Review Article

LITERATURE SURVEY OF FLUE GAS TREATMENT UNIT FOR PACKAGED GASOLINE GENERATORS.

ABSTRACT

A literature survey of Flue Gas Treatment Unit for Packaged Gasoline Generators is reported. Due to shortfall in power supply from National Grid of most developing nations, most businesses relied on package generators for electrical power supply for their economic activities. Flue gases containing CO, CO_2 , SO_2 and NO_X were being released into the environment by these fossil fired package generators. The CO is known to be detrimental to health of living beings and at the same time ozone layer depletive. On the other hand, the CO_2 has been contributing to the green house effects. These militating dangers/risks arising from the usage of these package generators strongly stimulated this study~~informed this review exercise~~. The global position on legislation, regulation and control of the emission of flue gases into the atmosphere has been articulated. Results of in-depth investigations by researchers into the methods/techniques of capturing CO, CO_2, SO_2 and NO_X from the flue gases have been highlighted. This study shows that ~~The incorporation~~incorporating ~~of these~~the capturing ~~methods~~ techniques for CO, CO_2, SO_2 and NO_X into the design and construction of the package gasoline generators will no doubt go a long way in keeping our environment healthy, safe and secured.

KEY WORDS: Flue Gas Treatment Unit, Emission Limit Values, Package Generators.

INTRODUCTION

By the end of the 20th century it was widely accepted that carbon dioxide and several other gases are involved in physical and chemical processes in the earth's upper troposphere and stratosphere that may result in global climate change. Arrhenius in 1896 forecasted rising global temperatures as a result of fossil fuel combustion. So-called green house gases (GHG), most importantly Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O) trap the outgoing solar radiation that is reflected by the earth's surface, which leads to global warming.[1] Although the most abundant greenhouse gas in the atmosphere is water causing approximately 2/3 of the greenhouse effect, the result of increasing concentrations of GHGs that cause the other approximately 1/3 is referred to as the "enhanced greenhouse effect", or, since it is primarily the result of human activities, the "anthropogenic greenhouse effect".[1] Consequent on the foregoing therefore, various regulations have been put into place to arrest this green house effect.

In order for society to meet up with its energy demand, various forms of energy sources have been harnessed by mankind. Most of these power plants are fired by fossil fuels which give CO_2, CO, SO_2, NO_X as by- products of combustion amongst others. CO_2 in particular has been identified as the most important green house gas. Various efforts are being made and several actions are being taken by the global regulating bodies to control and limit the emission of CO_2 and other green house gases. These efforts that focus on design /capture concept are not extended to the gasoline package generators. In the developing countries, the package generators which are actually designed as standby generators now play the function of source of main power supply for businesses and homes. The attendant implications are that CO_2, CO, SO_2 and NO_x are being indiscriminately emitted into the environment to the detriment of health and global warming which could result from the greenhouse effect. Consequent on the foregoing some action plan is required to arrest this indiscriminate pollution of the environment arising from the gasoline package generators' emissions among others. This literature survey therefore seek to articulate the global legislation framework in place, research efforts and actions taken so far to control the emission of flue gases into the atmosphere. Here lies the justification for this review.

THE PACKAGED GASOLINE GENERATOR AND FLUE GASES

Generators range from extreme large structures such as turbo-generators as in thermal power plants, nuclear power plants, hydro power plants, geothermal power plants, Brown gas generator, wood gas generator, wind and tidal power plants to package units used in the home, emergency and leisure as standby sources of power. Generators could be classified according to source of energy hence we have thermal generators, geothermal generators, hydro generators and solar generators. Also generators could be classified based on the source of fuel: such generators include natural gas generators, gasoline generators, diesel generators, brown gas generators and wood gas generators among others. Such package generators are variously referred to as portable generators, portable electric generators, portable power generators, home standby generators, commercial generators and marine generators.[2] The power range for a variety of these package generators varies from about 800watts to 15 kilowatts.[2] These generators could be classified according to manufacturers and marketing outfit. A few of such names include: Honda, Yamaha, Norwall power systems, Binatone, Firman, Elemax and Tiger.

