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# Environmental Pollution and Measurement of Gas Flaring

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## ABSTRACT

A flare is a combustion device that uses air or steam to burn associated, unwanted or excess gases and liquids released during production or by pressure relief valves during unplanned over-pressuring of plant equipment in many industrial operations, such as oil-gas extraction, refineries, chemical plants, coal industry and landfills. Several environmental problems caused by gas flaring such as air and noise pollution. In addition, flaring is a significant source of greenhouse gases emissions, contributing about 400 Mt-$CO_2$ emissions worldwide. Reduction of the environmental pollution to prevent the greenhouse gases emissions by reduce or recover the flare gas, there is a pressing need to know the composition, distribution and volume of flares and how it has changed over space and time. This paper provides an overview about the following: gas flaring and its composition, and its relevant environmental impacts. It also describes the flaring measurement techniques in industry by studying: government legislation, flow meter challenges, measurement technologies and flow meter calibration.
**Keywords:** Environmental Impacts, Greenhouse Gases Emission, Flare Gas Measurements, Flow Meter Challenges.

## I. INTRODUCTION

Gas flaring, which is the combustion of the unutilized excess gas (associated gas) from wells, hydrocarbon processing plants or refineries, either as a means of disposal or as a safety measure to relieve pressure [1]. It is a major environmental problem, contributing an amount of about 150 billion $m^3$ of natural gas is flared around the world, contaminating the environment with 400 Mt-$CO_2$ annually [2,3]. Losses from flares are the largest loss in many industrial processes, such as oil-gas production, refinery, chemical plant, coal industry and landfills. Wastes or losses to the flare include process gases, fuel gas, steam, nitrogen and natural gas. Gas flaring has significant environmental and economic consequences that need to be addressed. Reducing flaring and increasing the utilization of fuel gas is a concrete contribution to energy efficiency and climate change mitigation [4]. This paper presents an overview on the flaring in industry according to the following:

- Gas flaring in industry and its composition
- Environmental pollution
- Measurement techniques in industry by studying
- Government legislation
- Flow meter challenges
- Measurement technologies
- Flow meter calibration

## II. METHODS AND MATERIAL

### A. GAS Flaring in Industry

Flaring is defined by Canadian Association of Petroleum Producers as the controlled burning of natural gas that cannot be processed for sale or use because of technical or economic reasons [5]. Flaring can also be defined by the combustion devices designed to safely and efficiently destroy waste gases generated in a plant during normal operation. Gas flaring is coming from different sources: associated gas, gas plants, well-tests and other places. It is collected in piping headers and delivered to a flare system for safe disposal. A flare system has multiple flares to treat the various sources for waste gases [6,7]. Most flaring processes usually take place at stack top with the visible flame. Hydrocarbons are burned as they exit at stack top. Height of the flame depends upon the volume of released gas, while brightness and color depend upon composition. Because of gas may contain corrosive compounds, so it can be quite destructive, and there might be the need to dispose huge amounts of gas in a short time. So, a way of open flame is used in flaring during well tests, production of associated gas, refining and other processing stages.

Installation of flare gas systems are on onshore and offshore platforms production fields, on transport ships and in port facilities, at storage tank farms and along distribution pipelines. As shown in Figure 1, a complete flare system consists of the flare stack or boom and pipes which collect the gases to be flared. The flare tip at the end of the stack or boom is designed to assist entrainment of air into the flare to improve burn efficiency [8]. Seals installed in the stack prevent flashback of the flame, and a vessel at the base of the stack removes and conserves any liquids from the gas passing to the flare. Depending on the design, one or more flares may be required at a production location.

