Design of Smokeless flare for an Associated Gas in a Production Oil field

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ABSTRACT---- ***The continuous flaring of associated gas by operators in the upstream sector of the petroleum industry has been a major source of concern to various governmental agencies and environmentalist. This work is aimed at designing a vertical high velocity gas burner to handle natural gas with maximum capacity of 6.3kg/s and high pressure drop of 1 psia across the flare. A liquid knockout drop is stalled to separate the liquid from gas and to eliminate liquid carryover into the flare. The flare is bounded by a bund wall and operated at noise level of 80dBA. The high velocity flare provides rapid air entrainment for premixing of air and gas before proceeding to the burner tip for combustion. The design calculations involve determination of the flare tip diameter, radiation effect, quantity of heat liberated, mass and volumetric flow rate, exit gas velocity, flare angle and pressure drop across the nozzles. The total capital cost of the design was estimated to be ₦ 18,879,749.00***

Keywords--- *Associated gas, Flaring, Pollution, Smokeless, Safety*

1. INTRODUCTION

Crude oil production is accompanied with an associated gas which over the years was flared. This is because the existing production facilities were not designed to handle the production of associated gas as it is difficult and capital intensive to compress and use for other purposes [1]. This leads to the continuous flaring of gas. Studies from satellite data indicated that more than 139 billion metre cube of gases were flared annually [2], an amount equivalent to 4.6% of the world natural gas consumption which totaled 3011 billion meter cube in 2008 [3]. Other research has reported that about 5% of the world's natural gas production is wasted by flaring [4]. This amount of flaring produces approximately 281 million tons of CO_2 emissions annually [5]. Emissions from flaring also contribute to the increasing earth's temperature and increase the natural greenhouse effect and even climate changes [6, 7]. Consequently, gas flaring causes health hazard through emissions that have been linked to cancers, asthma, chronic bronchitis, blood disorders, and other diseases [8, 9]. Flaring can also release pollutants such as particulate soot [10, 11], oxides of nitrogen (NO_x), sulfur oxides (SO_x), and volatile organic compounds [12].

Most hydrocarbon flares are known to be luminous due to the carbon particles formed in the flare. Under certain conditions, these particles are released from the luminous flares as smoke. The smoke in flare is a result of high temperature cracking and polymerization reaction in limited amount of oxygen within the flare core. Gas flaring causes noise and air pollution problems. Excessive noise is hazardous to health and prolong exposure to high noise levels can cause permanent hearing damage. At low noise levels, fatigue may result [13].

Some of the gases emitted during gas flaring such as CO, NO_x can cause serious health and environmental problems [14, 15]. Hence, an environmentally friendly use of natural gas as an alternative source of fuel became necessary in order to alleviate the problems associated with it [16, 17]. Apart from being a source of air pollution, the effect of thermal radiation on human and equipment during gas flaring is a major factor being considered in the design of flare systems. Various experiments conducted to determine the effect of thermal radiation on human revealed that with an intensity of 6.31kw/m^2, pain threshold was reached in seconds and blistering occurred after 20 seconds. While on the skin of white rats, the same intensity produced burns in less than 20 seconds and pain threshold followed quickly [18, 19]. Also, different studies on the impact of the petroleum industry and gas flaring on the mangrove ecology and soil fertility respectively revealed the disadvantages associated with it [20, 21]. The earlier flare systems were merely open-ended piece of pipe mounted on at all stacks. With increasing rate of hydrocarbon consumption worldwide, a more effective and reliable flare systems have been developed. The kaldair flares which utilizes the skin adhesion effect is one of such type. Another is the indair flare, which was developed for a range of high and low pressure flares, is ideally suited for emergency blow down or continuous gas flaring on offshore platform and onshore oil fields. Its operation is reliable with the advantage of having low radiation, short flare length, smokeless combustion, reliable ignition without wind effect. Other flare systems developed include stedair flares which is a range of steam injected flare. This smokeless burning, low pressure gas release is used in refinery, petrochemical and chemical plants. Enclosed flares are extremely safe, reliable, easy to maintain and environmentally friendly. This type of flare guarantees complete destruction of waste gases, eliminate smoke and odour, with low noise level making it suitable for urban use [22].

To satisfy the most stringent environmental noise and nuisance control regulations, small holding high technology burners replace highly visible open burner. A low-density ceramic replaces a high maintenance refractory linings, passive acoustic sense and gravel bed replaces expensive noisy and troublesome injection water spray and forced air blower [22]. Therefore, the need to develop a more sophisticated flare system with dependable flare front, pilot ignition system, liquid seals and knockout drums to prevent smoky burning of gases has arisen. To accomplish this, the system is operated through high velocity, turbulent mixing natural air drift and swirling of waste gases into a vortex, thus, reducing cost and eliminating frequency of repairs.

2. DESIGN MODEL FORMATION

The design of a flare system involves the determination of certain parameters; flare stack diameter, height, radiation level, heat of combustion, exit velocity, wind distortion and pressure drop. The flare diameter depends on the volume ratio of maximum conceivable flare flow to the average flare flow. It is usually calculated using a velocity ratio which is a dimensionless group known as the mach number (N_{ma}). For this design, we can permit the velocity of $0.2N_{ma}$ for normal and frequent conditions. Table 1 shows details of design parameters. The flare tip diameter, d is determined using the equation (2.2).

$$N_{m\alpha} = 11.61 \times 10^{-2} \frac{W}{pd^2\sqrt{\frac{T}{KM}}} \tag{2.1}$$

