INTERNATIONAL JOURNAL OF

ENVIRONMENTAL EDUCATION & INFORMATION

Volume 19, Number 2 (2000)

Published by
School of Environment & Life Sciences, University of Salford
in association with
Tidy Britain Group, Going for Green and
Foundation for Environmental Education in Europe

ISSN 0144-9281

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INTERNATIONAL JOURNAL OF ENVIRONMENTAL EDUCATION AND INFORMATION

Volume 19, Number 2
(April - June 2000)

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*ENVIRONMENTAL EDUCATION AND INFORMATION** *Volume 19, Number 2 (2000), pp.99-114*
(submitted 8/98; accepted 1/99)

Gas flaring in Nigeria: Converting flue gas pollutants into revenue-earning fertilizer by the low-cost retrofitting of flare stations

by

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ABSTRACT

Atmospheric pollution, environmental acidification and acid rain caused by flue gas emissions from the flare stations of upstream oil-producing companies are known not only to result in damage to masonry work, street structures, vegetation and human health, but also to alter the ecological balance and ecosystems. This paper surveys the consequences of gas flaring to the environment, the impact of gas utilization projects on annual flare statistics, the legal framework for atmospheric pollution, the selection of efficient and cost-saving air pollution control equipment, and the process technology features of the air pollution control system selected, all of which are summarized and discussed. The blueprint for a low-cost retrofit at flare installations for the conversion of flue gas pollutants into revenue-yielding fertilizer is shown, as it provides the basis for the economy of the process technology conceptualized by this work.

* *Int. J. Env. Educ. & Inf.* (published by the School of Environment and Life Sciences, University of Salford, Allerton Building, Frederick Road, Salford, M6 6PU, U.K.)

INTRODUCTION

There is currently great and growing national and international concern for environmental protection. Two of the global manifestations of this concern have been:

1. The 1972 Conference on the Human Environment held in Stockholm, Sweden, which produced the declaration on the human environment.

2. The 1992 Earth Summit and Global Forum held in Rio de Janeiro, Brazil, which produced the five Rio documents (Keating, 1993):

   (a) The Rio Declaration on Environment and Development
   (b) The United Nations Programme of Action from Rio (Agenda 21)
   (c) A Statement of Principles to Guide the Management, Conservation and Sustainable Development of All Types of Forests
   (d) The United Nations Framework Convention on Climate Change
   (e) The Convention on Biological Diversity

In addition to these are the follow-up United Nations Conferences, namely, the 1994 Conference on Population and Development held in Cairo, Egypt and the 1995 Social Summit held in Copenhagen, Denmark.

Natural gas flaring in Nigeria by upstream[†] oil-producing companies is a source of worry and a pertinent aspect of this global environmental concern. There can be no wholesome environmental protection if gas flaring and its resultant emissions are allowed to reduce our atmosphere to a mere dustbin. This paper will examine natural gas flaring at the flowstations of upstream oil-producing companies, with the aim of abatement and control of environmental pollution and acidification from the standpoint of conceptual design and process development.

The objects of this paper are:

1. To examine the consequences of gas flaring to the environment.
2. To weigh the influence of gas utilization projects on annual flare statistics.
3. To survey the legal framework for atmospheric pollution on the basis of the lessons and experiences of other countries.
4. To review the technology available for the removal and control of flue gas emissions.
5. To select air pollution control equipment on the basis of cost-saving potential and efficiency of purification.
6. To reveal on the basis of profitable product potential the technology features of the air pollution control system selected.
7. To make recommendations on the basis of the findings.

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† *upstream* - oil/gas production and extraction; *downstream* - oil/gas processing

CONSEQUENCES OF GAS FLARING TO THE ENVIRONMENT

Gas flaring is a common sight in the oil-producing areas of Nigeria. The outcomes of gas flaring are environmental pollution, environmental acidification and acid rain.

