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Waste to Wealth through the Incineration of Waste Tyres and Recovery of Carbon Black

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Abstract– **Solid waste management is a problem industrial and municipal areas in the world face daily. In the United States of America, there are up to one hundred and fifty (150) waste-to-energy combustion plants in operation. These plants equally exist in Europe and Asia (Switzerland incinerates about 75% of its solid waste, Sweden incinerates 60% and compost up to 25% of its solid wastes; Japan incinerates about 50%). In Nigeria, there is no known waste-to-energy or waste to wealth combustion plant in existence. In this work, a bench experiment was carried out on incineration of waste vehicle tyres in limited supply of air. The weights of waste tyres used ranged from 22kg – 93kg while the maximum temperature of combustion obtained for test runs ranged from 359 - 586 ^{0}C. The weight of carbon black recovered ranged from 0.44 - 3.2kg. The solid by product of the incineration (carbon black) was collected and analyzed. This product could be used as raw material for small scale industries in production of printing ink, paint, shoe polish, dry cell and battery heads. It is also expected that the results can be used to design an industrially and environmentally friendly carbon black recovery plant from waste tyres.**

Keywords– **Carbon Black, Incineration, Energy, Waste and Tyres**

I. INTRODUCTION

Waste to energy combustion or waste to wealth through combustion and recovery of useful products is a method of handling an increasing percentage of municipal waste. Waste to wealth is a very important factor in the overall integrated solid waste management strategy. The traditional term "incineration" has acquired a bad connotation in the mind of the public due to the poor operation of some waste combustors. Therefore, the term waste-to-energy combustion is now widely used in place. The term incineration refers to modern practice of burning of waste that cannot be recycled economically [1].

Combustion of wastes has long been recognized as a final disposal solution, because the organic matter is destroyed and only solid residues remain. By comparison, land-filling is a solution that amounts to storage, with the continuing risk of unwanted consequences (Taylor, 1992; Jones, 1994). As of the year 2000, over 90 percent of municipal waste is combusted in Japan, 75% in Europe, where landfill of organic matter is essentially prohibited. In the United States, only 15 percent is combusted although in some states, it approaches 50 percent: the low cost competition of landfills has been a major factor in limiting combustion. Waste combustion results in discharge of gaseous and particulate matter to the atmosphere and causes public concern for health and the environment. In order to take advantage of combustion technology, great efforts and continuous evolution have been applied to minimize negative effects. In addition, it is necessary to dispose of the solid residues of combustion which have the potential for harm if not properly managed, mainly due to the solubility of metals, and the risk that they potentially impose on the environment. Based on 2001 data, scrap tyres represented nearly 5.7 million tons, or about 1.8 percent, of the total solid waste stream generated annually in the United States. In terms of quantity, this percentage translates to nearly 281 million waste tyres (RMA, 2002a). These in turn are part of the estimated 1.4 billion scrap tyres that are generated worldwide.

Markets consumed approximately 218 million scrap tyres, whole or shredded, from this annual waste stream. Fifty-three percent of these were used as tire-derived fuel (TDF), 19 percent as ground and stamped rubber products, 18 percent as civil engineering applications, 7 percent as exports, and 3 percent as miscellaneous exports (RMA, 2002a). The remainder of this waste stream, roughly 6 million tyres, went to stockpiles, landfill disposal, single-material tire "monofills," or was disposed of illegally in some manner.

Scrap tyres are composed of natural and manufactured synthetic rubbers, along with various additives, as shown in the following list:

- Synthetic rubber
- Natural rubber
- Sulfur and sulfur compounds
- Silica
- Phenolic resin
- Oil (aromatic, naphthenic, paraffinic, etc.)
- Fabric (polyester, nylon, etc.)
- Petroleum waxes
- Pigments (zinc oxide, titanium dioxide, etc.)
- Carbon black
- Fatty acids
- Inert materials
- Steel wire

(RMA, 2002b)

