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INSTALLATION OF LEAN PREMIX AND REMOTE FUEL STAGING SYSTEM IN INDUSTRIAL PROCESS HEATER FOR NEXT GENERATION NOX EMISSIONS CONTROL

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Abstract:
John Zink Hamworthy Combustion (JZHC) has completed the first installation and startup of the SOLEX combustion system in the Vacuum Tower Feed Furnace at a GS Caltex refinery in South Korea. The patented SOLEX™ burner compromises a lean premix zone of combustion, where the air-to-fuel ratio (AFR) is adjusted based on the conditions of the fuel gas and combustion air, paired with a remote fuel staging zone of combustion. To provide next generation NOx emissions, the combustion system includes a controls package that allows for single digit NOx emissions across all typical refinery fuel gas compositions from startup to full heater load.

For this installation, JZHC provided thirty-two (32) SOLEX burners as part of the system solution. This paper outlines key design aspects, describes the installation and startup, and provides a summary of the emissions performance of the SOLEX combustion system.

SOLEX Burner Design Aspects

The SOLEX burner utilizes the technologies of lean premix and remote fuel staging as the basis for achieving sub-10 ppm NOx emissions due to their theoretical performance as well as their need for no additional burner operating costs. The alternative technology available to the industry for achieving sub-10 ppm NOx emissions is post treatment through a selective catalytic reduction (SCR) bed, which has a significant capital cost or can be difficult or impossible to implement in a retrofit application. Furthermore, SCR technology has continuous operating costs regarding ammonia or urea injection.

Lean Premix Zone

The main flame zone of the burner uses a fuel-air mixture that is fuel lean in nature with a lambda that is specific to the fuel composition, combustion air temperature and the overall firing rate. These are the factors that directly influence the NOx and CO production. The combination of these factors determines the excess air required to reduce the flame temperature to the desired level to maintain low thermal NOx generation. On a high level, the requirement for excess air in the premix zone increases as the hydrogen concentration and air preheat temperature increase. Effectively, higher premix excess air equates to a lower premix heat release and higher staged heat release as the total air requirement of the burner remains constant.

A curve for each fuel gas and combustion air temperature can be generated through testing; however, the curves were found to be able to be represented by a generic form and generated on a unique basis by converting the fuel and combustion air characteristics into a singular value. The value used for this is the stoichiometric adiabatic flame temperature. For any particular NOx value, the excess air requirement (presented in form of lambda) can be calculated as a function of the stoichiometric adiabatic flame temperature. This methodology makes it simple to implement calculations with reliable and accurate results. Figure 1 displays a graph of the trend for a single value of NOx generated in the premix zone of combustion. Specific values are removed as they are held as intellectual property.

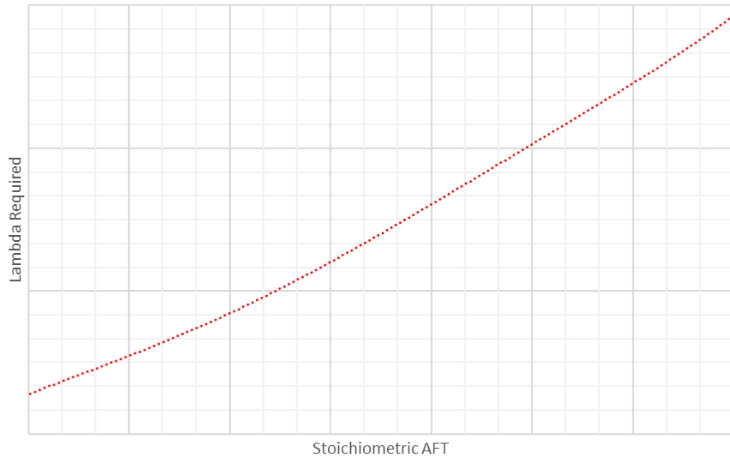

Figure 1: Generic Premix Required Lamba Curve

This calculation is run continuously providing the real-time AFR requirement of the premix zone of combustion. Utilizing a control system and a forced draft combustion air blower, the NOx and CO performance can be maintained through a wide range of operating conditions.