Gas flaring gives rise to the emission into the atmosphere of oxides of nitrogen (NO_X), oxides of sulphur (SO_X) and oxides of carbon (CO_X), including particulate ash. These emissions result in environmental pollution. The transformation in the atmosphere of these oxides into acids gives rise to the phenomenon of environmental acidification as the following chemical equations show (Oguejiofor, 1997):

Oxide of nitrogen: The oxidation of nitrogen monoxide by atmospheric oxygen to form nitrogen dioxide is shown:

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

Nitrogen dioxide dissolves in atmospheric water to give nitrous acid (dioxonitrate III acid) and nitric acid (trioxonitrate V acid) in accordance with the chemical equation:

$$2NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq)$$

Oxide of sulphur: Sulphur dioxide reacts with atmospheric water to form the unstable aqueous sulphurous acid (trioxosulphate IV acid) as shown:

$$SO_2(g) + H_2O(l) = H_2SO_3(aq)$$

Sulphurous acid is oxidized by atmospheric oxygen to form sulphuric acid (tetraoxosulphate VI acid) as shown:

$$2H_2SO_3(aq) + O_2(g) \rightarrow 2H_2SO_4(aq)$$

Oxide of carbon: The unstable carbon monoxide is transformed to carbon dioxide (carbonic anhydride) by oxidation with atmospheric oxygen as follows:

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

Carbonic anhydride combines with atmospheric water to form carbonic acids as shown:

$$CO_2(g) + H_2O(l) = H_2CO_3(aq)$$

These atmospheric acids fall as rain, dew, fog or smog, causing harm to steel structures, masonry work and vegetation.

Table 1 shows the alarming flare figures from 1970 to 1995, which translate into environmental pollution, atmospheric acidification and acid rain. In 1989, petroleum production companies flared about 18 billion cubic metres of natural gas. Table 2 shows the components and percentage composition of the flue gas emissions. The oxides of nitrogen (NO_X) component of the flue gas stands at 76.57%. Table 3 shows the impact of gas flaring on the poor rural agricultural community near the Izombe flowstation, Imo State. There is a 100% loss in the yield of crops cultivated 200 metres away from the flowstation, decreasing to a 10% loss in yield one kilometre away from the flare.

Figures 1 and 2 suggest that the Nigerian environment is threatened by acid rain caused by the colossal waste of gaseous resources by flaring.

TABLE 1: Gas production and utilization in Nigeria from 1970 to 1995 (Source: Central Bank of Nigeria, 1996)

Year	Production (million m^3)	Utilization (million m^3)	Flaring (million m^3)	Utilization (%)	Flaring (%)
1970	8,029	72	7,957	0.90	99.10
1971	12,975	185	12,790	1.43	98.57
1972	17,122	274	16,848	1.60	98.40
1973	21,882	395	21,487	1.81	98.19
1974	27,170	394	26,776	1.45	98.55
1975	18,656	323	18,333	1.73	98.27
1976	21,276	659	20,617	3.09	96.91
1977	21,924	972	20,952	4.43	95.57
1978	21,306	1,866	19,440	8.76	91.24
1979	27,619	1,546	26,073	5.60	94.40
1980	24,551	1,647	22,904	6.71	93.29
1981	17,113	2,951	14,162	17.24	82.76
1982	15,382	3,442	11,940	22.38	77.62
1983	15,192	3,244	11,948	21.35	78.65
1984	16,255	3,438	12,817	21.15	78.85
1985	18,569	3,723	14,846	20.05	79.95
1986	18,539	4,622	13,917	24.93	75.07
1987	17,085	4,794	12,291	28.06	71.94
1988	20,253	5,516	14,737	27.24	72.76
1989	25,053	6,323	18,730	25.24	74.76
1990	28,163	6,343	21,820	22.52	77.48
1991	31,588	7,000	24,588	22.16	77.84
1992	32,465	7,058	25,406	21.74	78.26
1993	33,445	7,536	25,908	22.53	77.47
1994	32,793	6,577	26,216	20.06	79.94
1995	32,980	6,910	26,070	20.95	79.05

