OGMP Technical Guidance Document - Flare Efficiency

> *DISCLAIMER: The OGMP Technical Guidance Documents (TGD) describe the practice for methane emissions quantification, following the different OGMP levels, at the time of their publication, to the best knowledge of the authors. These are living documents and will be updated as practices evolve, and new data or technologies become available.*
>
> *The Framework (section 4.4) acknowledges that 'there may be challenges outside of an OGMP company's control, which prevent reporting at levels 4 or 5 for both operated or non-operated ventures within these timeframes (e.g. should an emerging technology to quantify methane emissions proves infeasible or unreliable). In these cases, if the relevant company can show that efforts consistent to [section 4.2.1 of The Framework] have been made to obtain and disclose methane emissions data at levels 4 or 5 then this shall be deemed to meet the reporting requirements and shall not impact the ability of the company to achieve or maintain gold standard'.*

Brief description of the source

There are two types of flares, elevated and ground flares. Elevated flares are more common and typically have larger capacities than ground flares. In elevated flares, a waste gas stream is fed through a stack which can be up to 100 meters tall and is combusted at the tip of the stack. The flame is exposed to atmospheric disturbances such as wind and precipitation. In ground flares, combustion takes place at ground level and is almost always unassisted. Ground flares vary in complexity, and they may consist either of conventional flare burners without enclosures or of multiple burners in refractory-lined steel enclosures.

The typical flare system consists of (1) a gas collection header and piping for collecting gases, (2) a knockout drum (dis-entrainment drum) to remove and store condensables and entrained liquids, (3) a proprietary seal, water seal, or purge gas supply to prevent flash-back, (4) a single- or multiple-burner unit and a flare stack, (5) gas pilots and an ignitor to ignite the mixture of waste gas and air, and, if required, (6) a provision for external momentum force (steam injection or forced air) for smokeless flaring. Natural gas, fuel gas, or inert gas such as nitrogen can be used as purge gas.

The flare system, together with the pressure relief system forms a critical part of the safety system and is designed to prevent escalation of accidents and dangerous situations. It is also used for the elimination of waste gas (i.e. gas from the process which is not recovered, such as dehydrator vents or compressor seal gas). Flaring, aside from portable flaring (see *Scope boundaries*), is rarely used in gas transmission, gas storage and gas distribution.

Flaring can be either continuous, intermittent or released in a discrete batch when purposefully depressurizing equipment for maintenance (e.g. where equipment is depressurizedand a discrete volume of gas is sent to flare, linked to single events – pipeline maintenance, compressor station blowdown). Methane emissions from flares can arise for different reasons which can be classified in two categories (incomplete combustion and vented emissions):

- Outside upper/lower flammability limits. i.e. Too rich or too lean to burn. In these cases, gas is sent to the flare stack which cannot support and is thus **vented** (i.e. uncombusted)

- Ignition source malfunction. In these cases, gas is sent to the flare stack but no ignition occurs because of pilot malfunction and thus the gas to the flare stack is **vented** (i.e. uncombusted), also known as a cold flare. Typical causes may include, but not be limited to, malfunction of the pilot itself, wind conditions, failure of an auto-ignition system (thermocouple), delay/failure in operating the manual ignition system, and malfunction in the flame front generator system

- When a flare is operating properly, the combustion efficiency[1] is lower than 100% and a small share of the gas is typically not combusted and released to the atmosphere (i.e. **incomplete combustion**)

Scope boundaries

All sources of methane emissions related to the incomplete combustion of waste gas as it is combusted in either a flare, enclosed flare or combustor are considered herein. They should be reported under Flaring[1]. For conditions where the flare is not lit (i.e. not combusting the gas and thus the gas is vented to atmosphere), this should rather be reported as venting or as an incident (see *Incidents, Third Party Damages and Emergency Stops TDG* and *Purging and Venting, Starts and Stops and Other Process and Maintenance Vents TGD)*. For batch flaring, if the discrete volume of gas vented to a flare is not fully isolated (i.e. isolation valves or pipeline stopples leak), the gas flared in excess of the isolated volume should also be quantified and reported under the *Incidents* TGD,

Note that incomplete combustion can also occur at other points in the process where fuel is burned for different purposes, such as engines, turbines or heaters. The related methane emissions should be reported under incomplete combustion (see *Incomplete combustion TGD).*

To obtain the Gold Standard, all material sources are to be quantified at level 4 or above. At asset level, this translates into the following principles:

- 95% of the emissions of an asset should be reported at level 4
- The assessment that given sources/devices are representing less than 5% of an asset emissions, should be done using level 3 quantification
- Source/device emissions within these 5% have to be reported at level 3

For detailed guidelines on materiality, please refer to the [*General guidance TGD*].

