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OPTIMIZATION OF FUEL CONSUMPTION IN VEHICLES: IMPACTS ON ENERGY EFFICIENCY AND OPERATIONAL SUSTAINABILITY IN THE TRANSPORTATION INDUSTRY

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A B S T R A C T

This study looked at some of the factors that affect the fuel consumption of vehicles. There are many factors such as proper tire pressure, clean air filter, total weight inside the compartment, idling, sudden acceleration and braking, using AC, changing the spark plugs etc. Taking care of all these factors can result in an increase in the fuel efficiency of the car. In this investigation, three cars, with different engine volumes and different makes, were chosen. Four parameters, namely, proper tire pressure, clean air filter, total weight, idling and their effect on fuel consumption were studied. The cars were driven inside the city under the real urban setting to find out whether altering these factors affect the fuel efficiency of the cars. In the second phase of the study, physical modifications like installing cold air intake, air dam, spoiler and diffuser were done. The results were collected to see if there is any improvement in fuel efficiency by using these modifications.

1. INTRODUCTION

Oil, gas and coal are three different types of fossil fuels. The reserves of these fossil fuels are not infinite, and it is probable they will run out completely one day. The rate at which these fuels are consumed is increasing day by day. Over 11 billion tons of oil in fossil fuel every year (Environmental and Energy Studies Institute, n.d.) is consumed by the world. Major portion of fossil oil is used in the transportation industry. There is no refuting the fact that at some point the oil reserves will reduce. It is also reasonable that instead of panicking and instead of asking how much oil is left, find ways in order to decrease this oil consumption. A little increase in the fuel efficiency of the car will go a long way in mind that the numbers of vehicles on the road are increasing daily. Shafiee and Topal (2009) presented a new formula for calculating when fossil fuels reserves are likely to be depleted. The new formula was modified from the Klass model and thus assumed a continuous compound rate and computed fossil fuel reserve depletion times for oil, coal and gas of approximately 35, 107 and 37 years, respectively. This meant that coal reserves are available up to 2112 and will be the only fossil fuel remaining after 2042. Owen et al. (2010) reported that while there are certainly vast amounts of fossil fuel resources left in the ground, the volume of oil that can be commercially exploited at prices the global economy has become habituated to is limited and will soon decline. The result is that oil may soon shift from a demand-led market to a supply constrained market. Detailed projections of world fossil fuel production including unconventional sources were created by country and fuel type to estimate possible future fossil fuel production by Mohr et al. (2015). Four countries were examined in detail. The Low and Best Guess situations suggest that world fossil fuel production may be greatest before 2025 and deteriorate quickly thereafter. The High scenario shows that fossil fuels may have strong growth till 2025 followed by a plateau lasting about fifty years before decreasing. Wiorkowsky (1981) reviewed and disapproved of the past methods for estimating volumes of fossil fuel remaining resources.

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Two newer approaches were proposed. One way to solve this problem is to find alternative fuels that may take place of these fossil fuels. Lots of research has been done in this area. Mahmudul et al. (2017) summarized the information on biofuel development, feedstocks around the world, oil extraction technic, biodiesel production processes. The paper also discussed the advantages of biodiesel compared to fossil fuel. The quality of fatty acid methyl esters of linseed oil (biodiesel fuel), was compared to palm oil; a highly saturated vegetable oil by Zaher and Gad (2016). Different fuel properties were compared. Saad et al. (2017) presented the utilization of the waste cooking oil as fuel for diesel engine. WCO was mixed with conventional petrol fuel (RON95) having lower density and higher volatility than WCO. Grushevenko et al. (2018) presented a long-term viewpoint for changes in the Russian road transportation sector's fuel mix. The calculations revealed that converting to natural gas and electricity would reduce the share of petroleum products from 95% in 2015 to about 80% by 2040. Pathak et al. (2018) reviewed the production, performance and emissions of biodiesel and compressed natural gas as replacement to fossil-based diesel for compression ignition engines. The review of experimental set-up used by different researchers for the studies and performance and emissions characteristics of CI engines with biodiesel was presented in this paper. An experimental investigation was conducted by Deep et al. (2017) to explore the possibility of castor biodiesel to be used as alternative fuel for an existing diesel engine. A series of experiments were carried out on the engine fueled with various castor biodiesel and diesel blends, over the whole range of engine loading settings. Othman et al. (2017) presented an inclusive review on the potential of biodiesel from different waste feedstock biodiesel such as waste cooking oil and waste plastic oil. In addition, the effect on the engine performance, combustion and exhaust emissions including details of engine and operating condition were also reviewed in this paper. Awad et al. (2018) presented a review on using alcohol and ether as substitute fuels in petrol engines. The objectives of this paper were to review the use of alcohol and ethers including butanol, methanol, ethanol, MTBE, and DME as fuels in SI engine. Use of Thyme oil as a substitute to diesel without any modifications in the engine was investigated by Kumar et al. (2019). The experiment was conducted on a 1500 rpm, four-stroke, water cooled diesel engine with single cylinder. Effects on the brake thermal efficiency, specific fuel consumption (SFC) and exhaust emissions were examined by adding Cerium Oxide Nano Additive.

