Enhanced Destruction and Removal Efficiency in Air Assisted Flares: Cimarron's DreamDuo and DRE-Max VFD Controller Integration

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Abstract:

Cimarron's innovative DreamDuo Air Assisted Flares and DRE-Max automatic VFD controller were the focus of a series of tests conducted in July 2022 and January 2023, with the goal of evaluating their performance in terms of Destruction and Removal Efficiency (DRE). This research, presented at the American Flame Research Committee annual conference 2023, showcases the significant improvements in DRE values achieved when integrating the DRE-Max VFD controller with Cimarron's advanced flare technology.

The tests utilized advanced measurement techniques, including Video Imaging SpectroRadiometry (VISR) and Passive Fourier Transform Infrared Spectroscopy (PFTIR), to accurately assess the flare's efficiency in destroying Methane and volatile organic compounds (VOCs). With the integration of the DRE-Max automatic VFD controller, Cimarron's DreamDuo Air Assisted Flares consistently achieved DRE values greater than 99.2%, demonstrating exceptional performance in minimizing environmental impact.

This presentation provides an in-depth analysis of the experimental methodology, the integration of the DRE-Max VFD controller, and the resulting improvements in DRE values. The findings highlight the potential for Cimarron's DreamDuo Air Assisted Flares to significantly reduce emissions and contribute to a cleaner environment, while setting new standards for the industry. Attendees will gain valuable insights into the cutting-edge technology and practical applications of these advancements in flare systems and their potential to revolutionize the way pollutants are managed.

Background

ARPA-E's REMEDY (Reducing Emissions of Methane Every Day of the Year) program is a three-year, $35 million research effort aimed at reducing methane emissions from three specific point sources from the coal, oil, and gas sector. These three sources (flares, engines, and active coal mines) are responsible for 10% of anthropogenic methane emissions. REMEDY seeks technical solutions that can achieve 99.5% methane Removal and Destruction Efficiency (DRE) and commercial scalability. If successful, REMEDY systems could dramatically reduce U.S. greenhouse gas (GHG) emissions at low cost. Cimarron was one of four teams working on reducing methane emissions from flares. Cimarron proposed at least four separate technologies in attempts to achieve 99.5% DRE for flares. These include 1) A DreamDuo Air Assisted Flare; 2) A hybrid flare concept, which is a crossover between a flare and a combustor; 3) A DRE-Max Automatic VFD Controller; and 4) A Computer Vision/Machine Learning based system. In order to verify the performance of our advanced flare designs and controls, Cimarron is also developing the instruments and methods for measuring the overall DRE and methane DRE for flares. Due to space limitation, only selected aspects (DreamDuo; DRE-Max and PFTIR methane DRE measurement) of the development work under REMEDY will be covered in this paper.

DreamDuo Air Assisted Flare

A flare is both a safety device and an emission control device. Flares will be needed for various industries for many decades to come, due to laws of economics. There is a concerted effort to move toward zero routine flaring in various industries. But zero routine flaring does not mean zero need for flares. It means the flares are mostly in standby mode, waiting to be used in emergency situations.

The DreamDuo flare is a patented (US Patent 11,067,272; and Hong [2021]) tandem flare marketed by Cimarron. This tandem flare has two gas risers, one for HP gas and the other for LP gas. HP gas refers to the High Pressure (HP) associated gas. It is the gas coming out of the well when drilling for crude oil. Table 1 (Column 5) gives an example of a HP gas from a specific well site. The LP gas refers to the Low Pressure (LP) tank vapor when crude oil is temporarily stored in holding tanks before the crude oil is sent away by trucks or by pipelines. Table 2 (Column 5) gives an example of a LP gas from a specific well site. Conventional air assisted flares are designed with a blower large enough to supply combustion air to ensure smokeless combustion of HP gas or LP gas or both. Most air assisted flares have fixed exit areas in their flare tips, see Figure 1. Incorporating a moveable part in the vicinity of the flare flame is challenging in many aspects, including perceived reliability issues of moveable parts, heat, metallurgy and longevity of the flare tip. The DreamDuo flare incorporates a spring-loaded variable-area orifice for its HP gas, thus eliminating the need for combustion blower for the HP gas, see Figure 2. DreamDuo has a smaller blower designed for the LP gas only. Depending on the flow conditions of the HP and LP gases required for the flare, the horsepower requirement of the air blower for a DreamDuo Air Flare could be reduced by up to 90%, when compared to a conventional air flare.

Table 1. Typical composition of a HP gas (flare gas stream 1, corresponding to volumetric flow rate Q_1).

