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ORIGINAL ARTICLE

Simulating the effects of turbocharging on the emission levels of a gasoline engine

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Abstract The main objective of this work was to respond to the global concern for the rise of the emissions and the necessity of preventing them to form rather than dealing with their after-effects. Therefore, the production levels of four main emissions, namely NO_x, CO_2, CO and UHC in gasoline engine of Nissan Maxima 1994 is assessed via 1-D simulation with the GT-Power code. Then, a proper matching of turbine-compressor is carried out to propose a turbocharger for the engine, and the resultant emissions are compared to the naturally aspirated engine. It is found that the emission levels of NO_x, CO, and CO_2 are higher in terms of their concentration in the exhaust fume of the turbocharged engine, in comparison with the naturally aspirated engine. However, at the same time, the brake power and the brake specific emissions produced by the turbocharged engine are respectively higher and lower than those of the naturally aspirated engine. Therefore, it is concluded that, for a specific application, turbocharging provides the chance to achieve the performance of a potential naturally aspirated engine while producing lower emissions.

1. Introduction

Spark ignition engines (SI, also known as gasoline engines) and compression ignition (CI, also known as diesel engines or direct injection (DI) engines) are the two major categories of internal combustion engines. SI engines have been widely used across Europe, while CI engines are wide spread globally. Their main application is for transportation. The major emissions of the SI engines are NOx, CO, CO2, and unburned hydrocarbons (UHCs). NOx is a general term referring to nitrogen oxides (i.e. NO (nitrous oxide), NO2 (nitrogen dioxide)). These pollutants form in extremely high temperature in-cylinder conditions of SI engines in the presence of nitrogen and oxygen from the air and the fuel [1]. Nitrogen oxides form acid rain which harms human health, deteriorates structures, pollutes waters and marine ecosystems, and destructs forests [2,3]. Moreover, they can penetrate deeply into lung tissues and cause irritations, cause or worsen respiratory diseases, or deteriorate heart diseases [4]. Carbon dioxide (CO2) is the main product of the hydrocarbon combustion reactions. The anthropogenic carbon dioxide is known as the main reason for aggravation of the

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greenhouse effect and global warming [5,6]. Carbon monoxide is a colorless, odorless, and tasteless gas that is slightly less dense than air. It is a product of partial oxidation of carbohydrates and forms when there is not enough oxygen available to combustion. In the presence of enough oxygen CO burns to produce carbon dioxide (CO2). CO has about 220 times greater potential to combine with hemoglobin in blood and thus lessens the oxygen delivery to the tissues and causes suffocation [7]. Moreover, CO contributes to formation of the tropospheric ozone [5]. Unburned hydrocarbons are actually the fuel molecules not burned during the combustion process in cylinder. Situated inside the crevices of the combustion chamber or precipitate on the walls of the chamber, they avoid the flame zone and thus remain unburned. These unburned fuel molecules then find their way to the exhaust fume and eventually the atmosphere [1]. The unburned hydrocarbons can cause respiratory problems, allergic issues or even immune deficiencies in children [8]. It is worth noting that there are significant evidence on the effects of generic air pollutants on fetal growth, preterm delivery, cardiac arrhythmia, and mortality [9–11].

