RESEARCH ARTICLE

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Development of A Prototype Extractor of CO_2 from Exhaust Gases

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ABSTRACT

A Prototype Extractor of CO_2 from Exhaust Gases adopting *Post-combustion capture process* is developed in this study and its performance was evaluated. The system consists of a small petrol engine of 1kw power, an absorber with volume of 0.00054 m^3, a balloon that can contain sizeable amount of exhaust gas, a washer of 0.0181 m^3, a compressor of 1hp, a dryer which consist of two compartment, with internal volume of 0.00093m^3 insulated with fibre glass to prevent heat loss. All of these component parts works in a circle, to convert stockpiled exhaust gases from exhaust manifold point source of an electrical power generating set into carbon (iv) oxide (CO_2). This system was carefully developed to ensure extraction of pure CO_2 from the waste emission gases. Study was conducted using the developed system to extract suspected CO_2 gaseous substance from exhaust gases. The obtained gaseous substance was assay for chemical analysis test using sodalime solution ($CaHNaO_2$). The result of the test confirmed the extracted gaseous substance as CO_2 gas by changing a colorless sodalime solution to a milk color. It is also found that the quantity of CO_2 gas generated increases with the increment of the quantity of the fuel consumed by the Petrol engine. The produced CO_2 gas can be utilized as commodity in the industrial production of materials and fuels. This work has elucidated one of the means of converting waste emissions (exhaust gases) to wealth and could help to reduce greenhouse effect thus providing a friendly environment for humans' inhabitants

Keywords: Carbon (iv) oxide, chemical analysis, CO_2 extractor system, exhaust gases, petrol engine.

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I. Introduction

The demand to prevent damaging changes in climate (greenhouse effect) due to increasing CO_2 concentration from human activities has led to development of CO_2 capture and storage (CCS) in this study. Findings from various researchers in the open literatures [1]-[4] have reported CO_2 as one of the major greenhouse gas contributing to the climate change and warn of extraordinary risks (including from storms, floods, droughts, heat waves and sea level rise) unless the build up of carbon dioxide in the atmosphere slows and then reverses in the decades ahead. CO_2 extraction, also referred to as Carbon capture and storage (CCS) is the process of capturing waste carbon dioxide usually from large point sources, such as a cement factory , biomass power plant, natural gas processing and fossil fuel-based hydrogen production plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere [5]. According to [6], extracting CO_2 from air is also possible, although far lower concentration of CO_2 in air compared to combustion sources presents significant engineering challenges. This brought about the need to develop CO_2 extractor from point sources, by capturing the exhaust gases and convert them to CO_2 gas. Reference [2] captured CO_2 from air using industrial process and noted that carbon (iv) oxide removal provides potential to offset carbon (iv) oxide emissions. Reference [7] noted that carbon (iv) oxide can be prevented from entering the air using a complete end-to-end system. Reference [8] designed, built and demonstrated outdoor system for capturing and concentrating carbon (iv) oxide to aid growing of micro-algae. The micro-algae was found to grow faster utilizing carbon (iv) oxide from concentrated sources. Reference [3] stated that concentration of carbon (iv) oxide has reached its highest level in roughly three million years, it will continue to increase. Reference [4] estimated that the average number of homes with generating sets in Nigeria is up to 60 million, thus the world need a better means of removing the gas out of the atmosphere.

It is interesting to point out that previous work done on CO_2 extraction using applicable imported CO_2 extractor system is very expensive, the reason may be due to incurred import duty in acquiring the foreign CO_2 extractor system. Therefore, a prototype extractor of CO_2 gas from exhaust gases point sources using locally available material is developed in this study. The CO_2 extractor system developed will help to convert these pollutants (Exhaust Gases) to CO_2 gas, by absorbing and stockpiled the exhaust gases in a safe storage unit of the system before converting it to CO_2 gas in the washer/dryer units of the extractor system, thus providing a friendly environment for humans' inhabitants. The obtained

CO_2 when process can be used as a refrigerant, fire extinguishers substance, for inflating life jackets, blasting coal, foaming rubber and plastics. The CO_2 gas substance could also be of great benefit in promoting the growth of plants in greenhouses, immobilizing animals before slaughter, and in carbonated beverages.