Name	C_xH_y	x	y	Volume fraction $F_1(C_xH_y)$	$x*F_1(C_xH_y)$	Fc(CH_4, flare gas 1)
Methane	CH_4	1	4	0.67	0.67	0.431
Ethane	C_2H_6	2	6	0.149	0.298	
Propane	C_3H_8	3	8	0.1	0.3	
Butane	C_4H_{10}	4	10	0.042	0.168	
Pentane	C_5H_{12}	5	12	0.013	0.065	
Hexane	C_6H_{14}	6	14	0.004	0.024	
Heptane	C_7H_{16}	7	16	0.003	0.021	
Carbon Dioxide	CO_2	1	0	0.007	0.007	
Nitrogen	N_2	0	0	0.012	0	
Total				1	1.553	

Table 2. Typical composition of a LP gas (flare gas stream 2, corresponding to volumetric flow rate Q_2).

Name	C_xH_y	x	y	Volume fraction $F_2(C_xH_y)$	$x*F_2(C_xH_y)$	Fc(CH_4, flare gas 2)
Methane	CH_4	1	4	0.17	0.17	0.060
Ethane	C_2H_6	2	6	0.23	0.46	
Propane	C_3H_8	3	8	0.31	0.93	
Butane	C_4H_{10}	4	10	0.18	0.72	
Pentane	C_5H_{12}	5	12	0.065	0.325	
Hexane	C_6H_{14}	6	14	0.017	0.102	
Heptane	C_7H_{16}	7	16	0.015	0.105	
Carbon Dioxide	CO_2	1	0	0.006	0.006	
Nitrogen	N_2	0	0	0.007	0	
Total				1	2.818	

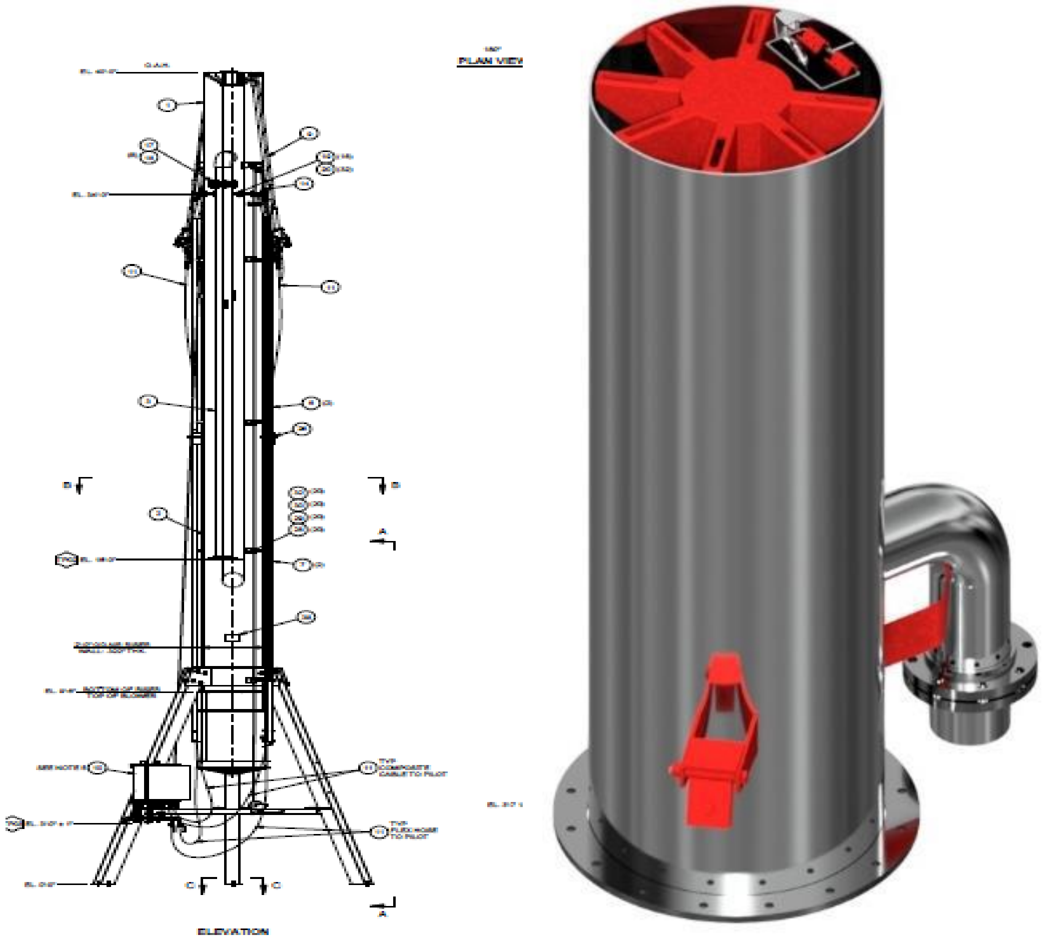

Figure 1. A conventional SFVP-0824x40 ft air assisted flare with fixed outlet areas offered by Cimarron. The center gas riser is for HP gas (connected to the red outlet spider nozzle). The riser hanging on the outside is for LP gas (connected to rectangular outlet). The air duct connected to the stack riser is supported by a tripod structure.

