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CHEMICAL CHARACTERIZATION OF FRESH AND USED ATF OF GEARBOX VIA FTIR SPECTROSCOPY

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ABSTRACT: *Automatic transmission (AT) systems are widely recognized for enhancing vehicle safety, comfort, reliability, and overall driving performance. During regular operation, the automatic transmission fluid (ATF) within the gearbox undergoes various physical and chemical changes. Some constituents of ATF—especially in its used state—pose potential risks to public health and the environment. This study aims to collect ATF samples from the gearbox of a bus engine and analyze them using Fourier-transform infrared (FTIR) spectroscopy. FTIR was utilized to characterize the chemical composition of both fresh and used ATF samples. Absorption bands in the 1704–1603 cm^{-1} region were attributed to carbonyl functional groups, while peaks at 869, 813, and 1603 cm^{-1} corresponded to newly formed aromatic hydrocarbons, including polycyclic aromatic hydrocarbons. The FTIR spectra of the used ATF revealed the presence of alcohols, aldehydes, and ketones, suggesting significant chemical and biological degradation.*

KEYWORDS: Automatic transmission fluid (ATF), Gearbox, FTIR.

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INTRODUCTION

A car gearbox, commonly referred to as a transmission, is a mechanical system responsible for transmitting power from the engine to the wheels. Its primary function is to allow the driver to regulate wheel torque and speed by selecting appropriate gear ratios. Gearboxes can generally be classified into two main types: manual and automatic. Manual transmission systems employ a clutch to engage or disengage the engine from the gearbox and a gear shift lever to manually select gears. In contrast, automatic transmissions shift gears autonomously, relying on hydraulic or electronic control systems. The choice of gearbox type depends on the vehicle's design, intended purpose, and driver preferences (Genta & Morello, 2020).

Automatic transmission fluids (ATFs) are vital for the proper functioning of transmission systems, particularly in the transportation sector (Zeng et al., 2013). ATF serves primarily to reduce friction between stationary and moving components, thereby minimizing wear during operation. This lubrication is achieved through specialized molecular additives that form protective tribological layers on component surfaces (Foo et al., 2002). Additionally, ATF mitigates the effects of dust, corrosion, and general wear, ensuring extended gearbox service life (Shri *et al.,* 2014). However, ATFs are continually subjected to varying ambient and operating conditions, which may lead to degradation of their lubricating properties and eventually cause severe transmission damage (Al-Ghouti et al., 2010). To prevent gearbox failure, ATF must be replaced before its protective performance significantly declines, while avoiding unnecessary replacement to minimize environmental impact and economic cost (Barret & Stover, 2005).

Used ATF refers to degraded transmission fluid that has become contaminated with metals, ash, carbon residues, water, varnish, gums, and other particulate matter. These contaminants, combined with fluid aging and thermal-oxidative degradation, can lead to mechanical malfunctions and reduced transmission efficiency (Hamawand et al., 2013). Consequently, timely replacement of ATF is essential to maintain gearbox reliability. Improper disposal of used ATF poses significant environmental and economic challenges. When discharged onto land, into water bodies, or incinerated as a low-grade fuel, used ATF can release toxic metals and pollutants, contributing to soil, air, and water pollution (Hamawand et al., 2013).

Fourier-transform infrared spectroscopy (FTIR) is a useful tool for distinguishing the chemical and physical differences between fresh and used ATF. FTIR spectra obtained on an absorbance basis allow for the evaluation of the fresh fluid's chemical constituents and the identification of compositional changes after a defined operational period (Upadhyay & Kumaraswamidhas, 2013).

EXPERIMENTAL METHODS

In this study, samples of automatic transmission fluid (ATF) were obtained from the gearboxes of bus engines. Five used ATF samples were collected from various automobile crankcases using clean, contamination-free bottles. Each sample was properly labeled according to its respective brand. For comparison, fresh ATF samples of the same brands were procured from authorized lubricating oil vendors in Jega town, Kebbi State, Nigeria.

