Low NOx Burner Maintenance in High Temperature Furnaces

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Abstract

Regulations requiring reductions in the NOx emissions from refining and petrochemical furnaces have led to the development of a "next generation" of Ultra-Low NOx burner technologies. This paper breaks down the features of the new technology burner designs and examines them systematically in relation to well-known and emerging maintenance issues, especially those encountered in high temperature applications, such as Ethylene cracking furnaces. In addition, the new technology designs will be compared to previous generation designs, with a discussion of their relative performance. Advantages of the new technologies will be highlighted. Finally, recommended solutions to various potential critical maintenance issues will be presented.

Introduction

Combustion equipment used in petrochemical and refinery furnaces presents its own unique set of maintenance challenges. Most of these maintenance problems are well documented and have been successfully addressed for decades. Usually, changes in the design of the combustion equipment itself, are what drive changes in the way these maintenance problems are handled. The latest design changes, driven by emissions control regulations, require that maintenance approaches adapt and address some new, and potentially more critical, issues.

The low NOx drive in California in the 1990s and the more recently proposed Houston area regulations have spurred the development of new burner technologies to achieve very low levels of NOx emissions. The California SCAQMD regulations required NOx emissions to be kept under 0.03 lb/MMBTU (HHV), or ~24-28 ppm. Presently, the Houston area proposed regulations require NOx emissions of less than 0.01 lb/MMBtu (HHV) fired duty (~7-8 ppm NOx) for furnaces having capacities of 100 MMBtu/hr or more. However, NOx trading and plant "bubble" permits make it attractive to try and achieve the lowest emissions possible

Initially, Selective Catalytic Reduction (SCR) was viewed as the only solution to the 0.01 lb/MMBtu requirement. However, since then, burner technology has been rapidly developed to meet the need. The emerging burner technology of choice for these new regulations utilizes "Ultra Lean Premix," which capitalizes on the low NOx emissions achieved by burning gaseous fuel under very lean conditions, in conjunction with fuel staging and internal furnace gas entrainment. This new technology is quite different from the late 1990’s state of the art in NOx control technology, which used diffusion flame burners with aggressive fuel staging and internal furnace gas recirculation. The Ultra Lean Premix and the staged fuel diffusion flame burner designs implement fuel injection and mixing strategies differently and so the usual sources of maintenance problems manifest differently in each design.

The objective of this paper is to list the various well known maintenance issues related to burners and to systematically examine the design features of the new technology in the light of each of these maintenance issues. The discussion will be expanded to include comparisons to older technologies’ performance in each category.

Ethylene Furnace and Burner Environment

Ethylene cracking furnaces, with operating temperatures in the furnace typically between 2000^0 F and 2300^0 F, present one of the most severe operating environments for burners and other equipment. The most recent technology applied to a majority of Ethylene cracking furnaces has a tall, narrow rectangular furnace volume. The process tubes are suspended from top to bottom in the middle of the furnace, usually in a single row along the long axis of the furnace, and the burners are mounted close to the walls of the furnace. Figure 1 shows a photo of the inside of a typical Ethylene cracking furnace.

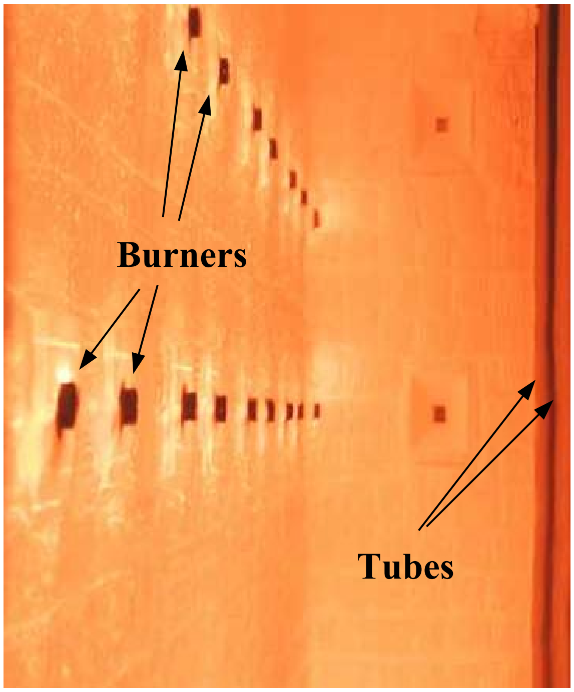

Figure 1 - Interior of a Typical Ethylene Cracking Furnace

The main objective in the design of the furnace is to try to achieve even heat delivery or some predetermined optimum profile of heat delivery to the process tubes. To do this the refractory material of the wall is heated by the burners and radiates heat to the tubes, thus using the refractory mass to create a more uniform heat delivery. In some of the older design furnaces of this type, spreading the heat input in a relatively uniform way over the wall surface was accomplished with many rows of radiant wall burners that have small heating capacities. In recent years, economics of operation and maintenance have driven a trend towards replacing rows of radiant wall burners with a single row of wall fired flat flame burners mounted on the floor and firing upwards along the wall.

Typically both the hearth burners and the radiant wall burners are mounted close to the refractory wall and establish their flames on the adjacent wall surface. Having a flame adjacent to a hot, insulating refractory wall creates severe operating conditions in two ways. First, the burner parts must now be located close to hot refractory that is being directly heated by the flame. Second the presence of the wall on one side prevents relatively cooler internal furnace gases from circulating on that side. Furnace gas circulation helps reduce NOx and remove heat from the vicinity of the burner.

The high operating temperatures and intense radiation within the typical Ethylene cracking furnace cause all exposed metal burner parts to be subjected to high levels of radiant heating from the furnace. This can result in high metal temperatures and heating of the gas or air/fuel mixture flows inside burner components, which, in turn, leads to potential maintenance issues that must be addressed in the burner design.

Burner Design Considerations

In addition to the environment inside an Ethylene furnace to which these burners are exposed, there are several considerations that will impact the burner maintenance requirements, which must be addressed in the burner design in order to maximize performance.

Burner Process

The main purpose of the burner is to mix fuel and air together in a way that can achieve stable, efficient combustion, produce good quality flame shapes, and minimize NOx emissions. To do this, the design must ensure that the proper amounts of fuel and air are introduced in the right locations within the burner and furnace. The air required for combustion is introduced into the furnace through the burners. When this air is drawn into and mixed with the burner fuel before delivery to the combustion zone, that portion of the burner is said to employ "premix" combustion. If the fuel is not mixed with the air ahead of the combustion zone, but delivered as pure fuel in the immediate vicinity of the combustion zone, the burner forms what is called a "raw gas" or "diffusion" flame.

When the fuel is introduced at different points of the air flow, the first portion of the fuel that encounters the combustion air is called the "primary" fuel. The combustion of the primary fuel forms the "primary flame." Fuel that is injected further downstream from the primary fuel, is called "staged" fuel. The burner design must insure proper mixing of the fuel and air in every location, so that complete combustion takes place with the specified minimum amount of excess air in order to achieve optimum overall furnace efficiency.

Protection of Burner Parts from Heat Damage

The points of introduction of both the fuel and air are only one concern for proper burner design. The internal furnace temperatures of 2100-2300 F found inside an Ethylene cracking furnace are high enough to cause scaling on even the most heat resistant metal alloys. Given enough time, this scale can build up and plug burner tip orifices and slots, resulting in flame pattern problems, or a loss of capacity. When scale forms, it consumes a portion of the metal from a burner tip, and can eventually result in enough loss of material to permanently affect burner performance. To keep burner component temperatures below the point where scaling is a problem, some burner tips are embedded in the tile so that only the necessary portion of the tip is exposed to the full furnace temperature. Figure 2 below shows a typical flat flame Ethylene furnace burner with the tips embedded in the tile.

