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EMISSIONS LEVEL APPROXIMATION AT COLD START FOR DIESEL VEHICLES

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***Abstract*—** This paper present a study regarding the emissions produced at the engine could start. Also, the paper presents a brief survey of current extra emissions estimation methods. The main goal of this work is to describe the relative cold start extra emissions as a function of exhaust gas temperature. Experimental research has been done for several light vehicles. There were been made six tests, in different temperature conditions. For measurements was used a the GA-21 portable analyzer. The parameters measured are: CO, NO, NO_2, NO_x, and SO_2. In order to accomplish a mathematical approximation of CO, NO, NO_2 and SO_2 in function of exhaust gas temperature, logarithmic approximations and polynomial regressions were used. The curves resulted from the mathematical model can be used to approximate the level of CO, NO, NO_2 and SO_2, for similar vehicles.

***Keywords*—** Cold start, Exhaust, Temperature, Diesel, Gas analyzer.

I. INTRODUCTION

Pollutant emissions from vehicles are responsible for about 60 % of air pollution in the urban areas. The big development of the industry in the last years has extended and develops the transportation from the all world. Very populated urban and rural areas are directly affected by the mobility increase and by the intense merchandises and population circulation. Road transportation represents the general vehicles and pedestrians movement, concentrated on the land meant on this porpoise (roads). The road traffic phenomenon its manifest in large territories, but also in small areas.

Because it was proven that an important population percentage is affected by diseases produced by chemical pollution, this question appear: what is the role of road transportation that uses internal combustion engines regarding to others pollution sources in human health problem.

The major pollutants emitted by motor vehicles including CO, NO, NO_2, SO_2, HC and suspended particulate matter (PM2,5, PM10), have damaging effects on both human health and environment degradation [1]. In internal combustion engines, the gases comprise a mixture of unburn hydrocarbons (HC), Carbon Monoxide (CO) and Oxides of Nitrogen (NO_x) [1], [2].

The approximation of chemical pollutants can by made using linear, exponential or polynomial regressions, Gaussien models, Lagrangian model, etc.. The Romanian, US, European and Asian studies shown that this pollutants can by approximated in function of different parameters using mathematical models [3].

II. METHODOLOGY FOR EXHAUST GAS MEASUREMENTS

Experimental research has been done for 4 light vehicles:

1) *Dacia Logan equipped with a 1461 (cm^3) Compression Ignition Engine with Power = 50 (kW) at 4000 (rpm) - fabrication year 2007.*

2) Opel Astra G, equipped with a 1686 (cm^3) Compression Ignition Engine with Power = 55 (kW) at 4000 (rpm) - fabrication year 2001.

3) Skoda Octavia, equipped with a 1896 (cm^3) Compression Ignition Engine with Power = 77 (kW) at 3800 (rpm) - fabrication year 2006.

4) Volkswagen Golf, equipped with a 1896 (cm^3) Compression Ignition Engine with Power = 85 (kW) at 3800 (rpm) - fabrication year 2001.

There were been made six tests, in different temperature conditions, from starting the engine to the point that optimum operating temperature is reached. The engines ware operated at idle speed throughout the measurements. In Figure 1 is presented the equipment and the placement of it in order to perform the measurements.

The six research tests were made as follows:

1) *12.02.2014 Test (ambient temperature~16 ºC);*
2) *12.02.2014 Test (ambient temperature~18 ºC);*
3) *12.02.2014 Test (ambient temperature~16 ºC);*
4) *15.05.2014 Test (ambient temperature~17 ºC);*
5) *15.05.2014 Test (ambient temperature~20 ºC);*
6) *11.02.2015 Test (ambient temperature~13*

ºC);

7) *12.02.2015 Test (ambient temperature~18 ºC).*

The GA-21 plus is a multi-functional flue gas analyzer. The analyzer is fitted with oxigen, carbon monoxide, nitrogen oxide, sulphur dioxide, carbon dioxide and all nitrogen oxides sensors [1].

Also, the air inlet, the ambient temperature and exhaust gas temperature are measured. Using the measured temperatures, gases concentrations and the fuel parameters, the analyzer calculates a variety of combustion parameters such as Stack Loss - SL, Efficiency - h, Excess Air - λ, Loss through Incomplete Combustion - IL [4], [5].

