}}\sqrt{\left[O_2\right]}dt \qquad (1)$$

Note: A and b are constants, the brackets represent concentrations of the enclosed species, T is the temperature, and t is the time. The exact time-temperature-O_2 history in industrial boilers is too complex to allow for solution of Eq. 1. Notwithstanding, the equation is instructive in showing that NO_x formation increases with temperature increases (exponentially weighted), time (linearly weighted) and O_2 concentration (square-root weighted). A technique known as distal surface combustion can reduce the contribution of all three factors.

Distal surface architecture. The elements of a typical burner are shown in **FIG. 1.** All combustion equipment requires metering of the fuel, metering of the air, a means of ignition and a means of stabilizing the flame. In a conventional burner, these functions are fulfilled by the fuel orifice, air register, burner pilot and one or more burner tiles, stabilizing cones or other bluff bodies or swirlers. In **FIG. 2,** a combustion surface has been added downstream (distal) from the burner, and the flame has been transferred from the burner to the distal surface, which now radiates heat to the process. The distal surface dramatically reduces NO_x. For example, a conventional burner generates about 50 parts per million (ppm) of NO_x, while NO_x from the distal surface is usually 5 ppm (i.e., an order of magnitude less). Why does this happen?

First, a porous ceramic body has an effective emissivity close to that of a perfect blackbody radiator; therefore, it transfers heat to the surroundings with much higher efficiency than the flame. This effect is made apparent by comparing gaseous species radiation from a natural gas flame with blackbody radiation from a solid (**FIG. 3**). The area under the curve of the blackbody radiator is much greater than the area under the curve for gaseous species radiation, and is proportional to the radiative heat transferred. Comparing blackbody radiation to gaseous species radiation shows that the blackbody surface has a greater ability to reduce flame temperature via radiative cooling. The result is dramatically lower NO_x.

Second, burner flame lengths in process heaters and boilers are typically measured in tens of feet. A long flame length, at high temperatures, provides ample combustion to generate NO_x. Conversely, with a distal surface, combustion is completed in inches, representing an order of magnitude less time for NO_x formation. Ultra-short flame lengths are possible because combustion is not kinetically limited, but rather mixing limited. In other words, the time it takes to mix the fuel and air is the principal determinant of flame length. Once fuel and air are mixed, the combustion reaction proceeds very quickly. By supporting combustion only after the fuel and air mixing are complete, the flame is confined to within and near the porous distal surface. Short flames eliminate flame impingement, as well. Another possible benefit of delayed ignition is the ability of the fuel and air to entrain flue gas. This process dilutes the O_2 and fuel concentrations before ignition—the third important factor in the NO_x equation.

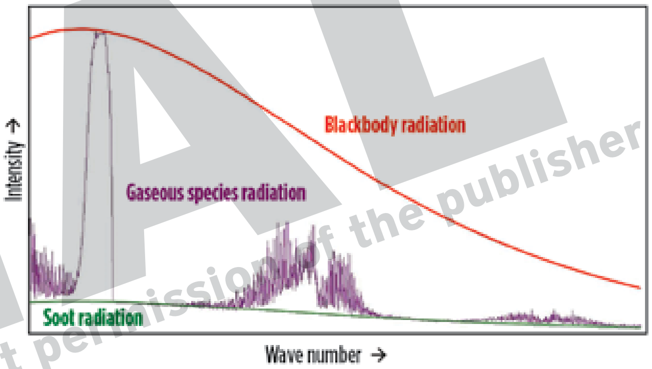

FIG. 3. Comparison of blackbody vs. spectral radiation for a gaseous fuel. A blackbody radiates with greater intensity than gaseous species radiation. The total radiant energy is given by the areas under the respective curves. By inspection, the area under the blackbody radiation curve is much greater than the area under the gaseous species radiation curve, indicating a much higher amount of radiant energy transferred.

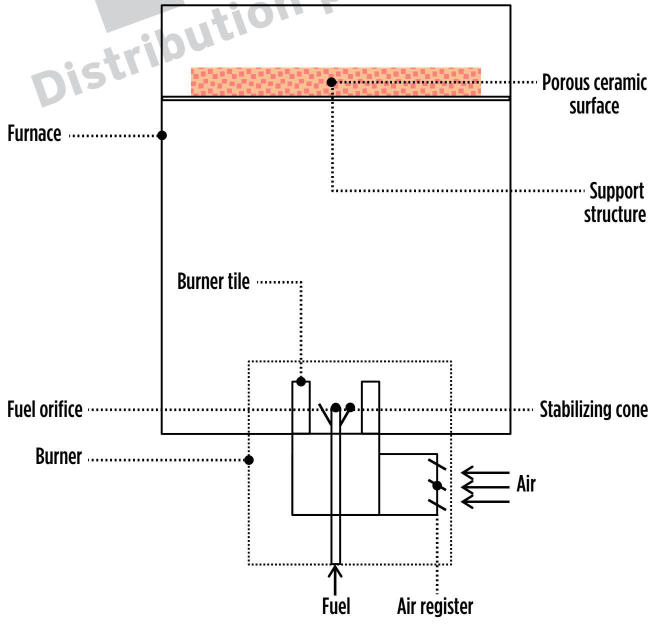

FIG. 2. Addition of a distal combustion surface. A distal porous ceramic surface has been added downstream of the burner. The flame is omitted. All combustion takes place within and nearby the distal surface. Under such conditions, NO_x is generally less than 5 ppm.

