Success Stories: Saudi Aramco High Pressure Air Assist System (HPAAS) for Smokeless Flaring

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Presented at the

American Flame Research Committee

2010 Pacific Rim Combustion Symposium

September 26th – 29th

Maui, Hawaii

1. Abstract

Over the last 10 years Saudi Aramco has developed and patented a smokeless flaring technology that utilizes high-pressure, supersonic air to provide smokeless combustion [1]. This technology, called High Pressure Air Assist System (HPAAS), was developed through an extensive research and development process, utilizing CFD modeling and full-scale combustion testing. HPAAS systems have been installed at dozens of Saudi Aramco facilities, creating clean burning flares where smoke once filled the skies.

Most of these units have been in continuous operation for over one year now, which has provided a method for determining the system effectiveness and reliability. A large range of sizes and operating conditions at these jobsites has provided a good basis for system comparison. Based on information collected from field operators, this paper explores the successes and issues experienced with flare tips, air delivery systems, and severe duty air compressors used in the design, as well as any issues with installation or modification of existing flares. Improvements, limitations, and future changes are also discussed.

2. Background

2.1 Why is HPAAS required?

Approximately 10 years ago, Saudi Aramco personnel became much more aware of the unsightly smoke that was being produced by many of their flare systems on a continual basis. The presence of this constant, visible pollution worsened the public perception of Saudi Aramco and the energy industry in general. They began a search for technology that would help clean up this smoke, and help show Saudi Aramco's commitment to safe, reliable, and responsible energy production. The solution needed to operate efficiently, eliminate the smoke, and also be cost effective. After a thorough investigation of the smokeless technologies available in the marketplace, they found that none of them worked well for their application.

Additionally, after investigating the performance of their existing utility flare tips, Saudi Aramco found that the current utility flare designs used at their facilities led to high grade-level radiation and reduced equipment life due to a low momentum flame and wind-induced low-pressure zones, resulting in flame pulldown. Figure 1 shows a typical utility flare at a Saudi Aramco facility.

Figure 1. Typical Utility Flare

2.2 Possible Solutions:

During their investigation, they found that readily available smokeless technologies included steam-assisted, pressure-assisted, or low-pressure air-assisted flare tips. Each of these technologies presented separate drawbacks that made it not feasible for the Saudi Aramco application. Saudi Aramco developed the High Pressure Air Assist System (HPAAS) as a solution. A previous paper discusses the development process and advantages of HPAAS over other designs in more detail [2]

3. <u>HPAAS System:</u>

3.1 Components and Operation

The main components of a HPAAS system include a flare tip with supersonic air injection nozzles, an air supply line on the flare stack (normally 2” or 3” diameter), a flow control system, an air receiver tank, and an air-compressor. As an alternative, in some cases the system can also be supplied with air from the existing plant instrument air.

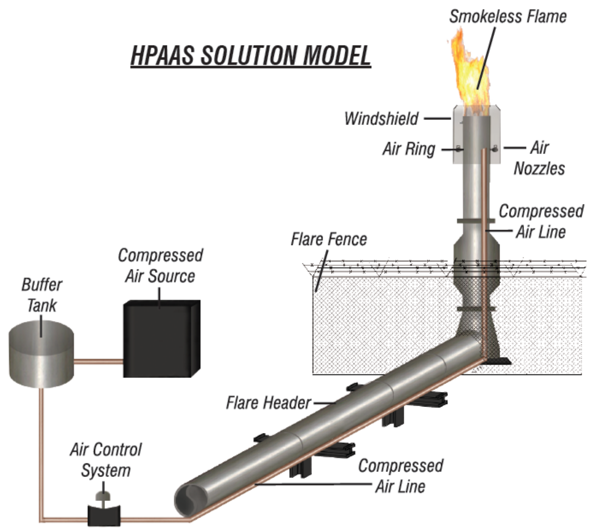

Figure 2. HPAAS System Components

The HPAAS flare tip includes a barrel-type flare tip with a large windshield. In the space between the windshield and the flare tip barrel, a high-pressure air injection manifold is mounted. The air manifold includes supersonic nozzles that are directed upward toward the combustion zone at the flare tip exit. Figure 3 below shows the main components of a HPAAS flare tip.