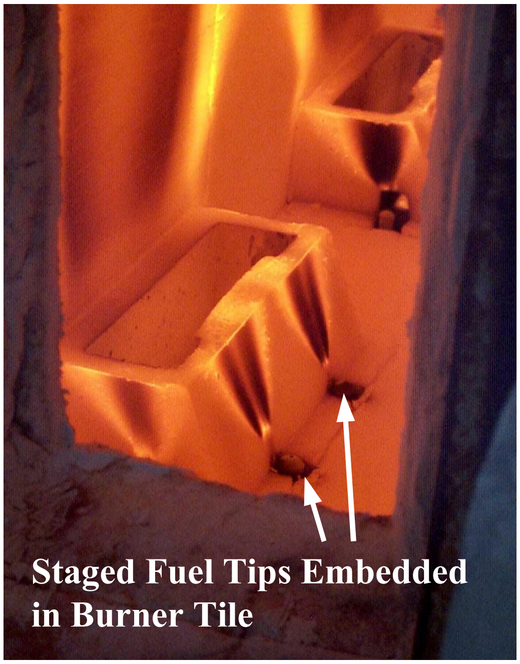

Figure 2 - Typical Flat Flame Ethylene Furnace Burner

Although this strategy keeps a majority of the burner away from the highest temperature regions, the components inside the furnace and just inside the tile surface are still vulnerable. It should be kept in mind that, as the furnace heats up, the tile surface exposed to the furnace quickly reaches the internal furnace temperature. Then, as the refractory begins to heat-soak, the temperature inside the refractory tile begins to increase. Figure 3 shows an example of a temperature profile through an 8 inch thick refractory block or burner tile under steady state conditions.

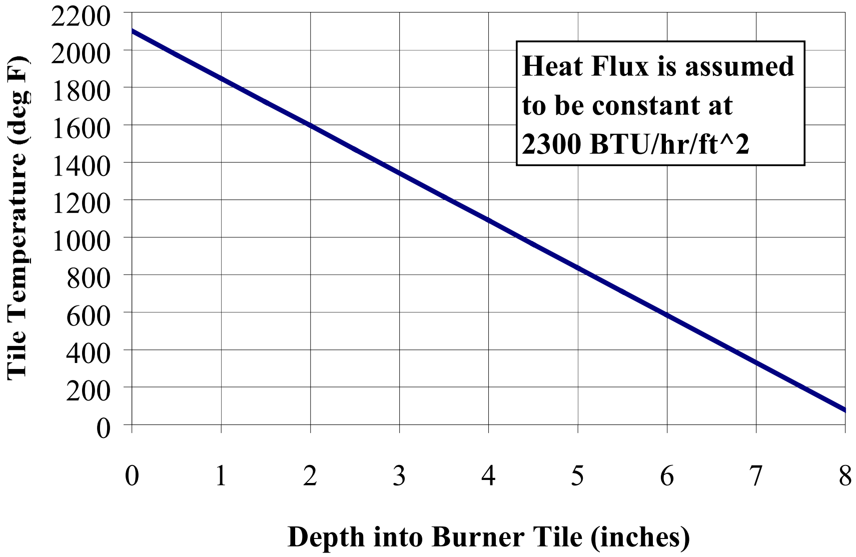

Figure 3 - Temperature Profile in Refractory at Steady State Conditions

As Figure 3 shows, the burner tile material is still above 1000 F for the first 4-5 inches nearest the inside of the furnace. Even though burner components may be protected from the furnace by a refractory tile, radiant heating from the tile can still make parts located in these areas susceptible to overheating, scaling or oxidation damage. Because the tile completely surrounds the component and is in very close proximity, it raises the shape factor (F_{1-2}) for radiation heat transfer in the following equation:

$$Q_{1-2} = A_1 F_{1-2} \sigma \left(\varepsilon_1 T_1^{\,4} - \varepsilon_2 T_2^{\,4} \right) \qquad [1]$$

where:
Q = Heat transfer from tile to burner component
A_1 = Surface area of burner component
F_{1-2} = Shape factor between burner component and tile
σ = Stefan-Boltzmann constant
ε_1 = Emissivity of burner tile
T_1= Temperature of tile material
ε_2 = Emissivity of burner component
T_2 = temperature of burner component

The higher this shape factor, the greater the heat transfer from radiation. The portion of burner components exposed to the full furnace temperature, and those located within the refractory near the inside of the furnace are still subjected to temperatures that can cause scaling, requiring the implementation of design strategies for additional cooling.

The additional cooling for these exposed components is provided by the flows of gas and/or air through the burner. Burner tips and risers (pipes connecting the fuel supply to the burner tip) are cooled by the flow of fuel gas, while premix tips, flame holders and air registers are cooled by the air flow through the burner. Even when the burner is out of service, the air doors and registers, which do not provide a tight seal when shut, allow some air flow through the burner. This air provides cooling for the burner components which can help to retard the effects of heat on the metallic parts.

Risers containing raw gas have the flow of gas to cool them, but when the fuel contains liquids, unsaturates, or heavy hydrocarbon components, there is also the possibility of coking inside the riser when the heat flux into the fuel gas is too high. If the fuel gas temperature is elevated enough, the heavier components will crack and can begin to form coke on the inside of the risers and tips. A buildup of coke will eventually plug the tip and/or riser and can insulate the tip metal from cooling effects of the gas flow, creating local areas of overheating. Therefore, high flow velocities must be maintained in the raw gas risers to minimize the residence time and associated temperature increase of the fuel gas to insure adequate cooling of the tip. The greater the expected heat flux, the higher the flow velocity required. Similarly, the flow of the fuel/air mixture in premix burners must be of sufficient quantity to absorb heat from the tip and keep it cool, while not allowing the temperature of the air/fuel mixture to become high enough permit flashback.

Flashback

Flashback is the sudden combustion of a premix mixture inside the premix tip and venturi mixer. It occurs when the flame speed of the burning mixture outside the premix tip exceeds the velocity of the mixture exiting the tip. When this happens, the flame can propagate back into the tip and ignite the mixture inside the tip and venturi mixer. When ignited, the mixture in the venturi can flash suddenly, making a popping noise, or can burn back and stabilize on the raw gas nozzle (orifice) that drives the venturi air inspiration, forming a diffusion flame inside the mixer. Flashback can be recognized by a popping or "barking" noise that will occur as the flame burns inside the burner tip or venturi. Because flashback can quickly damage the venturi mixer and tip, when it is observed, the operator should immediately shut off the burner and determine what additional actions to take to eliminate the unsafe conditions.

The flame propagation speed of the premix mixture is affected by three main factors: air/fuel ratio, mixture temperature, and fuel composition. Changing the proportion of fuel in the mixture (making the mixture "richer"), raising the mixture temperature, and/or increasing the amount of volatile components such as Ethylene, Acetylene, or Hydrogen in the fuel will increase the flame speed of the mixture. The burner must be designed so that exit speed of the mixture leaving the premix tip will always exceed the flame speed for the known operating conditions, even when the burner is operating at turndown. The tip exit area, the shape of the exit (slot or hole) and the exit velocity profile are all carefully engineered to ensure that the burner will not flashback at any point in the normal operating range with the design fuels. As explained later, certain operational and maintenance issues may cause distortion in the tip exit, thereby loosing its designed shape, which can lead to flashback damage in the burner.