It is difficult but not impossible to use alternative fuels in place of fossil fuels. The main hurdle is not easy availability of alternative fuels to the public. It is a long-term solution and has great promise but, in the times, to come. In current situation it is best to do fine tuning of the vehicle by changing the different parameters that affect fuel consumption readily such as, proper tire pressure, clean air filter, total weight inside the compartment, idling, sudden acceleration and braking, using AC, changing the spark plugs, opening the windows, driving habits etc. The above-mentioned factors can be altered without any major modification in the vehicle. Redsell et al. (1993) described a programme of statistical analyses on test data to investigate the effects of several factors on car fuel consumption. Many factors such as route, ambient pressure, vehicle speed, frequency of gear change, deceleration etc affecting the fuel consumption were measured. Thomas et al. (2014) studied the effects of low tire pressure, open windows, rooftops and hitch mounted cargo, and trailers on the fuel economy and emissions on a passenger sedan, minivans and sport utility vehicle. It was reported that low tire pressure cases resulted in negligible 10% more fuel consumption. It was investigated that the reduction in the tailpipe CO_2 emission directly reduced the fuel consumption by Varghese (2014). In his work, the role of tire pressure on fuel economy was also investigated. Three mathematical vehicle models were developed to capture and represent the influence of tire pressure on fuel consumption. 5% increase in fuel economy was observed by increasing the tire inflation pressure from 2 bar to 3 bar. Mullins (2010) examined the effect of tire pressure on fuel economy. It was shown that lower tire pressure increased the horsepower necessary to propel the automobile. Effect of intake air filter condition on the vehicle fuel economy was explored by Norman et al. (2009). The effects of a clogged air filter on the economy of vehicles operating over prescribed test cycles was studied. Research on the impact of vehicle weight reduction on fuel economy for various types of vehicles was conducted by Casadei and Broda (2007). A full forward looking physical based model was developed for each base line vehicle using commercial software. It was concluded that fuel economy improvement from weight reduction was more at slow moving vehicle speeds, but it was almost equal in percentage in both spark ignition and compressed ignition cars. Gautam (2010) developed two empirical models to find the impact of the weight of a vehicle on average fuel economy of passenger cars and light trucks. It was suggested that fuel economy is increased by 14 percent when there was a decrease in ten percent of the vehicle weight. Rahman et al. (2014) evaluated the fuel consumption and emissions parameters under high idling conditions when diesel blended with Jatropha curcas biodiesel in a diesel engine. Fuel consumption was increased under all high idling conditions for biodiesel – diesel blends. To study the influence of driving style on fuel consumption of city buses under different road conditions and vehicle masses, a method for summarizing driving style characteristic parameters based on vehicle engine combined model was proposed (Ma et al. 2015). It was observed that the operation behavior in accelerating process significantly affects the fuel economy. Rahman et al. (2013) reviewed the impact of idling on fuel consumption and exhaust emission and available idle reduction technologies for diesel vehicles. It was reported that idling fuel consumption rate can be as high as 1.85 gal/h. Karim and Burn (1980) investigated the characteristics of dual fuel operation under cold intake temperatures, primarily from the viewpoint of engine performance and exhaust emissions. Operational and environmental evaluation of diesel engines burning oxygen enriched air or oxygen enriched fuels was presented by Rakopoulos et al. (2004). Two techniques regarding engine performance characteristics, environmental repercussions and economy of operation were evaluated.

