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DETERMINATION OF WEAR ELEMENTS IN STEYR URSUS TRACTOR LUBRICATING OIL USING ATOMIC ABSORPTION SPECTROSCOPY (AAS)

Ahmad[1,2], H. I., M. L. Suleiman[2], D. Ahmad[3] and D. D. Yusuf[2]

[1]Department of Agricultural Engineering
Faculty of Engineering
Bayero University, Kano-Nigeria
[2]Department of Biological and Agricultural Engineering
Faculty of Engineering
Universiti Putra Malaysia
Email: habibu1963@yahoo.co.uk,

ABSTRACT

A study was conducted to determine the presence and level of wear elements in engine lubricating oil of steyr ursus tractors. Ten tractors engaged in refuse collection and disposal within Kano metropolitan area were selected and their engine oils samples collected over a period of three months at intervals of one week. The oil samples were prepared for elemental determination using atomic absorption spectroscopy (AAS) by dry ashing and aquaregia solutions. Results indicated presence of eight elements (Zinc, Copper, manganese, Nickel, Copper, Cobalt, Lead and Chromium). Data was analysed using SAS package in completely randomized design with no replications. The ANOVA show significant differences between the tractors in element concentrations for Fe, Cu, Ni, Cr and Zn. However, using available concentration limits in the literature, chromium is the only element found exceeding tolerable limit. Chromium is an alloy constituent of engine parts principally concerned with engine power generation. The study recommends regular monitoring of wear elements in order to obtain satisfactory performance and avoid premature failure during critical period of operations.

Keywords: *Wear elements, lubricating oil, tractor engine, Atomic Absorption Spectroscopy (AAS), Steyr Ursus tractor, metal alloy, engine parts, premature failure*

INTRODUCTION

The tractor engine develops power by converting the chemical energy contained in fuels into mechanical and other forms of energy. Our present age may sometime be called the fossil fuel age since most of our present power use is coming from stored fuel. Diesel fuel has become the dominant fuel for farm tractors. Conventional piston engines have hundreds of parts, and the reciprocating units must be stopped and started thousands of time per minute. Hence efficient lubrication is essential for any machine system with several moving parts.

Lubrication accounts for a significant proportion of equipment failures. Improper lubrication practices are at the heart of many equipment reliability issues. Studies have shown that 70-85% of equipment failures are self induced, meaning that maintenance practices and processes are directly responsible for the failures. As such, it's obvious that proper lubrication is vital to the success of reliability and, in turn, operational assurance and cost control. Without proper lubrication, excessive friction would consume much of the engine power and the moving parts would wear at a rapid rate. In addition to reducing friction, a lubricant acts as a cushion agent between the mating parts and can transport heat away from bearings.

Carbon formation can cause poor engine performance and can cause damage to it. Carbon may pack in and around the piston rings, causing them to stick in the ring groove. This prevents the proper operation of the piston ring. This may result in blow-by, poor compression, excessive oil consumption and scoring of cylinder walls. Carbon may build up on the piston head and in the cylinder head. Carbon may also form on the underside of the piston to an extent such that heat transfer is hindered which can result in the overheating of the piston. Pieces of carbon may break off and drop into the oil pan, where they may be picked up by the lubrication system. They could then clog oil channels and lines so that the flow of the lubricant oil to the engine parts would be dangerously reduced. A good lubricating oil must be sufficiently resistant to heat and be able to operate in the condition prevailing in the engine to bring the amount of carbon to a minimum [1].

Lubricating oil serves as an effective seal to reduce the blowby of combustion gases past piston rings. Also, lubricating oil acts as a cleansing agent by removing carbon deposits inside tractor engines.

Adekoya and Otono [2] investigated tractor repair models in Nigeria and attributed the relatively higher repair costs to the high costs of imported parts, misuse of tractors, and the lack of preventive maintenance.

