EFFECTS OF EXHAUST GAS RECIRCULATION ON PERFORMANCE AND EXHAUST GAS EMISSIONS OF SPARK IGNITION ENGINES

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ABSTRACT

The purpose of internal combustion engines is the production of mechanical power from the chemical energy contained in the fuel. Internal combustion engines can be classified into spark ignition (S.I) engine which is the focus of this work and compression ignition engine. S.I engine exhaust gas emissions which consist of oxides of nitrogen (NO_X), carbon monoxide (CO) and unburned hydrocarbons (HC) are a major source of urban air pollution. This work investigated the effects of exhaust gas recirculation (EGR), engine speed and engine load on performance and exhaust gas emissions of spark ignition engines. Eleven S.I engine parameters were considered in this work which was divided into three input parameters and eight output parameters. The effects of variations in the input parameters on the output parameters were simulated using artificial neural network software implemented in MATLAB 7.9 environment developed by the authors. From the results obtained, it can be shown that NO_X emissions reduced significantly with increase in EGR level while CO and HC emission increased moderately. Specific fuel consumption increased slightly with increase in EGR level while the other four performance parameters reduced with increase in EGR. It can be concluded from this work that for improved performance and low exhaust gas emissions, S.I engines should be operated at low levels of EGR.

***Keywords**: Performance, Emissions, EGR and S.I Engines*

Introduction

The purpose of internal combustion engines is the production of mechanical power from chemical energy contained in the fuel (1). In internal combustion engines, as distinct from external combustion engines, the energy is released by burning or oxidizing the fuel inside the engine (1, 2). The fuel-air mixture before combustion and the burned product after combustion are the actual working fluids. Internal combustion engines can be divided into spark ignition engine which is the focus of this work and compression ignition engines.

Spark ignition (S.I) engines are a major source of urban air pollution. S.I engines exhaust gasses contain oxides of nitrogen (NO_X), carbon monoxide (CO) and organic compounds which are unburned or partially burned hydrocarbons (HC) (1, 3, 4, and 5). The relative amounts depend on engine design and operating conditions (1). Two of the most important variables in determining spark ignition engine emissions are the fuel/air equivalence ratio and exhaust gas recirculation (EGR). (6, 7, 8) EGR is a process by which part of the exhaust gas is use of recycled exhaust to dilute the engine intake mixture has effects on exhaust gas emissions and performance of S.I engines. Operating conditions such as engine load and engine speed also have effects on exhaust gas emission and performance of S.I engines (1, 9, 10). Fuel which powers the internal combustion engine has been a powerful motivator for government decision malting and foreign policy since the last century. Countries have been invaded and wars fought over petroleum. Germany lost World War II in part because it ran out of gasoline (11, 12). Given the concern over worldwide oil reserves and greenhouse gasses, it is not surprising that considerable research is devoted to increasing the efficiency of internal combustion engines, especially for the spark ignition engines, a major consumer of petroleum and a major source of greenhouse gasses (1, 11). This work is set to investigate the effects of exhaust gas recirculation, engine speed and engine load on exhaust gas emissions and performance of spark ignition engines.

Research Methodology.

In this work, eleven engine parameters were considered. These parameters were grouped under input parameters (independent variables) and output parameters (dependent variables)

2.1. Input Parameters

These are made up of two engines operational parameters and one engine design parameters. The parameters considered are:

i. Engine load (operation parameter)
ii. Engine speed (operation parameter)
iii. Exhaust gas recirculation (design parameter)

i. Engine load: This was varied at five levels from 0% loading condition to 100% loading condition. 360 kN represent 100% loading condition. Thus, the engine loads that were considered are 0%, 25%, 50%, 75% and 100%.
ii. Engine speed: For spark ignition engines, the maximum engine speed is not usually greater than 5000 rpm due to mechanical difficulties and it is not usually less than 1000 rpm. Therefore, the engine speeds considered are: 1000 rpm, 2000 rpm, 3000 rpm, 4000 rpm and 5000 rpm.
iii. Exhaust gas recirculation (EGR): It is very difficult to apply EGR at high loads since it will lead to abnormal combustion of the engine. Therefore, 0% EGR level is used as the baseline in this work and it was now varied at four levels above this value. The EGR value considered in this work are: 0%, 10%, 15%, 20% and 25%

2.2. Output parameters

The output parameters considered in this work are made up of five engine parameters and three exhaust gas emission parameters. The parameters considered are:

i. Specific fuel consumption (SFC) – (performance parameters)
ii. Brake power (BP) – (performance parameters)
iii. Brake mean effective pressure (BMEP) – (performance parameters)
iv. Thermal efficiency (η_{th}) – (performance parameters)
v. Exhaust gas temperature (Te_G) – (performance parameters)
vi. Unburnt hydrocarbon (HC) – (exhaust gas emission)
vii. Carbon monoxide (CO) – (exhaust gas emission)
viii. Oxides of Nitrogen (NO_X) – (exhaust gas emission)

2.3 Simulation Procedure

The effect of the variations in the input parameters on output parameters were simulated using artificial neural network software implemented in MATLAB 7.9 environment developed by the author. Fig 1 shows the flow chart for the simulation procedure.

