

**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<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> has been contributing to the green house effects. These militating dangers/risks arising from the usage of these package generators strongly 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<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> from the flue gases have been highlighted. The incorporation of these capturing methods for CO, CO<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> 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 20<sup>th</sup> 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<sub>2</sub>), Methane (CH<sub>4</sub>) and Nitrous Oxide (N<sub>2</sub>O) trap the outgoing solar radiation that is reflected by the earth's surface, which leads to global warming.<sup>[1]</sup> 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".<sup>[1]</sup> 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<sub>2</sub>, CO, SO<sub>2</sub>, NO<sub>x</sub> as by-products of combustion amongst others. CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>, CO, SO<sub>2</sub> and NO<sub>x</sub> 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.<sup>[2]</sup> The power range for a variety of these package generators varies from about 800watts to 15 kilowatts.<sup>[2]</sup> 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.

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.<sup>[3]</sup>

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.<sup>[4]</sup> 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.<sup>[4]</sup> These 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.<sup>[5]</sup> 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.<sup>[5]</sup>

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.<sup>[5]</sup> 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.<sup>[5]</sup>

## 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  $\text{mg}/\text{nm}^3$ , 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  $\text{SO}_2$ ,  $\text{NO}_x$  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.

#### 116 **S60.43 Standard for Sulfur Dioxide ( $\text{SO}_2$ )**

117 (a) On and after the date on which the performance test required to be conducted by  
118 S60.8 is completed, no owner or operator subject to the provision of this subpart  
119 shall cause to be discharged into the atmosphere from any affected facility any  
120 gases that contain  $\text{SO}_2$  in excess of: (1)  $340\text{ng}/\text{J}$  heat input ( $0.8\text{lb}/\text{MMBtu}$ ) derived  
121 from liquid fossil fuel or liquid fossil fuel and wood. (2)  $520\text{ ng}/\text{J}$  heat input ( $1.2$   
122  $\text{lb}/\text{MMBtu}$ ) derived from solid fossil fuel or solid fossil fuel and wood residue.

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

$$125 P_{\text{SO}_2} = [y(340) + z(520)] / (y + z)$$

126 Where  $P_{\text{SO}_2}$  = prorated standard for  $\text{SO}_2$  when burning different fuels simultaneously  
127 in  $\text{ng}/\text{J}$  heat input derived from all fossil fuels or from all fossil fuels and wood  
128 residue fired.

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

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

#### 131 **Sulfur Content of Liquid Fuels Directive 1999/32/EC on Reduction of Certain** 132 **Liquid Fuels (26<sup>th</sup> April 1999).**

133 Sulfur content of gas oil not to exceed 0.1 %. Member states shall take all necessary  
134 steps to ensure that as from 1 January 2003 within their territory heavy fuel oils are  
135 not used if their sulfur content exceeds 1.0% by mass. Alternatively, where the  
136 emissions of sulfur dioxide from the plant are less than equal to  $1700\text{mg}/\text{nm}^3$  at an  
137 Oxygen content in the flue gas of 3% by volume on a dry basis. The reference  
138 method adopted for determining the sulfur content shall be that determined by:

139 a) ISO Method 8754 (1992) and PrEN ISO 14596 for heavy oil and marine gas oil

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

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

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

145 On 5<sup>th</sup> December 2012, Ministry of Environmental Protection (MEP), National  
146 Development and Reform Commission and Ministry of Finance jointly issued a "12<sup>th</sup>  
147 five-year plan on Air Pollution and Control in key regions". The plan was approved  
148 by the China's State Council earlier. The three key regions are: Beijing-Tianjin-  
149 Hebei, Yangtze River Delta and Pearl River Delta and 10 city clusters, involving 19  
150 provincial level jurisdictions and 117 cities. These areas cover only 14% of the  
151 country's land area, but accounts for nearly half (48%) of the country's population,  
152 71% of the nations GDP and 52% of the country's coal consumption. The air  
153 pollutants emission level is 2.9 to 3.6 times higher than the nation's average.

