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Review Article

Environmental Implications of Flaring and Venting in Crude Oil and Natural Gas Production

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Abstract: It is believed that production of crude oil and natural gas without flaring and venting is neither technically nor economically feasible. In the face of this challenge, it is pertinent to understand the technical, economic, environmental, and social effects of flaring and venting in the production of crude oil and natural gas. This paper is a review of the role of flaring and venting in the production of oil and gas and an exposition of the environmental consequences of flaring and venting with respect to the production of crude oil and natural gas. The study exhaustively and systematically revealed the global and local effects of flaring and venting of natural gas on the environment and thereafter suggested various mechanisms through which flaring and venting could be drastically reduced using commercial models, regulation, new technologies and re-injection.

Keywords: Flaring, Venting, Production, Natural Gas, Crude Oil, Fossil Fuel, Environment, Exploitation

1. Introduction

Emissions from fossil fuel and biomass burning account for most energy-related air pollution in most parts of the world [1]. Energy-related emissions are released through the entire spectrum of oil and gas activities, from upstream emissions during crude oil and natural gas extraction and production to end-use emissions from petroleum burned for transport, heating, cooking and the like. Production of crude oil and natural gas is a major operation of the petroleum industry which involves nearly 100 countries around the world [2]. The process of production of crude oil and natural gas leads to the emission of some gaseous compounds into the air. Combustion of oil and gas, release from leaking equipment, intentional releases, release due to operational failures and poor handling are some of the sources of these air emissions.

The option to release gases to the atmosphere by flaring and venting is an essential practice in crude oil and natural gas production, primarily for safety reasons [3]. Flaring is the controlled burning of natural gas produced in association with crude oil in the course of routine crude oil and natural gas production operations whereas venting is the controlled release of unburned gases directly into the atmosphere [4, 5]. In conventional oil and gas production practices, the availability of a flare or a vent ensures that associated natural gas can be safely disposed of in emergency and shut-down situations. When crude oil is the primary target of production and the associated natural gas can neither be safely stored nor used commercially, it is advisable to either flare or vent the gas in order to reduce the risk of fire and explosion.

Flaring and venting of natural gas represent loss in the total value of produced hydrocarbon and therefore the need to optimize the operation of crude oil and natural gas production [6]. Although there are varieties of mechanisms that may potentially be used to reduce flaring, it may not be feasible to sell some or all of the gas for reasons that are often a combination of geography, availability of customers, and government energy policies [7]. Similarly, it may also not be technically or economically feasible to re-inject all the gas into underground reservoirs. Therefore, gas may have to be flared as a waste product. In some cases, venting may be preferable to flaring, depending on considerations such as local noise impacts, toxicity of gases being produced, and hydrocarbon content of the gas [8].

Environmental and resource conservation considerations are among critical reasons why flaring and venting should always be minimised as much as reasonably practicable and consistent with international safety considerations. The selection, design, specification, operation and maintenance of most flares and vent stack in oil and gas industry is governed by the provisions of ANSI/API STD 537 (the same provisions as ISO 25457) and ANSI/API STD 521 [9, 10, 11]. Apart from the ability to diversely affect the local environment, flaring and venting produce emissions which have had the potential as a main contributor to global warming and continue to do so [12]. In developing African countries, like in most other oil and gas producing nations, there are stipulated penalties for flaring associated natural gas aimed at discouraging unnecessary burning of natural gas to conserve the hydrocarbon energy resource. This regulation coupled with other strategies are responsible for the decline in the percentage of the natural gas flared in Nigeria over the years as shown in the table below:

Table 1. *The Volume of Gas Produced, Utilised and Flared in Nigeria (x 10^3 standard m^3).*

Year	Production	Utilisation	Flared	% Flared
2005	60,466.0	37,656.5	22,809.7	37.72
2006	64,842.5	41,610.5	23,232.0	35.83
2007	73,818.2	50,693.4	23,124.8	31.33
2008	73,687.0	54,692.4	18,994.6	25.78
2009	63,093.2	47,904.9	15,188.3	24.07
2010	79,844.5	64,419.5	15,425.0	19.32
2011	84,006.3	69,736.2	14,270.1	16.99
2012	84,838.3	71,663.7	13,174.6	15.53
2013	79,626.5	67,507.7	12,118.8	15.22
2014	86,325.2	75,172.9	11,152.3	12.92
2015	85,232.2	75,535.9	9,687.3	11.37

Source: DPR Statistical Bulletin, 2014 and OPEC Statistical Bulletin, 2016.

