NUMERICAL INVESTIGATION OF THE EFFECT OF THE AIR/FUEL RATIO IN A NATURAL GAS POWERED CONVERTED COMPRESSION IGNITION ENGINE

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ABSTRACT

The gradual tightening of emission norms and the increasing use of conventional fuels increase the search for alternative fuels. With the developing drilling technology, while the ease of extraction of natural gas increases, its cost is also decreasing. Both its high lower heating value and less harmful gas emission as a result of combustion make natural gas more attractive. With the increasing control technology, studies on the conversion of compression ignition (CI) engines to natural gas powered spark ignition engines are also increasing. In this study, a diesel engine with a high compression ratio of 17.5:1 was converted into a spark-ignited natural gas engine using a 0/1-dimensional numerical program. Then, the effects of using diesel for the same start of combustion (SOC) times and using natural gas (NG) at different Air/Fuel (A/F) ratios on the performance and emission values were investigated. When the results were examined, it was seen that for similar conditions with CI combustion, NG use provides 14.53% increase in power and 14.86% reduction in fuel consumption. In addition, when the A/F ratio was 31, it was observed that while a 64% reduction was achieved in NO_X emission, the soot emission remained at the levels of 10^6 -10^7 g/kWh.

Keywords: NG, Spark ignition, Compression Ignition, AVL Boost,

1. INTRODUCTION

Although the use of electric vehicles increases, it is predicted that the use of internal combustion engines will continue in both the transportation sector and the stationary power generation sector in the near future (Liu and Dumitrescu, 2018). However, the continued use of internal combustion engines does not mean that conventional diesel or gasoline use will continue. By increasing the use of fuels such as NG, LPG, syngas etc. instead of these fuels, efforts to reduce both emissions release and fuel costs are increasing rapidly. Among these alternative fuels, natural gas is the most remarkable with government incentives and developing drilling technology (Liu continued, 2019a). In the US, the transformation of heavy-duty vehicles using diesel to spark ignition engines using natural gas has gained momentum, especially in recent times. It is estimated that approximately 20% of heavy-duty vehicles operating with diesel will turn into spark-ignition vehicles operating with NG in 2025. (U.S. Energy Information Administration, 2016).

The formation of pollutant emissions such as soot and NO_X is observed with the diesel fuel sprayed on the compressed air forming a rich and poor mixing zone. This happens in engines that use spark-ignition gasoline, mostly in the form of HC and CO emissions. However, in the use of natural gas, it creates a homogeneous air-fuel mixture and reduces both the formation of soot and HC and CO emissions with the low carbon number it contains, while reducing NO_X emissions by decreasing in-cylinder temperatures (Liu continued, 2019b).

Raine et al., (1988) modified naturally aspirated diesel engines with different compression ratios such as 18:1, 15:1 and 13:1 in a way that they can run on natural gas. Afterwards, they investigated the effects of compression ratio as well as ignition timing and air-fuel ratio. The results obtained with the use of only natural gas were compared to the use of only diesel at different speed and load conditions. It was observed that thermal efficiency, exhaust temperature and maximum pressure value increase at high speeds and loads (Raine continued, 1988). Meyer et al. (1992) converted a 320 kW heavy-duty diesel engine to run on natural gas only. They observed an increase in hydrocarbon emissions due to early flame extinction during idling and low load operation. However, a slight increase in power and torque values was observed under high speed and full load, while a decrease in thermal efficiency. In addition, while NO_X emissions improved by 61%, the decrease in thermal efficiency was around 19% (Meyer continued, 1992). Liu and Dumitrescu