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

Ambient Quality	Air	$\text{PM}_{10}$	$\text{SO}_2$	$\text{NO}_2$	$\text{PM}_{2.5}$	$\text{PM}_{2.5}$ (In 3 Key
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					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 targets

Total Emission Reduction Targets	SO <sub>2</sub>	NO <sub>x</sub>	Industrial PM
National Targets By 2015	8%	10%	No target
Targets in Key Regions By 2015	12%	13%	10%

If successfully implemented, the plan is estimated to result in SO<sub>2</sub> emission reduction of 2.28million tons/year, NO<sub>x</sub> 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.<sup>[7]</sup>

## RESEARCH EFFORTS TO MINIMIZE POLLUTION

Promoting effect of SO<sub>2</sub> on selective catalytic reduction (SCR) of NO by NH<sub>3</sub> over a CuO/Al<sub>2</sub>O<sub>3</sub> catalyst sorbent has been investigated. Transient experiment, x-ray photoelectron spectroscopy (XPS) insitu Drift, NH<sub>3</sub>-TPD and temperature-programmed reduction (TPR) were used to evaluate the promoting mechanism. Ammonia oxidation experiments and TPR in H<sub>2</sub> suggest that sulfation of the catalyst sorbent weakens the catalyst's oxidation ability and inhibits NH<sub>3</sub> oxidation to NO in the process of SCR, which may be another main promoting effect of SO<sub>2</sub> on SCR.<sup>[8]</sup> Also, liquid-like nanoparticle organic hybrid materials (NOHMs) consisting of silica nanoparticles with a grafted polymetric canopy were synthesized. Previous work on NOHMs has revealed that CO<sub>2</sub> capture behaviours in these materials can be tuned by modifying the structure of the (polymetric canopy. Because SO<sub>2</sub>, which is another acidic gas found in flue gas, would also interact with NOHMs, this study was designed to investigate its effect on CO<sub>2</sub> capture in NOHMs. In particular, CO<sub>2</sub> capture capacities as well as swelling and CO<sub>2</sub> packing behaviours of NOHMs were analyzed using thermogravimetric analysis and RAMAN and attenuated total reflectance (ATR) Fourier transform infrared (FTIR) spectrometers before and after exposure of NOHMs to SO<sub>2</sub>. It was found that the SO<sub>2</sub> absorption in NOHMs was only prominent at high SO<sub>2</sub> levels (I.E 3010 PPM; P<sub>Tot</sub> = 0.4mpa far exceeding the typical SO<sub>2</sub> and CO<sub>2</sub> for the same absorption sites (i.e ether and amine groups) resulted in a decreased CO<sub>2</sub> captured capacity of NOHMs.<sup>[9]</sup> On the other hand, CO<sub>2</sub> 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 indispensable for meeting stringent climate targets need to be complemented with air capture, removing CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions.<sup>[10]</sup> the removal of CO<sub>2</sub> from flue gases is done with the desire to reduce greenhouse emissions among other factors. The Econoamine FG Process is one such plant that recovers CO<sub>2</sub> from flue gases, using an inhibited 30weight percent of Monoethanolamine (MEA) solution. It recovers 85-95% of the CO<sub>2</sub> in the flue gas. The only commercial absorbents active enough for recovery of dilute CO<sub>2</sub> from atmospheric pressure gas are monoethanolamine and other primary amines.<sup>[11]</sup>

204 The absorber diameter can be approximated from equation 2:  
 205 Absorber dia,(m) =  $\text{Asqrt}[(\text{te/d})/(\% \text{CO}_2)]$  (2)  
 206 Stripper diameter =  $0.13 \cdot \text{sqrt}(\text{te/d})$  (3)  
 207 Solvent loading and circulation rate (rich solvent circulation rate) =  $0.71 \cdot (\text{te/d})$  (4)  
 208 Power consumption Kw =  $(0.4 + 16.4(\% \text{CO}_2)) \cdot (\text{te/d})$  (5)

209 Where A = 0.56 at 3% CO<sub>2</sub> to 0.62 for 13% CO<sub>2</sub>,  
 210 Te/d = tonne/day CO<sub>2</sub> recovered,  
 211 %CO<sub>2</sub> = volume %CO<sub>2</sub> in flue gas before cooling (wet basis) and  
 212 M = meters.<sup>[11]</sup>

