THE RESULTS OF RETROFITTING DIESEL ENGINES OF CITY BUSES WITH SIC PARTICULATE FILTERS

Tsetsegmaa Agvaantseren
postgraduate
Battugs Sukhee
Doctorate in Engineering Sciences
Mongolian University of Life Sciences
Scientific Supervisor: **Bayarsuren Badarch**
Doctorate in Engineering Sciences, Professor
University of Science and Technology Ulaanbaatar

Abstract. Diesel vehicle emissions are a significant source of fine particulate matter (PM) and gaseous pollutants in urban environments. The article presents the results of measurements of particulate matter emissions from 25 city public transport buses by trapping soot in diesel particulate filters (DPF). The studies were carried out on city buses of category M_3 in operation, in real public transportation and driving in real traffic conditions along the regular route of the city of Ulaanbaatar. For research and non-regulatory purposes, PM sample masses were determined by gravimetric method. During six months of warm and cold seasons, 346.651 kg of soot was filtered out of 25 buses. A city bus emits an average of 0.6866 grams of particulate matter (PM) into the city's atmosphere for every kilometer traveled under actual operating conditions. Thus, retrofitting a conventional diesel engine with a silicon carbide particulate filter significantly reduces particulate emissions.

Key words: particulate matter, diesel particulate filter, diesel retrofit, fuel sulfur, actual road emissions.

РЕЗУЛЬТАТЫ МОДЕРНИЗАЦИИ ДВИГАТЕЛЕЙ ГОРОДСКИХ АВТОБУСОВ САЖЕВЫМИ ФИЛЬТРАМИ SIC

Цэцэгмаа Агвааанцерен
аспирант
Баттугс Сухээ
доктор технических наук
Монгольский университет сельского хозяйства
Научный руководитель: **Баярсурен Бадарч**
доктор технических наук, профессор
Университет науки и технологий Улан-Батор

Аннотация: Выбросы дизельных автомобилей являются значительным источником мелких твердых частиц (ТЧ) и газообразных загрязнителей в городской среде. В статье представлены результаты измерений выбросов твердых частиц от 25 городских автобусов общего пользования путем их улавливания в сажевых фильтрах (DPF). Исследования проводились на находящихся в эксплуатации городских автобусах категории M_3 в реальных условиях обслуживания и вождения по регулярному маршруту города Улан-Батора. Для исследовательских и ненормативных целей массы отобранных проб ТЧ определялись гравиметрическим анализом. В течение шести месяцев теплого и холодного сезонов из 25 автобусов отфильтровано 346 651 кг сажи. Городской автобус выбрасывает в атмосферу в среднем 0,6866 грамма твердых частиц на каждый пройденный километр в реальных условиях эксплуатации. Таким образом, дооснашение старого дизельного двигателя обычной конструкции сажевым фильтром из карбида кремния значительно снижает выбросы твердых частиц.

Ключевые слова: твердые частицы, сажевый фильтр, дооснащение дизельного двигателя, сера в топливе, фактический дорожный выброс.

Introduction. The results of a study of annual emissions of air pollutants' sources in Ulaanbaatar indicates that the vehicle accounts for more than 10% of the total pollution, of which city buses emit 70% of PM, 20% of nitrogen oxides and 31% of sulfur compounds [1]. This in-depth study is a continuation of a pilot study on the possibility of reducing PM emissions from conventional diesel buses running on high sulfur fuel by retrofitting them with DPF. The PEMS (Portable Emission Measurement System) test result showed that the use of SF can reduce PM emissions by up to 97%, but along with this, we needed to investigate how long the filtration efficiency can be maintained, what are the actual road emissions of buses, in order to further improve the filter regeneration process.

Materials and methods. For the experiment, 24 city buses were retrofitted with a DPF system, consisting of three cassette type filters each, and operated under real public transport conditions on a variety of routes in the city. At the same time, no restrictions were placed on the sulfur content in the fuel, and any diesel fuel provided by the market was used and no additional restrictions were applied, as no subsequent analysis of the chemical composition of suspended particles was planned. Sampling before and after passing the exhaust gas through the particulate filter, followed by laboratory weighing, is the most commonly used method for determining PM concentrations in diesel engines [2]. We used this method for our purposes as follows: By the end of the day, when each bus arrived at the fleet, a designated employee replaced the filter elements with r regenerated ones, while keeping a separate log for each bus, where he recorded each filters own number and weight of three clean filters, as well as odometer readings. And then the mass of each uncleaned filter was determined gravimetrically, the value was entered in the logbook, and the mass of filtered soot with this filter was determined from the difference in the masses of the filters before and after regeneration. The sum of the masses of soot from three filters of one group was determined by the total mass of filtered soot from this bus for day and recorded on the journal. Thus, the actual emissions of city buses were experimentally investigated over a period six months.

