Fuel Consumption Modeling of an Automobile with a Leaked Exhaust System

P.K. Oke, B. Kareem, O.E. Alayande

***Abstract*—Daily increase in density of traffic as a result of increase in population of vehicle users necessitates a greater control of emissions from combustion engines. Most of these exhaust components were created as a result of incomplete burning of the gasoline, a lot of the early work to reduce them was centered on improving the mixing and burning of the air and fuel. Efforts on fuel consumption have since continued but still, the effect of a hole on any part of the exhaust system in relation with fuel consumption rate have not been investigated. Sequel to this, the effects of leaks (with respect to the diameter and location of the leak) on the motor vehicle and its exhaust system as a whole and specifically on fuel consumption rate is investigated, and a mathematical model formulated to this effect. The mathematical model (called FUCON+) is a specialized model for Honda CRVs; and can predict fuel consumption rate with respect to leakage on the exhaust system.**

***Index Terms*— Traffic, density, leaks, exhaust, modeling, maintenance.**

I. Introduction

A car exhaust system consists of a series of pipes that links the burnt exhaust gases in the engine cylinder through an exhaust manifold, catalytic converter, silencer and muffler to the atmosphere [1-4]. The exhaust systems consist of tubing, which are used for discharging or expelling burnt gases or steam through the help of a controlled combustion taking place inside the engine cylinder [5,6]. The major components used in a typical automobile exhaust system are: exhaust manifold, resonator, catalytic converter, exhaust pipe, muffler, tail pipe, 'Y' pipe and ball flanges [7,8]. The products of combustion from internal combustion engines contain several constituents that are considered hazardous to human health, including CO, UHCs, NOx, and particulates (from diesel engines). In a bid to reduce the effects caused by these gases, all of these components are especially designed to provide suitable and effective exhaust flow, reduction of noise and emission levels and conversion of the gases to water vapour and carbon (iv) oxide at the exhaust [9,10]. However, the exhaust system does more than all these, as it has an effect on the engine performance. In an attempt to reduce emission and its effects, several devices have been developed to arrest the dangerous emissions [9]. A thermal reactor is seldom used to oxidize UHC and CO [2]. Catalytic converters utilize a catalyst, typically a noble metal such as platinum, rhodium, or palladium, to promote reactions at lower temperatures. In all cases, an arrangement which requires that the engine be operated with a rich mixture which decreases fuel economy is emphasized.

It is worthy of note that the exhaust gases or moisture must be at or above a certain temperature [1]. This is why the converter is placed close to the engine. Second, there must be a certain minimum surface area of catalyst for the gasses to come in contact with. This is the reason for the honeycomb design. It provides a large surface area in a small space. Third, the ratio of exhaust gas to air must be maintained within very rigid limits [2,3]. These limits are maintained by placing a special sensor in the exhaust just before the converter. This sensor detects variations in the ratio and signals the fuel supply system to increase or decrease the amount of fuel being supplied to the engine.

The dominant factor in automobile activity operational efficiency and profitability is maintenance philosophy [11,12]. Engine designers have so far, done great works in ensuring that exhaust are reduced to the minimal, and as much, harmless, bearing in mind fuel efficiency, engine and engine components life. Fuel economy, exhaust emission and engine noise have become important parameters not only for engine competitiveness, but also are subjected to legislation becoming more severe every few years. Over the years, many have argued about the actual effect(s) of a leak in the exhaust system on the fuel consumption rate of an automobile system. This research work seeks to provide reliable and technical reasons on the point of discourse by developing a model to evaluate the fuel consumption rate with respect to leakage diameter and length on the exhaust system.