It has been shown that production of crude oil and natural gas without flaring and venting is neither technically nor economically feasible. In the face of this challenge, it becomes pertinent to understand the criticality of the technical, economic, environmental, and social effect of flaring and venting in the production of crude oil and natural gas. A review these concerns of flaring and venting of natural gas from oil and gas production will help explain the need for the search for ways through which flaring and venting of natural gas could be optimized or their impacts reduced.

2. Flaring and Flare Systems

Flaring is the controlled burning of natural gas in the course of routine oil and gas production operations [13]. This burning occurs at the tip of a flare stack or boom. 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 [14]. 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 [15]. A flare is normally visible and generates both noise and heat [16]. During flaring, the burned gas generates mainly water vapour and carbon dioxide [17]. Efficient combustion in the flame depends on achieving good mixing between the fuel gas and air, 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. The percentage combustion efficiency of a well-designed and operated flare are often higher than 98% [18].

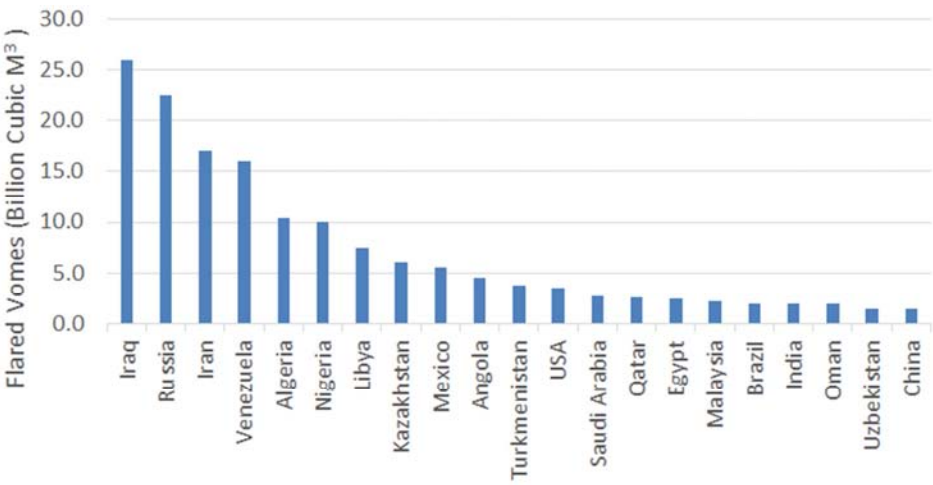

Figure 1. *Top 20 Flaring Countries in the World (Source: Flaring and Venting of Associated Petroleum Gas: Current Development and Effects of marginal Oil. Energy Research Architecture, December, 2015).*

The gas to be flared at the flare stack in oil and gas production process may come from a variety of sources. It may be the excess gas not used for power generation, unburned process gas from the process facilities, gas from process upsets, equipment changeover or maintenance [19]. Occasionally, production shutdowns may require the temporary flaring of all the gas stored on or arriving at a facility, to release high pressure and avoid a catastrophic situation occurring [20].