Figure 3. HPAAS Flare Tip Components

Compressed air is supplied to the high-pressure air line, which feeds supersonic nozzles that are located on the air manifold inside the flare tip windshield. These air nozzles inject air upwards into the combustion zone. The air supplied by the nozzles provides only a small portion of the air required for smokeless combustion. Most of the smokeless assist air is pulled in from the surrounding environment by the high velocity of the air nozzles. The path of air within the windshield space, air jet pattern, air momentum, windshield design, and nozzle orientation are all key design features of the HPAAS tip. The air mixes with the combustion gas at the tip exit to produce smokeless flaring.

The design and arrangement of the supersonic air injection nozzles and the use of high pressure air allows the HPAAS system to operate at extremely high efficiencies, using a much smaller amount of air than low-pressure blower-assisted designs. Additionally, the use of high-pressure air allows a small (2” or 3”) air supply line to be utilized. This enables the system to be easily retrofitted to existing flare systems.

3.2 Early Installations and Feedback:

In the early stages, HPAAS systems were installed at 5-10 select Saudi Aramco facilities for testing. A variety of jobsites were chosen, and HPAAS tips in sizes ranging from 48” to 84” were tested beginning in 2001. These early installations provided the data needed to develop and refine the HPAAS technology.

3.2.1 Jobsite A

A HPAAS system was installed in jobsite A in 2002. The system utilized a first-generation HPAAS design and a portable diesel-powered air compressor. The tip operated well and provided good smokeless performance, as can be seen in Figure 4 below:

Figure 4. Jobsite A with HPAAS

Even though the system was operating acceptably, management decided to replace the system with the newer generation HPAAS system in 2008. This newer system included improvements in the air nozzle design that reduced the amount of air required for smokeless operation. Additionally, the new system included an electric-powered air compressor that was more suitable for the desert environment and required less maintenance than the diesel-powered system.

3.2.2 Jobsite B

A HPAAS system was installed in jobsite B in 2001. Figure 5 below shows the before and after performance of this unit.

Figure 5. Jobsite B With and Without HPAAS

Real data from these jobsites was used to improve the design, and eventually the HPAAS design was completed and patented. HPAAS was an overwhelming success for Saudi Aramco and for the inventor, Mr. Mazen Mashour. The technology won numerous awards including:

- Gold Medal at 2006 Saudi Inventors Convention
- Excellent Achievement Award from the Malaysian Association of Research Scientists in 2006
- Gold Award and 2nd Place Overall at Geneva's 34th International Inventors' Conference in 2006
- Winner of 2007 Arab Thought Foundation’s Innovation Award

After the HPAAS technology was proven at select jobsites, Saudi Aramco management decided to make a larger-scale application of the technology. This was a big step taken by Saudi Aramco to clean up their air and help improve their image in an age of “green energy”. This took a large investment of time and capital, and it would be difficult to quantify the monetary payback for these changes, if any. The main driving factors for this step were twofold. One was to help clean up the air and get rid of the continuously smoking flares. The other was to test and prove the technology in a large-scale application, which would make it easier to prove the usefulness of this technology to other end users worldwide.

4. <u>Southern Area Project:</u>

4.1 Project Plan and Execution

It was decided that a large number of the GOSP (Gas Oil Separation Plant) facilities in the Saudi Aramco Southern Area would be upgraded with HPAAS. The majority of the flares in this area had continuous flowrates of gas going to the flares as a result of purge, relief valve leakage, and control valve leakage. Since all of these were utility flares without any smokeless assist, they were producing smoke 24 hours per day. In 2008 Zeeco and the Al-Rushaid Group established a joint venture that became the exclusive licensee for building and selling HPAAS flare systems. Zeeco and Al-Rushaid were put in charge of upgrading 28 flare systems in the Southern Area.

