Tyre Pressure Model For Predictingfuel Consumptionof Vehicles On Ghana Roads

P.Y. Andoh, F. Davis, Y.A.K. Fiagbe, T. Alhassan

ABSTRACT: In the world today, due to the high cost of running a vehicle, there has been many researches to find ways of minimizing running cost. Components of the running cost come from the tyre, fuel, spare parts of vehicles and also ensuring safety of the vehicle. This paper presents the effect the tyre pressures of vehicles on fuel consumption and ways to optimize running cost due to tyre pressure. In this study, the tyre pressures were measured for different types of vehicles at two public institution campuses (Kwame Nkrumah University of Science and Technology and Kumasi Polytechnic) and three public transport stations (Asafo, Roman Hill and Kejetia) in Kumasi Metropolis to ascertain how tyre pressures of these vehicles have deviated from the recommended tyre pressures stated by the manufacturers. Also the fuel consumption was measured to develop a model between the fuel consumption and the tyre pressure which was used to predict the amount of fuel consumption by a vehicle on Ghana roads. It is concluded that, 73% of the data collected for the different vehicles fall within the predicted results obtained from the developed model and 13% fall within the experimental error; hence the developed model can be used to predict the amount of fuel consumed by vehicles. It was found out thatabout 97% of vehicles surveyed in Kumasi Metropolis had their tyre pressures deviated from the recommended tyre pressuresthereby,increasing the fuel consumption of the vehicle.

KEYWORDS: Tyre, Tyre Pressure, Fuel Consumption, mathematical model

1 INTRODUCTION

Tyres are part of the backbone of a car, truck, piece of construction equipment or bicycle. Tyres add traction, braking, steering and load support to vehicles while also absorbing shock and creating a smooth and comfortable ride. Vehicle tyres can affect not only the way vehicles are handled, but also can affect the overall performance and fuel economy of the vehicle. Incorrect air pressure in tyre causes the tyre to fail which can lead to crush and possibly injure the driver and the passengers [2]. As an automobile moves, the surface of the tyre and the road come into contact which continually peeled apart. In addition, each surface (both the tyre and the road) is deformed slightly so that in effect, the wheel is rolling uphill. These effects combine to produce a rolling resistance. A ratio of 1:5.3 or more than a two percent is found for the effect on fuel economy for every ten percent change in rolling resistance for highway driving and a ratio of 1:9.6, or about a one percent fuel economy change for every ten percent change in rolling resistance for urban driving [1]. Overall, rolling resistance makes up a relatively small percentage of the losses in a typical vehicle; it accounts for about four percent of a vehicle's energy expenditure at low speeds and about seven percent at highway speeds [7].

- *P. Y Andoh is currently a lecturer in mechanical engineering department in Kwame Nkrumah University of Science and Technology, Ghana, PH-011233242235674. E-mail: andohp_2@yahoo.com*
- *F. Davis is currently a lecturer in mechanical engineering department in Kwame Nkrumah University of Science and Technology, Ghana, PH-011233244675710. E-mail: fkdav@yahoo.com*
- *Y. A. K. Fiagbe is currently a lecturer in mechanical engineering department in Kwame Nkrumah University of Science and Technology, Ghana, PH-011233244833980. E-mail: yakfiagbe@yahoo.com*
- *T. Alhassan is currently a lecturer in mechanical engineering department in Kumasi Polytechnic, Ghana*

However, these modest losses are substantial when in the context of the entire US, where automobile travel accounts for the largest source of energy use with petroleum combustion causing 2438Tg (106 tons) CO2 or forty three percent of the emissions in 2004. Globally, the situation is similar, where in 1990 the transportation sector was responsible for some twenty five percent of the world's energy use, and twenty two percent of the global CO2 emissions [7] Tyres are specified by the vehicle manufacturer with a recommended inflation pressure, which permits safe operation within the specified load rating and vehicle loading. Most tyres are stamped with a maximum pressure rating. For passenger vehicles and light trucks, the tyres should be inflated to what the vehicle manufacturer recommends and not maximum pressure indicated on the sidewall. Regardless of its size, tyre's load capacity, durability, traction and handling is dependent on using the recommended inflation pressure. Since both too little and too much pressure sacrifices the tyres' performance, maintaining the "right" inflation pressure is very important. According to Hillier (1991), under inflation or overloading leads to rapid wear on each side of the tread and internal damage to the casing, whereas “over inflation” wears the centre of tread. Kipping the tyre pressure to the recommended value guaranteed occupant safety, comfort, vehicle fuel economy [6]. Significant research works draw some correlation between the tyre pressure and the fuel consumption such that as tyre pressure increases, fuel consumption decreases until it reaches the recommended pressure and then increases. This implies that both below and above the recommended tyre pressure affect the fuel consumption adversely. However, none of the researches was able to provide define model that relates tyre pressure to fuel consumption. This paper seeks develop a model to relate the effect of tyre pressure on fuel consumption.

