LSV™ Burner Technology for Improved Efficiency, Reliability and Low-NOx: A Case Study

Air Products installed new low-NOx LSV™ (Large Scale Vortex) burners in a new Steam Methane Reformer in Westlake Louisiana in 2004. This 110 MM scfd (123,000 Nm^3/hr) hydrogen reformer was built by Technip USA and it was equipped for the first time with Air Products proprietary LSV™ burners. The total firing rate at full capacity is around 900 MM Btu/Hr (264 MW) and it is distributed using 126 down-fired burners in 9 burner rows.

The LSV™ burner is based on a highly stable fluidic flame stabilizer and a highly efficient and unique fuel injection system. The nozzle-mix flame stabilizer enables the primary flame to operate at ultra-lean conditions for low NOx operation over an extended operating range without the aid of a mechanical flame retention device. It is suitable for operation with purge gas and natural gas or refinery fuel gas.

Shortly after start-up of the Westlake reformer a performance test was conducted. The design capacity was achieved and the NOx emissions met the expected and required levels, however, due to burner-furnace interactions, tube wall temperature uniformity and flame patterns needed improvement. In response, a team was commissioned to optimize the burner to improve the reformer operation using experimental and engineering design tools.

Recently, the modifications recommended by the team were implemented leading to significant improvement of furnace operation and tube temperature uniformity. This uniformity allowed further optimization of the reformer operating parameters, ultimately resulting in much higher overall efficiency of Westlake operation. This paper discusses the before and after cases.

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Background

This paper will give an account of Air Products' experience with the most recent installation of Air Products proprietary low-NOx LSV™ burners on Westlake Steam Methane Reformer (SMR). These burners reflect the state-of-the-art technology developed and first field tested in the year 2000 on New Orleans SMR [1, 2]. The present paper points to experiences with the "as installed" or original burners and modified burners on Westlake reformer. Westlake SMR is a large hydrogen plant supplying hydrogen over-the-fence to nearby refinery customers as well as feeding Air Products hydrogen pipeline along the US gulf coast. The reformer configuration is down-fired, down-flow with a horizontal convection section.


Figure 1. Westlake steam reformer.


Figure 2. LSV™ burner installation.

In addition to hydrogen production, the plant exports steam to nearby refinery customers. Figure 1 shows the side view of Westlake reformer. The LSV™ burner installation with preheated combustion air ducts is shown in Figure 2. The reformer was started up in April 2004 at design hydrogen production rate of 110 MM scfd (123,000 Nm^3/hr). There are 126 LSV™ burners and total firing rate was approximately 900 MM Btu/hr (264 MW). The makeup fuel for reformer is fefinery fuel gas (RFG) and remaining fuel is PSA purge gas. The split between RFG and purge gas is 30:70 on heat input basis. The design combustion air preheat is 640 °F (338 °C). The reformer has nine (9) burner rows and eight (8) tube rows.

LSV™ Burner

The LSV™ burner is based on proprietary know-how from Air Products and Chemicals, Inc. The burner is manufactured and commercialized by John Zink Company under a license from Air Products and Chemicals, Inc. To improve flame stability, the burner uses a unique fluidic flame stabilizer. As shown in Figure 3, in the LSV™ burner design, the flame stability is reached by creating a large scale vortex in the center of the flame. This flame stabilizing vortex is created by mixing part of the air with a small portion of the fuel at dissimilar velocities. The LSV™ burner, contrary to other ultra low NOx burners, does not contain metallic or ceramic flame stabilizers.

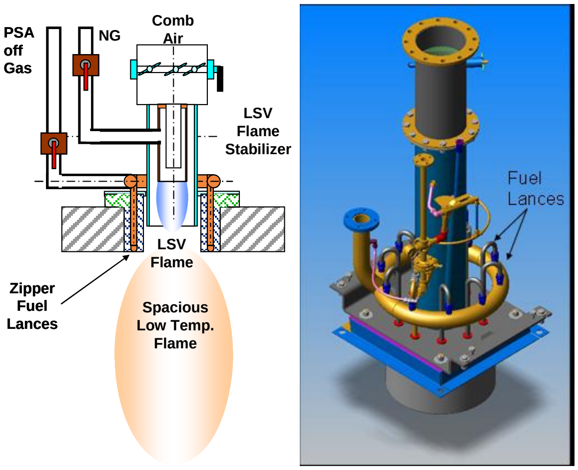

Figure 3. LSV™ burner design schematic and actual hardware.