In direct measurements the temperature values and the concentration of those gas elements which are detected by independent electrochemical sensors are obtained. The electrochemical cell indications are proportional to the volume concentration of the detected elements expressed in (ppm) (parts per million). The following quantities are obtained by means of direct measurement: volume concentration of CO (ppm); flue gas temperature T gas and ambient temperature, expressed in (ºC); volume concentration of NO (ppm); volume concentration of SO_2 (or any other optional cell) (ppm); volume concentration of O_2 (%) [1], [4].

Fig. 1. Vehicle pollution measurements

III. Research Results

The results resulted after the six tests were downloaded and it was created a database in order to analyze them. To exemplify, 11 February 2015 Test will be presented as follows.

Measurements were made from cold engine start, saving reports at every two minutes. The test contains 9 reports for exhaust gas temperature ranging from 25 to 60 (°C). The collected data are saved as database in order to analyze the results.

For every report following parameters are saved: CO, NO, NO_2, NO_x, SO_2, CO_2 H_2 (mg/m^3); exhaust gases temperature measured at exhaust pipe end, T_{gas} (ºC); ambient temperature, T_{amb} (ºC); excess air factor λ. The results of collected data for 11 February 2015 Test are presented in Table I.

TABLE I
Air pollutant concentartions for 11.02.2015 Test

Tgas (°C)	Tamb (°C)	CO (mg/m^3)	NO (mg/m^3)	NO_x (mg/m^3)	NO_2 (mg/m^3)	SO_2 (mg/m^3)
25,0	13,1	601,25	183,5	283,72	2,056	11,44
29,9	13,0	270	207,7	322,79	4,112	8,58
34,7	12,8	242,5	206,3	320,73	4,112	2,86
42,5	12,4	223,75	203,6	316,62	4,112	0
46,7	12,3	223,75	198,3	308,4	4,112	0
51,7	12,3	205	198,3	308,4	4,112	0
52,8	12,1	306,25	171,5	267,28	4,112	0
53,9	12,1	1250	83,08	129,52	2,056	0
58,4	12,2	1241,2	62,98	100,74	4,112	5,72

The main pollutants variations depending on exhaust gas temperature are centralized and analyzed. The concentration of carbon monoxide is high for Diesel engine cold start. Until the exhaust gases reaches a temperature of about 30 (ºC), the concentration of CO is between 400 and 1000 (mg/m^3). The maximum NO values, about 225 (mg/m^3) are reached when the engine is warming. In sulphur dioxide case, the maximum values are registered at engine start (around 25 (mg/m^3)). Also, in this case, NO_2 values oscillates until T_{gas} reaches an optimum temperature (about 50 (ºC)), when it will tend to 1 (mg/m^3). It can be concluded that the highest pollutants values are recorded until the point when exhaust gas temperature is 35 to 40 (ºC).

IV. Mathematical Model

In order to accomplish an approximation model to estimate the pollutants (produced by the combustion of gasoline) concentrations at engine cold start, will be used all the data collected from the six tests. Pollutants values (CO, NO, NO_2, NO_x and SO_2) and exhaust gas temperature (T_{gas}) from all six tests are grouped in one worksheet [1]. To realize the mathematical approximation of CO, NO, NO_2, NO_x and SO_2 in function of exhaust gas temperature, will be used several variable functions. This model can use for chemical pollutants approximations. It is needed accomplishment of a data base for vehicles specific pollutants. pollutants analyses and usage of an approximation model [1].

The collected data were processed for each representation of the measured values, obtaining a theoretical curve given by a regression equation [1], [6]. It was whished to result a theoretical curve similar to the collected values curve [1]. The values for all six tests are centralized in Table II. The values are ordered in function of exhaust gas temperature (in ascending order).