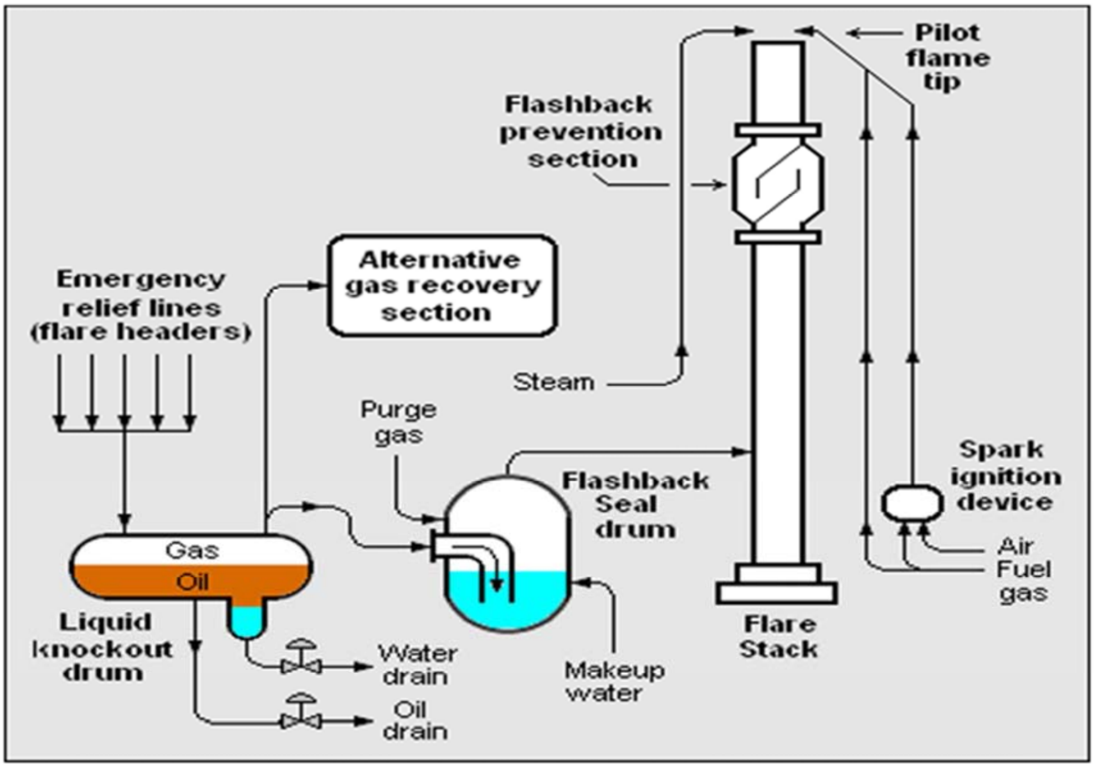

Figure 2. *Sketch of a typical Flare System.*

3. Venting

Venting is the controlled release of gases into the atmosphere in the course of oil and gas production operations [21]. These gases might be natural gas or other hydrocarbon vapours, water vapour, and other gases, such as carbon dioxide, separated in the processing of oil or natural gas [22]. In venting, the natural gases associated with the oil and gas production are released directly into the atmosphere and not burned. Safe venting is assured when the gas is released at high pressure and is lighter than air such that the strong mixing potential of high-pressure jets ensures proper mix of the discharged hydrocarbon gases with the air down to safe concentrations at which there is no risk of explosion [23]. Venting is normally not a visible process. However, it can generate noise, depending on the pressure and flow rate of the vented gases. In some cases, venting is the best option for disposal of the associated gas. For example, in some cases, a high concentration of inert gas is present in the associated gas. Without sufficiently high hydrocarbon content, the gas will not burn and flaring is not a viable option. Sometimes the source of inert gas may come from the process systems. The purging of process systems with inert gas may, in itself, justify venting as the safest means of disposal.