In addition to the supply and installation of the HPAAS flare systems, this project also included extensive CFD analysis and full-scale combustion testing of the HPAAS tips to confirm the unit design. This work was completed at the Zeeco Research and Development Facility in Broken Arrow, Oklahoma under the supervision and guidance of Mazen Mashour, the HPAAS inventor. The CFD and combustion testing were useful for several reasons. The new project included several flare tip sizes that had never been tested in the field with the HPAAS system. CFD modeling provided an additional method for confirming the flare tip design would work for these new sizes. Combustion testing at the Zeeco Research and Development Facility was also helpful, since the Zeeco facility has much more capability for flow measurement, data acquisition, modifications, pictures, and videos than is available at most of the Saudi Aramco facilities.

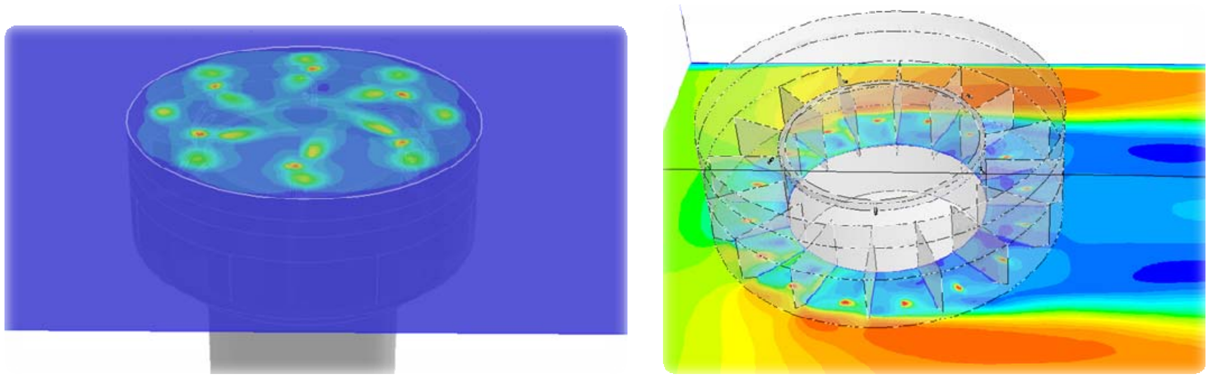

Figure 6. CFD Modeling Showing Air Jet Velocity and Crosswind Impacts

Based on his lessons learned from his previous HPAAS installations, Mr. Mashour was able to make improvements to the system design for the Southern Area Project. These improvements included the following:

- The air nozzle design, sizing, and orientation was optimized. This ensured proper air distribution to the combustion zone for smokeless performance and proper air distribution around the flare tip perimeter to prevent flame pulldown. The windshield design was also modified to increase the resistance to strong winds and improve entrained airflow from the surroundings.

- The tips were able to utilize the Zeeco HSLF pilot, which offered longer service life, better flame stability, and improved reliability compared to the existing flare pilots.

- The air compressors were also greatly improved on the Southern Area Project. The main purpose of these improvements was to increase the system efficiency, extend the service life, and reduce the maintenance requirements. The Project Engineers worked with compressor specialists to develop a special compressor package suitable for extended operation in the severe heat and sandstorms common for Saudi Arabia.

The HPAAS systems were delivered to Saudi Arabia and installed in 2008 and 2009. The HPAAS systems were easy to install with no major problems experienced during the installation and startups. The design of the HPAAS system was ideal for these retrofits, because the only modification to the flare stack was the addition of a small (2" to 3") air supply line along the flare stack. This resulted in very short shutdown times ranging from 2-7 days.