Level 3 Quantification Methodologies

Hereafter for simplicity, flares and combustors are referred to as 'flares' and the process to combust gas from a system as 'flaring'. The following are considered as providing Level 3 estimates:

Continuous or Intermittent Flaring

---

[1] Emissions from incomplete combustion from combustors can alternatively be reported under Incomplete combustion, in line with applicable regulatory constraints

Gas flow to the flare	Directly measured or indirectly determined using a mass balance. For batch flaring, engineering calculations are also appropriate (see Level 4 for more details)
Gas composition	Directly sampled or indirectly determined using a mass balance/ process simulation. In cases where the methane content can be assumed to meet a regulated specification (e.g. underground gas storage, gas transmission, gas distribution and LNG terminals), the gas specification compositions may be applied[2]
Destruction efficiency[3]	Assume annual average 98%[4] destruction efficiency – i.e. 2% of methane passes through to atmosphere

As noted above, for conditions when the flare is not lit and thus acts as a vent, report those emissions as venting.

Accepted emissions quantification methodologies[5] or those prescribed by local regulation are considered as providing Level 3 estimates, provided they are specific for the source type and consider gas flow, gas composition and destruction efficiency. Practitioners should use quantification methodologies that best represent conditions and practices at their facilities and adjust the estimation methods, where warranted, to more accurately estimate emissions given differences between the reference system on which the methodology is based, and their systems.

Level 4 Quantification Methodologies

Direct measurement, Measurement-based Emission factors and process simulation

Measurements (including continuous or periodic monitoring) or emission factors developed based on representative measured emissions are considered Level 4 emissions quantification. Measurements may be taken that represent the total flow, associated methane content and the destruction efficiency of each considered flare. Alternatively, these factors do not need to be individually quantified if a robust measurement technology, which directly determines the methane emissions from flaring, is used. In addition, process simulation and engineering calculations are considered appropriate to determine gas flow at level 4 and process simulation models, and applicable engineering calculations can be used to determine the methane destruction efficiency of flares. All this can be based on representative flare systems and operating/environmental and applied to all like systems.

The following are considered as providing Level 4 estimates:

Continuous or Intermittent Flaring

---

[2] Within the EU, regulated specifications and quality standards may be applied

[3] Combustion efficiency is often used interchangeably with destruction efficiency and they are, therefore, often confused. Destruction efficiency is a measure of how much of the original hydrocarbons are destroyed (to form CO_2 and CO), while combustion efficiency is a measure of how much of the original hydrocarbons burn completely and are transformed into CO_2 and water vapor.

[4] Applies to non-aspirated flares (i.e. aspirated, or assisted, flares are flares that do use steam, air or other gasses to aspirate additional air in the combustion zone)

[5] Published reference technical guides, academic papers

Gas flow to the flare	Continuous direct measurement or measurement-based indirect estimate using a mass balance/process simulation.
	For batch flaring, engineering calculations are also appropriate
Gas composition	Continuous measurement or sample measurement
	In cases where the methane content can be assumed to meet a regulated specification (e.g. underground gas storage, gas transmission, gas distribution and LNG terminals), the gas specification compositions may be applied[6]
Destruction efficiency[7]	Measurement-based methane destruction efficiency applied or destruction efficiency determined through the application of correlations based on representative sampling
	Engineering calculations can also be used, where applicable

Level 4 emissions quantification should be based on measurements conducted on a representative sample. System configurations, environmental and operating conditions (e.g. flare type, flare size, heating content of the gas, gas flow, wind conditions[8]) should be considered in determining 'like' systems that carry common parameter value. Each system that is not 'like' will require determination of a separate parameter value for that system based on the appropriate measurement or modelling studies. For guidelines on the methodology to develop a statistically representative sample, please refer to the Uncertainty TGD.

