

Impact of air conditioning system operation on increasing gases emissions from automobile

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Abstract. The paper presents a study concerning the influence of air conditioning system operation on the increase of gases emissions from cars. The study focuses on urban operating regimes of the automobile, regimes when the engines have low loads or are operating at idling. Are presented graphically the variations of pollution emissions (CO, CO₂, HC) depending of engine speed and the load on air conditioning system. Additionally are presented, injection duration, throttle position, the mechanical power required by the compressor of air conditioning system and the refrigerant pressure variation on the discharge path, according to the stage of charging of the air conditioning system.

1. Equipment used for experimental studies

Equipment used for experimental determinations, includes a car which is equipped with air conditioning, a diagnostic equipment and an analyzer of exhaust gases.

The car used in the study, was Renault-Dacia-Logan I facelift 2008 with the characteristics indicated in the following table, from [4].

Table 1. Vehicle characteristics

Maximum power [Hp]	Maximum rotation of engine [rpm]	Engine type	Engine volume [cm ³]	Cylinders number	Type of fuel and fuel system	Environmental standard	Maximum authorized weight [kg]
85	5250	K7M 800	1598	4	Gasoline/ Multipoint injection	EURO IV	1540

The basic components of the automotive air conditioning system-AC figure 1, are compressor (1), evaporator (2), condenser (3) and expansion device (4). In a automotive AC system, the belt-driven compressor is mounted on the engine crankshaft, thus the compressor speed will vary with engine speed. The refrigerant mass flow rate and cooling load change with compressor speed.

The AC system refrigerant is R134a. The refrigerant R134a, [5], [7] is also known as Tetrafluoroethane (CF₃CH₂F) from the family of HFC refrigerant.

The R134a was introduced as the first refrigerant substitute and may replace R12 in practically all applications, such as in household refrigerators, automobile air conditioners, heat pumps, and commercial refrigeration.



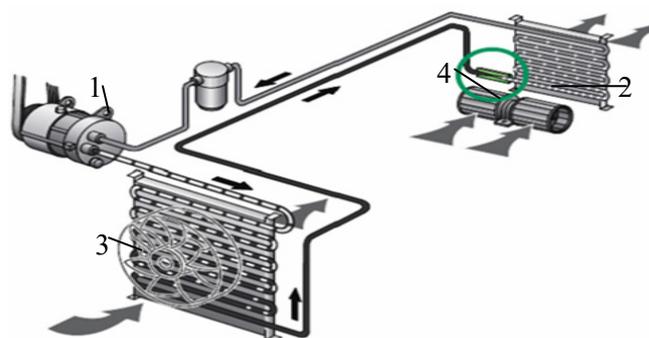


Figure 1. Refrigeration system for automotive.

The R134a is nonflammable, toxicologically safe and thermally and chemically stable, [5]. The physical properties [7], the safety and environmental data are presented in table 2.

Table 2. Refrigerant properties

Agent	Boiling Point at 1.013 bar [°C]	Critical Values		TLV- TWA [ppm]	ASHRAE 34 Safety group	ODP	GWP 100
		t_c [°C]	p_c [MPa]				
R134a	-26.1	101.1	4.06	1000	A1	0	1300

Equipment used to diagnose car and taking over operating parameters is of type Autocom CARS CDP+, [3].

Type gas analyzer is Johnson Controls - Ultimax 600, 800-65 model, produced by Johnson Controls Automotive Electronics in France. The analyzer can measure the following emissions (table 3) in case of engine with gasoline.

Table 3. Emissions measured with analyzer - Johnson Controls-Ultimax 600

Emission/ Characteristic	Range of variation	Precision
CO	0-5 %	0,01%
CO ₂	0-16 %	0,1%
HC	0-2000 [ppm]	1 [ppm]
O ₂	0-21%	0,01%
		0,1% (O ₂ >4%)
Air ratio	0,8-1,2	0,001
CO revised	0-5%	0,01%
Rotation range	300-7000 [rpm]	10 [rpm]

2. Experimental determinations

Using presented equipment, were carried out experimental determinations at idle and low load regimes. The measured values for emissions of exhaust gases (CO, CO₂, HC, O₂), the time for fuel injection process (T-inj) in milliseconds (ms), power consumed by conditioning compressor (Power-AC), pressure of refrigerant (Pressure-AC), air ratio and throttle position, all for some rotation regimes, are presented in the table 4, for all steps of using air conditioning system (AC). Using the values of parameters which are indicated in Table 4, were represented graphs in figures 2 to 5.