The Table 1 shows the technical specifications of the DAEWOO BS106 bus, used in the experiment:

Table 1

Technical specifications of the tested buses [3]

Engine model	DE12
Engine Displacement (cc)	11051
Number of Cylinders	6
Compression Ratio	17.1
Aspiration	Atmospheric, naturally
Exhaust gas treatment system	No
Max Power (kW@RPM)	165kW@2200 min^{-1}
Max Torque (Nm@RPM)	800 Nm@1400 min^{-1}
Manufacture year	2009
Bus curb weight (kg)	9015 kg

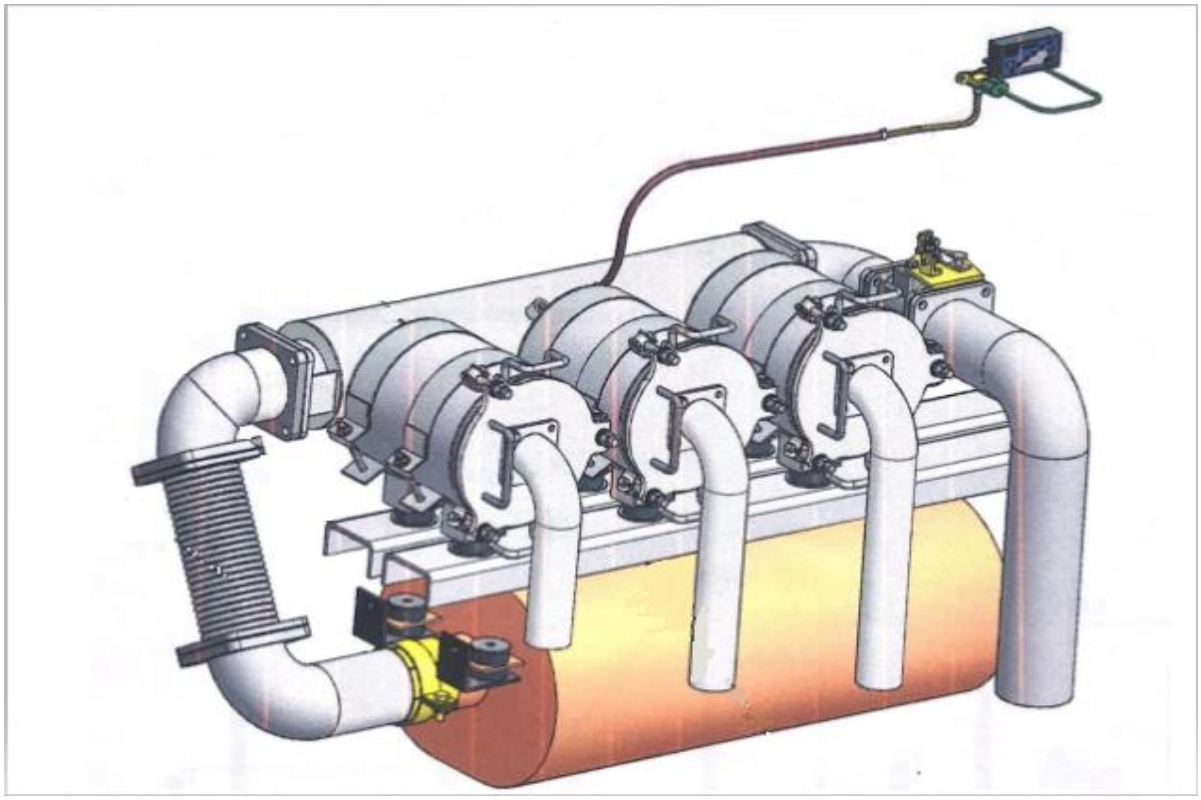

Figure 1. DFP assembly for DAEWOO BS106 bus

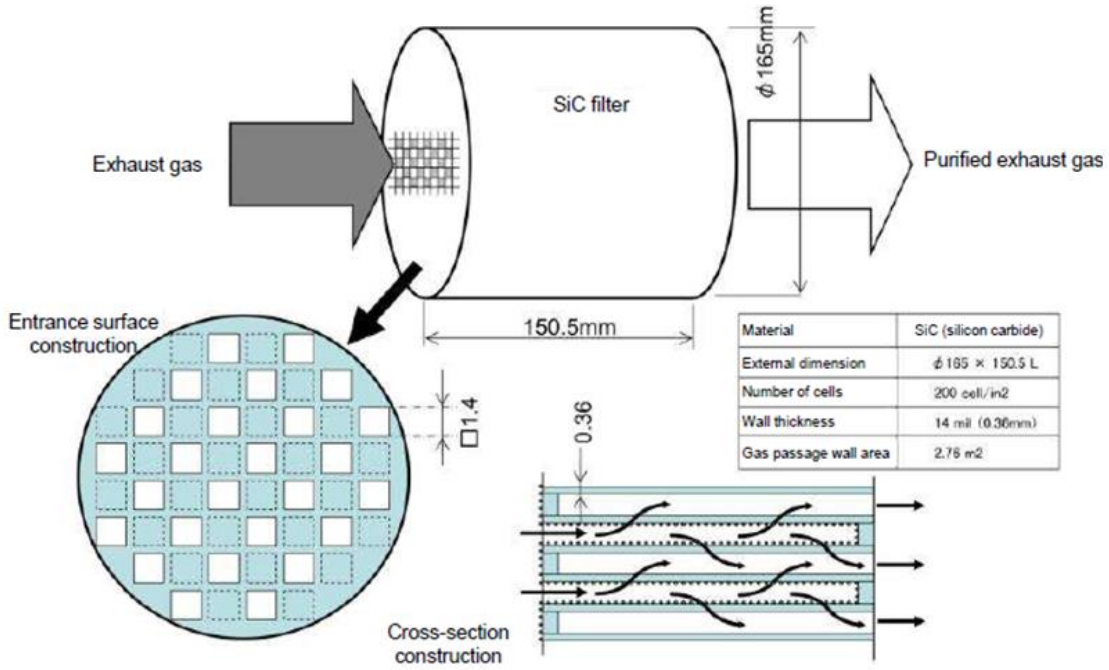

Figure 2. Structure of the SiC wall flow filter