Remote Fuel Staging Zone

An additional set of gas tips are utilized with the fuel fired remotely from the burner premix flame. This zone of combustion requires autoignition temperature within the furnace for operation. The main drivers of emissions from this zone of combustion are the mixing length with the flue gas, the temperature of the flue gas, and the oxygen content of the flue gas. These factors are well known and established in the industry through staged gas burner technology.

The firing split is derived by the following formula.

$$HR_{Total} * \lambda_{Total} = HR_{Premix} * \lambda_{Premix}$$

Where HR is heat release and λ is lambda, which is equal to the inverse of equivalence ratio or the sum of 1 and the excess air expressed as a percentage.

Rearranging for premix fuel split

$$Premix\ Firing\ \% = \frac{HR_{Premix}}{HR_{Total}} = \frac{\lambda_{Total}}{\lambda_{Premix}}$$

The lambda of the premix zone is calculated as described in the Lean Premix Zone section. The furnace operator can input the target firebox lambda (generally 10-20% excess air), and the firing split will be calculated appropriately.

Introduction to Customer Process

GS Caltex's vacuum tower feed furnace was operating with JZHC staged air/staged fuel combination burners with the oil firing mechanism removed. To meet regulatory requirements, an SCR in the heater convection section was utilized. By reducing combined stack NOx emissions from this heater and an adjacent heater with ULN burners to below 15 ppm, GS Caltex would be able to run the heater without using the SCR. JZHC proposed replacing the 32 existing burners in the vacuum tower feed furnace with SOLEX burners, fitting within the existing cutouts. A CFD study was performed to investigate if any issues would arise from the retrofit.

The results of the CFD study indicated that the SOLEX burner would not have a significant impact on the operation of the heater. A few of the interesting results are shared below.