Recently many numerical studies have been conducted also to calculate the drag on vehicles due to the add-on devices. Air drag is directly proportional to the fuel consumption of the car. Lower the drag, greater will be the fuel economy. Koo et al. (2017) investigated the role of anterior air dam in the flow around sedan passenger cars using computational fluid dynamics. It was concluded that the front air dam reduced the lift force of the vehicle. To reduce the aerodynamic drag, the performance of the underbody aerodynamic drag reduction devices was evaluated by Cho et al. (2017), based on the actual shape of a sedan type vehicle. Reduction in the drag by employing the drag reduction devices was reported. Reddy and Lokanadham (2017) performed computational fluid dynamics analysis on aerodynamic effects in a passenger car. The effect of several spoiler designs at rear and roof were investigated. Arya et al. (2017) simulated a passenger car by attaching add on devices to reduce the drag force by CFD approach. The study was conducted by attaching the spoiler and diffuser to the car. A numerical study was undertaken by Sucipto and Widodo (2016) by installing multiple channel diffusers on the rear bus body. The results showed that the multiple channel diffuser could increase the aerodynamics performance of the bus. Sudin et al. (2014) reviewed on the research performance of active and passive flow control on the vehicle aerodynamic drag reduction. Vortex generator, spoiler and splitter were used in the study. A study of drag reduction devices for production pick-up trucks with a body on frame structure using full scale wind tunnel testing and CFD simulations was described by Taniguchi et al. (2017). It was found out that there was a close association of the flow structure around the tail gate and the air drag. Das and Riyad (2017) did a CFD analysis of passenger vehicles at various angles of rear end spoilers. The influence of rear spoilers on the generated lift, drag and pressure distributions was investigated. An aerodynamics study of a generic car model with wheels and underbody diffuser was presented by Huminic and Huminic (2017). The results showed that the vortices which originated from the rear wheelhouses had a major impact on the aerodynamics of the underbody diffuser. This resulted in an increase of drag and lift of the body. Knight et al. (2019) investigated the effect of vehicle ride height and diffuser ramp angle on downforce and efficiency.

Literature survey clearly indicates that a lot of work has been done in fuel economy field in a broader sense, but still there is a need to gather more data, generated by running the vehicle in urban setting without any controlled conditions. The fuel consumption data of the car with frequent start-stop circumstances under different effecting parameters is still scarce. This paper is an effort to bridge this gap and to get the statistics for the fuel consumption of vehicles under different parameters. In addition, the numerical studies do show, that there is reduction in drag by doing certain modifications on the car, but they do not quantify that how much fuel can be saved by these modifications. In the second part of the paper, actual modifications (cold air intake and aerodynamic) are done on the vehicle and real fuel consumption due to the alterations have been recorded. The main idea is to investigate the fuel savings, if any, due to the changes.

2. ROAD TESTING SETUP

Three cars of different make and engine size were selected. Care was taken that the selected cars represent large group of cars that are on the middle east region roads now a days. The specifications of the three cars are given in table 1:

Table 1. Specifications of cars

	Horsepower	Engine Size	Weight
Car A	198	2.4 L	1437 kg
Car B	292	3.6 L	1785 kg
Car C	240	2.0 L	1730 kg

Ten readings of fuel consumption for each car were recorded, without any alteration and without changing any parameter. This was termed as a "normal state" that served as a reference point for the other readings taken in this study. In order to take a reliable reading of fuel consumption, it was made sure that the car ran for at least 50 – 60km between two successive readings. Testing was done in normal urban conditions with frequent stops. The fuel consumption data at normal state for three cars in given in table 2:

Table 2. Fuel consumption at normal state

Fuel Consumption of Cars (km/L)			
	Car A	**Car B**	**Car C**
1	7.66	7.58	13.16
2	8.48	7.86	14.08
3	7.55	7.43	12.5
4	7.20	7.35	12.66
5	6.70	7.79	13.33
6	7.33	7.52	13.89
7	6.99	7.46	14.49
8	7.16	7.48	13.16
9	7.08	7.80	14.49
10	7.30	7.55	13.33
Average	**7.35**	**7.58**	**13.51**