Figure 3. DPF installed on the buses

Figure 4. Each filter has its own number

Figure 5. Filter mass before regeneration

Figure 6. Filter mass after regeneration

Results. The 24 buses' exhaust smoke was measured in the beginning of the experiment. Then after installation of DPF, the measurements were conducted again. The compared results of before and after of installing DPF is shown in Figure 7.

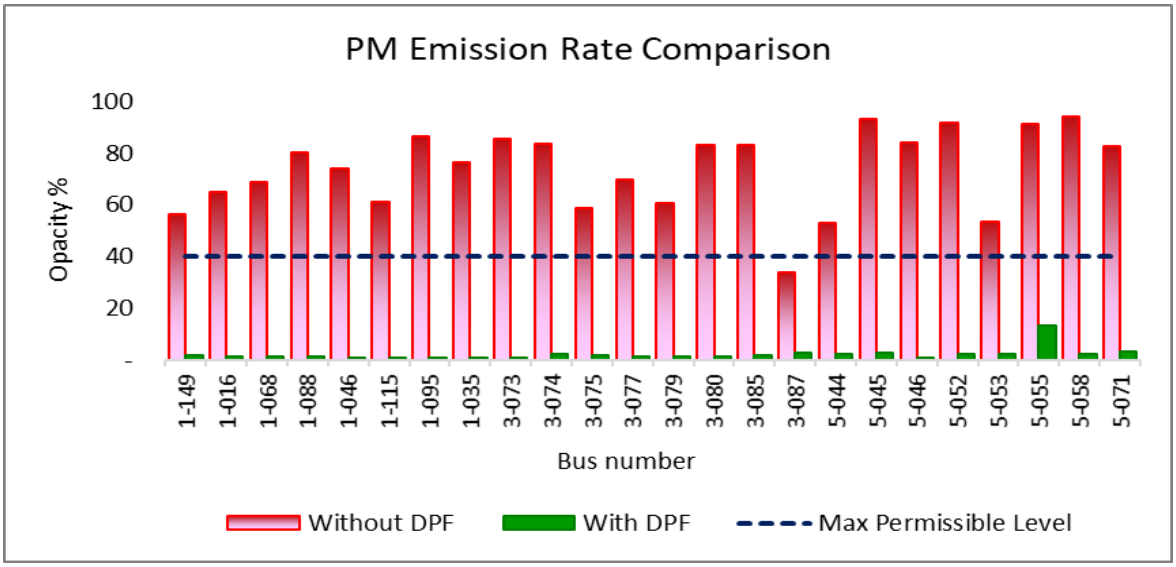

Figure 7. PM Comparison opacity of exhaust gas - before vs. after retrofitting the DPF

Table 2

The result of measuring the exhaust opacity of buses before and after the installation of the DPF