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The energy and power delivery to the economies of the developing nations has been dwindling over the years. The quality of power generated , that is supply relative to demand has been on the decline, even in the face of new power stations coming on stream the National Grid. This short fall in meeting the National demand has been so severe that virtually all serious business concerns have to procure one form of generating set or the other in order to guarantee the smooth continuity of their businesses.[3]

The brand of these generators that are fossil fuel fired release flue gases into the environment. Flue Gas has been defined as gas that exits to the atmosphere via a flue which may be a pipe, channel or chimney for conveying combustion from a fireplace, oven, boiler or steam generator.[4]Flue gases are produced when coal, fuel oil, natural gas, wood or any other fuel is combusted in an industrial furnace or boiler, a steam generator in a fossil fuel power plant or other combustion sources.[4These gases are treated as pollutants. Flues can be referred to as “stacks”, and they may be found in the form of chimneys, ducts, or simple pipes. Large amount of flue gases are generated around the world on daily basis, with heavy industry and the power industry in particular being responsible for a huge percentage of the total generated. The contents of flue gases are quite variable. The medium being burned can contribute a number of different compounds, and the conditions under which combustion is occurring can also generate more or less emissions. Incomplete combustion at low temperatures or in poorly managed facilities, for example, tends to generate more pollution.[5] Components of flue gases include: water vapor, carbon dioxide, nitrogen, particulates, oxygen, carbon monoxide, nitrogen oxide, hydrocarbons, and sulfur oxide. Some of these compounds are potentially harmful for the environment, making these gases an issue of concern among environmental advocates. Flue gases can also be hazardous for human health, as might occur if they were trapped in an air inversion which pinned them close to the ground for several days, forcing people in the area to inhale hazardous pollutants which could damage their lungs.[5]

There are a number of ways in which flue gases can be controlled, and the processes which produce flue gases are often heavily regulated to force emissions levels down. One of the best methods is to avoid generating them at all, either by using alternative technology, improving plant efficiency levels, or studying ways in which operating conditions could be improved to reduce the production of combustion by-products.[5] Gases which cannot be prevented can be trapped using filters and scrubbers which clean the air coming out of flues so that when it is released into the environment, it contains primarily harmless components. Scrubbing flue gases can even be profitable for a savvy company. For example, the food industry is willing to pay for purified carbon dioxide extracted from flue gases. [5]

LEGISLATIONS/REGULATIONS ON POLLUTION

. It is not possible to produce comparative tables with emission limit values for the two regions (that is, EU and USA) because emission limit values are defined in different ways. In the EU, values are defined in terms of mg/nm^3, whereas In the US values are expressed as nanograms per joule heat input. For the EU, emission limit values are defined in Annex III-VII in the Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants (the "LCP directive"). Emission limits are defined for SO_2, NO_X and dust. Furthermore, there are provisions for combustion plants co-incinerating waste in Annex II of the directive 2000/76/EC of 4 December 2000 on the incineration of waste. For the USA, emission limit values related to combustion plants are given in Title 40 (Protection of Environment), Part 60 (Standards of Performance for New Stationary Sources) in subparts Da, Db, Dc and GG.

S60.43 Standard for Sulfur Dioxide (SO_2)

(a) On and after the date ~~on~~ in which the performance test required to be conducted by S60.8 is completed, no owner or operator subject to the provision of this subpart shall cause to be discharged into the atmosphere from any affected facility any gases that contain SO_2 in excess of: (1) 340ng/J heat input (0.8lb/MMBtu) derived from liquid fossil fuel or liquid fossil fuel and wood. (2) 520 ng/J heat input (1.2 lb/MMBtu) derived from solid fossil fuel or solid fossil fuel and wood residue.

(b) When different fossil fuels are burned simultaneously in any combination, the applicable standard (in ng/J) shall be determined by proration using the formula:

$P_{SO2} = [y(340)+z(520)]/(y+z)$

Where P_{SO2} = prorated standard for SO_2 when burning different fuels simultaneously in ng/J heat input derived from all fossil fuels or from all fossil fuels and wood residue fired.

Y = percentage of total heat input derived from liquid fossil fuel and

Z = percentage of total heat input derived from solid fossil fuel.

Sulfur Content of Liquid Fuels Directive 1999/32/EC on Reduction of Certain Liquid Fuels (26th April 1999).

Sulfur content of gas oil not to exceed 0.1 %. Member states shall take all necessary steps to ensure that as from 1 January2003 within their territory heavy fuel oils are not used if their sulfur content exceeds 1.0% by mass. Alternatively, where the emissions of sulfur dioxide from the plant are less than equal to 1700mg/nm^3 at an Oxygen content in the flue gas of 3% by volume on a dry basis. The reference method adopted for determining the sulfur content shall be that determined by:

a) ISO Method 8754 (1992) and PrEN ISO 14596 for heavy oil and marine gas oil
b) EN Method 24260 (1987) ISO 8754 (1992) and PrEN ISO 14596 for gas oil.