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

222 In another development, atmospheric O<sub>3</sub>, CO, SO<sub>2</sub> and NO<sub>y</sub>\* were measured at a rural  
 223 agricultural site in the Yangtze Delta of China. Positive correlation between CO and NO<sub>y</sub>\* with  
 224 a slope ( $\Delta[\text{CO}]/\Delta[\text{NO}_y^*]$ ) of 36 (ppbv/ppbv) for the winter and night time measurements.  
 225 Value for industrialized countries~(10ppbv/ppbv). Where NO<sub>y</sub>\* = (NO + NO<sub>2</sub> + PAN +  
 226 Organic Nitrates + HNO<sub>3</sub> + N<sub>2</sub>O<sub>5</sub> +---). The highest CO/NO<sub>y</sub>\* ratio (30 – 40ppbv/ppbv)  
 227 occurred in September-December 1999 and June 2000. The good correlation between CO  
 228 and the biomass burning tracer CH<sub>3</sub>Cl and the lack of correlation with the industrial tracer  
 229 C<sub>2</sub>Cl<sub>4</sub> suggest that the burning of biofuels and crop residues is a major source for the  
 230 elevated CO and possibly for other tracer gases as well. SO<sub>2</sub> to NO<sub>y</sub>\* ratio = 1.37ppbv/ppbv.  
 231 High value of ratio is as a result of use of high sulfur coals in China. The measured  
 232 SO<sub>2</sub>/NO<sub>y</sub>\* and  $\Delta\text{CO}/\Delta\text{NO}_y^*$  were compared with the respective ratios from the current  
 233 emission inventories for the region, which indicated a comparable SO<sub>2</sub>/NO<sub>y</sub>\* emission ratio,  
 234 but a large discrepancy for CO/NO<sub>x</sub>. The observed CO to NO<sub>y</sub>\* ratio was more than 3 times  
 235 the emission ratio derived from inventories.<sup>[13]</sup>

236 Also, large eddy simulation (LES) of the gas-second order moment (SOM) of particles  
 237 model based on the two fluid method coupled with the subgrid-scale (SGS) reaction  
 238 submodel was applied to investigate SO<sub>2</sub> and NO<sub>x</sub> emissions circulating fluidized bed (CFB)  
 239 combustors. The SGS reaction submodel based on the eddy dissipation concept (EDC)  
 240 model was developed considering the effect of particles to circulate the SGS reaction rates.  
 241 The predicted results by the model are in agreement with the experimental data. The flow  
 242 characteristics including concentration and SOM of particles were analyzed. The simulation  
 243 results show that the particles including coal and desulfurized particles were sufficiently  
 244 mixed. The velocity fluctuation of particles was enhanced for the combustion process, and  
 245 the velocity fluctuation in the axial direction was about twice higher than that in the radial  
 246 direction. It was observed that the SGS reaction of gas not only improved the homogenous  
 247 reaction of gas but the heterogeneous reaction also.<sup>[14]</sup>

248 In another investigation, Iron oxide supported on alumina as a catalyst/absorbent for use in  
 249 the simultaneous removal of NO<sub>x</sub> and SO<sub>x</sub> from power plant stack gases is reported. A dry-  
 250 contacting process underdevelopment would operate under net reducing conditions at  
 251 temperatures of 370<sup>0</sup> to 540<sup>0</sup>C. Iron oxide is converted to the ferrous state. No is reduced to  
 252 NH<sub>3</sub> and SO<sub>2</sub> is removed as ferrous sulfide or sulfate. Regeneration with air provides SO<sub>2</sub>  
 253 and reforms Fe<sub>2</sub>O<sub>3</sub>. The reduction of SO<sub>2</sub> by CO and H<sub>2</sub> was studied in fixed bed reactors to  
 254 determine the effects of temperature and of the other reactive components of flue gas except  
 255 (flyash) on the rate of reaction and the products formed. H<sub>2</sub>S and COS react with FeO to  
 256 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<sub>2</sub> were also reduced.<sup>[15]</sup>