CFD Velocity Vectors

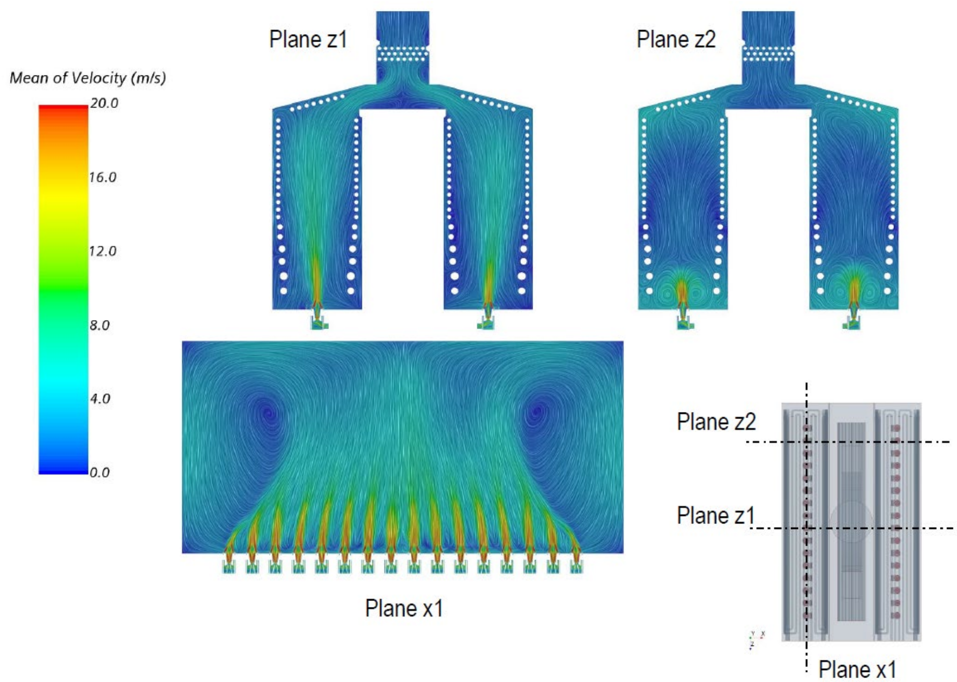

Figure 2: CFD Velocity Vectors, Original Burners

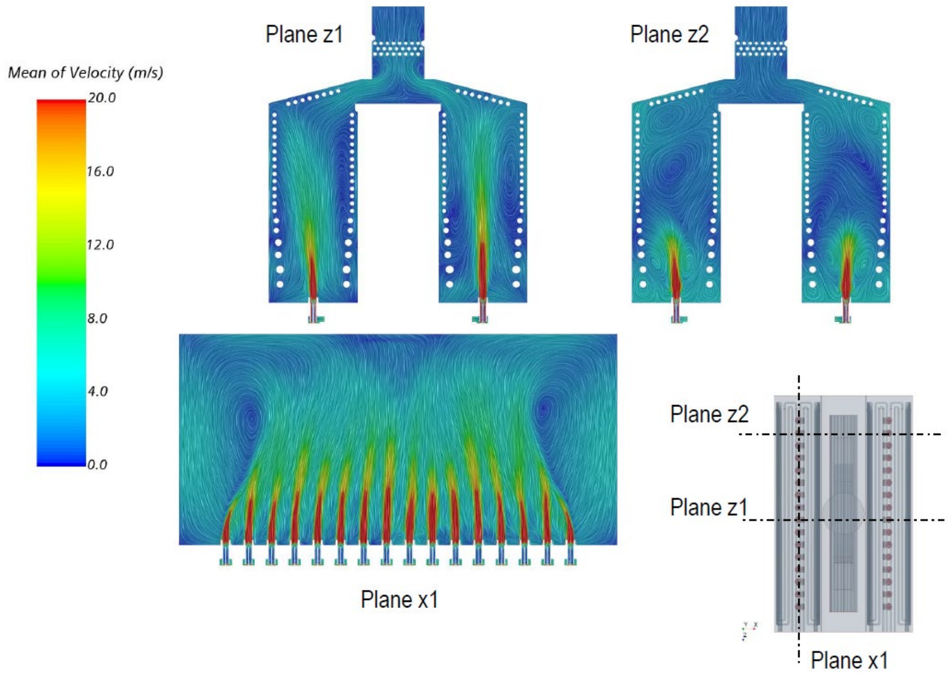

Figure 3: CFD Velocity Vectors, SOLEX Burners

The flue gas recirculation with the original burners installed shows a well-known pattern that arises from large burner to end wall spacing relative to the burner-to-burner spacing. The recirculation of flue gas is largely biased to the end wall due to the low energy state that can be achieved there. As the existing burner cutouts were reused, the same pattern was seen with the SOLEX burners. However, the SOLEX burner flue gas recirculation zone was compressed somewhat in comparison to the flue gas recirculation from the original burners.

