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Air Intake Cooling Motor Vehicle Performance Enhancement

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AIR INTAKE COOLING
MOTOR VEHICLE PERFORMANCE ENHANCEMENT

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Abstract

This research examined the practical effects of cooling the intake air, on the combustion characteristics of a modern motor vehicle operating under simulated road conditions as well as its subsequent impact on the environment. The cooling effect was achieved by taking a typical air conditioning rig as fitted to a modern motor vehicle and incorporating it into the induction system of the car.

The test vehicle used was a 1993 Renault Safrane 2.0Vi standard passenger car that was modified as part of the research to facilitate the extraction of the required test information. A series of tests were conducted using ambient temperature air and cold air delivered by the air conditioning rig. The results obtained were consistent and conformed to general automotive beliefs regarding power, fuel consumption and emissions.

1.0 Introduction

An engine that confines a quantity of gas by means of a piston/cylinder mechanism may at least be considered a PVT system. This refers to the fact that it can be described thermodynamically in terms of its pressure (P), temperature (T) and volume (V). Pressure, volume and temperature are properties that describe the condition of a gas at any instant and this is referred to as its state. When a gas changes from one state to another it is said to have undergone a process. This process can be represented graphically on a PV-diagram as shown in Figure 1.

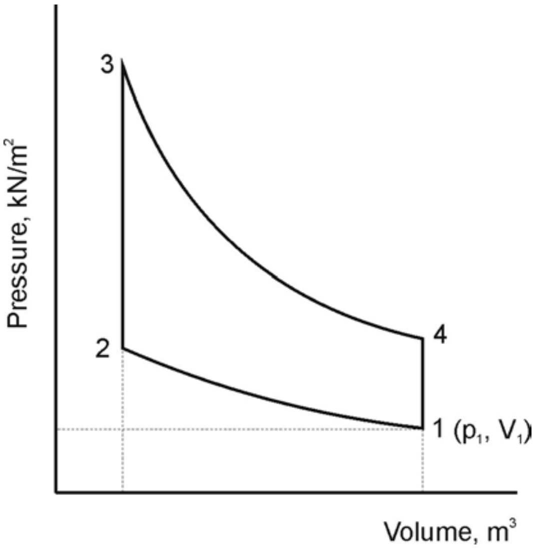

Figure 1: The ideal Otto cycle [1]

If the pressure and volume of a gas is known then the co-ordinates of a point (P1, V1) can be plotted. The points describe the various states of a gas and lines joining such points represent the processes undergone in changing from one state to another.

The manner in which those three properties of a gas (pressure, volume, temperature) relate to each other is described by the three basic gas laws: Anthon's, Boyle's and Charles Law. When these laws are combined for a process involving any sample of an ideal gas, the General Combined Gas Equation is obtained:

$$\frac{p \cdot V}{T} = c$$

Where: p – Absolute Pressure, N/m^2,

V – Volume, m^3,

T – Absolute temperature, K,

c – Constant.

For a given sample the constant (c) is

$$c = m \cdot R$$

therefore

$$\frac{p \cdot V}{T} = m \cdot R$$

and

$$m = \frac{p \cdot V}{T \cdot R}$$

where: m – mass (kg)

R – the specific gas constant for that gas.

According to physics, density (ρ) is

$$\rho = \frac{m}{V}$$

This test involves cooling the intake air, which will have an effect on the density of the air. Cold air is denser than warm air and so the mass of air entering the cylinder will increase. According to the basic gas laws and the General Combined Gas Equation this change in density should result in an increase in power from the engine.

2.0 Experiment

The experimental process involved researching various texts, coupled with connecting, adapting and modifying many systems to facilitate obtaining relevant information to support the research.

2.1 Motor vehicle technology

The test vehicle used was a Renault Safrane 2.0Vi presented to the DIT by Renault Ireland. This vehicle is a standard passenger car and has not been specially manufactured or designed for vehicle testing. The car is equipped with an Engine Management System which controls the performance of the vehicle through all its driving needs. By changing an external parameter, such as the air temperature, it is hoped that a chain of reactions will occur that may not be in accordance with engineering theory but make perfect automotive sense.