In the event of emergency flaring, methane emissions from flaring should be quantified based on the best available data. Missing data can be determined using level 3 quantification.

Gas Flow

Widely accepted measurement equipment and techniques for determining gas flaring flow are to be employed. Following is a non-exhaustive list of such measurement solutions[9] [10]:

- Ultrasonic Flowmeters

- Thermal Mass Flowmeters

- Differential Pressure Flowmeters – for non-emergency flares

---

[6] Within the EU, regulated specifications and quality standards may be applied

[7] Combustion efficiency is often used interchangeably with destruction efficiency and they are, therefore, often confused. Destruction efficiency is a measure of how much of the original hydrocarbons are destroyed (to form CO_2 and CO), while combustion efficiency is a measure of how much of the original hydrocarbons burn completely and are transformed into CO_2 and water vapor.

[8] Where relevant data exists, to apply to engineering calculations and process simulations (wind tunnel studies)

[9] More details on various detection and measurement equipment can be found at CCAC, *Conduction Emissions Surveys, Including Emission Detection and Quantification Equipment – Appendix A of the OGMP Technical Guidance Document,* 2017

[10] More details on various detection and measurement equipment can be found at Marcogaz, *Assessment of methane emissions for gas Transmission and Distribution system operators,* 2019 – Section 7 (p. 34-39)

- Turbine meters – for non-emergency flares

Level 4 reporting approaches recognize that flares may accept gas from several sources within a facility, all at different flow rates, particularly during upset or emergency conditions. To account for this, a mass balance approach is deemed appropriate provided it is measurement based with the primary sources of gas to flare measured.

For batch flaring[11] (i.e. with discrete volumes flared tied to a single event), a simple engineering calculation is appropriate to determine the volume of gas released from the equipment and then convert it to a mass. As a simple example of depressurizing a fully isolated system, the following calculation may be useful:

$$V_r = V_i - V_f = V_i - \frac{P_i V_i T_f}{P_f T_i}$$

Where:

V_r = the volume of gas released (i.e. sent to flare) as a result of equipment/system depressurization

V_i = Volume of gas within the equipment/system prior to depressurization

V_f = Volume of remaining in the equipment/system following depressurization

P_i = Initial pressure of the gas in the equipment/system to be depressurized

P_f = Remaining pressure of the equipment/system (atmospheric pressure if fully depressurized)

T_i = Initial gas temperature prior to depressurization

T_f = Gas temperature in the equipment/system following depressurization

Gas Composition
Widely accepted sampling equipment and techniques for determining gas composition should be employed. Following is a non-exhaustive list of such measurement solutions[12] [13]:

- Online gas chromatograph

- Gas sampling at regular interval[14]

- Portable gas chromatography

- Dräger tubes

---

[12] More details on various detection and measurement equipment can be found at CCAC, *Conduction Emissions Surveys, Including Emission Detection and Quantification Equipment – Appendix A of the OGMP Technical Guidance Document,* 2017
[13] More details on various detection and measurement equipment can be found at Marcogaz, *Assessment of methane emissions for gas Transmission and Distribution system operators,* 2019 – Section 7 (p. 34-39)
[14] More details on acceptable interval available in [General TGD]

- Standard/regulatory gas composition

Destruction Efficiency

Measurement-based methane destruction efficiency, destruction efficiency determined through the application of correlations based on representative sampling, or in some cases (as discussed below) process simulation and/or engineering calculations are considered Level 4 emissions quantification. Measured combustion efficiency factors may also be used, recognizing they will provide a conservative reported value compared to destruction efficiency. For guidelines on the methodology to develop a statistically representative sample, please refer to the Uncertainty TGD. Following is a non-exhaustive list of emerging measurement techniques:

- Passive optical gas measurement systems:
  - Video Imaging Spectral Radiometry (VISR)
  - Passive Fourier Transform Infrared (pFTIR)
- Active optical gas measurement systems:
  - Open-Path OP-FTIR
- Differential Absorption Lidar (DIAL)

As noted above, for conditions when the flare is not lit and thus acts as a vent (i.e. destruction efficiency 0%), report those emissions as venting.

