Flaring in a closed environment: scalability and emission control

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Abstract

Flaring introduces significant environmental and economic concerns due to emissions of CO_2, CO, and especially methane (CH_4), a greenhouse gas far more potent than CO_2. To address this, the sector is pursuing solutions like flare gas recovery, combustion optimization, and design improvements. In this paper, Centro Combustione Ambiente S.p.A. (CCA), within the project "AMELIA_S" sustained by "Regione Puglia", contributes studying their combustion performance aiming to the optimization of the components and their operational capacities. Using high-precision analyzers CCA accurately measured key pollutants and calculated combustion-related efficiencies: Combustion Efficiency (CE), Destruction Efficiency (DE), and Destruction and Removal Efficiency (DRE). These results were compared to the University of Alberta's semi-empirical CE equation for offshore flares. All calculations were embedded into a LabView-based software interface developed in-house, enabling integrated data acquisition and real-time analysis. Testing across multiple configurations, windshields significantly enhance combustion by increasing methane destruction. However, the effect of pilot ignition was less conclusive when windshields were absent. Overall, the results showed strong repeatability and internal consistency, validating the reliability of closed-environment flare testing for performance and emissions optimization.

Introduction

Flaring may be required for safety reasons: extracting and processing oil and gas involves dealing with exceptionally high and changeable gas pressures that could cause an explosion. This means that safety flaring allows operators to rapidly de-pressurize their equipment and manage unpredictable and large pressure variations by burning excess gas; in addition, this gas may contain harmful pollutants and burning it helps destroy most toxic compounds. Anyway, it has to be considered that flaring has strong environmental and economic implications while serving for operational purposes such as safety and equipment maintenance. It is also about methane (CH_4) slip that is 25 times more efficient at trapping heat than CO_2 over a 100-year period and 80 times more powerful as a warming gas on a 20-year timeframe [2].

Content

Centro Combustione Ambiente S.p.A. (CCA) is contributing thanks to its great operational capacity: retrofitting a combustion chamber usually used for industrial burners, CCA has acquired the ability to install flares with different sizes in such a way that it can carry out measurements in channeled flows giving stable and repeatable results, thanks to Greens Combustion Ltd that provided the objects under examination and its engineers. A great added value has been the work done from the analyzers point of view; three devices have been used: Horiba PG350 for O_2 and NO_x detection; Ratfish for TOCs detection through *Flame Ionization Detector* (FID); Horiba VA-5111 for CO, CO_2 and CH_4 detection through *Non-dispersive infrared* (NDIR).

Thanks to the high accuracy of these measurements, CCA had the opportunity to evaluate in a very reliable way the several efficiencies usually used to study a combustion process:

- Combustion Efficiency (CE):

$$CE = \frac{([CO_2] - [CO_2]_{amb})}{([CO_2] - [CO_2]_{amb}) + [CO] + ([CH_4] - [CH_4]_{amb})} \tag{1}$$

- Destruction Efficiency (DE):

$$DE = \frac{([CO_2] - [CO_2]_{amb}) + [CO]}{([CO_2] - [CO_2]_{amb}) + [CO] + ([CH_4] - [CH_4]_{amb})} \tag{2}$$

- Destruction and Removal Efficiency (DRE):

$$DRE_{CH_4} = 1 - \frac{\dot{m}_{CH_4,out}}{\dot{m}_{CH_4,in}} \tag{3}$$

In addition, these efficiencies have been compared to the University of Alberta's Combustion Efficiency equation [1], a semi-empirical equation for offshore flares:

$$CE_{UoA} = 1 - 0.00166 \left(\frac{LHV_{CH_4}}{LHV_f}\right)^3 e^{\left(\frac{0.317\, U_w}{(g\, d\, U_f)^{\frac{1}{3}}}\right)} \tag{4}$$

Consequently, all these equations have been implemented in a LabView code written by CCA's engineers who created an intuitive and complete software interface for data acquisition and calculation: the software is also versatile, acquiring data from DCS code, analyzers and calculation code while displaying in several graphs the behaviors of the desired parameters.