The Safrane engine capacity is 1995cm^3 with a compression ratio of 9.2:1. This car employs a Renix Multipoint Sequential Injection System as outlined in Figure.2.

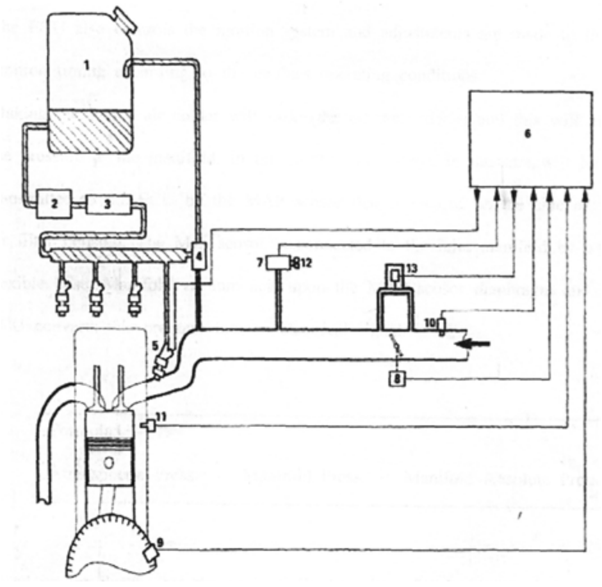

Figure 2: Schematic layout of the Renault Injection System [2]

The injection system in Figure 2 is an electronically controlled pressure/speed type of fuel injection system. The amount of fuel injected is a linear function of the pressure in the manifold which is measured by the manifold absolute pressure (MAP) sensor, and the engine speed is measured by the speed sensor located at the flywheel. The Electronic Control Unit (ECU) is programmed with a predetermined injection duration which is dependant on the air intake pressure and speed. These pre-determined injection duration’s can be altered to suit various conditions that may arise from time to time and are designed to ensure suitable air/fuel mixture strength for complete and efficient combustion. The ECU also controls the ignition system and adjustments are made to the ignition timing according to the engines operating conditions [2].

Cooling the intake air will make it denser and this will affect the pressure in the manifold. In this system a change in pressure is transmitted to the ECU by means of a MAP sensor located on the side of the air filter housing.

Based on the theory that the engine will draw in a fixed volume of air per revolution, the Renault Renix system calculates the air/fuel ratio using the speed/density method. But before calculating the mass of a quantity of air, the temperature of the air must be known. The temperature of the air is constantly measured and monitored by the air temperature sensor, which in conjunction with a MAP sensor allows for an accurate evaluation of the density of the air entering the engine, resulting in optimum burning of the required mass of fuel [2]. The next important sensor is the throttle position sensor, as part of the test procedure this is set to operate within a certain range so as not to exceed part throttle/load during testing. If full throttle conditions were achieved then the fuel enrichment would influence the emission and economy readings to the point of rendering the results useless. Because the vehicle is driven under load at part throttle, 3rd gear was used as the top gear selection for all tests. This allowed for some consistency in the reading obtained for emissions, consumption and power allowing useful comparisons and evaluations to be made.

2.2 Handprint for the test:

This is a set pattern that was used for all tests carried out under ambient and cold conditions. The purpose of the handprint is to eliminate as many variables as possible in an effort to ensure the test procedures used were similar at all times.

2.2.1 The Modular Gas Analyser (MGA – 1200)

This is a compact three gases analyser that measures the Carbon Monoxide (CO), Carbon Dioxide (CO_2) and Hydrocarbons content of the exhaust emissions by non-dispersive infra – red technology and the percentage Oxygen O_2 content by a Galvanic cell. The unit has also been expanded to give a Lambda or Air/Fuel ratio and a corrected CO value [3]. After a warm up period of 15 minutes the analyser is ready to use. As part of the initial preparation procedure an exhaust extension pipe was fitted between the engine manifold and the catalytic converter, this pipe is accessible from the engine compartment. The exhaust probe from the machine is then fitted into the exhaust extension pipe and cemented in to prevent exhaust gas leaks and eliminate any potential fire hazards. As the vehicle is being tested under both conditions this machine will interface with the Rolling Road gathering and recording data for future evaluation and comparison purposes.