As mentioned earlier, the normal state readings were used as a reference and other readings obtained by changing the parameters were compared to them. Four parameters, namely, proper tire air pressure, addition of 100 kg weight in the car, idling for three minutes and changing the air filter were chosen for getting the fuel consumption data. It was kept in mind that all the selected parameters were easy to change with minimal cost. The main idea was to observe if these simple factors could effect the fuel economy or not? The road tests were performed by changing one parameter at a time starting from filling in the proper tire air pressure, moving on to add 100 kg weight in the car, then idling the car for three minutes when starting, and lastly, changing the old air filter with the new one.

3. RESULTS

3.1 Changing the parameters

Ten readings were taken for each parameter in the sequence already mentioned above, for all the three chosen cars. Tables 3-5 show the recorded readings.

Table 3. Fuel consumption by changing different parameters for Car A

	Fuel consumption (km/L)			
	Proper tire air pressure	Adding 100kg weight	3 minutes idling	Changing air filter
1	8.39	7.21	6.77	12.25
2	9.55	6.87	7.10	11.28
3	10.41	7.29	7.13	12.63
4	9.39	7.21	6.88	10.30
5	10.83	7.68	7.22	11.65
6	10.30	7.07	7.01	9.06
7	10.97	6.70	6.65	9.49
8	11.27	6.75	6.68	10.62
9	10.80	7.06	7.02	11.15
10	11.40	6.81	6.90	10.79
average	10.33	7.06	6.96	10.92
% difference from normal state	**27%**	**-4%**	**5.3%**	**32%**

Table 4. Fuel consumption by changing different parameters for Car B

	Fuel consumption (km/L)			
	Proper tire air pressure	Adding 100kg weight	3 minutes idling	Changing air filter
1	7.59	7.34	7.56	8.10
2	7.58	7.39	7.62	7.80
3	7.60	7.31	7.51	7.85
4	7.59	7.33	7.43	7.90
5	7.58	7.29	7.51	7.71
6	7.59	7.18	7.48	7.89
7	7.59	7.28	7.45	7.79
8	7.57	7.23	7.50	7.79
9	7.59	7.32	7.46	7.90
10	7.60	7.28	7.44	8.01
average	7.59	7.29	7.49	7.87
% difference from normal state	**0.1%**	**-3.8%**	**1.2%**	**3.7%**

Table 5. Fuel consumption by changing different parameters for Car C

	Fuel consumption (km/L)			
	Proper tire air pressure	Adding 100kg weight	3 minutes idling	Changing air filter
1	14.71	12.35	13.16	14.08
2	14.29	12.66	12.99	14.28
3	13.70	11.91	13.33	14.08
4	14.92	1176	13.16	14.08
5	13.89	12.50	13.33	14.29
6	13.51	12.20	12.82	14.08
7	14.28	12.66	13.70	14.28
8	13.51	12.19	13.51	14.29
9	13.89	12.04	13.33	14.08
10	14.28	12.50	12.99	14.08
average	14.10	12.27	13.23	14.16
% difference from normal state	**4.1%**	**9%**	**2.1%**	**4.6%**

3.2 Cold air-Intake installation

Cold air intake system was installed only in car B. There is no report in the literature about the effect of this modification on the fuel economy. The purpose of this physical modification is to move the air filter outside the engine compartment so that cooler air can be sucked into engine for combustion. This brings more oxygen in the chamber that results in more power and better fuel consumption. Figure 1 shows the actual cold air intake system installed on the car. Table 6 gives the data for cold air intake with and without A/C.

Figure 1. Cold air intake system

Table 6. Fuel consumption after installation of Cold Air intake

Fuel consumption with cold air intake (km/L)		
	with A/C	without A/C
1	8.547	10.736
2	8.488	10.774
3	8.571	10.752
4	8.517	10.846
5	8.706	10.744
6	8.517	10.752
7	8.503	10.752
8	8.747	10.921
9	8.603	10.737
10	8.503	10.869
average	8.570	10.788
%	**12%**	**30%**

3.3 Aerodynamic modification

The effect of few aerodynamic modifications such as air dam, rear air spoiler and air diffuser is tabulated in table 7. Figure 2 shows the modifications done on Car B.

