FLARE PILOT TECHNOLOGY TO ADDRESS ENVIRONMENTAL, SOCIAL, AND GOVERNANCE (ESG) GOALS

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INTRODUCTION

The 21st century will continue to require companies to strive to be good stewards of the environment and optimize resources to build a cost-effective, sustainable future. Further reductions of existing carbon footprints require a significant focus on reducing emissions associated with flaring, resulting in the desire for higher efficiency flare pilots and ignition systems to lower or even eliminate fuel gas usage and the possibility of flare flame-out where large quantities of hydrocarbon gases could be vented to the environment. The shift towards hydrogen (H_2) fuels as a way to reduce carbon footprints has created challenges for traditional pilot designs, which cannot handle hydrogen as a fuel gas. This paper discusses current and future technology developments to address these challenges, including 100% H_2 fuel, ballistic flare ignition, reduced hydrocarbon fuel consumption, Artificial Intelligence (AI) integration, higher reliability and stability pilots, and rapid ignition systems that allow pilots to be off during plant operation. These improvements offer a more comprehensive range of pilot operational modes to address the ESG need to limit CO_2 output.

BACKGROUND

The post-World War II economic boom brought with it a new and challenging set of problems in both the refining industry and the conservation of the environment. Industrial growth and population concentration in urban areas meant more pollution. Much of the early discussion about refineries and pollution centered on Los Angeles, where the population increased from approximately 2,000,000 people in 1940 to 4,000,000 in 1950. This increase in population density, along with geographic and environmental factors in the Los Angeles area, created severe smog. During this time, governmental agencies and trade associations took notice of the impact of refining and petrochemical manufacturing on the environment.

One of the earliest steps to address atmospheric pollution came from the American Petroleum Institute (API) when H.G. Vesper gave the opening remarks at the annual meeting in 1952. Vesper stated, “It has been suggested that there has been perhaps too much emphasis on the general question of atmospheric pollution…However, those of us who are particularly concerned with the subject and who recognize its importance both technically and as a public relations matter certainly do not agree that it has been overdone.” API went further in the presentation of a paper written by Vance N. Jenkins to explain, “the policeman is coming to check on the air pollution activities of the petroleum institute.” The quote continues, “not as a result of a large or sudden increase in pollution in refining centers of the industry, but as the result of the bringing forth of a new as yet unproved theory regarding the nature and cause of air pollution in such areas.” The comment was misguided on why the industry needed to change, but the sentiment that the policeman would be watching for violations held true. These early comments were the first of many steps that led to the development of API 521, Pressure-Relieving and Depressuring Systems, which contains a safety and design section concerning flares. API 521 addresses the need for continuous pilots and other requirements to ensure a stable flare flame. Congress and the EPA enacted the Clean Air Act in 1970 in response to increased emphasis on pollution control. The Clean Air Act included the New Source Performance Standard (NSPS) for constructing new combustion equipment and the National Emission Standard for Hazardous Air Pollutants (NESHAP), which created limits on a list of hazardous materials and designated Non-Attainment Areas. Non-Attainment Areas are regions considered to have poor air quality with levels of hazardous pollutants higher than the limits defined in NESHAP. NSPS and NESHAP both require that flare designers design the flare not to exceed a particular velocity based on the flare gas composition and that the flare system have at least one continuous pilot. The presence of a continuous flare pilot flame must also be proven.

Until recently, pilot fuel usage and emissions were generally not scrutinized. While NSPS and NESHAP do not specifically address pilot emissions, pilots can be considered a contributor to the total emissions of the flare system. Furthermore, pilots are typically continuously burning on a flare system and emit some small emissions 24/7. Pilot fuels are typically natural gas or propane but can also include refinery fuel, which is the waste product of many varied refinery processes. These fuels contain carbon in some form, which, when combusted, will create CO_2, a major greenhouse gas contributor. Note that, per the EPA's Importance of Methane in the Global Methane Initiative, the greenhouse gas impact of CO_2 (i.e., products of combustion from burning flare pilot) is a factor of one, while the impact of unburned methane, CH_4 (i.e., a pilot or flare that has been snuffed and is venting), is 27 to 30 times higher than CO_2 over 100 years. This factor shows the importance of eliminating unburned CH_4 in flaring as well as eliminating venting and flare malfunctions. Some flare systems may only have one or two pilots, whereas others may have dozens of pilots, such as a multi-point ground flare field. There are also tens of thousands of pilots in the shale oil field plays used for natural gas disposal. Flaring issues can be further complicated in the Upstream market, where many flare systems have low-quality pilots that lack sophisticated pilot monitoring technology. Frequent failure of these unreliable upstream pilots creates a big environmental problem by allowing flare gases to vent into the atmosphere. The development of cameras calibrated specifically to see the infrared spectrum of unburned hydrocarbon allows agencies to "see" what flares are not operating correctly. These cameras have been used in the refining and upstream markets.

