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Waste to Heat and Power: Directing the Automotive Radiator-Heated Air to Improve Combustion

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Abstract

Engine coolant heated in the engine block loses the heat of combustion to the atmosphere through the radiator. The radiator coolant becomes cooler, and, with the assistance of the water pump resumes the cycle of absorbing heat and discharging it to the atmosphere. The air drawn across the radiator grid, by forced or natural convection, usually flows undirected over the engine and into other parts of the vehicle underhood. Depending on the prevailing temperature of the environment, this air from the radiator may be beneficial or of no help for the cooling of the engine outer wall. A temperature sensor can detect when the aft-radiator air is beneficial for cooling the engine, and direct it over the engine, or when it does not improve engine cooling, in which case it may be diverted from the engine to the sides in the underhood, and channeled away through the vehicle underbody either below the driver location or at the vehicle rear. In either case, there is enough heated air exiting the radiator to provide the needed air mixture for combustion and for turbocharging the engine. In most designs, this is currently provided by exhaust gas through the Exhaust Gas Recirculation (EGR) system. But the exhaust gas is highly contaminated, and causes problems such as coking in turbochargers and in the EGR. The benefit of getting the air from the cooling system rather than from the exhaust system is that the air from the former is relatively clean and, therefore, better for improved combustion and for turbocharging. In this exploratory study, a method is presented for redirecting some of the aft-radiator air to the combustion chamber and to the turbocharger, as needed.

Keywords: automotive; engine coolant; convection; radiator; combustion; exhaust gas recirculation (EGR); air duct.

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1. Introduction

With a continuously increasing thermal load on vehicles due to a demands which are largely consumer-comfort driven, innovative thermal management system concepts are required in order to accommodate the changes in heat rejection associated with a given trend, or to realize a specific design or performance objective. One such innovation is the utilization of the aft-radiator air for combustion [1, 2].

The engine air intake is typically located behind and above the radiator (Figure 1). Some of the heated air coming through the radiator grills disperses over the engine, and the rest exit through the wheel wells and under the car [3]. If the air path is redirected in a controlled manner to the engine air intake, such an approach would provide three instant benefits, namely, increased engine intake air temperature for combustion, aversion of exhaust air directed to the engine through the EGR, and the elimination of the EGR.