The calculation of flare stack height is based on normal pipe diameter size and is given as

$$H = 3d \tag{2.2}$$

The quantity of heat liberated (Q) during gas flaring is calculated as

$$Q = WH_c \tag{2.3}$$

The flare tip gas exit velocity, U_f is given as

$$U_f = \frac{V_g}{\frac{\pi d^2}{4}} \tag{2.4}$$

$$V_g = W\left(\frac{V}{M}\right)\frac{T_1}{T_2} \tag{2.5}$$

$$\Delta P = \frac{1}{[1+\left(\frac{k-1}{2}\right)N^2 ma]\frac{k}{k-1}} \tag{2.6}$$

Equation (2.6) is pressure drop across the flare tip during flaring. The efficiency of the knock out drum used in separating gas-liquid mixture is a function of the gas local factor, volumetric flow, the cross-sectional area and the densities of the gas and the liquid, given as.

$$\lambda = \frac{V_g}{A}\sqrt{\frac{Q_g}{Q_l - Q_g}} \tag{2.7}$$

Flare distortion caused by wind is determined by the speed of wind and the exit velocity of gases. The direction of wind is important in this design, hence the flare angle is:

$$tan\theta = \frac{U_{max}}{U_f} \quad (2.8)$$

Table 1: Design parameter and values used

Parameters	Values
Heat of Combustion (H_c) KJ/Kg	50×10^3
Flare tip gas Pressure KPa	101.30
Vapour mass flow (W) Kg/s	6.30
Temperature of flow gas (T_1)^{o}K	313.00
Mol.Wt of gas mixture (M)	21.00
Wind Speed (U_{max}) m/s	35.60
Ratio of Specific Heat Capacity (C_p/C_v)K	1.10
Gas Composition	C_1-C_4

3. 3.0 SAFETY AND LOSS PREVENTION DURING GAS FLARING

Fire and explosions are major hazards associated with gas flaring and often result to injury to personnel and damage to equipment. The potential is evaluated using the Dow process [23]. A numerical fire and explosion index (F&EI) is calculated based on the nature of the process and properties of the material. The material factor (MF) is a number ranging from 0-60 that indicates the magnitude of energy released in a fire explosion. A larger index value indicates a high potential of hazard.

$$MF = H_c \times 4.3 \times 10^{-4} \quad (3.1)$$

Determination of MF is considered to properly design flare system that will reduce the risk of fire explosion.

4. CONSTRUCTION MATERIAL AND COST ESTIMATION

Flare is expected to give out reasonable amount of heat during operation. So, the construction material is selected to withstand high thermal stress. AISI 301s is austenitic stainless steel with high chromium and nickel content which can be used for its resistance to corrosive and heat. Incoloy 8000H Iron-Nickel with chromium alloy is also considered as an extension of the austenitic stainless steel. They are used in extreme conditions due to their good resistance to a wide range of corrosive materials. Also, high tensile carbon steel coated with thermal sprayed metallic aluminum and nickel alloy bolts should be used for mounting the flare tip. Table 2 shows the total cost estimate of design and construction.

Table 2. Total Cost Estimate for the design

Purchase Equipment Cost (PEC)	**Direct Installation cost (DC)**	**Indirect Installation Cost (IC)**
Flare cost (FC) ₦ 8,420,938.40	Foundation & support 0.12 PEC	Engineering 0.10 PEC
Instrumentation 0.1 FC	Handling & Erection 0.40 PEC	Constr. & field exp.0.10 PEC
Sales tax 0.03 FC	Electrical 0.01 PEC	Contract fee 0.10 PEC
Freight 0.05 FC	Piping 0.01 PEC	Start-Up 0.01 PEC
	Painting 0. 01 PEC	Contingencies 0.03 PEC
Total PEC ₦ 9,936,708.60	₦ 5,564,560.40	₦ 3,378,480.00

5. RESULT AND DISCUSSION

The design has been executed to handle a flare capacity of 6.3kg/s of natural gas without smoke formation. Table 1 shows the design parameters and specification. The cost estimated for the design is shown on Table 2 and gives the three stages of the design with the different cost estimate. This means that the actual work can be done in stages.

Similarly, Table 3 shows the result of the design calculation and equipment specification. The exit velocity obtained in the design is high. This will enhance rapid air entrainment and turbulent mixing of air and gas, so that complete combustion is readily achieved without additional cost associated with steam, water spray, and air blowers. The design is worth carrying out to reduce the health hazards caused by carbon-monoxide produces during incomplete combustion. Also, the release of carbon particulates into the atmosphere will be reduced.

Table 3: Design Calculations and Equipment Specification

Parameters	**Values Obtained**
Height of Flare (H) m	1.11
Flare Tip Diameter (d) m	0.37
Heat Liberated (Q) KW	3.15×10^5
Volumetric Flow (Vg m^3/s	7.73
Exit Velocity (U_f) m/s	71.90
Pressure drop (ΔP) KPa	6.74

6. CONCLUSION

A smokeless flaring system has been designed for an associated gas in a production oil field with minimal environmental impact. With the nozzle at high velocity jet, rapid air entrainment and turbulent mixing of air and gas, complete combustion is readily achieved. The knockout dream is installed to serve to separate liquid from gas for recycling or venting during emergency. Although, this design is modeled to eliminate completely the problems associated with gas flaring, further research could consider the effect of air ingression and flare flash back by introducing air arrestor, seal at the flare tip, perforated wind shield and fins to check flash back.

Nomenclature

W	Vapour mass flow rate
P	Flare tip gas pressure
H_c	Heat of combustion
V	Volume of gas at STP
V_g	Volumetric flow rate of gas
M	Molecular weight of associated gas flared
U_{max}	Maximum speed of wind
U_f	Flare tip exit velocity
ϱ_l	Density of liquid (49.6 Kg/m^3)
ϱ_g	Density of gas (0.0084 Kg/m^3)
λ	Gas load factor
T_1	Temperature of gas flow
T_2	Temperature of gas STP
Π	Pie

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