2 MATERIAL AND METHOD

The research is carried out within Kumasi metropolis in Ghana.In other to ascertain how far vehicles have their tyre pressure deviated from recommended values, the tyre pressure of a number of vehicles were taken fromKwame Nkrumah University of Science and Technology (KNUST), Kumasi and Kumasi Polytechniccampuses and Asafo, Roman Hill and Kejetiapublic transport stations in Kumasi metropolis.A case study approach was adopted for the research considering constraints as well as the scope of the study.

2.1 Measurement of Tyre Pressure

The tyre pressure data was collected from a total of 660 vehicles. All the tyre pressures for each vehicle were measured using tyre pressure gauge and compared to the manufacturers recommended tyre pressure. Sample data is presented in Table 1. The average tyre pressures in each vehicle for both measured and recommended were computed. The difference between the average measured tyre pressure and average recommended tyre pressure were then computed to establish the percentage deviation of the tyre pressure.

TABLE 1: MEASURED TYRE PRESSURE OF VEHICLES AT TRANSPORT DEPARTMENT OF KNUST

VEHICLE	MEASURED TYRE PRESSURE (N/mm2)(MTP)				MANUFACTURERS RECOMMENDED TYRE PRESSURE			
	FR	FL	RR	RL	FR	FL	RR	RL
1	0.179	0.1655	0.1655	0.2068	0.2068	0.2068	0.2206	0.2206
2	0.262	0.262	0.1655	0.1517	0.2551	0.2551	0.2965	0.2965
3	0.2758	0.2758	0.3378	0.3378	0.3516	0.3516	0.4482	0.4482
4	0.131	0.131	0.1517	0.2068	0.2137	0.2137	0.262	0.262
5	0.2344	0.2344	0.2068	0.2344	0.2068	0.2068	0.262	0.262
6	0.2689	0.2758	0.2068	0.2689	0.2068	0.2068	0.2689	0.2689
7	0.2068	0.1931	0.3447	0.1655	0.3103	0.3103	0.4137	0.4137
8	0.2	0.1931	0.1517	0.1793	0.2137	0.2137	0.2206	0.2206
9	0.1034	0.3172	0.2206	0.2068	0.2068	0.2068	0.2206	0.2206
10	0.2551	0.0827	0.2137	0.2758	0.3103	0.3103	0.4137	0.4137

The data were grouped into percent deviation ranges of (0.01 – 10), (10.01 – 20), (20.01 – 30), and above/below 30. Deviation results are presented in Table 2.

TAble 2: Deviation of Tyre Pressures from that recommended

DEVIATION	KNUST	K-POLY	ASAFO	ROMAN HILL	KEJETIA
ABOVE +30%	2	0	0	0	0
+(20.01 – 30)%	1	0	0	1	0
+(10.01 – 20)%	4	3	5	3	2
+(0.01 – 10)%	11	2	15	12	25
Recommended	2	0	8	3	10
-(0.01 – 10)%	9	5	32	23	71
-(10.01 – 20)%	30	23	58	27	72
-(20.01 – 30)%	29	21	27	28	59
BELOW -30%	12	6	5	3	11
TOTAL	100	60	150	100	250

2.2 Tyre Pressure Verses Fuel Consumption

2.2.1 Measurement of tyre pressure and fuel consumption of KNUST shuttle buses

The effects of tyre pressure on vehicle performance cannot be overlooked since research has shown that it has effect on tyre wear, fuel consumption, and rolling resistance. It is also assumed that when the tyre pressure is below or above the recommended tyre pressure, more fuel may be consumed. This means that more fuel will be needed for the same amount of distance to be covered.Tyre wear can cause tyre blowout, causes discomfort in driving and makes it unsafe to drive the vehicle. Tyre wear also affects the fuel used since it may lead to more fuel consumption. Tyre blowout can also cause accidents. When the rolling resistance is decreased or increased, it can cause tyre wear and also make it unsafe to handle the vehicle. Rolling resistance can also leads to more fuel consumption.Hence a case study was conducted on KNUST campus to establish a relation between the tyre pressure and the fuel consumption. The experiment seeks to find out the effect of tyre pressure on the fuel consumed by vehicles. The experiment was carried out for three (3) months period using one of the shuttle buses to develop a model from the results obtained. In each day tyre pressures, odometer reading, and the fuel reading were recorded for the vehicle. Records were taken at intervals of three (3) hours and the results obtained for the vehicleis presented in Fig. 4.