2.2.1 Thermometers

To obtain Mass flow rates from a Psychometrics chart, a wet and dry bulb thermometer was fitted into the air filter housing, Figure 3.

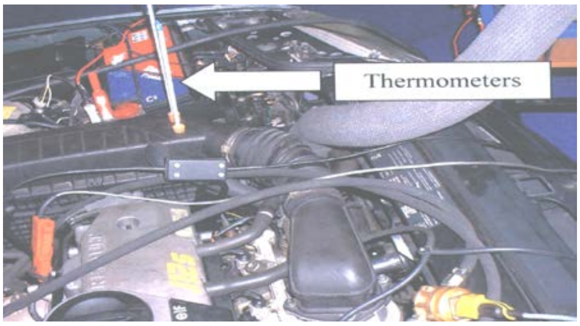

Figure 3: Thermometers fitted to air filter housing

2.2.3 Air Condition Rig

The Safrane is not fitted with air conditioning and so the engine was supplied externally with cold air from a typical air condition rig as fitted to a modern vehicle, this unit had an on/off button and three operating speeds. The connection that joined the air condition rig to the intake system is shown in Figure 4.

Figure 4: Connection of air condition rig and the intake system

The pipe connecting the intake system and the air conditioning rig is designed to be open to the atmosphere while also allowing the air from the rig to be directed into the intake air stream. This effectively allowed the engine to draw in as much or as little air as is required for each load condition. With the air conditioner turned on, a number of tests at the three different speed settings were performed. These tests were based on the general response, from the engine (stalling, erratic running, slow build up of speed etc.) as the vehicle was being driven on the rolling road and the power outputs achieved at each setting. It was decided that the best Cold air results were obtained using an air velocity of 5.6m/s, which is at speed position No.2. With the preliminary work now concluded the process of testing, compiling and comparing of data for cold air and ambient air temperature conditions could begin.

3.0 Rolling Road – Custom Power Test

The Custom Power Test was chosen as a test procedure on the rolling road that could be reproduced almost identically each time the test was performed. After positioning on the rollers, the vehicle is connected to the Interface box. The rpm tongs is connected to the No.1 lead and connections are also made for temperature and pressure. A fuel consumption meter is also connected directly into the fuel system between the supply and the injector fuel rail to monitor fuel consumption. The computer setting complied with the DIN 70020 standard.

3.1 Testing

The vehicle RPM range for testing was set between 1500 and 3500 rpm, rising in increments of 250rpm. Each test lasts 20 seconds with a further 20 seconds of clear out time in between the increments. Because the rolling road can interface with the gas analyser, the % vol. CO at each increment and the maximum only values of CO, CO_2, HC and O_2 are recorded. A fuel meter allows for the specific fuel consumption at the different incremental stages to be measured and recorded.

When the test is complete the computer screen displays 3 lines:

P – Norm (red line) represents the engine performance as a function of ambient temperature and air pressure. This “brake power” is determined by the algorithm in the computer software and is in accordance with the selected DIN 70200 standard.

P – Wheel (blue line) is the power actually measured by the rolling road dynamometer at the vehicle wheels.

P – Drag (green line) is the power absorbed or wasted by the transmission and running gear and is measured by the rolling road as the vehicle coasts down to a stop.

During testing with the cold air, the dry bulb thermometer showed air temperature of 306K, and during the testing without cooling, the air temperature was 308K. Average results for the testing with cold air and ambient air temperature is presented in Tables 1 and 2.