CFD Temperature Contours

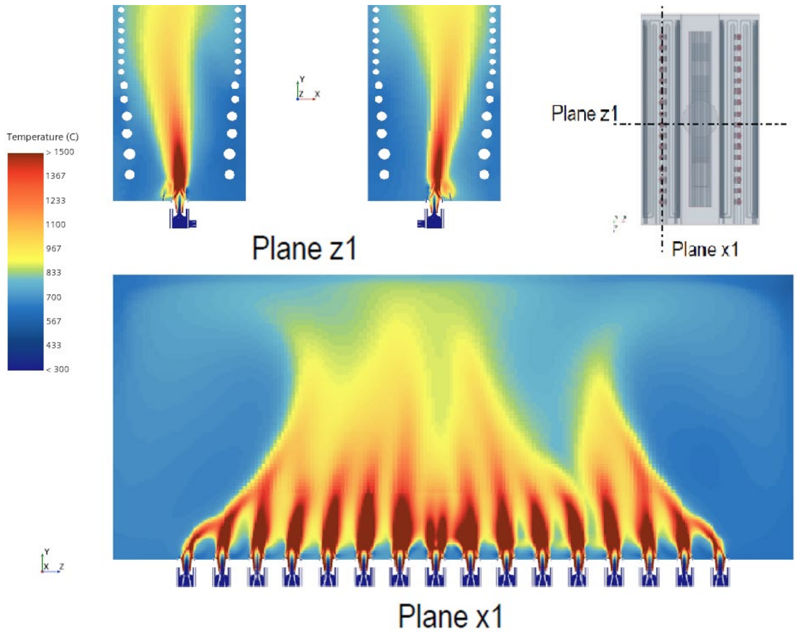

Figure 4: CFD Temperature Contours, Original Burners

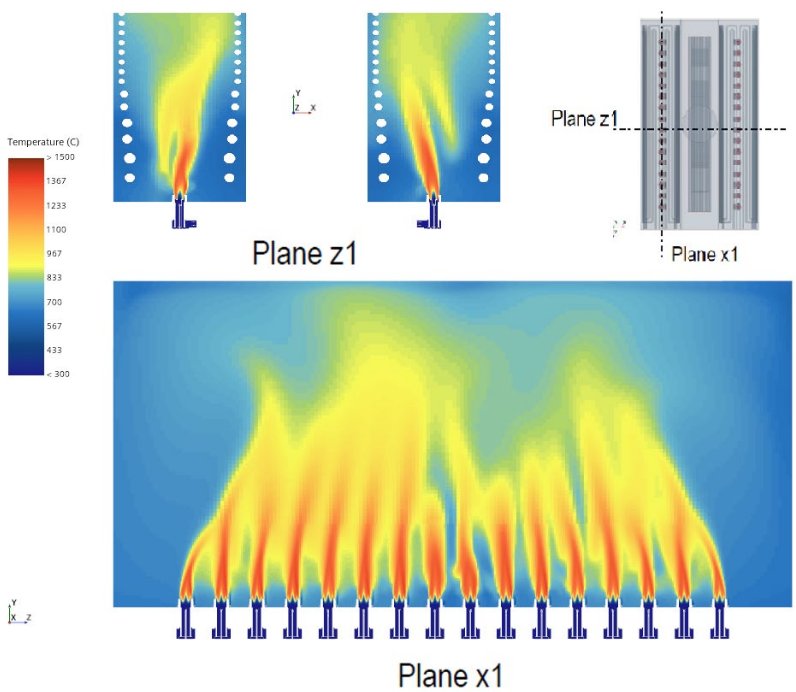

Figure 5: CFD Temperature Contours, SOLEX Burners

Generally, CO iso-surface of 2000 ppm is utilized for indication of flame volume. Due to the nature of lean premix and remote fuel staging, the 2000 ppm iso-surface of CO is much shorter than observed flame lengths. For comparing flame length, the combustion gas temperature was utilized as an approximation. As expected, the SOLEX burner results indicated significantly lower peak gas temperatures, correlating to their lower NOx generation. The temperatures in the upper regions of the firebox showed very similar values. This indicated no additional concerns for utilizing SOLEX burners in the application.