(2019) investigated the effects of ignition timing, equivalence ratio and engine speed at low load and speed in a converted diesel engine running on natural gas. During this study, the effects of the special combustion chamber of the diesel engine on the combustion stages were also evaluated. When the results obtained were examined, it was seen that the combustion took place in two stages due to the special design of the combustion chamber. In general, it was concluded that the in-cylinder pressure, temperature and heat release values decreased with increasing equivalence ratio. Liu (2018) modified a diesel engine to run entirely on natural gas. Afterwards, the effects of natural gas components, ignition timing, equivalence ratio and engine speed on combustion characteristics were investigated experimentally and numerically. Experiments examining the equivalence ratio were performed at a compression ratio of 13.1:1 for low-medium load and low speed. With the increase of Air/Fuel ratio, in-cylinder pressure, heat release rate and combustion rate decreased. In addition, with increasing Air/Fuel ratio, the maximum pressure value and the indicated mean effective pressure values decreased, while the thermal efficiency value first increased and then decreased. (Liu, 2018)

In general, it has been observed that there are limited studies in the literature on the conversion of a diesel engine to a spark-ignition engine that can only work with natural gas. While these studies generally have a low compression ratio, it has been observed that the experiments and numerical studies are mostly performed under low loads and speeds. In addition, in these studies, it was seen that rather than performance and emission comparison, extensive information was given about in-cylinder combustion characteristics.

In this study, a 3-cylinder diesel tractor engine was modeled as 0/1-dimension by transforming it with a spark plug assembly instead of a diesel injector and a low-pressure NG fuel injector mounted on the intake manifold. Then, the use of diesel and natural gas at the same SOC times and for the same fuel A/F ratio was compared, and the effects of using natural gas at different A/F ratios on performance and emission values were examined.

2. ENGINE SIMULATION MODEL WITH AVL BOOST

In the study, the model converted from a compression ignition engine to a spark ignition natural gas engine and analyzed in 0/1-dimension with the help of AVL Boost was given in Figure 1. When Figure 1 is examined, it is seen that SB1 and SB2: system boundary conditions, MP1-MP10: measuring points, CO1 and CO2: intercoolers, PL1 and PL2: intake and exhaust manifolds, I1-I3: natural gas injectors, C1-C3: cylinders, 1-30: the connection elements, R1: restrictive element, TC1: turbocharger, and E1: Engine. The analyses were carried out as "general species" in order to obtain emission values. CH_4 was used as an NG fuel surrogate and sent as premixed from the suction port. While the features related to the engine were given in Table 1, the simulation parameters were given in Table 2. As seen in Figure 1, natural gas was injected from the intake ports from multiple points. In both diesel and natural gas usage, the SOC time was taken as +0 CA ATDC for initial analyses while the A/F ratio was set as 26.8. Afterwards, the combustion characteristics and emission changes in the use of natural gas for different A/F ratio were examined without changing the SOC time.

Table 1. Engine Specifications

Specification	**Value**
Displaced volume - total (cm^3)	2930
Number of cylinders	3
Bore / Stroke (mm)	104 / 115
Connection rod (mm)	182
Compression ratio (-)	17.5:1

Table 2. Simulation parameters

Parameter	Value
Engine speed (m/s)	***2300***
Start of Combustion (° CA ATDC)	***0***
Air/Fuel ratio (-)	22, …***26.8***,…30
Lower Heating Value (MJ/kg) (CH_4-Diesel)	50-44

