PERFORMANCE ASSESSMENT OF MINE-X SOOTFILTERS MOVENPICK HOTEL, BEIRUT, LEBANON

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INTRODUCTION

The combustion of diesel fuel is a source of carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), a complex mixture of hydrocarbons (HC), as well as particulate matter (PM). The generated diesel particulate matter (DPM) is a mixture of solid particles that include metals, ash, soot, and minerals that promote the condensation of hydrocarbons, sulfuric acids, and water vapor on their surfaces. The emitted DPM consists mainly of fine particulates (diameter < 2.5 μm) as well as ultra fine particles (diameter < 0.1 μm) that readily suspend into the atmosphere (Gong and Beaglehole, 2000). This report presents an assessment conducted on the DPM reduction efficiency of two Mine-X Sootfilters recently fitted to one of six Onan 800 kW generators (Engine # 1) currently operating at the Beirut Movenpick Hotel (Figure 1). All six engines run on diesel fuel that is imported in accordance with the official specifications published on the 22nd of August 2002[1] (Appendix A) (Official Gazette, 2002). The sulfur content of the Lebanese diesel specifications (0.035 % by mass) are relatively higher (by 7 to 35 times) in comparison to the European Union, United States, and Scandinavian countries (0.001 to 0.005 % by mass) as depicted in Figure 2.

[1] There is a widespread concern that the quality of the imported diesel fuel to Lebanon does not conform with the government set specifications, particularly with respect to the fuel sulfur content

(a): general overview of the Movenpick exhaust chimney

(c): The six Onan generators at the Movenpick

(b): Engine # 1 fitted with the Mine-X Sootfilter

Figure 1. The exhaust gas chimney and diesel engines operating at the Movenpick Hotel, Beirut

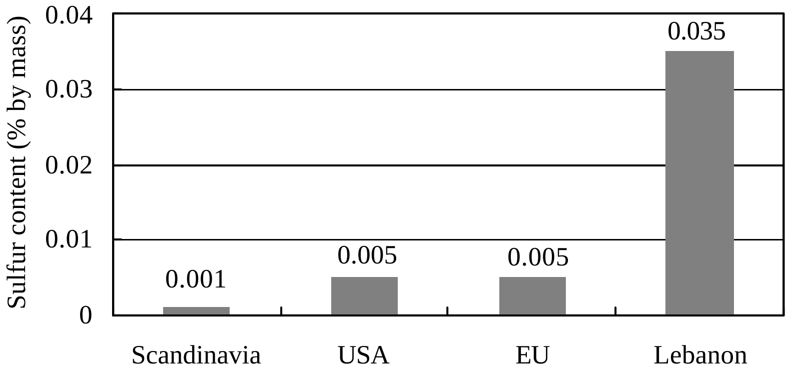


Figure 2. Sulfur content of Lebanese diesel fuel versus other countries

The main objective of this study is to assess the performance of the two installed Mine-X Sootfilters on the reduction of PM emissions resulting from the operation of an Onan 800 kW generator operating at the Movenpick Hotel in Beirut.

THE MINE-X SOOTFILTER TREATMENT PROCESS

The Mine-X Sootfilter (Figure 3) is a catalyzed wall-flow particulate filter that has been developed by DLC International Inc., Canada, to reduce the emission of DMP, CO, and HC resulting from the operation of heavy-diesel fueled industrial enginers. The soot-filter is composed of ceramic honeycomb wall-flow filters that channel the exhaust flow towards microscopic pores within the honeycomb walls thus trapping a large portion of the DPM particles before release into the atmosphere. The trapped DPM particles are then burned within the Mine-X Sootfilter in a continuous manner at a temperature ranging between 380-420 ^{o}C thus regenerating the filter and reducing maintenance. The soot-filter also reduces CO and HC emissions as a result of its catalyst coating that enhances complete combustion. The filter may also increase the NO_2/NO ratio. The pollution reduction rates that have been reported by the manufacturer are presented in Table 1.