CFD Tube Metal Temperature

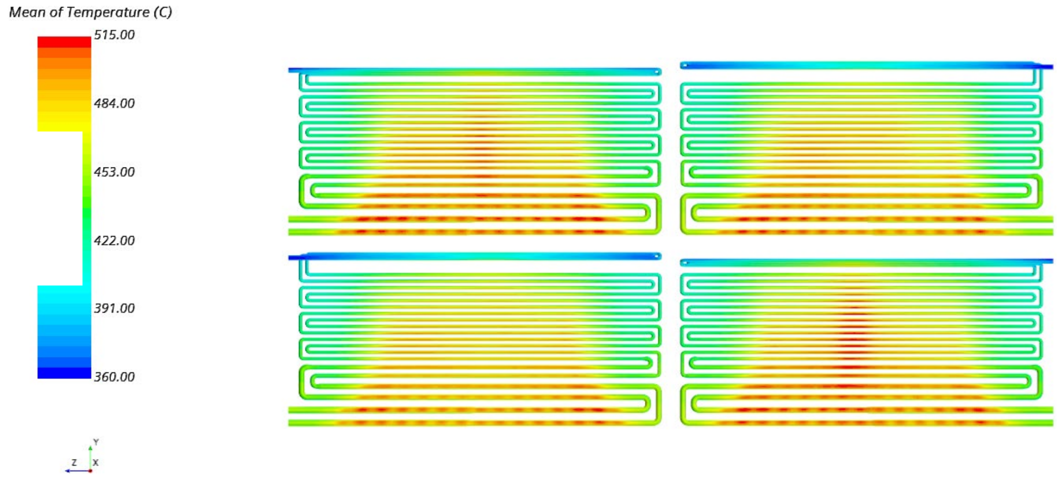

Figure 6: CFD Tube Metal Temperature, Original Burners

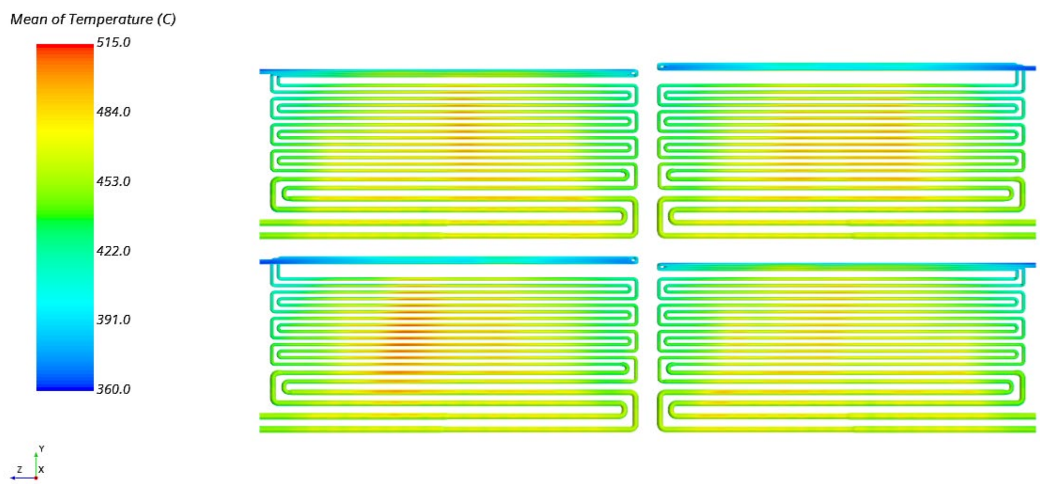

Figure 7: CFD Tube Metal Temperature, SOLEX Burners

Peak tube metal temperatures were 11 deg C lower with SOLEX burners, and the maximum heat flux was reduced by 4%. A reduced heat transfer was observed in the lower coils, but an increased heat transfer was observed near the end walls. The reduced heat transfer in the lower coils was expected as this is typical for lower flame temperature burners. The increased heat transfer near the end walls is believed to be due to the previously described flue gas recirculation pattern improvement. The radiant efficiency was calculated to be very similar with the two models.

Commissioning Process

Introduction

Startup of the heater was performed in May 2022 with JZHC personnel present. This was the first installation of the SOLEX burner technology in the field.

The SOLEX burner has distinct operating zones that are started in a specific order. First, the primary zone is ignited, followed by the premix zone and lastly followed by the staged fuel zone. The primary zone serves as an ignition method for the light-off of the premix zone. The heat release to the premix zone is then increased until the firebox temperature permissive for staged fuel firing is achieved. At this point, the staged fuel flow is increased until the desired firebox excess air is achieved. JZHC supplied an industrial computer programmed with the equations to determine proper values of AFR and zonal fuel splits based on the fuel gas composition, combustion air temperature and burner firing rate. The timelines of the firing of these zones and the implementation of computer setpoints as well as any relevant observations and recommendations are summarized below.

Primary Zone Firing

The SOLEX burner installed in the GS Caltex heater uses a custom ignition lance, identified as the primary zone, that is designed to light all the premix tubes. It is partial premix in nature and produces a swirling uniform ignition flame. As with any light-off device, location and orientation are critical to performance.