According to the experimental determinations and the accompanying graph representations (Figure 2 - 5), it follows that the operation of the AC installation in stages II, III and IV leads to a significant increase in HC emissions.

However, in case of using stages II, III and IV for AC system, HC emissions are within the limits imposed by Euro 4 standard (for idle and low loads, HC emissions are less than 100 [ppm]). Still, it is recommended that, especially in urban traffic, only first stage of AC should be used, thus contributing to reducing pollution in urban areas.

Using Multi brand type Autocom CARS CDP+ Scanner, there were taken the variations in measurements, engine speed, injection duration, throttle position, power consumption by AC compressor, refrigerant pressure, all for the steady position of the throttle and the shift from the operation without AC system to the function in its fourth stage. Charts are shown in Figure 6, 7, 8, comments and conclusions being indicated for these variations.

Table 4. Experimental measurements for idle and low load regimes for engine

Stage of AC	Rotation [rpm]	CO [%]	CO ₂ [%]	HC [ppm]	O ₂ [%]	Air ratio	Power AC [kW]	Pressure AC [bar]	T-inj [ms]	Throttle position [%]
Without AC	550	0.03	15.1	6	0.14	1.006	0.46	7	3.2	0.43
	1000	0.04	15.2	4	0.07	1.002	0.54	7	2.4	0.46
	1500	0.03	15	3	0.07	1.002	0.6	7	2.65	0.49
	2000	0.03	15.1	4	0.06	1.002	0.86	8	2.62	0.58
	2500	0.02	14.9	3	0.08	1.003	0.76	7	2.88	0.64
Level I AC	550	0.04	15.2	11	0.07	1.002	0.64	8	4.05	0.44
	1000	0.03	14.9	9	0.38	1.017	0.66	7	3.17	0.46
	1500	0.04	15.1	7	0.06	1.002	1.05	8	2.87	0.50
	2000	0.02	15	9	0.06	1.002	1.25	8	3.18	0.59
	2500	0.02	15.0	6	0.07	1.003	1.52	9	3.25	0.64
Level II AC	550	0.01	14.6	35	0.58	1.027	0.85	10	4.45	0.44
	1000	0.01	14.4	26	0.82	1.039	0.88	9	3.35	0.46
	1500	0.01	14.9	23	0.07	1.002	2.03	9	3.32	0.50
	2000	0	14.8	21	0.07	1.003	1.42	9	3.05	0.58
	2500	0.03	15.1	20	0.06	1.002	2.23	11	3.18	0.64
Level III AC	550	0.02	14.9	39	0.08	1.003	0.96	11	4.62	0.44
	1000	0.01	14.4	31	0.88	1.042	1.26	11	3.41	0.46
	1500	0.01	14.4	27	0.8	1.039	1.85	11	3.15	0.49
	2000	0.01	14.9	28	0.06	1.002	1.76	10	3.15	0.59
	2500	0.03	15.1	24	0.06	1.002	2.42	13	3.42	0.65
Level IV AC	550	0.02	14.8	48	0.12	1.004	1.26	12	4.75	0.44
	1000	0.02	15	42	0.1	1.004	1.86	12	3.54	0.46
	1500	0.01	15	35	0.07	1.004	2.2	12	3.32	0.49
	2000	0.03	15.2	34	0.05	1.001	2.28	12	3.35	0.59
	2500	0.04	15.2	31	0.05	1.001	3.14	13	3.63	0.65