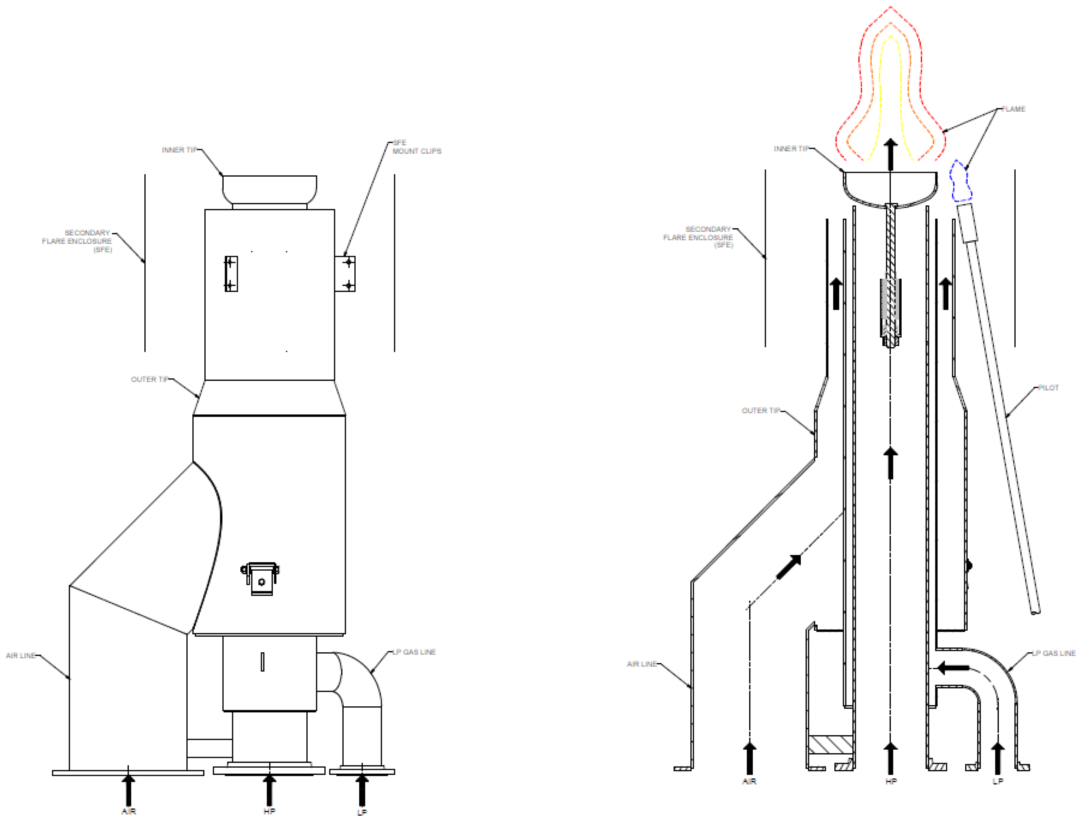

Figure 2. Cimarron's Patented DreamDuo Air Assisted Flare

Automatic VFD Control for Air Flares

There is a near absence of regulations for assisted flares when it comes to the control of the assisting medium. Flares are generally regulated by Code of Federal Regulations 40CFR60.18. Refinery flares are subjected to additional regulations known as Refinery Sector Rules (RSR, 40 §63.670). The majority of flares in use in the US today are in upstream oil and gas production, not refinery flares.

Per 40CFR60.18, a flare is assumed to achieve 98% DRE if these conditions are met: 1) the flare has at least one continuous pilot or its equivalence; 2) the flare does not smoke more than 5 minutes in any two-hour period; 3) the flare gas has sufficient heating value (BTU/scf) exceeding a threshold value (200 or 300 Btu/scf), depending on the type of flare it is; 4) the exit velocity of the flare does not exceed a threshold value that is computed from the heating value of the flare gas.

