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Natural Gas Flaring in Nigeria, its Effects and Potential Alternatives – A Review

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ABSTRACT

Nigeria is a country blessed with vast oil and natural gas resources, due to inadequate management of resources most of the natural gas is flared. One of the most pressing challenges today is global warming. Gas flaring has been known to deliver carbon dioxide and other ozone depleting substances which cause unnatural weather change. This paper focuses on gas flaring; its definition, composition, types and classifications. It also highlights the policies that have been made in Nigeria concerning gas flaring and provides alternative solutions to gas flaring.

Keywords: natural gas, flaring, emissions, effects, alternatives.

INTRODUCTION

Nigeria is located in western Africa, sharing borders with the Republics of Niger and Chad to the north, the Republic of Benin to the west, and the Republic of Cameroon to the east. It is fortunate to have a large oil reserve, which has supplied the funding for development in other areas. Nigeria is Africa's leading oil provider and the world's thirteenth largest oil supplier, with crude oil accounting for 65 per cent of total government revenue, it has the ability to produce two million five hundred thousand barrels of crude oil per day at full operating capacity (EITI, 2018; Nigeria High Commission, 2021). The crude oil is extracted from a reservoir that also contains gas, which is produced at the same time as the oil. A flow station separates the accompanying natural gas from the oil. However, due to the country's weak domestic gas market, roughly 75% of the related gas is flared in Nigeria. The amount of gas flared is projected to be 2 bcf/d the greatest amount of any country belonging to OPEC (Abdulkareem et al., 2012).

Nigeria was ranked 7th in a report published by World bank on the top nations involved in the flaring of natural gas this can be seen in Table 1. The top seven nations have produced about 40% of the world's yearly oil for the previous nine years, and they are also responsible for majority of all worldwide gas flaring. Consequently, at Nigeria's existing pace of exploration, the oil reserves should keep going for an additional 37 years, while gas reserves will keep going for about 110 years (Ayoola, 2011).

The oil industry's profits, and incomes have made significant contributions to the Nigeria's economic well-being. Its exploration, however, has resulted in a slew of socio-ecological issues. The negative consequences of releasing undesired byproducts associated with flaring into the environment cannot be overlooked (Audu et al.; Lawrence, 2016; Okoli, 2013). Natural gas flaring has a severe environmental impact owing to carbon emissions, additionally it results in a loss of financial resources. Oil corporations burned $1.24 billion worth of natural gas in 2020, enough to supply power to 804 million Nigerians for an entire year (Akinpelu, 2021).

Several toxic chemicals are released into the environment during flaring, which have been related to gastrointestinal issues, Skin disorders, tumours, cerebral, hormonal, and developmental impacts, as well as cytological and

Table 1. Top 10 flaring countries from 2013–2018 [World Bank, 2020]

Ranking	Countries	2013 (bcm)	2014 (bcm)	2015 (bcm)	2016 (bcm)	2017 (bcm)	2018 (bcm)
1	Russia	19.9	18.3	19.6	22.4	19.9	21.3
2	Iraq	13.3	14.0	16.2	17.7	17.8	17.8
3	Iran	11.1	12.2	12.1	16.4	17.7	17.3
4	USA	9.2	11.3	11.9	8.9	9.5	14.1
5	Algeria	8.2	8.7	9.1	9.1	8.8	9.0
6	Venezuela	9.3	10.0	9.3	9.3	7.0	8.2
7	Nigeria	9.3	8.4	7.7	7.3	7.6	7.4
8	Libya	4.1	2.9	2.6	2.4	3.9	4.7
9	Mexico	4.3	4.9	5.0	4.8	3.8	3.9
10	Angola	3.2	3.5	4.2	4.5	3.8	2.8

respiratory problems atherosclerosis, and hypertension, among other diseases. It also generates a lot of heat and pain (Enetimi, 2017). According to recent research, gas flaring modifies the concentration of water ions (particularly sulfate, carbonate, and nitrate), pH, and conductivity of heavy metals (such as lead and iron) in rainfall. Its impact on vegetation as a result of variations in soil quality characteristics and temperature, leads to a decrease in growth and production (Idah, 2017).

The world has a major environmental dilemma today because it emits a lot of greenhouse gases, which adds to the general problem of global heating/warming. (Generon, 2019, Elehinafe et al., 2020). Global heating is projected to have lengthy, and often devastating repercussions. It leads to higher average temperatures and temperature extremes, as well as extreme weather events including hurricanes, hot spells, dry spells, snowstorms, rainstorms, floods etc. (Bradford, 2017).