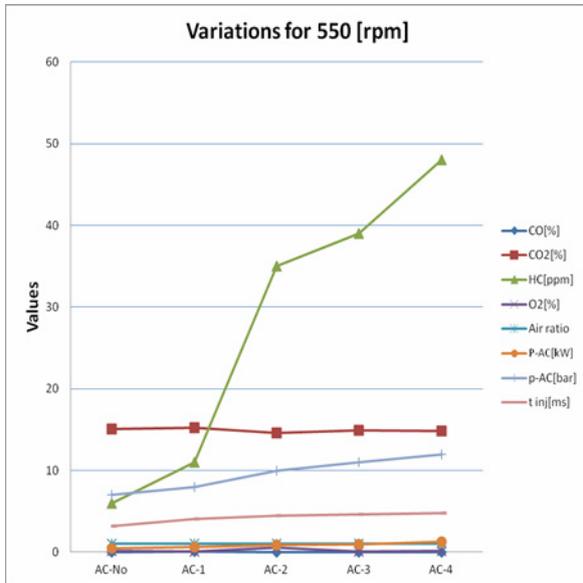


Figure 2. Determinations for 550 [rpm] engine rotation.

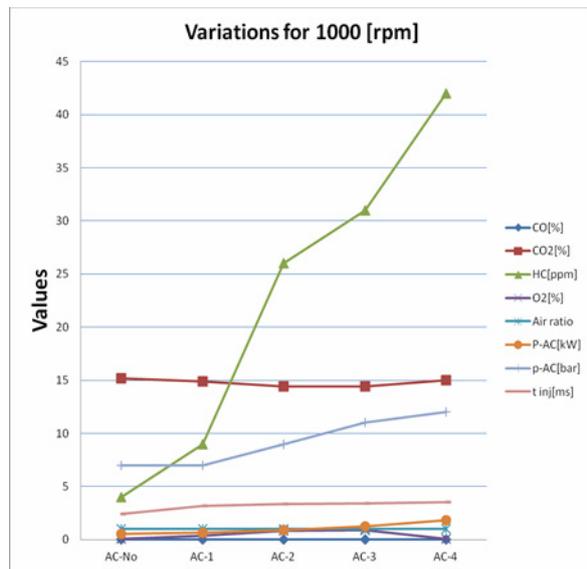


Figure 3. Determinations for 1000 [rpm] engine rotation.

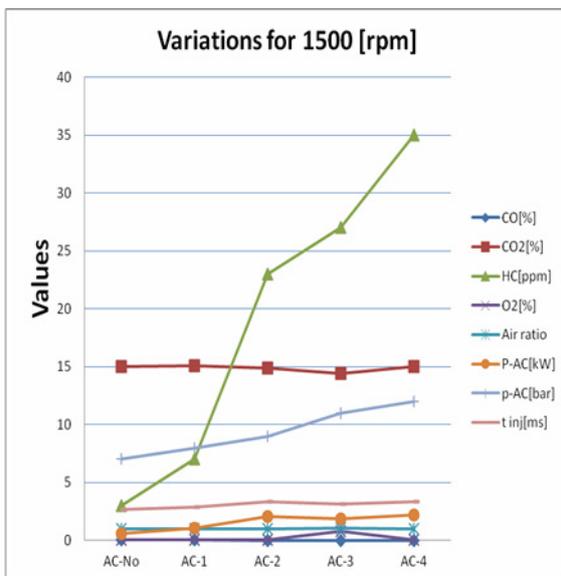


Figure 4. Determinations for 1500 [rpm] engine rotation.