II. Materials and Methods

The materials and method adopted for the development of the prototype CO_2 extractor system were considered in this section. The materials required for the fabrication of the prototype CO_2 extractor system are commercially available and affordable.

A. Design of Absorber

The absorber was carefully designed to collect the stockpiled exhaust gases in a flexible bag called balloon which is made of water resistant- polyester material that can be inflated and filled with smoke. The absorber is a cylindrical pipe covered at both ends with inlet and outlet to enable the movement of exhaust gases in and out of it. During combustion, certain carbon (black) dirt might leak out of the exhaust, the absorber keeps the dirt below it, and sends the flue gases to the balloon for stockpile purposes before discharging to the Receiver/ Washer component of the extractor system. The Volume of exhaust gas the absorber can contain is calculated to be $0.00054m^3$ using (1) as follows:

$$V = \pi R^2 h \tag{1}$$

Where R is the radius of the cylinder = *0.03m and h is the height of the cylindrical pipe = 0.33m*

B. Design of Receiver/ Washer

The receiver/washer component of the system decontaminates the CO gas when mixed with water displaced the hydrogen constituent of the reaction and forms CO_2 as shown in (2).

$$CO + H_2 0 \rightarrow CO_2 + H_2 \tag{2}$$

This component is designed considering the volume of gas it will contain using (3) as follows:

$$V = \pi R^2 h. \tag{3}$$

Where: r is the radius of the cylinder = 0.12m, h is the height of the cylinder = 0.4m

Thus, the receiver/washer component designed in this work can contain $0.0181m^3$ of flue gases.

C. Design of Compressor

The compressor device aids continuous pumping of the obtained CO_2 from the Washer component of the system till it gets to the final stage where the dried CO_2 is ready for storage. The compressor mass flow rate and its isentropic efficiency is obtained utilizing dimensionless numbers including head coefficient Ψ, flow coefficient ∅, and Mach number M as follows:

The compressor impeller Velocity (U) is determined using (4) extracted from the study of [9] as follows:

$$u = \frac{\pi d N}{60} \tag{4}$$

Where:

d is the discharge diameter = 0.04m and N is the compressor speed=3000 rev/min

U is thus obtained as 1.745 ms^{-1}. The compressor head coefficient Ψ is calculated as 6.44 using (5) extracted from the study of [10] given as:

$$\Psi = \frac{C_p T_{in}\left(\pi^{\left[\frac{k-1}{k}\right]-1}\right)}{0.5U^2} \tag{5}$$

Where:

C_p is is the constant pressure specific heat = 0.03735 $Kjmol^{-1}K^{-1}$

T is the temperature of CO_2 from compressor = 31.1°C = 304k

k is the specific heat ratio = 1.4

U is the impeller Velocity /the blade tip speed

The compressor Mach number, M is also obtained as 0.00283 using (6) given as:

$$M = \frac{U}{\sqrt{KRT_{in}}} \tag{6}$$

Thus, the Compressor Flow Coefficient is obtained as follows:

$$\emptyset = \frac{\dot{m}}{\frac{\pi}{4}\rho d^2 U} \tag{7}$$

$\emptyset = 83.33.$

Where:

d is the discharge = 40mm = 0.04m

ρ is the density of CO_2 = 1562KgM^{-3}, and

U is the impeller the blade tip speed

D. Design of Belt

Motion transfer between the driver and the follower or driven section of the compressor unit in this work is attained using belt driver medium designed for as follows:

Taking Diameter of the driver (d_1) =0.06 m, Diameter of the follower (d_2) = 0.13 m, Speed of the driver (N_1) =1500 rpm, the required speed of the follower (N_2) is obtained using (8) given as:

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \tag{8}$$

The required speed (N_2) of the follower is calculated as 693 rpm.

E. Determination of the Belt Peripheral Velocity

Thus, the Peripheral velocity of the belt on the driving pulley (V_1) and driven pulley (V_2) are calculated using (9) as follow:

$$V = \frac{\pi d N}{60} \tag{9}$$

The Peripheral velocity (V) is determined as 2.177 ms^{-1}

Where x is the distance between the two pulley diameters,

Thus, the effective belt length is estimated to be 1.38 m.