Table 1: Results of testing with Cold air

COLD AIR										
rpm	**v km/h**	**P-norm kW**	**P-wheel kW**	**P-drag kW**	**Torque Nm**	**Consum. g-kWh**	**CO % Vol**	**CO_2 % Vol**	**HC Ppm Vol**	**O_2 % Vol**
1490	**31**	18.6	15.2	18.5	119	310.3	1.51	12.96	167	1.8
1750	**36.5**	21.4	17.4	21.3	116	295.2	0.5	12.95	135	1.7
1990	**41.5**	23.9	19.3	23.7	114	293.7	0.49	13.59	103	1.9
2230	**46.5**	28	22.8	27.8	119	284.1	0.54	13.45	106	1.5
2500	**52.5**	31.3	25.4	31.1	119	279.1	0.58	14.15	98	1.1
2740	**57**	33.6	27.1	33.4	117	285.5	0.69	13.79	80	0.9
2980	**62**	35.3	28.	34.9	113	282.8	0.63	14.40	75	0.7
3240	**67.5**	36.8	28.7	36.4	108	288.2	0.63	13.95	62	0.6
3500	**73**	38.7	29.8	38.3	105	290.2	0.63	13.94	71	0.6

Power Data

Norm Power	p-norm	39 kW corrected according to DIN70020
Engine output	p-eng	38.5kW
Max power at 73 km/h or 3500rpm		
Max. torque 119 Nm at 51 km/h or 2450 rpm		

Emissions

Max. CO = 1.5%Vol. at 1490 rpm.
Min. CO = 0.49%Vol. At 1990 rpm.
Max CO_2 = 14.44%Vol.
Max. O_2 = 2.2%Vol.
Max. HC = 154 ppm.
Max. Consumption = 290.2 g/kWh

Table 2: Results of testing with Ambient temperature air

AMBIENT TEMPERATURE										
rpm	**v km/h**	**P-norm kW**	**P-wheel kW**	**P-drag kW**	**Torque Nm**	**Consum. g-kWh**	**CO % Vol**	**CO_2 % Vol**	**HC Ppm Vol**	**O_2 % Vol**
1480	**31**	18.7	15.3	18.6	120	325.3	2.23	13.29	163	1.9
1720	**36**	21.9	17.9	21.7	121	302.7	1.01	13.45	134	1.8
1990	**41.5**	23.9	19.3	23.9	114	287.1	0.49	13.62	128	1.9
2230	**46.5**	27.7	22.5	27.5	118	273.1	0.59	13.83	109	1.5
2490	**52**	30.7	24.8	30.5	117	276.9	0.64	13.4	92	0.9
2750	**57.5**	32.7	26.1	32.5	113	279	0.73	14.13	102	0.09
2990	**62.5**	33.9	26.6	33.7	108	287.6	0.69	14.08	77	0.7
3260	**68**	35.4	27.3	35.1	103	286.4	0.68	14.11	70	0.7
3500	**73**	36.5	28.1	36.5	100	287.4	0.65	14.15	63	0.7

Power Data

Norm Power	p-norm	37 kW corrected according to DIN70020
Engine output	p-eng	36.5kW
Max power at 73 km/h or 3500rpm		
Max. torque 118 Nm at 51 km/h or 2440 rpm		

Emissions

Max. CO = 2.23%Vol. at 1490 rpm.
Min. CO = 0.49%Vol. At 1990 rpm.
Max CO_2 = 14.62%Vol.
Max. O_2 = 1.9%Vol.
Max. HC = 181 ppm.
Max. Consumption = 287.6 g/kWh

4.0 Power Data

The highest power values (P – norm) corrected according to DIN 70020 obtained during tests were at 3500rpm, for ambient temperature 37kW and for cold air 39kW. In percentages, this represents an increase in power for cold air of 5.4%. This would be a significant increase, but it is necessary to calculate for how much extra air mass. An Anemometer positioned at the intake opening shows an air velocity of 3.9m/s for max power achieved at 3500rpm. If the diameter of intake opening is 0.052m then it's area is 0.002123716m^2.

According the formula

$$Q=V\cdot A$$

volume flow rate, Q, is 0.008282494m^3/s.

The Specific air volume for ambient temperature and for cold air is calculated from a Psychrometric chart by using the readings from dry and wet bulb thermometers. The mass flow rate for both testing conditions at 3500rpm can be calculated as follows:

$$\text{Mass Flow Rate} = \frac{\text{Volume Flow Rate}}{\text{Specific Volume}}, \quad \frac{\text{kg}}{\text{s}}$$

The results are presented in Table 3.