In 2003, the API issued API 537, Flare Details for General Refinery and Petrochemical Service. API 537 is now the primary industry source for flare design and reference. This standard addresses further steps in flare design to ensure flame stability by specifying the number of pilots on a given size flare tip and the specific performance requirements of the pilots. These performance requirements include a minimum heat release of 45,000 Btu/hr per pilot, proven stability in winds up to 100 mph, and a rainfall test of two inches of water per hour at 85 mph.

Today, those in the industry understand flare emissions better than ever. The evolution of flaring emission control has gone from venting to flaring, flaring with smoke to flaring without smoke, clear flame to visible flame (clear overaerated flames have a low hydrocarbon destruction efficiency), to the current day where lower flare emissions are going to be required. Carbon control technologies, once never considered, are prevalent in the industry. Not only is the policeman knocking on the door, but also the protestor, the community, your neighbor, and the environment – creating the need for a modern view of ESG policies and practices. Adding equipment will be contingent on reducing current emissions levels, especially in non-attainment locations. This paper will provide more details on ways to reduce the amount of carbon (unburned hydrocarbon and CO_2) emitted from a pilot system.

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METHODS TO REDUCE CONTINUOUS FLARE PILOT EMISSIONS

FOREWORD

The ensuing sections must be compared against the safety and performance advantages of a typical high-performance pilot system with multiple continuously operating pilots. Each facility needs to understand its site's risks and benefits to each option against or in conjunction with this standard system. Pilot systems in their current form have been used in the industry since the 1950s. The longevity of performance history provides excellent assurance of the equipment's ability to achieve its intended purpose and determine the maintenance cycle. The most convenient benefit of typical multi-pilot systems is the operational ability to set the system in place and monitor the pilot condition over the years without extensive maintenance due to limited moving parts or instrumentation.

BALLISTIC IGNITION

One method to reduce carbon emissions from continuous pilots is to eliminate the continuous gas pilot. Conventional thought is that a flare system needs a continuous pilot for safe operation. Systems not using continuous pilots will need to be proven. Implementing a ballistic ignition system can eliminate continuous emissions and safely light the flare. The ballistic ignition system was developed in the mid-20th century for the offshore production market in the North Sea, where the desire to eliminate critical utilities made this innovation possible. In cases where gas is rarely sent to the flare, the ballistic ignition system may be an attractive option. Early models of the ballistic ignition system used a rocket-propelled pyrotechnic charge launched through a dedicated tube that exited near the flare tip. The projectile would strike a plate, causing a small explosion, igniting the flare gas at the flare tip. Early systems suffered from projectile hang-ups and unreliable ignition, and if the flare system was onshore, incendiary particles could cause fires at grade.

One of the most significant advantages of the ballistic ignition system is that all control components are at grade. Modern ballistic systems no longer use an explosive charge for ignition and have evolved to be safer and highly reliable. Options include pressure-driven units that use either air or nitrogen. Most use a non-explosive pyrotechnic device that can ignite the flare by kinetic force when the projectile strikes a plate. Upon striking the plate, the projectile will send a shower of high-temperature sparks over the flare tip, thereby igniting the flare gas. If the timing of the system is correctly set up, the ignition of the flare gas should be instantaneous on the first attempt. Additionally, the pyrotechnic bursts have a wider spark field for more reliable ignition. Modern units include a projectile catcher. The ballistic ignition system may be used to ignite either the pilot or the flare.

DIRECT SPARK IGNITION

Like the ballistic ignition system, the direct spark ignition system eliminates the continuous gas pilot from the flare system, and because of that, there are no emissions generated from a continuous pilot. The philosophy is simple; an electric ignition rod is placed near the flare gas exit. Upon the start of the ignition sequence, electricity is sent to the ignition rod. The ignition rod and transformer will create a high-voltage arc, either across a gap built into the ignition rod system or across a gap between the ignition rod and the flare tip. The energy of the arc is sufficient to ignite the flare gas. Depending on the manufacturer, the spark is either an instantaneous pulse or no more than a few seconds. Direct spark ignition systems often run continuously, regardless of whether a flame is present. Some direct spark systems may ignite a

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slipstream of flare gas. The advantage of using the slipstream is that a flame stabilization component may be fabricated into the flare tip for increased stability.