An effective lubricant analysis program will promote equipment availability, reduce or eliminate lubrication problems, protect operating equipment against excessive or premature wear, reduce plant delays and downtime, and reduce maintenance overall operating cost. Ohta et al. [3] used AAS technique and determined levels of wear for copper, iron, chromium, aluminium and silica. Schumacher and Gerven [4] determined the levels of iron, copper, chromium, silicon, lead, and aluminum wear metals in each sample collected from diesel engines fueled with different ratios of biodiesel. Thus, the aim of this study is to determine the presence and concentrations of wear elements found in Steyr Ursus tractor engine lubricating oil as part of on-going efforts [5] [6] toward developing preventive maintenance strategy for tractors in Kano State of Nigeria.

METHODOLOGY

Kano-City, Nigeria as the study area: Location and Population

Kano (12^o 00$^'$N and 8^o 31$^'$E) is a city in Nigeria and the capital of Kano State in Northern Nigeria. Its metropolitan population is the second largest in Nigeria after Lagos. The Kano Urban area covers 137 sq.km and comprises six Local Government Area (LGAs) - Kano Municipal, Fagge, Dala, Gwale, Tarauni and Nassarawa - with a population of 2,163,225 at the 2006 Nigerian census. The Metropolitan Area covers 499 sq.km and comprises eight LGAs - the six mentioned above plus Ungogo and Kumbotso - with a population of 2,828,861 at the 2006 Nigerian census.

Selection, Specification and Use of Steyr Ursus Tractor by REMASAB

Many makes of two-wheel, four-wheel and four-wheel-drive tractors are used in Nigeria. These include Steyr, Fiat, Massey Fergusson, John Deere, Valvet, Case International, Kubota, etc. Because of rising need of tractors in Nigeria during the late 70's, two tractor assembly plants were established, one for Fiat and another for Steyr. To date these two brands are very common in most parts of the country. However, it is only the Steyr plant that is presently giving skeletal technical services on its products. The steyr tractors used in this study were purchased from the Steyr plant Company in Bauchi (300 km from Kano) in 2003.

The Refuse Management and Sanitation Board (REMASAB) are using these Steyr tractors for collecting and transporting refuse from household collection centres to township dumping sites in the densely populated Kano Metropolitan area.

One set of tractors are carrying front loading buckets powered through the hydraulic system of the tractor and another set drawing tipping trailers. Based on availability of the tractors, the tractors can be interchanged from loader to transporter. One loader may be loading about 3-5 transporters and together form a gang/team. Depending on the relative distance between the collection centre and the dumping site, the loader may be overworked than the transporter or vice versa. The map of Kano metropolitan is shown in Figure 1 with dot circled and the area has a population of over 2million . It is a great challenge to REMASAB handling domestic, commercial and industrial refuse generated on a daily basis. The technical specifications of the tractor used in this study are indicated in Table 1.

Table 1: Specifications of Steyr Ursus tractor

Technical characteristics	Steyr Ursus 4514 DL
Number of cylinders	4
Bore/Stroke	98X127mm
Displacement	3.9L
Power	72hp (53.7kW)
Gears	8 forward 2 reverse

Source: TractorData.com, 2011

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Collection of Samples from Steyr Ursus Tractors

The bottom plate area where the drain screw is located was washed thoroughly to avoid any substance getting into the sampling sachet. The drain nut was unscrewed gently while attaching the collecting sachet closely. This was to avoid air carrying many elements into the sample. About 10 ml was collected from the engine sump during each sampling. With this small quantity being drawn each time, the oil level in the sump will not be lowered below the limit to warrant topping before change of oil which will dilute the elements concentration and lead to wrong interpretations.

Samples were taken from ten (10) tractors for three (3) oil changes at weekly intervals for three (3) weeks. This will give 90 samples or treatments. However due to the investigative nature of the study, some tractors were not available for sample collection during the designated times, thus 61 samples were collected and further treated for elemental determination.

Sample preparation for element determination

10mg of the 10ml collected from the tractor engine was placed in a crucible and ashed using dry ashing technique in an oven at 450^{o}C to remove all carbon content. The remaining ash was then digested by dissolving in an aqua-regia solution (HCl and HNO_3 in a ratio of 1:3). The mixture of the ash and aqua-regia was then evaporated/dehydrated at 50^{o}C. The remaining solid was then dissolved in another aqua-regia solution and filtered. The filtrate was then dissolved in fresh nitric acid for preservation and extraction/determination of total elements present. The preserved samples were taken for determination of elemental concentrations using AAS machine at Soil Science Department, Bayero University, Kano.