Conditions	Dry Bulb K	Wet Bulb K	Specific Volume, m^3/kg (Psychometric chart)	Vol. Flow Rate M^3/s	Mass flow rate kg/s
Ambient Temp.	308	294	0.885	0.008282494	**0.009411925**
Cold Air	306	293	0.88	0.008282494	**0.009358750**
Difference	2	1			**0.000053175**

Table 3: The mass flow rate for both testing conditions at 3500rpm

Results in Table 3 show that for a difference in air temperature of 2 Kelvin, the vehicle gets an extra 2kW of power at 3500rpm for an increased air mass flow rate of 0.568%.

4.1 Fuel Consumption

The specific fuel consumption is related to the power and this is evident from the results obtained by the fuel consumption meter during the testing. Results are presented in Figure 5.

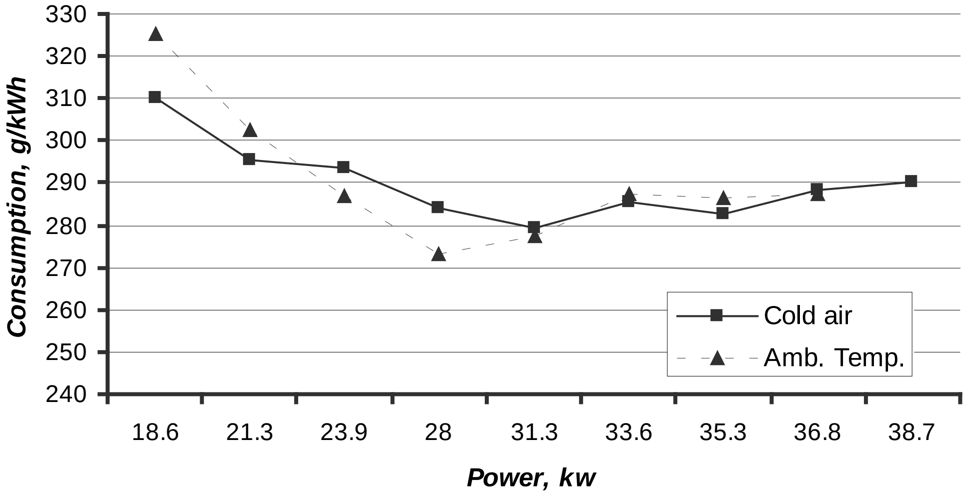

Figure5: Consumption / Power values for Cold Air and Ambient Temperature

For the maximum power of 39kw at cold air conditions, the fuel consumption meter shows a maximum consumption of 290.2 g/kWh, and for maximum power of 37 kW at ambient temperature conditions, a maximum consumption of 287.6 g/kWh. Comparison of these maximum values suggests that the consumption per kilowatt-hour is slightly greater under Cold Air conditions.

4.2 Emissions

The emission readings were all extracted from the exhaust pipe before the gasses entered the catalytic converter. In Figures 7a., 7b.,and 7c., values of CO, CO_2 and HC are shown for different rpm values at cold air and ambient temperature conditions.