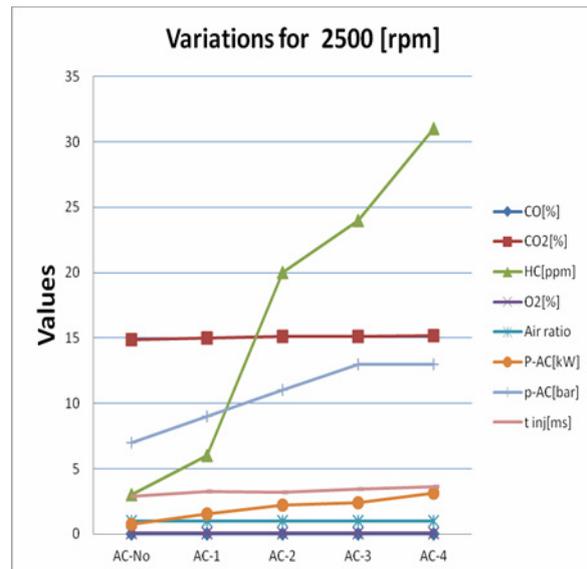
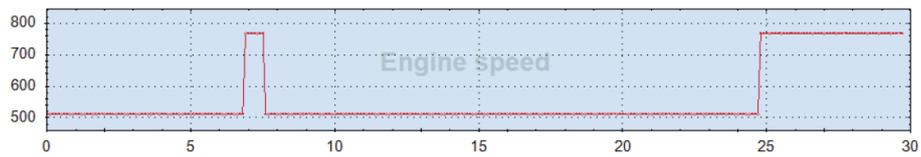


Figure 5. Determinations for 2500 [rpm] engine rotation.

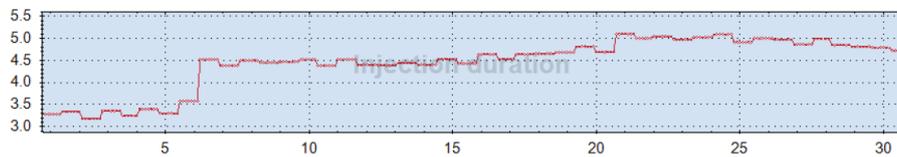
Petrol - Engine speed

Value	Max	Min
768 Rpm	768 Rpm	512 Rpm



Petrol - Injection duration

Value	Max	Min
4.72 ms	5.1 ms	3.18 ms



Petrol - Measured throttle position

Value	Max	Min
44	44	44



Petrol - Power consumption by AC-compressor

Value	Max	Min
1240 W	1300 W	620 W



Petrol - Refrigerant pressure

Value	Max	Min
12 Bar	12 Bar	8 Bar

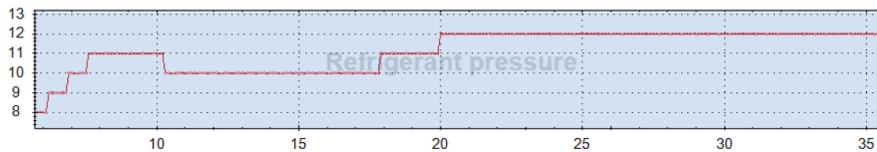


Figure 6. Values obtained with diagnostic equipment Autocom.

According to figure 6 and to the measured values (Table 4 and Figure 2-5), for running the engine at approximately 550[rpm] and coupling successive the AC system in all stages, we can indicate the following:

-- When changing into first gear of AC (starting at 5 second), there occurs a 30 % increase of the injection time (which will lead to increased fuel consumption) to cope with 40-50 % increase of power necessary for the AC compressor. It is noticed that the throttle position remains constant at 44%. Due to the increase of fuel consumption, in the first phase, is realized an increase in speed engine, that will be to approximately 760 [rpm], along with an increase of the refrigerant pressure in the discharge of the AC installation compressor. After about 2.5-3 seconds from the working start of the installation of AC in first stage, we can see a stabilization of the engine speed at $n = 510$ [rpm], a slight reduction in the injection duration and reduction the power required by the AC compressor (seconds 8 -10).

-- When the AC system operates in first gear, as compared to the situation when the AC installation does not work , there can be noticed a doubling of HC emissions , a small increase in CO emissions and a reduction in the amount of O₂ in the flue gas and respectively a reduction in the lambda coefficient (air ratio).

