EFFECTS OF IDLING AND PART-LOAD CONDITIONS ON THE EMISSIONS OF HYDROCARBONS AND CARBON MONOXIDE IN A SPARK-IGNITED ENGINE

Ibrahim A. I. Aly, Mohamed N. Saeed,
Mohsen M. Osman, Mohamed K. Ibrahim and Abdelfattah I. Addelfattah
Mechanical Engineering Department, Faculty of Engineering,
Alexandria University, Alexandria Egypt.

ABSTRACT

Investigations were conducted on a spark-ignited engine for the concentrations of hydrocarbons (HC) and carbon monoxide (CO) emitted under idling as well as part-load conditions. The speed ranges of 600-1200 RPM (no-load) and 1200-2000 RPM (part-load) were studied. Spark timing was varied between 20 degrees BTDC to 10 degrees ATDC . Concentrations of HC and CO emissions were measured by a portable infrared exhaust gas analyzer . The study shows that the concentrations of HC and CO emissions in the exhaust manifold can be reduced by increasing the engine idling speed, raising the coolant temperature, and retarding the spark timing . Increasing engine speed at no-load conditions would decrease blowby flow rate . During the warm-up period, both the blowby flow rate and the concentrations of unburned HC & CO would decrease. The concentrations were correlated in a time-dependent form.

INTRODUCTION

Spark-ignited engines in modern automobiles and light trucks still constitute a considerable source of air pollution. The engine exhaust is the source of carbon monoxide (CO) emissions. The exhaust, the crankcase, the carburetor, and fuel tank are the sources of unburned hydrocarbons (HC)

Patterson and Henein[1] reviewed the effects of engine design and operating variables on HC emissions. They suggested that the effect of any variable should be considered in the formation of quench regions in the combustion chamber. A post-quench oxidation would then take place within the cylinder. Then there would be further oxidation in the exhaust system.

Many models were developed for the prediction of HC emissions under normal operating conditions of the engin. Among those were the models by Agnew and Green[2], Daniel[3], Hicks et al[4], Heywood[5], Sherman and Blumberg[6], Tabaczynski et al[7], Lavoie[8], Lavoie et al[9], and Yuen and Servati[10].

The mechanisms of formation and oxidation of CO were studied by Newhall[11], Keck and Gillespie[12], Fenimore and Moore[13], Heywood[5], and Kataoka and Hirako[14]. Newhall[11] found that the rate-controlling reaction are the three-body radical combination reactions involving H, O_2, and HO_2. The studiesby Keck and Gillespie[12] and Delichatsios[15] showed that at peak cylinder pressures and temperatures equilibration times for CO are so short that the CO concentration rapidly equilibrates in the burnt gases downstream of the reaction zone following combustion.

In the above literature most of the work has been done on spark-ignited engines at normal operating conditions (cruising mode). The scope of very rich mixtures has not received enough coverage although it is prevailing in the case of traffic jams in congested cities.

This study is concerned with the effect of engine operating parameters on the concentrations of HC and CO under idling and part-load conditions. The study also investigates the effect of engine operating parameters on the blowby flow rate and both the HC and CO concentrations during the warm-up period.

EXPERIMENTAL APPARATUS AND PROCEDURES

A four-stroke, four-cylinders, spark-ignited LADA BA3-2106 engine was used for conducting the experiments. The engine has a bore of 79 mm, a stroke of 80 mm, and a compression ratio of 8.5:1. The engine is coupled to a hydraulic dynamometer of maximum power and speed of 220 KW and 6000 RPM, respectively. The dynamometer is equipped with a revolution counter and a load cell. A schematic layout of the experimental set-up is shown in Figure (1).