Burner Adjustment

Typically burners are designed so that they will pass just slightly more than the amount of air needed for the maximum heat release when the air doors are fully open. However, when burners are placed at different elevations within a furnace, as they are with Ethylene crackers, the negative pressure within the furnace (or "draft") that is available to draw in the air for combustion decreases with elevation. This difference can be about 0.0115"WC of pressure for each foot of height in a 2000 F firebox (Reed, 1981). Typically, burners for these applications are designed to meet the maximum heat release at the location with the least available draft, and utilize an air adjustment mechanism to compensate for locations where more air flow is possible.

Premix burner designs use a fuel jet and venturi arrangement to aspirate all or a part of their own combustion air, making them less dependant on the furnace draft. This feature makes premix burners well suited for applications like large Ethylene furnaces where the draft is different at various elevations. Radiant wall burner designs that also use secondary air, however, must rely on the furnace draft for the secondary air flow. This means that when secondary air is used, burners lower in the furnace, if identical, may be capable of air flows greater than that required to achieve the maximum heat release.

The new technology Ultra Lean Premix low-NOx radiant wall burners are typically operated with 100% premix, meaning that the burner fuel draws in all of the air required for combustion. This makes these new burners less susceptible to differences in furnace draft than the prior technology, which typically used secondary air. With the new low-NOx burners, the ratio of air to fuel is critical for good NOx performance. Therefore, when air to the furnace is adjusted using the burners, the air doors must be set to the same position for all of the burners in any given elevation of the furnace. If the air doors are only closed somewhat for one or two burners in a row, these burners will produce higher NOx than the others. In addition, if the air doors of all the elevations of new low-NOx burners are set to the same position, then the burners on the lowest levels of the furnace will contribute more air, potentially affecting their stability, while the burners at the higher levels will have less air, increasing NOx emissions and their potential for flashback.

Metallurgy

Because the burner components subjected to high temperature operation do not have large stresses or heavy loading, the primary concern in selecting an alloy for these parts is the rate at which the metal will oxidize, or scale. Table 1 below shows the oxidation rates for various alloys at both 2000F and 2100F.

Table 1 - Alloys and Scaling Rates

Alloy	Form	Chrome Content (%)	Nickel Content (%)	Oxidation Rate at 2000 F (in/yr)	Oxidation Rate at 2100 F (in/yr)
CK	Cast	24-28	18-22	0.035*	0.065*
HK or HC	Cast	24-28	18-22	0.035	0.065
HL	Cast	28-32	18-22	0.040	0.060
HP	Cast	24-28	33-37	0.040	0.075
HX	Cast	15-19	64-68	0.025	0.040
Alloy 214	Wrought	16	75	0.001	0.003
Alloy 230	Cast/Wrought	22	57	0.0034	0.008
RA 330	Wrought	19	35	0.007	0.008

Taken from Metech report to John Zink Company, Dated June 25, 2001

* - Assumed to be the same as HK

Stainless steels and heat resistant alloys are protected by the Cr_2O_3 layer that forms on the surface of the material in an oxidizing atmosphere. At temperatures above 1830 F, the Cr_2O_3 oxide layer that protects chrome alloy steels from further oxidation begins to volatilize resulting in progressive oxidation and reduction of material thickness. The additional elements present in some of the alloys listed above help to stabilize the Cr2O3 at higher temperatures and reduce the oxidation rates for that material.

When in operation, the intrinsic cooling effects of the gas and air flows through the burner typically keep the tip metal temperatures well below the point where oxidation and scaling begins to occur. This allows the selection of more economical alloys such as CK-20 to be used for burner tip construction while still achieving a long life.

The only time when special attention must be paid to the protection of these CK-20 tips is when a burner is taken out of service while the furnace is at full operating temperatures. Even though the flow of air leaking through the burner may help to cool the tip a little, a CK-20 tip brought to full furnace temperature will begin to scale. The scaling can result in changed burner tip orifice or slot shapes, or in worse cases, result in complete loss of parts of the burner tip due to progressive oxidation. In both cases there will be loss of control and shaping of the gas and air flows, resulting in poor flame quality and burner performance. For this reason, burners with CK-20 tips should not be left out of service in a furnace operating at full temperature for long periods of time.

Conventional Burner Design

As mentioned before, in the 1990s, the burner design that was widely used for Low NOx applications was a diffusion flame burner with internal furnace gas recirculation. John Zink's trade name for that technology was INFURNOx. INFURNOx utilizes the fuel pressure to induce and recirculate large amounts of furnace flue gas and mix the flue gases with the fuel inside the furnace before ignition occurs. In this arrangement a small amount of the fuel is used to establish a primary stabilizing flame and the majority of the fuel is mixed with the flue gas in the secondary zone of the burner. Figure 4 shows a schematic of the INFURNOx burner process as implemented in a Hearth Burner.

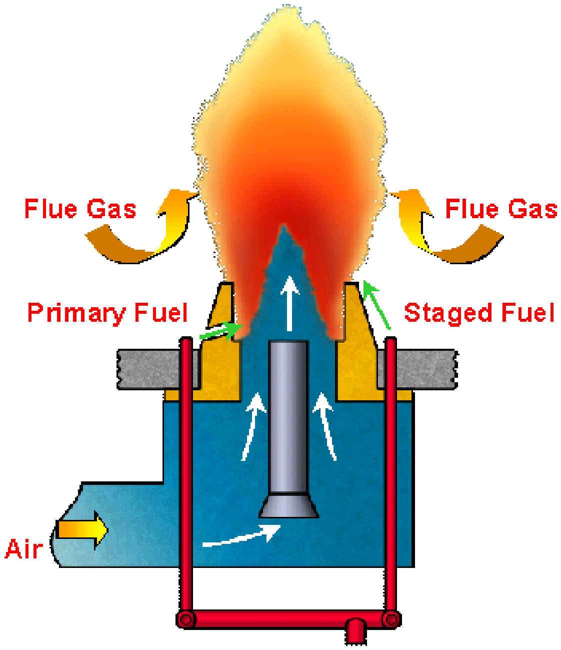

Figure 4: Schematic of INFURNOx burner process in a Hearth Burner

New Technology Burner Design

Ultra-Lean Premix is the newest strategy for NOx control that can yield NOx emissions performance of 10-20 ppm in actual Ethylene furnaces and less than 10ppm in single burner tests. Ultra-Lean Premix uses the technique of maximizing the quantity of air in a fuel-air premix far beyond the stoichiometric requirements for the fuel. The excess air in the premix flame absorbs heat from the combustion reaction and lowers flame temperature. Since flame temperature is the dominant factor driving NOx production it follows that the more fuel lean the mixture, the lower the NOx produced.

The two curves shown in Figure 5 represent the NOx emission performance of a diffusion flame and a premixed flame. The X-Axis is the fraction of air in the fuel/air mixture with the origin representing 100% fuel. The Y-Axis represents relative NOx emissions. It should be noted that Figure 3 is merely a representation of relative behavior and not an exact graph. The premixed flame has a bell shaped curve with NOx emissions dropping off steeply on either side of the stoichiometric point. The diffusion flame continues to emit more NOx as the amount of air is increased beyond stoichiometry until at a certain point where the heat absorption of the large mass of excess air begins to dominate and the NOx emissions begin to fall. The new Ultra-Lean Premix technology takes advantage of the NOx emissions behavior of a premix flame by making the primary fuel and air mixture as lean as possible, while operating within the flammability limit.