Bus number	Opacity of Exhaust Gas, %		PM reduction, %
	Without DPF	With DPF	
1	56.40	1.60	97.16
2	64.90	1.00	98.80
3	68.70	1.00	98.50
4	80.20	1.30	98.37
5	73.80	0.60	99.19
6	60.90	0.90	98.52
7	86.40	0.90	98.96
8	76.10	0.70	99.08
9	85.50	0.80	99.06
10	83.30	2.20	97.36
11	58.40	1.70	97.09
12	69.50	1.40	97.98
13	60.40	1.00	98.34
14	83.20	1.00	98.80
15	83.00	1.90	97.71
16	33.80	2.70	92.01
17	52.90	2.30	95.65
18	93.20	2.50	97.32
19	83.90	0.80	99.05
20	91.60	2.00	97.82
21	53.30	2.20	95.87
22	91.10	13.00	85.75
23	94.10	2.40	97.45
24	82.40	3.20	96.11
Average PM	73.625	2.045	97.22

The Table 3 shows the weight of the filter, filtered DTS from the bus diesel:

Table 3

The amount mass of soot filtered by DPF from buses

Bus number	Amount of soot mass filtered by DPF from buses per month, kg							Grand Total, kg
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	
1	3312	2925	2802	1284	1049	-	-	11.372
2	3682	4821	5270	2886	2379	2022	1094	22.154
3	1892	4070	4482	3874	1241	1424	2617	19.600
4	2026	2488	3124	3851	2283	1977	1018	16.767
5	2982	4842	3017	-	-	-	-	10.841
6	1590	4983	4185	433	-	-	-	11.191
7	-	3174	4105	4875	2712	1994	2277	19.137
8	-	3345	4892	4320	3638	2295	2418	20.908
9	-	3022	4003	6405	3630	1866	2796	21.722
10	-	2107	2026	3292	1599	1014	-	10.038
11	-	1908	2771	2134	1016	1062	494	9.385
12	-	1908	2827	2271	837	576	276	8.695
13	-	4752	5264	3552	1796	1405	-	16.769
14	-	2125	4871	2528	1344	1096	517	12.481
15	-	2625	4352	2912	1267	2399	694	14.249
16	-	2524	4462	2954	1480	1328	372	13.120
17	-	1555	3149	3719	3272	3360	3282	18.337
18	-	3065	4256	2574	2969	1615	2811	17.290
19	-	1896	2623	2303	1649	1575	2931	12.977
20	-	3150	3720	4106	845	979	2808	15.608
21	-	1754	2274	1695	2186	2157	2914	12.980
22	-	349	2600	-	-	-	747	3.696
23	-	2963	2654	2906	3032	994	831	13.380
24	-	1066	4500	2902	3191	2295	-	13.954
Grand Total, kg	15.48	67.42	88.23	67.78	43.42	33.43	30.897	346.651

In 6 months, 346.651 kg of soot was filtered from 24 buses. The data from studies were analyzed primarily using analysis of variance (ANOVA) techniques.