Notice none of these four criteria includes anything about how to control an air blower for an air assisted flare. Due to this absence of regulations, assisted flares can be purchased without any automatic control on the air blower. This is analogous to buying a car without having a self driving function. The end user or operator of the flare is supposed to figure out how to control the flare blower, just like a driver is supposed to learn how to drive a car. Under-aeration of a flare leads to smoking, which is a violation of the federal laws. Tests have shown that over-aeration can lead to reduced DRE values for flares, per McDaniel, M. [1983], Pohl, J. and Soelburg, N. [1985], Allen, D. and Torres, V. [2011], and U.S. EPA Office of Air Quality Planning and Standards [2012]. Due to widespread misconceptions (that a yellow flame means incomplete combustion, or that a blue flame is cleaner than a yellow flame), operators often over-aerate their flares.

To avoid over-aeration, the air blower should follow the loads of the HP and LP gases. In order to control the amount of combustion air, a blower can be equipped with a damper or a Variable Frequency Drive (VFD). A VFD-controlled blower consumes much less power when the frequency is reduced from 60 Hz. A blower without a VFD and relying on a mechanical damper to control the combustion air will consume roughly the same power as the maximum power required for the blower whenever it is in operation. Due to the saving of operation costs, VFD is preferred over a damper when it comes to blower control.

In general, high flare gas flow rates would demand a high amount of combustion air, and hence the VFD of the blower would need to run at a higher frequency, and vice versa. The control of VFD would appear to be straightforward and intuitive. However, due to the existence of two gas streams (HP and LP) and how they are routed to different parts of the flare tip, the optimal control of the VFD is not trivial. If there is a single gas stream, it would be logical to experiment using a simple x-y correspondence, where x is the gas flow rate, and y is the VFD frequency. When there are two variables (HP flow and LP flow), the optimal frequency is less than obvious to determine. Some end users have tried to add the flow rates together to a combined flow rate (thousand standard cubic feet per day, or MSCFD), but a combined flow rate of 0.5 MSCFD could mean 0.5 MSCFD of HP or 0.5 MSCFD of LP or any combination in between. The HP and LP gases are very different in compositions. Adding the two flow rates together will not work well for obvious reasons. Cimarron developed an automatic VFD controller for air flares incorporating a proprietary algorithm. It is marketed under the trade name “DRE-Max”, see Figure 3. DRE-Max VFD controller typically takes two flow rates (measured by mass flow meters) as inputs, and sends out a frequency as an output to the VFD drive of the blower motor.

Figure 3. Cimarron's DRE-Max™ Automatic VFD Controller for Air Assisted Flares.

VISR Method and What It Measures

The Video Imaging Spectral Radiometry (VISR) technology developed by Providence Photonics simultaneously measures spectral radiances from both combustion product and unburned hydrocarbons across the entire flame at a 20-30 Hz frequency to determine flare Combustion Efficiency (CE). With the VISR method, flare DRE is calculated from the measured flare CE value using a DRE-CE correlation equation developed in previous tests (2010 TCEQ flare study [2011] and 2016 PERF flare tests per Moris J [2019]). The DRE measured by the VISR method is for the hydrocarbons as a group, not specifically methane DRE.

PFTIR Method and What It Measures

Fourier Transform InfraRed (FTIR) Spectroscopy, also known as FTIR Analysis, is an analytical technique used to identify organic, polymeric, and, in some cases, inorganic materials. The FTIR analysis method uses infrared light to scan test samples and observe chemical properties. In its usual active mode, the FTIR instrument sends infrared radiation of about 10,000 to 100 cm^{-1} through a sample, with some radiation absorbed and some passed through. The absorbed radiation is converted into rotational and/or vibrational energy by the sample molecules. The resulting signal at the detector presents as a spectrum, typically from 4000 cm^{-1} to 400 cm^{-1}, representing a molecular fingerprint of the sample. Each molecule or chemical structure will produce a unique spectral fingerprint, making FTIR analysis a great tool for chemical identification. In other words, the fingerprint of a chemical substance is due to absorption of an infrared light source with well known characteristics. This method is often called Active FTIR since an infrared light is sent through the sample. A retroreflector is often used to allow placing the infrared light source and the infrared receiver in the same instrument housing. When applied to elevated flares, this method has the challenges of placing the retroreflector in the right location (by a tall pole, a crane, or a drone).

Passive FTIR (aka PFTIR) is different from traditional (active) FTIR. Instead of sending an infrared beam of known characteristics through the sample, PFTIR relies on passively observing the infrared radiation from the sample, see Figure 4. Dr. Robert Spellicy of IMACC pioneered the use of PFTIR for flare applications. When applied to a hot flare plume, many challenges arise: 1) signal strength is affected by many factors, including concentrations, plume thickness (depth), and temperature (to the 4^{th} power); 2) background noise, such as astray sunlight, clouds, scattering from dust; 3) absorption of CO2 signal in the hot plume by ambient CO2 and water vapor.