Theory of AAS Technique

Atomic absorption spectroscopy (AAS) is a spectroanalytical procedure for the quantitative determination of chemical elements employing the absorption of optical radiation (light) by free atoms in the gaseous state.

Atomic absorption spectroscopy (AAS) determines the presence of metals also in liquid or directly in solid samples (www.en.wikipedia.org/wiki/Atomic_absorption_spectroscopy). Metals that can be determined using AAS include Fe, Cu, Al, Pb, Ca, Zn, Cd and many more. It also measures the concentrations of metals in the samples. Typical concentrations range in the low mg/L (ppm) range (www.gmu.edu.depts/SRIF/tutorial/aas/aas.htm).

In their elemental form, metals will absorb ultraviolet light when they are excited by heat. In atomic absorption, there are two methods of adding thermal energy to a sample. A graphite furnace AAS uses a graphite tube with a strong electric current to heat the sample. In flame AAS, we aspirate a sample into a flame using a nebulizer. The flame is lined up in a beam of light of the appropriate wavelength. The flame (thermal energy) causes the atom to undergo a transition from the ground state to the first excited state. When the atoms make their transition, they absorb some of the light from the beam. The more concentrated the solution, the more light energy is absorbed.

Each metal has a characteristic wavelength that will be absorbed. The AAS instrument looks for a particular metal by focusing a beam of ultraviolet light at a specific wavelength through a flame and into a detector. The sample of interest is aspirated into the flame. If that metal is present in the sample, it will absorb some of the light, thus reducing its intensity. The instrument measures the change in intensity. A computer data system converts the change in intensity into an absorbance.

As concentration goes up, absorbance goes up. The researcher can construct a calibration curve by running standards of various concentrations on the AAS and observing the absorbances. Then samples can be tested and measured against this curve. The atomic absorption spectrometer uses the principals of quantum mechanics.

Although the atomic absorption spectrophotometer (Figures. 1 and 2) is quite expensive, the technique is very wide-spread. However, with AAS it is possible to determine about 70 elements (mainly metals) at very low concentrations (www.standardsbase.com/tech/FinalHUTechAAS.pdf), if corresponding lamps for the elements are available.

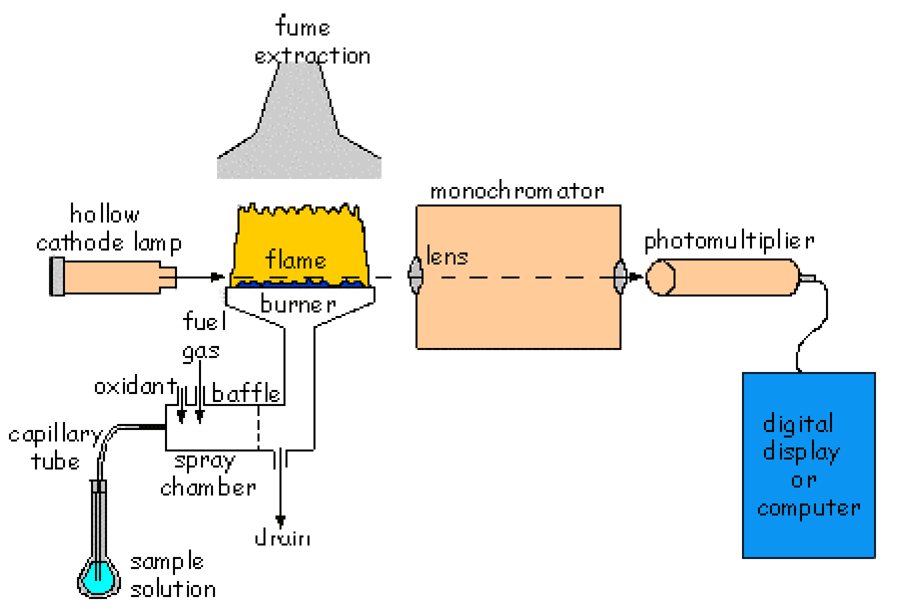

Fig. 1. A schematic diagram of atomic absorption spectrometer
(source: http://www.thebritishmuseum.ac.uk/science/techniques/sr-techaas.)