The ANN model used is:

$$y_k = \sum_{l=1}^{N_H} W_i\, \varphi \left(\sum_{j=1}^{N} W_{ij}\, I_l \right) - - - - - - - - (1)$$

Where

y_k = outputs of the ANN model
K = number of output
N_H = number of neurons in the hidden layers
H = number of hidden layers
W_i = synaptic weights connecting the hidden layers with output
W_{ij} = synaptic weights connecting the inputs to the hidden layers
N = number of inputs
φ = activation / transfer function
I_j = Inputs to the ANN model

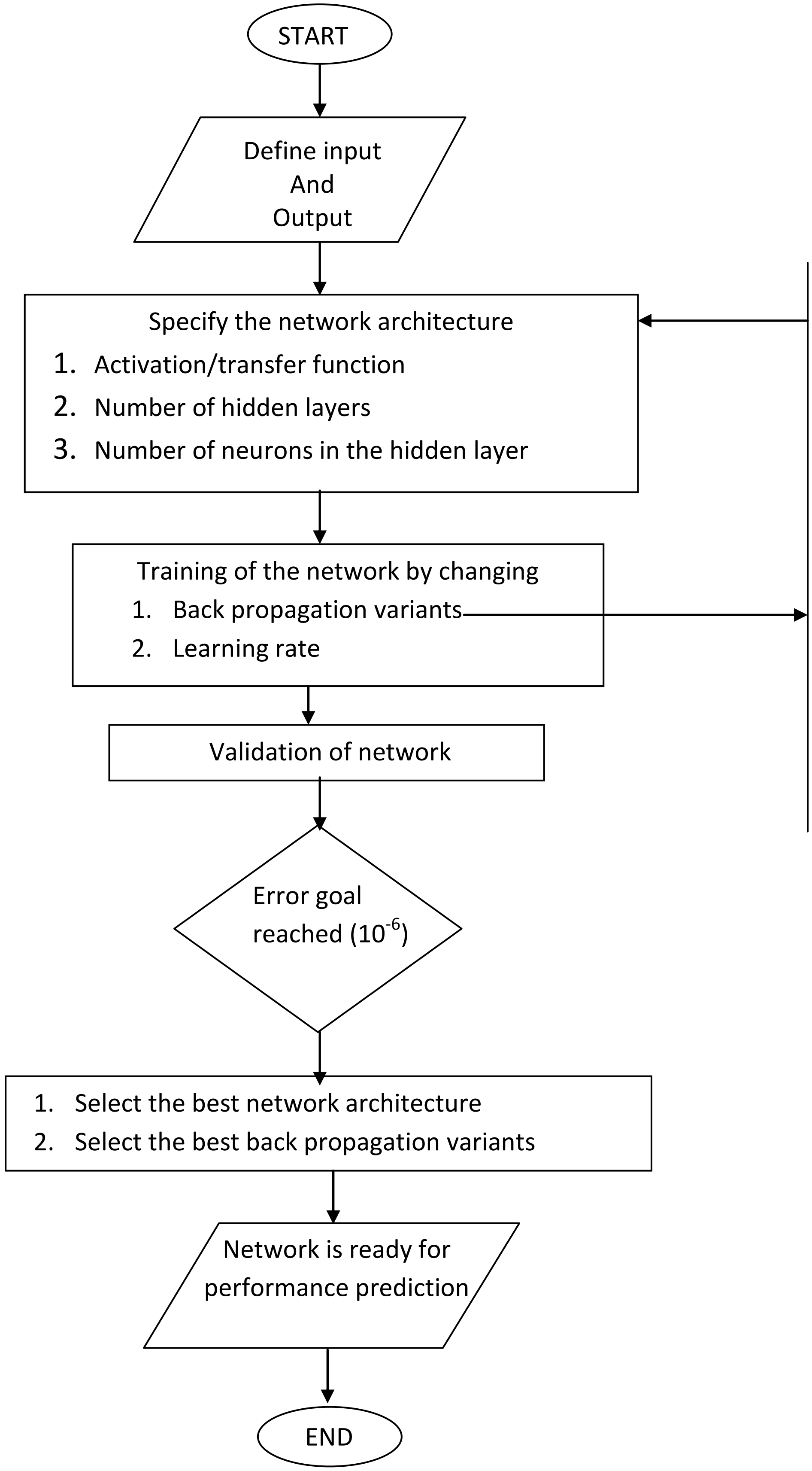

Figure 1: Flow Chart of the ANN Model used for Simulation\

Results and Discussions

The effects of EGR on performance and exhaust gas emissions of S.I engines were presented in Fig.1 to Fig.8. Form the figures, it can be shown that as the level of EGR increases, the values of BSFC reduces moderately and the values of HC and CO emissions increase marginally at all engine speeds and at all engine loads. The figures also show that as EGR level increases, the values of BP, thermal efficiency, BMEP and exhaust gas temperature reduce moderately while NO_X emission reduces significantly at all engine speeds and at all engine loads. This result indicates that EGR is used primarily to control NO_X emission of S.I engines