The disadvantages of the direct spark ignition system are that for the ignition system to light, there must be the correct amount of flare gas available near one of the ignition sources. Wind can greatly affect reliable ignition as well. Large tips may require many ignitors around the circumference of the flare tip. Another consideration is that the direct spark ignition system requires that there are ignition components and wiring at the top of the flare tip. In some cases, the ignition probe can be lengthened to move the wiring connection lower on the flare tip, but if the wiring fails, the system cannot be repaired until the flare system is shut down. Remedies to this problem can be high-temperature wiring and shielding or even a retractable system that could be used without shutting down.

REDUCED FLARING THROUGH DATA ANALYTICS

More emphasis has been placed on reducing flaring than ever before. Until recently, flaring was considered a part of normal operations in a facility. The primary driver was a loss of production and not eliminating carbon in the environment. Using Artificial Intelligence is an innovative approach to address environmental and economic challenges. Ironically, this option has little to do with the flare system itself. With AI and other complementary programs, all but the most unexpected flaring events could be eliminated. While this solution greatly improves the flare operation, flare pilots will require one of the other options discussed to reduce carbon generation.

The potential usages for AI to reduce flaring are:

- Data Analytics – AI algorithms can analyze the historical data of a plant and flare system and potentially identify root causes of unit upset. The analytics can point operators to problem areas that may not be at all obvious.
- Monitoring – Once the root cause is understood, operators continuously monitor system parameters and proactively make changes to a process unit long before a unit shutdown can happen.
- Machine Learning – Using machine learning, the operators can train the AI to look for patterns that can lead to flaring events and then automatically make changes or alert operators.
- Process Optimization – AI algorithms can then be used to reduce waste and operate the plant at a highly efficient level.

RAPID IGNITION SYSTEMS

Rapid ignition systems rely on electronic ignition and expedited fuel delivery to initiate pilot ignition within five seconds of activation. Typical pilot systems can take minutes to deliver fuel gas from the fuel header to each pilot. This long duration has prevented end users from turning off pilots during normal operation due to the concern of venting unburnt hydrocarbons or other header gases reaching the flare tip exit before the pilots can be reactivated. Pilots remaining continuously active drive CO_2 production, fuel expenditure, and replacement maintenance. Turning off pilots measurably increases service life, saves money, reduces CO_2, and can even reduce the required flare tip and pilot maintenance requirements.

Different manufacturers have different methods of achieving rapid ignition. One method for rapid ignition systems activation is a signal to notify flare gas is progressing toward the flare tip exit. This can be in the form of either a deep liquid seal system that signals the pilots to ignite at 90% seal depth, a header valve opening, or process PSV activation. This method would allow all flare pilots to be completely off until needed. Though operationally, to ensure the pilots would activate when required, testing each pilot once per week for a limited period to confirm ignition and monitoring systems are functioning normally is suggested.

Facilities under 40 CFR regulation must have "*the presence of flame,*" typically interpreted as one pilot active at all times. One active pilot can rotate between the available flare pilots once weekly for this type of facility to spread the equipment usage. Activation of the remaining pilots can be through either a signal as previously described or optical confirmation of increased heat release. Optical confirmation can be through CCTV, IR monitoring, or UV monitoring. Many factors must be considered before pilots are turned off on a flare system. Tip diameter, wind, and composition, to name a few, can affect flare performance. An in-depth safety and environmental review should be performed before any flare ignition and monitoring system changes are made.

Returning the system to standby depends on the type of activation. For deep liquid seal systems, once the water height returns to 85% of breakover and is trending downward in pressure, the system can purge the flammable gases downstream of the liquid seal with nitrogen. Once the purge is complete, extinguish the recently activated pilots and return to standard service. Header valve and PSV systems would need to purge the entire header downstream of the valve after closure to sweep the hydrocarbons from the system. Some regulatory agencies may not accept valves as a method to confirm the absence of hydrocarbons and would need a shallow liquid seal or possibly monitoring systems such as Lower Explosive Limit (LEL) or Gas Chromatograph (GC) for positive confirmation. Lastly, optical systems can return to standby operation through either minimum signal strength or visual confirmation of the CCTV.