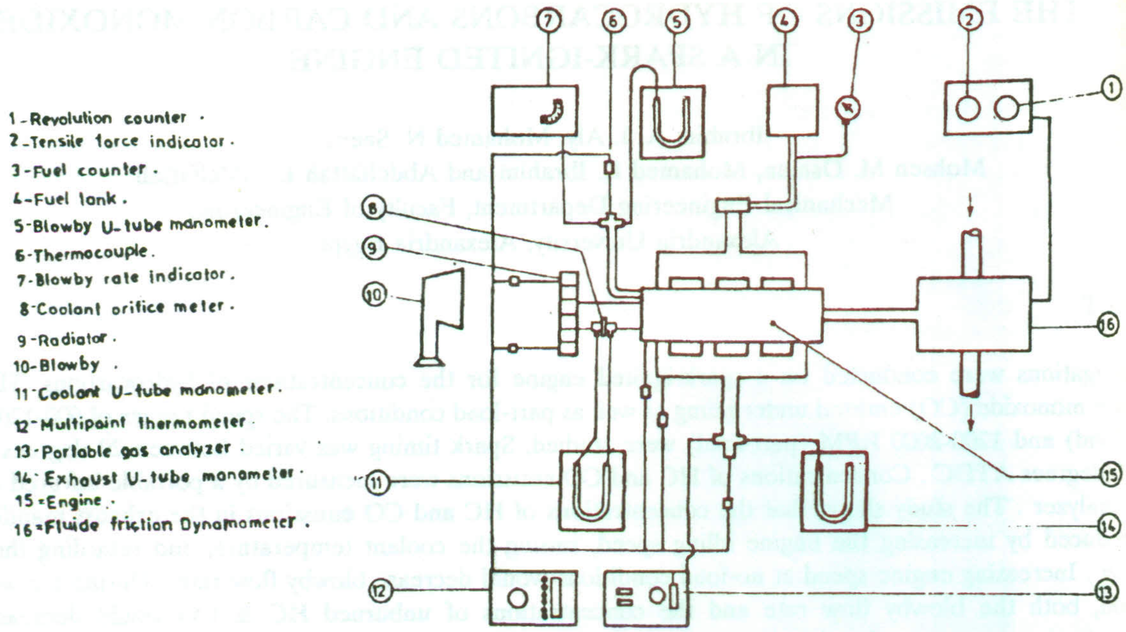

Figure 1. Schematic of apparatus and instrumentation.

Temperature measurements were taken at six locations: entry and exit of engine coolant, engine oil, engine blowby, exhayst-gas manifold, and exhaust-gas tailpipe. Shielded thermocouples of the J-type (iron-constantan) were assembled, calibrated, and securely installed. The thermocouples were connected to a multipoint digital readout through a six-channel selector.

The rate of fuel consumption was measured by using a fixed volume of fuel and a stop watch. The mass rate of flow of intake air was measured by using a Taylor-yype anemometer. The mass rate of flow of engine coolant was measured by using an orifice meter. The blowby flow rate (liters/min) was measured by a household gas meter. The blowby meter was connecte to the crankcase breathing system.

The HC and CO emission concentrations were measured by a portable infrared exhaust gas analyzer connected to the exhaust tailpipe. The accuracy of measurements was + 5 ppm for HC and + 0.05% for CO.

The engine was started and warmed up untill it reached steady-state operational conditions. The speed was adjusted to the required value. The idling speed range of 600-1200 RPM was investigated for no-load conditions while the speed range of 1200 to 2000 RPM was investigated for a constant torque of 50 N.M. The required engine load was obtained through the dynamometer controls. The following quantities were routinely measured during each test:

- Engine speed, - Engine load, - Spark timing, - Mass rate of flow of fuel, - Mass rate of flow of engine coolant, - Engine coolant temperature, - Blowby flow rate, - Blowby temperature and pressure, - Engine oil temperature (sump),

- Exhaust manifold temperature, - Intake-air temperature, - Exhaust tailpipe temperature and pressure, - HC emission concentration, - Co emission concentration

The following quantities were then clculated for each run:

- Mass rate of flow of intake air, - Air-fuel ratio, - Rate of energy release, - Brake power, - Brake specific fuel consumption, - Brake mean effective pressure, - Brake thermal efficiency

RESULTS AND DISCUSSIONS

Fuel Economy

Figure (2) shows the effect of engine speed on the rat of fuel consumption at no load for various spark timing It appears from the figure that the rate of fu consumption increases with the increase in speed for the idling range of 600-‘1200 RPM. This increase in fuel consumption is to overcome the increasing friction. On the other hand, the figure shows that the rate of fuel consumption decreases as the timing is advanced from 10 degrees ATDC to 20 degrees BTDC. The improvement in fuel economy may be attributed to the increase in the indicated work of the engine. As the spark is advanced, the rate of pressure rise decreases and the gas pressure attains higher values during the expansion stroke. This means a resulting increase in the work integral $\int$ PdV.