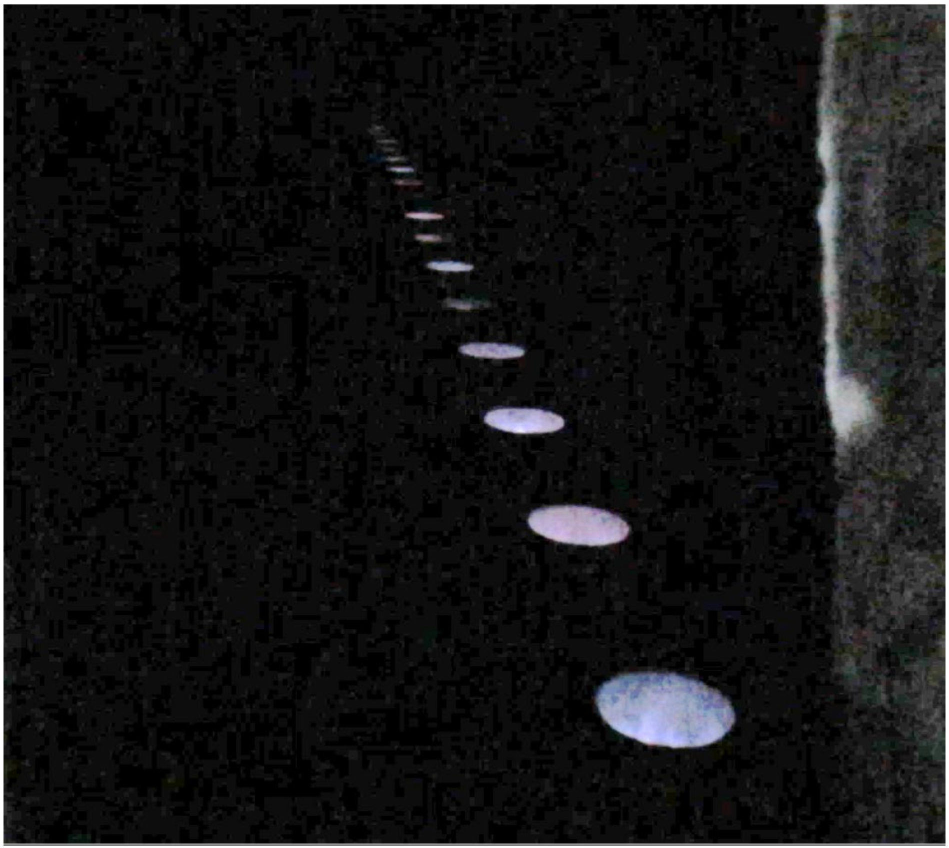

Figure 8: SOLEX Burner Primary Zone Firing

Premix Zone Firing

The premix zone was first ignited on the evening of 6 May by slowly opening the manual isolation valves on the burners. JZHC personnel were on site and advised on the manual valve open position as to achieve proper AFRs for each burner based on visual flame appearance. With appropriate experience and knowledge, the visual appearance of the premix flame on the SOLEX burner can be used as adequate feedback for manual control of this zone of combustion during initial startup.

JZHC recommends utilization of a low flow regulator for light-off to minimize the requirement for manual adjustment of burners.

Figure 9: Premix Zone Firing (Manual Operation)

Once all the premix zones were ignited, the fuel valves were gradually adjusted open, and airflow through the burners was increased as the process flow was increased. The burners were kept in manual operation at this time. Once the fuel valves are fully open, the system can be put in automatic control at this condition.

Staged Zone Firing

The burner heat release while operating with the premix zone only was increased until the firebox temperature permissive for initiating staged fuel flow was met. This was achieved on 9 May.

All staged fuel valves on the burners were opened so that the flow would be provided evenly across the furnace. The staged fuel flow was brought in slowly to allow for visual observation of the flame as well as to monitor the values of CO and O_2 in the firebox. The value of CO started at zero before the addition of staged fuel and did not increase through the process. Furthermore, as the fuel flow was increased, the excess O_2 in the firebox reduced correspondingly to the industrial computer setpoints. Staged fuel addition can be achieved by slowly lowering the target excess O_2 on the DCS screen. Figure 10 is an image of the furnace at the normal operating heat release rate with all burners and fuel zones firing.

 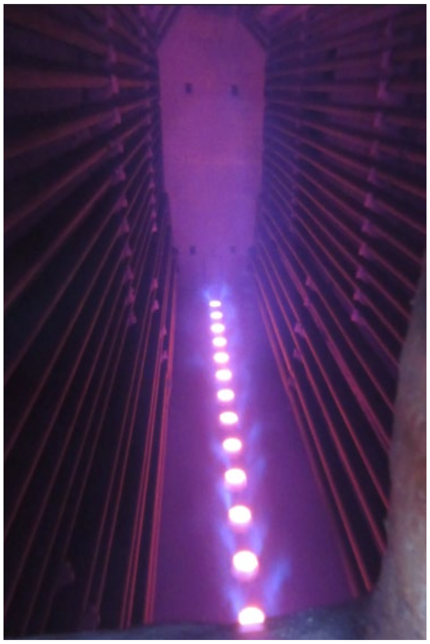

Figure 10: SOLEX Burner Design Firing

Automatic Control Implementation

The industrial computer setpoints were implemented on 12 May following confirmation of their accuracy. The critical item that was discovered on this day was a closed valve on the fuel gas composition analyzer. With this valve closed, the measured value of hydrogen in the fuel gas was less than 2% when the actual value was approximately 50%. Once the valve was opened, the fuel gas composition read correctly, and the recommendations were in alignment with the manual configuration of the heater.

