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TESTS OF A PROTOTYPE VENTURI SCRUBBER SYSTEM

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SYNOPSIS

The performance of a prototype venturi water scrubbing system, treating the exhaust of a 150 kw diesel engine, was evaluated in a dynamometer laboratory and underground installed on a 5 m^3 load-haul-dump mining vehicle. Results of the dynamometer trials were in close agreement with the underground tests, demonstrating that a 65 to 75% reduction in soot levels, a 35% reduction in sulphur oxides and some removal of nitrogen dioxide can be achieved. Filtration of the captured soot from the contaminated scrubbing water was also shown to be feasible. With water recycling, therefore, water consumption can approach that of the best bath type scrubbers, while soot capture is at least doubled.

INTRODUCTION

Because conventional bath-type water-scrubbers had been found to have relatively modest emission control performance (Lawson and Vergeer 1977), a program to develop a more efficient scrubbing system was initiated by the Canada Centre for Mineral and Energy Technology (CANMET) of the Department of Energy, Mines and Resources Canada. The success of a laboratory prototype venturi scrubber designed to treat the exhaust of a 60 kw 5.6 litre diesel (Mogan et al 1983), prompted the decision to include this device in the spectrum of diesel emission control options which were to be tested under the umbrella of the "Three-government (United States Bureau of Mines, Ontario Ministry of Labour, and CANMET) Collaborative Program on Diesel Emissions Reduction Research and Development" (Dainty et al 1986). Accordingly, CANMET engaged a Canadian manufacturer of heavy underground diesel equipment to design and construct a system to treat the exhaust of a 136 kw air-cooled diesel, installed in a 5 m^3 load-haul-dump (LHD) mining vehicle (Branje 1981), the standard test vehicle of the Collaborative Research Program.

Since efficient exhaust scrubbing with the venturi required several times the quantity of water needed for exhaust cooling, the contractor was also asked to develop a water filtration system. The contaminated water could then be used to augment the fresh water supply carried on-board (Branje 1984). The scrubbing system, however, included two 400 litre water tanks, sufficient for reasonable underground trials without recycling, in case soot filtration did not prove feasible.

Some adjustments were made to the system during steady-state trials at CANMET's dynamometer facility. The unit was then forwarded to the Ontario Research Foundation (ORF) for performance testing with their computer-controlled dynamometer and dilution tunnel. Finally, the complete system was installed in the 5 m^3 LHD at Michigan Technological University's experimental mine to evaluate its impact on mine air quality.

THE SYSTEM

An electric-start LHD unit was selected by the contractor in order to create sufficient space within the engine-end skirts for two 400 litre water tanks. As the filtration system ultimately proved successful, this large on-board water supply was not needed. A single stainless-steel venturi, 50 cm long, was close-coupled to a smooth transition header which merged exhaust from both banks of the V-8 diesel. Seven litres per minute of clean water were supplied to the four water nozzles at the throat of the venturi by means of a 24 volt piston pump (electric pumps were selected for convenience; a hydraulic or air-driven pump could, of course, be used on a flame-proof machine). Water flow was cut off during engine idle by a transmission-pressure actuated switch. Contaminated water was separated from the exhaust in an impingement type mist eliminator. Scrubbed exhaust was discharged through a downward facing outlet, while contaminated water was withdrawn from the mist eliminator by a rubber-impeller self-priming 24 volt pump. The contaminated water was pumped into a 44 cm by 75 cm cylindrical fabric filter entirely contained in one fresh water tank. The venturi, one tank and the mist eliminator were located between the skirt and engine, Figure 1, with the second tank and pumps on the opposite side in a similar location.

CANMET TESTS

The CANMET tests were intended to establish that the system was operating properly. Thus, the complete assembly, including water tanks, recycle filter and pumps were connected to a 136 kw air cooled diesel in CANMET's dynamometer bay, in a configuration which was as close as possible to that required for mounting within the confines of a 5 m^3 LHD. Some difficulties were encountered measuring an accurate back-pressure with the close-coupled exhaust system

