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DESIGN OF INDUSTRIAL GAS BURNER TO MANAGE SOOT PRODUCTION DURING GAS FLARING

UGOCHUKWU KENNETH UDEZE; & KENECHI MARKANTHONY ONWUGHALU
Department of Electrical Electronics Engineering, Federal Polytechnic Oko.

Abstract
This research was conducted to foster solution to soot production problem during gas flaring by designing industrial gas burner that will effectively burn the gas and prevent release of soot. To achieve this objective, two different natural gas samples labelled A, B with different methane composition of 70% and 60% respectively where investigated at different flow rate ranging from 50-250kg/hr. taking into consideration two different burner dimension which include burner pipe diameter and burner pot diameter. Aspen HYSYS simulation software version 8.1 was used to simulate the flare burner system while analytical models were used to ascertain relationship between the parameters. The results of simulation showed that as the mass flow rate of natural gas increased from 50-250kg/hr. the mass of air required for complete combustion increased from 130-340kh/hr. for sample A, 160-395kg/hr. for sample B, While the analytical developed showed that as mass flow rate of natural gas increases from 50-250kg/hr. burner pipe diameter increased from 18-56cm for sample A, 22-63cm for sample B while burner pot diameter increased from 18-56cm for sample A, 22-75cm for sample B. it is therefore concluded that lighter gas sample required lesser air, smaller burner diameter, smaller burner pot diameter for efficient flare process.

Key words; *Gas burner, Gas flaring, Natural gas, Soot formation*

Introduction
Globally and in Nigeria particularly, both on-shore and off-shore oil producing facilities engage in gas flaring procedure with the aim of reducing the pressure which is associated with the gas produced alongside the oil and referred to as

associated gas. This procedure of flaring associated gas is usually considered as safety measure by production engineer. It is also seen as a means of disposing excess associated gas produced alongside oil in the platforms (Ajoola 2011) and (Farina 2010). According to Hassan and Konhy (2011) flaring of associated gas is inevitable in the oil producing platform in Nigeria today because of the low level of advancement in gas processing facilities in Nigeria which includes the LNG (liquefied Natural Gas system). GTL (Gas to Liquid system). CNG (Compressed Natural Gas system), PNG (Pipe Natural Gas) and GTP (Gas to Power) and safety

Figure 1 Gas flare facility (Source, Gas flare images 2019)

Natural gas flaring in Nigeria alone has contributed to one percent of global carbon monoxide emission and eighty percent of carbon monoxide emission in the world is emitted by only eighteen countries. Some other gaseous emissions associated with gas flaring are carbon soot, carbon (iv) oxide and Sulphur (iv) oxide. These emissions are responsible for series of devastating effects on the environment as well as some harmful effect on the human being which include respiratory track irritation and infection, incessant migraine and cancer of the lungs (Ajoola 2011).

Gas flaring is as old as the oil production in Nigeria. According to Ajugwo (2013), the volume of natural gas flared in Nigeria yearly during crude oil production is about seventeen point two-billion-meter cube (17.2 billion M^3). According to World Bank (2011) more than eighty percent (80%) of associated gas flaring is done in the developing countries with Nigeria, Iran and Iraq flaring over 10 billion cubic meters per year individually. According to Diugwu et al (2013), Flaring of associated gas in Nigerian can be tied to many reasons, one, for safety of oil production equipment due to high pressure gas produced alongside oil production and maintenance of oil production facilities, two gas flaring could be used as a means of quality assessment procedure during well testing in this case, low grade gases are flared until the gas with the required quality are produced and finally due to lack of gas processing and utilization facilities close to oil production platforms