-- When operating the AC installation in second stage (start on ten seconds), the mixture is low (increase of O₂ in the flue gas and increase of air ratio), is realised a decrease of CO and CO₂ are also taking place at the same time with an approximately 300% increase of HC emissions, emissions which however are within the limits imposed by Euro 4 standard (HC emissions are less than 100 ppm)

-- The operation of the AC in stage III (start on 15th seconds) and then in stage IV (start on 20th seconds), we can notice a continuous increase in the HC emissions, a slight increase of CO₂ and CO, and a reduction of O₂ as compared to the previous functioning rates. At the same time there is a continuous increase pressure on AC compressor discharge, an increase in the power consumed by the compressor and also an increase in injection time which determine the fuel consumption increase.

According to figure 7 and to the measured values (Table 4 and Figure 2-5), for running the engine at approximately 1500[rpm] and coupling successive the AC system in all four stages, we can indicate the following:

-- After changing into first gear of the AC (starting at 5th seconds), with a delay of about 2 seconds there is an increase of 25 % of the injection time (which will lead to increased fuel consumption) to cope with the increase with 40-50 % of the power required by the AC compressor. It is noticed that the throttle position remains constant at 50 %. Due the fuel consumption increase, there takes place an increase in engine speed up to approximately 1550 [rpm], along with an increase of the refrigerant pressure in the AC compressor discharge. After about 3-4 seconds from coupling first stage of the AC installation, we can see a stabilization of the engine speed at $n = 1550$ [rpm], a slight reduction in the injection time (seconds 8 -10).

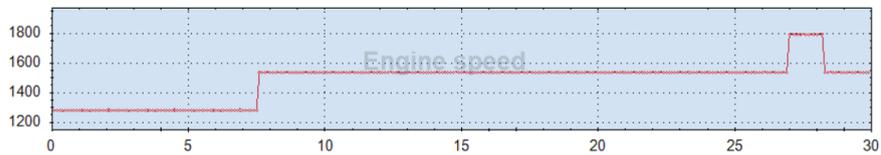
-- When the AC system operates in first gear (starting at 5th seconds), as compared to the situation when the AC installation does not work , there can be noticed a doubling of HC emissions, a small increase in CO emissions and a reduction in the amount of O₂ in the flue gas.

-- When operating the AC installation in second stage (starting at 10 seconds) , the mixture is low (increase of O₂ in the flue gas and increase of the mixture air ratio), is realised a decrease of CO and CO₂ emissions, which are taking place at the same time with an approximately 300% increase in HC emissions, emissions which however are within the limits imposed by Euro 4 standard (HC emissions are less than 100 ppm).

-- When the AC is working in gear III (starting at 15th seconds) and then in gear IV (starting at 20th seconds), we can notice a continuous increase in the HC emissions , a slight increase of CO₂ and CO emissions, and a reduction of O₂ as compared to the previous functioning rates (when it is working in first and second gear). At the same time there is a continuous increase of discharge pressure of AC compressor and an increase in the power consumed by the compressor.