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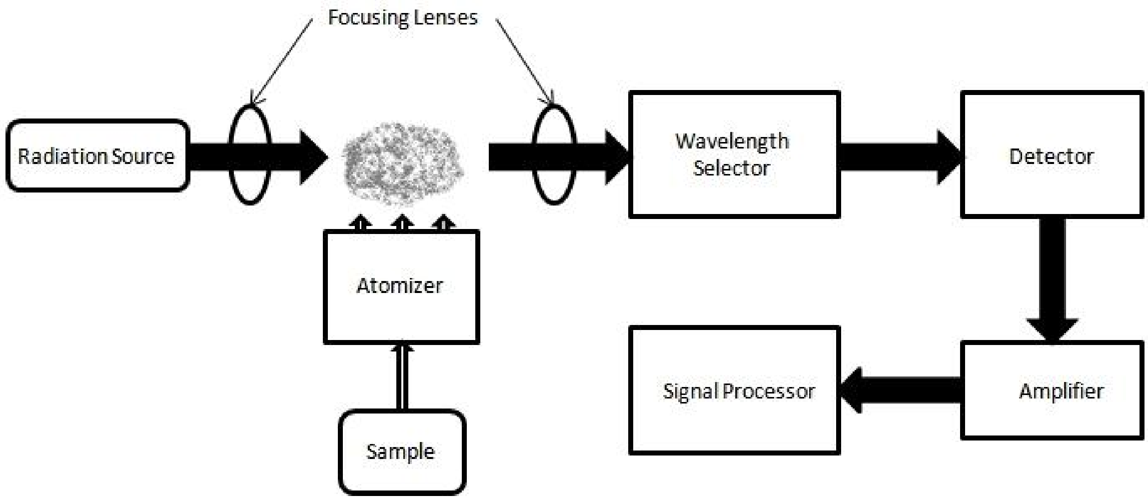

Fig. 2. Atomic absorption spectrometer block diagram (Source:Wikimedia Commons.)

Specification and operating parameters of AAS machine

The specification and experimental set up of Buck 210 VGP AAS machine is given in Table 2. The 61 samples preserved for elemental determination were investigated for elements whose lamps were available in laboratory. Only eight lamps were thus used in the determination and results obtained for them.

Table 2: Brief Specifications and operating parameters of Buck 210 VGP

Model	**Buck 210 VGP**
Burner-Atomizer	Laminar flow, single-slot burner, all-titanium adjustable atomizer, adjustable bead, optional N20
Monochromator	Elbert grating with 600 lines/mm
Focal Length	250nm
Wavelength range	190-900nm (Automated wavelength selection)
Detection Limits (ppb)	
Calcium	50
Copper	5
Iron	50
Lithium	50
Magnesium	5
Silver	0.5
Nickel	3
Lead	0.8
Selenium	0.7
Gas Regulator	Interlock on N20, flashback arrester, optional flame sensor
Ignition	Manual
Power Requirement	100, 115, 200,40V
Dimensions (HXWXD)	30.5X27.9X99.1cm
Weight	27kg

Source: Extracted from www. medwow.com/med/atomic-absorption/buck-scientific/buck-210-vgp/2936.model-spec

RESULTS AND DISCUSSION

The AAS result is presented and discussed under analysis of variance between tractors and element concentrations, regression equation for element concentration prediction and analyzing source of element within the engine components. These results are part of an ongoing postgraduate research

Regression Analysis

The regression analysis result of the eight elements standards used for the AAS machine is given in Table 3. These were used in converting the AAS readings to obtain actual concentrations of each element present in the tractor samples. A sample of the calibration data plot for Chromium is shown in Figure 5. The ANOVA table and DMRT for Chromium are in Table 4 and 5 respectively. The independent variable X is the AAS reading while the outcome or dependent variable Y is the element concentration. All the regression equations (Table 3) show good agreement between the variables with more than 60 % variation of the elements concentrations being explained or accounted for by the machine reading [7]. If the AAS machine setting is fixed, the elemental concentrations from subsequent oil samples taken overtime could easily be computed with these equations and compared with standard limits for maintenance decisions. Luckily many AAS machines have in-built sealed optical compartments that protect the optics from laboratory environments (www.shimadzu.ru/brochures/aa6200.pdf). This ensures high sensitivity and reproducibility over the lifetime of the instrument.