TABLE 2: Emissions from gas flaring in 1989
(Source: NEST, 1991)

Flue gas component	Quantity emitted (tonnes per annum)	Percentage of total emissions
Dust particles	2,700	7.66
SO_X	160	0.45
CO_X	5,400	15.32
NO_X	27,000	76.57
TOTAL	35,260	100.00

TABLE 3: The impact of gas flaring on the rural agricultural community near the Izombe Flowstation, Imo State
(Source: NEST, 1991)

Distance of crops from flowstation (metres)	Loss in crop yield (%)
200	100
600	45
1,000	10

INFLUENCE OF GAS UTILIZATION PROJECTS ON FLARE FIGURES

A noticeable reduction is observed in percentage gas flare figures from 1970 to 1995 (Table 1). However, to a great extent, flare levels overwhelm utilization levels, despite the commissioning of gas development/utilization projects such as gas re-injection plants and the National Fertilizer Company of Nigeria (NAFCON) plants which commenced fertilizer production and gas usage in 1987. It is unlikely that the flare statistics will be reduced drastically in the future, despite the recent commissioning of natural gas utilization projects, namely:

1. Aluminium Smelter Company of Nigeria (ALSCON), Ikot Abasi, which commenced operation in January 1998.

2. Mobil's Oso Condensate Project, Akwa Ibom State, commissioned in April 1998.

This is probably because the oil wells are ageing, giving rise to more gas production.

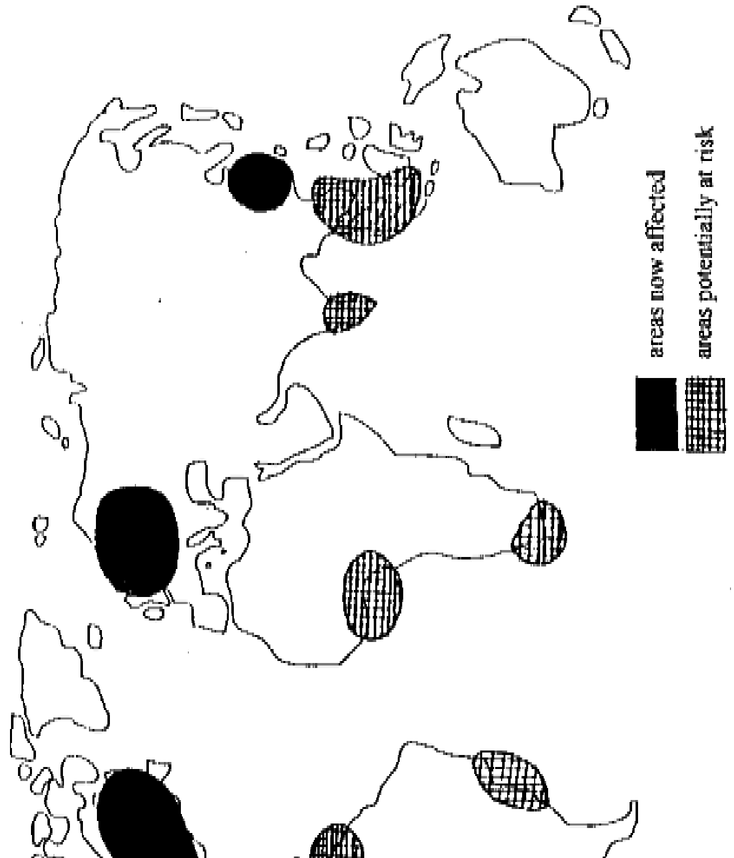

FIGURE 1: World pollution: Acid rain and sources of acidic emissions (latest available year)
(Source: *Philip's World Atlas and Gazetteer*, 1998)