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RESULT AND DISCUSSIONS

This section presents the FTIR spectroscopy results for the automatic transmission fluid (ATF) collected from bus engines. All samples were examined using a Perkin-Elmer Spectrum 1000 FTIR spectrometer to determine the chemical composition based on absorbance characteristics of the materials both prior to and after service. The spectra of the used transmission fluids were then analyzed and compared with those of the fresh fluids, which served as the reference baseline.

The FTIR result of the fresh and used automatic transmission fluid is shown in fig. 3.1 to 3.10

Fig 3.1: FTIR result of sample A1

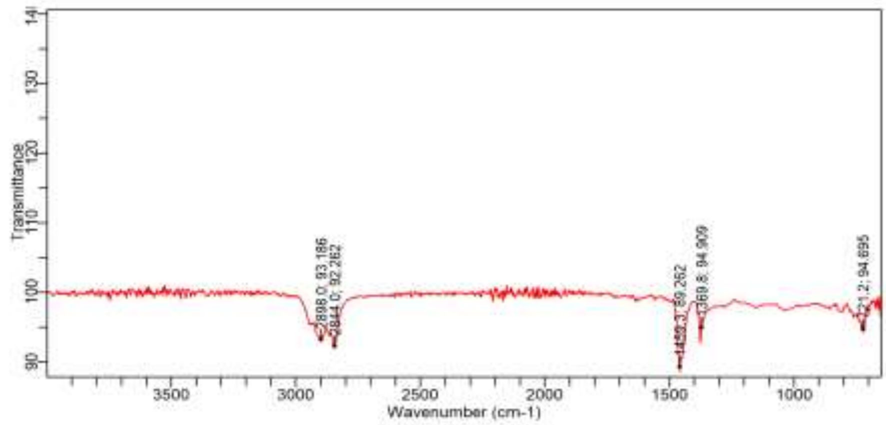

Fig 3.2: FTIR result of sample A2

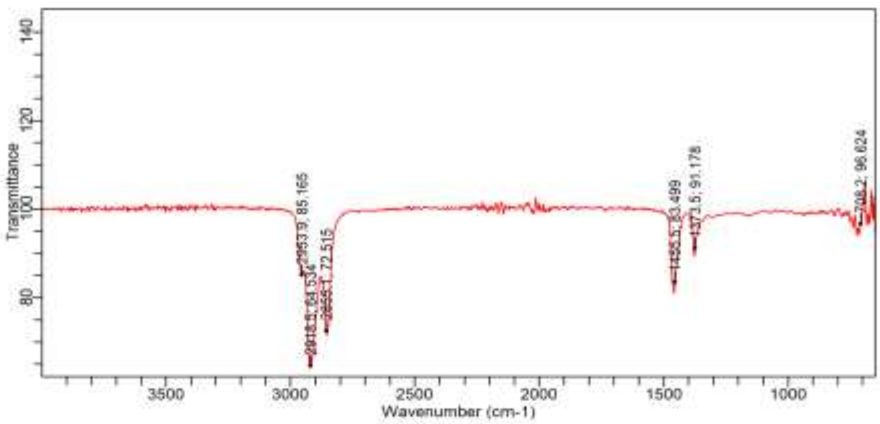

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Fig 3.3: FTIR result of sample B1