Table 3: Regression equations and R^2 values for the wear metals calibration standards

s/no	Wear element	Regression equation	R^2 Value
1	Chromium	Y = 669.44x	0.889
2	Cobalt	Y = 49.115x	0.9518
3	Copper	Y = 44.527x	0.9857
4	Iron	Y = 653.7x	0.9911
5	Lead	Y = 32.128x	0.6256
6	Manganese	Y = 662.63x	0.9335
7	Nickel	Y = 491.15x	0.9516
8	Zinc	Y = 497.19x	0.9939

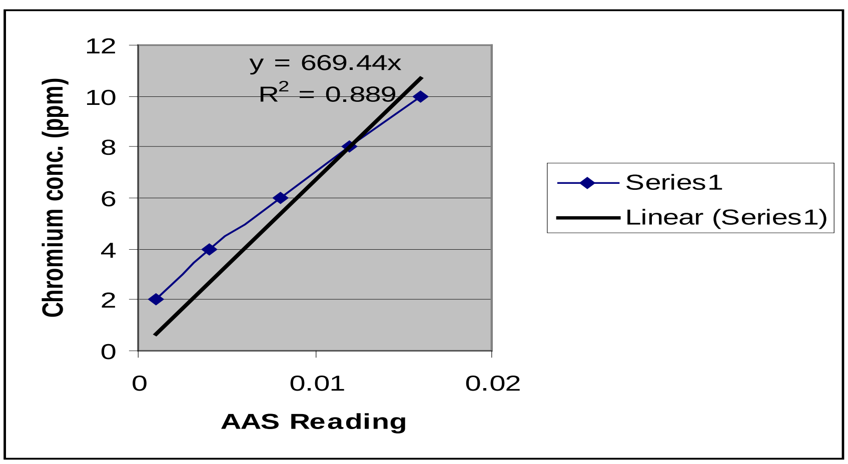

Fig. 5. Standard calibration curve for Chromium

Table 4: ANOVA Table for Chromium

Source	DF	SS	Mean Square	F Value	Pr > F
Rep	1	0.00028667	0.00028667	88.80	<.0001
tractor	9	0.00029635	0.00003293	10.20	<.0001
Error	50	0.00016142	0.00000323		
Corrected Total	60	0.00074056			

Table 5: DMRT ranking for Chromium element for ten tractors

Tractor No.	**Chromium element**	
	Mean	**Ranking[1]**
1	0.005250	C
2	0.007400	C
3	0.007429	BC
4	0.007167	C
5	0.009571	AB
6	0.005143	C
7	0.010857	A
8	0.011833	A
9	0.010000	A
10	0.010333	A
SE		

[1]Means with similar letters are not significantly different

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The ANOVA for the 8 elements show significant differences between the tractors for Iron, Copper, Nickel, Chromium and Zinc. There were no significant element concentration differences between the tractors for Manganese, Cobalt and Lead. Iron and copper are catalytic wear elements that react with water in oils to form products that could restrict oil flow. As little as 0.1% water in oil can increase oil's oxidation rate up to ten times under certain conditions. While all machines are at risk, of particular concern are those that operate in high humidity environments and/or have cycling temperatures. REMASAB tractors are working through the rainy season unlike tractors used for field crop operations. Rust causes loss of surface profile, embitterment of the surface, and deposit formation as rust particles flake off from surfaces and fall into the lube oil system. Not only does this destroy the surface finish, but the rust particles then circulate throughout the system causing particle-induced failures. Therefore, closer monitoring of these wear elements concentrations could prolong machine life even if the lubricant has not been degraded. With this monitoring an optimum lubricating oil change period could be arrived at, unlike the rigidly followed time interval/hours run recommended by manufacturers.