Deep liquid seal systems, in combination with rapid ignition systems, would be best suited to Flare Gas Recovery Units (FGRU). FGRUs recover flare gases and recompress them into the facility fuel system or feed for reuse. FGRUs are typically sized for the continuous header flow unique to each facility. Emergency rates and events above the FGRU capacity progress to the standby flare. The rapid ignition system would activate at this operational change before the flare gas arrives at the flare tip exit.

Multi-stage systems utilizing a small continuous flare system and a large emergency flare can also benefit from a rapid ignition system. Because emergency reliefs aren't frequent, not keeping all the pilots on for large emergency flares, which typically have many pilots, will greatly reduce total pilot operation duration.

Manufacturers have varying methods to achieve multi-second rapid ignition. Equipment enabling this technology is installed within several meters of each pilot near the flare tip exit. This equipment is not able to be installed while a flare is online due to the proximity to the flare tip exit but can be installed on any flare during a turnaround within a day or provided with the initial installation.

Low CO_2 Release Pilots

Most facilities are unable to reduce CO_2 production by converting over to 100% H_2 fuel without significant capital investment. An easy way to reduce the CO_2 output of pilots is to lower the hydrocarbon fuel use. There are a few methods to achieve this goal.

In some cases, pilot suppliers may provide a pilot with wind and rain resistance exceeding that required by API, but at the expense of higher fuel consumption. If the site is in an area where weather conditions do not require a pilot with wind resistance this high, then the supplier might allow fuel gas pressure to be lowered, thus lowering the pilot fuel consumption.

Finally, to reduce the CO_2 production of the pilots, remove some of the hydrocarbon and replace it with H_2. Some pilot manufacturers can accommodate some amount of H_2 in their standard pilot.

Full Fuel Spectrum Pilots (100% H_2 – 100% Natural Gas - 100% Butane)

A perennial problem that has vexed the flare industry is the ability of a flare pilot to ignite the entire spectrum of typical fuels using an electronic ignition method to allow quick ignition of an automated system. Historically, the typical spectrum consisted between natural gas and heavy LPG. LPG is 100% propane in many countries, but in East Asian countries, this fuel (heavy LPG) is typically near 50/50 mol% propane/butane. The electronic ignition of this typical range of fuels has been achieved by most major manufacturers for their pilots.

Over the last few years, companies have focused more on achieving zero emissions for facilities, a goal that requires using a carbon-free fuel, most commonly H_2. H_2 has a very high flame speed which will cause a flashback into the fuel-air line if used with a standard pilot. If a flashback occurs, the pilot can no longer ignite the flare tip and will degrade to become completely non-functional within days of continuous maloperation. The method most manufacturers have used to achieve the use of H_2 fuel is to shift the fuel-air mixture toward fuel rich to slow the flame speed of H_2 and prevent flashback. These fuel-rich pilots work well with natural gas and H_2 but not LPG. A large majority of facilities use LPG as a startup, shutdown, and backup fuel, thus requiring a secondary backup pilot system for these situations. This is not desirable from a maintenance, replacement, or capital cost point of view.

Recent developments by at least one manufacturer have led to pilot technology capable of running through a wider spectrum of fuels, including electronic ignition of 100% H_2, 100% natural gas, and 100% butane within a single pilot assembly. This would allow a single pilot able to be used for zero-emission H_2 fuel during normal operations and still have the availability of running natural gas or LPG during brief outages of H_2.

Future Technology

The end goal is zero carbon emissions. What other technologies could help progress toward this goal? Ammonia has been brought up as a possible fuel replacement due to the availability and ease of transportation. The current process can use ammonia by converting it to H_2 and then using that as the pilot fuel. This conversion from ammonia as a transportation fuel to H_2 as a combustion fuel adds cost and inefficiency. A few concerns with using ammonia would need to be overcome before this chemical could become a viable pilot fuel.

Health hazards – ammonia has OSHA-regulated exposure limits that need to be maintained for a safe working environment. In the case of an unlit release of ammonia, the pilots would need to be elevated to allow dispersion to dilute the chemical below the limits of 50 ppm averaged in an 8-hour work shift. To ensure wide acceptance of the technology, manufacturers and end users should target below the odor threshold of 5 ppm.