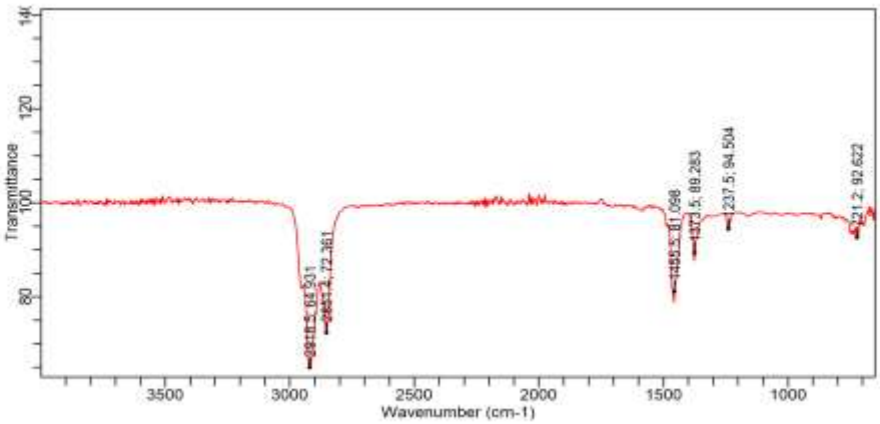

Fig 3.4: FTIR result of sample B2

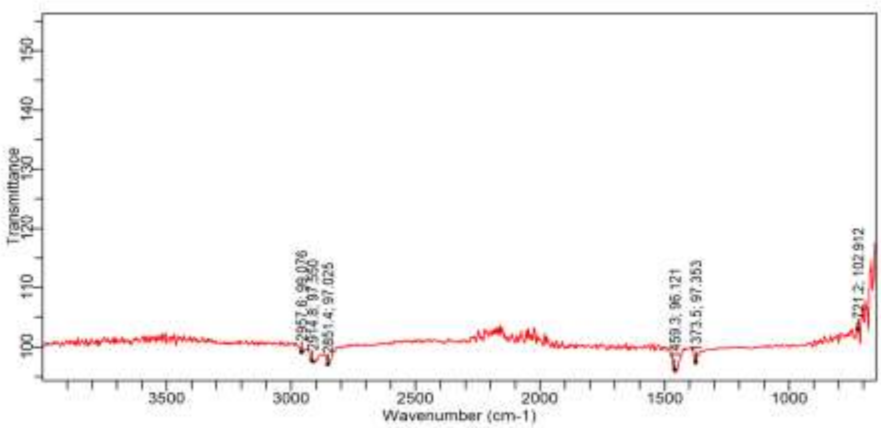

Fig 3.5: FTIR result of sample C1

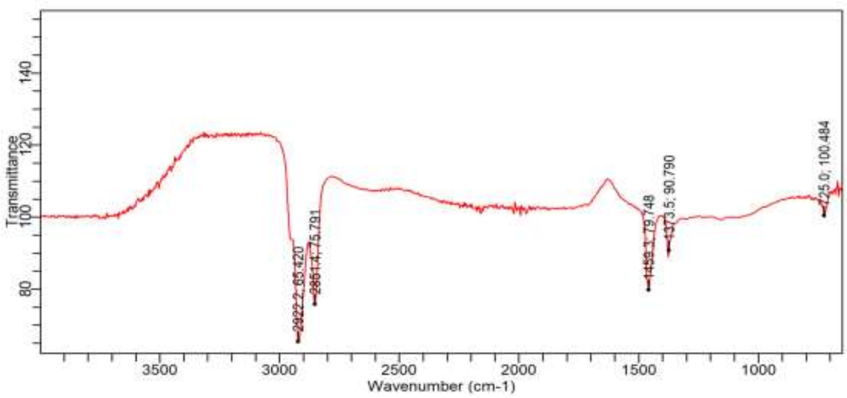

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Fig 3.6: FTIR result of sample C2