Performance Results

NOx Emissions Performance

The main driver behind the installation of the SOLEX burner was the reduction of the NOx emissions. The CEMS used for this heater is on a shared stack with an adjacent heater and JZHC ULN burners. The NOx emissions are consistently under the requirement of 15ppm combined from the two heaters without requiring SCR operation. The figure below shows a recent trend of the combined heater NOx emissions.

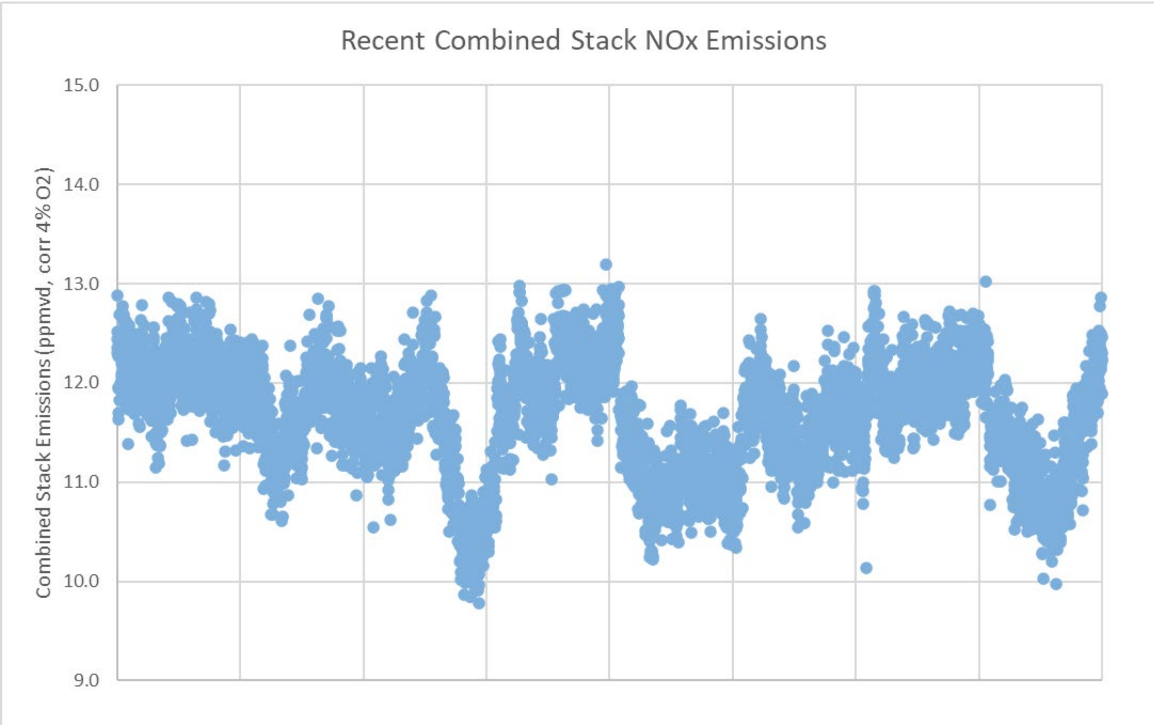

Figure 11: Combined NOx Emissions with Adjacent Heater

The emissions of the vacuum tower feed furnace NOx were measured directly during a follow-up visit to the customer site in August 2022. The emissions by handheld calibrated Testo measurement were 4 ppmvd when corrected to 4% O2 reporting basis. The emissions of the adjacent heater were 31 ppmvd when corrected to 4% O2 reporting basis. With the relative duty splits, this has reasonable alignment with the combined emissions value being reported by the CEMS.

Operational Swings

Each day the furnace sees a swing in heat demand due to a catalyst loading operation. The recommendations for AFR and zonal fuel split have allowed for continual automated operation through the swing in heater demand. Figure 12 is a trend of the furnace excess oxygen during the firing rate change.