TABLE I I
Air pollutant concentartions for all Tests

Tgas (°C)	Tamb (°C)	CO (mg/m^3)	NO (mg/m^3)	NO_x (mg/m^3)	NO_2 (mg/m^3)	SO_2 (mg/m^3)
16,2	18,4	962,5	230,4	250,76	20,28	2,86
20,6	19,6	941,25	226,4	246,74	20,28	14,3

22,9	17,2	753,75	218,4	241,03	22,61	14,3
23,0	19,6	606,25	227,8	250,13	22,33	17,16
23,4	18,4	666,25	218,4	241,03	22,61	28,6

TABLE I I - CONTINUE

25,0	13,1	601,25	218,4	240,47	22,05	11,44
25	13,1	601,25	225,1	247,17	22,05	11,44
25,7	19,8	326,25	217,0	239,69	22,61	8,58
27,5	18,3	266,25	211,7	228,16	16,44	22,88
29,9	17,1	635	217,0	229,04	11,96	31,46
29,9	13,0	270	206,3	210,47	4,112	8,58
29,9	13	270	206,3	210,47	4,112	8,58
31,2	18,3	225	213,0	225,39	12,33	8,58
34,5	17,2	591,25	219,7	232	12,24	14,3
34,7	19,8	308,75	207,7	228,26	20,56	2,86
34,7	12,8	242,5	207,7	211,81	4,112	2,86
34,7	12,8	242,5	203,6	207,79	4,112	2,86
35,1	18,2	210	203,6	216,01	12,33	2,86
37,7	19,9	298,75	198,3	220,93	22,61	2,86
38,5	17,2	510	198,3	216,50	18,18	5,72
39,9	18,2	177,5	198,3	210,65	12,33	2,86
40,7	19,8	292,5	198,3	216,82	18,50	2,86
41,6	17,2	468,75	176,8	195,00	18,12	0
42,4	18,4	166,25	191,6	201,9	10,28	0
42,5	12,4	223,75	183,5	187,69	4,112	0
42,5	12,4	223,75	183,5	187,69	4,112	0
43,8	19,8	291,25	170,1	188,68	18,50	0
44,0	17,2	472,5	166,1	184,28	18,12	0
45,1	17,2	473,75	158,1	168,30	10,18	0
45,2	18,4	153,75	179,5	187,78	8,224	0
45,9	19,9	261,25	174,2	194,76	20,56	0
46,6	18,4	148,75	174,2	184,48	10,28	0
46,6	18,4	142,5	175,5	185,82	10,28	0
46,7	12,3	223,75	158,1	162,23	4,112	0
46,7	12,3	223,75	168,8	172,95	4,112	0
46,8	17,3	483,75	152,7	165	12,24	0
47,2	18,4	121,25	151,4	161,7	10,28	0
48,2	19,8	247,5	171,5	187,96	16,44	0
48,9	17,2	456,25	171,5	187,87	16,35	0
49,2	18,1	112,5	119,2	129,54	10,28	0
50,7	17,4	115	93,8	104,08	10,28	0
51,4	17,4	127,5	151,4	161,7	10,28	0
51,7	12,3	205	96,48	100,59	4,112	0
51,7	12,3	205	113,9	118,01	4,112	0
52,8	12,1	206,25	83,08	87,192	4,112	0
52,8	12,1	206,25	83,08	87,192	4,112	0
53,1	16,4	391,25	65,66	84,164	18,50	0
53,9	12,1	125	62,98	85,036	22,05	0
53,9	12,1	125	62,98	85,048	22,06	0
57,2	16,3	136,25	77,72	104,44	26,72	5,72
58,4	12,2	124,25	96,48	137,59	41,11	7,79
58,4	12,2	124,25	148,7	189,85	41,11	8,72
73,1	16,2	271,75	142,0	183,16	41,12	6,9
94,6	16,5	261	146,0	191,29	45,23	8,6

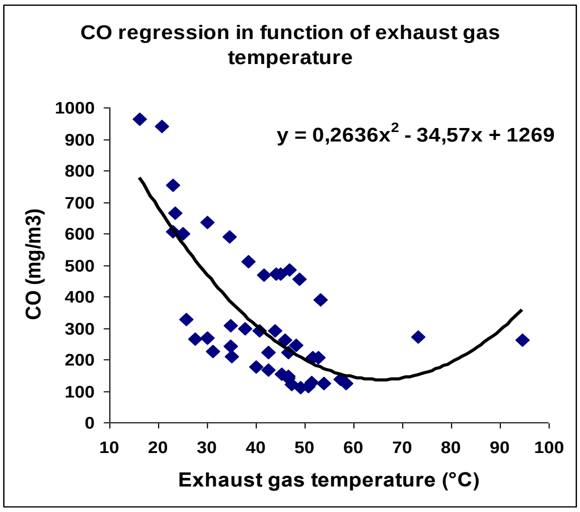

Fig. 2. CO concentration variation in function of exhaust gas temperature

In the figures (Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6) are presented the resulted curves and equations, for CO, NO, NO_2, NO_x (resulted value for all nitrogen oxides) and SO_2 variations in function of exhaust gas temperature (measured at exhaust pipe end).