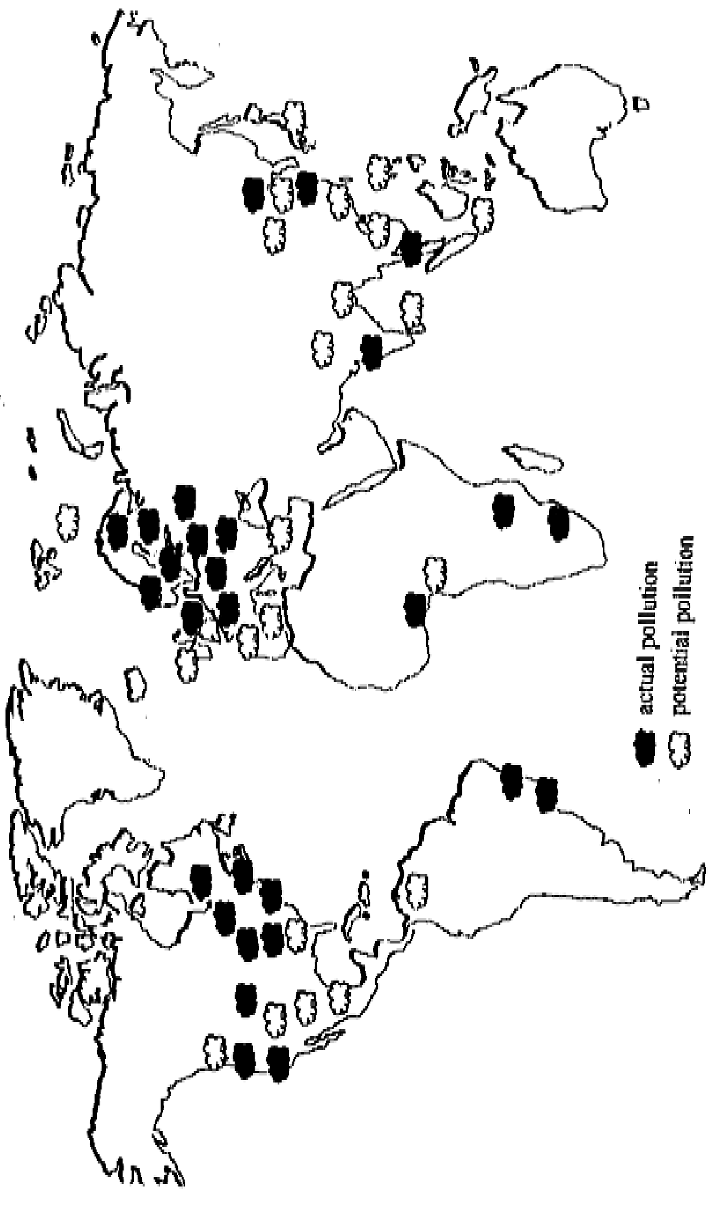

FIGURE 2: Global acid rain pollution
(Source: Hare, 1990)

The Nigerian Liquefied Natural Gas (NLNG) Project, Bonny and the Methanol Plant scheduled to commence operations in October 1999 and 2001, respectively, are gas utilization projects which are expected to cut down flaring levels drastically. Because of unforeseen future circumstances, this expectation may not be realized quickly. This paper offers a complement (and not an alternative) to the gas development/utilization projects which are yet to minimize overwhelmingly the current alarming flaring levels.

LEGAL FRAMEWORK FOR ATMOSPHERIC POLLUTION

The UK lesson

In 1952 massive smog engulfed London for four days, killing 3,000 people, the elderly, the sickly and the young (Acid Rain Information Centre, 1986). The UK Government enacted legislation to prevent the re-occurrence of this kind of disaster - the Clean Air Act of 1956, followed by the Clean Air Act of 1968. The Environmental Protection Act of 1990 embraced the Clean Air Acts of 1956 and 1968.

Nigeria's legal system is British-oriented and so there exist (1) the Federal Environmental Protection Act 1988 (usually cited as FEPA Act 1988), and (2) the Federal Environmental Protection Agency (Amendment) Decree 1992 (Decree No. 59 of 1992).