4. Environmental Concerns of Flaring and Venting

4.1. Technical (Safety)

The availability of a flare or a vent is absolutely necessary in oil and gas production operations. It ensures that safe disposal of the hydrocarbon gas inventory in the process installation is possible in emergency and shut-down situations. Where gas cannot be stored or used commercially, it is essential that the risk of fire and explosion be reduced by either flaring or venting. Even where associated gas is being sold or reinjected, small amounts of gas will still need to be flared or vented for safety reasons. Oil and gas processing and storage equipment is often operated at high pressures and temperatures. When abnormal conditions occur, the control and safety systems must release gas to the emergency flare or vent to prevent hazards to the employees or public. Good maintenance and operating strategies are the main mechanisms used to keep this already small volume as low as practicable. Emergency flares are normally fitted with pilot systems maintaining a small flame as the ignition source in case the full size flare is activated. Recent technology has designed and installed flare system to operate without pilot flame and hence without emission when not active [24]. The toxicity of the gases being disposed is another safety issue in the application of flaring and venting [25]. In some situations, the toxicity of the gas relative to the toxicity of its combustion products may need to be considered when choosing between flaring and venting as a means of disposal. An example would be where gas containing hydrogen sulphide is being produced. Hydrogen sulphide gas can be fatal if inhaled; even at low concentrations but if burned the resulting sulphur dioxide is relatively less toxic [26].

4.2. Environmental Effects and Consequences

Environmental agencies independent to the oil and gas industry sometimes express concerns about the environmental impacts of flaring and venting. One such concern relates to the potential for global climate change. Both carbon dioxide and methane (the major component of natural gas) are known as greenhouse gases associated with concerns about global warming [27]. Flaring produces predominantly carbon dioxide emissions, while venting produces predominantly methane emissions. The two gases have different effects, however. The global warming potential of a kilogram of methane is estimated to be twenty-one times that of a kilogram of carbon dioxide when the effects are considered over one hundred years [28]. When considered in this context, flaring will generally be preferred over venting the same amount of gas in the design of new facilities where sufficient amounts of gas will be produced to run a flare. While there are still many uncertainties in our understanding of the complex issue of climate change, it makes sense to avoid the unnecessary release of carbon dioxide or methane into the atmosphere, where practicable. This point to a need to reduce emissions in a reasonably practicable way. Apart from the concern of global climate change, flaring and venting also have the potential to contribute to local environmental impacts such as local air quality [29]; and thus this aspect need to be properly managed. Although the global warming potential of methane when compared to carbon dioxide usually suggests that flaring is a more environmentally attractive option than venting, onshore oil and gas developments sometimes prefer venting because it is less visible and produces less noise [30]. In all cases, the company has the responsibility to make parties involved aware of all aspects of the issue to ensure reasoned decisions are taken and supported.

4.3. Resource Conservation

The natural gas burned in a flare or vented to the atmosphere is a natural resource which could be effectively used as a source of energy or for production of beneficial chemicals and petrochemicals. This is another valid concern being expressed about flaring and venting. The need to obtain as much value as practicably possible from the production of hydrocarbon has kept the oil and gas industry in continuous search for ways to minimize flaring and venting without violating safety considerations. Many oilfields currently still in production were started several decades ago, when there was less concern about conservation of resources than there is today. The issue of global warming was not identified but oil and gas companies were constantly seeking methods to reduce wastage of natural gas and maximise the financial returns from the resources being developing. In 1950, the Indonesian oil industry flared 95% of the total volumes of associated gas that it produced but this volume declined to approximately 28% by 1985 [31]. The rate of improvement of the extent to which natural gas resources were conserved in mature oil producing regions were dependent on some factors among which were the availability of local markets for the gas and governments incentives to consumers and suppliers / investors [32].

5. Mechanisms for Reducing Flaring and Venting

5.1. Commercialization of Associated Gas

This option could be achieved through access to international markets, development of local markets, remote field and infrastructure interface, creation of incentive framework, creation of investment friendly fiscal and gas pricing policies by the government and potential applicability of carbon credits.

5.2. Regulation, Legislation and Promotion of Application of Best Practices

A robust associated gas utilisation policy is best tool that could be used to minimise flaring of associated gas, if implemented. Some key regulatory processes could also be used to monitor and reduce the volume of associated natural gas flared or vented from oil and gas production process. They may include: Creation of very strict permission to flare procedure, imposition of reasonably huge fines on flaring and venting of associated gas, facility design guidance to eliminate or reduce flaring and venting, requirement for meters to be installed to measure flared and vented volume of gas, elimination of routine flaring approvals for pipelines and facilities etc.