To reduce NOx in the stack effluent, the LSV™ burner creates special furnace gas flow and temperature patterns using novel staged fuel injection nozzles. The patented fuel nozzles with slotted tip geometry inject purge gas fuel to mix with air, combustibles and furnace gases to create local conditions that are unfavorable for NOx formation or which favor the reduction of already formed NOx [3]. At the same time, the flame needs to be stable not only at design conditions, but also over a large turndown ratio. Flame bending that causes flame-impingement on the radiant tubes should be avoided at all times. The stability of the flame is determined by the burner design and by the firebox geometry and heat-flux patterns. Unfortunately, the conditions favoring low NOx are generally contradictory to the conditions of creating stable flames. This has to be optimized with burner design and burner spacing in the firebox to retain low-NOx benefits.

Westlake Start-up Experience (Before Case)

The Westlake reformer was started up in April 2004. The plant reached design capacity for hydrogen production and export steam with some process constraints. Figure 4 shows the start-up flames when reformer was just heating up whereas Figure 5 shows burner flames at design hydrogen capacity. In Figure 5, two burner row pictures are compared side by side to show initial signs of furnace instability which showed up as cold and hot tube zones in the furnace and will be discussed in more detail later. The non-uniformity in tube wall temperatures was visible by looking at burner row 5 (hot) and burner row 6 (relatively cold).

Figure 4. Startup flames.

Figure 5. Furnace instability as indicated by hot and cold burner row 5 and 6 respectively.

A performance test was carried out on the reformer to measure and compare several parameters against design values including process gas subheader temperatures, crossover temperatures, tube wall temperatures, and NOx emissions. The most striking evidence of furnace instability apart from visually hot and cold tube rows was a wide variability in process gas sub-header temperatures.

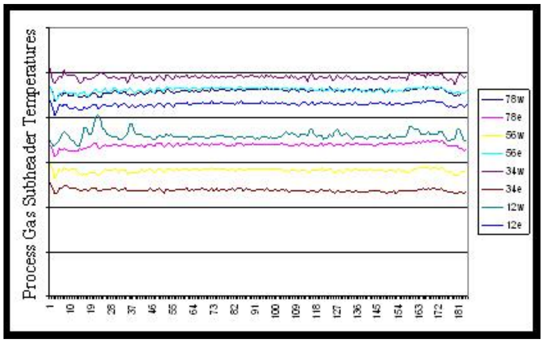

Figure 6. Process gas outlet subheader temperature variability.

The Figure 6 shows the sub-header temperature difference of almost 130 °F (72 °C) between hottest and coldest sub-headers. The desirable sub-header temperature difference from operations point of view is less than 70 °F (39 °C). Another undesirable effect of wide subheader temperature variability is the impact on tube and catalyst life at design rates. Due to above concern, a complete temperature survey of reformer tubes was carried out. A detailed survey on 368 tubes indicated that certain tubes were already at their design or service temperature of the tube metal and the difference between hottest and coldest tube (Max – Min) was 200 °F (111 °C). The desired value should be less than 100 °F (55 °C). On the upside, the pre-SCR NOx emissions measurements indicated 22 ppmvd NOx corrected at 3% O2. This was well within expectation for the RFG fuel consisting C1 = 45%; C2, C3, C4 = 30%; Olefins = 15% and H2 = 10% and air preheat of 640 °F (338 °C).

At this point the project team decided to understand the flame characteristics and also balance the reformer using standard means. A fact finding team was sent to the reformer site to perform activities such as: shaving off tube wall temperature peaks by trimming individual burners at hot-spots, reducing header fuel to relatively hot rows, balancing combustion air to various finger ducts based on excess oxygen measurements in flue tunnels and determining flame length based on CO concentration (see Figure7). Extensive field work comprising individual burner firing adjustments as well as balancing combustion air distribution to 9 finger ducts and 9 makeup fuel headers did not produce noticeable improvement in eliminating hot and cold tube rows. Flow visualizations using baking soda injection from burner ports indicated undesirable flow patterns in the form of rising furnace gases from bottom to top and it was observed that furnace instability simply moved from one location to another location with numerous balancing attempts. In addition, to our surprise, the CO measurements confirmed expected flame length for burner firing capacity. Therefore, the mal-distribution in tube wall temperatures had to be due to undesirable furnace gas currents and burner-furnace interaction.

Figure 7. CO sampling to determine flame length.