Performance testing – meeting a future ammonia pilot's API wind and rain requirements would require extensive testing. This testing would also necessitate the venting of ammonia during ignition and extinguishing of the pilot. All manufacturers equipped with pilot test stands have them located near grade for ease of blower simulation of the wind and rain. The grade level dispersion of ammonia presents challenges to maintaining a safe environment for the testing engineers, staff in nearby buildings, and populations near the test site. Considerable cost and preparation would be needed to perform this testing, and as such, no manufacturer has tested ammonia in pilots and hasn't tested in a flare tip since the late 1990s.

Low reactivity – ammonia is more difficult to burn than natural gas and other fuels due to the low heating value, slow flame velocity, shifted UEL and LEL flammability limits, and high autoignition temperature. The slow flame speed of 0.23ft/s versus 1.0ft/s for natural gas significantly reduces the stability of the fuel by loosening the flame's anchoring capability inside the pilot weather shield. Unique to ammonia, explosive limits are 15.5% LEL and 27% UEL. To put into perspective, ammonia can accept a range of 3.7-6.5 volumes of air per volume of fuel for combustion. Methane can accept 6.7 to 20 volumes of air. Therefore, the allowed span of air volumes reduces from 13.3 with methane to 2.8 with ammonia. The small window of variance in air volume will create difficulties in wind resistance and utilizing heavy fuels such as LPG as a backup option. High autoignition temperature increases the difficulty of fuel ignition by raising the energy input requirement for combustion. During continuous combustion, the fuel provides energy to heat the incoming gas for ignition and further combustion. The low heating value requires three times the volume of natural gas to reach the API heat release, further reducing the energy available to resist wind and ignite the flare gas. The researcher believes ammonia will be very challenging to utilize as a robust pilot fuel but that it is achievable.

Ideal improvements in the downstream market are pilots rated for higher wind speeds, particularly in coastal areas, better fuel efficiency, and more robust construction materials than current designs. The higher-rated windspeed feature is attractive to refineries and petrochemical facilities during adverse weather. Proven performance in winds greater than 170 mph would provide a certain level of comfort for those facilities during high weather events. Fuel-efficient pilots that always ignite the flare are desirable and will be a must-have technology. The extreme service that pilots are subjected to can cause them to fail on a regular basis. A pilot that can be routinely enveloped in the flare flame and last longer than 5 to 7 years would be highly sought after.

The upstream market also has a strong need for improvements in pilot technology, as evidenced by poor-performing flare sites in the Permian and other upstream locations that have been highlighted by both environmental groups, regulators, and news organizations. Utilizing optical monitoring equipment mounted in helicopters, numerous flare systems were shown to have failed pilots and were thus venting hydrocarbon vapors into the atmosphere. As a result, many upstream operators that had traditionally focused on low-cost, low-technology pilots have shifted their focus towards utilizing more reliable and robust pilot technology to prevent such scenarios.

Ideal Flare System

Ideal differs from facility to facility, but the general concepts below can be applied, modified, and adapted to many systems.

- Pilots utilize H_2 as fuel. Backup H_2 bottles combined with a facility pipeline provide redundancy to a single fuel source.
- Pilots utilize rapid ignition systems to reduce total usage and extend service life.
- FGRU to capture flare header gas during 95% of the service life of the flare system.
- Enclosed flare to achieve 99%+ DRE of smaller events above the capacity of the FGRU.

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- Purged with nitrogen.
- Valve operation to enact staging.

- Large, elevated emergency flare for the 1% of cases above the capacity of the enclosed flare.
  - Purged with nitrogen.
  - Deep Liquid Seal to enact staging.
- AI implementation to reduce major flaring frequency and duration.

CONCLUSIONS

As ESG policies become more important to companies' overall health and profitability, manufacturers, users, and trade associations need to innovate pilot ignition systems to lower emissions without degrading safety. Emissions from flare pilots are not insignificant and are continuously present. There is an opportunity to reduce pilot emissions in some ways mentioned.

During the early front-end engineering and design stage, new facilities can incorporate many of these options into their ESG plans. These technologies are not required to be used together. They have synergies to provide layers of benefit when used simultaneously, but each of the options described can be used independently. Most existing petrochemical and refining service facilities can incorporate one or more of these options during their next pilot replacement. In evaluating ESG goals for your company, be sure to know all options available to best suit the needs of your unique facilities.