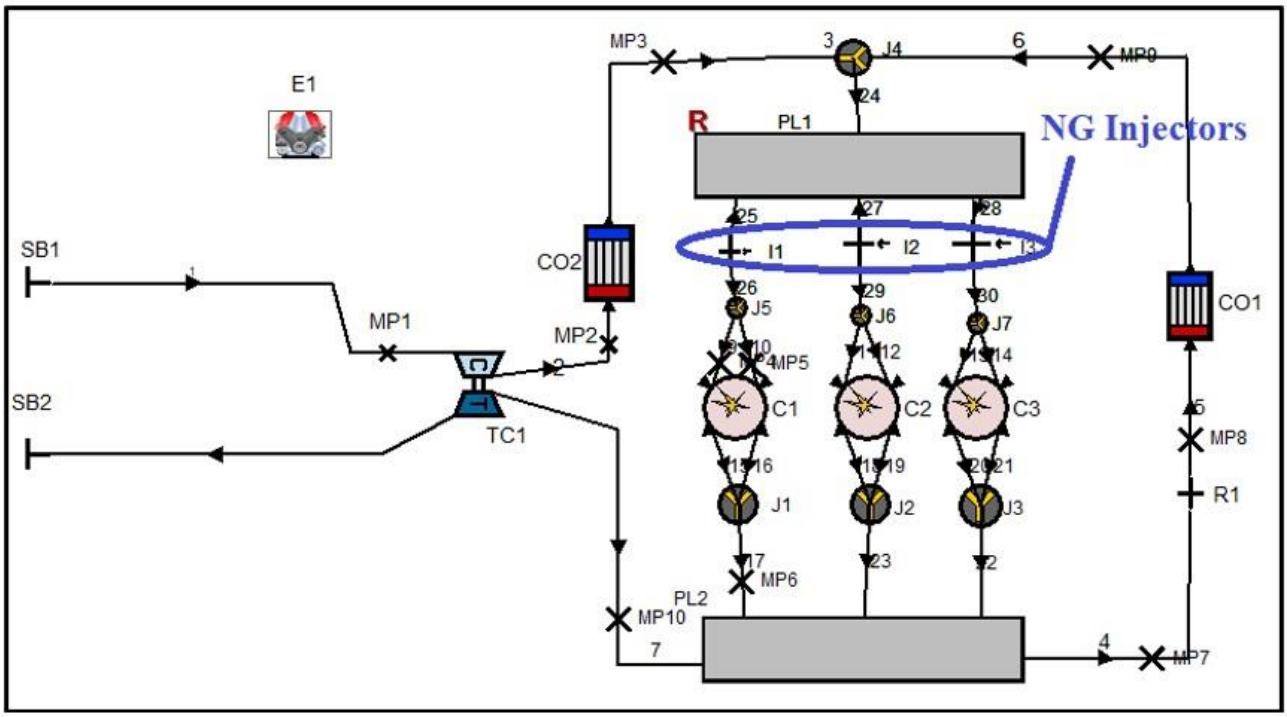


Figure 1. AVL Boost model of the converted engine

3. RESULTS AND DISCUSSION

In this section, the effects of NG use on performance, in-cylinder combustion characteristics and emission values for different A/F ratios in SOC time +0 CA ATDC at 2300 rpm were examined and compared with diesel fuel use. Figure 2 shows the variation of brake power and specific fuel consumption with A/F ratio in NG usage. At +0 CA ATDC, a 14.53% increase in power and a 14.86% decrease in fuel consumption were observed in NG use compared to diesel use. Afterwards, the increase in A/F fuel ratio only in NG use, worsening combustion and decreasing chemical energy decreased the brake power, while fuel consumption increased. NG usage seems more advantageous than diesel usage even for 29.5 A/F ratio in terms of brake power since both fuel consumption and fuel unit cost are lower.