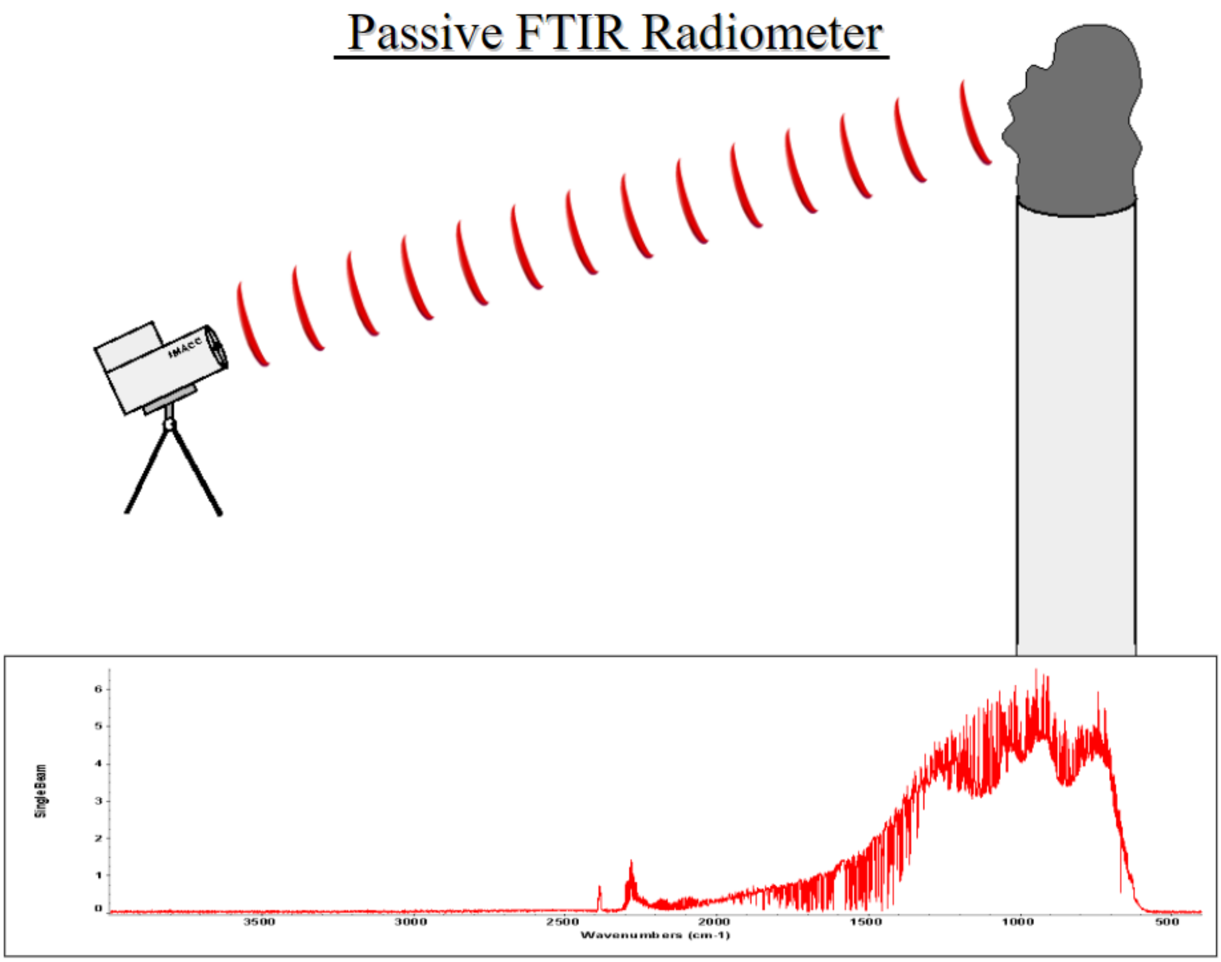

Figure 4. Illustration of PFTIR for Flare Emissions Measurements.

PFTIR has the advantage of not needing a retroreflector. The instrument is placed at grade aiming in the downstream (post combustion zone) of a hot flare plume. It can measure the concentration integrated over the optical path for many compounds, including CO, CO2, methane, ethane, ethylene, propane, propylene and higher hydrocarbons. It can even measure ammonia and NO. The disadvantages of PFTIR include 1) bulky telescope and calibration cart, 2) difficulty in setting up the instruments, 3) the numerous and tedious calibrations before the tests; 4) the use of liquid nitrogen to cool the detector; 5) the time interval for each test is typically 30 to 60 seconds.