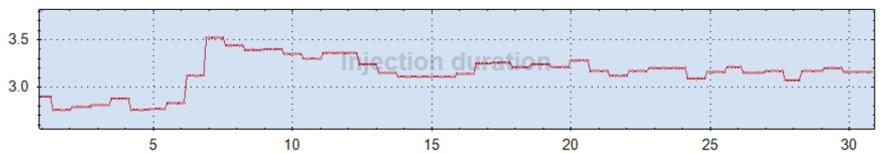
Petrol - Engine speed

Value	Max	Min
1536 Rpm	1792 Rpm	1280 Rpm



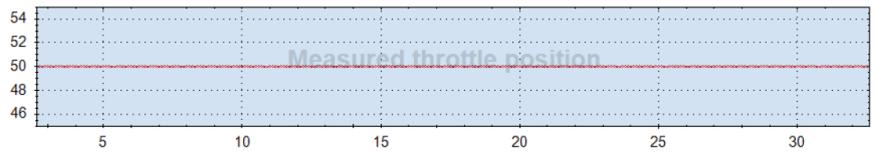
Petrol - Injection duration

Value	Max	Min
3.16 ms	3.52 ms	2.76 ms



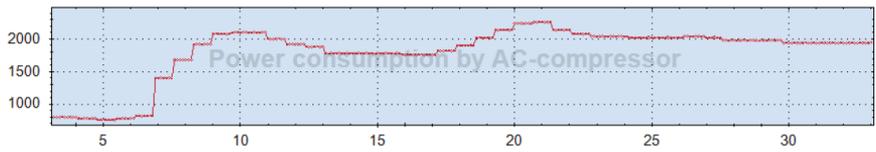
Petrol - Measured throttle position

Value	Max	Min
50	50	50



Petrol - Power consumption by AC-compressor

Value	Max	Min
1940 W	2260 W	760 W



Petrol - Refrigerant pressure

Value	Max	Min
12 Bar	13 Bar	8 Bar



Figure 7. Values obtained with diagnostic equipment Autocom

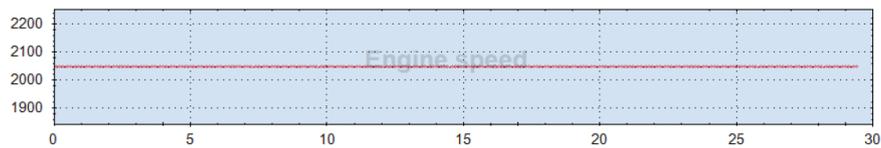
According to figure 8 and to the measured values (Table 4 and Figure 2-5), for running the engine at approximately 2000 [rpm] and coupling successive the AC system in all four stages, we can indicate the following:

-- When changing into first gear of the AC (starting at 5th seconds), there is an increase of 22 % for the injection time (which will lead to increased fuel consumption) to cope with the increase with 40-

50% of the power required by the AC compressor. It is noticed that the throttle position remains constant at 59 % and the engine rotation remains constant, being a high value.

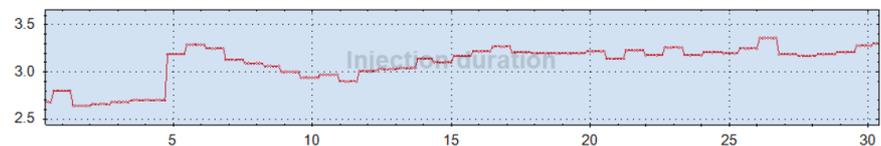
Petrol - Engine speed

Value	Max	Min
2048 Rpm	2048 Rpm	2048 Rpm



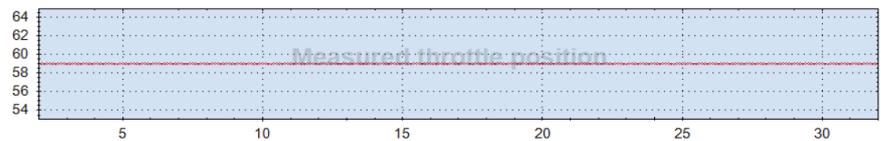
Petrol - Injection duration

Value	Max	Min
3.30 ms	3.36 ms	2.64 ms



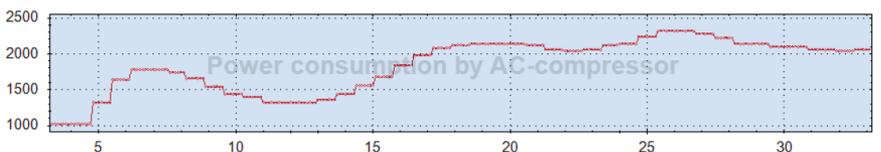
Petrol - Measured throttle position

Value	Max	Min
59	59	59



Petrol - Power consumption by AC-compressor

Value	Max	Min
2060 W	2320 W	1020 W



Petrol - Refrigerant pressure

Value	Max	Min
11 Bar	12 Bar	9 Bar

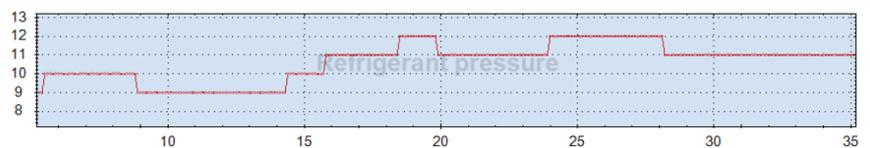


Figure 8. Values obtained with diagnostic equipment Autocom.