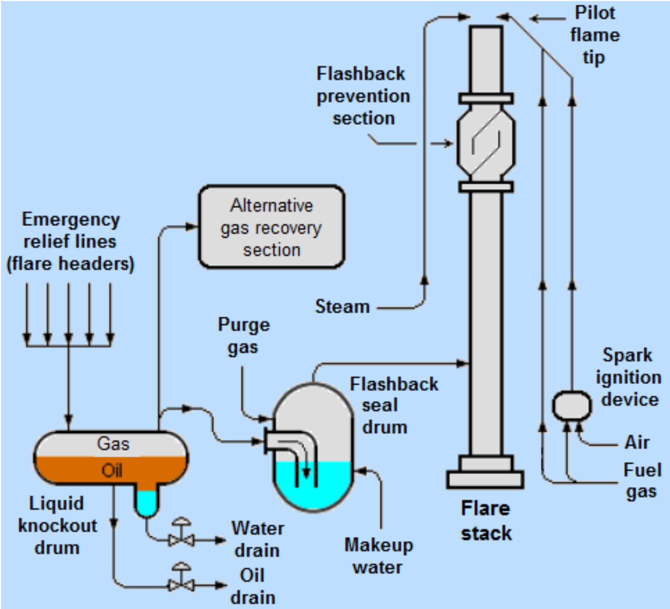


**Figure 1:** Overall flare stack system in a petroleum refinery [8].

A flare is normally visible and generates both noise and heat. During flaring, the burned gas generates mainly water vapour and $CO_2$. Efficient combustion in the flame depends on achieving good mixing between the fuel gas and air [9], and on the absence of liquids. Low pressure pipe flares are not intended to handle liquids and do not perform efficiently when hydrocarbon liquids are released into the flare system [10].

Flaring processes can be divided into three groups: emergency flaring, process flaring and production flaring [11]. Emergency flaring occurs in case of fire, break of valves, or compressor failures. A huge volume of gas with high velocity is burned in a short duration of time. Process flaring usually comes with a lower rate. During petrochemical processing some waste gases are removed from the production stream and then flared. Amounts of flared gas at such processes can vary from a few cubic meters per hour during normal functionality to thousands cubic meters per hour during plant failures [12]. Production flaring occurs in the exploration and production sector of oil-gas industry. Large amounts of gas will be combusted during the evaluation of a gas-oil potential test as an indication of the capacity of the well for production. Potential test provides operator some measurements such as initial reservoir pressure, pressure drawdown and fluid flow rates.

**a. Flare gas composition**

Flare gas consists of a mixture of different gases. The composition depends upon the source of the gas going to the flare. Associated gases released during oil-gas production mainly contain natural gas (NG). NG is more than 90 % methane ($CH_4$) with ethane and a small amount of other hydrocarbons; inert gases such as $N_2$ and $CO_2$ may also be present. Flare gas from refineries and other process operations will commonly contain a mixture of hydrocarbons and in some cases hydrogen. However, landfill gas, biogas or digester gas is a mixture of $CH_4$ and $CO_2$ along with small amounts of other inert gases. There is in fact no standard composition and it is therefore necessary to define some group of flare gas according to the actual parameters of the gas. Changing gas composition will affect the heat transfer capabilities of the gas and affect the performance of the measurement by flow meter. An example of waste gas compositions at a typical plant is listed in Table 1 [7].

The value of the gas is based primarily on its heating value. Composition of flared gas is important for assessing its economic value and for matching it with suitable process or disposal. For example, for transport in the upstream pipeline network, the key consideration is the $H_2S$ content of the gas. Gas is considered sour if it contains 10 mol/kmol $H_2S$ or more [13].

**B. Environmental Pollution**

Nowadays, gas flaring is one of the most challenging energy and environmental problems facing the world. Environmental consequences associated with gas flaring have a considerable impact on local populations, often resulting in severe health issues. Generally, gas flaring is normally visible and generates both noise and heat. Ghadyanlou and Vatani were calculated the thermal radiation and noise level as a function of distance from the flare using commercial software for flare systems. The results of these calculations are presented in Table 2.

Table 1: Waste gas compositions at a typical plant [7].