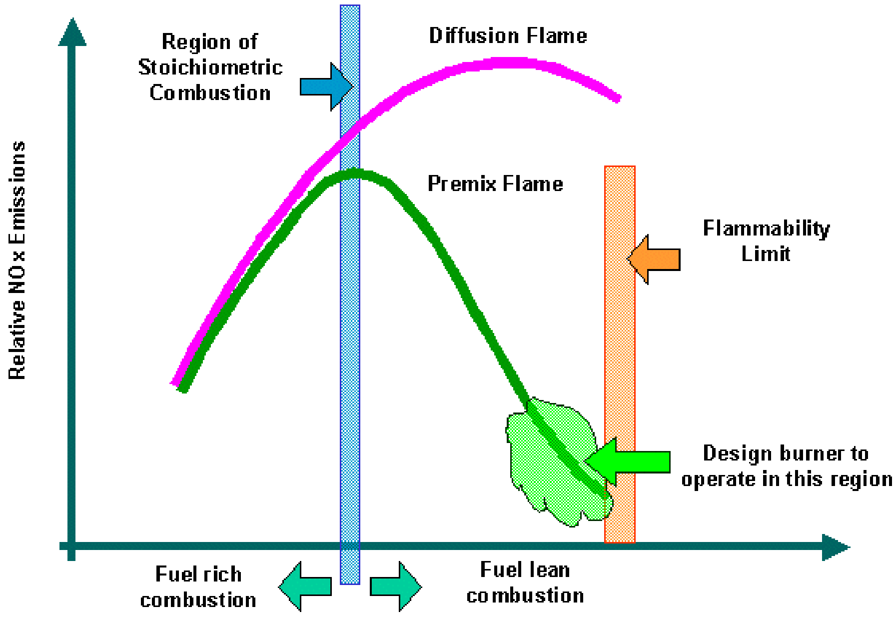

Figure 5: Comparison of NOx performance of Premix Vs Diffusion Flames

Figure 6 is a schematic illustrating how Ultra-Lean Premix may be implemented in an up-fired or Hearth Burner. The primary fuel, which is a fraction of the total fuel, is injected into a venturi eductor. This primary fuel educts the **entire** combustion air volume and is thoroughly mixed with the air before combustion.

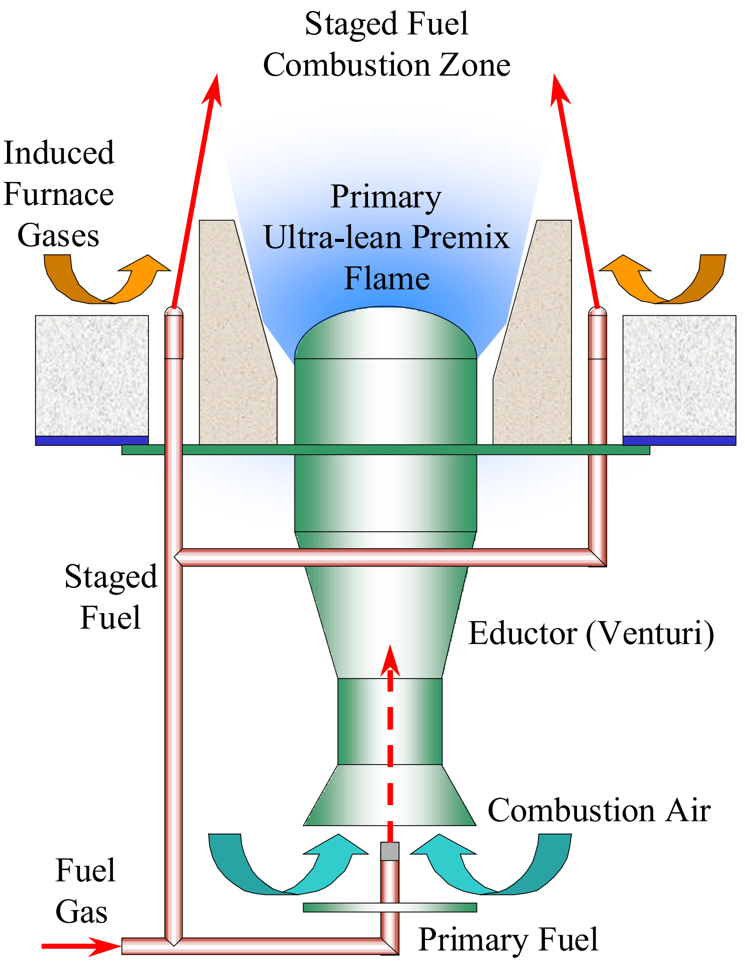

Figure 6: Schematic of an Ultra-Lean Premix Burner

Thus, when this mixture exits the tip and ignites, the primary fuel combusts in an environment with very high excess air. As mentioned before, the excess air absorbs heat from the flame, reducing temperatures and minimizing NOx formation. As excess air levels in the primary combustion zone are increased (making the mixture more and more fuel-lean), more air mass is present to absorb heat from the flame, and NOx emissions continue to reduce.

The remaining fuel for the burner (called “staged” fuel) is injected so that it mixes with inert internal furnace gases, in a manner similar to the INFURNOx technology, before it encounters the remaining oxygen from the ultra-lean primary combustion zone and ignites. Inert combustion products from the primary combustion zone further dilute the staged fuel combustion reaction. Furnace efficiency is maintained since the excess air from the ultra-lean primary combustion zone is consumed in the combustion of the staged fuel to provide a furnace exhaust gas with no more than the desired level of excess oxygen.

The same scheme can be applied to radiant wall burners with the exception that the secondary fuel is generally injected from a centrally located tip rather than multiple peripheral tips. Figure 7 shows the schematic of an Ultra Lean Premix radiant wall burner.

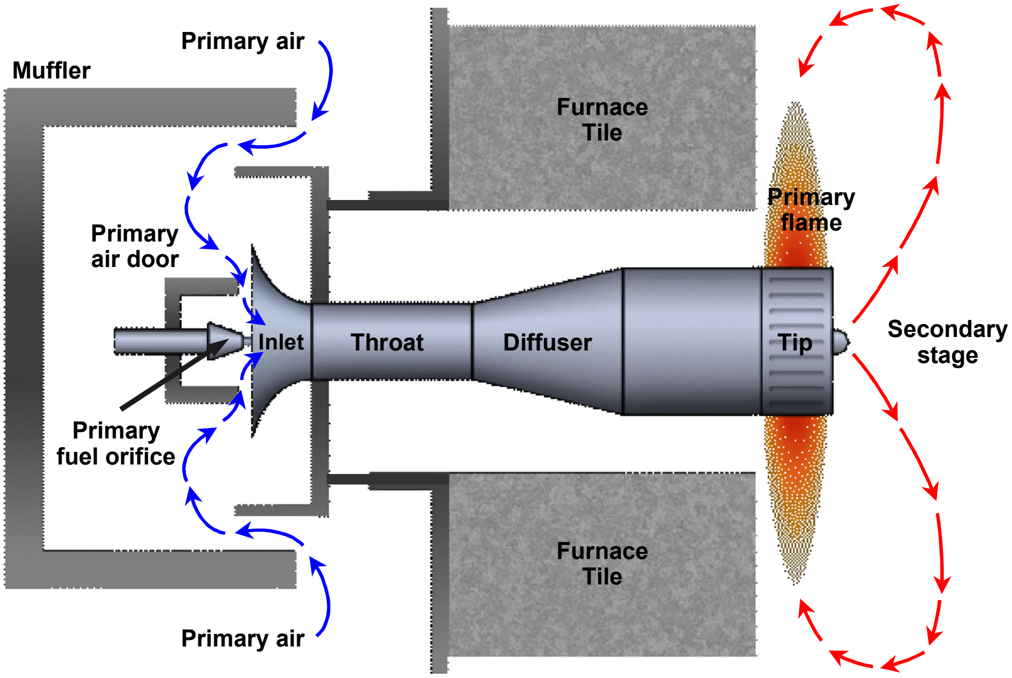

Figure 7 - A Ultra Lean Premix Radiant Wall Burner

Burner Maintenance Issues in Ethylene Furnaces

The classical burner maintenance issues that face the Ethylene Industry are diverse. This section explains the source of each of these problems and each one's effect on the new Ultra Lean Premix burner designs. For the reader's convenience, paragraphs discussing the new technology will have the words "***new technology***" highlighted. In the next section the various existing maintenance strategies as well as the emerging techniques that will become more prevalent in the future, will be discussed.