Westlake Optimization Study

A basic understanding of furnace gas recirculation patterns and an interaction between burner-to-burner flames was necessary to fix above discussed issues at Westlake. A CFD model for entire furnace confirmed field observations of undesirable furnace gas recirculation currents. A hypothesis was developed based on field observations and CFD simulations that a wide flame envelope associated with a relatively high firing rate in the given combustion space (footprint based on burner spacing and the relative distance of tube rows on each side) results in furnace instability and large spread in process gas header temperatures. This is more pronounced for reformers having higher firing intensity. The firing intensity is defined as total reformer firing capacity divided by footprint of reformer box interior. Undesirable furnace gas recirculation patterns in the form of "updraft" or "chimney" in certain burner rows affected the reformer local duty by bringing in colder furnace gases from bottom of the reformer to the top region near flames and produce flame impingement in certain burner rows. It was understood that by reducing individual flame diameter, it will create an additional "breathing" space around flame jets, reduce burner-to-burner interaction and perhaps eliminate undesirable furnace gas updraft problems as well as tube temperature non-uniformity. Specific recommendations after the plant visit and comprehensive CFD modelling include:

1. Reduce furnace instability by reducing burner-to-burner interaction in the reformer furnace using improved combustion of RFG fuel and improved fuel tip design.
2. Maintain NOx emissions within regulation limits.

To improve the probability of success and reduce risk, a two-pronged approach was followed to determine field modifications on LSV™ burners.

- A comprehensive computational model was developed for the current furnace including burners, tubes, flue gas extraction tunnels and it was validated using field data. This model was then used as a test bed for simulating new recommendations. The recommendations included changing fuel injection strategy and mixing with combustion air and furnace gases. These simulations confirmed improvement in furnace gas flow patterns and temperature uniformity among rows.
- Promising solutions with modified tip geometry for improved mixing were further tested in the laboratory furnace for flame stability and NOx emissions at various reformer operating conditions.

Figure 8. Pathlines of fuel jets and combustion air.

The first modification included changing selective purge gas fuel tip design with multi-level fuel staging strategy, changing injection angle and also changing mixed-fuel gas velocity to improve mixing with combustion air. The proprietary tighter flame envelope and multi-level staging strategy was confirmed using CFD modelling as shown in Figure 8. Here fuel jets were mixed at several levels with combustion air to provide a flame squeezing effect. This enabled improved recirculation around main flame jet and at the same time providing breathing room between neighbouring burners.

The second modification included a proprietary “mixed fuel” approach where trim fuel and PSA purge gas were mixed together in the fuel manifold so as to dilute heavies (and olefins) contained in the RFG fuel.. The modified burner firing in the laboratory also confirmed much tighter flame envelope and under 20 ppmvd NOx emissions.

Westlake (After Case)

\Plant downtime after hurricane Rita was efficiently utilized for burner modifications work. Selective purge gas fuel tip change-out and mixed-fuel piping modification on all burners were accomplished within 2-weeks. After operation readiness inspection, the hydrogen plant was successfully started up (see Figure 10). The flames were straight and stable at even 20% production rate during the start-up (see Figure 9).

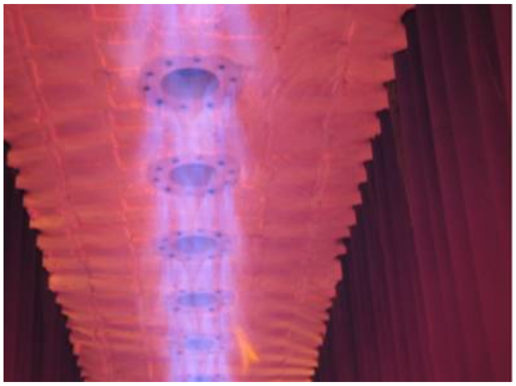

Figure 9. LSV™ burner flames at 20% plant rate.

In addition, the team confirmed exceptional tube wall temperature uniformity as well as excellent furnace operation at all production rates. The results after burner modification indicate top-notch reformer performance in flame characteristics, tube wall temperature uniformity and NOx emissions.

The CFD simulations of before and after flames with actual flame photographs for all 9 burner rows are shown in Figures 11 and 12. The original burner flames did not form tight pencil type structure and deflected either to the left or to the right due to burner interaction. On the other hand, modified burners produced straight pencil type flames. These flames had sufficient momentum to travel straight, initiate rapid burnout and provide sufficient breathing room for normal entrainment of furnace gases.

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Figure 10. LSV™ burner flames at 95% plant rate.

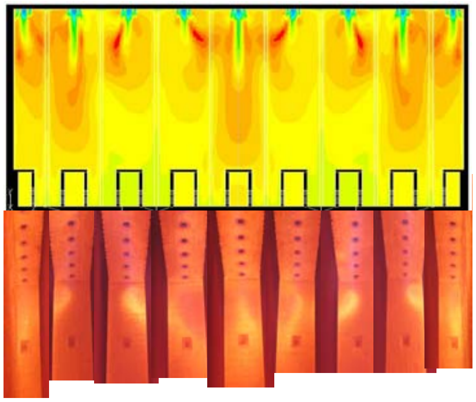


Figure 11. Slightly bending and smoky flames before modification.