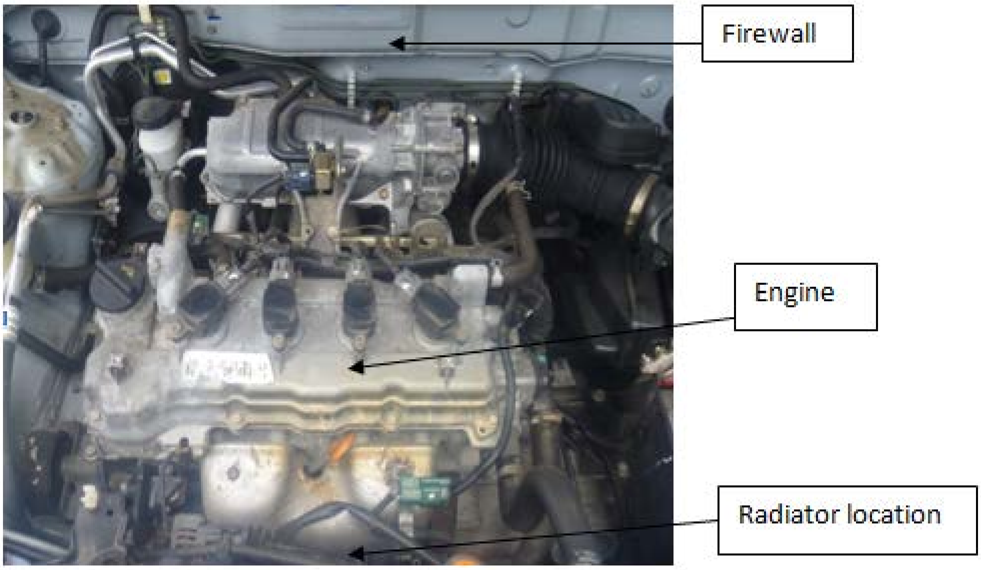


Figure 1: Automotive engine

Increased engine intake air temperature: The fresh, cold air entering the engine air intake has to be heated to an elevated temperature before ignition. With warmer air coming from the radiator, less energy is expended in raising the temperature of the incoming air. This provides a savings in the amount of fuel that need be used to increase the air temperature. Heat output into the engine compartment from the radiator is significantly (>5x) more than the output due to the exhaust manifold. Therefore an even higher intake air temperature may be obtained by taking the air from the radiator than from the exhaust manifold [4].

Avoiding EGR air: The exhaust gas recirculation (EGR) system returns exhaust air into the engine intake with a primary purpose of preheating the air intake. However, the EGR system is riddled with complications such as sticky valve from coking. It is also feeding relatively dirty (exhaust) air containing NOx and CO into the engine air intake. This potentially results in increased raw gas emission [5, 6]. Because the air coming from the radiator is atmospheric, and thus relatively clean, it does not have the soot and NOx-rich particles that accompany EGR air. The engine therefore burns cleaner, and performs better.

Elimination of the EGR: Naturally, the EGR is eliminated when its function is successfully replaced by the radiator-directed air system. The residual benefits of eliminating EGR include component cost elimination, vehicle weight reduction and assembly installation cost reduction.

Ordinarily, such modifications as air deflectors, air dams, air ducts require the mitigation of the temperature in the engine compartment to prevent overheating [7, 8]. But when the harnessed air is directed into the engine intake for combustion, the high temperature incoming air is desirable because not only is this radiator fan air flow diverted from the engine compartment thereby reducing vehicle underhood temperature, but also, this approach eliminates the otherwise needed energy to raise the air temperature for combustion [9]. Some of the same air may be directed to the turbocharger in a vehicle that is equipped with one.

2. Materials and Methods

The experiment was conducted on a Nissan Almera Tino. The Nissan Almera Tino has a 1.8L petrol inline engine producing 114 Hp of power at 5600 rpm. The baseline emission properties of the engine are shown in the Table 1.

Table 1: Emission characteristic of Nissan Almera Tino

S/N	PROPERTY	VALUE
1.	Fuel Consumption	10.3 L/100 km
2.	CO_2 emission	186 g/km

The engine is first run as is, and data collected. It is then modified to investigate the effect of replacing the EGR-supplied intake air with air coming in from the radiator.

In the modified design, a conduit channels the flow from the radiator to the air-intake port (Figure 2a, b).

Temperature sensors are placed before and after the radiator, and a mass flow meter are measures the airflow. A fuel consumption sensor is added at the fuel intake to measure the flow consumption rate of the engine for a given configuration.

After priming, the engine is run steadily for 15 minutes at each rpm setting, with rpm settings of 1000, 2000, 3000, 4000 and 5000 for each configuration. The mass flow rate and the heat capacity of the aft-radiator air coming into the intake manifold are determined.

The mass flowrate is

$$\dot{m} = \rho A v \qquad (1)$$

where

ρ = density of the intake-approaching air

A = duct cross sectional area, and

v =velocity in the duct.