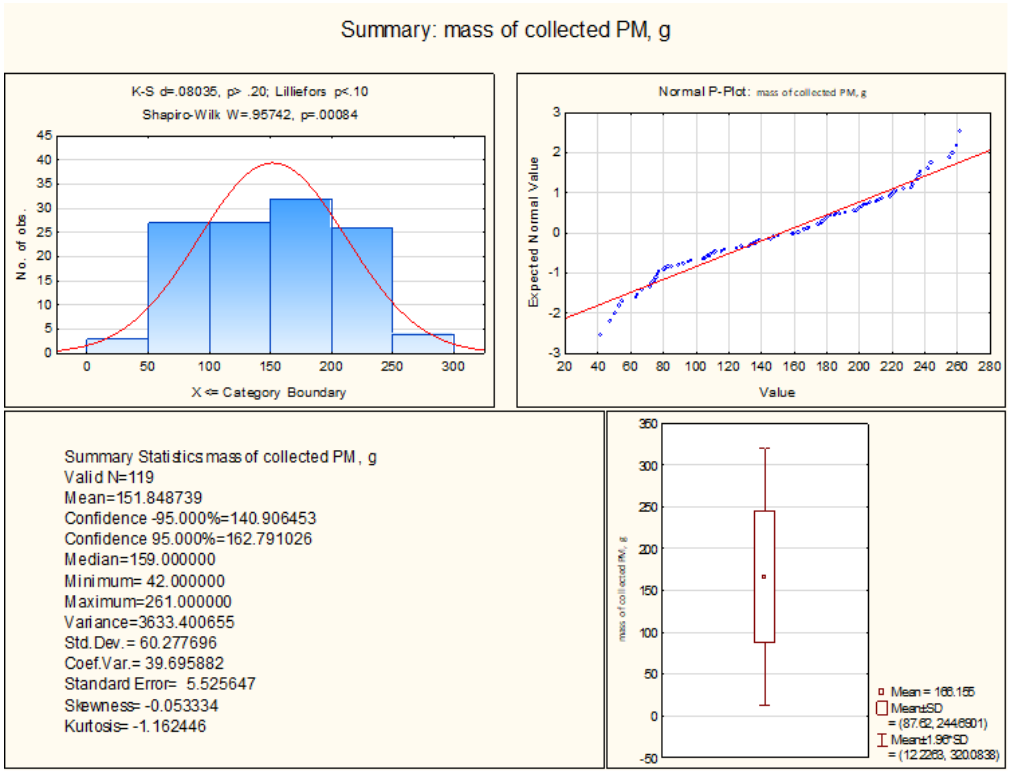

Figure 8. The results of the analysis of the data of masses of collected soot by DPF

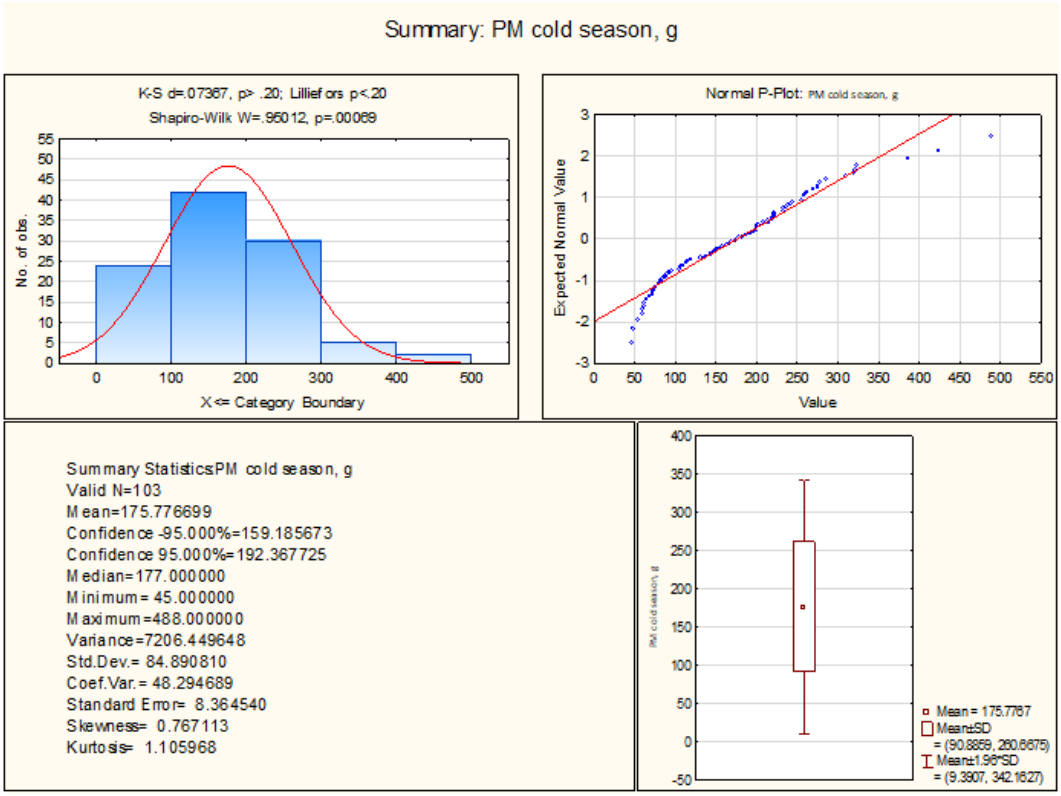

Figure 9. The results of the analysis of data on the mass of collected soot by the DPF in the cold season