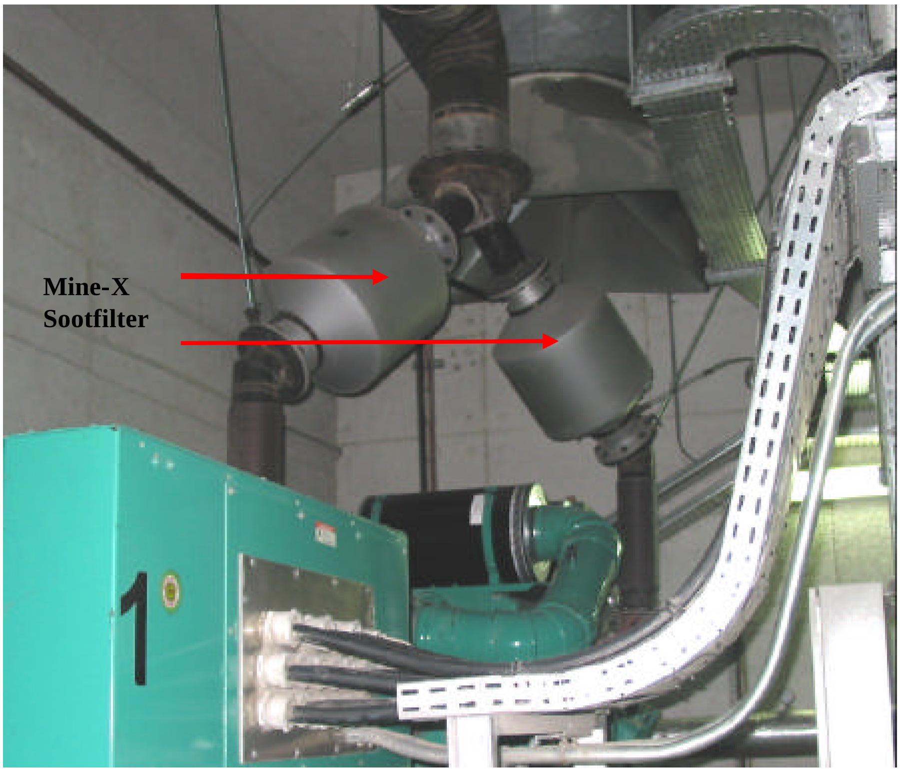


Figure 3. The two Mine-X Sootfilters installed on Engine # 1 at the Movenpick Hotel, Beirut

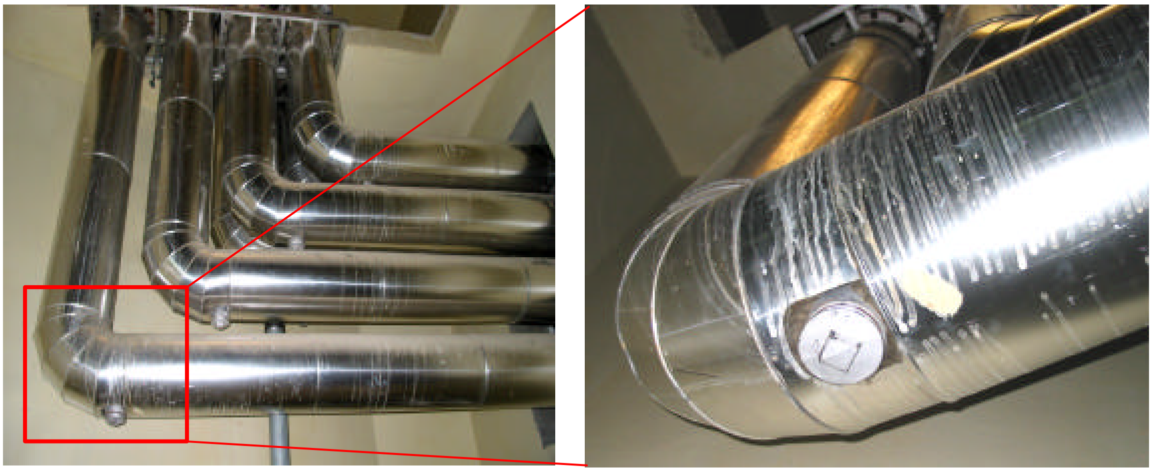
Table 1. Removal efficiencies reported by Mine-X Sootfilter manufacturers (DCL, International Inc., 2002)