| **Flare gas constituent** | **Gas composition, %** | | **Flare gas, % average** |
|---|---|---|---|
| | **Min.** | **Max.** | |
| **Methane** | 7.17 | 82.0 | 43.6 |
| **Ethane** | 0.55 | 13.1 | 3.66 |
| **Propane** | 2.04 | 64.2 | 20.3 |
| **n-Butane** | 0.199 | 28.3 | 2.78 |
| **Isobutane** | 1.33 | 57.6 | 14.3 |
| **n-Pentane** | 0.008 | 3.39 | 0.266 |
| **Isopentane** | 0.096 | 4.71 | 0.530 |
| **neo-Pentane** | 0.000 | 0.342 | 0.017 |
| **n-Hexane** | 0.026 | 3.53 | 0.635 |
| **Ethylene** | 0.081 | 3.20 | 1.05 |
| **Propylene** | 0.000 | 42.5 | 2.73 |
| **1-Butene** | 0.000 | 14.7 | 0.696 |
| **Carbon monoxide** | 0.000 | 0.932 | 0.186 |
| **Carbon dioxide** | 0.023 | 2.85 | 0.713 |
| **Hydrogen sulfide** | 0.000 | 3.80 | 0.256 |
| **Hydrogen** | 0.000 | 37.6 | 5.54 |
| **Oxygen** | 0.019 | 5.43 | 0.357 |
| **Nitrogen** | 0.073 | 32.2 | 1.30 |
| **Water** | 0.000 | 14.7 | 1.14 |

Table 2: Thermal and noise emissions from flaring [1].

| **Distance, m** | **Thermal radiation, kW/m$^2$** | **Noise level, dB** |
|---|---|---|
| 10 | 5.66 | 86.3 |
| 20 | 5.87 | 86.19 |
| 30 | 6.04 | 86.02 |
| 40 | 6.14 | 85.78 |
| 50 | 6.17 | 85.50 |
| 60 | 6.14 | 85.18 |
| 70 | 6.04 | 84.83 |
| 80 | 5.88 | 84.46 |
| 90 | 5.67 | 84.08 |
| 100 | 5.42 | 83.68 |

Global emissions from gas flaring stand for more than one-half of the annual Certified Emissions Reductions (CER) (624 Mt-$CO_2$) currently issued under the Kyoto Clean Development Mechanisms (CDM) [2]. However, flaring is considered as much safer than just venting gases to the atmosphere [2,13]. Pollutants of flare and their health effect are summarized in Table 3.

$CO_2$ and $CH_4$ are greenhouse gases (GHG) that, when released directly into the air, traps heat in the atmosphere. The climate impact is obvious, suggesting a great contribution to global GHG emissions. For example, about 45.8 billion kilowatts of heat into atmosphere of Niger Delta from gas flared daily released [15]. As a result of the environment, gas flaring has raised temperatures and rendered large areas uninhabitable. $CO_2$ emissions from flaring have high global warming potential and contribute to climate change. About 75 % of the $CO_2$ emissions come from the combustion of fossil fuels [6]. $CH_4$ is actually more harmful than $CO_2$. It has a 25 times greater global warming potential than $CO_2$ on a mass basis [13]. It is also more prevalent in flares that burn at lower efficiency [15]. Therefore, there are concerns about $CH_4$ and other volatile organic compounds (VOC) from oil and gas operations.

Table 3: Pollutants of flare and their health effect [14].

| **Chemical name** | **Health effect** |
|---|---|
| Ozone in land | In low densities eye will stimulate and in high densities especially children and adults it will cause respiratory problems. |
| Sulphide hydrogen | In low densities it will effect on eye and nose which result in insomnia and headache. |
| Dioxide nitrogen | It will effect on depth of lung and respiratory pipes and aggravates symptoms of asthma. In high densities it will result in meta-haemoglobins which prevents from absorption of oxygen by blood. |
| Particles matter | There is this believe that it will result in cancer and heart attack. |
| Dioxide of sulphur | It will stimulate respiratory system and as a result aggravating asthma and bronchitis. |
| Alkanes: Methane, Ethane, Propane | In low densities it will result in swelling, itching and inflammation and in high densities it will result in eczema and acute lung swelling. |
| Alkenes: Ethylene, Propylene | It will result in weakness, nausea and vomit. |
| Aromatics: Benzene, Toluene, Xylene | It is poisonous and carcinogenic. It influences on nerve system and in low densities it will result in blood abnormalities and also it will stimulate skin and result in depression. |

Pollutants such as sulfur oxides ($SO_x$), nitrogen oxides ($NO_x$) and VOC also discharged from flaring [1,6,16-19]. Ezersky and Lips [19] were studied an emissions in US from a number of oil refinery flare systems in the Bay Area Management District (California). They were concluded that, the emissions ranged from 2.5 to 55 tons/day of total organic compounds, and from 6 to 55 tons/day SOx. Therefore, flare emissions may be a significant percentage of overall VOC and sulfur dioxide

($SO_2$) emissions. A smoking flare may be a significant contributor to overall particulate emissions [20].