5.3. Application of New Technologies

Some new technological developments have been applied to either reduce the volume of natural gas being flared or vented or convert the associated natural gas which would have been flared into another product. These are a few;

5.3.1. The Automatic Ignition System

Eliminates the issue of small amount of pilot gas which is always needed to keep the conventional flare system burning. The system is designed in such a way that the flare is automatically ignited when there is process failure and need to flare arises. The automatic ignition system has been installed on some offshore platforms in Norway.

5.3.2. Liquefaction Technologies

Have been designed to convert natural gas to liquids which are easily transported over far distances where markets are available. The Liquefied Natural Gas (LNG) and the Gas to Liquid (GTL) process plants are typical examples. Many of these process plants have been built in Nigeria, Qatar, Algeria, Libya etc.

5.3.3. Pilot Projects

Have also been used to convert natural gas to other easily marketable products. Small gas-fired mini turbine generators have been used to generate electricity from natural gas from oil fields. The generated electricity could be easily sold in the downstream energy market.

5.4. Re-injection of Associated Gas

This option involves re-injecting the associated natural gas into underground reservoir to maintain reservoir pressure during production. Re-injection of extracted associated gas is used as secondary recovery mechanism for increasing production; especially for aging fields. The associated gas is separated from the oil at the wellhead and then pumped back into the field to enhance the oil recovery factor. This associated gas could be recycled several times without being wasted, as it may still be recovered and used towards the end of the active life of the field. It is a practicable option for some oilfields, but not in all cases. The capital requirements for installation of the re-injection facility may make it economically non feasible for small oil fields. There are also some situations where the geological nature of the underground formations is such that the injected gas would migrate back to the oil production wells too easily, leading to inefficient and energy intensive gas recycling [33]. The availability of re-injection options for reducing flaring and venting of natural gas is therefore limited by economics and geology.

6. Discussions

Associated natural gas has been flared and vented from oil and gas production processes since the first oil well was drilled and produced till date. Crude oil and natural gas exist under huge pressure in underground reservoirs; the pressure is a safety risk and thus the associated gas may need to be flared or vented at production site. In other cases, for reasons that are often a combination of geography and availability of customers for gas, as well as local political factors, some or all of the associated gas produced with the oil is flared [34]. Crude oil has been the primary target for investors in the oil and gas industry. It could be argued that this fact coupled with the difficulty in finding markets locally for the associated natural gas has been the real reasons for the flaring and venting of associated natural gas.

The flared and vented gas contain some compounds that are toxic to man and the environment. Flaring and venting poses different threats: while flaring burns the associated gas and therefore creates carbon dioxide, venting releases the natural gas which is predominantly methane into the environment. Although both carbon dioxide and methane are greenhouse gases and thus have the potential for global warming, a kilogram of methane is twenty-one times more potent than the same amount of carbon dioxide.

The realization that flaring and venting of associated natural gas is a waste of energy resource coupled with the fine being imposed on producing companies for the release of greenhouse gases into the atmosphere has led the oil and gas industry to continually evolve ways through which flaring and venting could be reduced. This has led to design installation of automatic ignition flare system, improvements in liquefaction technologies (LNG, GTL etc) and the application of the injection of associated natural gas for secondary recovery.

7. Conclusion

The review of the concerns of flaring and venting of natural gas from crude oil and natural gas production has explained the need to search for ways through which flaring and venting of natural gas could be reduced and their impacts reduced as well. The research has revealed that no single approach to dealing with associated gas will be appropriate for all projects or locations. In practice, it is suggested that a choice made from a variety of creative and logical approaches be applied to address flaring and venting concerns in specific operations. It is also advised that governments, public and private institutions should provide an energy policy framework which will encourage and allow companies or institutions to select from various approaches in order to achieve the best practicable outcome in particular circumstances.

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