Despite the devastating effect of gas flaring to both humans and the environment globally, there are still some justifications to gas flaring. Some of the justifications are one, flaring of gas is the only means of preventing high pressure build-up on oil production facilities due to pressure of associated gas produced alongside oil from the oil wells especially in situations where there is no gas processing, storage or utilization facilities close to the oil production platform. Two, gas flaring can be a means of quality control in a situation where the gas produced from the well is of low quality, flaring will continue till the required quality of gas is produced and finally in situations where there are no reservoirs suitable for gas reinjection, the associated gas produced will be flared. Atmospheric effect associated with emissions from flaring and venting in the oil and gas industry are generally influenced by a number of factors, including flare/vent design, operating conditions and chemical composition of petroleum–associated gas (Omiyi 2001) and (Elvidge et al 2009)

However, it has been identified that the gas flaring system used in Nigeria flaring process is ineffective. This is evidence in the yellow color of the flaring flame, constant release of black carbon soot and black rain water usually witnessed widen and around oil production and refining area in Nigeria see figure 2. This release of the black soot and other invisible pollutant has resulted in health challenges such as respiratory track irritation, eye inching, incessant migraine and cancer of the lungs. Therefore, if we most flare, we most flare efficiently to avoid the release of these pollutants. But the questions are

1. How can we achieve efficient gas flaring in Nigeria since we must flare?
2. How will efficient gas flaring solve the problem of carbon soot associated with gas flaring in Nigeria?

Hence, this research is design to answer these questions which is specifically points at design of industrial sized burner that will be used to achieve efficient gas flaring by first developing a model that will provide the relationship between flare gas flow and chemical properties and burner design parameters using appropriate analytical and simulation tools available in literatures.

Figure 3, commercial burners. (Suranga 2014)

Therefore, the main aim of this research is to design an industrial sized burner that can be used to achieve efficient gas flaring for both oil production platforms and oil refineries. And the objectives are

1. To develop models that will present the relationship between flare gas flow parameters (gas flow rate, composition,) and burner design parameters (burner pipe diameter, burner pot diameter) for complete combustion.
2. To simulate the gas flare process as a combustion process in a reactor using Aspen HYSYS version 8.1.
3. To determine the relationship between the flare gas parameters (gas flow rate, and gas composition) and the quantity of oxygen required for complete combustion using data from the simulated combustion reactor in objective 2.
4. To analyze the model developed in objective one using the relationships obtained in objective three. In order to find out the relationship between burner design parameters and oxygen requirement for efficient gas flaring system.

Materials and Method

The materials and methods used in the research will be subdivided into three main section, namely

1. Development of models that will show the relationship between natural gas flow rate, flame velocity and burner pipe diameter for different natural gas composition
2. Simulation of burner using aspen HYSYS simulation software version 8.1 to show the relationship between flare gas flow rate and volume of oxygen/air required for complete combustion of the gas
3. Then development of model that will show relationship between burner pot diameter, number of burner pot holes, and volume of air required for complete combustion

Hence, the materials that will be used in this research include, Aspen HYSYS simulation software version 8.1 for the simulation of the burner. The data to be used are be sourced from gas flare system of gas boasting station in Niger Delta and petroleum refining gas flare system. Microsoft excel spread sheet will be used for plotting the graphs and chart for analysis. Other relevant information such as burner design parameters are being sources from most recent literatures. The methods that will be adapted to achieve the objectives are

1. Analytical models are developed to determine the relationship between the natural gas parameters (gas flow rate) and burner parameters (burner port diameter and burner pipe diameter)
2. Aspen HYSYS simulation software version 8.1 was used to simulate gas burner using reactor unit operation and flare gas parameter using flare gas from gas dehydration station in Niger Delta.
3. Microsoft excel was used to plot the graph of relationship between the flare gas flow parameter and burner design parameters using data generated from analytical model
4. Microsoft excel was used to plot the graph of relationship between the flare gas flow parameter and air (oxygen) used for efficient combustion using data from aspen HYSYS model.
5. Combine the relationship derive from the analytical model and simulation model to develop a graphical model that will help in estimation of the required burner parameters for any given flare gas composition for efficient flare system.