Flare gas has a significant impact on environment due to possible presence of some harmful compounds. The scale of impact depends on composition of the flare gas [9]. The impacts of flare emissions therefore include [6,15-18]:

- the low quality gas that is flared releases many impurities and toxic particles into the atmosphere.
- harmful effects on human health associated with exposure to these pollutants and the ecosystems.
- products of combustion can be hazardous when present in high amounts.
- the waste gas contains $CO_2$ and $H_2S$, which are both weakly acidic gases and become corrosive in the presence of water.
- acidic rain, caused by $SO_x$ in the atmosphere, is one of the main environmental hazards.
- acid rains wreak havoc on the environment destroying crops, roofs and impacting human health.
- CO causes reduction in oxygen-carrying capacity of the blood, which may lead to death.
- uncontrolled $NO_x$ emission could be injurious to health.
- when $NO_x$ reacts with $O_2$ in the air, the result is ground-level ozone which has very negative effects on the respiratory system and can cause inflammation of the airways, lung cancer etc.

In addition of the above, gaseous pollutants like $SO_2$ that are once emitted into the atmosphere have no boundaries and become uncontrollable and cause acid deposition. Several toxicological/epidemiological investigations during the last few decades have shown that the effect of this gas is severe. Sulfuric and nitric oxides are the major causes of acid rain and fog which harm the natural environment and human life [21]. Also ozone has been revealed to cause damage. Ozone is also produced by the photochemical reaction of VOC and $NO_x$ as the main components of the oxidant. The oxidant accelerates the oxidation of $SO_2$ and $NO_x$ into toxic sulfuric and nitric acids, respectively. The removal of VOC and NO is very important to reduce the concentration of ozone [22].

On the other hand, because the most flare gas normally has not been treated or cleaned, pose demanding service applications where there is a potential for condensation, fouling (e.g., due to the build-up of paraffin wax and asphaltine deposits), corrosion (e.g., due to the presence of $H_2S$, moisture, or some air) and possibly abrasion (e.g., due to the presence of debris, dust and corrosion products in the piping and high flow velocities) [23].

The quantity of the generated emissions from flaring is dependent on the combustion efficiency [9]. The combustion efficiency generally expressed as a percentage is essentially the amount of hydrocarbon converted to $CO_2$. It is the ratio between the mass of carbon in the form of $CO_2$ which is produced by the flare and the mass of carbon in the form of fuel entering the flare. In other words, the combustion efficiency of a flare is a measure of how effective that flare is in converting all of the carbon in the fuel to $CO_2$. There are some factors effects in the efficiency of combustion process in flares such as heating value, velocity of gases entering to flare, meteorological conditions and its effects on the flame size [24]. Properly operated flares achieve at least 98 % combustion efficiency in the flare plume, meaning that hydrocarbon and CO emissions amount to less than 2 % of species in the gas stream [25], demonstrated that properly designed and operated industrial flares are highly efficient. Many studies indicated that flares have highly variable efficiencies between 62 - 99 % [26,27]. In order to increase the combustion efficiency, the steam or air is used as assistant in flares, which create a turbulent mixing, and better contact between carbon and oxygen [28]. Excess air has implications on emissions, specifically related to the creation of $NO_x$. The availability of extra nitrogen found in the air and additional heat required to maintain combustion temperatures are favourable conditions for the formation of thermal NO [29]. Moreover, greater amounts of excess air create lower amounts of CO but also cause more heat loss [9].

Thus, a reduction of GHG emissions is a crucial issue. One way to reduce GHGemissions is carbon capture and storage, which involves capturing of GHGat emission sources and storing it, where it is prevented from reaching the atmosphere [6]. Environmental and economic considerations have increased the use of flare gas recovery systems to minimize the amount of gas being flared [1,10]. Flare gas recovery reduces noise and thermal radiation, operating and maintenance costs, air pollution and gas emission and reduces fuel gas and steam consumption.