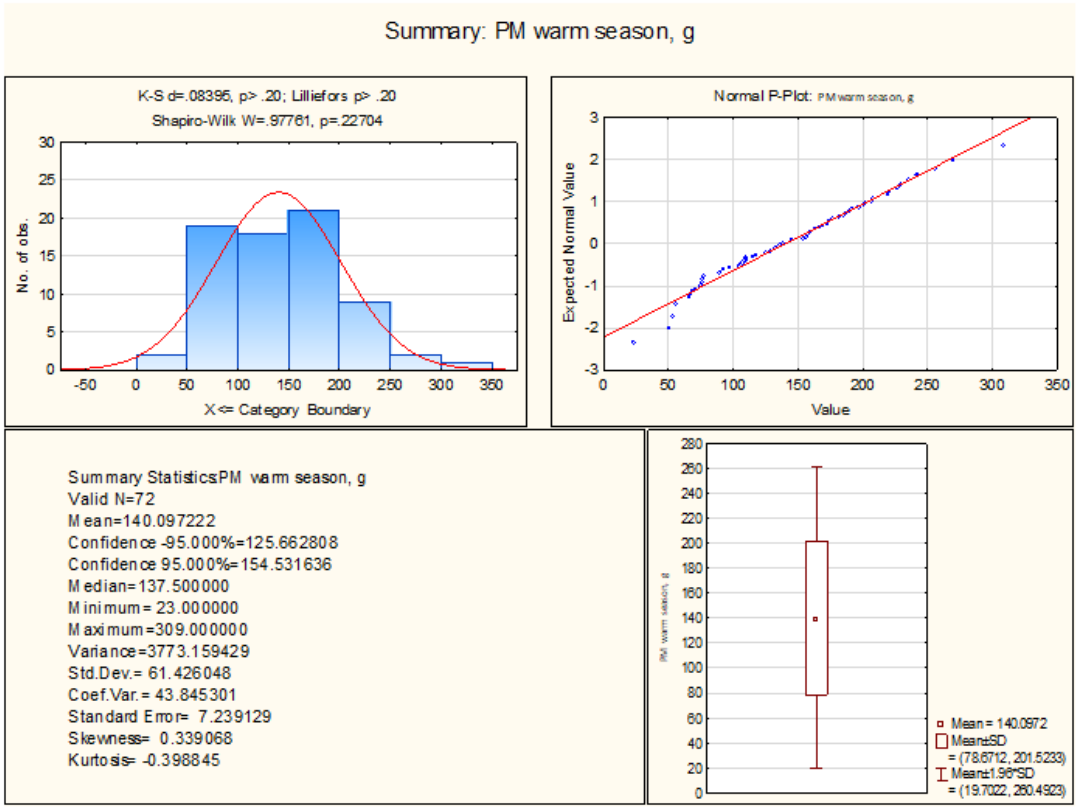

Figure 10. The results of the analysis of data on the mass of collected soot by the DPF in the warm season