Development of models that will show the relationship between flare gas flow rate and burner pipe diameter

The general equation for flow of fluid along pipeline or conduit is given as

$$Q = \ell VA \qquad 2.1$$

Where Q (kg/s) is mass flow rate, V (m^3/s) is volume flow rate, A (m^2) is cross-sectional area of the pipe or conduit and $l(\frac{kg}{m3})$ is density of fluid. For the flow of the natural gas of density of ℓ in the burner pipe towards the burner pot with mass flow rate of Q, to achieve a complete combustion, the natural gas flow will be supplies at volume flow rate corresponding to flame velocity of its constituent. According to Harker and Allen, (1972) and Joseph, (2016) the flame velocity of composite gas such as natural gas is the algebraic sum of product of the individual gas flame velocity and molar fraction. Hence

$$V_{NG} = V_m I_m + V_e I_e + V_p I_p + V_b I_b + \ldots\ldots \qquad 2.2$$

Where V_{NG} is flame velocity of natural gas, $V_m I_m$is the product of flame velocity of methane, and its molar fraction in the natural gas, $V_e I_e$product of flame velocity of ethane and its molar fraction in the natural gas and that of other combustible natural gas components.

Substituting equation 2 in equation I, we have that

$$Q_{ng} = \ell(V_m I_m + V_e I_e + V_p I_p + V_b I_b + \ldots\ldots)A$$

Assuming that the burner pipe is in cylindrical shape

$$A = \frac{\pi {D_o}^2}{4} \qquad 2.3$$

Hence equation 4 becomes

$$Q_{ng} = \ell(V_m I_m + V_e I_e + V_p I_p + V_b I_b + \ldots\ldots)\frac{\pi {D_o}^2}{4} \qquad 2.4$$

Making D_o the subject in equation above, we have

$$D_o = \sqrt{\frac{4Q_{ng}}{\ell(V_m I_m + V_e I_e + V_p I_p + V_b I_b + \ldots\ldots)\pi}} \qquad 2.5$$

From equation 6 above, it can be deduced that there is a direct relationship between mass flow rate of natural gas and the burner pipe diameter. Hence the lager the mass of gas to be flared, the bigger the diameter of the burner pipe for complete combustion. It can also be deduced that the relationship between gas density, gas flame velocity and burner pipe diameter is indirect. The flame velocity of the major component of natural gas as presented by Harker and Allen, (1972) is shown in table 1 below

Table 1 combustible gases and their flame velocity

Natural gas components	Flame velocity ()
Methane	0.401
Ethane	0.398
Propane	0.390
Butane	0.378
Pentane	0.377
Hexane	0.364
Heptane	0.352

From the table above, it will be observed that the lighter the gas, the higher its flame velocity. This is because light gases flow faster in air stream than heavier gases. The density and mass flow rate of the natural gas component is sourced from aspen HYSYS simulation platform.

Table 2 the molar composition of combustible gases in the three natural gas sample

Components	Molar fraction of sample A	Molar fraction of sample B
Methane	0.70	0.60
Ethane	0.105	0.23
Propane	0.053	0.055
Butane	0.051	0.051
Pentane	0.005	0.005
Hexane	0.003	0.003
Heptane	0.002	0.002

Hence, using that the flame velocity of combustible gas is given as

$V_{NG} = V_m I_m + V_e I_e + V_p I_p + V_b I_b + \ldots\ldots,$

Therefore, the flame velocity of the gas samples will be given as

From the results above the flame velocity of the two natural gas sample are 0.3987 and 0.3958. Hence, equation 2.5 can be represented separately for the three gas samples as

$$D_{Ao} = \sqrt{\frac{4Q_{ng}}{0.3998\ell_A\pi}}, \quad D_{Bo} = \sqrt{\frac{4Q_{ng}}{0.3988\ell_B\pi}}$$

It has been identified that density of gas depends on temperature, pressure and composition of the gas, therefore the density of the two natural gas samples at the operating flare condition according to aspen HYSYS simulated platform shown below in figure 3.8 are 3.417 kg/m^3, and 3.113kg/m^3 Hence, the equation above is finally represented as thus;

$$\boldsymbol{D_{Ao}} = \sqrt{\frac{4\boldsymbol{Q_{ng}}}{1.3665\boldsymbol{\pi}}}, \qquad \textbf{2.6}$$

$$\boldsymbol{D_{Bo}} = \sqrt{\frac{4\boldsymbol{Q_{ng}}}{1.2447\boldsymbol{\pi}}} \qquad \textbf{2.7}$$

Simulation of the burner using aspen HYSYS simulation software.