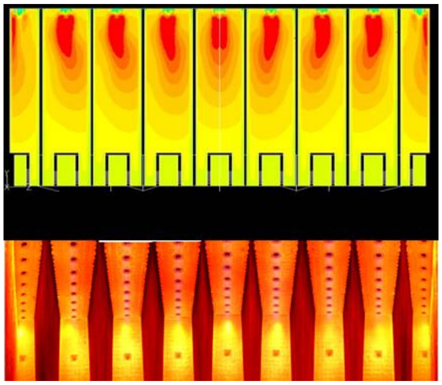
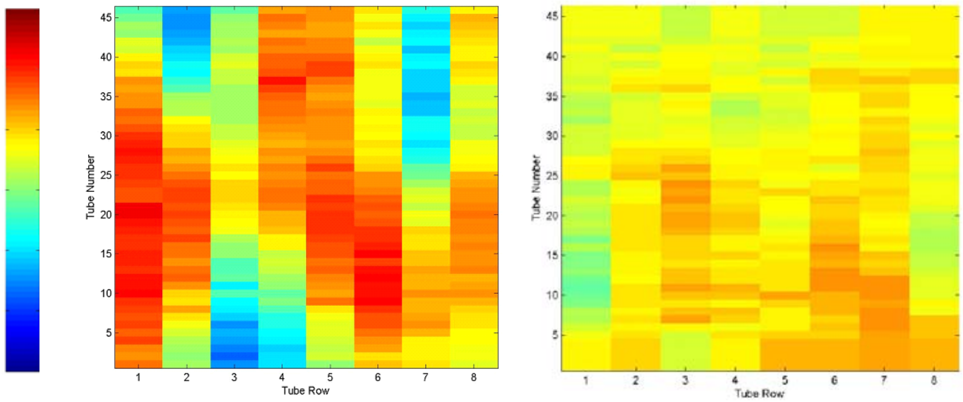


Figure 12. Straight and clear flames after modification.



	Westlake Before	Westlake After
Capacity	**110 MM scfd**	**110 MM scfd**
TWT ΔT (max-min)	**200°F**	**84°F**
TWT ΔT (max-Avg)	**100°F**	**30°F**

Figure 13. TWT color raster plot: before vs. after.

Plant operations carried out a complete survey of reformer tube temperatures before and after burner modifications. The largest benefit after modifications was extraordinary uniformity in tube wall temperatures. The average tube wall temperature was more than100 °F (55 °C) lower than maximum service temperature of process tubes at design rate and the standard deviation in tube temperatures was less than 15 °F (8 °C). The color raster plot of measured tube wall temperatures before and after modifications is shown in Figure 13.

Table I. Process benefits with LSV™ burners.

Parameters	**Before Modifications**	**After Modifications**	**Industry Typical**
Measured Tube Wall Temperature Difference, (Max – Min) for 368 Process Tubes	200°F	80°F	180°F
Process Gas Outlet Temperature Difference, (Max – Min) for eight subheaders	130°F	25°F	80°F

In addition, the spread in process gas outlet temperatures from various sub-headers was narrowed to less than 25°F. The secondary benefit from above developments was the ability to raise the process gas outlet temperature. The process benefits of optimized LSV™ burner before and after modifications are quantified in Table I.

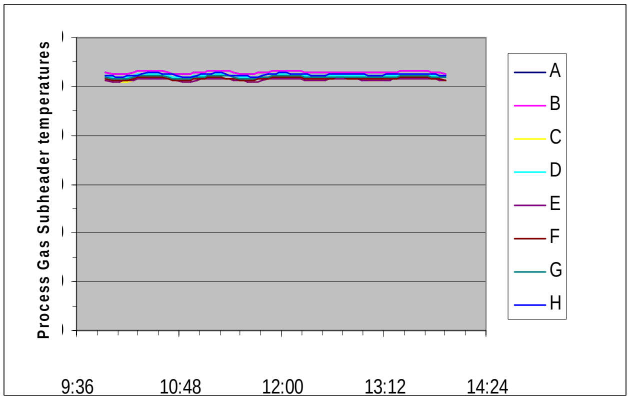


Figure 14. Straight and tight band of process outlet subheader temperatures.

Measured process gas subheader temperatures from various subheaders collapse in a tight band of straight lines separated by less than 25 °F (14 °C). This is shown in Figure 14. This kind of predictable behaviour is ideal for reformer operation. Operators can track their process gas outlet set point temperature easily at various production rates and optimize conversion.