The arbitration method will be PrEN ISO 14596. The statistical interpretation of the verification of the sulfur content of the gas oil used shall be carried out in accordance with ISO Standard 4259 (1992).[6]

CHINA'S "TWELFTH FIVE-YEAR PLAN" ON AIR POLLUTION PREVENTION

On 5th December 2012, Ministry of Environmental Protection (MEP), National Development and Reform Commission and Ministry of Finance jointly issued a "12th five-year plan on Air Pollution and Control in key regions". The plan was approved by the China's State Council earlier. The three key regions are: Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta and 10 city clusters, involving 19 provincial level jurisdictions and 117 cities. These areas cover only 14% of the country's land area, but accounts for nearly half (48%) of the country's population, 71% of the nations GDP and 52% of the country's coal consumption. The air pollutants emission level is 2.9 to 3.6 times higher than the nation's average.

Comment [U2]: When was this earlier? You need to be specific

i) The Plan sets ambient concentration targets for the first time, thus:

Comment [U3]: This does not make any meaning. Table number is not included, why? Your informtion should be in line with your research focus.

Ambient Air Quality	PM_{10}	SO_2	NO_2	$PM_{2.5}$	$PM_{2.5}$ (In 3 Key Regions)
Concentration Targets	10%	10%	7%	5%(Expected Target)	6%(Binding Target)

ii) The Plan sets more ambitious emission targets in key regions than the national tagets

Total Emission Reduction Targets	SO_2	NO_X	Industrial PM
National Targets By 2015	8%	10%	No target
Targets in Key Regions By 2015	12%	13%	10%

Comment [U4]: This row/column does not show the total emission reduction targets. You need to redraw the Table. In addition, the Table is not numbered.

If successfully implemented, the plan is estimated to result in SO_2 emission reduction of 2.28million tons/year, NO_x emission reduction of 1.48million tons/year and PM emission reduction of 1.48 million tons/year and VOCs emission reduction of 1.525 million tons/year. And it is expected to bring over $317 Billion (2 trillion Yuan RMB) society benefit.[7]

Comment [U5]: If successfully implemented what? This is an incomplete statement. Please rewrite!

RESEARCH EFFORTS TO MINIMIZE POLLUTION

Promoting effect of SO_2 on selective catalytic reduction (SCR) of NO by NH_3 over a CuO/Al_2O_3 catalyst sorbent has been investigated. Transient experiment, x-ray photoelectron spectroscopy (XPS) insitu Drift, NH3-TPD and temperature-programmed reduction (TPR) were used to evaluate the promoting mechanism. Ammonia oxidation experiments and TPR in H_2 suggest that sulfation of the catalyst sorbent weakens the catalyst's oxidation ability and inhibits NH_3 oxidation to NO in the process of SCR, which may by another main promoting effect of SO_2 on SCR.[8] Also, liquid-like nanoparticle organic hybrid materials (NOHMs) consisting of silica nanoparticles with a grafted polymetric canopy were synthesized. Previous works on NOHMs has revealed that CO_2 capture behaviours in these materials can be tuned by modifying the structure of the (polymetric canopy. Because SO_2, which is another acidic gas found in flue gas, would also interact with NOHMs, this study was designed to investigate its effect on CO_2 capture in NOHMs. In particular, CO_2 capture capacities as well as swelling and CO_2 packing behaviours of NOHMs were analyzed using thermogravimetric analysis and RAMAN and attenuated total reflectance (ATR) Fourier transform infrared (FTIR) spectroscopes before and after exposure of NOHMs to SO_2. It was found that the SO_2 absorption in NOHMs was only prominent at high SO_2 levels (I.E 3010 PPM; P_{Tot} = 0.4mpa far exceeding the typical SO_2 and CO_2 for the same absorption sites (i.e ether and amine groups) resulted in a decreased CO_2 captured capacity of NOHMs.[9] on the other hand, CO_2 capture and storage (CCS) has the potential to develop into an important tool to address climate change. Given society's reliance on fossil fuels, widespread adoption of CCS appears indispensible for meeting stringent climate targets need to be complemented with air capture, removing CO_2 directly from the atmosphere. The only feasible techniques involve either absorption or adsorption on a sorbent. With such techniques, energy is required only to regenerate the sorbent. This regeneration process operates on the sorbent mass, which scales with the mass of the CO_2 captured rather than the much larger mass of the air. Carbon-free renewable and nuclear energy resources are theoretically sufficient for human kind's energy needs. It is unclear however whether these resources can be deployed rapidly and widely enough to overcome socio-political obstacles related to costs, environmental impact and public acceptance. Point-source CO_2 capture and storage (CCS) allows for continued use of fossil fuels in power plants and in steel and cement production while largely eliminating their CO_2 emissions.[10] ~~the~~ The removal of CO_2 from flue gases is done with the desire to reduce greenhouse emissions among other factors. The Econoamine FG Process is one such plants that recovers CO_2 from flue gases, using an inhibited 30weight percent of Monoethanolamine

Comment [U6]: Investigated by who? The Reviewer believes that this is not part of your research work, so you need to reference the past researcher.