Japan's strict NO_X standards

The percentage content of NO_X in flue gas emissions from natural gas flaring in Nigeria is 76.57% (Table 2). This requires a stringent clean-up standard. The Government of Japan imposed the world's strictest NO_X standards in 1979, which include 60 ppm for new gas-fired boilers, 130 ppm for large oil-fired boilers, and 100 ppm for furnaces in ammonia plants and ethylene crackers (Parkinson, 1983). Though this standard concerns controlled gas combustion in boilers, which may not be applicable to uncontrolled combustion (natural gas flaring), the interest of this paper in Japan's NO_X standards is that they stimulated research for the removal of NO_X from flue gas in Japan.

TECHOLOGY FOR NO_X TREATMENT AND REMOVAL

Nigeria's gas flaring in upstream flowstations of oil-producing companies is one of the established sources of NO_X releases. NO_X is formed during the flaring process by the heat of combustion, which may be controlled by decreasing the flame temperature.

How to deal with NO_X

The technologies available for NO_X treatment and removal ($DeNO_X$) are:

1. Efficient combustion systems comprising:

    a) controlled combustion;
    b) staged combustion.

2. Post-combustion clean-up or flue gas treatment made up of:

   a) selective catalytic reduction (SCR);
   b) gas-liquid absorption system (GLAS);
   c) gas adsorption system (GAS).

Controlled combustion technology includes methods of enhancing combustion efficiency by the reduction of excess air, the lowering of flame temperature, the re-circulation of flue gas and the use of special burners. Staged combustion technology involves combustion modifications and improvements to burn a fuel-rich mix initially, and then the addition of more air later to complete combustion.

Post-combustion clean-up is about the SCR of NO_X to elemental nitrogen and water by the injection of ammonia in the presence of a catalyst. The following chemistry of the action represents the clean-up process:

$$2NO + 2NO_2 + 4NH_3 \xrightarrow[\text{catalyst}]{CuSO_4 / V_2O_5} 6H_2O + 4N_2$$

Copper sulphate, vanadium pentoxide or tungsten trioxide may be used as catalysts. The Hitachi Zosen and the Kawasaki processes are catalytic systems which use ammonia as the reducing agent. Catalyst systems operate at lower temperatures (288-454°C) and remove 80-90% of the NO_X. Catalyst systems are complementary to, not an alternative to, the efficient combustion controls described above.

The post-combustion clean-up of flue gas by means of GLAS is the dissolution of the soluble gaseous pollutants in solvents by countercurrent flow through packed, plate or spray towers. GAS is the use of dry adsorbent like activated carbon and molecular sieves in removing the final traces of objectionable gaseous pollutants. GAS may be applicable as back-up clean-up facilities for the removal of traces contained in the discharges from controlled combustors.

SELECTION OF AIR POLLUTION CONTROL EQUIPMENT

Selecting the most suitable atmospheric pollution control equipment and process involves a technical evaluation of several factors, such as the source, composition and properties of the pollutant emissions, and how to collect and transfer the pollutants. The gas scrubber has comparative advantages over other types of air pollution control equipment, namely, the gas adsorber, the direct incinerator (flame combustion) and the catalytic combustor (Table 4). The comparative advantages are:

1. The gas scrubber has lower capital and running costs than the gas adsorber and direct incinerator. Flue gas denitrification, the $DeNO_X$ process by catalysis, is expensive and only Germany, the US and Japan have been able to afford fitting catalytic systems to about 150 plants. The catalysts are vulnerable to contaminant poisoning.

TABLE 4: Air pollution control equipment characteristics (Source: Peters and Timmerhaus, 1981)