Tyres present unique and challenging disposal problems because of their size, shape, and physical and chemical properties. Land filling of whole tyres consumes a large volume of landfill space because the tyres are relatively incompressible and 75 percent of the space a tire occupies is empty (Clark et al., 1993). Tyres can also migrate, or “float,” upward to the landfill surface where they can breach the landfill cover. As a further complication, tyres can harbor vectors and are by design resistant to breakdown by mechanical or thermal means as well as by biological degradation. Burying whole tyres in municipal solid waste landfills avoids processing costs but does nothing to mitigate the disposal problems associated with whole tyres. Therefore, whether by regulation or choice, the shredding or splitting of tyres is becoming increasingly common as a part of the disposal process (Clark et al., 1993). Some other forms of tire reduction that have been considered use ultra-high-pressure water (Frenzel, 1993) or a cryogenic process using liquid nitrogen to produce crumb material (NASA, 1997). Tire reduction can effectively eliminate the problems that are associated with whole tyres. The main disadvantage of tire reduction is that it is an energy-intensive extra step that can add appreciably to disposal costs. In a variation of landfilling, shredded tyres can be buried in special single-waste landfills called monofills. Monofills allow easy recovery of tire shreds for potential use at a later date.

One of the most effective means of dealing with many wastes (including tyres), to reduce their harmful potential and often to convert them to an energy form, is incineration. In comparing incineration (the destruction of a waste material by the application of heat) to other disposal options such as land burial, the advantages of incineration are:

- The volume and weight of the waste are reduced to a fraction of their original size.
- Waste reduction is immediate; it does not require long-term residence in a landfill or holding pond.
- Waste can be incinerated on-site, without having to be carted to a distant area.
- Air discharges can be effectively controlled for minimal impact on the atmospheric environment.
- The ash residue is usually nonputrescible, or sterile
- Technology exists to completely destroy even the most hazardous of materials in a complete and effective manner.
- Incineration requires a relatively small disposal area, compared to the land area required for conventional landfill disposal.
- By using heat-recovery techniques the cost of operation can often be reduced or offset through the use or sale of energy. (IIA, 1972)

Incineration will not solve all waste problems. Some disadvantages include:

- The capital cost is high.
- Skilled operators are required.
- Not all materials are incinerable (e.g., construction and demolition wastes).
- Supplemental fuel is required to initiate and at times to maintain the incineration process

Literature search revealed a few reported works on waste to wealth in Nigeria. Some of these include the production of Laterite bricks using blended incinerated corn-cob ash cement by Ogunbode and Apeh 2012; Mohamed and Taher 2006 who investigated the physical and chemical properties of rice husk straw ash and its effects on cement paste produced from different cement; Mohammed in 2009 studied the use of bottom ash from municipal solid waste incineration as road construction material; In Nigeria, there is no known record of the amount of used tyres generated periodically. However, as is obtainable in other countries, it constitutes a disposal challenge. This work was undertaken to investigate an alternative means of its disposal with a view to obtaining useful products that can serve as raw materials for small scale industries.

II. MATERIALS AND METHODS

A) Description of the bench scale experiment

The design drawing and the photographs of the bench scale incinerator for the discarded waste tyres are shown:

The set up consist of the following components namely:

1. Cylindrical combustion chamber
2. Conical channel for flue gases
3. Carbon harvesting chamber
4. Filters
5. Flue gas chimney
6. Connecting flanges
7. Insulation
8. Loading door
9. Limited air inlet channel
10. Structural frame
11. Locking device

The combustion chamber of the experimental incinerator is double walled with insulating materials in the middle of the walls. Short half inch pipes are connected from the outside to the inside of the combustion chamber in opposite directions. This is to allow limited flow of air from the outside to the inside of the combustion chamber. The conical section of the experimental incinerator helps to channel flue gas to the filters in the harvesting or precipitation chamber. The flue gas after passing through the line of filters exit to the atmosphere via the chimney. The waste tyres are loaded into the combustion chamber through the door. The locking device is applied to secure tight closing of the door. The waste tyres are lit in the chamber with a pilot flame before the door is tightly shut.

B) Principle of Operation

The tyres burn in limited supply of air and thus produce thick smoke which flows through the conical channel to the line of filters in the harvesting chamber. The thick smoke contains numerous carbon black particles as it leaves the combustion chamber. The filters are arranged in such a way that flow of smoke is retarded in the harvesting chamber. Velocity flow is reduced resulting in precipitation of the carbon particles on the filters. After combustion of a specified weight of waste tyres and the equipment cools down to ambient temperature, the conical section, the harvesting chamber and the chimney are dismantled for harvesting of the carbon black. This harvesting helps to clean up the system making it ready for combustion of the next batch.