## III. RESULTS AND DISCUSSION

### Measurement Techniques in Industry

Lack of monitoring equipment and limited oversight make it difficult to quantify the scale of gas flaring around the world. For example, in some regions of Russia, only half of the flares have flow monitors [30]. In addition, many countries do not publicly report gas flaring volumes, leading to significant uncertainty regarding the magnitude of the problem [31]. In fact, to avoid scrutiny, it may be in the producers or governments interest to limit access to data on gas flaring levels. Much of the official information on the amount of gas flaring comes from environmental ministries or statistical agencies within various governments. However, during the last decade, increased use of military satellites and sophisticated computer programs has been used to measure gas flaring. These efforts seek to correlate light observations with intensity measures and flare volumes to produce credible estimates of global gas flaring levels.

Recently, an increased has been awareness by several countries worldwide towards emissions monitoring, measurement and reduction for both environmental and economic reasons. The World Bank estimates that between 150 to 170 billion cubic meters of gases are flared or vented annually, an amount worth approximately $ 30.6 billion, equivalent to 25 % of the United States' gas consumption or 30 % of the European Union's gas consumption per year [2,3,32,33]. The EPA estimates that the cost of compliance will rise to $ 754 million per year by 2015 for gas wells alone [34]. Geographic shows that a small number of countries contribute the most to global flaring emissions. At the end of 2011, 10 countries accounted for 72 % of the flaring, and twenty for 86 % [8]. In 2012 Russia and Nigeria accounted for about 40 % of global flaring [35]. Major flaring countries around the world are shown on Figure 2.

Improving the reliability, completeness and accuracy of flare data is expected to promote flare reduction activities and investments. Furthermore, data improvements at the country level will support efforts of the Global Gas Flare Reduction (GGFR) Partnership to enhance the quality of data on flare and vent volumes at the global level [23].The accurate, responsive and reliable measurement of flare gas is essential in order to assure proper operation of the flare gas system, which protects potentially hazardous combustible gas to maintain a safe working environment and to avoid environmental contamination. This an overview presents the methods of the industry practice for measuring flare gas volume.

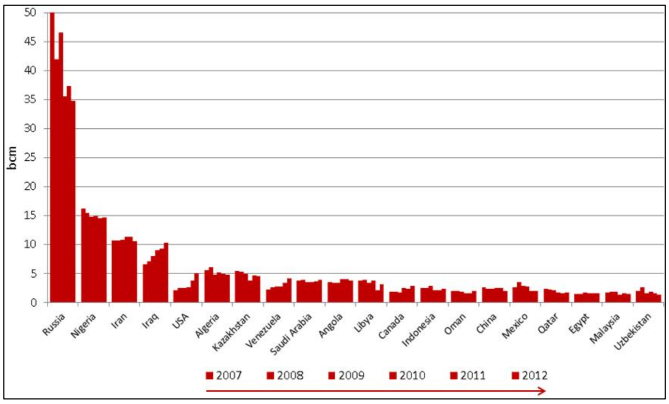


**Figure 2:** Top 20 gas flaring countries (NOAA satellite data) [35].

**a. Government legislation**

Flare gas is a significant waste of a valuable non-renewable energy resource and harms the environment through GHG and other emissions. Flaring and venting measurement has been identified as an important cross-cutting issue where the Global Gas Flaring Reduction Partnership (GGFR) could make a meaningful contribution to the global flaring reduction agenda by collecting and disseminating a best practice [23]. Regulations were implemented in 1993 relating to the measurement of fuel and flare gas for calculation of $CO_2$ tax in the petroleum activities on the Norwegian continental shelf [36]. Recently, with gas prices soaring, and new government legislation on the horizon, producers, refineries and chemical companies have been looking for a cost effective solution to reduce emissions, and to provide tighter control for both leak detection and mass balance. To tolerate the extreme process conditions often found in a flare line, yet provide accurate measurement to comply with regulators such as the Energy and Utilities Board [37], the technology of choice is of most importance. Many metering technologies have been tried and tested, and continue to be with little success today. To understand why the results have been dismal, one needs to fully understand the application and the limitations for the various flow-metering technologies available.