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II. Methodology

A vehicle with a new exhaust system (comprising of resonator, catalytic converter, muffler and its pipes) was used for the research. Before the commencement of the research, the vehicle was serviced; also the complete exhaust system of the vehicle was replaced with the new one to ensure a good condition and a reliable result during the experiment. During the period of the experiment, the vehicle was stationary and the engine allowed operating in slow running mode in order to eliminate the effects of speed, acceleration, drive pattern and cruise control on the fuel consumption rate. The following items were used during the course of the

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experiment; two hoses (with diameter 1.5cm), two tightening rings, a measuring can, veneer caliper, a stop watch and 50 litres of fuel. The hose from the fuel tank was connected to the external measuring can with the 1.5cm diameter hose with two tightening ring clip. The external fuel tank was filled with 1 litre of fuel before the commencement of the experiment. Four tests were conducted with two trials per test on the exhaust pipe at two different times: first, the effect of varying the diameter of the leak on fuel consumption rate; second, the effect of varying the length at which the leak occurs on fuel consumption rate.

The following describe the various steps taken while carrying out the experiment (the vehicle used is a Honda CRV jeep).

Step 1: The vehicle was made to stay in a fixed position. The default exhaust pipe of the vehicle was removed and replaced with a new one.

Step 2: The pipe leading to the fuel tank was disconnected after the fuel pump. The pipe from the fuel pump was then extended with the first hose, using one of the tightening rings.

Step 3: The fuel return pipe was disconnected from the injector. The second hose was then connected to the injector at the fuel return outlet, using the other tightening ring.

Step 4: The measuring can was used as the external tank. A little quantity of fuel was poured into the external tank and with the intake and return hoses put into the external tank; the engine was allowed to operate under slow running for 45 seconds. This was done so that the intake and return hoses will retain some amount fuel in order that our results may not be affected.

Step 5: The overall length of the complete exhaust system was measured, and its value was recorded as L_0.

Step 6: The measuring can was filled with one litre of fuel and the engine was made to start under slow running without any puncture on the exhaust pipe; the time taken to use up the one litre of fuel was taken (using a stop watch) and its value recorded as t_0.

Step 7: Step 6 was repeated for leak diameters 5mm, 10mm, 15mm and 20mm on the following locations of the exhaust system: between the exhaust manifold and catalytic converter (43.7cm from the exhaust manifold outlet); between the catalytic converter and silencer (138.40cm from exhaust manifold); very close to the silencer outlet (233.70cm from exhaust manifold) and muffler mouth (355.60cm from exhaust manifold)

Step 8: The leaks were repaired after every puncture for each location on the exhaust pipe using oxy-acetylene gas welding process.

Step 9: Steps 6- 8 were carried out again and their average values were used.

During the course of this experiment, it was ensured that: the vehicle used was serviced shortly before the commencement of the experiment; the correct quantity of fuel was used and the accurate time taken; the engine was made to run at a constant speed; and the leaks were properly repaired after each exercise. The configuration of the exhaust system used for the experiment is shown in Fig. 1.

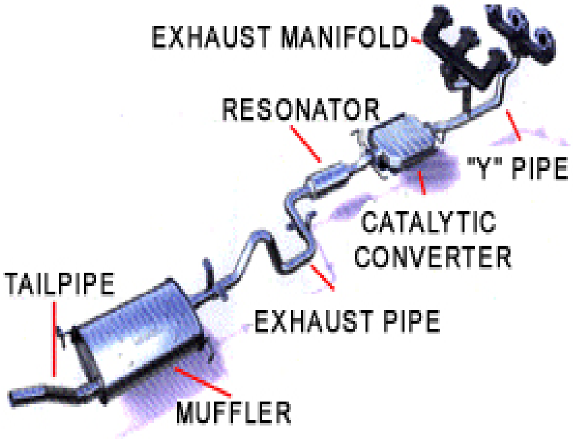

Fig. 1. Diagram showing a complete exhaust system

III. RESULTS AND DISCUSSION

The results obtained from four trials experimentation on exhaust system of overall length, L_0 of 419.10 cm are shown in Figs. 2-5, respectively.