In addition, infrastructure built for oil and gas production might have disastrous repercussions for wildlands. Heavy machinery is used to build roads, the infrastructure, and drilling sites, which has the potential to harm enormous swathes of vegetation. The damage is frequently irreparable. The extraction of fossil fuels takes place on almost 12 million acres of public land. As a result of this, large sections of habitat needed by fauna and humans are frequently lost. If oil and gas corporations leave these locations in the future, regeneration of the land might take years (Esterhuyse, 2018).

As a result, this review article is intended to inform the readers about gas flaring and its repercussions in Nigeria. It also investigates the research gap that exists and recommends the strategies for further research into potential environmental gas flaring solutions. This will provide a more conclusive understanding of the existing techniques for the health risks associated with the exposure to these gases.

OIL AND GAS EXTRACTION

Oil and natural gas formation

Oil is a dense liquid with an appearance that can range from black to brown to amber. Oil is a complex combination of hydrocarbons made up of atoms or molecules of carbon, hydrogen, sulfur, nitrogen, oxygen, and metals that developed millions of years ago from animal and plant remnants accumulated in sand and silt and crushed by sedimentary rock layers. (CAPP, 2021). Natural gas and oil are made up of dead biological material that has collected on the bottoms of seas, lakes, and swamps over hundreds of millions of years. Oil is generally made up of dead microalgae (phytoplankton), whereas coal and natural gas are predominantly made up of land plants (World Ocean Review, 2021).

Oil and natural gas exploration

The multi-staged process of extracting petroleum from the Earth has been split into three categories: The first category is concerned with obtaining oil and natural gas from the earth, securely transporting it over thousands of kilometers, and lastly transforming these resources into sources of energy and completed produce. At various stages of the process, environmental pollutants are released into the surrounding environment.

Crude oil is obtained from the reservoirs containing both gas and oil. Natural gas has two major sources: "non-associated" gas, which comes from the fields that exclusively generate gaseous hydrocarbons, and "associated" gas, which comes from the fields that also produce crude oil. The associated gas, is isolated from the unrefined petroleum at a Flow Station. (IEA, 2021; EnergyHQ, 2017; Fawole et al., 2016).

Seismic surveys are carried out in the hunt for suitable geological formations that potentially produce oil resources. This is accomplished through the employment of two research approaches. The first method entails detonating subsurface incendiary devices near the deposit and observing the seismic effects to determine its position and magnitude. The other method is to collect the information from the seismic waves that occur naturally (Poursartip et al., 2020).

Drilling a deep hole in the earth is the initial step in the extraction of oil. Afterwards, a tubular steel casing is inserted in the hole, guaranteeing the solidity of the construction. To improve the flow of crude oil, more holes are drilled. HCL is used to solvate the pollutants in the drilled well. Hence, carbonate, lime, scale, rust and carbonite deposits are effectively acidified. After drilling, HCL is also utilized to dispose of remaining cement. Subsequently, a "Christmas tree" is installed at the head of the well to control the fluid pressure and flow rate. (Pearson, 2019).

The major recovery stage begins when the entire equipment has been connected. Many natural mechanisms, such as gravity drainage, are exploited in this procedure to extract oil. In the first stage, the recovery rate is frequently less than 15 per cent. As more oil is extracted, the subsurface pressure declines to the point where it can no longer bring out oil from the earth. The second stage of recuperation begins at this point. Secondary petroleum recovery can be accomplished using a variety of methods. This usually entails injecting fluids underground to raise the pressure. The typical recovery percentage after primary and secondary oil recovery processes is rarely greater than 45 per cent. The final step of the extraction process is the third-order recovery. This is accomplished in a variety of ways. The first method uses thermal heating to lower the viscosity of the oil. The second method is to introduce gas into the deposit. Chemical flood is the final method. It entails combining thick, insoluble polymers and H_2O, then infusing them underground. Tertiary recovery provides for an extra fifteen per cent of the deposit's oil output (Vishnyakov, 2020).