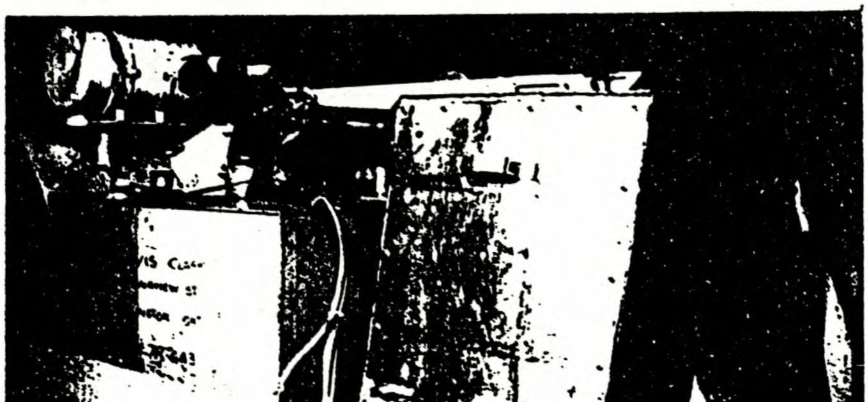

Figure 1: The venturi, mist eliminator and water tank installed in a 5 m^3 load-haul-dump vehicle

designed for the vehicle. The problem was finally solved by adding a length of straight pipe upstream from the venturi, Figure 2. As a consequence of the erroneous back-pressure measurements, the venturi throat was enlarged and then finally rebushed to almost its original diameter of 4.24 cm after accurate back pressure readings were obtained. The discontinuity resulting from the throat insert, however, raised the back-pressure to a level which was higher than necessary for the soot capture achieved.

The engine was operated at the maximum speed for which the venturi was designed, 2200 rpm, and 474 Newton meters for these steady-state CANMET tests. At this load/speed, the engine was quite efficient, generating merely 56 mg/m^3 of soot. The scrubber captured only 50% of this soot at a pressure-drop of 8.6 kilopascals (85 cm H_2O).

The soot filter appeared to function well during the test program, delivering clear water to the supply tank with a negligible increase in back-pressure. The soot cake seemed to be readily removed by back-flushing with the city water supply; insufficient soot was collected, however, to determine if the filtration was truly reversible. Tests showed that soot could also be filtered from the contaminated water with throw-away cartridge filters. Back-pressure measurements suggested that at least three cartridges would be needed per shift for a 5 m^3 LHD.

DILUTION TUNNEL PERFORMANCE TESTS

The venturi and mist eliminator were connected to a 150 kw air cooled diesel at the Ontario Research Foundation's emission test facility. Water was supplied to the venturi from the city mains, and contaminated water was discarded. The scrubbed exhaust was conveyed to the inlet of a 25.4 cm diameter double dilution tunnel, Figure 3.

The dilution tunnel was operated in single dilution mode for the tests, with a dilution ratio of 3.2:1. The computer controlled dynamometer cycled the engine through a program which mimicked the load and speed profile encountered when loading a heavy consolidated ore from an ore pass. This heavy cycle generated about 98 mg/m^3 of soot, containing about 38% dichloro-