Table 1 shows that thermal efficiency decreases with increase in engine load at all equivalence ratios while all the other parameters increase with increase in engine load at all equivalence ratios. Engine speed of 3000 rpm gives the minimum value for BSFC, maximum value for BP, maximum value for BMEP, maximum value for thermal efficiency and maximum value for NO_X emission at all equivalence ratios. Engine speed of 5000 rpm gives the maximum value for exhaust gas temperature. CO and HC emissions increase significantly with increase in engine speed with maximum value at 5000 rpm at all equivalence ratios.

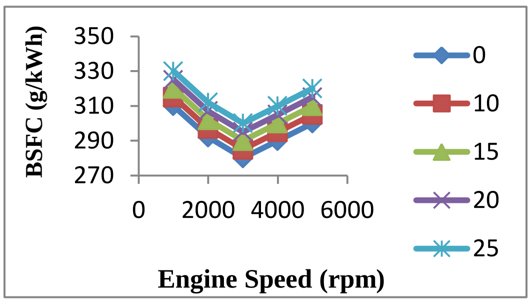

Figure 4.1: Effect of Exhaust Gas Recirculation on BSFC.

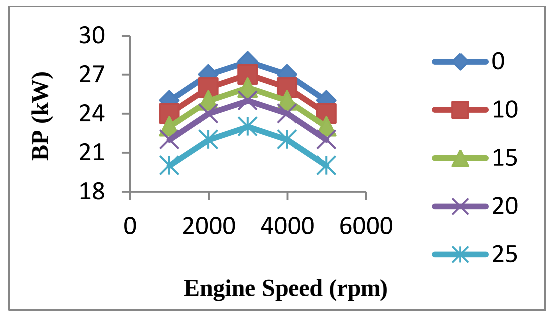

Figure 4.2: Effect of Exhaust Gas Recirculation on Brake Power (BP).

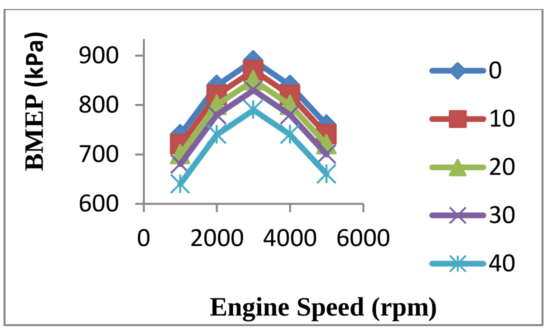

Figure 4.3: Effect of Exhaust Gas Recirculation on BMEP.

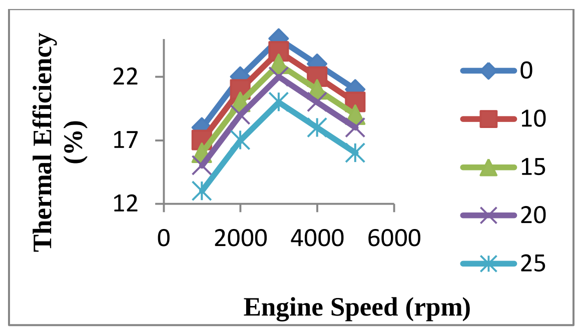

Figure 4.4: Effect of Exhaust Gas Recirculation on Thermal Efficiency.

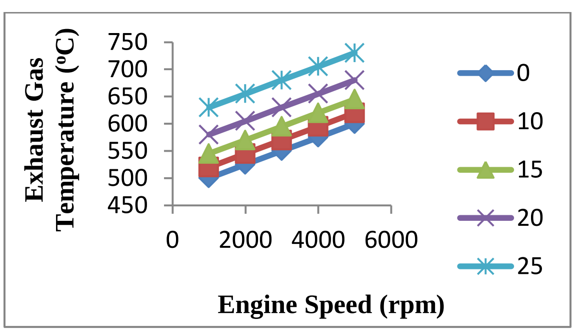

Figure 4.5: Effect of Exhaust Gas Recirculation on Exhaust Gas Temperature.