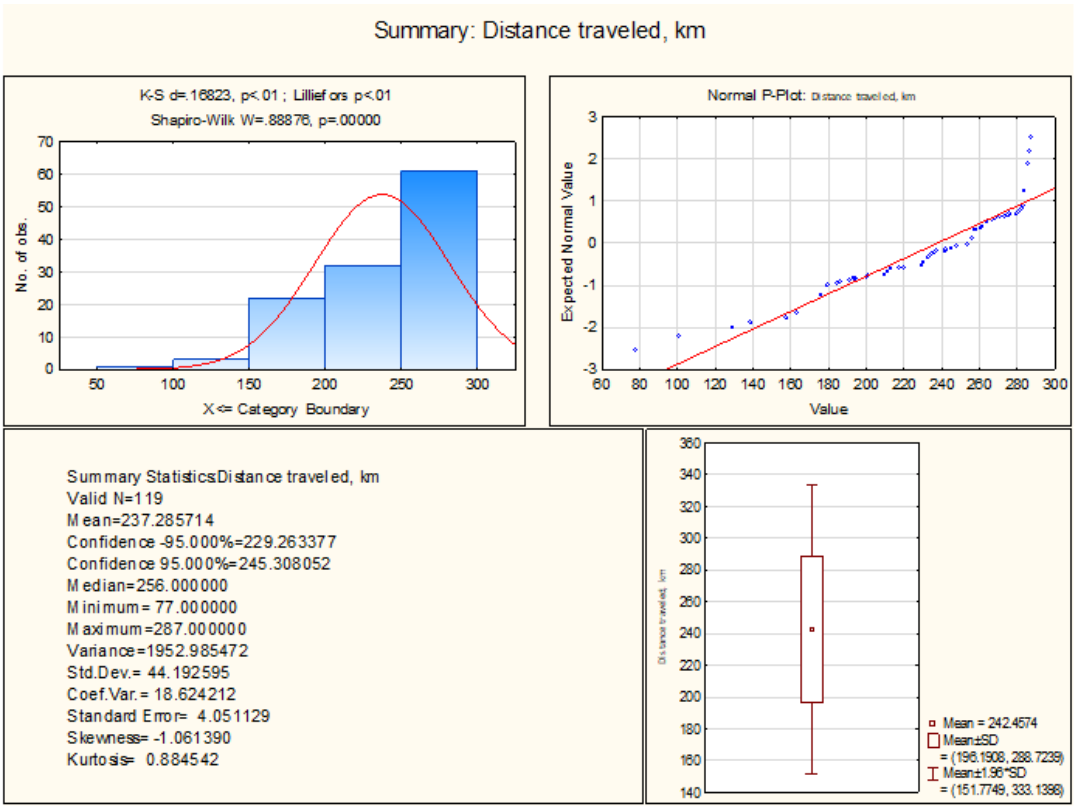

Figure 11. The results of the analysis of data on the distance travelled

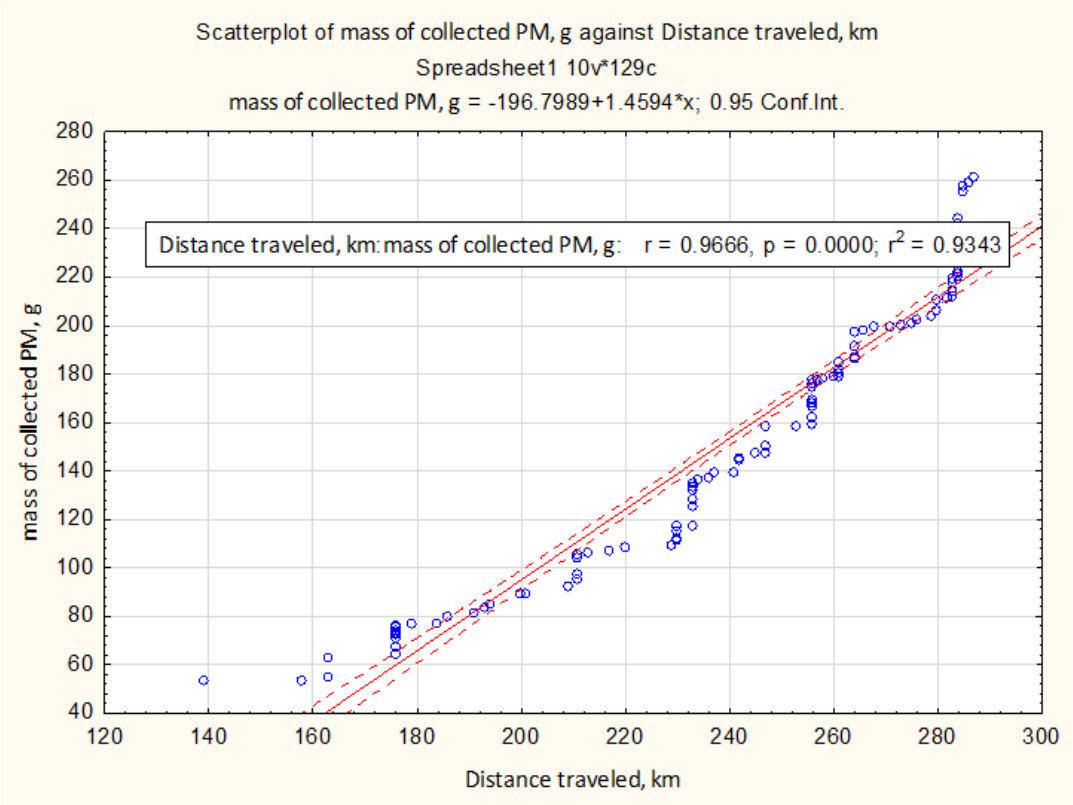

Figure 12. Scatterplot of mass of collected PM against distance traveled

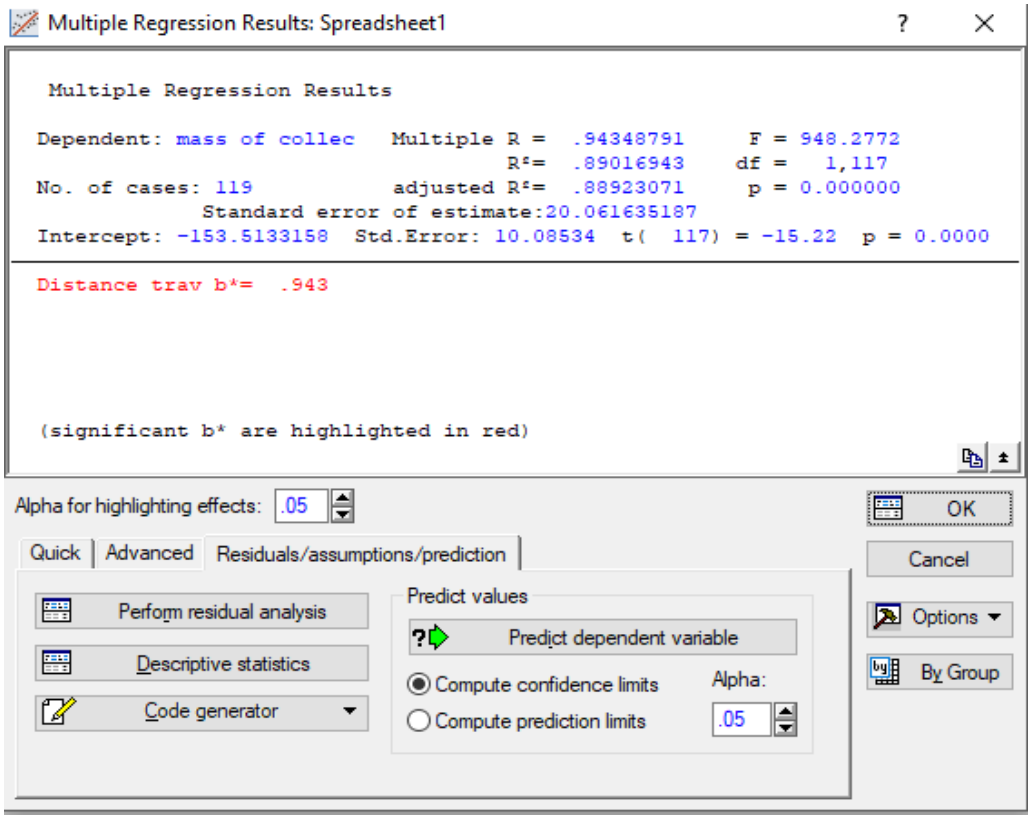

Figure 13. Multiple regression results of mass of collected PM against distance traveled

Regression Summary for Dependent Variable: mass of collected PM, g (Spreadsheet1)
R= .94348791 R²= .89016943 Adjusted R²= .88923071
F(1,117)=948.28 p<0.0000 Std.Error of estimate: 20.062

N=119	b*	Std.Err. of b*	b	Std.Err. of b	t(117)	p-value
Intercept			-153.513	10.08534	-15.2214	0.000000
Distance traveled, km	0.943488	0.030639	1.287	0.04179	30.7941	0.000000

Figure 14. Regression summary of mass of collected PM against distance traveled

Analysis of Variance; DV: mass of collected PM, g (Spreadsheet1)

Effect	Sums of Squares	df	Mean Squares	F	p-value
Regress.	381652.4	1	381652.4	948.2772	0.00
Residual	47088.9	117	402.5		
Total	428741.3				

Figure 15. Analysis of variance of mass of collected PM against distance traveled

Discussion. To make the best decision on reducing harmful emissions from buses, we need to have a clear understanding of their actual road emissions. The technical level of diesel engines is assessed in terms of fuel efficiency and environmental performance [4]. In this experiment, actual PM emissions from conventional diesel engines of public transport buses in Ulaanbaatar were determined. Evaluation of the mass of soot collected on DPF in real time and in real operating conditions is necessary to determine the real contribution of city buses with a conventional diesel engine to the air pollution of the capital and can serve as a basis for further selection of diesel retrofit technology.