Tests

Multiple sets of tests have been conducted in the oil field since July 2022. Due to limitation of space, not every set of tests will be covered here.

The first set of DreamDuo flare tests were conducted on July 27th, 2022. The flare model was DreamDuo DDAA-10820x70, see Figure 5. The flare had an overall height of 70 feet, and received two streams of waste gases, namely HP gas and LP gas. The flare was located in the Permian Basin near Midland, Texas. The flare was equipped with two mass flow meters. The mass flow meters measured flow rates for HP gas and LP gas, which are fed into the DRE-Max VFD controller for the automatic control of the blower's VFD, see Figure 6. VISR from Providence Photonics was the method for measuring flare CE and DRE values.

Figure 5. DreamDuo Flare Firing 130 MSCFD of LP gas.

Figure 6. DRE-Max Automatic VFD Controller (Red Arrow) with Two Flow Meters (White Arrow) Used in Tests on July 27th 2022.

The second set of DreamDuo flare tests was conducted on January 11th, 2023, and continued to January 12th, 2023.   The flare tested was the same flare tested in July 2022, with refinement to the DRE-Max VFD controller, especially the minimum frequency setting of the VFD drive.   Since reducing methane emissions was the primary goal of the REMEDY program, ARPA-E specified the requirement of measuring methane DRE for the flare. Due to this technical requirement, PFTIR was chosen as the preferred method for measuring flare DRE and methane DRE. Methane DRE measurement is much more involved than flare DRE, as will be elaborated below.

From Flare DRE to Methane DRE

Combustion Efficiency (CE) and Flare DRE can be measured by PFTIR using Equations (1) and (2).

Combustion Efficiency (CE) for a flare can be calculated from:

$$\text{Flare CE } = \frac{[\text{CO2}]}{[CO]+[CO2]+[THC]+[soot]} \qquad \text{Eq. (1)}$$

Flare Destruction & Removal Efficiency (DRE) can be calculated using the following equation:

$$\text{Flare DRE} = \frac{[\text{CO2}]+[\text{CO}]}{[CO]+[CO2]+[THC]+[soot]} \qquad \text{Eq. (2)}$$

A shortcoming of this method: it does not measure DRE of methane for the flare. In other words, it does not measure the DRE for any specific gas of interest.

Methane DRE of a flare is defined as the fraction of methane in the flare gases that is converted to other compounds. Conceptually, if we know the number of methane molecules going into the flare flame, and the number of (unburned) methane molecules leaving the flare flame (vented to atmosphere), the DRE of methane can be calculated in the following formula:

$$\text{DRE of methane} = 1 - \frac{\text{number of methane molecules vented to atmosphere}}{\text{number of methane molecules going into the flare inlets}} \qquad \text{Eq. (3)}$$

The PFTIR analysis is able to determine the concentration of different species integrated over the optical path through the hot plume of the flare flame. Each methane molecule contains one carbon atom. It is advantageous to calculate methane DRE in terms of methane bound carbon atoms.

$$\text{Fc}(\text{CH}_4, \text{plume}) \ = \frac{[\text{CH4}]}{[\text{CO}]+[\text{CO2}]+[\text{THC}]+[\text{soot}]} \qquad \text{Eq. (4)}$$

where Fc(CH4, plume) is the methane carbon fraction in the flare plume, defined by the number of methane-bound carbon atoms in the hot plume of the flare, over the total number of carbon atoms in the hot plume of the flare; [CH4] is the concentration of methane integrated over the depth of the hot plume in the optical path of the PFTIR, measured in ppm*m; [CO] is the concentration of carbon monoxide integrated over the depth of the hot plume in the optical path of the PFTIR, measured in ppm*m; [CO2] is the concentration of carbon dioxide integrated over the hot plume in the optical path of the PFTIR, measured in ppm*m; [THC] is the concentration of all hydrocarbons integrated over the depth of the hot plume in the optical path of the PFTIR, measured in ppm*m, and weighted by the number of C atoms in the molecules of each hydrocarbons.