Since the stocks of land oil supplies are diminishing, the quest for their reserves beneath the bottom of the sea begins. Drilling platforms are developed for this purpose, which is a complex, costly, and time-taking procedure – It takes two years to construct the mining platform. They can be indelibly attached to the bottom (about ninety meters) or glide on floats secured with an anchor system. Deep-sea mining rigs are connected to a network of wells that extract oil from permeable rocks. Oil is obtained from the gas as well as from the drilling platform. The raw material obtained is transported to a factory or drilling and transporting vessel through a pipeline system. The oil and gas are subsequently transferred to a container and brought onshore. The volume of oil obtained is not only determined by the boring methods used. The geological features, such as rock permeability, the power of natural forces, the deposit's porosity, or the oil's viscosity, are critical (PCC Group Product, 2021).

OVERVIEW OF GAS FLARING

Gas flaring

The open-air combustion of fuel gas i.e. "Gas flaring" is produced by various processes such as oil and gas retrieval, petrochemical processes, and extraction of discharge gases (World Bank, 2021). It is the method of burning unwanted or unused combustible gas that would otherwise be immediately discharged into the atmosphere. Gas flaring is done to convert the CH_4 content of the gas, into the products which are less fatal to the persons in the flare site's surroundings. (Olusegun, 2016).

The two forms of flare gases utilized in the petroleum and natural gas sector are; associated gas and non-associated gas. Associated gases are the gases liquefied in oil at formation pressure and expelled throughout the oil extractionn process. Lighter hydrocarbons and other impurities are disseminated in heavier molecules of deep reserves under high pressures when the working pressure drops from formation to atmospheric pressure. The associated gases are separated from the liquids and discharged when the high pressure is decreased to ambient levels at the fountainhead in the surface facilities. Non-associated gases are the gases obtained during uncommon situations such as the initial process, process disruptions, and cessation activities. Gases are continually gathered from a variety of processes and delivered to tall stacks to be burned for process protection and operation. This form of flare gas has a lower ecological consequence than associated gas flaring due to its small volume. (Yazdani et al., 2020; Soltanieh et al., 2016).

Composition of flare gas

Flared gas is frequently composed of a mixture of gases. The gas supply for the flare system determines the composition. The bulk of the related gases generated during oil and gas production are composed of natural gas. Natural gas comprises than 90% methane (CH_4), a trace of ethane, and a few other hydrocarbons; inert gases such as N_2 and CO_2 may also be present. Refineries and other process industries often flare a combination of hydrocarbons and, in certain situations, H_2. In contrast, landfill gas, biogas, and digester gas are a combination of CH_4 and CO_2 with trace quantities of other inert gases. The changes in gas composition impact both the heat transmission capacities of the gas and the performance of the flowmeter. Table 2 depicts a typical plant's waste gas components. (Peterson et al., 2007).

Classification of flaring

Flaring can be divided into the following categories.

Initial start-up flaring

During the dedication and early start-up phases of a plant or process unit, fluids are injected to new facilities and equipment to test the production of goods for sale (oil, LPG, condensate, etc.). Some associated gas may be flared through the early stage of the plant's operation, or for reservoir management reasons before all of the gas compressors are commissioned (Bahadori, 2014).

Continuous production flaring

After the plant or process unit has been operational for a while, this type of flaring happens. Continuous production flaring is defined as a regular, uninterrupted gas stream sent to a flare stack because there is no cost-effective way to enhance the value of gas for a routine flash gas venting in upstream production. (IPIECA, 2021).

Operational/non-continuous production flaring

This type of flaring can happen for a number of reasons, both intentional and unplanned. Planned non-continuous production flaring can occur as a result of routine checks, facility closures, well completions, workovers, and fluids unloading, etc. Unplanned non-continuous production flaring includes mechanical equipment faults, instrument failures, and difficulties in restarting well production. (IPIECA, 2021).

Gas flaring system

Gas flares, also known as flare stacks, are used to eliminate waste gas and lower non-waste gas pressures that can cause equipment to fail. By reducing gas pressures with pressure-relief valves, flare stacks used with non-waste gases act as safety systems. These gas flares not only reduce equipment strain but also keep gas processing equipment from becoming over-pressurized. (Globalspec, 2021).

The pressure regulator is an important component that automatically releases fluids when the industrial equipment is burdened with excessive pressure. Pressure regulators are needed by industrial design rules, standards and regulations. Flare headers, which are massive pipe systems, transport the discharged fluids to a vertically raised

Table 2. Gas composition of flare gas at a typical downstream plant [Peterson et al., 2007]

Composition	Percentage flared (%)		
	Min	Max	Average
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
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

flare. The gases are burnt as they leave the flare stacks. The flow rate of the combustible material in joules per hour impacts the magnitude and luminosity of the resulting inferno (Wermac, 2021).