3 MODEL DEVELOPMENT AND VALIDATION

The least squares method of regression and correlation was used to develop the model between the fuel consumption and the tyre pressure. In the least squares method, the equation for the model is given by

$$f = \beta_0 + \beta_1 p + \beta_2 p^2 \pm e \quad (1)$$

Wherefis the fuel consumption, pis tyre pressure, β0, β1, and β2 are constants for the polynomial which would be determined from the data obtained, and eis the error.Using the least square method, three equations can be used to determine the values for the constants. Thesethree equations are given as

$$\sum_{i=1}^{i=n} f = \beta_0 n + \beta_1 \sum_{i=1}^{i=n} p_i + \beta_2 \sum_{i=1}^{i=n} p_i^2 \quad (2)$$

$$\sum_{i=1}^{i=n} p_i f = \beta_0 \sum_{i=1}^{i=n} p_i + \beta_1 \sum_{i=1}^{i=n} p_i^2 + \beta_2 \sum_{i=1}^{i=n} p_i^3 \quad (3)$$

$$\sum_{i=1}^{i=n} p_i^2 f = \beta_0 \sum_{i=1}^{i=n} p_i^2 + \beta_1 \sum_{i=1}^{i=n} p_i^3 + \beta_2 \sum_{i=1}^{i=n} p_i^4 \quad (4)$$

The thirty (30) data values obtained from the vehicle understudy were used to determine the summations for various parameters in equations 2 to 4and the results obtained are used to obtained equations 5 to 7.

$$31\beta_0 + 9.79\beta_1 + 3.12\beta_2 = 4.17 \quad (5)$$

$$9.79\beta_0 + 3.12\beta_1 + 1.01\beta_2 = 1.31 \quad (6)$$

$$3.12\beta_0 + 1.01\beta_1 + 0.33\beta_2 = 0.41 \quad (7)$$

Therefore, values for the three constants can be found by solving equations 5 to 7 simultaneously. Thus, the values for three constants are β0 = 3.63, β1 = -21.40 and β2 = 32.39. Equation (1) is therefore

$$f = 3.63 - 21.40p + 32.39p^2 \pm e \quad (8)$$

This model was then verified if it represents the true picture of the data collected. To verify the model, two steps were carried out. First of all, the root mean square (R2) values were found using the least squares method for correlation. The root mean square R2 values of correlation, determines how closely the variables are associated. The root mean square (R2) values were found using the equation (9)

$$R^2 = \frac{\beta_1 \sum_{i=1}^{i=n} (p_i - \bar{p})(f_i - \bar{f}) + \beta_2 \sum_{i=1}^{i=n} (p_i^2 - \bar{p}^2)(f_i - \bar{f})}{\sum_{i=1}^{i=n} (f_i - \bar{f})} \quad (9)$$

Using the data obtained, the root mean square (R2) value was found to be 0.93.Secondly, the model was verified by comparing the measured results and the predicted results from the model and the results obtained are illustrated in Fig 5. Using 95% confidence, the predicted model can be written as

$$f = 3.63 - 21.40p + 32.39p^2 \pm 1.96\sigma_e, \quad (10)$$

where σ_e represent standard deviation of the error values.$\sigma_e$isdefined as$\sigma_e = \sqrt{\frac{\Sigma(e-\bar{e})^2}{N}}$, where N is the number of data values. Using the results obtained, $1.96\sigma_e = 0.025$. Hence the model can be written as

$$f = 3.63 - 21.40p + 32.39p^2 \pm 0.025. \quad (11)$$

3.1 Validation of the Model

The model was validated by performing series of tests on four other shuttle buses and the results obtained were then compared with the predicted results obtained from the model. The tests wereconductedover three (3) months period using four of the shuttle buses to validate the results obtainedfrom predicted results. In each day, tyre pressures, odometer reading, and the fuel reading were recorded for the vehicle. Records were taken at intervals of three (3) hours and the results obtained for the fourvehicles are presented in Fig. 5 to Fig. 8.

4 DISCUSSION OF RESULTS

4.1 Deviation of Tyre Pressure from recommended value

The results obtained from the measured tyre pressure in KNUST as illustrated in Fig. 1 shows that almost all one hundred (100) vehicles studied deviated from the recommended tyre pressure. Only two (2) out of the 100 vehicles studied, representing two (2) percent, conformed to the manufacturer's recommended tyre pressure. The remaining ninety eight (98) vehicles, representing ninety eight (98) percent, deviated from the recommended tyre pressure.