Since smoking of flares is prohibited by federal laws (40 CFR 60.18), we can focus the applications of the current invention in non-smoking flares. If we assume the flare produces negligible amount of soot in the hot plume, Eq. (4) can be simplified to:

$$\mathrm{Fc(CH_4,\ plume)} = \frac{\mathrm{[CH4]}}{\mathrm{[CO]+[CO2]+[THC]}} \qquad \text{Eq. (5)}$$

In the above equation, [THC] can be also expanded to

$$\mathrm{[THC]} = [\mathrm{CH_4}] + 2[\mathrm{C_2H_4}] + 2[\mathrm{C_2H_6}] + 3[\mathrm{C_3H_6}] + 3[\mathrm{C_3H_8}] + \cdots \qquad \text{Eq. (6)}$$

Eq. (6) can be written in another format:

$$[THC] = \sum_{x=1}^{x=\infty} \mathrm{x}\left[\mathrm{C_xH_y}\right] \qquad \text{Eq. (7)}$$

We can calculate $\mathrm{Fc(CH_4, flare\ gas)}$, the methane carbon fraction in the flare gas, defined by the number of methane-bound carbon atoms over the total number of carbon atoms in the flare gases in the following equation. If there is only one flare gas stream (ie, the flare has a single inlet), the methane carbon fraction in the flare gas is:

$$\mathrm{Fc(CH_4, flare\ gas)} = \frac{\mathrm{F(CH_4)}}{\sum_{x=1}^{x=\infty} \mathrm{xF}\left(\mathrm{C_xH_y}\right)} \qquad \text{Eq. (8)}$$

where $F(CH_4)$ is the volume fraction of methane in the single flare gas stream; $F(C_xH_y)$ is the volume fraction of each hydrocarbon C_xH_y. In practice, when x is greater than a certain threshold, for example, 8, the volume fraction of the hydrocarbon C_xH_y may be very small, and therefore could be neglected. The upper bound of x could be infinity in theory but in practice can be set at a finite integer such as 4-8, depending on the composition of the flare gas.

If there are two flare gas streams, the methane carbon fraction from all the flare gases can be calculated from the following equation:

$$\mathrm{Fc(CH_4, flare\ gases)} = \frac{Q_1F_1(\mathrm{CH_4})+Q_2F_2(\mathrm{CH_4})}{Q_1\sum_{x=1}^{x=\infty}\mathrm{x}F_1\left(\mathrm{C_xH_y}\right)+Q_2\sum_{x=1}^{x=\infty}\mathrm{x}F_2\left(\mathrm{C_xH_y}\right)} \qquad \text{Eq. (9)}$$

where $F_1(CH_4)$ is the volume fraction of methane in flare gas Stream No. 1 (for example the HP gas); Q_1 is the volumetric flow rate of flare gas Stream No. 1; $F_2(CH_4)$ is the volume fraction of methane in flare gas Stream No. 2 (for example the LP gas); Q_2 is the volumetric flow rate of flare gas Stream No. 2. It is possible that a flare may have multiple gas inlets and risers to receive more than 2 flare gas streams.

In general, the methane carbon fraction in the flare gas can be calculated from the following equation, if there are n flare gas streams:

$$\mathrm{Fc}(\mathrm{CH_4},\ \text{flare gases}) = \frac{\sum_{i=1}^{n} Q_i F_i(\mathrm{CH_4})}{\sum_{i=1}^{n} Q_i \sum_{x=1}^{x=\infty} \mathrm{x} F_i(\mathrm{C_xH_y})} \qquad \text{Eq. (10)}$$

where $F_i(CH_4)$ is the volume fraction of methane in flare gas Stream i; Q_i is the volumetric flow rate of flare gas Stream No. I; $F_i(C_xH_y)$ is the volume fraction of hydrocarbon C_xH_y in flare gas Stream i; x is the number of carbon atom in each molecule of hydrocarbon C_xH_y, n is the total number of flare gas stream, i is the index of the flare gas stream.

For example, a tandem flare has two flare gas streams, HP gas stream and the LP gas stream. We can designate HP gas as flare gas stream 1, and LP gas as flare gas stream 2. In this example, n is 2. In another example, a flare could have three inlets and three risers to receive three separate flare gas streams, HP gas, MP (Midium Pressure) gas and LP gas. In this second example, n is 3.

Methane DRE can be calculated from the following equation:

$$\text{Methane DRE} = 1 - \frac{\mathrm{Fc}(\mathrm{CH_4},\text{plume})}{\mathrm{Fc}(\mathrm{CH_4},\text{flare gas})} \qquad \text{Eq. (11)}$$

Methane DRE for an elevated flare can be calculated from Equations (5), (10) and (11).