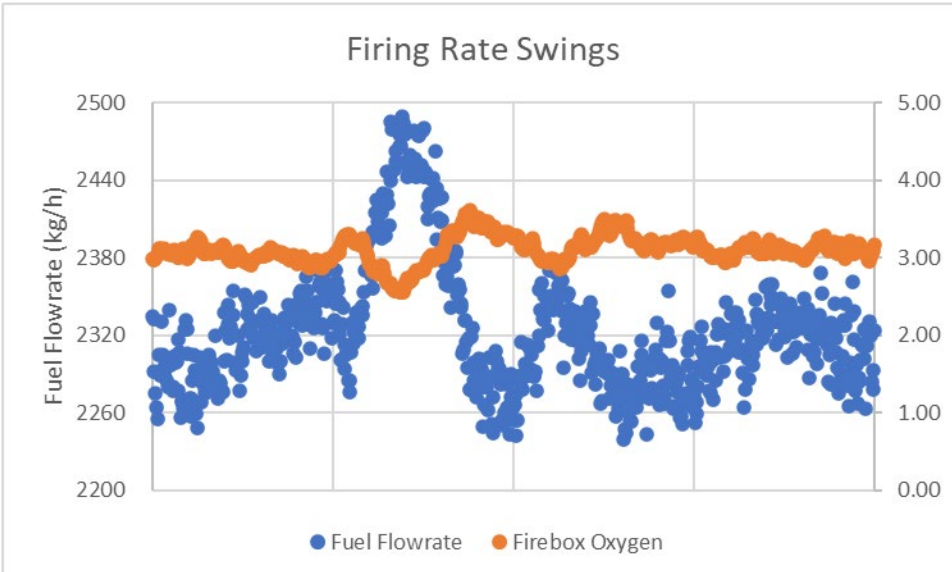

Figure 12: Operation Swing, Firing Rate Change

Fuel gas composition swings are a typical part of burner operation within a refinery. Of particular note for premix burners is the swing of hydrogen concentration in the fuel gas. Swings in fuel gas composition between 50% and 60% hydrogen have been observed and operated through the SOLEX burner and its control system without adverse effects. Figure 13 is a trend of the furnace excess oxygen during a typical hydrogen concentration change.

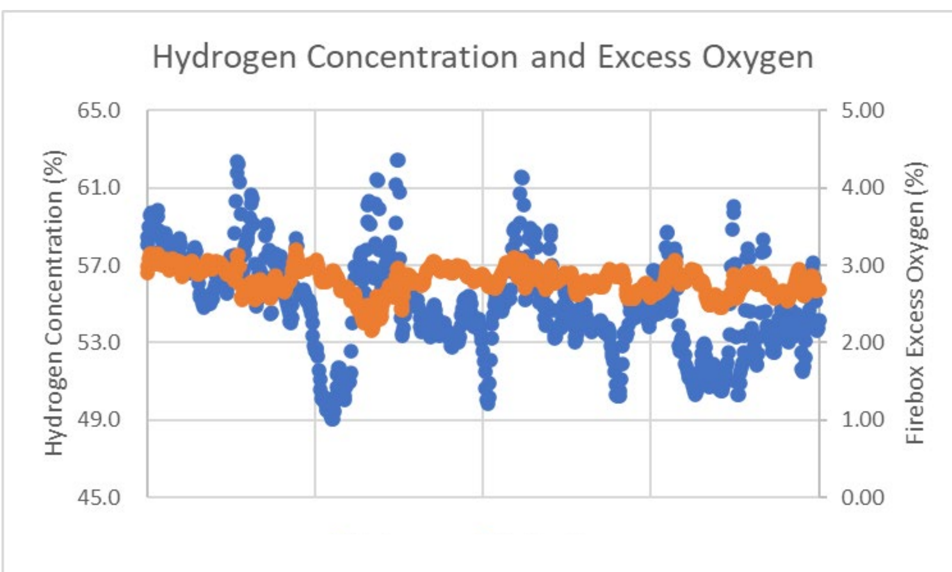

Figure 13: Operation Swing, Fuel Composition Change

Summary

For this installation, JZHC provided thirty-two (32) SOLEX burners as part of the system solution. The SOLEX burner uses lean premix and remote fuel staging to achieve single digit NOx performance across the operating range of the burners. The burner was retrofitted into existing burner cutouts and started up in May 2022 in GS Caltex's vacuum tower feed furnace. The burner is continuously producing single digit NOx emissions through swings in fuel gas composition and firing rates by utilizing dynamic control of the premix air to fuel ratio and the firing split between the premix and staged fuel zones of the burners.