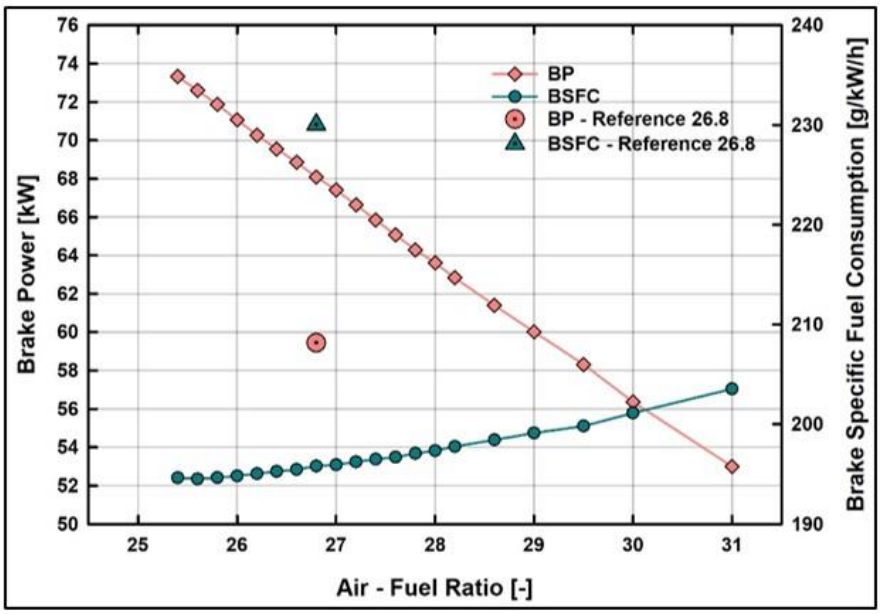


Figure 2. The effect of A/F ratio on brake power and brake specific fuel consumption

Figure 3 shows an increase of 14.55% in BMEP and 17.48% in BTE in NG fuel use compared to diesel fuel use. BMEP and BTE values decreased due to the worsening of combustion with the increasing A/F ratio in natural gas use and the decreased amount of fuel. However, BTE values in NG use were higher than diesel use in all A/F uses, while the limit value for BMEP value was above 29 for A/F ratio. Raine et al., (1988) showed a slight increase in thermal efficiency and mean effective pressure values under high speed and load after the natural gas conversion in a naturally aspirated diesel engine. In addition, it was observed that efficiency and torque values decreased with increasing Air/Fuel ratio. Similarly, Liu et al. (2018) found in their study that BMEP and BTE values decreased with increasing A/F ratio at medium load and low-speed values.

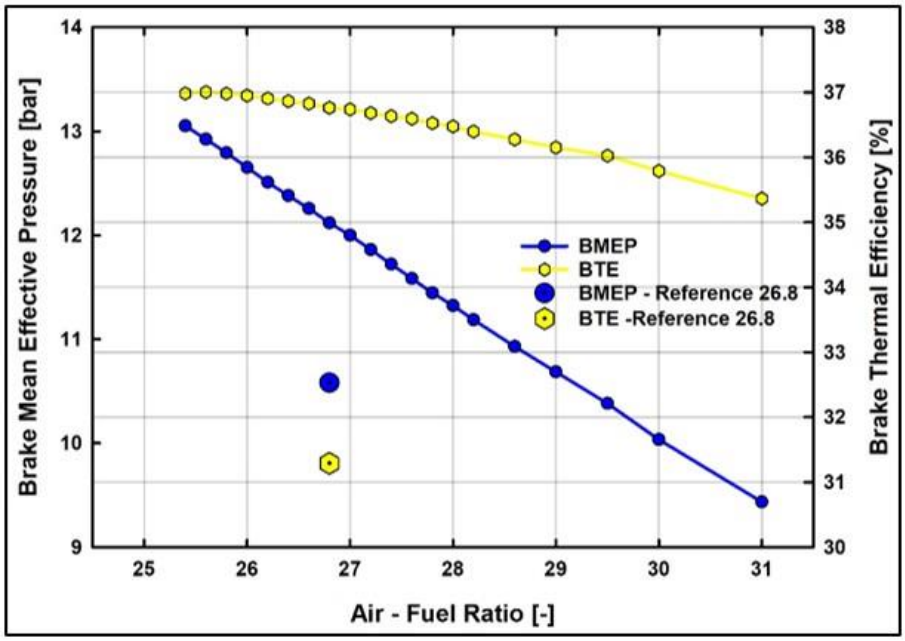


Figure 3. The effect of A/F ratio on BMEP and BTE

When Figure 4 is examined, it is seen that the average temperature and pressure values increased by 2.96% and 23.44% respectively in the use of NG according to the use of diesel fuel. In SI conversion, sending the NG premixed and the high lower heating value had an effect. Then, with the increasing A/F ratio, the in-cylinder pressure and temperature values decreased as the combustion worsens. Liu et al. (2018) showed that the maximum pressure value decreased with increasing A/F ratio at medium load and low speed values.