F. Determination of the Selected Belt Length (L)

The required Length of an open belt, (L) to function effectively with both the driving pulley and the driven pulley is given as:

$$L = \frac{\pi}{2}(d_1+d_2) + 2x + \frac{(d_1-d_2)^2}{4x} \tag{10}$$

G. Design of Dryer

The dryer consist of a drying agent embedded in a designed cylindrical iron pipe insulated using fibre glass with a heating coil incorporated underneath. These are put in place to remove moisture content of the gaseous substance exit from the washer/receiver component of the system. The fibre glass ensures that heat does not spread from the heating chamber to the environment. The drying agent used in this research is silica gel. According to [11], Silica gel is required to remove all moisture present in a gaseous CO_2 before it is sent to the heater. The Volume of gas the dryer can contain is obtained as follow:

$$Volume = \pi R^2 h \qquad (11)$$

Where: R is the radius of the cylinder = *0.03m* and h is the height of cylindrical iron pipe= 0.33m.

Thus, the designed dryer can contain $0.00093m^3$ gas volume.

H. Selection of CO_2 Storage

Carbon dioxide (CO_2) has no liquid state at pressures below 5.11177atm. This is why CO_2 is unstable and so cannot be stored in a liquid form. Thus, the storage for CO_2 gas produce in this work is selected taking into consideration the following designed characteristics:

i. Be dry and free, not corrosive.
ii. Must be well sealed.
iii. The design pressure shall be equal or higher than the maximum working pressure.
iv. Storage vessels for CO_2 shall be provided with a suitable device which prevents over pressurization above the maximum design limits of the vessel and should be provided with a device to prevent overfilling.

I. Selection of Petrol Engine for Exhaust Gases Production

A fairly used Petrol engine of 1000 W was selected to suit the purpose of the research. The generator also serve as a source of driving component via belt connection for motion transmission purpose.

J. Material Selection Criteria

Some of the design factors taken into consideration in selecting materials for the fabrication of the designed CO_2 extractor system so as to enhance its efficiency, reliability, workability, stability and sustainability include:

i. Availability of the material: The materials to be used in the fabrication of the machine must be readily available locally in order to lower the cost of fabrication.
ii. Rigidity and strength: The machine frame must be such that it is rigid enough to resist bending and with adequate strength to support the weight of all the components put together.
iii. Cost: Cost of materials to be used for the fabrication must be relatively cheap, yet meeting the standard requirements for efficient workability of the machine. This factor will also affect the marketability of the machine

K. The CO_2 Extractor System Design Drawings

The detailed conceptual drawing of the designed CO_2 extractor system taking into account the aforementioned design parameters and conditions was done using Solidworks computer aided design CAD application software because of the provision for features such as; 3D solid modelling as shown in Fig. 1, large and complex assembly design, automatic drawing view creation and update, advanced surface design and flattening, direct model editing and CAD import/export to mention but a few. The isometric view of CO_2 extractor system is presented in Fig. 2 while the orthographic view of the designed system showing the front, plan and side views of the machine is shown in Fig. 3. The developed Prototype CO_2 extractor system is as shown in Fig. 4.

L. Operating Principle of a Prototype CO_2 Extractor

The developed Prototype CO_2 extractor system shown in Fig. (1) is set in operation by starting the petrol engine (2) to produce exhaust gases as a waste fumes output of its combustion process, the produced exhaust gases from the power generating petrol engine goes to the absorber (3) section of the system, what the absorber does is to filter and remove unwanted solid particle residue from the exhaust gases generated and sends the filtered gas to the balloon (4) for storage. The compressor component unit (8) of the system functioning as a pump, pumps the stored exhaust gases through the washer component unit (7) for continuous spraying of water to purify the carbon-monoxide and thus converts it to carbon (iv) oxide. The continuous pumping functioning of the compressor (8) thus aids sending the generated CO_2 gas to the dryer unit section (9) of the system for moisture remover purposes and ensures a fully dried CO_2 gas with the help of the heater (10). The produced fully dried CO_2 gas is continuously stored in CO_2 gas storage cylinder (11).