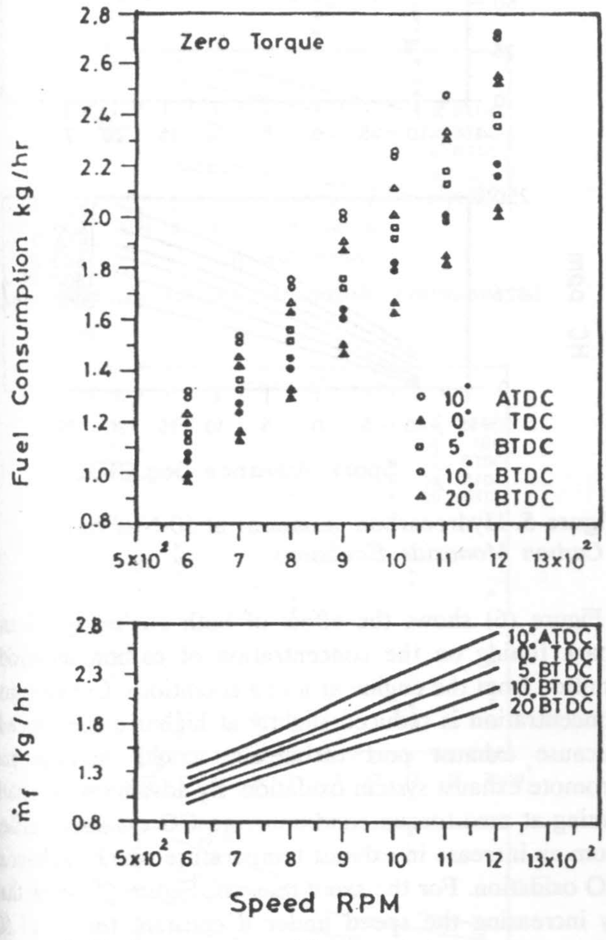

Figure 2. Fuel economy at iding conditions.

The effect of spark advance on the brake specific fuel consumption (BSFC) is presented in Figure (3) for the constant part-load torque of 50 N.m and various engine speeds. The figure shows that the effect of spark timing on BSFC is more infuential than the effect of speed. If the spark timing is retarded from 20° BTDC to 10° ATDC, the BSFC may increase by over 15%. On the other hand, the speed change from 1200 to 2000 RPM increases the SBFC by 8% only.

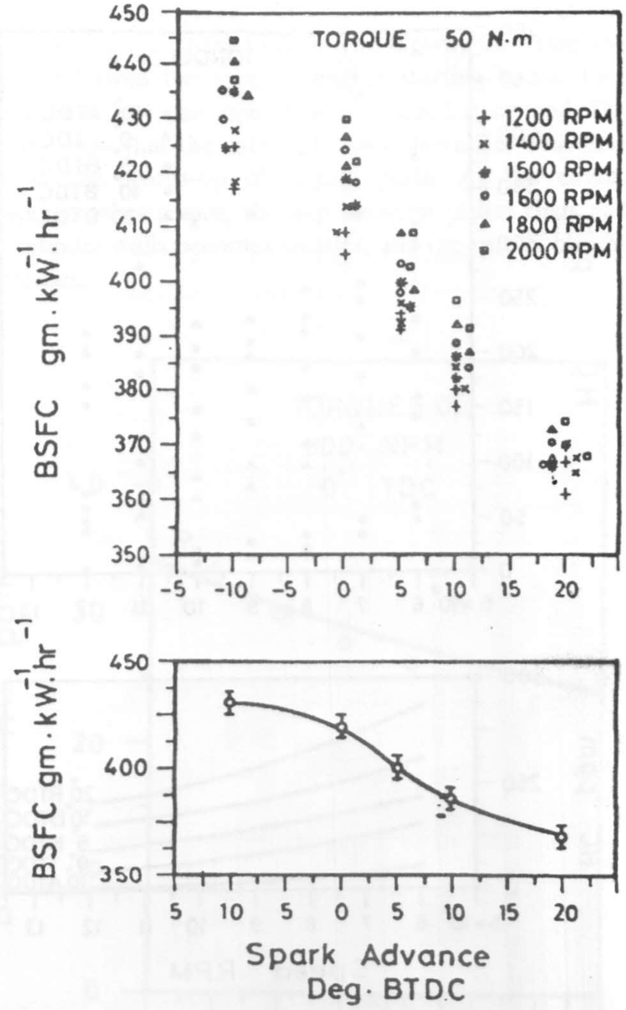

Figure 3. Fuel economy at part-load conditions (torque = 50 N.m).