The main essence of the simulation is to determine the volume of oxygen vis a vise the volume of air require to completely combust different volume of Natural gas of different composition ratio. The burner is simulated using aspen HYSYS simulation software using conversion reactor unit operation. Two different gas composition were simulated each represented a unique kind of natural gas flared at different gas flare system. Natural gas stream labeled A has least methane composition of 70% with higher composition of heavier gas which is gas commonly found in predominant oil well as associated gas, natural gas sample labeled B has 60% methane. See table 2 above. The combustion process natural gas sample is carried out at same condition. To determine the volume of oxygen, needed for combustion of each sample at different sample flow rate. The stoichiometry analysis of natural gas is shown in table 3 below

Table 3 stoichiometry analysis of natural gas combustible components

Natural gas component	Number of moles of Oxygen requirement for complete combustion	CO_2 produced	H_2Ovapor produced

Methane (CH_4)	2 moles of oxygen	1 mole of CO_2	2 moles of H_2O vapor
Ethane (C_2H_6)	3.5 moles of oxygen	2 mole of CO_2	3 moles of H_2O vapor
Propane (C_3H_8)	5 moles of oxygen	3 mole of CO_2	4 moles of H_2O vapor
Butane (C_4H_{10})	6.5 moles of oxygen	4 mole of CO_2	5 moles of H_2O vapor
Pentane (C_5H_{12})	8 moles of oxygen	5 mole of CO_2	6 moles of H_2O vapor
Hexane (C_6H_{14})	9.5 moles of oxygen	6 mole of CO_2	7 moles of H_2O vapor

Figure 4 combine simulation of combustion process of the three natural gas streams

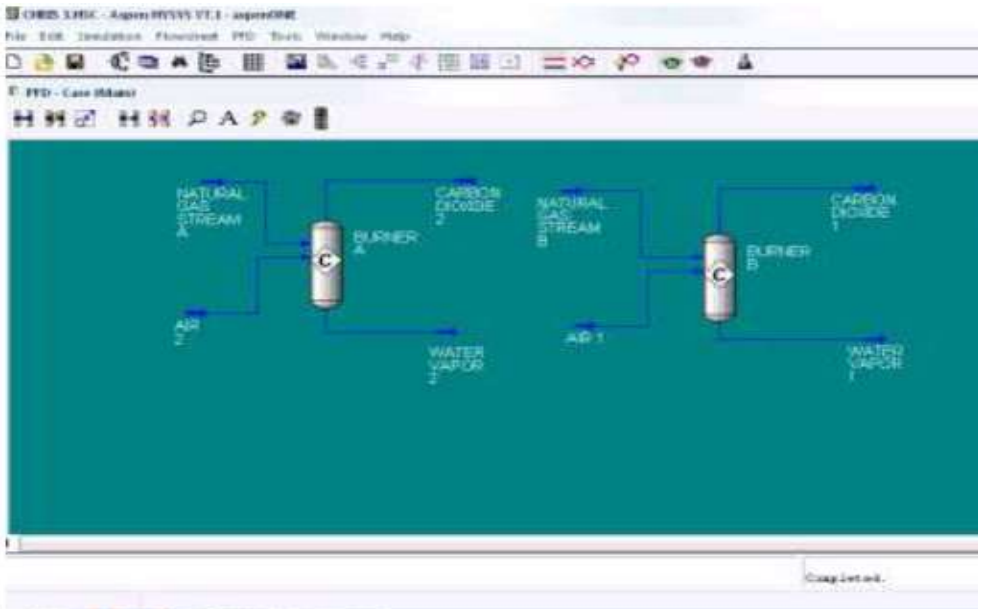

Table 4 the flow conditions of the three natural gas streams

Condition	Value
Temperature	40ºC
Pressure	350kpa (4bar0
Flow rate	1005kg/hr.