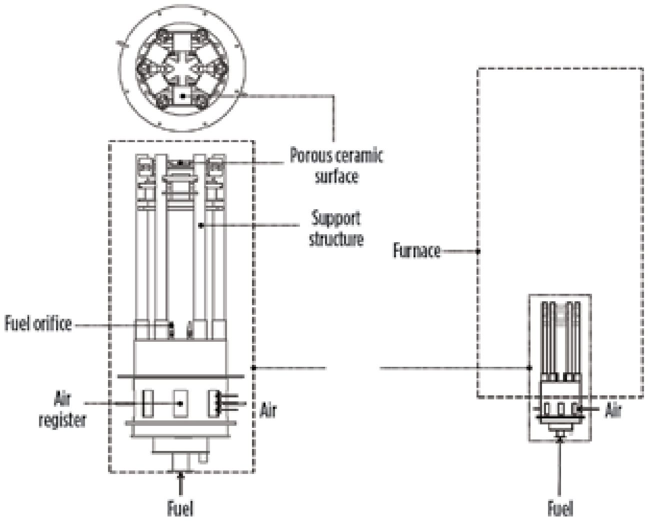

FIG. 4. Integral burner/distal surface assembly. Distal surfaces are added downstream of the burner proper as part of an integral burner assembly. This allows for a burner-for-burner replacement, whereby high NO_x of flame-impinging burners are swapped one-for-one with the integral burner/distal surface assembly.

Delek burner upgrades. The typical way that the distal surface is installed in a heater is shown in **FIG. 2.** It is also in commercial use in once-through steam generators (OTSGs). In these configurations, the technology operates in units with fired capacities as high as 62.5 MMBtu/hr. However, Delek preferred to install an integral burner-distal-surface assembly, because such an assembly would give Delek the ability to perform burner-for-burner replacements without the need to modify the heater. **FIG. 4** shows the integral assembly that was developed. In this case, no additional surfaces are installed in the heater. Rather, the burner assembly contains both the burner and the distal surface. One of the challenges to installation was refinery fuel that contained varying amounts of hydrogen (H_2). H_2 has markedly different combustion properties compared to hydrocarbons. For example, H_2 has triple the flame speed and burns over an air-to-fuel range that is more than six times wider than natural gas.

These characteristics conspire to form flames prematurely, lengthen flames and inflate NO_x. Moreover, bringing the distal surface closer to the burner requires faster mixing than afforded by conventional burner designs.

To ensure that the final design would operate successfully under these conditions, the vendor[4] performed extensive testing in its facility, which varied excess O_2, H_2 content, turndown and flame detection locations. These variables were tested with various burner and structural support configurations, with Delek approving the final test matrix. The final design required the development of a novel technology to enhance mixing, stabilize the flame and reconfigure specially designed distal surfaces.

State of the art. The new product has successfully proven itself in full-scale laboratory testing over H_2 concentrations ranging from 0% to 70%, and under anticipated turndown conditions and a wide range of excess air scenarios. The next step is installation in Delek's Tyler, Texas refinery before the end of the year.

Delek's FCC preheater is a six-burner heater. Two of the six burners are to be replaced in the operating heater. The goals of this demonstration are twofold: to demonstrate that the burners can be safely swapped while the unit is in operation, and to demonstrate that flame lengths are reduced and flame impingement is eliminated. Pending a successful result, the remaining four burners will be replaced and NO_x emissions will be measured.

With this and other efforts, Delek seeks to further establish its commitment to environmental stewardship and enhanced value for shareholders and society.

NOTE

[a] The other major species containing NO_x is nitrogen dioxide (NO_2). However, for industrial combustion systems operating at 2%–5% excess O_2, NO_2 is a relatively minor component and not considered further.

REFERENCES

[1] Zeldovich, Y. B., *Acta Physicochim,* USSR, Vol. 21, Iss. 577, 1946.
[2] Fenimore, C. P., "Formation of nitric oxide in premixed hydrocarbon flames," 13th International Combustion Symposium, The Combustion Institute, Pittsburgh, Pennsylvania, 1970.
[3] ClearSign Combustion Corp., Seattle, Washington, www.clearsign.com.