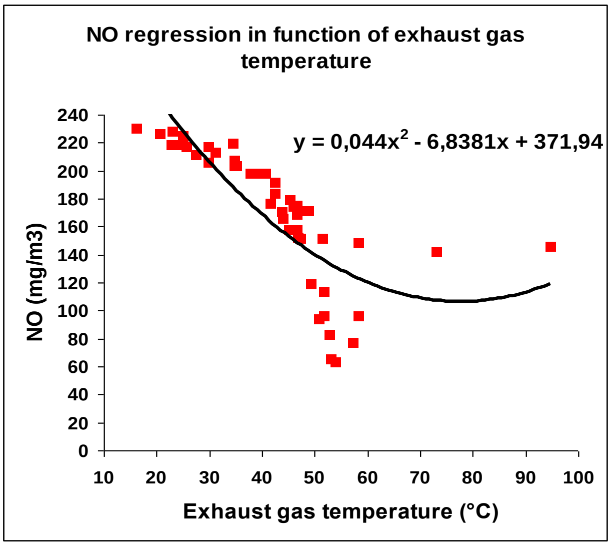

Fig. 3. NO concentration variation in function of exhaust gas temperature

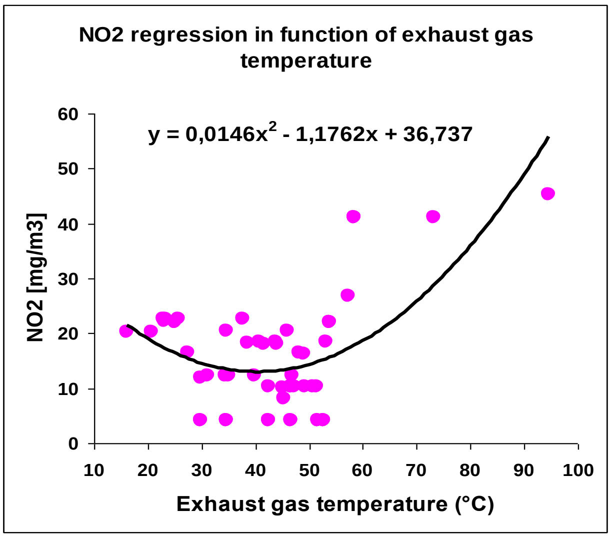

Fig. 4. NO_2 concentration variation in function of exhaust gas temperature

For this five analyzed chemical pollutants, in order to realize a unitary model, it can be written equations of pollution concentration variation depending on exhaust gas temperature (Eqs. 1, 2, 3, 4 and 5) [1].

$$CO_{approx} = 0,2636 \quad T_{gas}^{2} \quad 34,57 \quad T_{gas} + 1269 \tag{1}$$

$$NO_{approx} = 0,044 \quad T_{gas}^{2} \quad 6,8381 \quad T_{gas} + 371 \tag{2}$$

$$NO_{2approx} = 0,0146 \quad T_{gas}^{2} \quad 1,1762 \quad T_{gas} + 36,737 \tag{3}$$

$$NO_{x\ approx} = 0,0466 \quad T_{gas}^{2} \quad 6,9389 \quad T_{gas} + 393,21 \tag{4}$$

$$SO_{2approx} = 0{,}01\ \ T_{gas}^{2}\ \ \ 1{,}2049\ \ \ T_{gas} + 36{,}239 \qquad (5)$$

Where: CO_{approx}, NO_{approx}, $NO_{2approx}$, $NO_{xapprox}$ and $SO_{2approx}$ = the approximated values of the CO, NO, NO_2, NO_x and SO_2 concentrations (mg/m^3) which describes the variations of the regression curves. After the introduction of the formulas and the graphical representation of the 5 pollutants, result the theoretical curves corresponding to the used equations (Fig. 7) [1].