Source (Ismael, 2012)

Data are generated from the simulated combustion process by varying flow rate of the natural gas stream and recording the corresponding volume flow rate of oxygen required for complete combustion. The values of the natural gas stream flow rate used are 50, 100, 150, 200 and 250kg/hr. while the corresponding values of oxygen required for their combustion is recorded.

Data presentation and discussion

Analysis and discussion of relationship between natural gas flow rate and burner pipe diameter for the two natural gas samples,

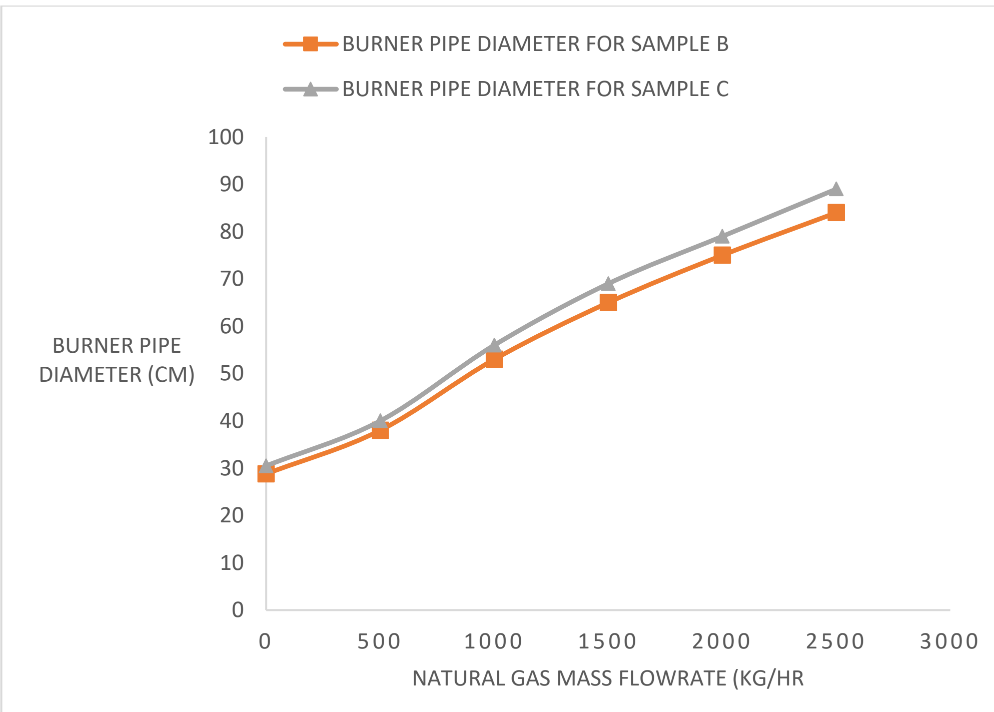

Figure 3.1 combined graphs of relationship between natural gas flowrate and burner pipi diameter for the three natural gas samples.

The combine graphs of the relationship between natural gas flow rate and burner pipe diameter for the three natural gas samples as shown in figure 3.1 show that at constant natural gas flow rate, natural gas sample A, with highest methane composition, 70% require smaller burner pipe diameter than natural gas sample B with methane composition 60% which requires biggest burner pipe diameter.