Comment [U7]: You need to cite the previous works refering to here.

(MEA) solution. It recovers 85-95% of the CO2 in the flue gas. The only commercial absorbents active enough for recovery of dilute CO_2 from atmospheric pressure gas are monoethanolamine and other primary amines.[11]

The absorber diameter can be approximated from equation 2:

Absorber dia,(m) = Asqrt[(te/d)/(%CO_2)] (2)
Stripper diameter = 0.13*sqrt(te/d) (3)
Solvent loading and circulation rate (rich solvent circulation rate)=0.71*(te/d) (4)
Power consumption Kw = (0.4 + 16.4(%CO_2))*(te/d) (5)
Where A = 0.56 at 3% CO_2 to 0.62 for 13% CO_2,
Te/d = tonne/day CO_2 recovered,
%CO_2 = volume %CO_2 in flue gas before cooling (wet basis) and
M = meters.[11]

Comment [U8]: This is a mix up. Why these equations in this section? This should be under Materials and Methods. By the way, the title of your work is a 'Review study', why these equations? Did you carryout any numerical analysis in this study? I don't agree with your work. If you did not carryout numerical analysis in this work, I will advise that you remove these equations and rewrite this section.

In similar vein, an experimental study on NO_x removal from a simulated diesel engine was carried out using dielectric barrier discharge (DBD) reactor for various electrode shapes to improve the removal efficiency. The electrode shapes employed in the experiment were a plane, a trench and multipoint configurations. The 0.5mm thickness of alumina (Al/sub2/O/sub3/) dielectric barrier was produced on a plane electrode via a powder flame spray. The DBD reactor with multipoint electrodes was applied to 20KVA diesel engine generator exhaust gas treatment. The contained NO_x= (NO + NO/sub2/) was abated from 70 to 40 ppm at no load to the generator and from 340 to 300 ppm at 50A load. The energy for NO_x removal is obtained to 32g/Kwh.[12]

In another development, atmospheric O_3, CO, SO_2 and NO_y* were measured at a rural agricultural site in the Yangte Delta of China. Positive correlation between CO and NO_y* with a slope (Δ[CO]/Δ[NO_y*]) of 36 (ppbv/ppbv) for the winter and night time measurements. Value for industrialized countries~(10ppbv/ppbv). Where NO_y* = (NO + NO_2 + PAN + Organic Nitrates + HNO_3 + N_2O_5 +---). The highest CO/NO_y* ratio (30 – 40ppbv/ppbv) occurred in September-December 1999 and June 2000. The good correlation between CO and the biomass burning tracer CH_3Cl and the lack of correlation with the industrial tracer C_2Cl_4 suggest that the burning of biofuels and crop residues is a major source for the elevated CO and possibly for other tracer gases as well. SO_2 to NO_y* ratio = 1.37ppbv/ppbv. High value of ratio is as a result of use of high sulfur coals in China. The measured SO_2/NO_y* and ΔCO/ΔNO_y* were compared with the respective ratios from the current emission inventories for the region, which indicated a comparable SO_2/NO_y* emission ratio, but a large discrepancy for CO/NO_x. The observed CO to NO_y* ratio was more than 3 times the emission ratio derived from inventories.[13]

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Also, large eddy simulation (LES) of the gas-second order moment (SOM) of particles model based on the two fluid method coupled with the subgrid-scale (SGS) reaction submodel was applied to investigate SO_2 and NO_x emissions circulating fluidized bed (CFB) combustors. The SGS reaction submodel based on the eddy dissipation concept (EDC) model was developed considering the effect of particles to circulate the SGS reaction rates. The predicted results by the model are in agreement with the experimental data. The flow characteristics including concentration and SOM of particles were analyzed. The simulation results show that the particles including coal and desulfurized particles were sufficiently mixed. The velocity fluctuation of particles was enhanced for the combustion process, and the velocity fluctuation in the axial direction was about twice higher than that in the radial direction. It was observed that the SGS reaction of gas not only improved the homogenous reaction of gas but the heterogeneous reaction also.[14]