Constituent	*Removal efficiency (%)*
Diesel particulate matter (by particulate count)	> 99[a]
Diesel particulate matter (by mass)	70-95[b]
Carbon monoxide	90
Hydro carbons	60-80
Nitrogen oxides	No change [c]

[a]: Ultra-fine and fine particles (diameter 10-500 nm)
[b]: Depends on sulfur level of fuel and duty cycle of engine
[c]: may increase the NO_2/NO ratio

SAMPLING METHODS

PM measurements were conducted on the exhaust flow of Engine # 1 (fitted with two Mine-X Sootfilters) and Engine # 3 (identical to Engine # 1 but not fitted with a soot-filter) to determine the removal efficiency of the two installed Mine-X Sootfilters. Samples were collected using a portable high-volume air sampler that was tightly fitted to a hollow metal pipe fastened to the condensate cleaning port of the engine stack (Figure 4). The engines were started and allowed to run for several minutes to reach stability, before being placed under an electrical demand load that ranged between 500 and 600 kW. This procedure was adopted to simulate real time operating conditions. Following the stabilization of the engines, pre-dried non-hygroscopic glass fiber filters were fitted on the portable high-volume air sampler to capture the PM particles having a diameter greater than 0.01 microns. Three sets of PM measurements were conducted between March 28 and April 7, 2003. Sampling was conducted over a period ranging between 1 and 15 minutes under the same exhaust flow rate for both engines (the exhaust flow was regulated via a valve that was used to connect the main chimney with the experimental setup). Note that, the internal pump of the high volume sampler was not used due to the high PM deposition rate encountered with Engine # 3 (not fitted with Mine-X Sootfilter) that impeded the flow in less than one minute thus limiting the significance of the sampling results. At the end of each sampling run, the filter was placed in a sealed plastic bag. The filters were then post-dried and weighed for particulate matter determination.



(a): The condensate cleaning ports that were used to withdraw flue gas

(b): The pipe fitted to the condensate cleaning port of Engine # 1 with a flow regulating valve

(c): The pipe terminal that was fastened to the high volume PM sampler

(d): The high volume PM sampler fitted to the pipe terminal

Figure 4. Experimental setup used to measure the mass of the deposited PM

SAMPLING RESULTS

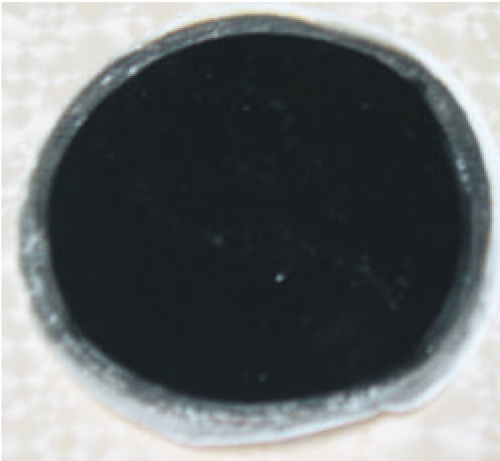
The results of the PM measurements conducted at the Beirut Movenpick Hotel are presented in Table 2. Note that, all PM measurements were conducted at the Environmental Engineering Research Center, American University of Beirut. Based on the results, the removal efficiency of the installed Mine-X Sootfilter was estimated at about 70 percent (Table 3). The Mine-X Sootfilters were also found to significantly reduce the intensity of the black color of the exhaust gases as depicted in Figure 5. Additional stack emissions were independently conducted by Overseas Consultants regarding the emission of CO, CO_2, NO, NO_2, and NOx (Table 4). The reported removal efficiencies appeared to be consistent with the manufacturer's specifications.