Fuel Tip Orifice Plugging

The foremost issue of importance with the fuel side of a burner is plugging of the burner tips. Plugged tip orifices will not allow fuel gas to pass through and will reduce the firing capacity of the furnace for the same available fuel pressure. Other effects of plugged tip orifices may include uneven flame patterns, overheating of burner components, tip coking, and flame instability. Burner tip orifices can become plugged from particulates in the fuel lines, such as line scale, salts, dirt, materials dissolved in liquids in the fuel, or from hydrocarbon liquids in the fuel that crack when they encounter the hot surface of the tip, leaving behind coke. Plugged tips must be cleaned quickly before more serious maintenance problems, such as flame impingement, can develop.

Tip Coking

Coke is a buildup of black carbonaceous material inside a burner tip. It may restrict or block off the flow through the burner tip and it can occur inside both raw gas and premix burner tips. If a burner tip is too hot and the burner fuel contains heavy hydrocarbons, unsaturates or liquids, these components may crack and leave coke behind when they encounter the surface of the tip. This coke can eventually plug raw gas fuel orifices or premix burner tip slots. Coking of these same components in fuel gas will occur as stagnant gas heats up and cracks in raw gas tips where the fuel orifices have been plugged with other materials. Unfortunately, with dirty fuel systems, it can often be difficult to discern whether coking plugged a burner tip, or whether a plugged tip caused the coking. The best way to prevent coking is to ensure that the burner tips are clean and remain clean so that the flows that keep the burner tips cool are not restricted.

Larger diameter fuel orifices minimize the possibility of trapping particulates, whatever their source may be, and higher gas flow velocities minimize the potential for fuel cracking. In order to achieve the improved NOx performance, however, some ***new technology*** Ultra Lean Premix burners will require the use of smaller fuel orifice sizes in many burner designs and may require fuel filters in order to prevent problems with plugging. Some other new burner designs, though, will actually benefit from having larger orifices than in the past, thus presenting an advantage. Smaller orifices are required in the Radiant Wall Burners on the primary fuel because the percentage of primary fuel is lower than previous designs, and because this fuel is injected at higher gas pressures to improve the amount of inspirated air. Small orifices are used on the staged fuel tip of these burners because multiple strategically directed jets are required for optimum low-NOx performance. On the other hand, the orifices used in ***new technology*** Hearth Burner designs tend to be larger because the new tips for the staged gas typically have only one orifice as opposed to the multiple drillings per tip that were used in previous generations. The venturi jets in the Hearth Burners are also typically a single orifice for maximum aspiration, so the holes tend to be larger. However, use of higher fuel pressure, which improves venturi aspiration, and consequently enables leaner mixtures, offsets the orifice size advantage somewhat.

It is important to note that all premix burners are susceptible to flashback if the primary fuel orifice in the venturi becomes partially plugged, because a reduction in gas flow will reduce the velocity of the air/fuel mixture exiting the premix tip. However, because the ***new technology*** burners are designed to operate with the premix in a "fuel lean" condition, a reduction in gas flow from plugging will make the premix mixture leaner, and decrease the flame speed, making the burner less likely to flash back than current technology burners.

Fuel Line Flow Restrictions

If materials build up in the fuel supply line that leads to the burners in the furnace, the pressure drop through the piping system will increase and flow can be restricted. When lines start to plug, the fuel pressure to the furnace must be increased, or burner and furnace capacity will be limited. In general, scale, dirt, and tars in the fuel are the primary cause of fuel line plugging, but occasionally foreign objects such as hard hats, rags, and weld scale can also get into a fuel line when it is open for maintenance.

Air Inlet Blockage

Although it does not occur very often, air inlet blockage happens when a foreign object gets into the air plenum or venturi of a burner. Sometimes this material can even come from the burner itself, like poorly constrained or damaged sound absorption material from a muffler. For burners operating in areas with even a light oil mist, a thin film of oil can form on the inside of the premix venturi. Dust from the incoming air can stick to this film and build up over time, blocking air flow. Reduced air flow can limit burner capacity and can eventually lead to overheating or possible flashback as well as elevated NOx emissions and flame impingement.

Air Leakage into Furnace

For furnaces operated under negative pressure, even small openings can allow significant quantities of air to leak into the furnace. The air leaking into the furnace increases the excess O2%

measured in the stack, independent of the air actually coming through the burners, and makes it look like the burners need adjustment. However, if the burners are adjusted to a lower furnace exhaust excess O2% when some of the air is coming from leakage, then the air leakage will replace some of the air that should be coming through the burner. For premix burners, this will make the premix mixture less lean, and will raise the NOx emissions from the primary flame. In addition, the lower air flow in the primary zone will reduce the tip exit velocity and will enrich the primary premix mixture, giving the flame a higher burning velocity. Both of these effects will increase the likelihood that the burner may flashback during operation, especially at lower firing rates. Air leakage into the furnace may also raise the NOx emissions from the staged fuel flames as well by increasing the local concentration of oxygen in the recirculated internal furnace gas. When furnace air leakage is high, the air coming through the burner may not be enough for the complete combustion of the fuel, causing the flames to grow larger and possibly impinge on the furnace tubes. In such a situation, the furnace may have to be operated at a higher excess O2%, sacrificing furnace efficiency in order to prevent the flame impingement.

Air leakage can come from many areas of the furnace including tube penetrations, sight ports, explosion doors, seams around burners, seams between furnace wall plates, open sample connections, and burners that are out of service. Figure 8 below shows pictures of places where air leakage has been discovered on actual operating furnaces. It is very important to seal any noticeable openings in order to prevent air leakage from interfering with proper furnace and burner operation. When a furnace is shutdown, leaks can be identified through a "smoke test." The test is performed by simultaneously creating a positive pressure inside the furnace and while generating smoke inside the furnace. Places where smoke leaks out of the furnace should be sealed or repaired.