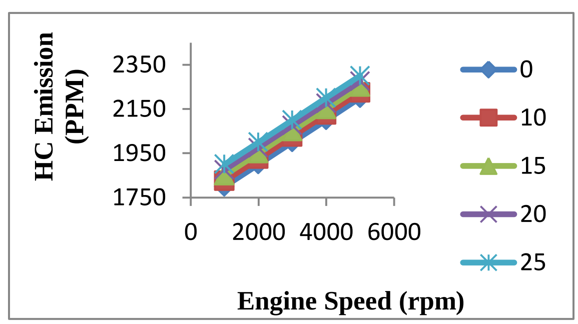

Figure 4.6: Effect of Exhaust Gas Recirculation on HC Emission.

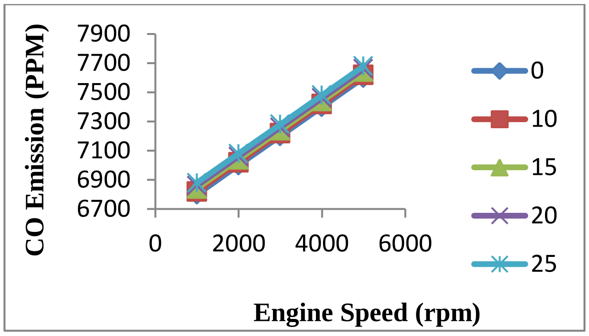

Figure 4.7: Effect of Exhaust Gas Recirculation on CO Emission.

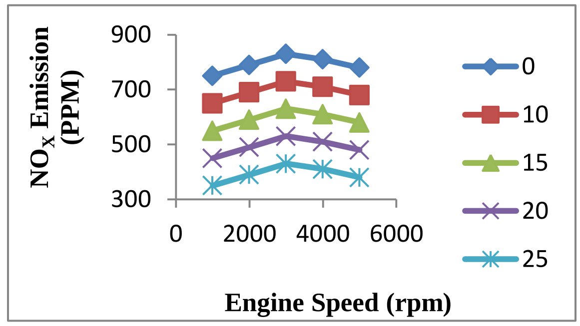

Figure 4.8: Effect of Exhaust Gas Recirculation on NO_X Emission.

Table 1: Effects of EGR and Engine Load on S.I Engine Operation

S/N	Engine Load (%)	EGR (%)	BSFC (g/kWh)	BP (kW)	BMEP (kPa)	η_{TH} (%)	T_{EG} (^oC)	HC (PPM)	CO (PPM)	NO_X (PPM)
1	0	0	240	21	410	25	480	1600	6600	580
2	25	0	255	22	510	24	510	750	6850	630
3	50	0	270	23	580	23	540	1900	7100	680
4	75	0	285	24	670	22	570	2050	7350	730
5	100	0	300	25	760	21	600	2200	7600	780
6	0	5	245	20	390	24	500	1625	6620	480
7	25	5	260	21	490	23	530	1775	6870	530
8	50	5	275	22	560	22	560	1925	7150	580
9	75	5	290	23	650	21	590	2075	7370	630
10	100	5	305	24	740	20	620	2225	7620	680
11	0	10	250	19	370	23	525	1650	6640	380
12	25	10	265	20	470	22	555	1800	6890	430
13	50	10	280	21	540	21	585	1950	7140	480
14	75	10	295	22	630	20	615	2100	7390	530
15	100	10	310	23	720	19	645	2250	7640	530
16	0	15	255	19	350	22	560	1675	6660	280
17	25	15	270	19	450	21	590	1825	6910	330
20	100	15	315	22	700	18	680	2275	7660	480
21	0	20	260	16	310	20	610	1700	6680	180
22	25	20	275	17	410	19	640	1850	6930	230
23	50	20	290	18	480	18	670	2000	7180	280
24	75	20	305	19	570	17	700	2150	7430	330
25	100	20	320	20	660	16	730	2300	7680	380

4. Conclusion

This work investigated the effect of three engine operating/design parameters on the performance and exhaust emissions of S.I engines. From the result obtained, it can be shown that NO_X emissions reduced significantly with increase in EGR while CO and HC emissions increase moderately. Specific fuel consumption increased slightly with increased EGR will the other four performance parameters reduced with increase in EGR. Exhaust gas emission and specific fuel consumption increased with increase in engine load while other engine performance parameters reduced with increase in engine speed of about 3000rpm gave the maximum values for several parameters considered in its work. It can be concluded from this work that for improved fuel economy, higher engine efficiency and low exhaust gas emissions, S.I engines should be operated at low engine loads, speed of about 300rpm and low level of EGR.

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