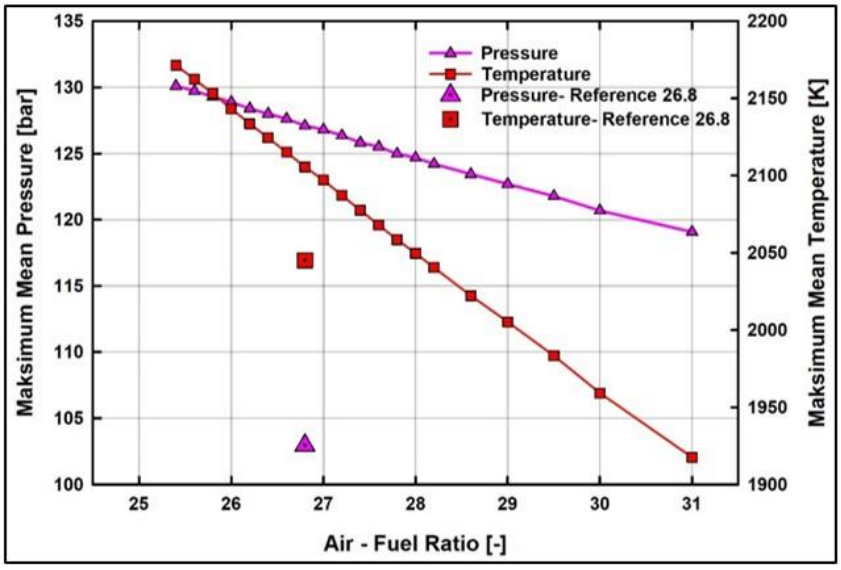


Figure 4. The effect of A/F ratio on maximum mean pressure and temperature

In Figure 5, although the compression pressure in TDC was less than diesel fuel in NG use, the maximum pressure value was higher than diesel. In addition, it was seen that the maximum pressure value in the cylinder decreases with the increasing A/F ratio in NG use.