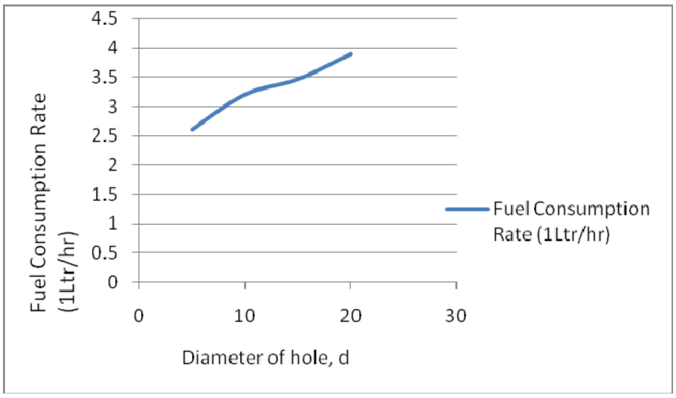

Fig. 2. Fuel consumption rate with leak holes d, located at L_1= 43.70cm from exhaust manifold (between manifold and catalytic converter).

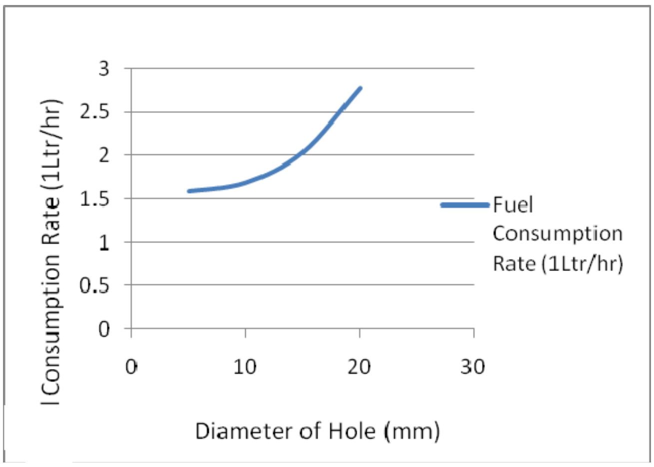

Fig. 3. Fuel consumption rate with leak holes d, located at L_2=138.40cm from exhaust manifold (between CAT converter and silencer).

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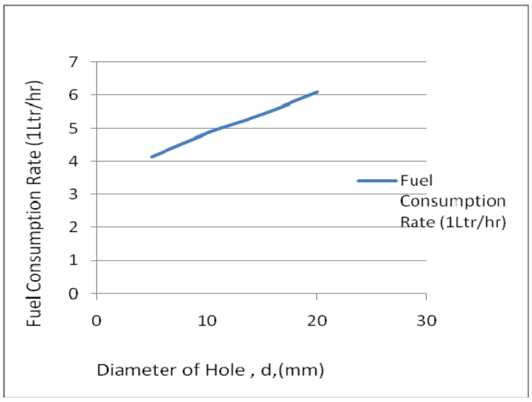

Fig. 4. Fuel consumption rate with leak holes d, located at L_3 = 233.70cm from exhaust manifold (very close to the silencer outlet)

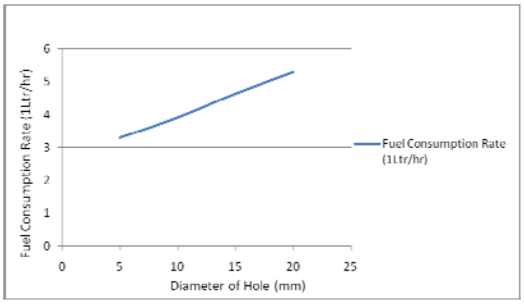

Fig. 5. Fuel consumption rate with leak holes d, located at L_4 = 355.6cm from the exhaust manifold (at the muffler mouth)

A leak/ hole in an automobile exhaust system affects, not only the health of its driver and passengers but also the fuel consumption rate and the engine performance. From the experiment and the results obtained from the experiment, the following deductions can be made: 1) the rate at which fuel is consumed increases with the hole diameter, regardless of its location on the exhaust system. That is, the rate of fuel consumption varies directly (although this might not be a proportionate variance) with the hole diameter; ii) considering the entire exhaust assembly, the region of the catalytic converter consumes fuel the most. The catalytic converter is responsible for the increased fuel consumption rate at point '2'. This is because it uses oxidation catalyst made up of ceramic beads coated with platinum to reduce HC and CO emissions. Due to catalytic action, the converter takes more fuel (for burning to achieve the desired essence); to convert HC, CO and other pollutants to water vapour and CO_2; iii) the rate of fuel consumption decreases with the length of the leak from the exhaust manifold; and iv) as the length and hole approaches the muffler, noise level reduces.