Typically, industrial plant flares have a knockout drum installed upstream to segregate significant volumes of liquid that may accompany the released gases (Figure 1). Steam is frequently injected into the flame to prevent the production of soot. A phenomenon called "over steaming" can occur when too much steam is supplied this leads to the decrease in efficiency of combustion and an increase in the level of gaseous emissions. A tiny amount of gas is continuously burned, similar to a pilot light, to keep the flare system running and ready for its principal role as an over-pressure safety device (Environmental Protection Agency, 2021).

- Knockout drum – this is used to remove any residual liquid from the discharged gases. There could be a variety of knockout drums: high-pressure and low-pressure drums are used to divert flow away from their respective pressure equipment. A cold relief drum is maintained separate from the wet relief system due to the risk of freezing.
- Water seal drum – this is used to keep the flame from flashing back from the flare stack's top.
- Gas recovery system – this is useful for partial plant starting and shutdowns, as well as other times. The recovered gas is injected into the fuel gas system of the entire industrial facility.
- Steam injection system – this provides an outward impulse force for optimal air-to-relieve-gas mixing and smokeless combustion.
- Continuous pilot flame (with its ignition mechanism) – this can be used to ignite flare gases.
- Flare stack – this includes a flashback avoidance component towards the top (Kayode, 2007; Lees, 2005; Shore, 2006; Smitsvonk, 2001).

Types of flares

There are many different types of gas flares. The three main types of flares include:

- ground flares,
- pit flares,
- elevated flares.

Ground Flares

This can either be closed or open pit. Figure 2 is a typical diagram of a closed ground flare. Ground flares are intended to conceal the flame while also reducing radiant energy and noise. They are made up of a refractory material-lined steel box or cylinder. They feature apertures around the base and are open at the top to allow combustion air to enter and could feature a variety of flare tips to enable turndown capabilities and flame distribution over the flare's area. They have been employed offshore on floating production storage and offloading complexes, and they are commonly used onshore in environmentally sensitive places (FPSOs). Majority of enclosed high-capacity flares are rectangular. Some of the benefits of using this type of flare are that it

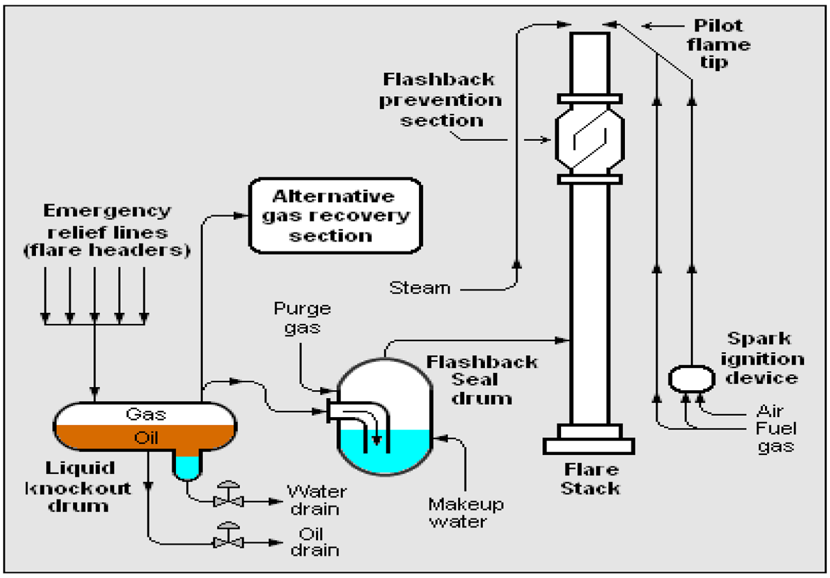

Figure 1. A schematic flow diagram of elevated flare stack system of an industrial plant (Barati et al., 2019)

releases little radiation and produces less noise (Argo Flare Services, 2021; Dey, 2021).

Pit Flares

Pit flares also known as pilot burners, are often parallel to the ground and visible through a fire brick wall, earthen wall, and/or fence that surrounds the flare pit. A burn pit should be placed away from all common work areas and operating plants, where the smoke and associated thermal plume will not threaten personnel or damage equipment. It should be at least 1,000 feet (305 m) long, clear of all structures and public car parks, households, and not be obstructed by local or general environmental conditions. Figure 3 depicts the appearance of a typical pit flare (Naoinc, 2021).