After about 2,5-3 seconds from coupling first stage of the AC installation, we can see a slight reduction in the injection time and a reduction (starting at seconds 7) in the power consumed by the AC compressor. In the working interval 5-7 seconds, when there takes place an increase of the

refrigerant pressure and also in power consumed by the AC compressor, as I mentioned, also increase the fuel consumption.

-- When the AC system operates in first gear (starting at 5th seconds), as compared to the situation when the AC installation does not work, there can be noticed a doubling of HC emissions, a small increase in CO and CO₂ emissions.

-- When operating the AC installation in second stage (starting at 10 seconds), the mixture is slightly low (slightly increase of O₂ in the flue gas and an increase of the air in fuel mixture), is realised a decrease of CO and CO₂ emissions, which are in the same time with an approximately 230% increase in HC emissions, emissions which however are within the limits imposed by Euro 4 standard (HC emissions are less than 100 ppm).

-- When the AC is working in gear III (starting at 15th seconds) and then in gear IV (starting at 20th seconds), we can notice a continuous increase in the HC emissions, an increase of CO₂ and CO emissions, and a reduction of O₂ as compared to the previous functioning rates (when it is working in first and second gear). At the same time there is a continuous increase pressure of refrigerant on AC compressor discharge, an increase in the power consumed by the compressor and also an increase in injection time which determine the fuel consumption increase.

According to experimental determinations and variations in real time, taken with Multi brand type Autocom CARS CDP+ diagnosing scanner, we can indicate that the using of air conditioning system in stages II, III and IV leads to a significant increase in HC emissions.

In this regard for reducing emissions of HC especially in urban traffic, it recommends using only the first stage of air conditioning system, thus helping to reduce pollution in urban areas.

In figure 9 are shown variations for engine speed, injection duration, throttle position, power consumption of air conditioning compressor and refrigerant pressure. These are shown when the air conditioning system is operating in stage II and the engine is accelerating from 760 [rpm] to approximately 2800 [rpm], at idle and low load regimes.

It can be seen a continuous increase for engine speed which is correlated with a continuous increase for throttle acceleration position. Power consumption of conditioning air compressor, increases with acceleration; in the same time, refrigerant discharge pressure in the installation of air conditioning remains constant approximately at the 10 [bar].

The duration for fuel injection decreases when the acceleration and speed are increasing, [1], [2], a normal aspect for idle load regimes. Meantime, can observe the higher HC emission at lower engine rotations; we observe also, at higher engine rotations, a slight increase in CO₂ and CO emissions, as shown in Figure 10.

In conclusion, if the engine runs at idle and low loads regimes, as was indicated, the HC emissions decrease with increasing engine speed, if the air conditioning system is functioning in the second stage which remains constant.