Hydrocarbon Emissions

Figure (4) shows the effect of both spark timing and engine speed on the concentration of hydrocarbons (HC) emitted at zero-torque operation. It appears that the HC concntration would decrease by retarding spark timing as a result of the increase in exhaust temperature and the associating promotion of HC oxidation. As for the effect of engine speed on HC emissions, the figure shows that the higher the speed, the lower the HC concentrations would be. The increase in engine speed improves the combustion process within the cylinder by increasing turbulent mixing and eddy diffusion. This promotes after-oxidation of the quenched layer that contains most of the unburned HC. Inaddition, a higher exhaust port turbulence at higher speeds promotes oxidation reactions through better mixing within the exhaust system.

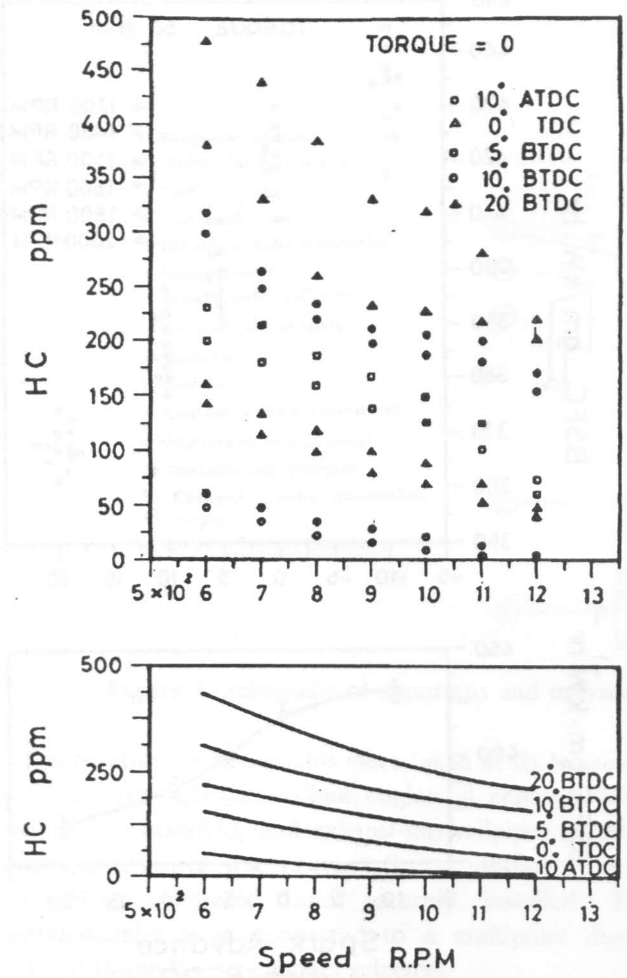

Figure 4. Hydrocarbon emissions at iding.

Figure 5 shows that by advancing the spark timing, the HC emissions would increase for the constant torque of 50 N.m. On the other hand, the increase in speed would reduce the HC concentration.

The effect of engine coolant temerature on the HC emission concentration was investigated for the coolant temperature of 45-75 °C at zero-torque conditions and 65-90 °C at the constant torque of 50 N.m. It was observed that the HC emission concentration would decrease slightly by increasing the coolant temperature.

The results show that the HC emissions at idling conditions are roughly double their values at the part-load torque of 50 N.m. This is because the combustion temperature (and subsequently the exhaust temperature) is higher at part load than no load. The results of the present study show that the exhaust temperature ranged between 300 and 725° for part-load operation.