Elevated Flares

The waste gas is channeled through a vertical chimney and subsequently combusted at the stack top. A flare header, knock out drum, and flare stack make up the elevated flare system. The flare header collects waste gas and condensate from the entire plant, the condensate is separated in the knockout drum, and the gas is finally burned in a high-elevation stack. The elevated flares system is named from the fact that poisonous gases are burned at the flare tip at a high elevation. Figure 4 shows how a typical elevated flare looks like (Dey, 2021).

Effects of flare gas in Nigeria

Increase in greenhouse gases and global warming

The complete combustion, in an ideal world, would react with all of the carbon in the fuel and convert it to atmospheric carbon dioxide. However, under certain conditions, the carbon conversion efficiency is lowered and the fraction of incomplete combustion or partially reacted species

Figure 2. Closed ground flare (Keynes et al., 2020)

Figure 4. Elevated flare (Keynes et al., 2020)

Figure 3. Pit flare (Getty Images, 2021)

leaving the flare increases. The possible emission of unburned methane 1 and black carbon, both significant short-lived climate forcing agents, is of particular interest. (Corbin et al., 2014). Black carbon, according to some estimates, is only next to carbon dioxide based on global warming effects. This is done by the absorption of sun rays, which raises the atmospheric temperature, as well as falling on ice and snow, which decreases their ability to reflect light. Furthermore, black carbon is a component of fine particulate matter, which has harmful effects on human health and is responsible for about 7,000,000 deaths annually due to air pollution (Climate & Clean Air Coalition. 2020; Okedere and Elehinafe, 2022).

Increase in health challenges

Within 15 kilometers of the flare site in the Niger Delta, which has over 45 active gas flare sites, these hydrocarbon emissions; carcinogens like benzopyrene, benzene, carbon disulfide (CS_2), carbonyl sulfide (COS), and toluene; metals like mercury, arsenic, and chromium; sour gas including hydrogen sulfide H_2S and sulfur dioxide (SO_2); and nitrogen oxides (NO_x), has been discovered (Knizhnikov et al., 2009; Mokhatab et al. 2006; Nwanya, 2011; Okedere et al., 2021). Renal failure, central nervous system depression, chills, fever, myalgia, respiratory irritation, nausea, vomiting, and headaches, myalgia, cardiovascular failure and altered neurobehavioral function, multiple airways and lung injury, cancer, alveolar damage, emphysema, and respiratory problems, endocrine dysfunction, low immunity, infertility, and autistic disorders are all known side effects of environmental contamination released by flaring gas (CPHA, 2000). Today Niger Delta has the lowest life expectancy in Nigeria, at around 40 years which is definitely a result of gas flare-ups in the state (Akanimo, 2009; Ejiogu, 2013).

Decrease in vegetation

Researchers have also conducted the studies to investigate the influence of gas flaring on the distribution and composition of species in the region. Plants, and indeed entire vegetation, are known to respond physiologically to environmental stressors such as temperature changes, trampling, and air pollution with toxic gaseous pollutants such as nitrogen oxides, carbon dioxide, carbon monoxide (American Association for the Advancement of Science, 2010). Acidification of the soil happens as a result of these contaminants, which diminishes soil nutrients. Due to the tremendous heat created and the acid nature of the soil pH, there is no vegetation in the areas surrounding the flare in some instances. Changes in temperature have several consequences on crops, including stunted growth, scotched plants, and wasted young crops (Aregbe, 2017).

Nigeria policies on flare gas

Not later than five years after the commencement of production from the relevant area, as according to Regulation 42 of the Petroleum Drilling and Production Regulations 1969 the licensee shall submit to the minister any feasibility study, program, or proposals that he may have for the utilization of any natural gas, whether associated with oil or not, which has been discovered in the relevant area was the first Nigerian policy on the use of associated gas. The Associated Gas Re-Injection Act of 1979 supplanted this because it did not directly address gas flaring. The Act required each oil and gas producing company to provide a comprehensive plan for either re-injection or commercial use of all associated gas generated by October 1, 1980. It was also stipulated that gas flaring was to become illegal from 1st January 1984 (Orji, 2014).