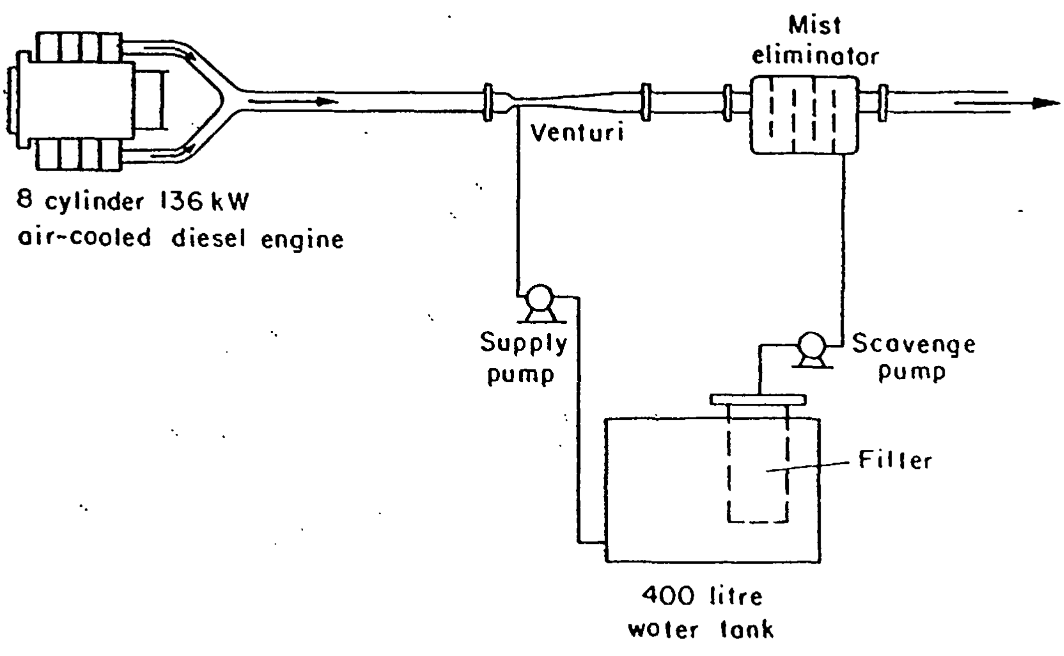

Figure 2: The CANMET test arrangement

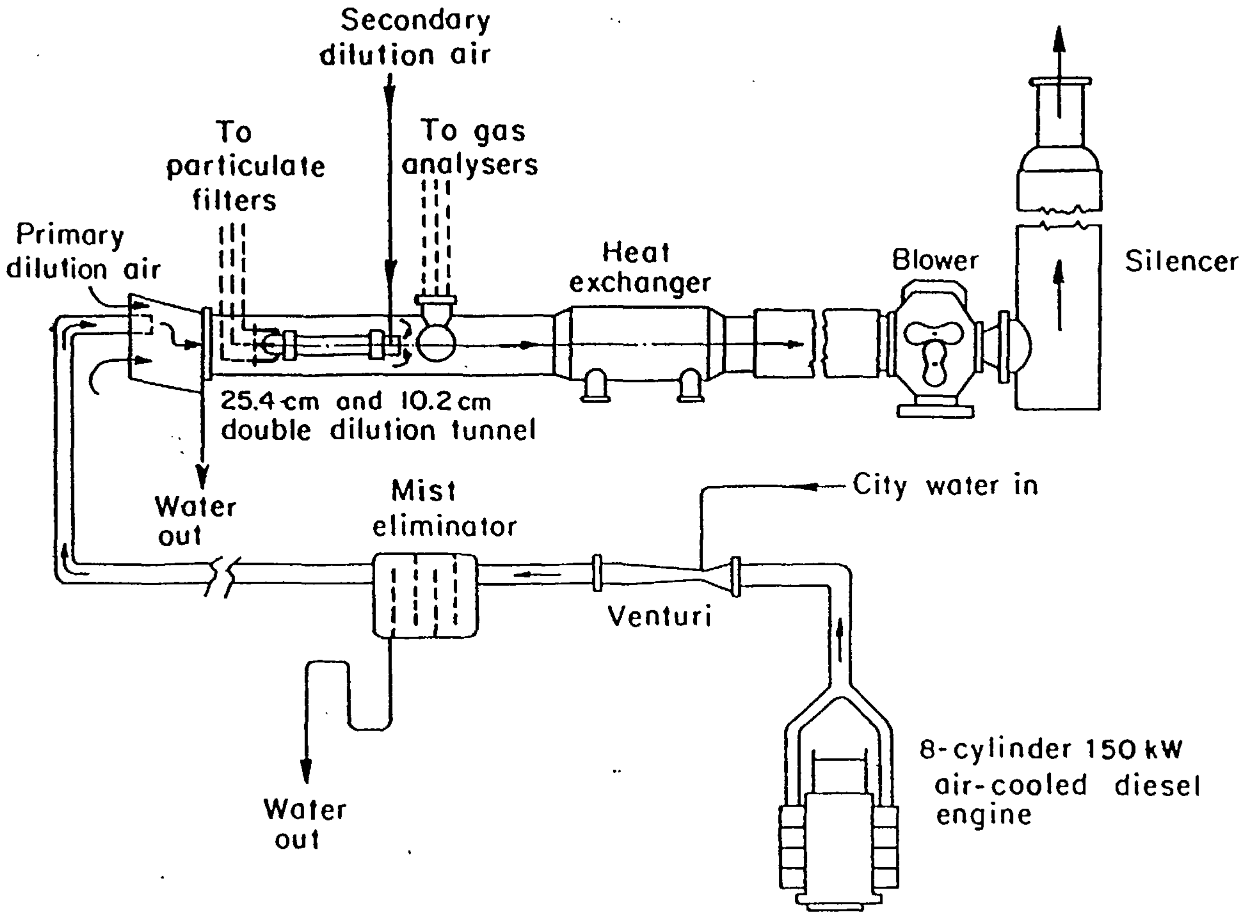

Figure 3: Test arrangement at the Ontario Research Foundation's diesel emissions facility

methane solubles. The test engine developed rated power at 2400 rpm rather than the 2200 rpm for which the venturi was sized. As a result, system back-pressure reached 11.5 kPa (117 cm H_2O), but this was in part attributable to the discontinuity in the throat.