Since this research considers two major parameters- diameter and length of leak-hole with respect to a leaking exhaust system. The general effects of hole (diameter) and length variations are as follows: i) an increase in back pressure- design factor designers have been battling with for years- trying to reduce it to its barest minimum; ii) for vehicles using fuel injectors, the leak alters or interferes with the oxygen sensor reading. Thereby sending a wrong reading to the ACS (automatic control system) - this results in inefficient combustion, poor fuelling and poor power; iii) enhances catalytic converter damage- which is quite expensive to replace; iv) in a more severe case, may cause backfire; and v) more fuel is consumed. The issue of length or location is also paramount. For instance, if the hole is before the sensor, it will affect the reading. Also if it is before the catalytic converter, it could damage it, else no effect; if it is on the muffler- noisier exhausts results.

The summary of the results of the four trials is shown in Table 1. The outcomes are modeled using multiple regression analysis (Eqn. 1) with the following parameters [13]:

α = the diameter of the hole/ leak on the exhaust system.
ψ = the location (length from the exhaust manifold outlet) where the hole/ leak occurs.
λ = the fuel consumption rate
β = coefficient of entity
i = the ith terms in each trial
n = number of terms being considered

$$n\beta_0 + \beta_1 \sum_{i=1}^{n} \alpha_i + \beta_2 \sum_{i=1}^{n} \psi_i = \sum_{i=1}^{n} \lambda_i \qquad ------1$$

Table 1: Experimental Results for Modeling

Fuel Consumption Rate, λ_1, where leak location , ψ is 43.7 cm.	2.60	3.20	3.46	3.89
Fuel Consumption Rate, λ_2, where leak location , ψ is 138.4 cm.	1.59	1.69	2.04	2.78
Fuel Consumption Rate, λ_2, where leak location , ψ is 233.7 cm.	4.15	4.86	5.43	6.10
Fuel Consumption Rate, λ_2, where leak location , ψ is 355.60 cm.	3.31	3.92	4.64	5.29
Diameter of Leak, α	5.00	10.00	15.00	20.00

The multiple regression analysis results for the first, second, third, and forth trials are respectively modeled as,

$$\lambda_1 = 2.190000 + 0.084000\alpha - 0.00000282\psi \qquad 2$$
$$\lambda_2 = 0.920000 + 0.0894000\alpha + 0.00000578\psi \qquad 3$$
$$\lambda_3 = 3.510000 + 0.128400\alpha - 0.00000414\psi \qquad 4$$
$$\lambda_4 = 2.630000 + 0.135000\alpha + 0.00000811\psi \qquad 5$$

From the models, fuel consumption rates can normally, be predicted ($R^2 \geq 0.9$) with a given leakage diameter and location on the exhaust system.

IV. Conclusion

From the research work carried out, it has been established that the rate of fuel consumption increases, approximately linearly, with increase in diameter of hole on the exhaust system; also that the location of leakage has a somewhat negligible effect on fuel consumption rate. Therefore, leakage location can only be considered for design purposes to maintain design accuracy. The knowledge of the effect of a leaking exhaust system on the rate of fuel consumption will

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help car owners and drivers to make better choices of maintenance policies for their exhaust system. The modeling results would help the vehicle owners in monitoring and controlling their fuel expenses. Vehicle owners could say, the hole is here or there, or on this or that, so it can still be tolerated. The models would also help vehicle designers to look into some design considerations at such points where the effect of leak is disastrous. This will promote better fuel economy and cleaner exhaust output. Having known the size of leaks and the locations, the rate at which fuel is consumed can be quantified.

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