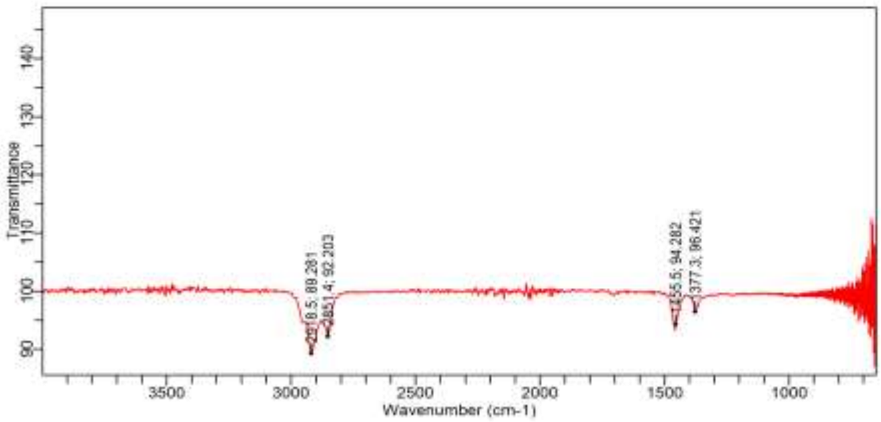

Fig 3.7: FTIR result of sample D1

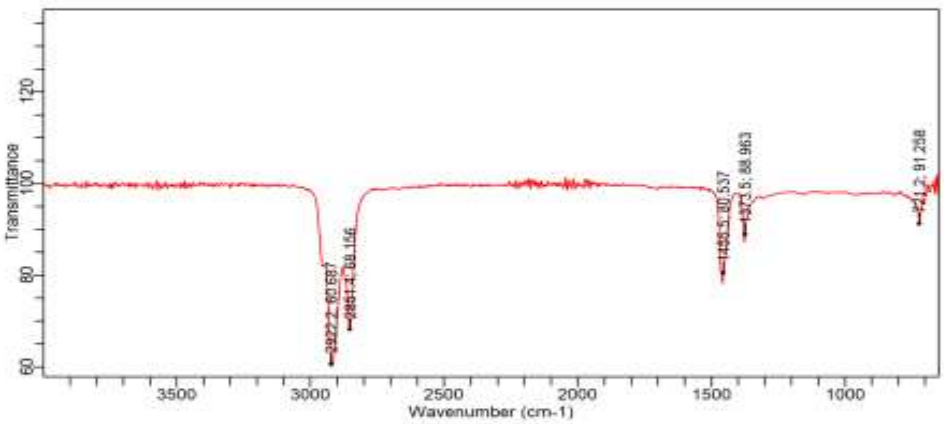

Fig 3.8: FTIR result of sample D2

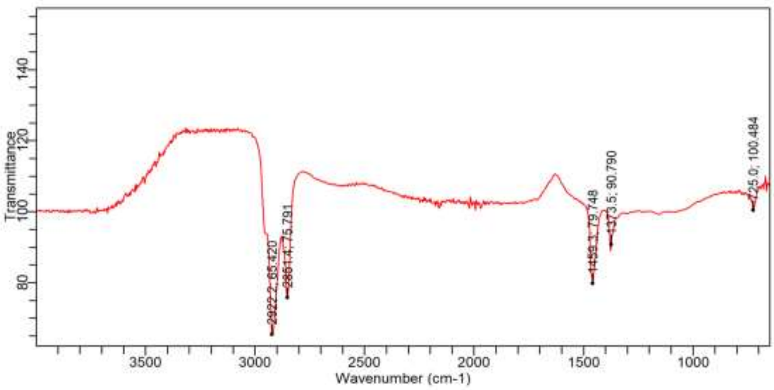

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Fig 3.9: FTIR result of sample E1

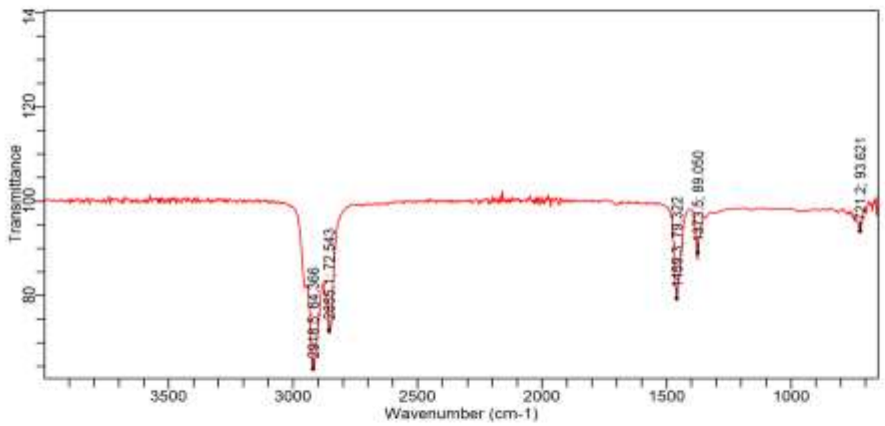
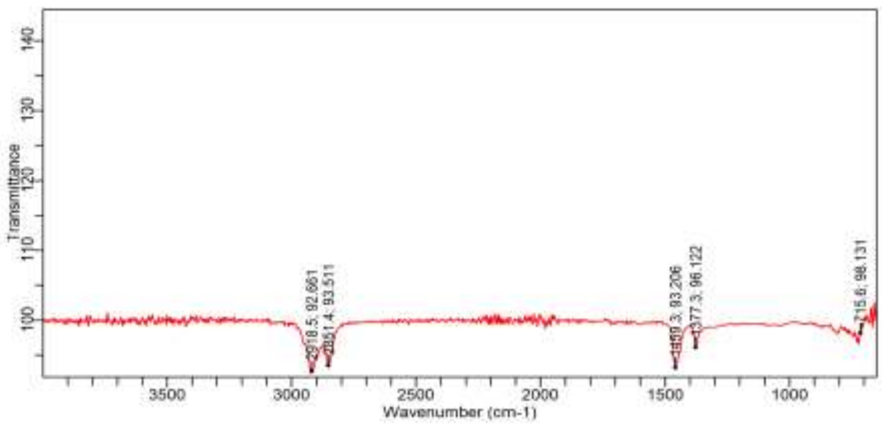