Table 2. Diesel particulate matter sampling results at the Beirut Movenpick Hotel

Sample number	*Mass of glass-fiber filter before sampling (g)*	*Mass of glass-fiber filter filter after sampling (g)*	*Sampling time (min)*	*Mass deposite (g/min)*
Engine without Mine-X Soot filter				
1	0.5629	0.5681	5	0.00104
2	0.5633	0.5709	7	0.00109
3	0.5533	0.5642	10	0.00109
Engine with Mine-X Soot filter				
4	0.5502	0.5505	1	0.00030
5	0.5628	0.5645	5	0.00034
6	0.5641	0.5673	10	0.00032
7	0.5638	0.5688	15	0.00033

Table 3. Estimated removal efficiency for the Movenpick installed Mine-X Sootfilter

Engine with Mine-X Sootfilter	*Engine without Mine-X Sootfilter*	*Removal efficiency (% by mass)*
Sample number	*Sample number*	
4	1	71
	2	72
	3	72
5	1	67
	2	69
	3	69
6	1	69
	2	71
	3	71
7	1	68
	2	69
	3	69
Average removal efficiency		**70**



(a) Filter paper after 5 minutes collected from Engine # 3 (with no soot-filter)

(a) Filter paper after 5 minutes collected from Engine # 1 (with soot-filter)

Figure 5. Flue gas color removal achieved by Mine-X Sootfilter

Table 4. Stack emissions measurements conducted by Overseas Consultants

Parameter	*Unit*	*Engine without Mine-X Sootfilter*	*Engine with Mine-X Sootfilter*	*Reduction efficiency (%)*
CO	ppm	473	107	77.4
CO_2	%	7.8	7.7	1.3
NO	ppm	964	934	3.1
NO_2	ppm	21	21	0.0
NO_x	ppm	985	955	3.0

LIMITATIONS AND CONCLUSION

While the test results showed an evident decrease in DPM levels after the installation of the Mine-X Sootfilters, several uncertainties are associated with the air sampling program (including sampling, handling, analytical methods, and sample size). The uncertainty was minimized by adopting the same sampling program (including the usage of similar sampling equipment, period, season, and time of day) for both Engine # 1 (with Mine-X Sootfilter) and Engine # 3 (without Mine-X Sootfilter) as well as repetitive sampling and analysis. The potential differences between the two sampled engines with respect to their combustion efficiencies can also be a possible source of uncertainty. Finally, it should be emphasized that emissions vary significantly in chemical composition and particle sizes among different engine types, engine operating conditions, fuel formulations, and age of emissions and as such can not be generalized (USEPA, 2002).

In conclusion, it can be stated within a reasonable degree of scientific certainty that based on the results of the testing program, the installed Mine-X Sootfilters have reduced the emission of DPM resulting from the operation of the Onan 800 kW diesel generator operating at the Beirut Movenpick Hotel by about 70 percent by mass. The achieved DPM removal efficiency is expected to increase with the improvement in the quality of the locally available diesel fuel when the sulfur content is reduced to match international standards.

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Appendix A

Diesel specifications as reported by the National Gazette on the 22nd of August 2002

Property	*Limits*	*Method*
Flash point Pensky Matens, °C	Min 55	ASTM D-93
Water and sediment by centrifuge, % vol	Max 0.05	ASTM D-2709
Cold filter plugging point, °C	Max -5 (Nov-March inclusive) Max 0 (April-October inclusive)	IP-309
Distillation temperature, at 760 mm Hg, recovered: at 250 °C, Vol % at 350 °C, Vol % at 370 °C, Vol %	 Max 65 Min 85 Min 95	ASTM D-86
Kinematic viscosity at 40 °C, cSt	Min 2.00 Max 4.50	ASTM D-445
Color	Orange	Visual
Ash % mass	Max 0.01	ASTM D-482
Sulfur % mass	Max 0.035	ASTM D-2622
Corrosion, copper strip (3hrs at 50 °C)	Max 1	ASTM D-130
Cetane number	Min 49	ASTM D-613
Cetane index	Min 46	ASTM D-976 or D-4737
Ramsbottom carbon residue (on 10 % residium), % wt	Max 0.3	ASTM D-524
Density at 15 °C, Kg/m^3	820-860	ASTM D-4052
Oxidation stability, g/m^3	Max 25	ASTM D-2274