In another investigation, Iron oxide supported on alumina as a catalyst/absorbent for use in the simultaneous removal of NO_x and SO_x from power plant stack gases ~~is~~ was reported. A dry-contacting process underdevelopment would operate under net reducing conditions at temperatures of 370^0 to 540^{0}C. Iron oxide is converted to the ferrous state. No is reduced to NH_3 and SO_2 is removed as ferrous sulfide or sulfate. Regeneration with air provides SO_2 and reforms Fe_2O_3. The reduction of SO_2 by CO and H_2 was studied in fixed bed reactors to determine the effects of temperature and of the other reactive components of flue gas except (flyash) on the rate of reaction and the products formed. H_2S and COS react with FeO to form FeS. Under readily attainable conditions, virtually complete removal of sulfur compounds was achieved for gas-phase residence times of about 1 to 10ms. NO and NO_2 were also reduced.[15]

On a similar note, Iron titanate catalyst ($F_eT_iO_4$) is a potential candidate for the substitution of conventional V_2O_5-WO_3(M_bO_3)/T_iO_2 and F_e/C_U-Zeolite catalysts for the selective catalytic reduction (SCR) of NO_x with NH_3 because of its high SCR activity and N_2.[16] Also, an Iron titanate catalyst with a crystalline phase, prepared by a co-precipitation method showed excellent activity, stability, selectivity and SO_2/H_2O durability in the selective catalytic reduction of NO with NH_3 in the medium temperature range.[17] Furthermore, a cyclic process is described for removing the oxides of Sulfur from flue gas by absorption at 625^0F and then converting the oxides to elemental sulfur by reduction of the spent absorbent. Pilot plant experiments are reported in which a solid absorbent of alkalized alumina in free and baffled fall is used to remove SO_2 and SO_3 from the combustion gas of a pulverized coal-fired furnace. The absorbent is then regenerated by heating with hydrogen or with steam-reformed natural gas. Fly ash does not interfere and attrition is negligible.[18] On the other hand, the effectiveness of limestone and dolomite in removing SO_2 from flue gas can be estimated by thermo-chemical reactions. Both lime and magnesia are shown to be suitable for removing SO_2 from hot flue gas, with lime more suitable than magnesia over the temperature range where furnace conditions and reaction kinetics are likely to be favorable.[19] on the other hand, one of the most important steps in the wet limestone gypsum flue gas desulfurization (WFGD) process is $CaCO_3$ dissolution, which provides the dissolved alkalinity necessary for SO_2 absorption. Accurately evaluating the $CaCO_3$ dissolution rate is important in the design and efficient operation of WFGD plants. In the present work, the dissolution of limestone from different sources in South Africa has been studied in a pH-stat apparatus under conditions similar to those encountered in wet FGD processes. The influence of various parameters such as the reaction temperature, ($30 \leq T \leq 70^0$C), $CaCO_3$ particle size ($25 \leq dp \leq 63$µm), solution acidity ($4 \leq pH \leq 6$) and chemical composition were studied in order to determine the kinetics of $CaCO_3$ dissolution. The results obtained indicate that the dissolution rate increased with a decrease in the particle size and increase in temperature.[20] The industrial flue gas treatment systems and services market is growing at a significant rate, driven by the stringent regulations in developed countries and the rising demand for electricity in the emerging economies. Pollution control can be segmented into: flue gas desulfurization, D_eNO_x, particulate control, mercury control and others (VOCs, dioxins, HCl and HF). The enforcement of federal laws and regulations that mandate the industries to install pollution control equipment have spurred the growth of industrial flue gas treatmen systems.[21]

In a similar vein, the Global and China flue gas desulfurization system industry is reported. The report firstly introduced flue gas desulfurization basic information included flue gas desulfurization, definition, classification and application among others. It also listed flue gas desulfurization upstream raw materials and downstream analysis and flue gas desulfurization marketing channels.[22]

Furthermore, the suitability of a mathematical model for circulating fludized bed (CFB) coal combustion was investigated. The model predicted the development of tar and other hydrocarbons valuating the agreement between the measured and calculated efficiency. [23]