One of the methods to improve the performance of internal combustion engines is to turbocharge them. Turbocharging was invented between 1909 and 1915 by Alfred Buechi, the Swiss engineer [12]. Movahed et al. researched the effects of concomitant injection of gasoline and CNG in 1.6 L turbocharged spark-ignition (SI) engine [13]. They revealed that BSFC, HC and CO emissions of gasoline mode at 4500 rpm and full load conditions are higher than 30% CNG mass fraction by about 24%, 80% and 75%, respectively. However, the cylinder peak pressure and raw NOx emissions of gasoline mode are lower by about 10% and 66%, respectively. Raw NOx emissions at 4500 rpm and full load conditions are 68% higher in the CNG mode, while BSFC, HC and CO emissions are 19%, 44% and 83% lower, consecutively. Silva et al. investigated the effects of turbocharging on a 2 L, light-duty gasoline engine. Their results reveal that turbocharging is an inexpensive and effective way for reducing fuel consumption and greenhouse gases production. 20% downsizing the engine, and boosting 20–50% the inlet pressure, they could lessen the fuel consumption about 6–14%. In addition, there is a decrease in pollutants: 2–4% for HC, 7–20% for CO, and 8–23% for NO [14]. Petitjean et al. researched fuel consumption and emissions in turbocharged SI gasoline engine experimentally [15]. They observed that the smaller turbocharged engine produces higher torques in the majority of the working speeds. They claim that CO2 emissions are significantly lower in turbocharged engines and the reason behind this is the improved fuel economy in turbocharged operations. That is, downsized turbocharged engines are capable of producing the same amount of power and torque as those of naturally aspirated engines, consuming less fuel and, therefore, releasing less carbon dioxide. Leduc et al. also suggested downsizing of gasoline engines as an efficient way to reduce CO2 emissions [16]. Their results revealed that use of small 0.8 L instead of genuine 1.6 L engine for powering the reference car, all other parameters being constant, leads to a reduction in vehicle fuel consumption. Olsson et al. claimed that using turbocharging on an HCCI engine is an effective way to reach high loads [17]. The ability of HCCI to provide high loads with very low NOx emissions is proven. The low exhaust temperature, which is characteristic of HCCI, combined with turbo charging causes pump losses. To keep efficiency high, it is therefore important not to use higher boost than needed to reach desired load. Gharehghani et al. experimentally investigate the thermal balance and performance of a turbocharged gas spark ignition engine [18]. The first law of thermodynamics was used for control volume around the engine to compute the output power, transferred energy to the cooling fluid, exhaust gases and also unaccounted losses through convection and radiation heat transfer. They also investigated the effect of shifting from gasoline to CNG fuel on production of NOx, HC and CO as well as performance characteristics of a turbocharged SI engine. They could reach about 85% increase in power using a turbocharger on SI engine running on CNG. Performance and emission improving of turbocharged DI diesel engine is evaluated by Mohebbi et al. [19]. Their results suggest that, although EGR is effective to reduce NOx by lowering peak of cylinder pressure and temperature, there is a substantial trade-off in increased BSFC and PM emissions due to the reduction of oxygen concentration in the cylinder intake air. Karabektas revealed in his paper the effects of turbocharger on the performance of a diesel engine using diesel fuel and biodiesel, in terms of brake power, torque, brake specific consumption and thermal efficiency, as well as CO and NOx emissions [20]. The evaluation of experimental data showed that the brake thermal efficiency of biodiesel was slightly higher than that of diesel fuel in both naturally aspirated and turbocharged conditions, while biodiesel yielded slightly lower brake power and torque along with higher fuel consumption values. It was also observed that emissions of CO in the operations with biodiesel were lower than those in the operations with diesel fuel, whereas NOx emission in biodiesel operation was higher. Shahed and Bauer confirmed that 40% downsizing of a DI diesel engine, along with turbocharging, yields a 23% reduction in fuel consumption [21]. Less fuel consumption means less CO2 emissions. Also, Pakale and Patel confirmed that turbocharging substantially reduces nitrogen oxides and improves fuel efficiency and power density [22]. Vitek et al. dealt with the investigation of turbocharger optimization procedures using amended 1-D simulation tools. The proposed method uses scaled flow rate/efficiency maps for different sizes of a radial turbine together with a fictitious compressor map [23]. King incorporated an invented 1-D model into the GT-Power engine simulation code to predict on-engine performance of the turbocharger. He investigated the effects of unsteady operation of turbocharger on internal combustion engine's performance [24].

There seems to exist a gap in the previous literature about the effects of turbocharger on the emissions of gasoline engines, considering the high useful powers turbocharging will provide. The main objective of this work was to fill this gap while responding to the global concern for the rise of the emissions and the necessity of preventing them to form rather than dealing with their after-effects. Therefore, the production levels of four main emissions, namely nitrogen oxides (NOx), carbon dioxide (CO2), carbon monoxide (CO) and unburned hydrocarbons (UHC) in gasoline engine of Nissan Maxima 1994 are assessed via 1-D simulation with the GT-Power code. Then, a proper matching of turbine-compressor is carried out to propose a turbocharger for the engine, and the resultant emissions are compared to the naturally aspirated engine, after a 1-D simulation of the turbocharged engine is carried out, utilizing the same code.

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