The effect of ambient temperature on PM emissions was also assessed.

Innovation: Actual PM emissions per kilometer from Ulaanbaatar public buses have been identified for the first time.

Conclusion. Twenty four buses retrofitted with DPF over six months at a fleet utilization rate of 86.6, an average of 13.615 kg of soot was collected from each bus, for a total of 340.386 kg. Actual daily PM emissions from bus in Ulaanbaatar are 166.155 g on average, and emissions per kilometer are 0.6866 g/km, which is 14.43% higher than Euro I standard.

As a result of a comparative analysis of monthly measurements of the warmest - July and the coldest - December months, it was found that the average daily soot

emission of one bus is 141.3 g in July and 175.8 g in December, and winter emission exceeds summer by 24.4% .

Practical significance: The developed DPF system can be applied on various types of vehicles with diesel engines, including trucks, road-building and agricultural vehicles, forklifts and backup generators in enclosed spaces, underground mines, etc., regardless of the sulfur content in the used fuel.

References

1. НАЧА, "Эх үүсвэрийн ялгарлын инвенторын 2016 оны жилийн тайлан," Улаанбаатар, 2017.

2. Heinz Burtscher, W. Addy Majewski, Imad A. Khalek, "Particulate Measurement: Collecting Methods," ECOpoint Inc. , Revision 2016.06. [Online]. Available: https://dieselnet.com/tech/measure_pm_col.php.

3. DAEWOO BUS CORPORATION, Owner's manual BS, BC, BV, BH, BX series, Busan, Korea: Technical center, 2009.

4. С.А. Гиевой, "Снижение Вредных Выбросов при эксплуатации автотракторных дизелей путем применения сажевого фильтра," Саратов, 2003.