In another development, the comprehensive test results of an ultra-micro Gas Turbo-Generator fed by a mixture of butane and propane gas at the University of Roma was reported. Key indicators of test are: Turbo-Generator rated power (~ 10 Kw); compressor efficiency (0.52~ 0.77); fuel consumption (0.0015 ~ 0.010kg/s) and turbine inlet temperature (858 ~ 1137K). The key limitation was the high fuel consumption which required optimization of the machine in order to reduce the fuel consumption and increase the bearings life time.[24] Also, a management protocol for electrical and thermal loads in housing scheme equipped with co-generative unit and renewable system has been described. This protocol optimally manages the instant power generation from co-generative and renewable devices.[25] A performance report is documented on the economic, technical and environmental feasibility tests on running a 20MW diesel generator on vegetable oil (palm oil). The main constraint identified in this report is the availability and cost of the vegetable (palm) oil. [26] The Malaysian AM cash market prices for palm oil stood at US $612 per metric Tonne.[27] Also global petrol price in USA stood at US$0.97 per litre, UK at US$2.18 and Nigeria at US$0.58 per litre respectively.[28] In the same vein World market gas prices averaged US$3.41 per gallon.[29] While Butane gas is priced £16.75 (or $27.3) per 4.5kg cylinder and Propane gas £16 (or $26.08) per 3.9kg cylinder.[30] Also, gasoline consumption for a 10KVA package gasoline generator stands at18 litres in 4.5 hours.[31]

SUMMARY OF LITERATURE REVIEW

Table 1: Summary of Legislation/ Regulation Review.

		EU	**USA**	**CHINA**
EMISSION LIMIT VALUES (ELV)		**mg/NM^3**	**ng/J Heat**	**ppbv/ppbv**
	ELV defined in	Annex III-VII in the Directive 2001/80/EC. Directive 1999/32/EC	Title 40 Part 60 Subparts Da, Db, Dc and GG.	“12TH 5-year Plan” on Pollution Prevention
SO_2	Liquid fossil fuel	0.1 by mass	340	10%. National target 2015 = 8%. Target region = 12%
	Solid fossil fuel	1.0% for heavy fuel oils Or for $\leq$ 1700mg/Nm^3 @O_2 content in flue gas of 3% by volume.	520	
	Combined	For heavy oil and marine gas oil: ISO method 8754 (1992) For gas oil; EN 2426O (1987)	P_{SO2} (see equation 1)	
	NO_2			7% National target 2015 = 10% Target region = 13%

SOURCE: Summary Of Legislation/Regulation Review above.

Table 2 Summary of capture methods from flue gas

S/No.	COMPONENTS	REDUCTION METHOD	MATERIALS	AUTHOR'S REFERENCE NUMBER
1	SO_2	Ambient content measured at rural agricultural site	Gas analyzers	[13]
2		Large eddy simulation (LES), Gas-second order moment (SOM) and CFB combustors coupled with sub-grid scale (SGS). (two-fluid method)	Coal and desulfurized particles	[14]
3		A dry contacting process for simultaneous removal of NO_x and SO_x from plant stack.	Iron oxide supported on alumina as catalyst	[15]
4		Cyclic process of removing SO_2 and SO_3 by absorption	Absorbent, alkalized alumina in free and baffle fall.	[18]
5		Thermo-chemical reactions using limestone and dolomite	Limestone, dolomite and magnesia	[19]
6		Limestone gypsum absorption	limestone	[20]
7	NO_x	Selective catalytic reduction (SCR) presence of SO_2 weakens NH_3 oxidation to NO	NH_3	[8]
8		Dielectric barrier discharge (DBD) reactor applied to 20KVA diesel engine generator	Al/sub2/O/sub3/ Alumina dielectric barrier	[12]
9		Ambient content measured at rural agricultural site	Gas analyzers	[13]
10		Large eddy simulation (LES) gas-second order moment (SOM) and CFB combustors coupled with sub-grid (SGS). (two-fluid method)	Coal and desulfurized particles	[14]
11		A dry-contacting process for simultaneous removal of NO_x and SO_x from plant stack.	Iron oxide supported on alumina as catalyst	[15]

12		Iron titanate catalyst+V_2O_5-WO_3 and Fe/Cu-Zeolite catalyst for SCR of NO_x with NH_3.	Iron titanate, Zeolite and NH_3	[16]
13		Catalytic reduction of NO with NH_3	SO_2/H_2O. iron titanate as catalyst.	[17]
14	CO2	Nanoparticle organic Hybrid materials (NOHMs) absorption of CO_2 was affected by the presence of SO_2 in the flue gas, that is reduction in CO_2 capture.	Nanoparticle organic Hybrid materials (NOHMs)	[9]
15		Absorption or adsorption	sorbent	[10]
16		Econoamine FG (Absorbents)	MEA	[11]
17	CO	Ambient content measured at rural agricultural site	Biomass burning tracer, CH_3Cl; Industrial tracer, C_2Cl_4.	[13]

SOURCE: Summary from literature review above.