The Alberta Energy and Utilities Board (EUB) guide 60 will soon be revised with regards to flaring, and other provinces in Canada are expected to follow suite [37,38]. The guide will state that measurement will be required for continuous or routine flare and vent sources at conventional oil-gas production and processing facilities where an average total flared and vented volumes per facility exceed 500 $m^3$/day [38,39].

Acid gas flared, either continuously or in emergencies, will need to be metered from gas sweetening systems regardless of volume and fuel (dilution or purge) gas added to acid gas to meet minimum acid gas heating value requirements and $SO_2$ ground level concentration guidelines.

EUB Guide 60 references EUB Directive 017: Measurement Requirements for Upstream Oil and Gas Operations officially released February 1, 2005 [40]. In this directive it specifies the following uncertainties that must be met:

- Measurement uncertainty for flare gas must be ± 5 %.
- Measurement uncertainty for dilution gas must be ± 3 %.
- Measurement uncertainty for acid gas must be ± 10 %.
- Accuracy specifications apply to the overall rangeability of the process conditions.

**b. Flow meter challenges**

Flare gas flow measurement applications present several unique challenges to plant, process and instrument engineers when selecting a flow meter system. There are many challenges when trying to measure flare gas, including large pipe diameters, high flow velocities over wide measuring ranges, changing gas composition, low pressure, dirt, wax and condensate. The applications of flare gas measurement have uniquely challenged with two diverse and critically important flow conditions: very low flow under normal conditions and sudden very high flows during an upset blow-down condition. In addition to both flow conditions, there several other important criteria when selecting, constraints and considerations a flow meter for flare gas applications, plant operators, managers, process and instrument engineers, must be considered [23,34,40]. These technical criteria to consider in a measurement technology for use on flare systems delineate as the following [23,34,39-41]:

- *Operating range*, the meter should be sized to accommodate the anticipated range of flows.
- *Accuracy*, the minimum required accuracy of the instrument will depend on the final use of the measurement data and applicable regulatory requirements.
- *Installation requirements*, the flow meter should be installed at a point where it will measure the total final gas flow to the flare and be located downstream of any liquids knock-out or disengagement drum.
- *Maintenance and calibration requirements*, all flow meters are susceptible to deteriorated performance with time and use; although, some are more robust than others.
- *Composition monitoring*, most types of flow meters are composition dependent which means their readings are affected by any changes in the composition of the metered fluid and, if the meter has been factory calibrated (national pipe thread (NIST) certified calibration for mixed hydrocarbon flare gases), any differences between the process fluid and the reference fluid. There are two primary options for composition monitoring: (1) sampling and subsequent laboratory analysis, or (2) the use of continuous analyzers.
- *Temperature and pressure corrections*, the flow meter will need temperature and pressure compensation features to correct the measured flow to standard conditions (101.325 kPa and 15 °C) or normal conditions (101.325 kPa and 0 °C).
- *Multi-phase capabilities*, normal practice, if there is a potential for liquids in the system, is to install a liquids knock-out or disengaging drum and measure the gas flow rate leaving the drum. If the gas stream contains high concentrations of condensable hydrocarbons (as is the case for vapors from crude oil storage tanks), the gas flow meter should be installed as close as possible to the knock-out drum and consideration should be given to insulating and heat tracing the line.
- *Monitoring records*,to comply with typical regulatory requirements, monitoring records should be kept for at least 5 years. These records should comprise the flow measurement data, hours the monitor is in operation, and all servicing and calibration records. Periods of missed monitoring should be limited to 15 consecutive days and no more than 30 days total per calendar year.

- *Flow verification*, where verifiable flaring rate is desired, the systems should be designed or modified to accommodate secondary flow measurements to allow an independent check of the primary flow meter while in active service.
- *Flow test methods*, the test methods that may be considered for making spot checks or determinations of flows in flare header (for example, where installation of a permanent monitoring system is not practicable, where preliminary flow information is sought, or as a secondary measurement for verification of a primary monitoring system).
- *Non-clogging, non-fouling, no moving parts* design for lowest maintenance.
- *Stainless steel wetted parts* and optional stainless steel process connections and enclosure housings.
- *Offshore platforms corrosive salt water*, may require use of stainless steel on all exposed instrument materials, including sensors, process connections and enclosures.
- *Agency approvals for installation in hazardous locations*, the entire flow metering instrument should carry agency approval credentials for installation in environments with potential hazardous gases; enclosure only ratings are inadequate (and risky).
- *Compliance with local environmental regulations*, meet performance and calibration procedures mandated within local regulations such as US EPA’s 10 CFR 40; 40 CFR 98; EU Directive 2007/589/EC; US MMR 30 CFR Part 250 and others.