On a similar note, Iron titanate catalyst (FeTiO<sub>4</sub>) is a potential candidate for the substitution of conventional V<sub>2</sub>O<sub>5</sub>-WO<sub>3</sub>(MoO<sub>3</sub>)/TiO<sub>2</sub> and Fe/Cu-Zeolite catalysts for the selective catalytic reduction (SCR) of NO<sub>x</sub> with NH<sub>3</sub> because of its high SCR activity and N<sub>2</sub>.<sup>[16]</sup> Also, an Iron titanate catalyst with a crystalline phase, prepared by a co-precipitation method showed excellent activity, stability, selectivity and SO<sub>2</sub>/H<sub>2</sub>O durability in the selective catalytic reduction of NO with NH<sub>3</sub> in the medium temperature range.<sup>[17]</sup> Furthermore, a cyclic process is described for removing the oxides of Sulfur from flue gas by absorption at 625<sup>o</sup>F 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<sub>2</sub> and SO<sub>3</sub> 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.<sup>[18]</sup> On the other hand, the effectiveness of limestone and dolomite in removing SO<sub>2</sub> from flue gas can be estimated by thermo-chemical reactions. Both lime and magnesia are shown to be suitable for removing SO<sub>2</sub> 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.<sup>[19]</sup> on the other hand, one of the most important steps in the wet limestone gypsum flue gas desulfurization (WFGD) process is CaCO<sub>3</sub> dissolution, which provides the dissolved alkalinity necessary for SO<sub>2</sub> absorption. Accurately evaluating the CaCO<sub>3</sub> 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 ≤ T ≤ 70<sup>o</sup>C), CaCO<sub>3</sub> particle size (25 ≤ dp ≤ 63μm), solution acidity (4 ≤ pH ≤ 6) and chemical composition were studied in order to determine the kinetics of CaCO<sub>3</sub> dissolution. The results obtained indicate that the dissolution rate increased with a decrease in the particle size and increase in temperature.<sup>[20]</sup> 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<sub>e</sub>NO<sub>x</sub>, 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 treatment systems.<sup>[21]</sup>

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.<sup>[22]</sup>

Furthermore, the suitability of a mathematical model for circulating fluidized 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.<sup>[23]</sup>

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.<sup>[24]</sup> 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.<sup>[25]</sup> 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. <sup>[26]</sup> The Malaysian AM cash market prices for palm oil stood at US \$612 per metric Tonne. <sup>[27]</sup> 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. <sup>[28]</sup> In the same vein World market gas prices averaged US\$3.41 per gallon. <sup>[29]</sup> 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. <sup>[30]</sup> Also, gasoline consumption for a 10KVA package gasoline generator stands at 18 litres in 4.5 hours. <sup>[31]</sup>

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## SUMMARY OF LITERATURE REVIEW

Table 1: Summary of Legislation/ Regulation Review.

EMISSION LIMIT VALUES (ELV)		EU mg/NM <sup>3</sup>	USA ng/J Heat	CHINA 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.	"12 <sup>TH</sup> 5-year Plan" on Pollution Prevention
SO <sub>2</sub>	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 $\leq 1700\text{mg/Nm}^3$ @O <sub>2</sub> 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 24260 (1987)	P <sub>SO2</sub> (see equation 1)	
	NO <sub>2</sub>			7% National target 2015 = 10% Target region = 13%

SOURCE: Summary Of Legislation/Regulation Review above.

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Table 2 Summary of capture methods from flue gas

S/No.	COMPONENTS	REDUCTION METHOD	MATERIALS	AUTHOR'S
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				REFERENCE NUMBER
1	SO <sub>2</sub>	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 <sub>x</sub> and SO <sub>x</sub> from plant stack.	Iron oxide supported on alumina as catalyst	[15]
4		Cyclic process of removing SO <sub>2</sub> and SO <sub>3</sub> 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 <sub>x</sub>	Selective catalytic reduction (SCR) presence of SO <sub>2</sub> weakens NH <sub>3</sub> oxidation to NO	NH <sub>3</sub>	[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 <sub>x</sub> and SO <sub>x</sub> from plant stack.	Iron oxide supported on alumina as catalyst	[15]
12		Iron titanate catalyst+V <sub>2</sub> O <sub>5</sub> -WO <sub>3</sub> and Fe/Cu-Zeolite catalyst for SCR of NO <sub>x</sub> with NH <sub>3</sub> .	Iron titanate, Zeolite and NH <sub>3</sub>	[16]
13		Catalytic reduction of NO with NH <sub>3</sub>	SO <sub>2</sub> /H <sub>2</sub> O. iron titanate as	[17]



			catalyst.	
14	CO <sub>2</sub>	Nanoparticle organic Hybrid materials (NOHMs) absorption of CO <sub>2</sub> was affected by the presence of SO <sub>2</sub> in the flue gas, that is reduction in CO <sub>2</sub> 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 <sub>3</sub> Cl; Industrial tracer, C <sub>2</sub> Cl <sub>4</sub> .	[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]
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SOURCE: SUMMARY FROM LITERATURE REVIEW ABOVE

### RELATING RESEARCH EFFORTS 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  $\text{SO}_x$ ,  $\text{NO}_x$ , CO and  $\text{CO}_2$  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  $\text{SO}_2$ ,  $\text{NO}_x$ , CO and  $\text{CO}_2$  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  $0.01 \times 60 \times 60 \text{kg/hr} = 36 \text{kg/hr}$ .