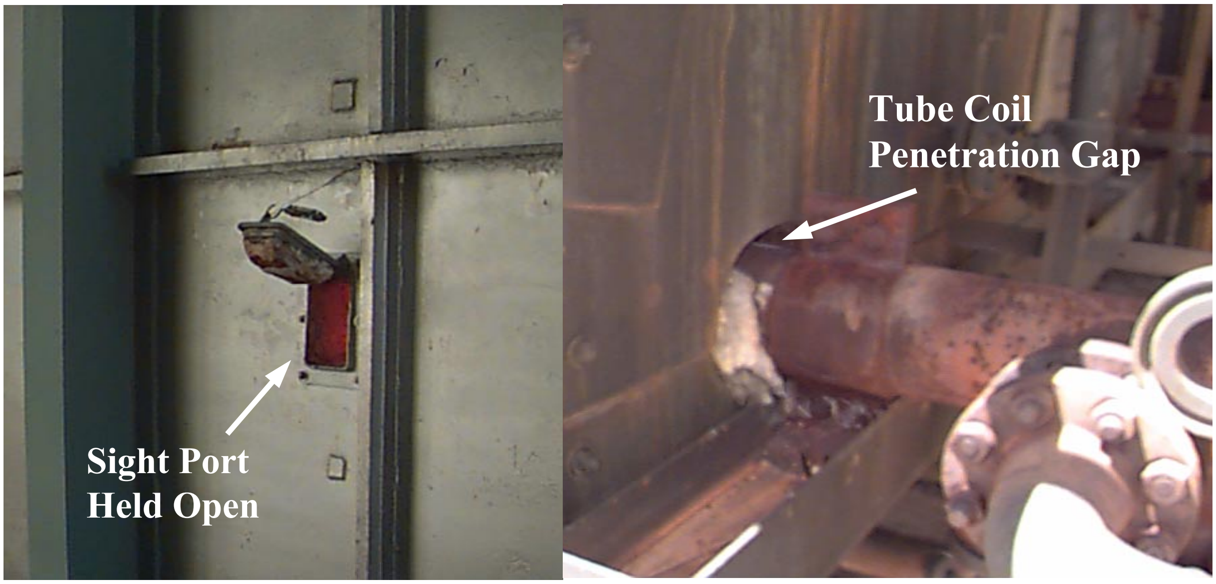

Figure 8 - Points of Furnace Air In-Leakage

The low level of NOx emissions achieved with ***new technology*** burners can be raised significantly by the detrimental effects of air leakage because it raises the oxygen content of the furnace gasses around the burner. However, it can be said that Ultra Lean Premix burners are less susceptible to increases in NOx emissions from air leakage than diffusion flame (raw gas) burners that use larger quantities of internal furnace gas recirculation. This is because the dilution required for NOx reduction in the primary flame of the Ultra Lean Premix burner comes from the air and not the flue gases in the furnace. In burners that use diffusion flames in both primary and secondary stages, a majority of the

NOx reduction comes from dilution by furnace gases. If the oxygen concentration in the furnace gas increases, combustion occurs closer to stoichiometric conditions, thus increasing NOx. It should be kept in mind that the secondary stage in the ***new technology*** Ultra Lean Premix burners *is* a diffusion flame and does rely on internal furnace gas recirculation for NOx reduction, making the burner susceptible to some NOx increase due to air leakage.

Tip Overheating

As mentioned before, although the flows of gas and air will provide sufficient cooling for burner tips to prevent overheating while the burner is in operation, once the burner is turned off, the tips can heat up and begin to oxidize or scale. Oxidation will erode the metal of the burner tip and can enlarge orifices and slots, changing burner flow and flame patterns. High temperature scale buildup can block orifices and insulate the metal of the burner tips away from the cooling flows of gas and air. Because oxidation and scaling can both interfere with proper burner operation, measures must be taken to insure that the burner tips remain cool, even when out of service. To do this, when a radiant wall burner is taken out of service, its air door should be left open at least 1" to allow a small amount of air to flow through the burner and cool the tip. The small amount of cooling that this air provides can be enough to keep the tip temperatures low enough to prevent scaling and oxidation.

A buildup of coke inside a burner tip will also insulate the tip metal from the cooling provided by the gas and air flows, even when the burner is in operation. In general, if a burner tip appears to be glowing inside the furnace, it is too hot and should be investigated. Any buildup of coke or scale should be removed to ensure that the intrinsic cooling of the burner design can protect the metal components of the burner.

The other situation where burner components may become overheated is when a premix flame has flashed back and stabilized within the premix burner tip or venturi. In this case, the flame can quickly overheat and damage the component in which it is burning if the situation is not corrected. Overheated tips may warp, droop, or crack resulting in altered flow area and in poor flame shape and mixing. In extreme cases, the entire tip may burn up or fall off, allowing flames to project onto the process tubes. Such a situation should be corrected immediately. Direct flame impingement will cause coking of the process tubes, which can lead to increased frequency of decoking, tube wall damage, or downtime due to tube failure.

Refractory Damage

Damage to the burner refractory may range from just small cracks in the block, to whole pieces missing from the tile. If there are open gaps or large chunks of refractory missing from the tile, the loss of refractory may result in overheating of the burner front plate and the heater casing to which it is attached. If this is not corrected, the heater shell may warp and the welds that hold the refractory anchors in place may be subjected to temperatures high enough to cause them to crack and fail. Small refractory cracks may have no effect on the burner performance, but should be observed to determine if they will eventually lead to a larger refractory failure. Large pieces of missing refractory or open cracks can affect the flame shape, NOx emissions or flame stability, and should be repaired or replaced immediately if the front plate or heater wall is overheating. Field experience has shown that the life of burner refractory is defined primarily by the refractory material itself and secondarily by the temperature at which it is operated. New refractory materials, such as Therm-Bond are expected to improve burner tile life, but have not been in service for enough years offer full conclusive proof.

Other than the geometry of the tile itself, the ***new technology*** burners use the same refractory materials and install the tile in the same fashion as the current technology. The condition of the refractory, however, may be more important to the proper flame shape and NOx emissions performance of the new technology burners. Hence, the usual care should be taken in the maintenance of the burner refractory for new technology burners as was done with conventional burners, with a greater emphasis on maintaining good condition.

Flame Impingement

When the flames from a burner are consistently burning on the surface of the process tubes, it is a condition called flame impingement. Flame impingement does not have an effect on the burner itself, but can cause coking and damage to the furnace tubes, which can result in a loss of production, or eventually tube failure. Flame impingement can occur either due to interaction between burner flames or due to a maintenance problem, such as plugged fuel orifices, damaged refractory, blocked air-flow, or furnace air leakage. Most often, if the burners were performing without impingement previously, correcting the flame impingement problem usually consists of fixing a developing maintenance issue that is the root cause of the problem. Flame interaction problems usually appear as the formation of large flame clouds or direct flame impingement on the tubes, and typically only occur either when burners of a new design are installed, or if furnace operating conditions are changed outside the original design. Later changes in fuel composition or fuel pressures can cause flame interaction impingement problems to manifest with burners that previously exhibited no problems.

Since the ***new technology*** burners demonstrate shorter flame lengths across the range of capacities, it is expected that they will have some advantages in avoiding flame impingement due to flame interaction. However, the flame impingement problems associated with maintenance related issues will be the same as with older technologies.

Burner Replacement, Disassembly, and Re-assembly Issues

When maintenance must be performed on a burner, often it must be disassembled to a degree in order to do the work. The disassembly must be performed with care to prevent damage to the burner components. In addition, reassembling the burner with all the parts in correct orientation is critical for proper performance. Damaging or altering the orientation of the components will affect the burner NOx performance, turndown, stability, and flame pattern. In order to prevent problems from incorrect assembly, one should have the latest version of the burner drawing available to verify proper dimensions, relationships between components, and alignment of burner tips to ensure that the burner functions properly upon reinstallation in the furnace. With radiant wall burners, for example, the two critical parameters that must be maintained are the insertion depth, and the rotational orientation of the staged fuel orifices. If something does not match the burner drawing, it should be corrected or replaced before reinstallation.

Orientation of burner parts is equally important for the ***new technology*** burners because it may greatly impact the burner NOx performance. These new technology burners achieve their improved NOx performance, not only by applying a different strategy, namely Ultra Lean Premix, but also by applying the fluid flow strategies more accurately than in the past. Hence it is very important to achieve correct orientation and dimensional tolerances (as noted on the burner manufacturer's drawing) on the burner components when reassembling a ***new technology*** burner. To make it easy to achieve higher accuracy in alignment and assembly in the field, the new burners are being designed with features to aid in assembly. For example, fuel tips are shaped differently if they have different drillings and positions. In addition, locating and positioning members are provided to center and orient flame holders and gas risers within the burner.