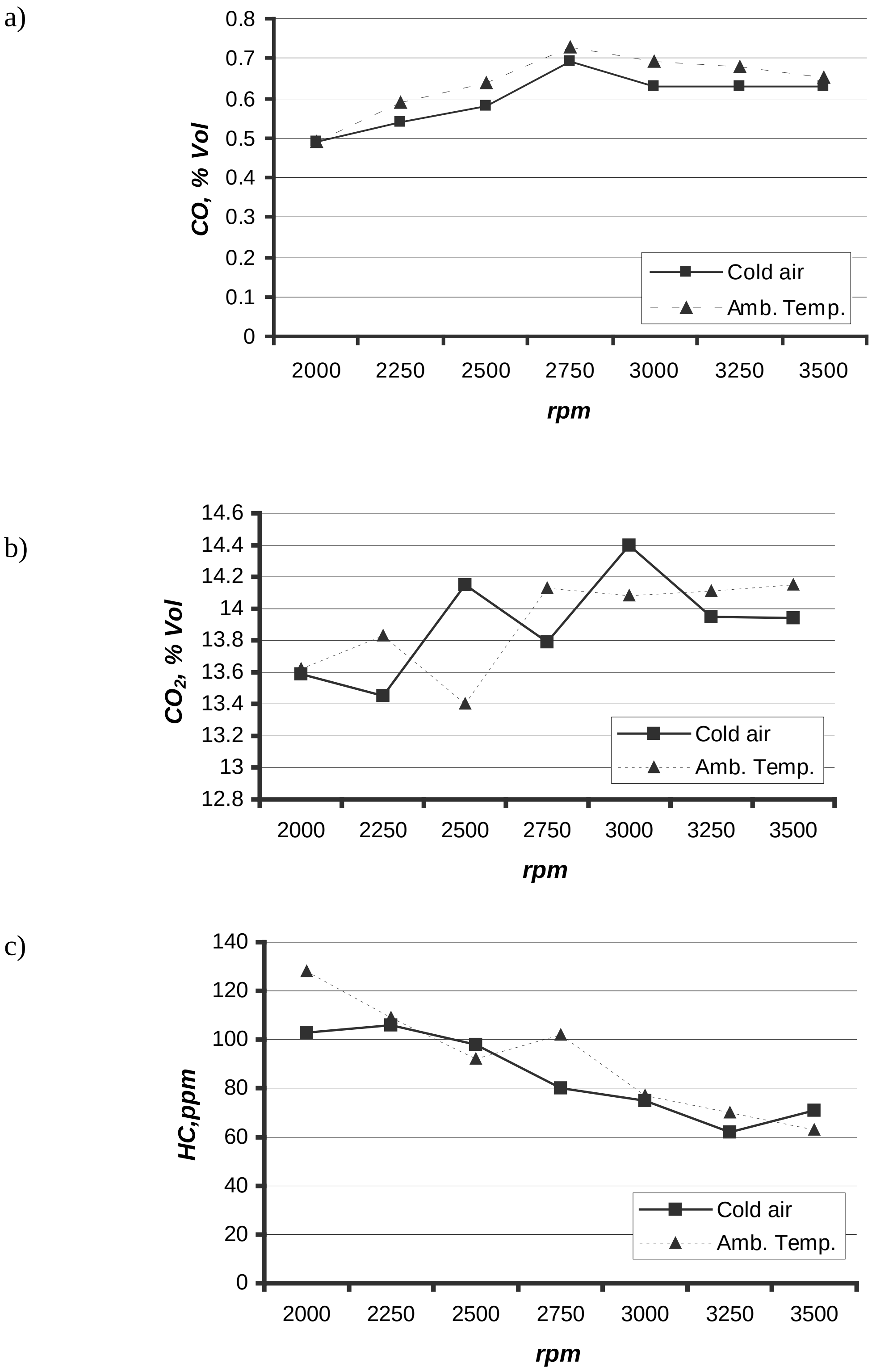

Figure 7: Values of exhaust gasses emission: a) CO, b) CO_2 and c) HC

5.0 Conclusions

The results under cold air conditions show that the power output of the engine increased by 2 kW.

A comparison of the Specific Fuel Consumption values over the consistent results range of 2000 to 3500 rpm for cold air and ambient conditions shows a rise in consumption figures to match the increase in power. The marginal increase favoured cold air conditions.

With emissions the difference was evident but small. Again to ensure a level of consistency in the values being evaluated the criteria used was spread over the range of 2000 rpm to3500 rpm. The ambient condition results were better in terms of lower emissions.

This research identified the potential of incorporating the air conditioning system on a car into the intake system to assist the vehicles power output. The system could be developed to operate mainly under maximum power conditions/acceleration thus maintaining some control over consumption and gas emissions at lower speeds and would require refrigeration to achieve lower temperatures.

The research also confirms that cooling intake air will only benefit power output and the cost of this power increase is extra fuel consumption.

References

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[3] Sun Operators Manual: The Modular gas Analyser MGA – 1200, 1991