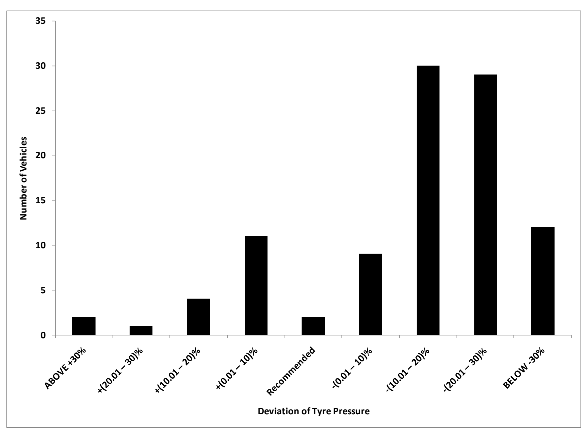

Fig. 1: Number of vehicles versus Deviation of tyre pressures inKNUST campus

With respect to the above phenomenon, eighty (80) percent of the deviating vehicles, being the vast majority, fallbelow of the recommended tyre pressurewhile the remaining eighteen (18) percent of the vehicles exceeded the manufacturer's recommended tyre pressure. The combine result of Kumasi Polytechnic and public stations (Asafo Market, Roman Hill and Kejetia) in the Kumasi Metropolisshown in figure 2 indicated three (3) percent conformed to the manufacturer's recommended tyre pressure (that is twenty three (23) out of the 660 vehicles). Six hundred and thirty seven (637) vehicles, representing ninety seven (97) percent, deviated from the recommended tyre pressure

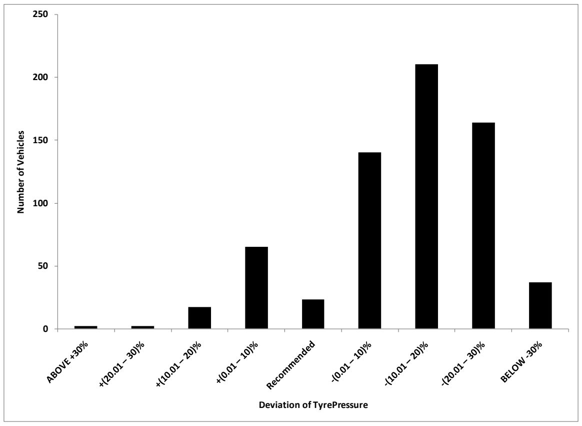

Fig.2: Number of vehicles versus Deviation of tyre pressures in Kumasi

Having carried out an extensive study on the tyre pressure of about six hundred and sixty (660) vehicles in the Kumasi metropolis it is very alarming to note that only three (3) percent of the vehicles conformed to the manufactures required tyre pressure. When a tyre is underinflated, most of the vehicle's weight is concentrated on the tread which is located just under the sidewalls of the tyre, rather than being spread out evenly across the full width of the tyre. This means that as the tyre rolls, the sidewall gets continually flexed and heats up. This affects both performance and safety of vehicle, thereby creating inconveniences for the driver and the passengers. Excess vehicle weight and high temperatures can cause additional flexing and stress on the sidewalls which can lead to tyre failure when driving on low tyre pressures. In addition, tyres with low pressure wear more quickly, degrade the vehicle's handling; lower the vehicle's load-carrying ability and thereby having effect on the fuel consumption. In a worst-case scenario, under inflated tyres can lead to a catastrophic blowout or tread separation. With the increase in fuel consumption and its effect on socio-economic development there is therefore the need to look at the issue at stake more critically.

4.2 The Effect of Tyre Pressure on the Fuel Consumption

Rolling resistance which is caused by deformation of the tyre in contact with the road surface is brought about as a result of the deviations in the tyre pressures of a vehicle. The increases in the rolling resistance of the tyre have also resulted in the increase of energy needed in order to move a vehicle. This has therefore contributed to the rise of the fuel flow rate as a result of changes in the tyre pressure illustrated in Fig. 3.

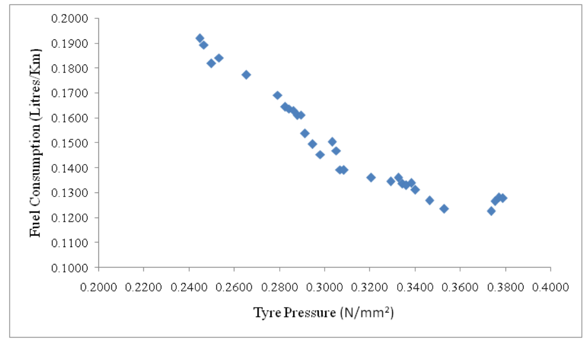

Fig. 3: Fuel consumption verses tyre pressure

It can be deduced that as the tyre pressure changes from the recommended tyre pressure, the fuel consumption rises. This is due to the fact that, more energy will be required to move the vehicle and also to maintain the designated speed required;hence,the energy need will increase andmore fuel will be required.To ascertain these results, four other shuttle buses were also tested and the results obtained are presented in Fig. 4.