Plant operators, managers, instrument and control engineers are then further challenged to comply with the environmental agencies and emissions trading regulations for their flares stipulating flow meter accuracy of ± 5 % of reading throughout the entire measuring range.

**c. Measurement technologies**

Flare gas systems range from single-line to a large flaring system with a complex array of tributary lines and mixed gases. The flow meters are good confirmed for very low flow measurement to detect the smallest of leaks and up to measure major upset conditions accurately at very high flows [34,42]. There are multiple air-gas flow measurement technologies to choose from and not all of them are well suited to the accuracy, reliability, rangeability and rugged operating environment in the oil-gas industry. For example, some flow meter technologies are better at measuring liquids than air or gases. The accuracy of some flow meters is influenced by heat and some sensor technologies are temperature-compensated to maintain accuracy. Moving parts are acceptable in some operating environments and in other environments they can require high levels of maintenance or repair or replacement [42].

A listing of the main flow meter measurement options and a qualitative rating of these against a range of important selection criteria is given in Table 4. The best choice will depend on the specific circumstances and application requirements. For existing flares it may be appropriate to first perform a manual measurement or estimation of the flow rate to assess the requirements of a permanent flow measurement system. For new applications, this approach may prove more expensive as installing equipment at a later stage is normally costly [23].

In most cases the flare gas will be wet and potentially dirty. At facilities where gas processing is being performed or the produced gas is being supplied by a variety of sources having differing compositions, the measurement technology will either need to be composition independent or easily corrected for variations in the gas composition. In the latter case, regular gas analyses may need to be performed. The cost of installing a flow meter, the ability to do so without requiring a facility shutdown and the ongoing calibration requirements will also be important considerations. The cost of running electric power and communications wiring to an instrument was a major consideration; however, the use of solar panels and wireless connections to data acquisition systems may now be considered in these situations. Measurement technologies that do not require electric power and only provide local readout are also an option.

Varying gas composition, large pipe diameters, high flow velocities over wide measuring ranges, low pressure, dirt, wax, acid gases and condensate are many challenges when trying to measure flare gas. For these reasons, traditional technologies such as insertion turbine meters, averaging pitot tubes, and thermal mass meters fall short of being an acceptable solution. Ultrasonic technology was developed for flare gas measurement back in the early 1980s by Panametrics in collaboration with Exxon in Baytown, TX. Today ultrasonic flow meters are the industry standard for flare gas measurement with more than 3000 installations worldwide in process plants and refineries, on and offshore [43,44].

### d.Flow meter calibration

Several metering technologies were calibrated and tested by API, first using a fixed gas composition, and then again using three very different scenarios. The fixed gas composition consisted of 1 % $CO_2$, 0.9 % $H_2S$, 97 % methane, 1 % ethane and 1 % propane. The changes made are outlined in the following three cases and deviations shown in the following [32]:

- Case 1: 0.53 % $CO_2$, 0.47 % $H_2S$, 51.08 % methane, 0.53 % ethane, 47.39 % propane
- Case 2: 0.4 % $CO_2$, 0.36 % $H_2S$, 38.8 % methane, 0.4 % ethane, 0.04 % propane, 60 % hydrogen
- Case 3: 12 % $CO_2$, 0.8 % $H_2S$, 86.22 % methane, 0.89 % ethane, 0.09 % propane

In all cases, changing gas composition had no effect on ultrasonic meters. The differential meters were affected due to the square root calculation, and thermal meters influenced by the heating properties of the gas [32]. Many flare meter installations, either per plant edict or for compliance with environmental regulations, require regular validation of calibration. Traditionally this has required a cumbersome and costly project to remove the meter from service and return it to a lab, which is particularly frustrating if the meter is found to still be within calibrated specifications [42]. The designers provides a simple to use tool to verify the flow meter is still within calibration without extracting the meter from pipe. This system consists of a portable special ready flow sensor (which can be used with any number of flow meters) and an additional benchmark calibration document to which field verification samples are compared [41,42].