C) Advantages

i. The equipment is portable and easy to dismantle and assemble
ii. Harvesting of carbon black particles is easy by pulling out the filters and collecting deposits on them, on the conical channel and chimney
iii. Materials of fabrication of the experimental incinerator are all locally sourced.
iv. The metallic deposits and ash after combustion are easily disposed
v. The combustion chamber is insulated for conserving heat energy which can be tapped and converted to another form of energy.
vi. The equipment is easy to operate requiring only one or two operators

D) Disadvantages

i. The equipment takes several hours to cool down to ambient temperature after combustion
ii. Atmospheric pollution is high due to exit of flue gases.
iii. Tangible amounts of carbon black are lost even though a large amount is deposited on filters, conical channel and chimney
iv. Condensation of water is observed on some portions of the harvesting chamber which mixes with some portions of the carbon black deposits to form paste or black liquid.

III. RESULTS AND DISCUSSION

The data obtained from the experiments are shown in the Table 1. From the data graphs were plotted to show the relationship between weight of tyres used and the products obtained. These are shown in Fig. 3 - Fig. 7. From the results it was observed that linear relationships exist between samples used and metal components obtained, time taken, and temperature. The amount of carbon black and ash produced had quadratic relationships with samples used. The equations showing these relationships are given in equations 1-5.

Chemical analysis of carbon black particles (Fig. 8), paste and liquid obtained were carried out and the result is presented in the Table 2. Comparing the data obtained from chemical analysis of the combustion products to the standard composition of carbon black shown in Table 3, it was observed that the carbon black obtained from the experiment compares favorably with that which is obtained from long flow or high-colour channels.

IV. CONCLUSIONS

From the results obtained the following conclusions can be made:

- Reasonable amount of carbon black can be recovered from combustion of waste tyres
- The equations obtained can be used to predict the amounts of products that can be obtained from waste tyres under similar conditions
- The reduction in size of waste tyres was significant and can be employed in waste management where landfills are used.
- Research can be carried out on the ash content to ascertain its suitability as road construction material (see Mohammed 2009)

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Table 1: Experimental result of combustion of waste tyres

s/n	Wt/ loading (kg)	Wt of metal compnt (kg)	Wt of ash/ batch (kg)	Wt of carbon black (kg)	Time (mins)	Max temp (^0C)
1	22	2.5	2	0.44	65	359
2	31	3.92	3.16	1.26	78	379
3	43	5.71	4.33	1.78	92	404
4	51	7.5	5.50	2.30	110	431
5	60	8.77	6.08	2.5	129	461
6	72	10.77	6.66	2.71	151	496
7	80	11.73	7.24	2.89	175	536
8	93	13.0	8.0	3.2	198	586

Table 2: Data for chemical analysis of products of combustion using Atomic Absorption Spectrometer (AAS) model 210 VGP: Buck Scientific

S/N	Samples (Carbon Black)	Parameters (%)			
		Carbon	Oxygen	Hydrogen	Volume content %
1	Powder	86.5	10.96	1.13	17.57
2	Paste	72.4	9.12	7.99	16.11
3	Liquid	23	13.91	30.73	12.18

Table 3: Composition of typical carbon black

Type	Carbon %	Oxygen %	Hydrogen %	Volume content %
High Colour Channel	88.4	11.2	0.4	18
Long flow channel	90.0	8.7	0.8	12
Reinforcing channel	95.2	3.6	0.6	5
Semi-reinforcing furnace	99.2	0.4	0.3	1.2
Reinforcing oil furnace	98.0	0.8	0.3	1.4
Thermal acetylene	99.5	0.8	0.05	0.06

(Source: Kirk, 1967)

(a)

(b)

Fig 1: Samples of waste tyres collected for the experiment

(a)

(b)

Fig. 2: Photograph of bench scale incinerator, (a) loading door open, (b) Set up tightly shut.