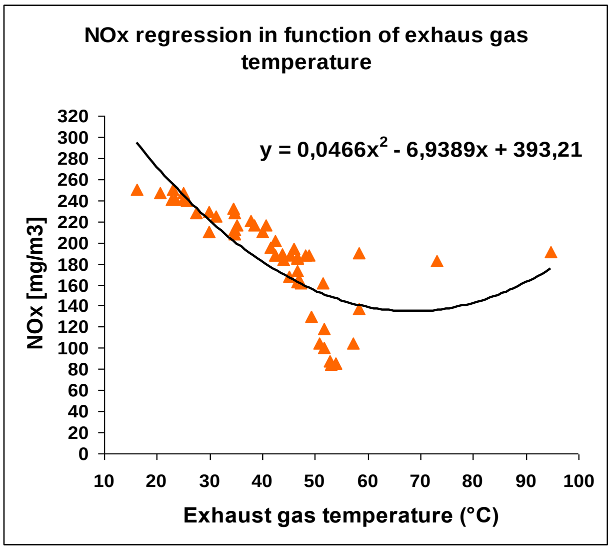

Fig. 5. NO_x concentration variation in function of exhaust gas temperature

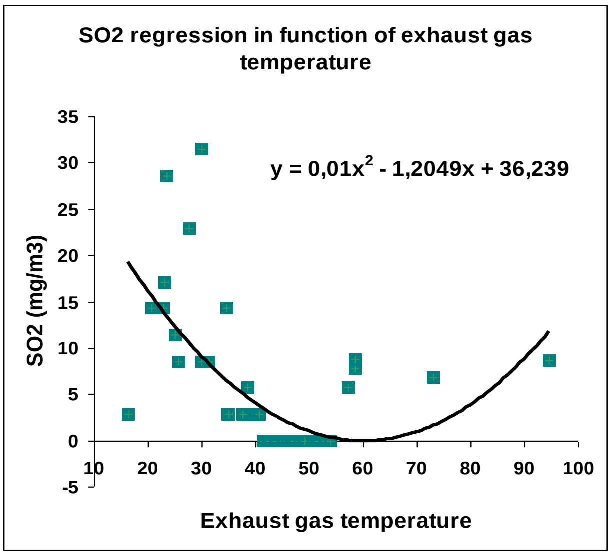

Fig. 6. SO_2 concentration variation in function of exhaust gas temperature

V. CONCLUSION

In order to use this analysis to approximate the level of vehicles specific pollutant parameters, at engine cold start for similar vehicles, a predictive mathematical model was realized. This model presented in the current paper can be used to approximate the level of air pollution (CO, NO, NO_2, NO_x and SO_2) depending on exhaust gas temperature (measured at the exhaust pipe end) [1].

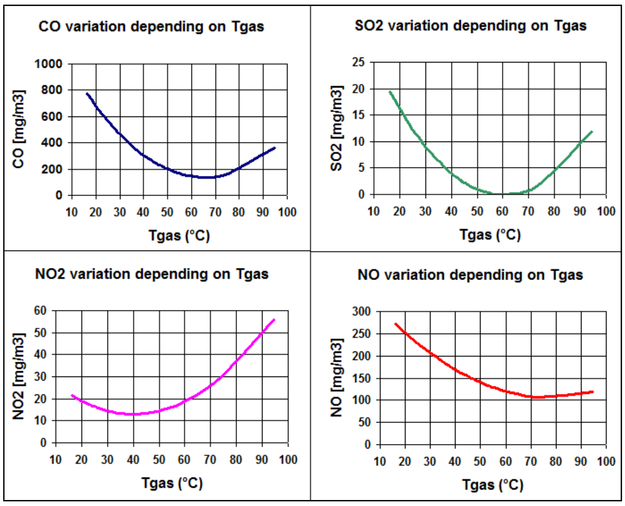

Fig. 7. Utilization of mathematical model for CO, NO, NO_2, and SO_2 estimation, in function of T_{gas} for Diesel engines

A database containing pollution information for various vehicles was created in 2013 and now is frequent updated with new values, being able to make comparative studies over the pollution level at exhaust pipe. The prediction model involves the analysis of a large number of data (pollutants, temperatures, engine function parameters) [1]. The collected pollutants values are used to generate approximation curves for studied pollutants, and after, the curves resulted from the mathematical model can be used to approximate the level 5 pollutants, for similar vehicles.

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