Remedies Available for Burner Maintenance Issues

So far this paper has outlined the typical maintenance problems with burners in high temperature furnaces, specifically Ethylene cracking furnaces, and highlighted the issues facing the new ultra low-NOx burner designs with regard to these problems. This section will describe various strategies available to minimize burner maintenance issues, with the new ultra-low NOx technologies in mind.

Proper Specification

The first opportunity to minimize burner maintenance issues when designing a new ultra-low NOx Ethylene furnace, or retrofitting an existing furnace for low-NOx is in the development of accurate burner specifications. These specifications are used as the basis for the burner design and should include information such as:

- Normal, minimum (turndown), and maximum required heat release
- Actual furnace temperatures at all operating conditions
- Information on what the allowable NOx emissions are for all firing conditions
- Desired excess O2
- Fuel compositions for all operating conditions
- Available draft at all levels in the furnace

The burner specifications determine the design of the burners and their various critical fluid dynamic properties, such as fuel gas tip exit velocities, air flow velocities, mixing lengths, and cooling effects. When these specifications are accurate and complete, a burner can be designed to perform optimally under the given conditions. If the specifications are not representative of actual operating conditions, or are overly broad, extending into ranges where the furnace is not actually operated, the burners may be operated outside the acceptable range of the critical flow parameters and may be prone to increased maintenance problems. These problems could include plugging of fuel tip orifices, inability to meet capacity, flashback, heat damage or flame pattern issues, depending on which operating conditions are outside the specified range.

For example, one common pitfall is to specify a burner for a heat release that is much higher than the usual operating point, with the intention of keeping that additional capacity in reserve for a contingency when the heater may need to be over-fired for some reason. The problem with oversized burners is that at the normal firing rate the velocities that mix the fuel and air, cool the burner components, and prevent the burner from flashing back are insufficient and create many of the complications explained before. The percentage of Hydrogen in the fuel gas can also have a strong influence on the burner design. If the actual fuel contains a greater amount of hydrogen than what was specified, the burners will be much more susceptible to problems with flashback

New technology low-NOx burner designs are even more sensitive to changes in the operational window. Smaller gas orifice sizes may be used, which can be more subject to plugging, and the Ultra Lean Premix approach can produce higher NOx when the fuel composition changes. In general, these new designs use a fuel injected venturi to draw in all of the air for combustion, and so, changes in fuel composition or pressure can reduce the amount of aspirated air and can reduce the maximum burner capacity.

Materials of Construction

Expensive high chrome and nickel alloys such as Alloy 230 or RA330 provide very low oxidation rates, even at furnace temperatures of 2100 F (see Table 1), resulting in a guaranteed long life for equipment that may have to be out of service in the operating heater. The nature of Ethylene heater operation, however, is such that the best process conversion efficiencies are achieved with the most uniform heat flux profiles, which only occur when all of the burners are in operation. Because of this, it is usually desired to have all of the burners in the furnace firing when the furnace is operating at full capacity. When in operation, the gas and air flows through the burner keep the burner tip metal cool, and out of the temperature region where scaling becomes a concern. Typically, burners are only taken out of service when the furnace is operating at turndown conditions, or during decoking. During these operating conditions, the internal furnace temperature is reduced by hundreds of degrees, and the possibility of the burner tips scaling is greatly reduced. In addition, the small flow of air maintained through the burners that are out of service serves to cool the tip when the burner is off. For these reasons, the economically optimum choice for most radiant wall burner tips has been to use CK-20, which is a cast version of 310 stainless steel. Other alloys can be selected that will have a lower oxidation rate, but because the CK-20 tips provide an acceptably long life under normal operating conditions, it has been the material of choice for burner tips.

In the future, it is inevitable that burner designs will have to become more aggressive about exposing components to heat in order to achieve lower NOx through accurate fuel and air delivery and mixing. Advanced materials can help provide long component life for parts that experience more severe heating conditions, such as flame holders and heat shields. Higher alloys such as HX are already being used as needed and mechanically rugged composite ceramics are being researched to provide long term solutions. Although advanced materials naturally cost more, the increase in cost is justified by the value of the low NOx performance that these newer burner designs can provide.

Operational and Shutdown Preventative Maintenance Practices

Just as periodic oil changes are required to prevent engine problems in a car, preventative maintenance tasks performed on burners will help to avoid major maintenance. Some of these preventative maintenance tasks can be performed when the burners are online, but some tasks require that the burner be out of service.

When the burners are online, they should all be adjusted to the same operation settings (for a given location on the furnace). Reducing the air flow to only one burner will make the primary flame richer, and will increase the NOx emissions for that burner and increase its chances for flashback. This is even more critical for the ***new technology*** Low-NOx burner designs that rely heavily on the excess air in the primary zone for NOx reduction. If the air flow is reduced to the point where there is not enough air for the combustion of the fuel from that burner, that burner's flame will “seek” additional oxygen in the furnace and will become longer and lazier. Conversely, reducing the fuel flow to only one burner will make the primary zone leaner and may cause flame instabilities.

When a burner is taken out of service, it is a good idea to run the air door or register through the full range of operation, and lubricate it if necessary. This will prevent the door from seizing once the burner is placed back in operation. If it is desired to eliminate the small quantity of air flow into the furnace from a burner that is out of service, the burner can be removed from the furnace and an insulated plate can be installed over the burner opening, as long as local plant safety regulations allow.

Prior to a full furnace shutdown it is a good practice to examine the flames and physical conditions of all the burners on the furnace. If there are burners with flame pattern problems, the shutdown may be the only opportunity to fix them. When troubleshooting a burner that was noted to have a flame pattern problem or other physical damage, it is a good idea to inspect the burner and compare it to the original drawings to make sure that all critical dimensions are maintained. This inspection will reveal if the burner has been damaged in any way from overheating, flashback, or mishandling. The burner tips should be checked and cleaned to remove any particulate buildup or coke, especially if the fuel system is known to be dirty or contain liquids. The burner venturi should also be checked and cleaned and the air doors should be run through the full range of operation.

When all of the burners are out of service due to a furnace shutdown or turnaround situation, the interior of the main fuel header should be inspected for the presence of particulates, tars, or scale that could plug burner fuel orifices. If found to be dirty, the header can be cleaned at that time using steam or a chemical cleaning solution to remove these contaminants. Again, this will be more critical on fuel systems that are known to be dirty and have no other particulate removal device.

New technology Low-NOx burners will have these same maintenance requirements, with an even greater emphasis on having a clean fuel system due to the smaller gas port sizes that are used on Radiant Wall Burners.

Fuel Filters

When the fuel system of a plant contains particulates or liquid hydrocarbons in the fuel, it is a maintenance problem in itself. Particulates and liquid hydrocarbons may quickly plug fuel orifices, reducing firing capacity, raising NOx emissions, and hurting burner stability. If the fuel system only has trouble with particulates, and not with liquids, a conventional filter can be used to clean the fuel stream. The openings in these filters should be smaller than the smallest burner fuel orifice in order to catch all the particulates that could plug the burner components. There is a small cost in pressure drop but fuel systems usually have the capacity to accommodate the drop across a typical filter.