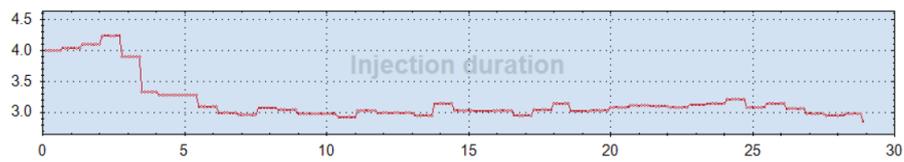
Petrol - Engine speed

Value	Max	Min
2816 Rpm	2816 Rpm	768 Rpm



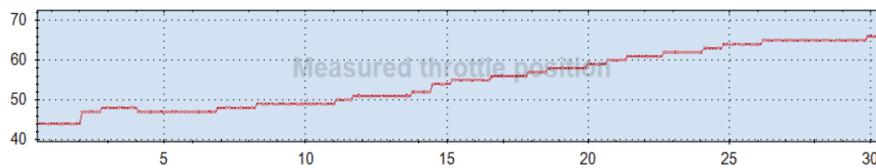
Petrol - Injection duration

Value	Max	Min
2.85 ms	4.24 ms	2.85 ms



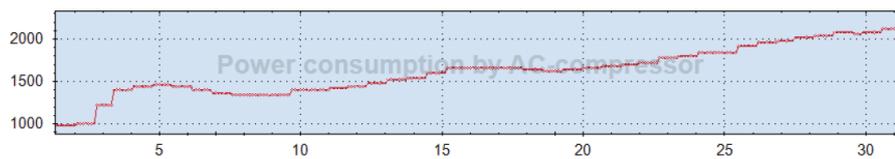
Petrol - Measured throttle position

Value	Max	Min
66	66	44



Petrol - Power consumption by AC-compressor

Value	Max	Min
2140 W	2120 W	980 W



Petrol - Refrigerant pressure

Value	Max	Min
10 Bar	10 Bar	9 Bar

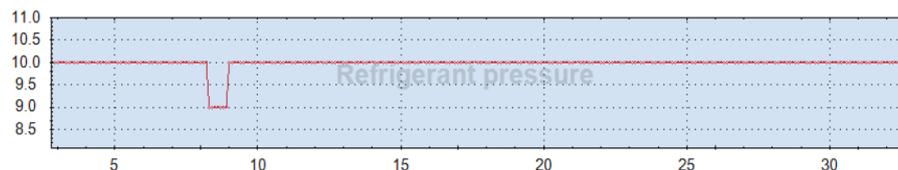


Figure 9. Values obtained with diagnostic equipment Autocom.

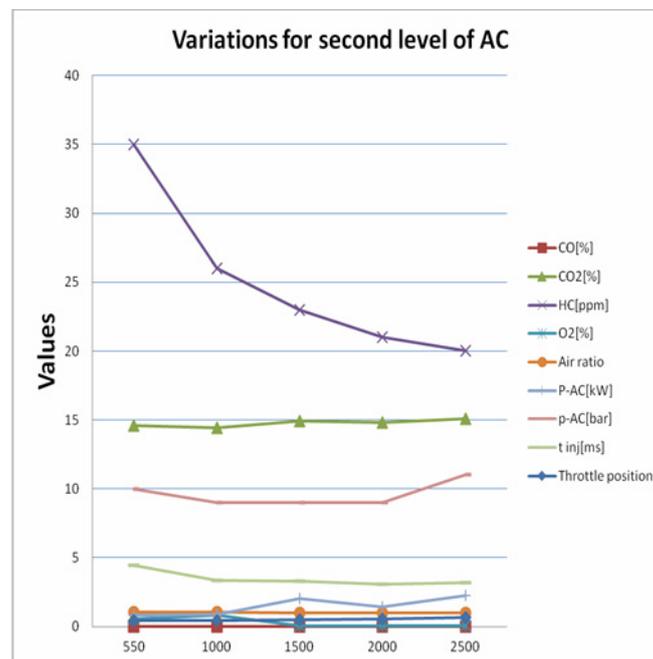


Figure 10. Determinations for second level of AC.

3. Conclusion

According to the experimental results, conclusion is that, when air conditioning system (AC) operate on stages II, III and IV leads to a significant increase in HC emissions.

- When the air conditioning system is functioning on II stage, has been an increase of 250% for HC emissions, compared with HC emissions when the air conditioning system is functioning in stage I.

However, these emissions are within the limits imposed by Euro 4 standard (for idling and low load); the standard provides that the HC emissions must be less 100 ppm.

- If air conditioning system operates on a stage maintained constant, then we can notice a reduction in emissions of HC with the increasing of engine rotation.

- In the sense of the work presented, if possible, is recommended especially in urban traffic, utilization only the first stage of air conditioning system, helping to reduce environmental pollution. If you need to use higher stages of air conditioning system, to reduce emissions of HC, is recommended that the engine to operate at high rotations (over 2000 [rpm]) because at the lower speeds are increases especially for the emissions of HC, as shown in figure 10. For example, if the air conditioning system is functioning in second stage at lower speeds then 2000 [rpm] is realised an increase between 25-65% for HC emissions, depending on speed working.

4. References

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