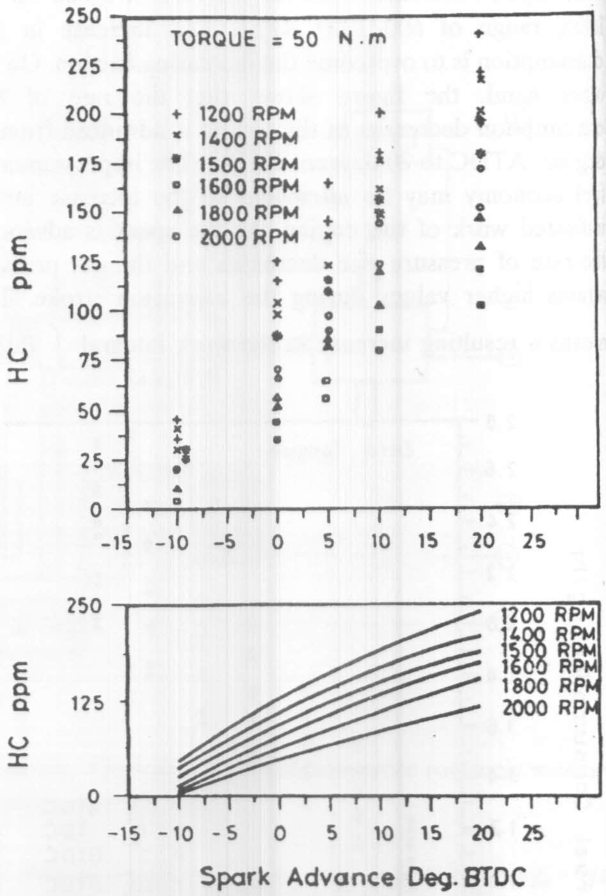

Figure 5. Hydrocarbon emissions at 50-N.m torque.

Carbon Monoxide Emissions

Figure (6) shows the effect of both engine speed and spark timing on the concentration of carbon monoxide emitted from the engine at idling conditions. CO emission concentration is reduced slightly at higher engine speeds because exhaust port turbulence would increase and promote exhaust system oxidation. By advancing the spark timing at zero-torque conditions the CO emissions arises from an increase in exhaust temperature which enchances CO oxidation. For the same reasons, Figure (7) show that by increasing the speed under a constant torque of 50 N.m, the CO concentration would decrease slightly. As the spark timing is advanced the CO emissions would increase.

As for the effect of engine coolant temperature on the CO emission, the results show thatlower coolant temperatures cause higher CO concentrations. However, this effect is not asw significant as the effects of spark timing and engine speed.

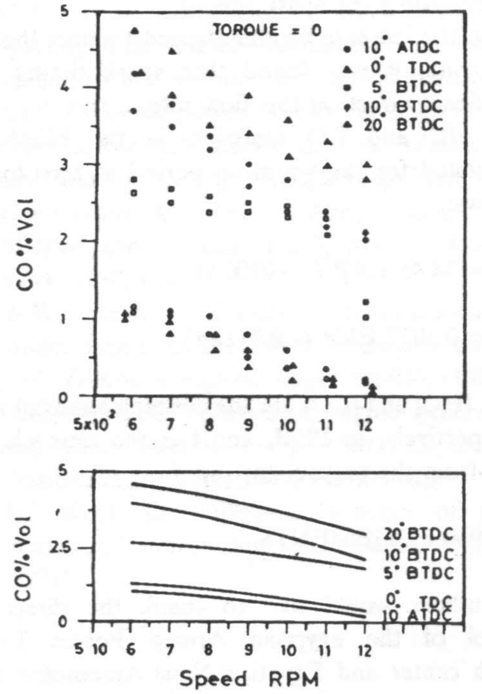

Figure 6. Carbon monoxide emissions at iding.

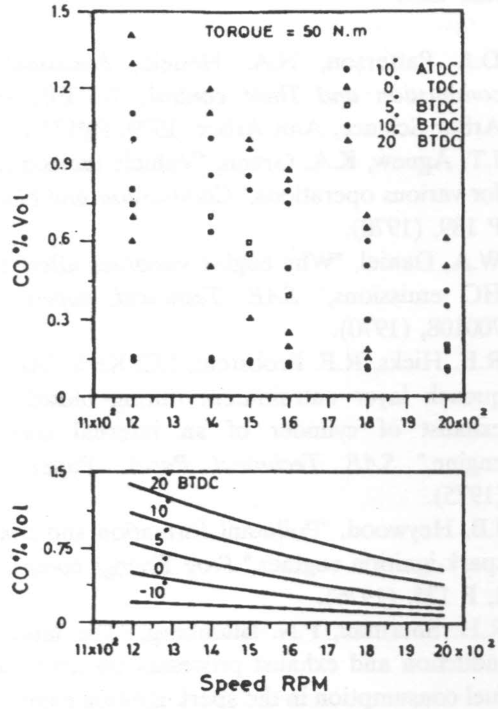

Figure 7. Carbon monoxide emissions at 50-N.m torque.

Blowby Rate and Emissions

It was observed that the rate of blowby decreases with increasing the engine speed. The speeds of 600 to 1200 RPM were investigated. No significant effect was caused by advancing the spark timing. The blowby flow rate was measured from the time of engine starting to the time when the steady state operation is reached at no load. The results show that the rate of blowby decreases with time due to the worm-up of engine parts. As the engine temperature increases, the gap between piston rings and the cylinder walls becomes smaller, and the rate of blowby decreases.