Particulate filters can be installed on each burner, or at the main header to the furnace. Having a filter on each burner will prevent scale from the fuel lines from getting to the burner tips, but involves added maintenance effort to clean each filter. A filter at the header to the furnace will catch most of the particulates coming from the main fuel system and is easier to clean, but allows the risk of contaminating the fuel in the downstream piping on the way to the burner. The best arrangement would be to have both, whereby the majority of particulates will be caught in the main fuel filter, which takes less labor to clean. In addition, the presence of the main filter will reduce the loading on the individual filters, which would then work only to protect against the small amount of contamination that may be picked up between the main filter and the burners. In some cases the lines between the main fuel header filter and the burners have been constructed of stainless steel to eliminate the possibility of scaling inside the fuel lines after the main filter.

The previous paragraph addresses only particulate filtering. Liquids that are entrained in the gas stream present an entirely different sort of clean-up challenge. These liquids are usually a carryover from distillation columns or compressor lubrication oil. They are able to get past the de-misters and knock-out devices to make it all the way to the burner because they are *very* fine droplets, with diameters on the order of 5 microns. Conventional filtering does not do a good job of capturing these droplets, even with high pressure drop designs. To address liquid droplet carryover, coalescing filters are usually employed. Instead of trying to physically block the droplet, coalescing filters use the technique of bringing the droplet into contact with special hydrophilic fibers that cause the droplets to coalesce, grow in size and drip off the bottom of the filter - out of the gas stream.

Coalescing filters are very effective at capturing the liquid when operating with the design flow rates. However, at flow rates higher than design, the performance of the coalescing filter abruptly reduces (called the break-through point). Usually the coalescing filter is 95% efficient or better but after break-through it is less than 50% efficient. One concern with the coalescing filter element is that it is susceptible to being quickly plugged by particulate matter. So, coalescing filter systems are usually sold in a dual filter arrangement with a particulate pre-filter followed by the coalescing filter. Usually, the economy of scale dictates that one coalescing filter system is used to treat all the fuel going to an entire furnace. In this case, care must be taken to ensure that the piping downstream of the filter is either thoroughly cleaned or replaced, to prevent the deposits already accumulated in the piping from contaminating the gas after it leaves the filter. The best choice is to replace the piping between the filter and the burners with stainless steel piping. On the one hand, the stainless steel pipe ensures that pipeline corrosion products do not get formed between the filter and the burners, while on the other hand the filter ensures that liquids do not reach the stainless steel pipe and create a new collection of fuel line deposits.

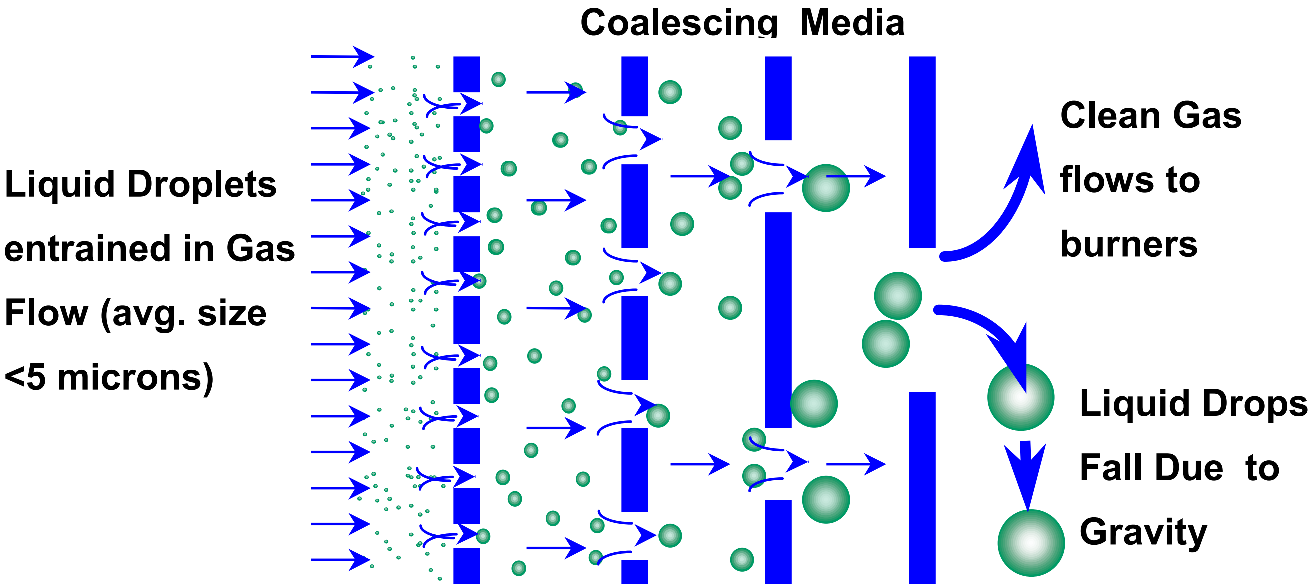

Figure 9 – Principle of Coalescing Filter operation.

In 1998, John Zink Company conducted a survey of six U.S. refiners to evaluate the use and effectiveness of coalescing filters. In almost all cases, the coalescing filter systems were of the aforementioned dual filter type. Since the sample number is quite small, the findings of this survey should not be interpreted as universal, but can be used to identify some trends.

This survey found that the coalescing filter systems had been installed due to chronic burner plugging problems. Surprisingly, in several cases, the filter systems were being *bypassed* on an almost permanent basis. Operators reported that the systems were bypassed because they developed a high pressure drop in a very short time after bringing the system on line, indicating a rapid plugging of pre-filter element. Repeated changing of the particulate pre-filter cartridge yielded no improvement. Cartridge replacements tried at various times after shutdowns, and during continuous operations had the same results: rapid plugging.

This experience showed that unless the piping system upstream of the fuel filter system is cleaned before installation and the production of particulates in processes upstream is within reasonable bounds, the filter itself would become a maintenance problem. To avoid this situation, the upstream piping must be cleaned or replaced and the pre-filter should be sized appropriately or equipped with a blow down system to handle the expected particulate loading. One manufacturer of filter systems recommends a sampling test in which a representative sample of the fuel is drawn for an extended period of time (days) to measure the particulate loading in order to correctly quantify the design criteria for sizing the filter system.

Successful users of coalescing filter systems reported that, once correctly sized and installed, a coalescing filter system can be a very effective way of reducing burner maintenance and downtime. In conclusion, it should be noted that coalescing filter technology is not new or unproven. It has been used successfully for many years in other applications like gas production and pipeline operations. Process furnace applications may present a more challenging problem due to the variety of fuels and age of existing piping and processes. Proper system evaluation, design and installation are required to prevent the filter system becoming a maintenance problem unto itself.

Conclusions

Over the years, burner designs have evolved and incorporated several features intended to reduce maintenance. For example, the intrinsic cooling of the gas and air flows through the burner and the use of higher alloys for burner tips have resulted in longer lives for these burner components. The high temperature environment present inside Ethylene cracking furnaces presents a more severe environment for burner operation because it can heat burner components to the point where they are damaged by oxidation or scaling. In addition the elevated temperature can increase the likelihood of coking inside burner tips when the fuel gas contains liquid hydrocarbons, unsaturates, or heavy components. It is therefore, even more critical that the good operating and maintenance practices outlined in this paper and in burner operating manuals be used for these high temperature furnaces.

The new technology ultra-low NOx burners that are being developed to meet new, more stringent NOx regulations have largely similar maintenance requirements as previous technology burners. The evolving new technology burner designs will, of necessity, need to be more aggressive than in the past, in order to be able to address the tighter NOx requirements. An improved understanding of the burner design by the end user coupled with proper operational practices and the application of preventive maintenance techniques can keep these new technology burner designs operating at peak NOx emission performance, even in high temperature furnace applications such as Ethylene crackers.

References

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