This trend is attributed to molar fractions of natural gas components, density and flow characteristics of the natural gas samples. The higher the molar fraction of the heavy components of the natural gas such as ethane, propane, butane pentane and others, and the lower the molar fraction of the light gas methane in the natural gas, the higher the density of the gas sample which will result to lower flow characteristics, therefore, larger burner pipe area will be required to enhance the flow capabilities of the natural gas sample to meet with the require flame velocity. While lighter natural gas sample with lesser molar fraction of the heavy component have lower density and better flow characteristics and require lesser burner pipe area to meet with the required flame velocity.

It is also observed from the trendless that the gas between the three lines are closer at the beginning but expands as the flow rate of natural gas increases. This trend behavior could be attributed to changes in flow characteristics of the heavier gas samples as flow rate increases. Though the increment may not significant.

Analysis and discussion of the relationship between natural gas flowrate and quantity of air needed for effective and complete combustion of the two natural gas samples

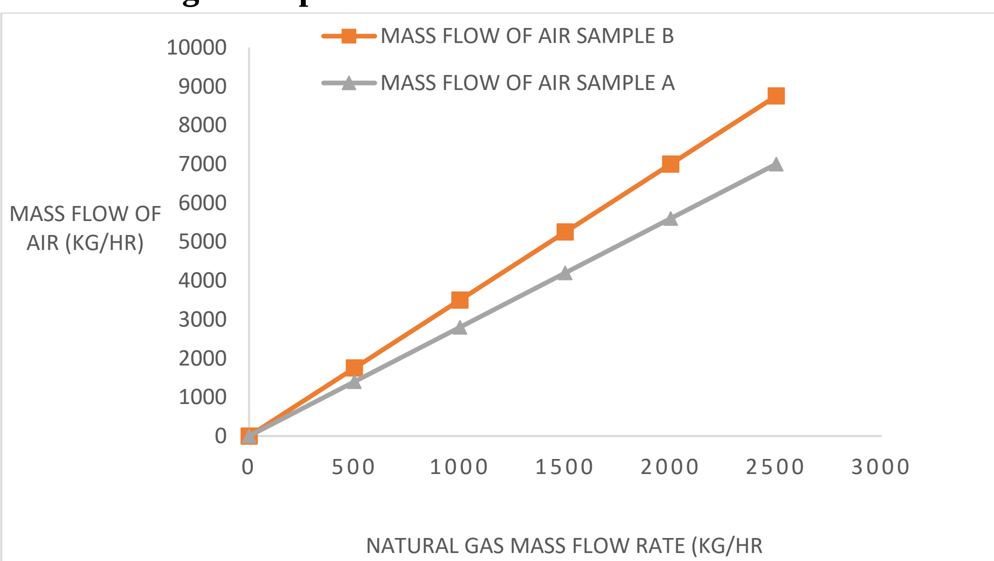

Figure 3.2 combined graphs of relationship between natural gas flowrate and quantity of air required for complete combustion for two natural gas samples.

The combine graphs of relationship between natural gas flow rate and quantity of air required for complete combustion for the two natural gas samples as shown in figure 3.2 show that at a constant natural gas flow rate, natural gas sample A, with methane composition 70% require the smaller quantity of air for complete combustion compare to natural gas sample B with methane composition 60%.

This is completely attributed to stoichiometry of combustion shown in chapter three, which shows that lighter alkane members require lesser number of moles of oxygen for their complete combustion while higher and heavy alkane members require greater number of moles of oxygen for complete combustion. Therefore, the natural gas sample with higher percentage by mole of methane will require lesser amount of air for its complete combustion while sample with greater percentage by mole of heavy alkane members will require more amount of air. See table 3

Analysis and discussion of relationship between natural gas flow rate and burner pot diameter for the two natural gas sample