Sources of Wear Elements and Allowable limits

The summary of source(s) of these elements from the tractor engine parts are presented in Table 6. Tractor number 4 produces highest concentrations in iron (15.68ppm) and Manganese (132.52ppm). Tractor number 6 produced highest in Copper (4.14ppm) and Cobalt (6.38ppm). Tractor number 9 produced highest in Nickel (7.86ppm) and Lead (2.02ppm). Tractor number 1 produced highest in Zinc (139.2ppm). Tractor number 8 produced highest in Chromium (10.71ppm). Tractor numbers **2, 3, 5, 7, and 10** were producing lower element concentrations than tractor numbers 4, 6, 9, 1, and 8. This shows that more attention should be given to those with higher concentrations in order to avoid premature failure during critical operation periods. Since the tractors are virtually performing similar operations interchangeably, the attitude of tractor operators may be contributing the elemental concentration differences.

Chromium, as an ingredient for cylinder block, cylinder liner and piston rings [9] [10], has concentrations higher than allowable limit of 5ppm in all the ten tractors. Cylinder liner and piston rings are essential components for getting maximum power from internal combustion engines. These components should be replaced whenever tractor power measurements decline below tolerable limits. The cost of changing parts is much lower than the cost of lost production.

Table 6: Engine component source(s) of the wear elements

ELEMENT	ALLOWABLE LIMIT[a] (ppm)	Max conc. determined (ppm)/ Tractor No.	ENGINE COMPONENT(S) WITH ELEMENT AS ALLOY CONSTITUENT	TRACTOR NO(S) EXCEEDING allowable limit CONC./Max conc. (ppm)
Zinc		139.2(1)	A common oil additive	
Chromium	5	10.71(8)	Cylinder block, cylinder liner, piston rings.	1(5.55ppm), 3(9.37), 4(8.03), 5(9.37), 6(6.69), 7(9.37), 8(10.71), 9(8.03), 10(9.37)
Nickel		7.86(9)	Cylinder liner (aluminium)[b]	
Lead		2.02(9)	Plain bearings	
Copper	20	4.14(6)	Cylinder head	
Iron	100	15.68(4)	Cylinder block, cylinder liner, cylinder head (aluminium)[b], piston rings, piston (aluminium)	
Cobalt		6.38(6)	Valve seats, hard coatings.	
Manganese		132.52(4)	Cylinder block, cylinder liner (silicon)[b], piston rings (silicon)	

[a]Source: Ohta et al. (1988), [b]Elements in brackets were not determined due to lack of appropriate lamp attachments for the AAS machine used in the study.

Many tractor operators are in the habit of over throttling during clutching or trying to impress people if their tractor engine is sound. This operational attitude cause excessive piston ring flutter as a result of overspeeding [10]. Thus, continued operator training and sensitization should never be neglected or considered unimportant.

CONCLUSION AND RECOMMENDATIONS

Conclusions

This study had the objective of determining the presence and level of wear elements in Steyr Ursus tractors as being used for refuse collection and disposal by REMASAB in Kano State of Nigeria toward developing strategies for better maintenance. The following could be deduced from the study:

i) All the ten tractors have certain quantities of chromium, nickel, copper, zinc, manganese, iron, cobalt and lead.

ii) Five of the elements were found being produced in quantities that have significant differences between the tractors.

iii) Chromium is the only element found in excess of allowable limit by all the tractors.

iv) Operator attitude (unnecessary overspeeding of engine) may be the cause of piston ring wear and thus producing chromium in the lubricating oil.

v) The power of the tractors could be greatly reduced by piston ring and cylinder wear.

Recommendations

From the results of this study, it is hereby recommended that:

i) More element lamps should be obtained for the AAS machine or more sophisticated equipment/technique (ICP-OES) be used to analyse the same samples in order to detect the presence of more elements.

ii) Basic research towards ascertaining the tolerable limits of wear for more elements should be undertaken for proper decisions to be taken on major/sensitive components of the tractor engine.

iii) Regular monitoring of wear elements should used by organizations with having tractors as means of preventing premature failure of components, which could be costly during critical periods of operation.

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