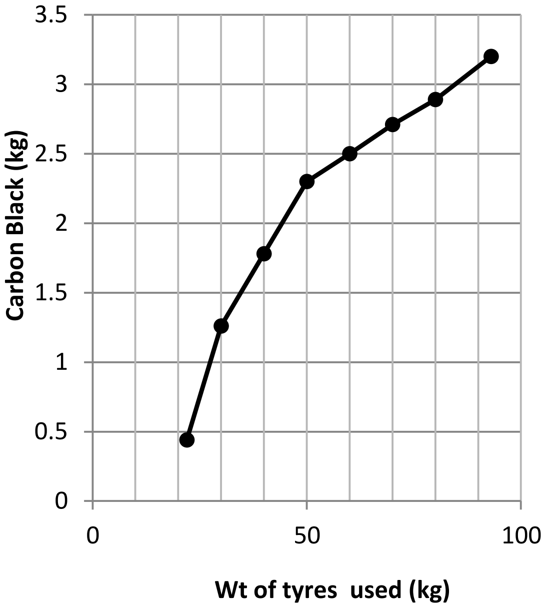

Fig. 3: Plot of Carbon Black Produced against quantity of tyres incinerated

$$Y= -0.000x^2 + 0.092x - 1.189 \quad R^2 = 0.982 \qquad (1)$$

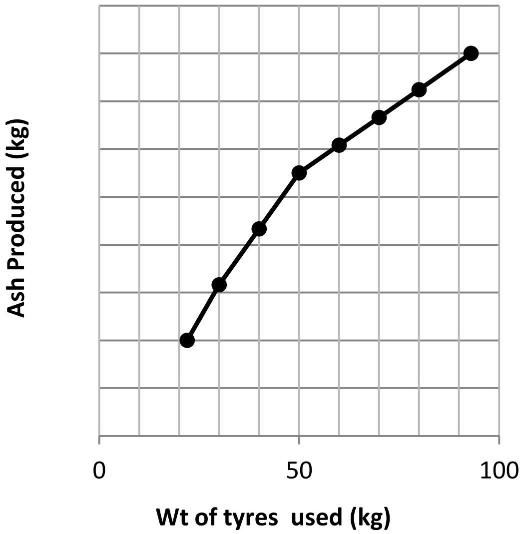

Fig. 4: Plot of Ash produced against quantity of tyres incinerated.