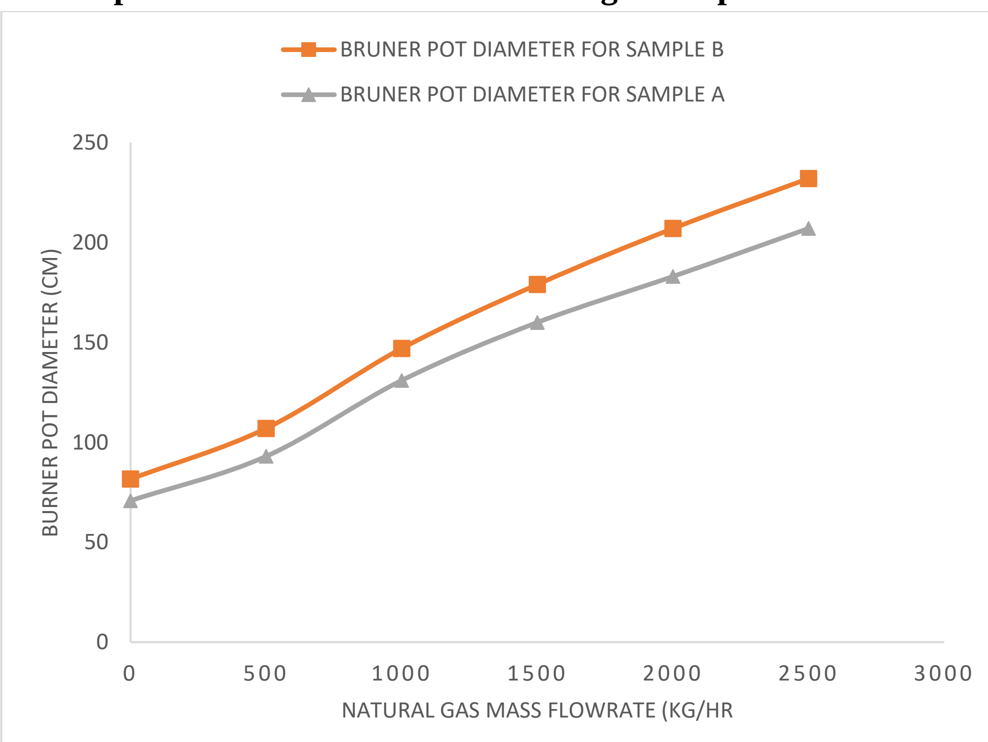

Figure 3.3 combined graph of relationship between natural gas flow rate and burner pot diameter for the two natural gas samples.

The combine graphs of the relationship between natural gas flow rate and burner pot diameter required to accommodate the needed quantity of air for complete combustion for the two natural gas samples as shown in figure 3.3 show that at constant natural gas flow rate, natural gas sample A, with methane composition 70% require smaller burner pot diameter compare to natural gas sample B with 60% methane composition.
This is also completely attributed to stoichiometry of combustion shown in table 3 which shows that lighter alkane members require lesser number of moles of oxygen for their complete combustion with corresponding lesser surface area of burner pot require to accommodate the oxygen for the complete combustion while higher and heavy alkane members require greater number of moles of oxygen for complete combustion with corresponding lager burner surface area needed to accommodate the large volume of oxygen for complete combustion.. Therefore, the natural gas sample with higher percentage by mole of methane will require lesser burner pot area to accommodate the lesser amount of air for its complete combustion while sample with greater percentage by mole of heavy alkane members will require larger burner pot surface needed to accommodate more amount of air.

Conclusion and recommendation

In conclusion, it has been successfully proved that there is urgent need to design industrial burner that will aid in ensuring that flaring process are conducted efficiently in order to avoid the environmental and health hazards associated with poor flaring system commonly found in Nigeria. In this research, we have shown that design of effective burner for flaring of gas is not only dependent on volume of gas flared but also on composition of the gas to be flared. In the research, two burner parameters were examined namely burner pipe diameter and burner pot diameter alongside volume of air and they were used as dependent parameter while natural gas flow rate was independent parameter, it was finally understood that increase in flow of natural gas for flaring require corresponding increase in burner pipe diameter, burner pot diameter and volume of air for effective and complete combustion. While natural gas samples with greater percentage by volume of heavy gases required greater volume of oxygen, burner pipe, and burner pot diameter with greater percentage by volume of lighter gases component.

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