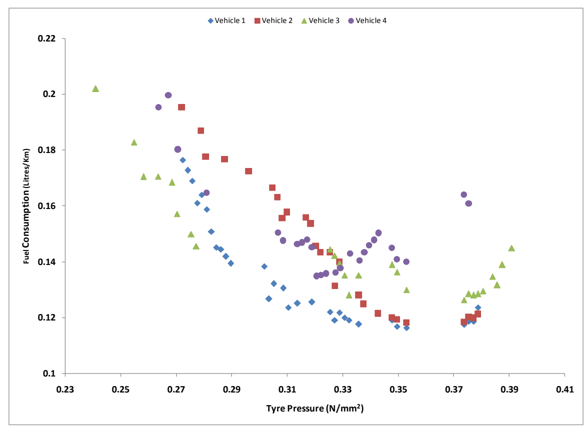

Fig. 4: Fuel consumption against tyre pressure for the four vehicles

From the four (4) plots, it seems that all the plots conform to the plot in Fig. 3 and also take a form of polynomial function with a degree of two. It can also be seen that, the fuel expenditure will increase in order to keep vehicles running, thereby, reducing the revenue the commercial drivers would have earned from their operations. However, these costs will then be transferred to the general public who patronize in commercial vehicles leading to high prices in fares, goods and services. Prediction of Fuel Consumption From Fig. 3, it could be seen that the relationship between the fuel consumption and the tyre pressures for the vehicleis in the form of equation (11)

$$f = 3.63 - 21.40p + 32.39p^2 \pm 0.025 \quad (11)$$

This equation although cannot be said to represent all vehicle types can be used to predict fuel consumptions for vehicles when their tyre pressures are known. The results obtained from the four other vehicles compared very well with the predicted results from the developed model.It was observed that 73% of the measured fuel consumptions fall within the predicted fuel consumption range while the remaining 27% fall outside the range. However, 13% deviated from the predicted range by ±5%, 7% by ±10% and the remaining 7% by ±15%. It could be deduced that since majority of the results fall within the predicted range and 13% within the experimental error, the model developed can therefore be used to predict the amount of fuel consumed if the tyre pressure of the vehicle is known.

5 CONCLUSION

Required tyre pressures are usually recommended by vehicle manufacturer and going by it ensures the optimum performance by the vehicle. The results of the research shows that only 3% of vehicle with Kumasi metropolis have their tyre pressure as that recommended, 97% had tyre pressures deviated. This implies that performances of other 97% are optimum and may be consuming more fuel. A model equation that relates fuel consumption to vehicle tyre pressure is developed by statistical method and presented as equation (11). The model equation can be used to predict the amount of fuel consumed by a vehicle for known tyre pressure. The result of validation of the model shows that, 73% of the data collected for the different vehicles fall within the predicted range, however, 13% fall within the experimental error. Hence the developed model can be used to predict the amount of fuel consumed by a vehicle on Ghana roads.

6 REFERENCE

[1] Alhassan T., “The Effect of Tyre Pressure on Vehicle Performance” Master'sthesis, Dept. of Mechanical Eng., Kwame Nkrumah University of Science and Technology., Kumasi, 2011.

[2] Calwell C., Ton M., Gordon D., Reeder T., Olson, M. and Foster S., (2003), "California State Fuel Efficient Tire Report", California Energy Commission, vol. 2, 600-03-001CR

[3] Gibson P., (2006) "Tire Maintenance Tips - Tire Pressure", EzineArticles.com

[4] Han B., (2007, July 20). “Off-Road Tires - A Beginner's Reference”, Retrieved May 6, 2010

[5] Hillier V. A. W., (1991) “Fundamentals of Motor Vehicle Technology”, 4th edition, Stanley Thornes Publishers limited

[6] Reed P. P. J. and Reid V. C., (2000), “Motor Vehicle Technology for Mechanics”, Motivate series

[7] Reimpell J. and Stoll H., (1996), “The Automotive Chassis”, 2nd Edition

[8] Stein, (2006), “Tires and passenger fuel economy: informing consumers, improving performance”, Transportation Research Board Special Report 286, National Research Council of the National Academy of Sciences, Washington, DC.

[9] Williams B., (2008), "The Importance of Tires." EzineArticles.com