The biggest problem experienced during the installation work was the late delivery of several of the permanent air compressors. The lack of the smokeless air supply equipment would have presented a huge obstacle for a conventional low-pressure blower assisted flare system; however, the design of the HPAAS system allows it to be operated temporarily with portable air compressors that are readily available in most locations. To avoid delaying startup of the plants, several portable diesel-powered air compressors were mobilized to these sites, so the HPAAS systems could be started up. In some cases, the flares were operated for several months on these diesel compressors until the permanent air compressors were delivered and installed. Extended plant shutdowns can be extremely costly, so this solution was strongly supported by the plant personnel.

4.2 Feedback from the Field

The 28 flare systems on the Southern Area project were installed and started up between January 2009 and November 2009. Therefore, at the time this paper is presented, all of the HPAAS systems have been in operation for about 1 to 1.5 years. The main goal of the Southern Area Project was to eliminate the continuous smoking from these flares, and this goal was achieved at every one of the jobsites. The project has been an overwhelming success. These flares no longer produce the continuous smoke trails that used to be seen when driving through this area of the country. The Southern Area flare systems operate with a range of flowrates and gas compositions. Additionally, the tips are a variety of sizes from 24-inch to 48-inch. Heights for the systems range from 28-ft to 128-ft. Some are located in very remote areas, while others are located in more highly populated areas. Despite all of these differences, the common result is that all flare systems are operating with smokeless performance.

Discussion with field engineers and operators at the Aramco facilities has provided useful information about the performance of the systems.

- The flare systems are running well. The flares always provide smokeless flaring during the normal, continuous flowrates. The flare tips are performing reliably and have not required any unplanned maintenance or plant shutdowns.

- The airflow control is automated at most of the jobsites, and it is controlled in the plant DCS. Air flowrate is adjusted up and down based on the gas flowrate to the flares. This ensures stable performance of the system and reduces the air and power usage. Since the DCS controls everything automatically, the operators do not have to make any manual adjustments to the system.

- The air compressors have been very reliable, and the operators have been pleased with their performance. Figure 7 is a picture of the air compressor, buffer tank, and airflow control equipment from one of the jobsites.

Figure 7. Smokeless Air System for Typical HPAAS Installation

- When the air compressors were initially ordered, the detailed design and testing had not been completed on the tips yet. Therefore, a conservative estimate was used to size the compressors. The actual air requirement for the smokeless air assist is much lower than was originally anticipated and is much lower than the capacity of the air compressors. This has resulted in additional cost savings for utilities and a very low duty cycle for the compressors, which will greatly extend the life and reduce the frequency of maintenance. It might also allow the additional compressor air capacity to be used for other functions within the plant.
- The flare pilots and ignition control system are operating with a high level of reliability. The flare pilots have remained lit under all weather conditions, which has ensured a stable ignition source for the flare tips.

4.2.1 Additional Benefits:

In addition to the elimination of the unsightly smoke, the HPAAS upgrades have also created some additional benefits. One of these is the reduction of the visibility of the flare systems. Even though all of these flares in the Southern Area are elevated flares, the overall visibility of them has been drastically reduced. The presence of a dark, orange flame and smoke trail used to make the flares visible from miles away, even for someone that is not looking for the flares. Just a scan of the horizon would make the location of all flares known.

Figure 8. Typical Smoking Flares in Saudi Arabia

The upgraded HPAAS flares operate with a clean, short yellow flame that is barely visible in many instances. Additionally, since there is no more smoke produced during the continuous operations, the flares are actually very difficult to see and identify from a distance. At many locations, it takes a trained eye to even locate the flare system. While other facilities in the area make their presence known with large, smoky vent stacks or flares, the Aramco facilities in the Southern Area are now able to operate in a more discrete and environmentally-friendly manner.