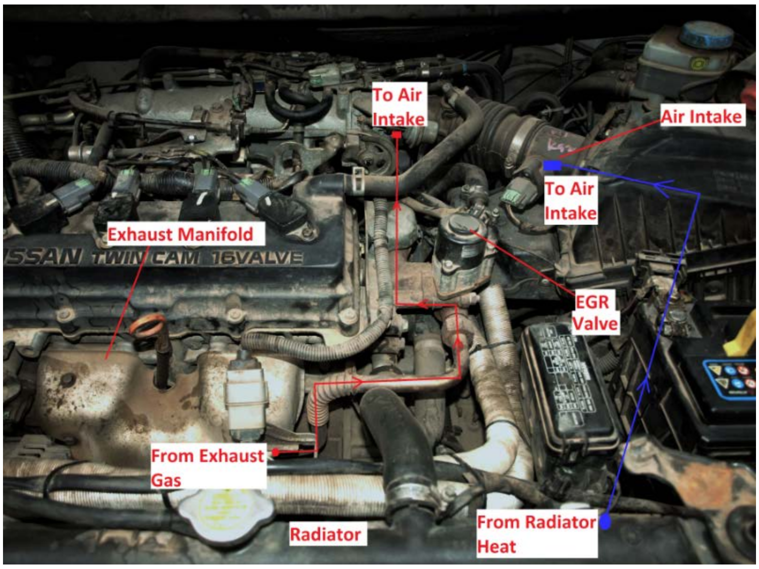


Figure 2a: Nissan Almera Tino

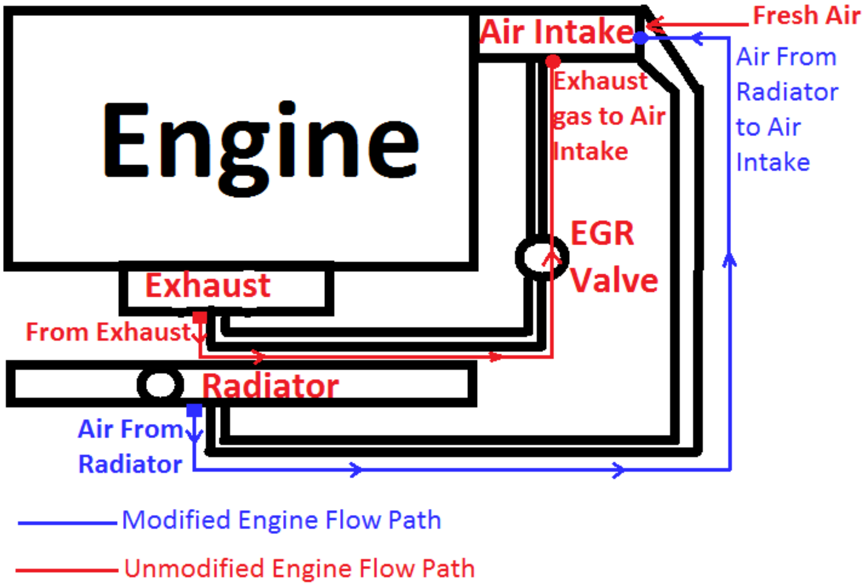


Figure 2b: Schematic of air flow

The thermal input is determined by the temperature rise of the intake air over the ambient air, and is given by:

$$\dot{Q} = \dot{m}\, s \Delta T \tag{2}$$

where

s =air specific heat, and

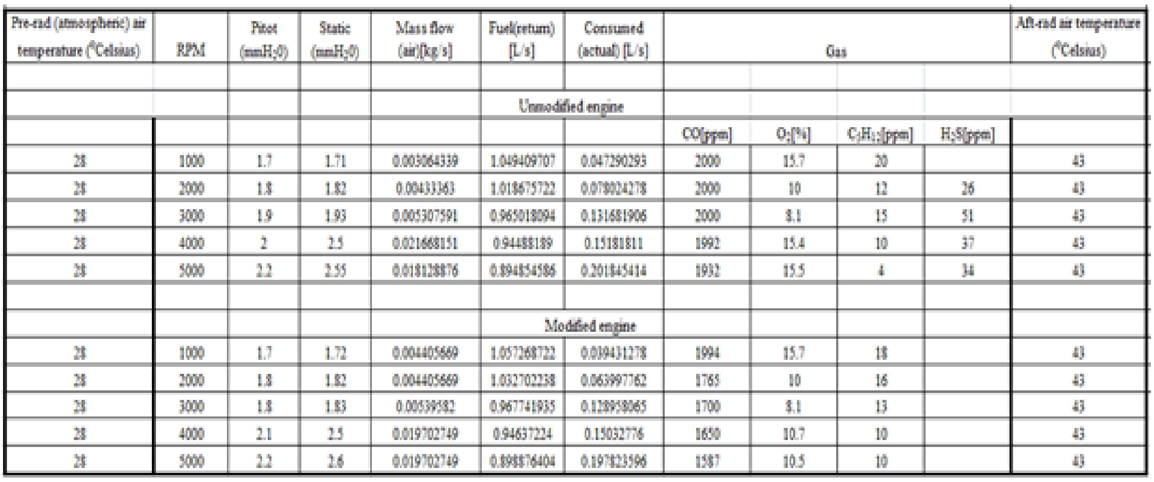
ΔT = temperature rise of intake air over ambient