Figure 2. Aerodynamic modifications

Table 7. Fuel consumption with aerodynamics modifications

	Fuel Consumption (km/L)			
	Air Dam (1 in.)	Air Dam (2 in.)	Rear Spoiler	Rear Diffuser
1	7.87	7.89	8.32	8.13
2	8	7.89	7.97	8.00
3	7.82	8.03	7.98	7.97
4	7.81	7.95	8.12	8.03
5	7.94	7.94	8.0	7.94
6	7.97	8.05	8.22	8.09
7	7.89	7.99	8.06	7.96
8	7.97	7.89	8.11	7.77
9	8.03	7.90	7.95	8.05
10	7.94	8.03	8.06	7.89
average	7.92	7.96	8.08	7.98
	4.3%	**4.77%**	**6.1%**	**5.0%**

Table 8 gives the fuel consumption data with all the aerodynamics and engine modifications in the cold and hot weather.

Table 8. Fuel consumption with all modifications

	Fuel Consumption (km/L)	
	All modifications (cold weather)	All modifications (hot weather)
1	9.058	8.547
2	9.025	8.539
3	9.074	8.547
4	9.074	8.571
5	9.066	8.557
6	9.049	8.559
7	9.025	8.566
8	9.083	8.566
9	9.082	8.718
10	9.091	8.559
average	9.063	8.573
% difference	**16.36%**	**11.6%**

4. DISCUSSION

The data obtained indicated that fuel consumption was affected by the change in the parameters selected for the study. For all three cars, there was an increase in the fuel economy of 27%, 0.1% and 4.1% respectively from the normal state, when proper air pressure was filled in the tires. Car A was having low air pressure (25 psi) as compared to other cars and an improvement in the fuel saving by about 3 km/L was seen immediately by just bringing the tire to recommended pressure. Car B tire pressure was already close to the manufacturers' recommended value so there was very little increase. This is an expected result as underinflated tires have more contact with the road that hurts the car's fuel economy as more power is needed for the engine to move due to extra friction. By adding 100 kg weight in the car, it was observed that fuel consumption of cars A, B and C increased by 4%, 4% and 9% from the normal state. This result shows that vehicle weight is an important factor in how much fuel the car consumes. The heavier the car, the more energy it needs to get moving. Extra weight in fact increases the rolling resistance, which is a force that resists the forward motion of the wheels. The third parameter studied was to idle the car for three minutes when starting up in the morning time or when the car was parked for more than 6 hours. As anticipated, the fuel economy decreased in all the three cars by 5.3%, 1.2% and 2.1% respectively. Reason to include this factor in the study was this, that drivers do idling in the middle eastern region religiously. It is a common belief among drivers that idling is needed to warm up the car so it can be more fuel-efficient. This is a misconception; idling was required when the cars had carburetors. Having the engine running for no reason is a waste of energy and it was clearly indicated in the data obtained with higher fuel consumption. There was a definite decrease in fuel consumption for all the three cars when the new air filter was installed. It was the parameter that increased the mileage of the cars the most. Economy increased by 32%, 3.7% and 4.6% respectively for Cars A, B and C. It is obvious that a clean air filter improves airflow to the engine and increases the engine performance and gas mileage. It can be concluded from the readings that without doing major overhaul of the engine a person still can save some fuel just by performing a regular checkup of the car. Keeping the proper air pressure in the tires and changing the clogged air filter on time can result in savings and are not costly as well.