Control equipment	Optimum size particle+ (microns)	Optimum con-centration (grains/ft^3)	Temperature limitations (°F)	Pressure drop (inches of H_2O)	Efficiency (%)	Space require-ments++	Collected pollutant	Remarks
Particulate Pollutant								
Mechanical collection								
Settling chamber	>50	>5	700	<0.1	<50	L	Dry dust	Good as precleaner
Cyclone	5-25	>1	700	1-5	50-90	M	Dry dust	Low initial cost
Dynamic precipitator	>10	>1	700	Fan	<80	M	Dry dust	
Impingement separator	>10	>1	700	<4	<80	S	Dry dust	
Bag filter	<1	>0.1	500	>4	>99	L	Dry dust	Bags sensitive to humidity, filter velocity and temperature
Wet collector								1. Waste treatment required 2. Visible plume possible 3. Corrosion 4. High temperature operation possible
Spray tower	25	>1	40-700	0.5	<80	L	Liquid	
Cyclonic	>5	>1	40-700	>2	<80	L	Liquid	
Impingement	>5	>1	40-700	>2	<80	L	Liquid	
Venturi	<1	>0.1	40-700	1-60	<99	S	Liquid	
Electrostatic precipitator	<1	>0.1	850	<1	95-99	L	Dry or wet dust	Sensitive to varying condition and particle properties

Gaseous Pollutant								
Gas scrubber		>1%	40-100	<10	>90	M-L	Liquid	Same as wet collector (see 1-4 above)
Gas adsorber		#	40-100	<10	>90	L	Solid or liquid	Adsorbent life critical High initial and operating costs
Direct incinerator		Com-bustible vapours	2000	<1	<95	M	None	High operating costs
Catalytic combustion		Com-bustible vapours	1000	>1	<95	L	None	Contaminants could poison catalyst

\+ Minimum particle size, collected at approximately 90% efficiency under usual operating conditions

++ S = small; M = moderate; L = large

\# Concentrations less than 2 ppm non-regenerative system; greater than 2 ppm regenerative system

2. The gas scrubber has more than 90% efficiency and operates at temperatures of 40-100°F (4.4-38°C) and a pressure drop of less than 10 inches (254 mm) of water. The gas adsorber has similar characteristics but the gas scrubber is a credible choice on the basis that the gas adsorber has high initial and operating costs and a critical adsorbent life.

3. Despite the cost advantage which the gas scrubber has over other air pollution control equipment, Table 4 shows that it requires waste treatment, corrosion control and high temperature operation. The desired product from waste treatment will be converted into a profitable commercial product, that is, revenue-earning fertilizer, as shown below. The high temperature of operation suggested by Table 4 will enhance the solubility of NO_X, SO_X and CO_X in the solvent water and this in turn will enhance the efficiency of the absorption process. The hot flue gas ensures this high temperature requirement.

The gas scrubber is therefore the most credible and feasible atmospheric pollution control requirement. It has the potential for cost savings and air purification efficiency.

Revenue-yielding fertilizer from waste treatment

When NO_X and other pollutants in the flue gas are absorbed in the gas scrubber, soluble nitric and nitrous acids are formed, as shown by the following chemistry of the action:

$$2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)$$

The acid-based effluent from the absorption tower may be neutralised with limestone chips or slaked lime and the product is calcium nitrate, as shown by the following:

$$CaCO_3(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$$

$$Ca(OH)_2(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + 2H_2O(l)$$

Some calcium nitrate mixed with lime is used as a fertilizer, air saltpetre. The resulting fertilizer (a profitable product from the waste treatment) could be sold to yield revenue for offsetting the capital and running costs of flue gas purification. The fertilizer should supplement the fertilizer made by NAFCON.

Limestone chips are readily available and affordable because there are huge deposits in Nigeria's cement plant sites and elsewhere, namely at Nkalagu in Enugu State, Ewekoro near Lagos, Okpella in Edo State, Gboko in Kogi State, Ashaka in Bauchi State, Calabar in Cross River State, and Sokoto in Sokoto State. Table 5 shows the levels of limestone production in Nigeria from 1991 to 1995. This confirms the abundance of limestone for the treatment of absorption effluent which yields a profitable fertilizer. Basically, profitable fertilizer is the economy of this process intended for the low-cost retrofitting of natural gas flaring facilities in Nigeria.