Table 4: The main types of flow meter technologies for flare gas measurement used in industry [23,41].

| Flow meter | | Characteristics |
|---|---|---|
| **Category** | **Type** | |
| Inline | Differential pressure meter<br>Common style:<br>orifice meters<br>venturi meters<br>annubars | - high tolerate of wet or dirty gas<br>- high calibration frequency<br>- high flow capacity<br>- high accuracy, from ±1 to ±5 % of full scale<br>- no electric power required<br>- rugged design<br>- low rangeability<br>- limited operating range<br>- flow resistance<br>- composition dependent<br>- no moving parts, maintenance can be intensive<br>- high installed costs |
| Inline | Vortex shedding | - moderate tolerate of wet or dirty gas<br>- composition independent<br>- moderate flow capacity<br>- moderate rangeability (in the range 30:1)<br>- accuracy, within ±2 % under ideal conditions<br>- low-pressure drops<br>- no moving parts<br>- low calibration frequency<br>- high installed costs<br>- electric power required<br>- not suited with low flow velocity (or where Reynolds number < 5000) |
| Insertion | Insertion (velocity probe),<br>Common style:<br>- thermal anemometer<br>- micro-tip vane nemometer<br>- Pitot tubes | - none to low tolerate of wet or dirty gas<br>- low to moderate calibration frequency<br>- composition dependent<br>- moderate to high flow capacity<br>- very low to high rangeability<br>- moderate accuracy, from ±1 to ±3 %<br>- electric power required (Pitot tubes, no required) |

Table 4 (continued): The main types of flow meter technologies for flare gas measurement used in industry.

| Flow meter | | Characteristics |
|---|---|---|
| **Category** | **Type** | |
| Inline | Transit-time ultrasonic | - moderate tolerate of wet or dirty gas<br>- composition independent<br>- high flow capacity<br>- high rangeability (in the range 2000:1)<br>- high accuracy, within ±2 %<br>- low calibration frequency<br>- electric power required<br>- no internal parts that can drift and cause inherent errors |
| Insertion (large diameter lines (> 6 inch)<br>Inline | Optical | - moderate tolerate of wet or dirty gas<br>- composition independent<br>- high flow capacity<br>- high rangeability (in the range 2000:1)<br>- high accuracy, within 2.5% to 7%<br>- low calibration frequency<br>- electric power required |
| Inline | Positive displacement meters "Bellows (or Diaphragm)" | - none tolerate of wet or dirty gas<br>- composition independent<br>- low flow capacity<br>- moderate rangeability (in the range 200:1)<br>- very high accuracy<br>- low calibration frequency<br>- no electric power required |
| Insertion | Rotameter | - low tolerate of wet or dirty gas<br>- composition dependent<br>- low flow capacity<br>- low rangeability (in the range 10:1)<br>- low to moderate accuracy<br>- low calibration frequency<br>- no electric power required |
| Inline | Turbine meter | - none tolerate of wet or dirty gas<br>- composition independent<br>- moderate flow capacity<br>- moderate rangeability (in the range 100:1)<br>- very high accuracy<br>- low calibration frequency<br>- no electric power required<br>- having moving parts |

## IV. CONCLUSION

Gas flaring is a significant waste of a valuable non-renewable energy resource and harms the environment through greenhouse gases and other emissions. These emissions have high global warming potential and contribute to climate change. Therefore, measurement of gas flare and its emissions are very important and has been very challenging. There several important criteria must be consideredwhen selecting, constraints and considerations a flow meter for flare gas applications, plant operators, managers, process and instrument engineers. Several of flow meter types are used for measuring flare gas such as insertion turbine meters, averaging pitot tubes, and thermal mass meters. However, ultrasonic flow meters are the industry standard for flare gas measurement with more than 3000 installations worldwide in different process plants. It can be concluded that, environmental and economic considerations have increased the use of flare gas recovery systems to reduce noise and thermal radiation, operating and maintenance costs, air pollution and gas emission and reduces fuel gas and steam consumption.

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