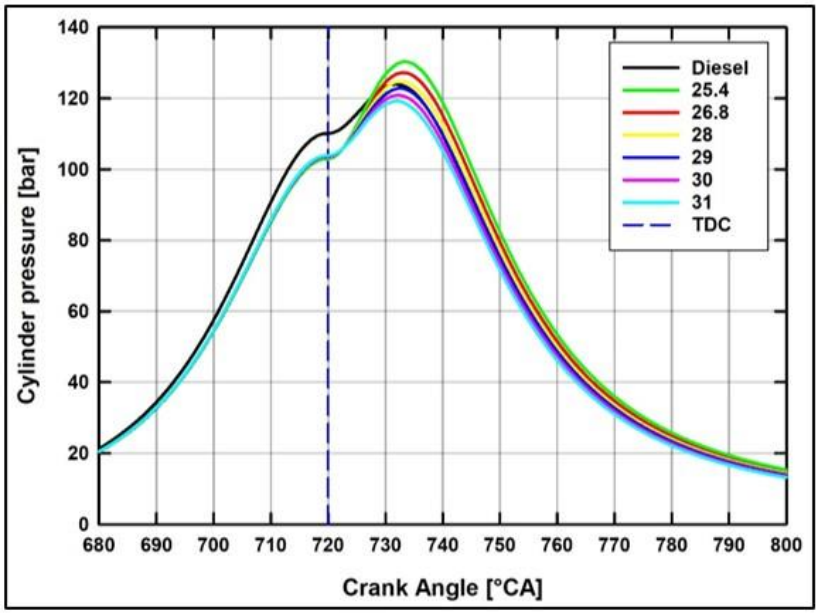


Figure 5. The effect of A/F ratio on in-cylinder pressure

Figure 6 shows the effect of A/F ratio on the in-cylinder heat release rate. The increased amount of A/F decreased both the chemical energy available per cycle and the flame velocity, causing the in-cylinder combustion to deteriorate and the rate of heat release to decrease. This decrease in the rate of heat release also had a negative effect on combustion performance, fuel consumption and THC emissions. Liu et al. (2018) in their study, both in-cylinder pressure, and in-cylinder heat release values decreased with increasing A/F ratio at medium load and low-speed values, which led to a decrease in the brake power produced. In addition, the decrease in the amount of heat generated in the cylinder caused the temperature values in the cylinder to decrease, as can be seen in Figure 7.