TABLE 3 – ALTERNATIVE/ENHANCEMENT SOURCES TO GASOLINE GENERATORS

S/No.	**ALTERNATIVE/ENHANCEMENT SOURCES TO GASOLINE GENRATORS**	**FUEL**	**LIMITATIONS**	**REFERENCE**
1	Micro Gas Turbo Generator at University of Roma	Mixture of Butane and Propane gas	High fuel consumption	24
2	20MW Diesel Generator test	Vegetable (Palm) oil	Cost and availability	26
3	Mathematical Modeling of Biomass Gasification	coal	Flue gas treatment not squarely addressed as primary objective	23
4	Power Quality Management	-	Addressed the efficiency in power usage but silent on flue gas managment	25

SOURCE: SUMMARY FROM LITERATURE REVIEW ABOVE

TABLE 4 – FUEL PRICES

S/No.	FUEL	PRICE	REFERENCE
1	Gasoline	USA = $0.97/Litre; UK = $2.18/Litre and Nigeria = $0.58/Litre.	[28]
2	gas	US$3.41 per gallon	[29]
3	Palm oil (vegetable oil)	US$612 per Metric Tonne	[27]
4	Butane Gas Propane Gas	4.5kg = £16.75 (or $27.3) 3.9kg = £16 (or $26.08)	[30]

SOURCE: SUMMARY FROM LITERATURE REVIEW ABOVE

RELATING RESEARCH EFFORTS OF MINIMIZING POLLUTION TO LEGISLATION

Legislations, Standards and Regulations from the EU, USA and China as detailed in Table 1 above are quite comprehensive in the regulating and control of flue gas emissions into the atmosphere. On the other hand, the research and investigations into the process, methodology and strategy for the removal of SO_X, NO_X, CO and CO_2 from flue gases as detailed in Table 2 has been thorough, detailed and thought provoking. References [8] to [20] have demonstrated various ways in capturing SO_2, NO_X, CO and CO_2 from flue gases. On the other hand, Reference [24] addressed mathematical model of biomass gasification while Reference [26] investigated Power Quality Management Protocol in residential buildings with co-generative capability, with the view of optimization of power usage. This report will be of immense benefit to developing economies that are grappling and tinkering with the possibility of providing adequate power. In another development, References [24] and [26] investigated alternative fuel regime (that is butane + propane gas and palm oil respectively) and generation methods to gasoline generators. According to Reference [24], the fuel (that is butane + Propane) consumption by the 10KW micro gas turbo generator at Roma = 0.01kg/s, that is 0.01x60x60kg/hr = 36kg/hr.

From Table 4, 4.5kg of Butane = US$27.3.

Therefore 0.5kg of Butane = (27.3/4.5)x0.5 = US$3.03

Therefore 0.5kg of Propane = (26.08/3.9)x0.5 = US$3.34.

Hence 1kg of gas (that is 0.5kg Butane + 0.5kg Propane) = US$3.03 + US$3.34 = US$6.37.

But the 10KW micro turbo generator consumes 36kg of mixed gas per hour. Hence the cost of running the 10KW micro turbo generator per hour = 36XUS$6.37 = US$229.32.

On the other hand, according to Reference [31], a 10KVA package Gasoline Generator consumes 18litres of petrol in 4.5hours. This implies that this package generator consumes (18litres)/4.5hrs = 4litres/hr.

But from Table 4, Reference [28] posits that a litre of petrol in Nigeria cost US$0.58. Hence the cost of running this 10KVA Package gasoline generator = 4x US$0.58 = US$2.32.

Comparing the US$2.32/hr for running this 10KVA package gasoline generator with the US$229.32/hr for running the 10KW micro turbo generator at Roma, this translates to a cost ratio of 1 to 98.85. The outcome of the Roma project is therefore a very inefficient result against the balance of economics and the background of already available operating generator efficiency in the global market. Consequent on the foregoing, the outcome of the Roma project will not be of immediate benefit as a substitute for package gasoline generators in the developing economies.

On the other hand, according to Reference [26], the testing of 20MW Diesel Generator using vegetable oil (that is palm oil) as substitute has some merit. According to Reference [27] from Table 4, the price of palm oil is US$612per metric tonne. This is approximately US$0.612 per litre. Also, according to Reference [29], the price of diesel is US$3.41 per gallon. This is approximately US$0.85 per litre. Since the price of palm oil is lower than that of diesel, it makes economic sense to investigate the viability of palm oil as a substitute fuel for the diesel generator. However, the price of petrol in Nigeria according to Reference [28] is US$0.58 per litre. Against this backdrop, the use of palm oil as a substitute fuel in Nigeria will amount to a bad economic decision.