The economic benefits of improved furnace stability and the resulting extraordinary tube wall temperature (TWT) uniformity are quantified in Figure 15. The difference between (Max – Average) tube wall temperature at Westlake was less than 30 °F (17 °C). The industry typical value is 90 °F (50 °C). Due to much tighter TWT distribution at Westlake, the allowable process gas outlet temperature can be increased, for example, by additional an 20°F, if downstream equipment such as transfer line pigtail material temperature limits, high temperature shift catalyst limits, etc. are amenable to above change. As mentioned before, higher process gas outlet temperature would enable higher conversion of syngas to hydrogen and improved plant efficiency. At $7/MM Btu ($6.64/GJ) fuel price and the example 20 °F (11 °C) increase, the annual cost savings can be $560k.

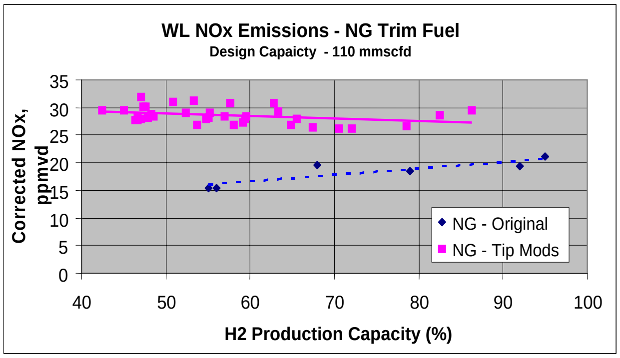
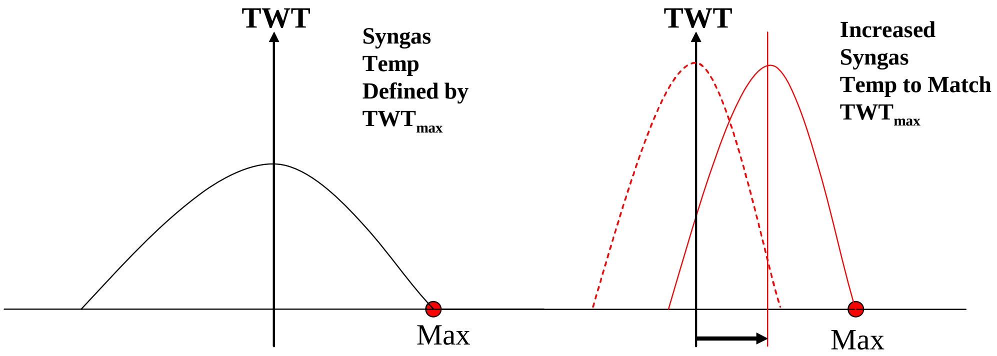


Figure 16. NOx emissions before and after of modifications (pre-SCR).

The key issue to study after achieving significant economic operating benefits was NOx emissions from the reformer after burner modifications. It was previously observed in the lab experiments before field modifications that improved staged fuel-combustion air mixing would result in increased oxidant availability in the flame region and higher thermal NOx formation. The pre-SCR NOx data with natural gas make-up fuel are shown in Figure 16 confirming previous findings. The data with RFG are slightly higher and vary depending on H2 content in the RFG fuel. The NOx data indicate still reasonably low-NOx performance (~ 30 ppmvd, pre-SCR) compared to other large reformers operating at equivalent operating conditions.



	Industry Typical SMR Furnace	Westlake LSV™Burner
Capacity	**110 MM scfd**	**110 MM scfd**
Syngas Temp Increase Potential	**Baseline**	**20°F (for example)**
Energy savings	**Baseline**	**2 btu/scf**
Annual Benefit ($)	**Baseline**	**$560 K @ $7/mmbtu NG**

Figure 15. Improved tube wall temperature (TWT) uniformity benefits.

Conclusions

The Westlake reformer is a key hydrogen production facility for Air Products pipeline in the Gulf Coast of Texas and Louisiana. Improved furnace performance coupled with low-NOx emissions provide a solid design basis for future plants in the region. In addition, learning from above modifications in the Westlake plant demonstrated that we now have the tools to diagnose furnace problems, and the LSV™ burners have been shown to be adaptable to implement model diagnosis. This experience and the added capabilities enable us to optimize existing and green-field reformers that have undesirable furnace gas recirculation patterns, wide tube wall temperature distributions (hot spots and cold spots), or furnace instability. Furthermore, this knowledge will allow us to optimize new reformers with respect to size and spacing of burners as well as process tubes. Such optimization could lead to significant capital savings.

References

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