TABLE 5: Production of principal solid minerals
(Source: Central Bank of Nigeria, 1995)

Year	Minerals (tonnes)				
	Cassiterite	Columbite	Coal	Limestone	Marble
1991	246.1	35.8	137,657.5	1,317,440.0	52,379.1
1992	107.5	38.2	100,073.0	3,034,767.0	21,191.3
1993	175.0	16.5	28,282.0	3,204,253.0	16,044.0
1994	208.3	17.0	25,000.0	3,239,030.0	17,035.1
1995	203.0	37.0	20,000.0	3,656,598.1	22,460.0

TECHNOLOGY FEATURES OF THE RETROFIT

The three main features of the retrofit are:

1. Collection and compression of the flue gas.

2. Low-cost gas absorption using locally available pebbles as column packings and water as the scrubbing solvent, all of which minimises capital and running costs.

3. Production of a profitable calcium nitrate fertilizer, which has revenue-yielding potential, given the fertilizer needs of the agricultural community in the rural and urban centres of Nigeria.

Figure 3 illustrates the blueprint flowsheet and the major technology features of the gas-liquid absorption system. Flue gas from flare sources is usually at slightly above ambient pressure and a temperature generally in excess of 250°F (121°C). Therefore, in order to accommodate the pressure drop through the packed column, the flue gas should be collected by a ceramic (silicon carbide) hood and transferred by a suction fan to a compressor. The gas should be compressed to somewhat less than 5 psig (34,482.8 Pa, or 0.35 bar, or 34,66 N/m^2). The gas stream should be admitted in the packed tower where 90% of the NO_X and other gaseous oxides, including about 80% of the particulates, are scrubbed off by the solvent water. The residual flue gas is released to the atmosphere, while the acid-rich solvent (at about 100-150°F (43-65.6°C)) discharges into a neutralisation reactor.

Limestone chips should be added into the neutralisation reactor which react with the acid-rich solvent to produce calcium nitrate fertilizer, water and carbon dioxide gas. The water should be discharged into any nearby stream, while the carbon dioxide should be recycled to the packed tower for scrubbing.