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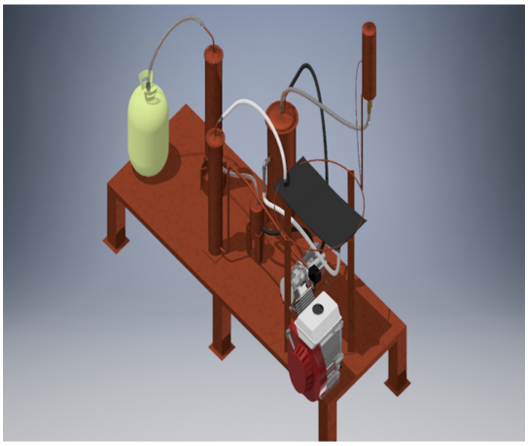

Fig. 1. 3D solid modelling of the designed CO_2 extractor system

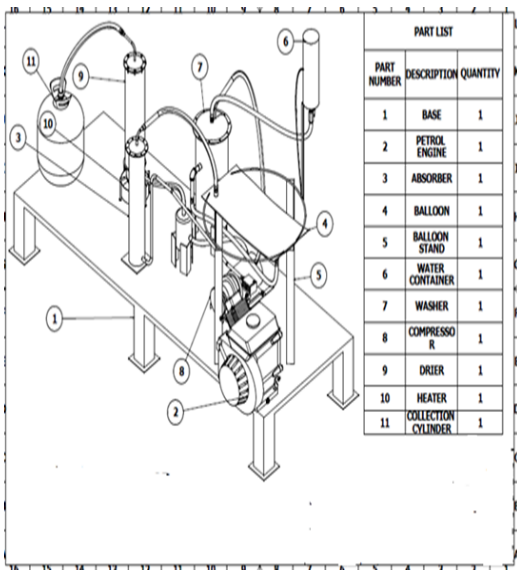

Fig. 2. Isometric view of the designed prototype CO_2 extractor.

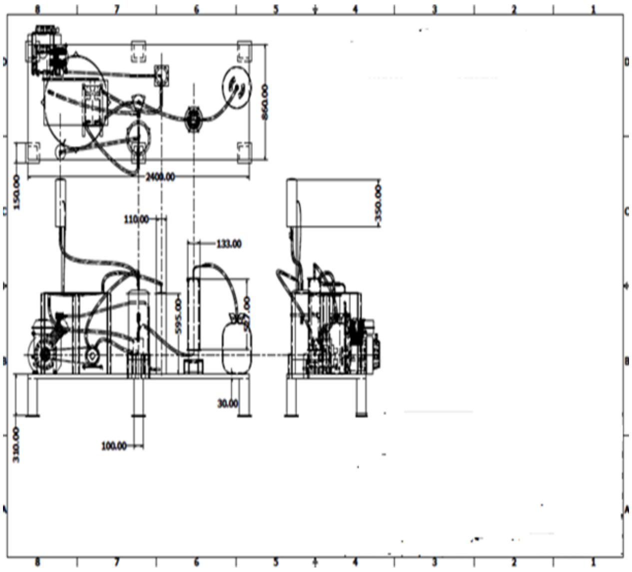

Fig. 3. Orthographic view of designed prototype CO_2 extractor.

III. Results and Discussion

A. Performance Evaluation of the Developed CO_2 Extractor System

Test was carried out to check the functionality of the developed CO_2 extractor system. The test was conducted by putting on the Petrol engine component part of the CO_2 extractor system in operation for exhaust gasses production process in view of conversion to pure CO_2 gas. In the cause of experimentation each part of the developed Prototype CO_2 extractor as shown in Fig. 4 performed effectively by extracting and stored up to 6 kg gaseous substance suspected to be CO_2 gas consuming 3 Liters of fuel (petrol) for a duration of 2 hours. Presented in Table I is the obtained experimental data during the performance evaluation test of the CO_2 extractor system developed in this study. The result from Table 1 revealed that the quantity of CO_2 gas generated increases with the increment of the quantity of the fuel consumed by the Petrol engine while simultaneously generating electrical power for other purpose as expected.