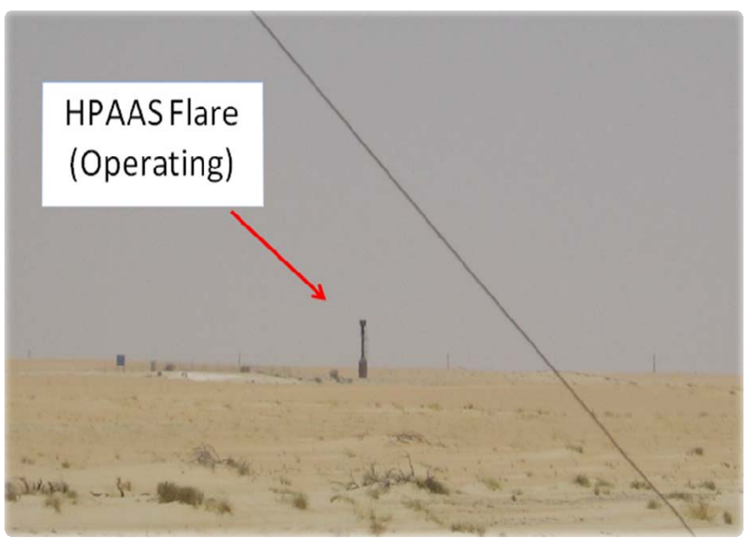

Figure 9. HPAAS Flare in Operation

4.2.2 Southern Area Case Study – Jobsite C

The flare at Jobsite C is located just over the hill from one of the major personnel compounds in this area of Saudi Arabia, which puts it in close proximity to a large number of people. The unit is also located very close to the highway. The original flare system produced considerable smoke on a daily basis, which was noticeable by the surrounding personnel. Additionally, due to the short height of the flare system, it also presented a possible hazard with smoke impacting driver visibility on the nearby highway. Below is a figure of this system before the current HPAAS upgrade.

Figure 10. Jobsite C Without Smokeless HPAAS

The flare tip at Jobsite C was replaced with a HPAAS flare tip in 2009. The improvements were noticed immediately. The new design provides clean, smokeless burning. The flare is also barely even noticeable from the road. What used to be visible from miles away, now is not even noticeable after you pass over the next hill. Saudi Aramco personnel have been especially happy with the performance of this flare system given its highly visible location.

Figure 11. Jobsite C With HPAAS Upgrade

4.3 Successes and Issues

4.3.1 Successes

- Overall, the HPAAS systems have been a success. The units provide smokeless operation during the normal flowrates and also provide safe burning of the waste gases during emergency flowrates. The systems have operated without any major problems.
- During the design stages of the Southern Area project, excessive noise was a concern due to the use of supersonic air nozzles. Fortunately it has not been an issue at the jobsites. The orientation of the nozzle exit points and the windshield design have helped to reduce the noise from the supersonic nozzles. The noise levels for these flare systems have been very low, and plant personnel have indicated that they never have any noise problems with the flares.
- The previous utility flare tip designs experienced large amounts of flame pulldown, which caused damage to the flare tips, pilots, gas seals, and other equipment near the top of the flare. The HPAAS design provides upward momentum that stands the flame up and eliminates flame pulldown.
- The previous utility flare tips produced high radiation levels due to lazy flames operating with a dark orange flame and a high emissive value. The HPAAS system stands the flame up and produces a clean yellow or light orange flame with a lower emissive value. This results in lower radiation levels in the surrounding areas.

Figure 12. HPAAS Flare Tip at Jobsite D

- Air delivery systems have provided reliable operation, and the air flow requirement is lower than originally expected. In cases where compressor maintenance is required, the HPAAS system is much easier to access and maintain than a low pressure blower-assisted system. Air compressor and air delivery systems for a HPAAS system are all located within the plant fence, away from the flare. This allows easier access and allows operators to stay outside of the flare sterile area. If any maintenance is required for the compressor then a temporary compressor can be mobilized. This eliminates the need for any shutdown for compressor maintenance. Low-pressure blower-assisted designs normally include a blower mounted directly at the flare system within the radiation sterile radius -- operators normally need to shut down the plant in order to access the blower for maintenance, so the HPAAS design offers a strong advantage.