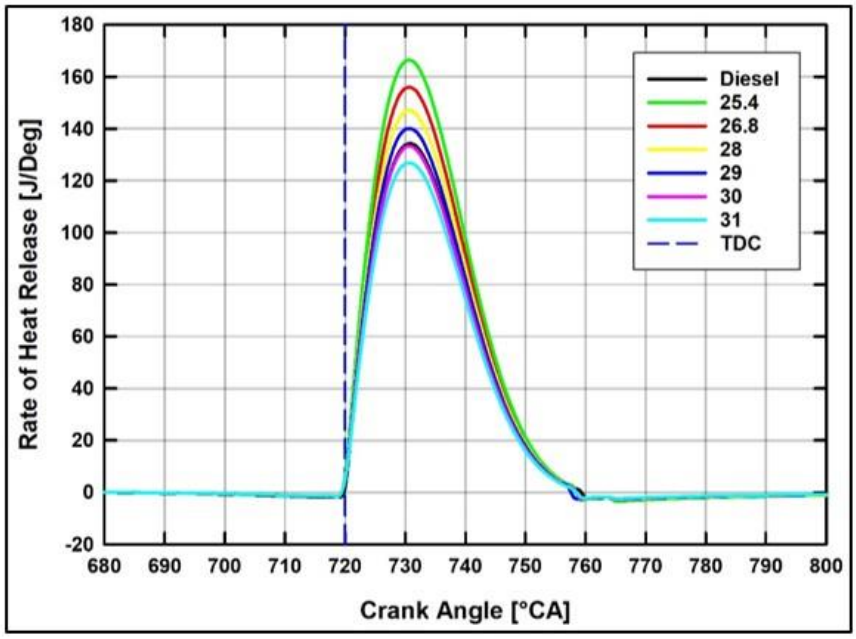


Figure 6. The effect of A/F ratio on in-cylinder rate of heat release

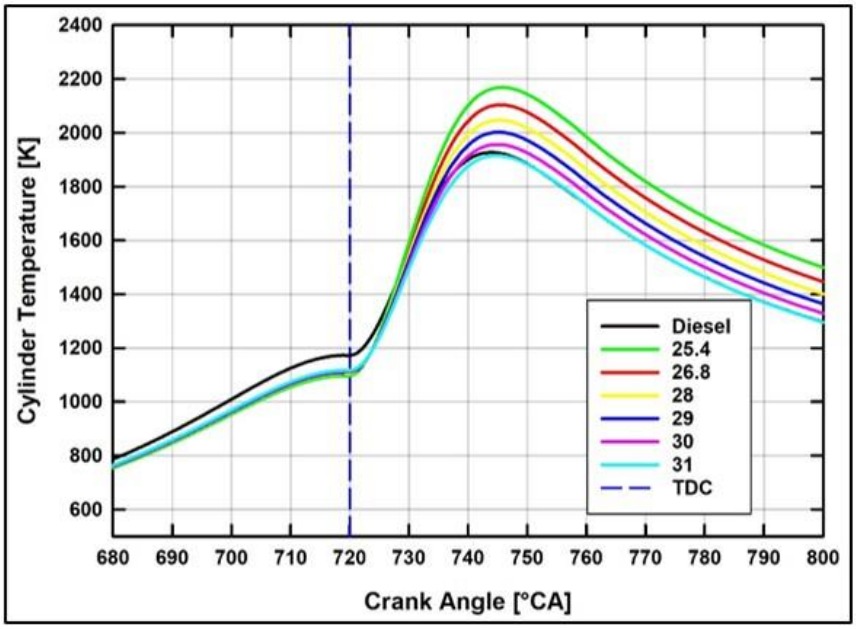


Figure 7. The effect of A/F ratio on in-cylinder temperature

Figure 8 shows the effect of A/F ratio on emission characteristics. The given NO_X and CO values were normalized according to diesel use at a rate of 26.8 H / Y at + 0 ° CA ATDC, and HC values were normalized according to NG use. It was observed that NO_X formation decreased with the decrease in-cylinder temperatures with increasing A/F ratio. When the A/F ratio was 31, NO_X formation was approximately 88%, CO emission 63% less, while HC emission increased 1.54 times.

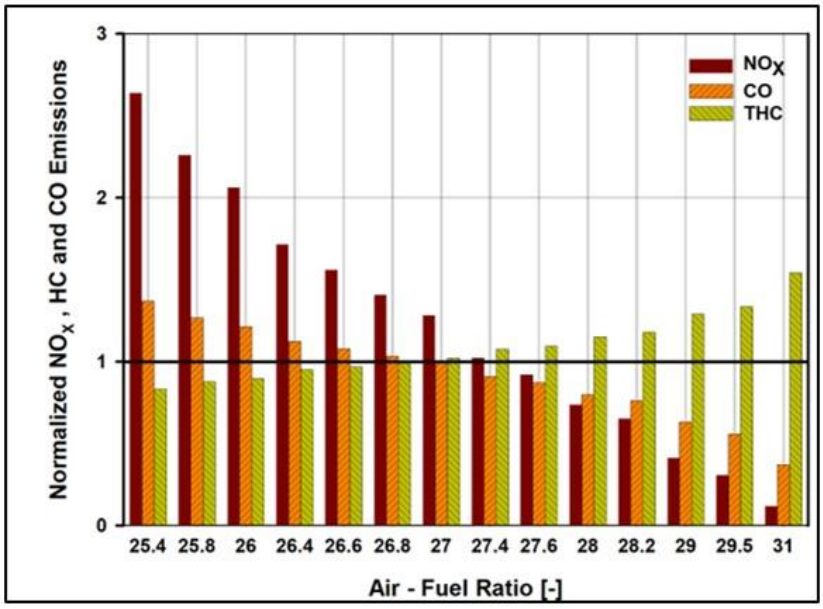


Figure 8. The effect of A/F ratio on emissions

4. CONCLUSIONS AND RECOMMENDATIONS

With the developing injector and control technology, during the rectification of a diesel engine that has completed its service life, the installation of a spark plug on the cylinder head and a low-pressure NG fuel injector mounted on the intake port is an economical approach. With the high compression ratio of the diesel engine, it can work in leaner mixtures and reduce NO_X emissions, especially with low in-cylinder temperatures. If the work done in general is to be evaluated:

1. It was seen that NO_X emission could be reduced by 64% in the study performed with only A/F ratio without any parametric study. It can be said that there is no need to use Selective Catalytic Reduction (SCR) by increasing this ratio with compression ratio, SOC time or combustion chamber changes.

2. In addition, since the formation of soot emission remained in the levels of 10^6 -10^7 g / kWh, there was no need to use Diesel Particulate Filter (DPF).

3. Under the same conditions, fuel consumption decreased while brake power increased due to the fact that natural gas was sent as premixed, the engine was turbocharged and the lower calorific value of natural gas was higher than diesel fuel.

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