At the end of the engine run for each rpm setting, the fuel consumption is determined. The fuel consumption rates at a given rpm setting are compared for both design modes. Also the exhaust gas is collected and analyzed at the end of each engine run. The particulates are recorded and compared for both design cases. This exhaust gas is passed through a gas analyzer, and the particulate content recorded.

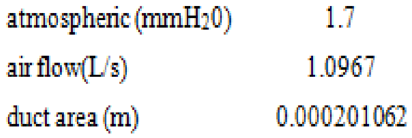
3. Results and Discussion

The prevailing conditions and the output data are shown in table 2.

Table 2: Engine input and output data



Pre-rad (atmospheric) air temperature (°Celsius)	RPM	Pitot (mmH_20)	Static (mmH_20)	Mass flow (air)[kg/s]	Fuel(return) [L/s]	Consumed (actual) [L/s]	Gas				Aft-rad air temperature (°Celsius)
					Unmodified engine						
							CO[ppm]	O_2[%]	C_5H_{12}[ppm]	H_2S[ppm]	
28	1000	1.7	1.71	0.003064339	1.049409707	0.047290293	2000	15.7	20		43
28	2000	1.8	1.82	0.00433363	1.018675722	0.078024278	2000	10	12	26	43
28	3000	1.9	1.93	0.005307591	0.965018094	0.131681906	2000	8.1	15	51	43
28	4000	2	2.5	0.021668151	0.94488189	0.15181811	1992	15.4	10	37	43
28	5000	2.2	2.55	0.018128876	0.894854586	0.201845414	1932	15.5	4	34	43
					Modified engine						
28	1000	1.7	1.72	0.004405669	1.057268722	0.039431278	1994	15.7	18		43
28	2000	1.8	1.82	0.004405669	1.032702238	0.063997762	1765	10	16		43
28	3000	1.8	1.83	0.00539582	0.967741935	0.128958065	1700	8.1	13		43
28	4000	2.1	2.5	0.019702749	0.94637224	0.15032776	1650	10.7	10		43
28	5000	2.2	2.6	0.019702749	0.898876404	0.197823596	1587	10.5	10		43



atmospheric (mmH_20)	1.7
air flow(L/s)	1.0967
duct area (m)	0.000201062

Figure 3a shows a decrease, albeit small, in fuel consumption rate with the modified engine. But even the worst case of 0.00149035 L/s savings at 4000 rpm (Figure 3b) translates to 5.37 L/hr or an extra 35 miles for a typical compact car. This arrangement therefore, in which the aft-radiator air is used for engine air intake rather than the exhaust air, has a benefit of fuel efficiency.

In figure 4, the modified design shows a conspicuous decrease in CO emission, with the difference widening at increasing rpm. For example, at 2000 rpm, there is a reduction of 11.75 percent in CO. That reduction increases to 17.17 percent at 4000 rpm, and to 17.86 percent at 5000 rpm.

Reduction in CO emission is the primary motivation for investigating this approach to engine air intake supply, and, as figure 4 shows, it is plausible that a significant reduction in CO emission can be achieved when the intake air comes from the proposed source rather than from the EGR.