It Can Generally Be Summarized That The Following Holds:

Comment [U10]: This is a bad sub heading. Is this your Conclusion section or what? It is advisable to move this part to Conclusion section.

1. Generators are devices that convert mechanical energy to electrical energy.
2. Power supply from National grid of most developing nations (Nigeria inclusive) is insufficient for economic activities.
3. Consequent on above, most businesses rely on package generators for electrical power delivery.
4. All generators that are fossil fuel fired release flue gases into the environment.
5. Most flue gases contain SO_2, $NO_{X,}$ CO and CO_2. The CO is detrimental to health of living men and animals and at the same time depletes the ozone layer. On the other hand the CO_2 contributes to the greenhouse effect.
6. Consequent on the above, World Health and Environmental regulating bodies have taken initiatives to regulate and reduce the emissions of these gases to as low as reasonably possible (ALARP).
7. Efforts are being made to develop purifying/capturing methods for these green house gases while at the same time seeking alternative renewable energy sources to replace energy sources that generates the green house gases.
8. Most of the improvement efforts on energy sources that are safe and efficient in usage have been geared towards grid equipment such as turbo-generators, boilers, Industrial furnaces, geothermal, hydro and solar energy.
9. Identified methods of capture of CO and CO_2 include the absorption of the gases using either the wet or dry methods.
10. Different storage and discarding methods were identified as means of managing the captured gases.

Comment [U11]: Irrelevants. Remove

The efforts and improvements made in the capture of SO_2, NO_X, CO and CO_2 were never targeted at the gasoline package generators. This appears to be an oversight in the sense that the package generators in the first instance were not actually designed as full time generators. Rather, they were designed to serve as standby and emergency units. But the acute deficit of power supply to economic businesses in developing nations and coupled with poor finances, have compelled the businesses to resort to usage of package generators as main power source. This has led to ample generation of SO_2, NO_X, CO and CO_2, the ODs and GHGs abundantly in the developing countries. Since the use of fossil fuel will remain with us for a long time to come, the need therefore arises for improvement action to be taken in minimizing the emission of the OD and GHGs from the package generators into the environment.

WHAT FURTHER IMPROVEMENTS NEED TO BE DONE?

From the foregoing, it is evident that much has been achieved in the Legislations, Regulation and Control of flue gases. Much of the emphasis has been directed to the large combustion plants (the “LCP directive”). The volume of research into the capture of SO_2, NO_X, CO and CO_2 from flue gas has been extensive. The implementation of the research outcomes have been so far directed mainly to the LCPs to the detriment of the package generators. The package generators will continue to be relevant in the scheme of economic and domestic activities in the developing economies in as much as the national power grids continue to be epileptic in their service delivery. Therefore, the attendant noise and flue (CO and CO_2 inclusive) pollution will be with the society for a long time to come. The immediate and urgent thing for now is to mitigate and embark on some control measures to limit this pollution to an acceptable statutory level. Hence the need is here now more than ever to incorporate the identified capture technique for SO_2, NO_X, CO and CO_2 into the package gasoline generators. Hence in the design and fabrication of the SO_2, NO_X, CO and CO_2 capture unit, emphasis should be placed on the absorption of the gases using either the wet or dry methods. Some form of sequencing should be done to align capturing process to discarding process in order to optimize the overall system. The outcome of this project effort will keep the environment safer and put more money in the pockets of business units, as the environment becomes cleaner, neater and safer hence minimized environmental and pollution litigations fines and expenses. Also the health and medical bills will drop.

CONCLUSION

The impact of high concentration of CO, CO_2, SO_2 and NO_X to human life is lethal and should not be treated with kid gloves. This severity index is more than enough justification for action to be taken to minimize the attendant scenario that leads to the over generation of these gases. The global position on legislation, regulation and control of Emission Limit Values (ELV) of flue gases has been articulated. All efforts directed towards limiting the indiscriminate and uncontrolled generation of CO, CO_2, SO_2 and NO_X is a welcome development. Various researchers have experimented on the means and methods/techniques to capture and trap these gases. The incorporation of these capturing methods in the package gasoline generators will go a long way in reducing the pollution of the environment through flue gases. The suggested alternative sources of power as substitute for the package gasoline generator by some of the researchers were found to be economically unviable. The review acknowledged the hazard levels of CO, CO_2, SO_2 and NO_X.

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