In the second phase of the study, engine modification was done in car B. Cold air intake system was installed and the car was driven to see if there is any benefit of this alteration. Different automobile magazines do talk about the decrease in the fuel consumption of the car when cold air intake is fitted. However, until now no experimental study was conducted to explore this factor. Cold air intake acts like a pair of lungs for the car. To generate more power, the cylinders must take in air to create the combustion that produces wheel-turning horsepower and torque. Since cold air contains more oxygen than hotter air, taking a higher volume of oxygen rich air allows the engine to burn fuel more completely thus increasing the combustion efficiency. This results in increasing power when using the same amount of fuel. Two sets of ten readings, with AC and without AC were taken after the installation of cold air intake system on car B. Keeping in mind that Car B was a sports car, there was a remarkable saving on the fuel with the cold air intake system. The fuel economy increased by 12% with AC and about 30% without AC. This is a huge amount of saving and it can be recommended to make use of this alteration wherever possible. The whole system can be bought readily from automotive shorts for different makes and models of cars and by spending few hundred dollars one can achieve a very good fuel economy. Another thing that can be noted is this, that AC plays a huge role in increasing the fuel consumption, though in the hot places like in middle east it is not possible to drive without it. One can do that only for three months of cold weather usually from November to January. In the third part of the study, aerodynamic modifications were done on car B. It should be kept in mind that to see the impact of these changes individually, the cold air intake was taken off the car. At first, air dam was installed under the front bumper of the car. Two road tests with different heights of the air dam (1 in. and 2 in.) were undertaken. The purpose of air dam is to deflect the oncoming air. It forces the maximum air to go over the top of the vehicle and allows less quantity of air to pass underneath the car. This reduces the aerodynamic drag on the car thus decreasing fuel consumption in the end. Fuel consumption decrease was about 4.3% with 1 in. and 4.7% with 2 in. air dam from the normal state. Second, rear diffuser and rear spoiler were fitted on the car one after the other. Air diffusers provide a space for the underbody airflow to decelerate and expand so that it does not cause excessive flow separation and drag, by providing a degree of recovery of pressure. The objective of using rear spoiler is to make the air see a longer, gentler slope from the roof to the spoiler that helps to delay flow separation thus decreasing the drag on the car. Both modifications resulted in an increase in fuel economy by 6.1% in case of spoiler and by 5% for rear diffuser. These aerodynamic modifications are much cheaper than the cold air intake system installation. A driver on budget can opt for these small alterations and still can save some fuel and money. Finally, the car was installed with cold air intake and all the aerodynamic modifications to study the overall effect of these. Car was driven in cold weather (from January to March) and in hot weather (from April to June) and the readings were taken. It is obvious that cold air intake system works better when the weather is already cold outside as the % difference decrease in the fuel from the normal state was noted to be about 16% whereas for the hot weather the fuel economy was increased by about 12%. To conclude, effect of combined alterations on the fuel economy was very positive. It will not only save some money for the driver over the year, but it can also save lots of fuel used by the cars that are on the road. As it is a known fact that the resources of oil are limited, so by adopting these modifications, fuel all around the world can be saved for a longer period.

5. CONCLUSION

This paper addresses the common driving conditions and their impact on fuel economy. Though several research papers have reported numerical studies on improving fuel economy, studies describing the actual performance of vehicle(s) subjected to various operating and design conditions are very limited. With the ever increasing gas prices, it is quite essential to quantify the effects of various parameters that directly control the consumption of fuel in the car. Three different cars fitted with gasoline engines were considered in this study. The parametric study was conducted under regular city driving conditions. From the parametric study it was observed that inflating car tires to the recommended tire pressure along with replacing air filter at regular intervals (such as during every oil change) appears to have reasonable impact on fuel economy.

Likewise, the impact of aerodynamic modifications and cold air intake were considered in this study as well. Cold air intake as compared to the regular air intake is at a much lower temperature and thus has higher density. Dense cold air has higher oxygen concentration, and this aspect aids the combustion of fuel in the engine. Better combustion leads to higher fuel economy. This characteristic was observed in this study.

Similarly, improving aerodynamics certainly decreases skin friction drag and therefore has a positive impact on fuel consumption. This feature was clearly seen in this study as well. As an extension of this work, more detailed analysis must be performed to understand the impact of design modifications. Though parametric study and design modifications deliver interesting results on fuel economy, detailed studies must be performed to clearly understand the gasoline engine's performance at various engine speeds and at various cold intake conditions. Based on the engine capacity, speed, compression ratio and valve timing, an optimum condition for the cold air intake can determined.

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