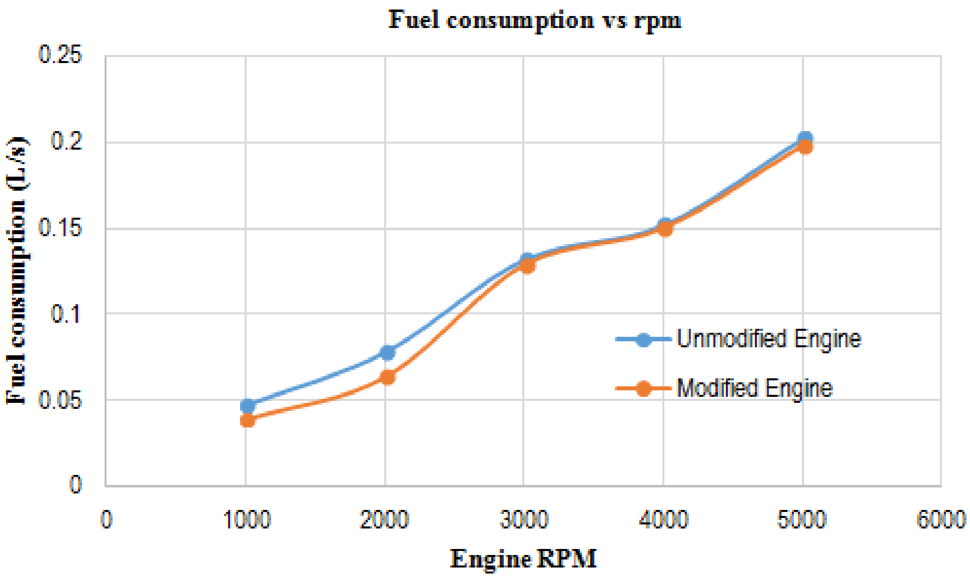


Figure 3a: Fuel consumption

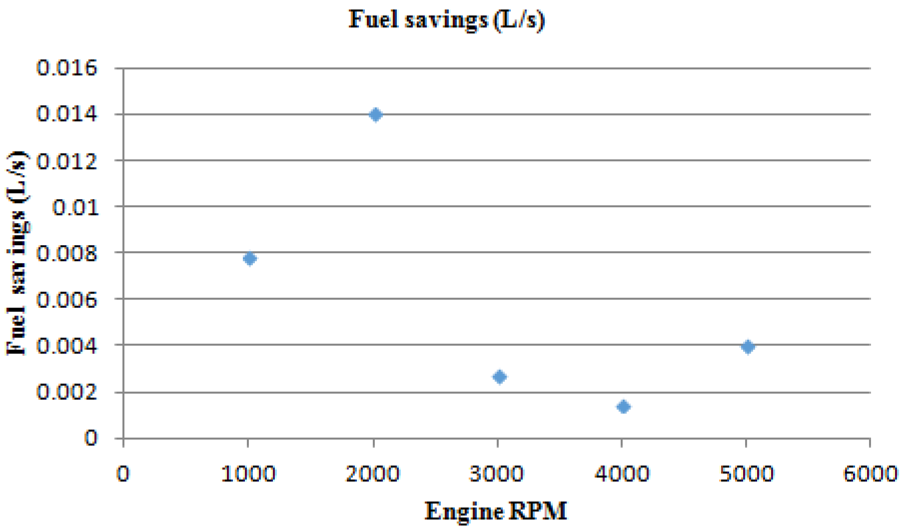


Figure 3b: Fuel savings

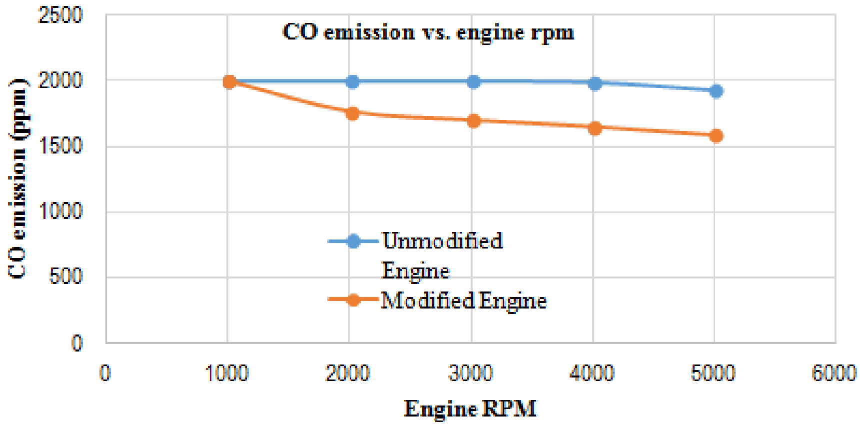


Figure 4: CO emission

The trend and the implication of the exhaust air oxygen content are not certain at this stage of the investigation, except to note that figure 5 suggests a validation of the deduction from figure 4, i.e. a more efficient combustion, hence less post-combustion oxygen, in the case of the modified design when compared with the benchmark.

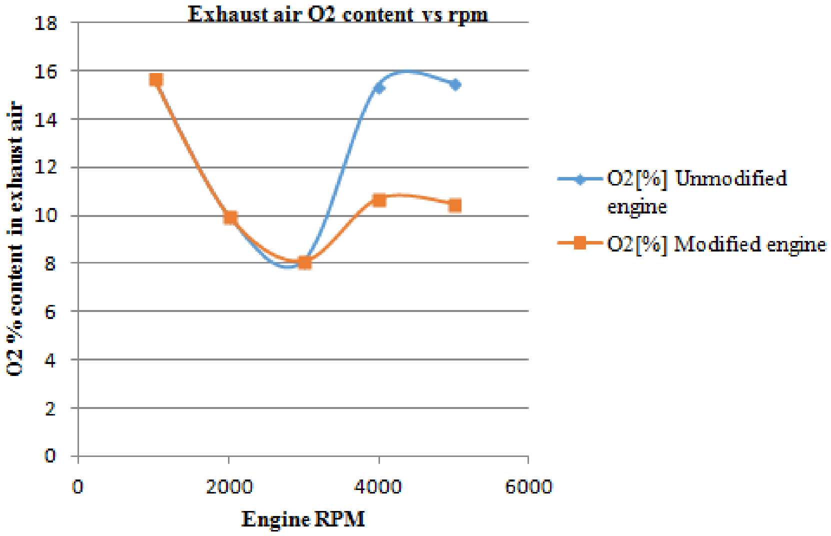


Figure 5: Post-combustion O_2 content

The results show a potential for improved engine performance when the aft-radiator air is employed in the intake instead of the exhaust air delivered by the EGR. To apply this method, it may be necessary to redesign the materials that line the inner surface of the hood so as to reduce the heat conducted into the outer surface of the hood. Components made of materials that are sensitive to extreme temperatures can be relocated or design changes can be made to provide better underhood airflow to avoid excessive hotspots [10, 11].

4. Conclusion

The study investigated the effect of replacing the exhaust air in the intake port with underhood air coming directly from behind the radiator fan. A comparison of the fuel consumption and CO emission between the

EGR-supplied intake air engine run and the radiator-supplied intake air case shows that there is less CO emission when the radiator-supplied air is used rather than air from the EGR. It also shows a reduction in the rate of fuel consumption.

Although more studies will need to be done to make a generalized statement, this exploratory study points to a viable strategy in vehicle design for increased energy efficiency.

5. Recommendation

It is worth conducting a more detailed study of a larger sample, both to determine a viable architecture for the aft-radiator air flow path in a production vehicle, and to provide enough quantitative data to enable a generalized statement.

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