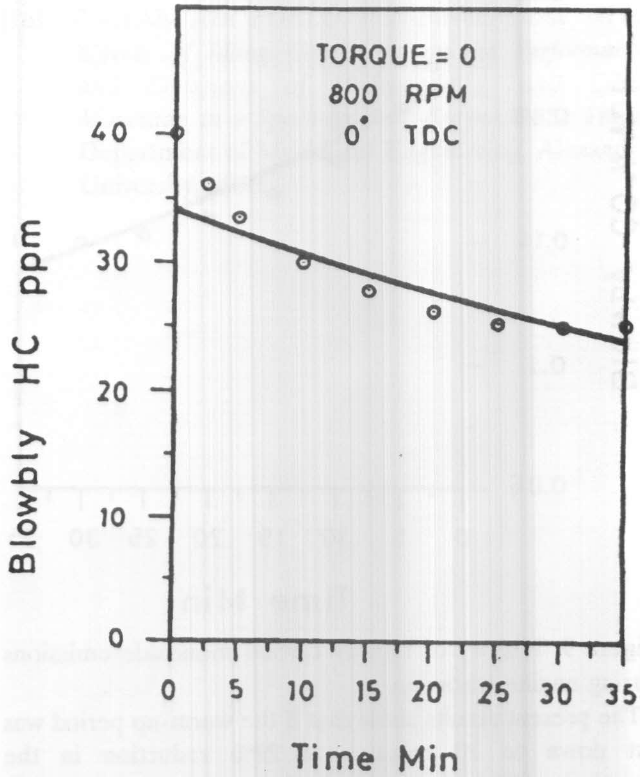

Figure 8. History of blowby hydrocarbon emissions during engine warm-up.

Figure (8) and (9), respectively, show the hydrocarbon and carbon monoxide concentrations in the blowby during the warm-up period. The figures show that both the HC and CO emissions decrease with time due to the increase in combustion temperature which improves HC and CO oxidation. Based on experimental measurments of HC and CO emissions of engine blowby, correlations were developed between both HC and CO concentrations and time elapsed during the warm-up period at zero torque as follows:

$$[HC] = 34.45 \, EXP(-0.0106 \, t) \quad (1)$$

$$[CO] = 0.1927 \, EXP(-0.0112 \, t) \quad (2)$$

Where [HC] and [CO] are the HC concentration and CO concentration, respectively, in part per million (PPM) and t is the time elapsed in minutes from the engine start-up. The above correlations apply for 800 RPM idling speed and TDC timing.

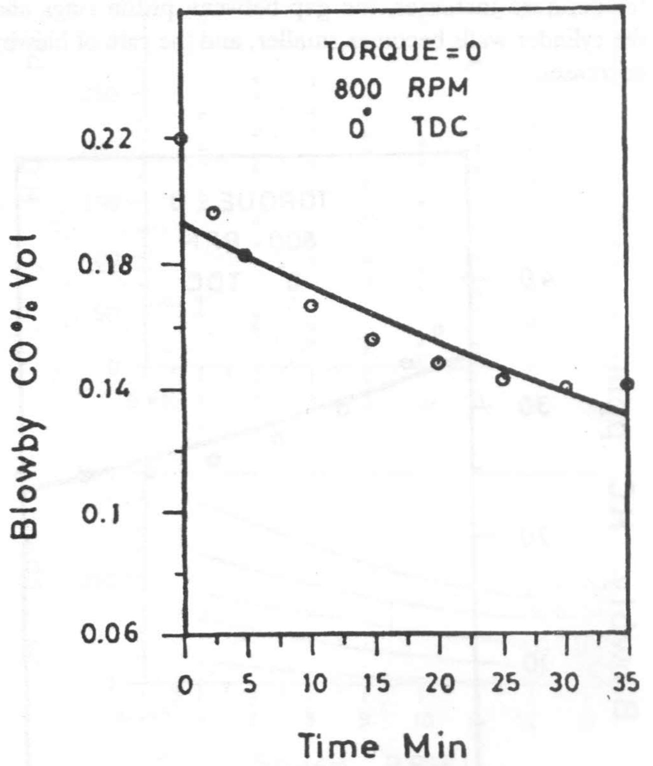

Figure 9. History of blowdy carbon monoxide emissions during engine warm-up.