Results

Firstly, the test matrix can be summarized as below:

Table 1. Test matrix

	A	B	C
Flare diameter (in)	4	8	14
Windshield	ON/OFF	ON/OFF	ON/OFF
Pilot	ON/OFF	ON/OFF	ON/OFF

From this test matrix, it has been possible to focus on how the presence of a windshield or pilot ignited influence the CE and DE. As example, let's take the flare with a diameter of 8 inches (see Fig.1): it is possible to state that the presence of a windshield helps the combustion process burning more methane; while it is not possible to state with absolute certainty that the pilot ignited increases the efficiency if the windshield is missing. Another analysis done is the comparison between different sizes of the same flare design to validate the scalability of the process (see Fig.2): it is remarkable how the results are coherent among them and their high repeatability highlights how the study of flares in a closed environment is possible, reliable and repeatable.

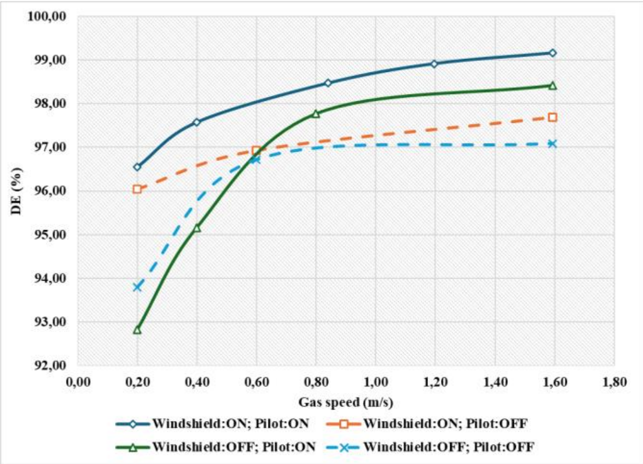

Figure 2. 8in flare – destruction efficiency depending on gas flow rate for a fixed windspeed of 6 m/s

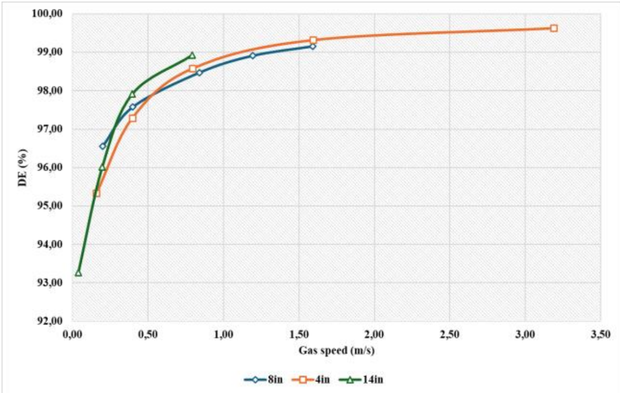

Figure 1. Comparison of DE for different flare sizes with same design (with windshield and pilot ignited) and fixed windspeed of 6 m/s

Nomenclature

d	Flare outer diameter (m)
g	Acceleration due to gravity (m/s^2)
LHV_{CH_4}	Methane lower heating value (MJ/kg)
LHV_f	Flare gas lower heating value (MJ/kg)
$\dot{m}_{CH_4,in}$	Methane inlet mass flow rate
$\dot{m}_{CH_4,out}$	Methane outlet mass flow rate
U_f	Exit gas speed (m/s)
U_w	Wind speed (m/s)

References

[1] Peebles, Bob & Esl, Accord & Stockton, Phil. (2022). Offshore flares: measurement and calculation of combustion efficiency, methane and CO2e emissions.

[2] Zand, Mazyar. (2024). Flaring in Oil & Gas: A Detailed Analysis of Environmental Impact and Sustainable Solutions.