Fig 3.10: FTIR result of sample E2



There were few notable differences in FTIR spectra between the five brands of fresh ATFs (Fig. 3.2.2, 3.2.4, 3.4.6, 3.2.8 and 3.2.10). All samples exhibited absorption bands within similar regions. However, in the FTIR spectra of the used ATFs, new bands appeared at 1237 cm^{-1} (Fig. 3.2.3), indicating the presence of short-chain carbonyl compounds derived from esters or acids, as reported by Kadam & Zingde (1985). Such compounds typically form through oxidative processes in lubricants (Vázquez-Duhalt, 1989), confirming that the fluid underwent chemical changes due to oxygen exposure. According to Ahmed et al. (2011), oxidation leads to fluid thickening, and with progressive oxidation, the lubricant gradually loses its lubricating capacity, resulting in increased corrosion and viscosity. The primary factor driving this deterioration is elevated operating temperatures or overheating and may also involve the formation of nitrates through the oxidation of nitrogen oxide compounds (Rashid et al., 1990; Kadam & Zingde, 1985). Marinović et al. (2012) further stated that exposure of organic compounds in lubricants to high temperatures and pressures produces oxidation and nitration products due to the presence of oxygen and nitrogen. The band

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observed at 725 cm^{-1} (Fig. 3.2.5) is attributed to the presence of unsaturated additives in the used fluid (Zieba-Paulus & Koscielniak, 1999). Similarly, a strong band at 2925 cm^{-1} and another at 1373 cm^{-1} (Fig. 3.2.5 and Fig. 3.2.7) correspond to the presence of mixed hydrocarbon compounds with short chain lengths and C–H branching vibrations within –CH– groups (Cann & Spikes, 2005). C–H stretching vibrations were observed in the range of 2957–2850 cm^{-1}. A prominent band at 1459 cm^{-1} and a weaker band near 1373 cm^{-1} are associated with compounds containing short hydrocarbon chains and branching methylene (–CH_2–) groups in the used fluids (Dominguez-Rosado & Pichtel, 2003). Furthermore, the band at 721 cm^{-1} present in all fluids corresponds to –CH_2– oscillations of at least a five-carbon chain, which indicates the presence of long-chain hydrocarbons in the gear oil. This band is also linked to aromatic C–H stretching, suggesting either a reduction in high molecular weight products or hydrocarbon polymerization reactions occurring during ATF aging (Diaby et al., 2009).

CONCLUSION AND RECOMMENDATIONS

The spectral results were analyzed, and FTIR bands observed at 1704–1603 cm^{-1} were attributed to carbonyl groups, while bands at 869, 813, and 1603 cm^{-1} were associated with the formation of new aromatic hydrocarbons, including polycyclic aromatic hydrocarbons. The FTIR spectra of the used ATF also revealed the presence of alcohols, aldehydes, and ketones, indicating significant chemical and biological degradation of the fluid.

These findings suggest increased oxidation, which can cause the lubricant to lose its lubricating capacity, thereby promoting corrosion and friction. Additionally, evidence of nitration implies that the automatic transmission components analyzed in this study were subjected to high temperatures and heavy loads. Consequently, it is recommended that ATF in such gearboxes be monitored and replaced more frequently to prevent corrosion and reduce frictional wear on gearbox components.

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