The present results show that if the warm-up period was cut down to 20 minutes, a 29% reduction in the cumulative CO emissions was achieved (i.e , to about 606 milligrams) while a 30% reduction in the HC emissions was recorded (i.e, to about 6.16 milligrams).

CONCLUSIONS

The effects of various operating parameters on the concentrations of unburned hydrocarbons and carbon monoxide emissions of a spark-ignited engine were investigated under the conditions of no load and part load for very rich mixtures ($10 < AF < 13$). The following are the conclusions of the investigations:

1. The concentrations of HC and CO emissions in the exhaust manifold can be reduced by increasing the engine idling speed, rsising the coolant temperature, and retarding the spark timing.
2. While the increase in idling speed reduces the blowby flow rate, it was found that spark timing has no significant effect on this flow rate.
3. The HC and CO emission in the blowby were correlated for the warm-up period at zero torque as follows:

$$[HC] = 34.45 \text{ EXP } (-0.0106\ t)$$

$$[CO] = 0.1927 \text{ EXP } (-0.0112\ t)$$

Where [HC] and [CO] are the concentrations of HC and CO, respectively, in PPM, and t is the time elapsed in minutes from the engine start-up.

ACKNOWLEDGEMENTS

The authors would like to thank the director and personnel of the egyptian Armed Forces Technical Research center and Egyptian Navy Automotive Service center.

REFERENCES

[1] D.J. Patterson, N.A. Henein, *Emissions from combustion and Their control*, 7th Edition, Ann Arbor Science, Ann Arbor, 1979, PP177-131.

[2] J.T. Agnew, K.A. Green, "Vehicle emissions levels for various operations," *Combustion and Flame*, 15, P 189, (1970).

[3] W.A. Daniel, "Why engine variables affect exhaust HC emissions," *SAE Technical papers*, Paper 700108, (1970).

[4] R.E. Hicks, R.F. Probstein, J.C. Keck, "Amodel of quench layer entrainment during blowdown and exhaust of cylinder of an internal combustion engine," *SAE Technical Paper*, Paper 750009, (1975).

[5] J.B. Heywood, "Pollutant formation and control in spark-ignition engines," *Prog Energy comust Sci*, V 1, P 135, (1976).

[6] R.H. Sherman, P.N. Blumberg, "The influence of induction and exhaust processes on emissions and fuel consumption in the spark-ignition engine," *SAE Trans*, V 86, P 3025, (1977).

[7] R.J Tabaczynski, C.R. Ferguson, K. Randhakrishnan, "A turbulent entrainment model for spark-ignition engine combustion," *SAE Trans*, V 86, P 2414, (1977).

[8] G.A. Lavoie, "correlations of combustions data for spark-ignition engine calculations: laminer flame speed, quench distance, and global reaction rates," *SAE Technical papers*, Paper 780229, (1978).

[9] G.A. Lavoie, J.A. Lorrusso, A.A. Adamczyk, "HC emissions modeling for spark ignition engines," *Combustion Modeling in Reciprocating Engines*, Mattavi and Amann (Eds.), Plenum Press, New York, 1980, p 409.

[10] W.W. Yuen, H. Servati, "Amathematical engine model including the effect of engine emissions," *SAE Technical Papers*, Paper 840036, (1984).

[11] H.K. Newhall, "Kinetics of engine generated NO and CO," *Twelfth Symp (Intl) Combust*, The Comustion Institute, 1969, PP 603-613.

[12] J.C. Keck, D. Gillespie, "Kinetics of pollutant formation," *Combustion and Flame*, V 17, P237, (1971).

[13] C.P. Fenimore, J. Moore, "Pollutant formation and destruction in flames," Combustion and Flame, V 22, P 343, (1974).

[14] K. Kataoka, Y. Hirako, "computations of emissions levels for various operations in spark-ignition engines," *Bulletin JSME*, V26, P 219, (1983).

[15] M.M Delichatsios, *The Kinetics of CO Emissions from an Internal Combustion Engine*, MS Thesis, Department of Mechanical Engineering, MIT, Cambridge, Massachusetts, 1972.

[16] I.A.I.Aly, *AIR POLLUTION-Investigations on the Effects of Idling Conditions on the Performance and Emissions of Hydrocarbons and Crbon Monoxide in a Spark-ignition Engine,* MSc Thesis, Department of Mechnical Engineering, Alexandria University, 1990.