TABLE I: Quantity of CO_2 Gas Generated in This Study

Petrol Utilized (Per Liter)	Time taken (per minutes)	CO_2 gas generated (per Kg)
0.5	20	1
1.0	40	2
1.5	60	3
2.0	80	4
2.5	100	5
3.0	120	6

B. Chemical Analysis of the Produced Gaseous Substance (CO_2 Gas)

With the view to obtain the chemical properties of the gaseous substance generated in this study, The suspected CO_2 gas was assay for chemical confirmatory test using a newly prepared sodalime solution ($CaHNaO_2$) produced in the Chemical Analysis Laboratory domicile in the Department of Industrial Chemistry, Federal University of Technology, Akure (FUTA). It is interesting to highlight that a colorless sodalime solution will change to a milky color if reacted with suspected CO_2 gas. The experiment was performed in a air-tight beaker to prevent air from entering the sodalime solution as shown in Fig. 5 displaying a colorless sodalime solution before reacting with the suspected CO_2 gas produced in this study. Fig. 6 display an immediate change in sodalime colorless solution to a milk color as detailed in chemical equation given in (12-14). This behavior confirmed production of CO_2 gas from exhaust gases as a means of conversion of waste to wealth.

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (12)$$

This reaction is generally delayed all alone, which is the reason the 'pop' part (sodium hydroxide) is added. NaOH act as a catalyst to work with a quicker by and large reaction

$$H_2CO_3 + NaOH \rightarrow NaHCO_3 \quad (13)$$

$NaHCO_3$ reacts further with slaked lime to form caustic soda as shown in (14):

$$\underset{\text{(Baking soda)}}{NaHCO_3} + \underset{\text{(slaked lime)}}{Ca(OH)_2} \rightarrow \underset{\text{(Limestone)}}{CaCO_3} + H_2O + \underset{\text{(Caustic Soda)}}{NaOH} \quad (14)$$

The extracted CO_2 gas attained in this study can be utilized as commodity in the industrial production of materials and fuels if produce and stored in large quantity.

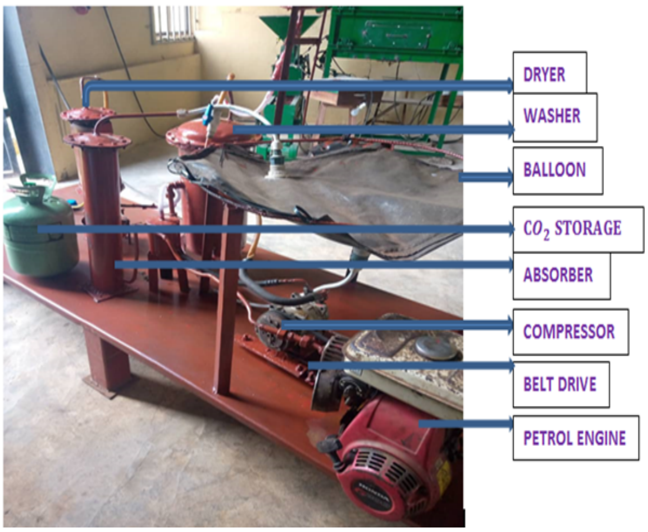

Fig. 4. The developed CO_2 extractor system in this study.

Fig. 5. Newly prepared sodalime solution ($CaHNaO_2$) before CO_2 gas reaction.

Fig. 6. Sodalime solution ($CaHNaO_2$) turned milky after reaction with CO_2 gas.

IV. Conclusion

A prototype extractor of CO_2 from exhaust gases has been developed in this study. The developed system consist of a small petrol engine of 1 kw power, an absorber with volume of 0.00054 m^3, a balloon that can contain sizeable amount of exhaust gas, a washer of 0.0181 m^3, a compressor of 1hp, a dryer which consist of two compartment, with internal volume of 0.00093 m^3 insulated with fibre glass to prevent heat loss. All of these component parts works in a circle, to convert stockpiled exhaust gases from exhaust manifold point source of an electrical power generating set into carbon (iv) oxide (CO_2). Performance evaluation of the system revealed that, each part of the Prototype CO_2 extractor performed effectively as confirmed CO_2 gas was produced based on chemical analysis confirmatory test. The CO_2 extractor successfully extracted carbon (iv) oxide (CO_2) from carbon monoxide, with an average of 1 kg extracted in 20 minutes using half litre of petrol. The result from the study revealed that the quantity of CO_2 gas generated increases with the increment of the quantity of the fuel consumed by the Petrol engine. This work has elucidated one of the means of converting waste emissions (exhaust gases) to wealth and could help to reduce greenhouse effect thus providing a friendly environment for humans' inhabitants.

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Conflict of Interest

Authors declare that they do not have any conflict of interest.

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