Test Results

The CE measurements and calculated DRE values are shown in Table 3. DRE values of greater than 99% are achieved for the majority of the tests, except when HP gas was at a low flow rate (45 and 100 MSCFD). This was due to over-aeration from the blower at such low flow rates. In other words, the minimum frequency for the VFD was set too high. Turning off the blower immediately sent the DRE values above 99%, see Tests 12a and 13. After adjusting the minimum VFD settings to 3 Hz, the over-aeration problem was resolved. Due to the special feature of the DreamDuo flare (HP gas goes through a variable-area orifice; the spring loaded bowl lifts and retracts according to pressure upstream of the bowl), the HP gas never needs the air blower to achieve smokeless combustion. Only the LP gas needs the blower to achieve smokeless combustion. It is tempting to turn the blower off when the blower is not needed for smokeless combustion. However, from a safety perspective, maintaining a minimum positive flow in the blower air duct is helpful in preventing heavier-than-air flare gas from coming down along the air duct, which is a safety hazard.

Table 3: Summary of Test Results (DRE-Max in Automatic Control) from July 27th, 2022.

Time		Test #	Efficiency (%)		
Start Time (CST)	**End Time (CST)**	**Test Description**	**CE Avg**	**DRE Avg**	**Notes**
11:42 AM	11:47 AM	Test 1c	98.67	99.3	45 MSCFD LP only
12:04 PM	12:09 PM	Test 1e	98.99	99.6	95 MSCFD LP only
12:23 PM	12:28 PM	Test 2a	98.29	99.0	95 MSCFD LP only
12:30 PM	12:35 PM	Test 2b	98.45	99.1	95 MSCFD LP only
1:09 PM	1:14 PM	Test 3c	99.15	99.6	60 MSCFD LP only
1:23 PM	1:27 PM	Test 4	99.15	99.7	1500 MSCFD HP only
1:28 PM	1:31 PM	Test 5	99.17	99.7	5000 MSCFD HP only
1:34 PM	1:37 PM	Test 6	99.05	99.6	5000 MSCFD HP only
1:41 PM	1:46 PM	Test 7	99.39	99.9	1100 MSCFD HP only
1:49 PM	1:53 PM	Test 8	99.47	100.0	500 MSCFD HP only
1:58 PM	2:02 PM	Test 9	99.48	99.9	220 MSCFD HP only
2:09 PM	2:13 PM	Test 10	99.63	100.0	330 MSCFD HP only
2:36 PM	2:41 PM	Test 11	92.29	93.9*	Minimum VFD setting was too high for 45 MSCFD of HP gas. HP gas never needs the blower.
2:45 PM	2:49 PM	Test 12	97.86	98.6*	Minimum VFD setting was too high for 100 MSCFD of HP gas. HP gas never needs the blower.
2:57 PM	3:02 PM	Test 12a	98.97	99.6	100 MSCFD HP only; blower turned off
3:03 PM	3:07 PM	Test 13	99.37	99.9	100 CFD HP only; blower turned off

*Low DRE due to improper minimum VFD setting

The flare DRE and methane DRE values from PFTIR measurements are shown in Table 4.

Table 4. Flare DRE Values Measured by PFTIR from January 11th, 2023.

Test	Date	Start Time	DRE-Max Setting	HP Flow Rate (MSCFD)	LP Flow Rate (MSCFD)	Flare DRE (%)	Methane DRE (%)
1	1/11/23	12:34:00	Normal	6079	34	99.8	99.9
2	1/11/23	12:43:00	Normal	3778	28	100.0	1.00
3	1/11/23	12:53:00	Normal	1855	20	99.9	99.9
4	1/11/23	13:02:00	Normal	1027	13	99.7	99.8
5	1/11/23	13:12:00	Normal	419	0	99.3	99.3
6	1/11/23	13:29:00	Normal	370	1	99.6	99.6
7	1/11/23	13:43:00	Normal	288	1	99.6	99.7
8	1/11/23	13:50:00	Normal	224	0	99.6	99.3
9	1/11/23	14:07:00	Normal	86	54	99.8	98.2
10	1/11/23	14:17:00	Normal	41	54	99.5	98.4
11	1/11/23	14:26:00	Normal	0	62	99.7	98.3

Conclusions

From the tests conducted in the oil fields near Midland TX, a Cimarron's patented DreamDuo™ air assisted flare equipped with flow meters and a DRE-Max™ automatic VFD controller was able to achieve greater than 99% flare DRE under all test flow conditions when DRE-Max was in control of the flare. Cimarron developed a novel method (patent pending) for measuring methane DRE of a flare using PFTIR. Methane DRE values are in general similar to flare DRE values. At low flow conditions, methane DRE values went below flare DRE values, but stayed above 98.2%. Future improvements to flare designs (for example the Hybrid flare, currently patent pending) and Computer Vision/Machine Learning based controls have the potential to achieve 99.5% methane DRE.

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