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

Therefore 0.5kg of Butane =  $(27.3/4.5) \times 0.5 = \text{US\$}3.03$

Therefore 0.5kg of Propane =  $(26.08/3.9) \times 0.5 = \text{US\$}3.34$ .

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

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 =  $36 \times \text{US\$}6.37 = \text{US\$}229.32$ .

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  $(18 \text{litres})/4.5 \text{hrs} = 4 \text{litres/hr}$ .

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 =  $4 \times \text{US\$}0.58 = \text{US\$}2.32$ .

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\$612 per 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:

1. Generators are devices that convert mechanical energy to electrical energy.

- 392 2. Power supply from National grid of most developing nations (Nigeria inclusive) is  
393 insufficient for economic activities.
- 394 3. Consequent on above, most businesses rely on package generators for electrical  
395 power delivery.
- 396 4. All generators that are fossil fuel fired release flue gases into the environment.
- 397 5. Most flue gases contain SO<sub>2</sub>, NO<sub>x</sub>, CO and CO<sub>2</sub>. The CO is detrimental to health of  
398 living men and animals and at the same time depletes the ozone layer. On the  
399 other hand the CO<sub>2</sub> contributes to the greenhouse effect.
- 400 6. Consequent on the above, World Health and Environmental regulating bodies have  
401 taken initiatives to regulate and reduce the emissions of these gases to as low as  
402 reasonably possible (ALARP).
- 403 7. Efforts are being made to develop purifying/capturing methods for these green  
404 house gases while at the same time seeking alternative renewable energy sources  
405 to replace energy sources that generates the green house gases.
- 406 8. Most of the improvement efforts on energy sources that are safe and efficient in  
407 usage have been geared towards grid equipment such as turbo-generators, boilers,  
408 Industrial furnaces, geothermal, hydro and solar energy.
- 409 9. Identified methods of capture of CO and CO<sub>2</sub> include the absorption of the gases  
410 using either the wet or dry methods.
- 411 10. Different storage and discarding methods were identified as means of managing  
412 the captured gases.

413 The efforts and improvements made in the capture of SO<sub>2</sub>, NO<sub>x</sub>, CO and CO<sub>2</sub> were  
414 never targeted at the gasoline package generators. This appears to be an oversight in  
415 the sense that the package generators in the first instance were not actually designed as  
416 full time generators. Rather, they were designed to serve as standby and emergency  
417 units. But the acute deficit of power supply to economic businesses in developing  
418 nations and coupled with poor finances, have compelled the businesses to resort to  
419 usage of package generators as main power source. This has led to ample generation of  
420 SO<sub>2</sub>, NO<sub>x</sub>, CO and CO<sub>2</sub>, the ODs and GHGs abundantly in the developing countries.  
421 Since the use of fossil fuel will remain with us for a long time to come, the need therefore  
422 arises for improvement action to be taken in minimizing the emission of the OD and  
423 GHGs from the package generators into the environment.

#### 424 425 **WHAT FURTHER IMPROVEMENTS NEED TO BE DONE?**

426 From the foregoing, it is evident that much has been achieved in the Legislations, Regulation  
427 and Control of flue gases. Much of the emphasis has been directed to the large combustion  
428 plants (the "LCP directive"). The volume of research into the capture of SO<sub>2</sub>, NO<sub>x</sub>, CO and  
429 CO<sub>2</sub> from flue gas has been extensive. The implementation of the research outcomes have  
430 been so far directed mainly to the LCPs to the detriment of the package generators. The  
431 package generators will continue to be relevant in the scheme of economic and domestic  
432 activities in the developing economies in as much as the national power grids continue to be  
433 epileptic in their service delivery. Therefore, the attendant noise and flue (CO and CO<sub>2</sub>  
434 inclusive) pollution will be with the society for a long time to come. The immediate and urgent  
435 thing for now is to mitigate and embark on some control measures to limit this pollution to an  
436 acceptable statutory level. Hence the need is here now more than ever to incorporate the

identified capture technique for SO<sub>2</sub>, NO<sub>x</sub>, CO and CO<sub>2</sub> into the package gasoline generators. Hence in the design and fabrication of the SO<sub>2</sub>, NO<sub>x</sub>, CO and CO<sub>2</sub> 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<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub>.

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