$$Y = -0.000x^2 + 0.167x - 1.210 \quad R^2 = 0.995 \qquad (2)$$

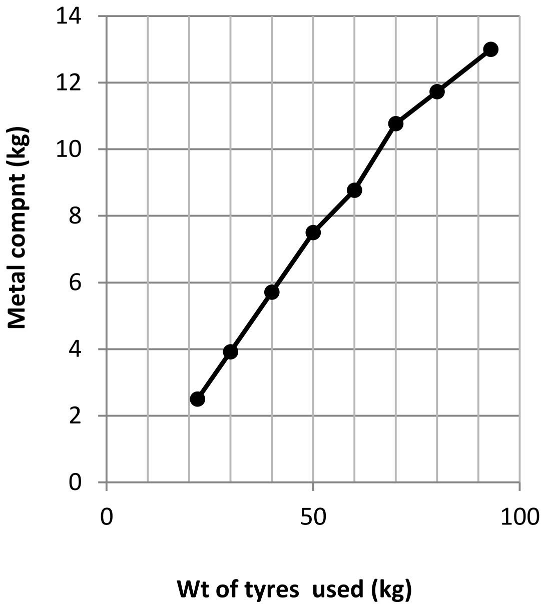

Fig. 5: Plot of Metal component produced against quantity of tyres incinerated

$$Y = 0.151x - 0.448 \quad R^2 = 0.988 \qquad (3)$$

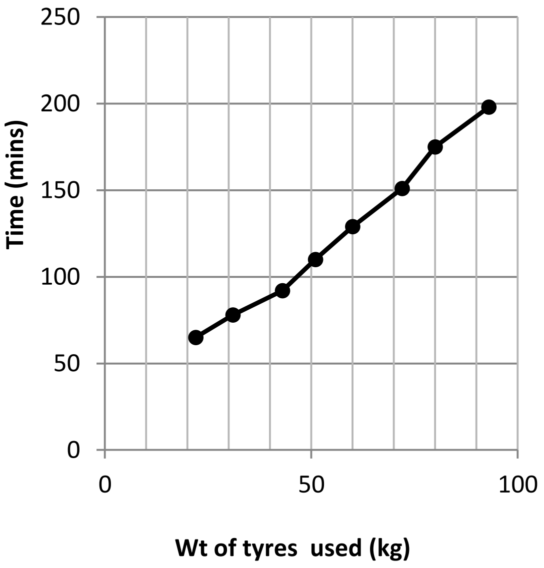

Fig. 6: Plot of time spent against quantity of tyres incinerated

$$Y = 1.922x + 16.15 \quad R^2 = 0.989 \qquad (4)$$

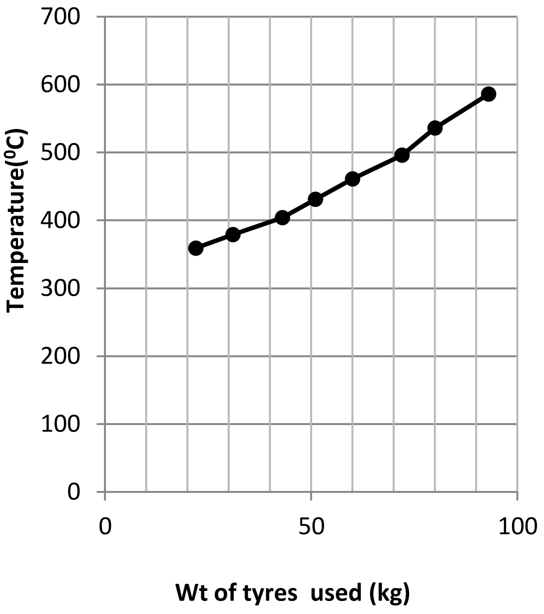

Fig. 7: Plot of temperature reached against quantity of tyres incinerated

$$Y = 3.201X + 275.6 \quad R^2 = 0.984 \qquad (5)$$

Fig. 8: Samples of Carbon Black collected from filters, conical section

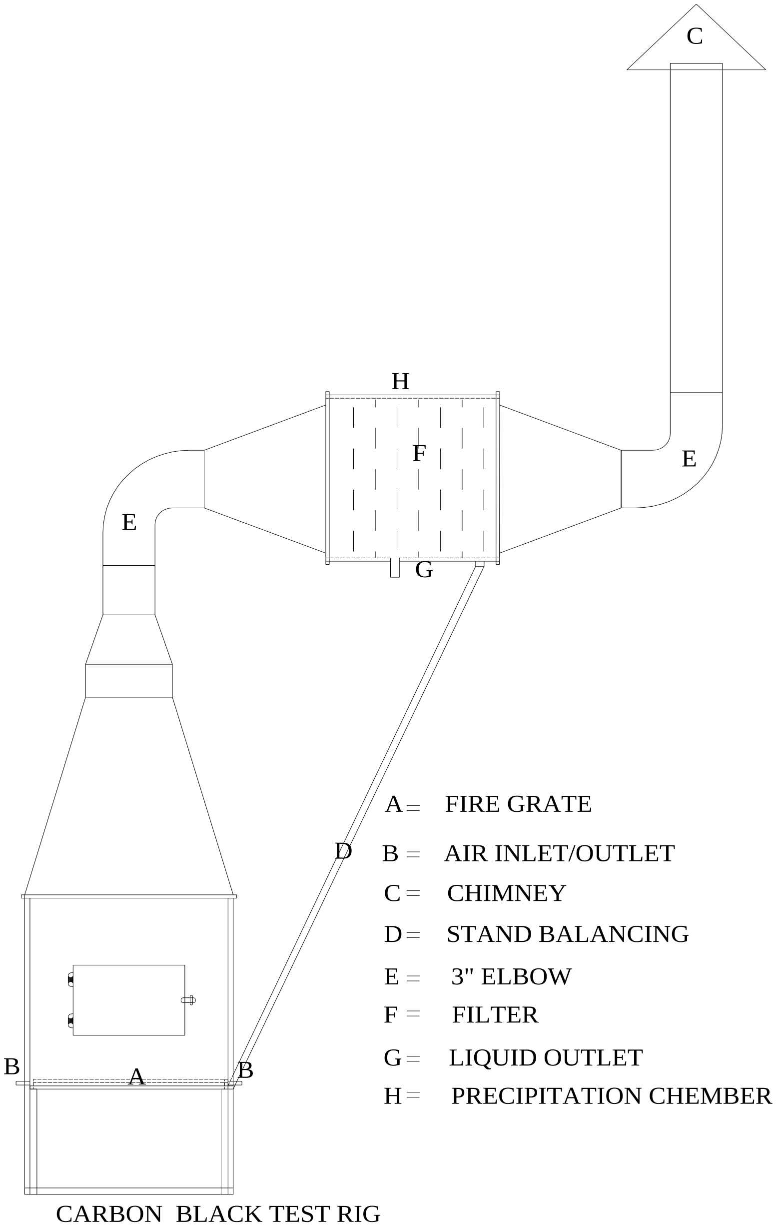

Fig. 9: Carbon Black Test Rig