4.3.2 Issues

- Just as with steam-assisted flare tips, excessive air flowrates in some cases can lead to pressure capping of the flame. Some operators are not familiar with a smokeless flare system that requires adjustment of the air flowrate based on the gas flowrate. These issues can normally be avoided with proper automation of the DCS system (if one is available); however, there is still the risk of pressure capping if the air flowrate is not adjusted properly.

- Each HPAAS system requires an air supply for smokeless operation (air compressors on this project). If air supply is lost, then damage can occur to the air injection system equipment at the flare tip. The flare tip itself will still operate reliably without air assist, but the smokeless air injection system can be damaged during loss of air. The newer generation HPAAS systems have been designed with more robust parts and the air injection nozzles are located below the top of the flare tip, outside of the highest heat zone. Both of these modifications make these items less sensitive to a loss of air supply. Damage of the air injection system due to loss of compressors has not occurred at any of the HPAAS jobsites in the Southern Area; however, the introduction of more equipment (ie, air compressors) into the flare system does increase the potential for downtime and maintenance.

5. Limitations and Improvements

5.1 HPAAS System without Gas Flow Measurement

Current HPAAS technology requires a control system (PLC, DCS, etc) that adjusts the air flowrate up and down based on gas flowrate. At some very remote locations, gas flow measurement may not be available. There are current investigations regarding a HPAAS system that can be set at a constant air flowrate, which will eliminate the need for any airflow adjustments. This will increase the continuous air usage rate, but will allow the system to be installed at locations without any gas flowrate measurement.

5.2 Adjustments for prevailing wind

Under extremely strong wind conditions, even with a HPAAS system installed, the wind can cause some flame pulldown on the downwind side of the tip, which can shorten the tip life and cause heat damage. In locations with extremely strong prevailing winds, it may be possible to adjust the air nozzle arrangement and location to compensate for the prevailing wind direction and make the flare tip more resistant to flame pulldown. This is a rare condition, but it is still under consideration.

5.3 Retrofits vs New Installations

The current HPAAS design is most suitable for retrofits, due to the small air supply line. For new installations, low-pressure blower-assisted systems are normally more cost effective, because the cost for air blowers is normally less than the cost for the air compressor and air control system. Current investigations are underway for utilizing a more cost-effective air delivery system that would make HPAAS more competitive for new installations. Since it was discovered on the Southern Area Project that the newer generation HPAAS requires even less air than originally anticipated, smaller compressors can be used on future projects, which will further reduce the cost.

5.4 Very High Smokeless Rates

HPAAS has currently only been used for applications with smaller, continuous smokeless rates. HPAAS has not been used for very large smokeless rates that may be required in some applications. Availability and cost effectiveness of larger air compressors are normally the limiting factor. Investigations are underway for modified air injection arrangements that will further increase the efficiency of HPAAS and increase the upper limit of the smokeless capacity.

6. Conclusions

HPAAS has proven itself as a very useful technology for retrofit applications of existing utility flares. It fills a niche that other technologies were unable to fill in a timely and cost-effective manner. HPAAS will continue to be a useful technology for these types of applications, and with improvements to the technology, it will be used in many more applications.

7. References

[1] Mashour, Mazen. “Flare Stack Combustion Apparatus and Method.” U.S. Patent 7,247,016 B2. July 2007.

[2] M. Mashour, S. Smith, N. Palfreeman, and G. Seefeldt, “New Technology: Saudi Aramco High Pressure Air Assist System (HPAAS) for Upgrading Existing Flares to Smokeless Combustion,” presented at International Flame Research Foundation 16th Members Conference, Boston, USA, 2009.