After failing to meet the goal of eliminating all flares by 1984, the year 2004 was picked as the next objective, followed by the Nigeria Gas Master Plan in 2008. By 2016, the federal government had agreed to postpone the deadline for ending gas flaring to 2020. The government established the Flare Gas (Prevention of Waste and Pollution) Regulation in 2018, which, on the one hand, prohibits gas flaring while, on the other, allows it under certain conditions. To flare gas, oil corporations would require permission from the president. For every 1000 standard SCF of flared gas, the companies that generate more than 10,000 BPD must pay a $2 fee. The companies generating less than 10,000 BPD must pay a charge of $0.5 for every 1000 SCF of gas flared. This was done in order to make enterprises reconsider flaring gas. However, because this strategy failed to prevent gas flare-ups, the deadline was once again extended to 2025. Nigeria, on the other hand, as a member of the World Bank's Global Gas Flare Reduction Partnership, has vowed to remove all flares by 2030 (Ojijiagwo et al., 2018).

Alternatives for the flaring of natural gas

Programs for flare gas power generation

Electricity can be generated from natural gas. Flare gas may be used to generate electricity in a variety of methods, including:
- natural gas-powered micro and large turbines,
- turbines powered by steam,
- internal combustion engines that reciprocate.

Flare gas can also be used to generate heat and power in a cogeneration system.

Secondary oil recovery using flare gas reinjection

Existing wells can be refilled with natural gas from natural gas wells to sustain production outputs and restore declining natural formation pressure. Since waste is eliminated, this self-sustaining system is cost-effective as well as the general efficiency is enhanced (Robinson, 2013).

Petrochemical Plant Feedstock

Biogas is the most often utilized raw ingredient in the production of petrochemicals. Flaring associated gas from oil and gas wells can be used to make syngas, ammonia, hydrogen fuel for vehicles, or rubber, glass, steel, and paint instead of associated gas from oil and gas wells. (Al-Samhan, 2021).

Liquefied Natural Gas (LNG)

LNG liquefaction and storage is a more environmentally friendly and budget alternative to gas flaring. Liquefied natural gas can be utilized on a large scale or at home after treatment (McFarlan, 2020).

Compressed Natural Gas (CNG)

This is methane that has been compressed to high pressure. At a pressure of 20–25 MPa, methane can be compressed and stored in cylinders retrieved from landfills and oil wells. Natural gas-powered vehicles can be fueled (Beigiparast et al., 2021).

PERSPECTIVES

This review critically covers gas flaring as a whole and the formation and exploration of crude oil. Crude oil is obtained from dead biological material collated on the bottoms of seas, lakes, and swamps over hundreds of millions of years. Seismic surveys are used to find crude oil reserves in the earth. Crude oil which contains water, oil and natural gas is extracted using an oil rig. After extraction the three components are separated using a separator and the natural gas is usually flared off when there is no proper storage or transportation technique set up for it. Flaring can be classified into 3 major categories, namely, initial start-up flaring, continuous production flaring and operational/non-continuous production flaring. There are a variety of flare types such as gas ground flares, pit flares, elevated flares but they all consist of the following components: knock out drum, water seal drum and flare stacks. Flaring has many disastrous consequences such as; decrease in the life expectancy of people living near flare sites due to poisonous emissions which lead to a variety of health challenges and diseases. Flaring also contributes to global warming, which is a major concern today as it causes extreme weather conditions, extinction of certain species and climate change.

Nigeria stands to gain a great deal from utilizing natural gas properly in terms of revenue and increased job opportunities, thus it is imperative that the flaring of natural gas should be stopped. Several alternatives have been proposed, such as; using flared gas to produce electricity and as a petrochemical feedstock, liquefying of flare gas and reinjecting it into the earth as a secondary oil recovery technique.

Nigeria has made several policies to reduce and subsequently end gas flaring and has set multiple deadlines which ended up being postponed time and time again. The new deadline to end gas flaring is by 2030. However, due to many setbacks, it is possible that the deadline may yet be shifted again.

CONCLUSIONS

Gas flaring is the practice of burning undesired combustion gas to lower the amount of methane in the gas, which is more harmful to the environment than carbon dioxide. It is also done to alleviate pressure in industries, to prevent explosions from huge volumes of reactive gases being vented, and to save money because alternative disposal procedures are more expensive than removing the gas immediately.

Despite the obvious advantage that gas flaring may seem to have, it is clear that flaring of natural gas is disadvantageous to all involved; to the land as it releases toxins into the atmosphere and stunts the growth of vegetation, to humans as it creates room for a variety of diseases; to the nation as the financial losses associated with gas flaring are high and to the world, as it contributes to global warming which in turn causes extreme climate, drought and melting of glaciers.

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