Process simulation models based on representative flare systems and operating/environmental conditions, validated by direct measurements and engineering calculations based on studies relevant to the flare condition can also be used to determine the destruction efficiency of the flare. Following are some examples of studies having conducted experiments, using wind tunnels, which have shown that waste-gas velocity at flare tip and external environmental factors (such as wind speed, atmospheric pressure, and relative humidity) have an impact on destruction efficiency. The following parametric model[15] can be used to estimate destruction efficiency in flares.

$$\eta = 1 - \frac{A * \exp\left(B * \frac{U_\infty}{(gV_j d_o)^{\frac{1}{3}}}\right)}{(LHV_{mass})^3}$$

Where

η = carbon conversion efficiency

LHV_{mass} = lower heating value (MJ/kg)

A = fuel-dependent coefficient (for natural gas: 156.4 $(MJ/kg)^3$, for propane- or ethane-based flare streams 32.06 $(MJ/kg)^3$)

B = fuel-dependent coefficient (for natural gas: 0.318, for propane- or ethane-based flare streams 0.272)

---

[15] Johnson, M.R. and Kosticuk, L.W., *A Parametric Model for the Efficiency of Flares in a Crosswind,* Proceedings of the Combustion Institute, 2002

g = gravitational acceleration (9.81 m/s^2)

V_j = flare tip exit velocity (m/s) – for batch flaring, the average flare tip exit velocity can be calculated

d_o = stack outside diameter (m)

U_∞ = wind speed (m/s) – for batch flaring, average wind speed over the duration of the event from nearest meteorological historical reporting or forecast can be used, for other types of flares, a statistically weighted average of efficiency taking into account widely varying wind conditions can be calculated using the following parametric dataset and model (e.g. weighted average of destruction efficiency based on historical meteorological data of wind speed)[16]

$$\bar{\eta} = \int_0^\infty P(U_\infty)\eta\big(U_\infty, V_j, D, HV\big)dU_\infty$$

Where

$P(U_\infty)$ = probability distribution function of wind speed, U_∞

$\eta\,(U_\infty, V_j, D, HV)$ = efficiency of the flare as function of wind speed and operating parameters

This empirical model is derived from data for flares burning methane and propane with a diameter between 12.2 mm and 49.8 mm, flow velocity between 0.5 m/s and 4 m/s and wind speed between 2 m/s and 17 m/s, with fuel dilutions using CO_2 or N_2 up to 80% (by volume). There are currently no published studies demonstrating the applicability of these equations for flares which operate under different conditions. Results of extrapolating these equations to flares operating outside of empirical test boundaries will increase uncertainty of this source as part of the reconciliation exercise (Level 5).

Example Models

Engineering models that capture one or more of the aspects necessary to quantify methane emissions from flaring (gas flow, gas composition and/or combustion efficiency) are considered Level 4 emissions quantification. Measured activity data can be continuous or based on representative sampling. Following are some examples of models which can be used to calculate combustion efficiency, necessary to determine methane emissions from flaring.

Modelling: Computational Fluid Dynamics

Quantitative analysis and verification of CFD (Computational Fluid Dynamics) models represents a valuable addition to physical measurements of emissions, CFD models needs to be validated against relevant field data.

CFD models are typically used for research purpose or to address a specific flare design challenge and are not used routinely by operators.

---

[16] Johnson, M.R, *Flare efficiency and emissions: Past and current research,* Carleton University, 2008, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjKzYeXu4XxAhUS2So KHeNbCrsQFjADegQIAxAF&url=https%3A%2F%2Fglobalmethane.org%2Fdocuments%2Fevents_oilgas_20 081203_oilgas-5Dec08_johnson.pdf&usg=AOvVaw0vp0eVGzih_tShEf57xxvd

Following is a non-exhaustive list of CFD models which can be used to complement measurements:

- Reduced combustion mechanism for C1–C4 hydrocarbons and its application in computational fluid dynamics flare modeling. Link

- Computational fluid dynamics modeling of laboratory flames and an industrial flare. Link

- Detailed Expressions and Methodologies for Measuring Flare Combustion Efficiency, Species Emission Rates, and Associated Uncertainties. Link

As with direct measurement, modelling may be performed for a representative sample of like systems and then applied to the larger population.