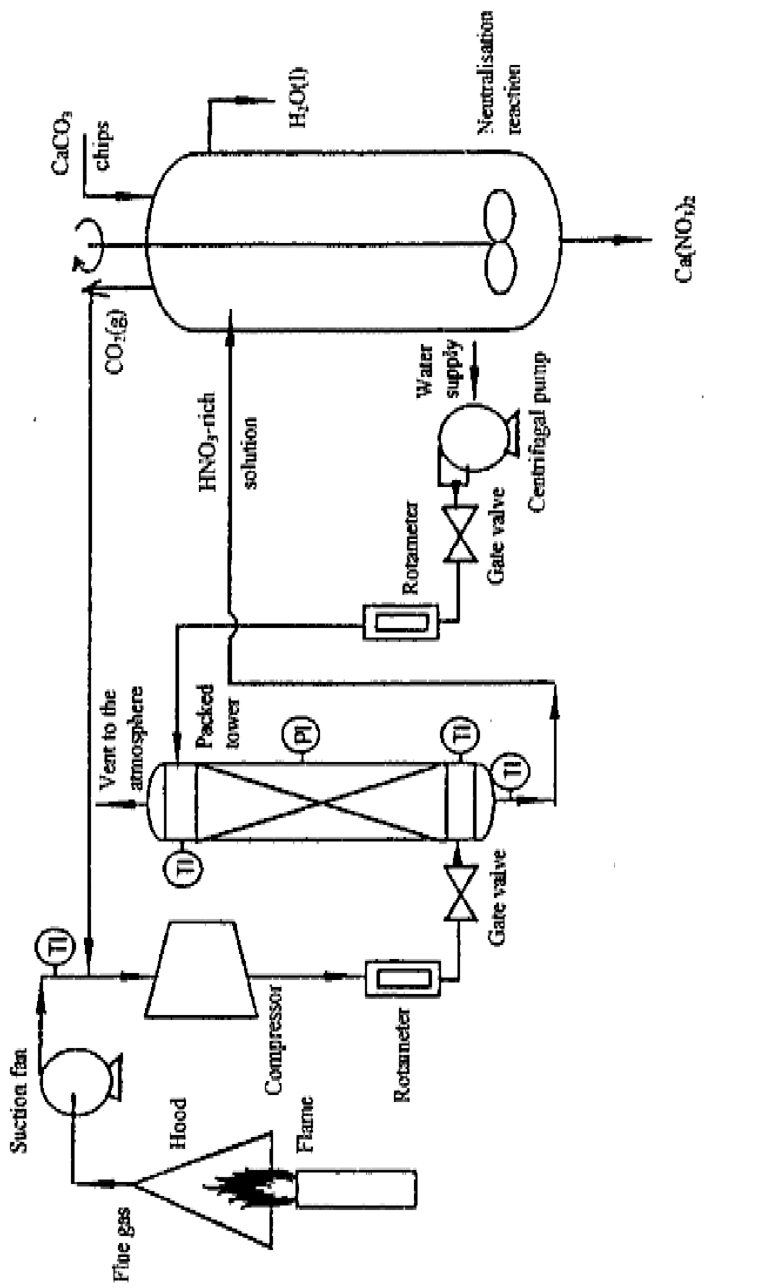

FIGURE 3: Technology features and blueprint flowsheet for the gas-liquid absorption system (GLAS)

DISCUSSION

The need for the environmentally friendly production of crude oil and its associated products by oil companies cannot be over-emphasised, as it is known that air pollution by flue gases causes environmental acidification and acid rain. The UK experience of air pollution caused by industrial emissions (Acid Rain Information Centre, 1986) showed that the destructive legacies of air pollution and its resultant acid rain are:

1. Widespread damage to masonry structures.
2. Unquantifiable cost to the health and wellbeing of residents in acid rain areas.
3. About £20 million needed per year for the replacement of corroded steelwork in Greater Manchester alone.
4. Irreparable loss to lakes and forests.

Another report showed that, in order to protect the environment and its ecosystems from the damaging experiences of air pollution, most Western European countries undertook to reduce industrial emissions by at least 30% by 1990 (Hinrichsen, 1988).

Given the growing national and international concerns manifested by the 1972 Stockholm Declaration, the 1992 Rio de Janeiro Earth Summit and the other follow-up conferences, Nigeria should join the countries that are implementing environmental protection schemes to enable her to enforce in the strictest terms emission controls in upstream crude oil production.

It is critical to state that, despite the alarming levels of gas flaring and its resultant emissions, upstream oil-producing companies in Nigeria are not doing enough to minimise atmospheric pollution and to ensure environmentally friendly production. Penalties involving the payment of a fine of ₦10 (equivalent to US$0.12 at the rate of ₦82 to US$1.0) by an oil operator for every 1,000 cubic feet of gas flared are no deterrent to the affluent oil-producing companies as a fine for gas flaring. Consequently, gas flaring has continued for both upstream oil-producing companies and downstream petroleum processing corporations (flaring of distillate or refinery gas) because of its cheapness; thus our atmosphere has been reduced to a mere dustbin.

The solution to gas flaring is to enforce by stringent legislation or decree the purification of flue gas emissions from the flowstations of oil-producing companies. This paper provides the blueprint for low-cost retrofitting at flare installations. A resultant profitable product from the flue gas purification system has revenue-earning potential, and thus provides the economy of the process.

CONCLUSION

"Every object continues in its state of rest or uniform motion in a straight line, unless an impressed force acts on it," states Newton's first law of motion. Although this law applies to the mechanics aspect of physics, it could be extended to other human activities, and in this case it is the source of all inertia - remaining static in old practices and habits. With regard to the perennial gas flaring practices in Nigeria, one of the keys to environmentally friendly production is to remove the reluctance to change the practice of gas flaring, with its associated untreated emissions which give rise to air pollution, environmental acidification and acid rain.

This work offers a solution to this environmental problem. The solution involves a low-cost retrofit for flue gas clean-up which produces revenue-yielding fertilizer.

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