Scrubber performance was determined from a comparison of contaminant levels in the scrubbed exhaust with those in the untreated (baseline) exhaust for the same heavy load cycle. The scrubber removed 73% of the soot (91% of the soluble fraction), 31% of the sulphur dioxide, 87% of the sulphates, 7% of the nitric oxide, and 20% of the volatile hydrocarbons (Ha et al 1985). Carbon monoxide levels were unchanged, and nitrogen dioxide increased by 57%; this latter could, however, have been a system artifact, due to nitric oxide oxidation in the long duct leading to the dilution tunnel.

MINE TRIALS

The complete scrubber system was installed on a 5 m^3 LHD vehicle at Michigan Technological University's experimental mine. For the air quality tests, the LHD moved ore from a muck pile at the end of an unventilated drift, 53 metres from the crosscut. The concentrations of diesel pollutants were measured at a fixed point 30 metres into the drift by laboratory instruments in a remote trailer, and by a portable analysis package mounted on the machine deck (Carlson et al 1986). There was some evidence of fog in the drift, Figure 4, which was not unexpected, as the tests were conducted in northern Michigan in late winter.

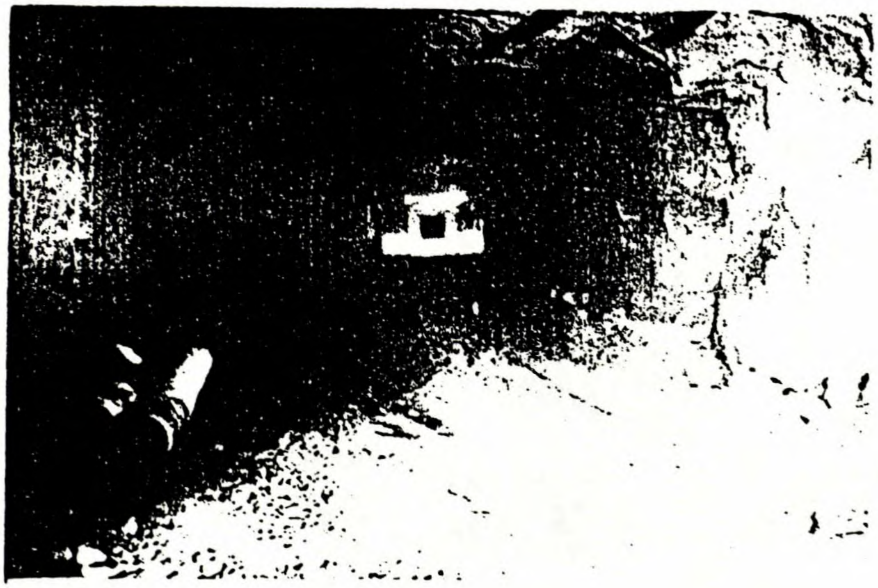

Figure 4: The scrubber equipped LHD in Michigan Technological University's underground laboratory

The LHD operator did not find the fog objectionable, however, and commented on the lack of odour and the overall impression that the air was quite clean.

The concentrations of diesel contaminants at the fixed point were two and one-half times those measured on-board (the LHD trammed partly in the ventilating air stream in the cross-cut, while the fixed point was part way up the unventilated heading so this was as expected). The reductions over uncontrolled levels were remarkedly similar for fixed point and on-board: soot - 66 and 67%, SO_2 - 35 and 35%, SO_4 - 90 and 91%, NO_2 - 41 and 43%, and NO - 36 and 35%, attesting to the reproducibility of the data. Carbon monoxide increased from 13 to 16.9 ppm at the fixed point, 4.1 to 7.6 ppm on-board, a probable consequence of increased back-pressure.

CONCLUSIONS

The underground performance of the venturi was very close to that measured in ORF's laboratory. Soot capture was slightly less underground (67 vs 73%); this is expected, since dynamometer modelling of the lighter underground cycle yielded less soot (88 vs 98 mg/m^3). Sulphur dioxide and SO_4 capture, 35 vs 31%, and 90 vs 87% were also quite similar. The apparent absorption of 42% of the nitrogen dioxide underground was consistent with, but twice the magnitude of some unpublished CANMET findings. This suggests that the 58% increase in NO_2 observed in the ORF study, could, indeed, have occurred in the line conveying the scrubbed gas to the dilution tunnel. The 35% decrease in nitric oxide in the mine, on the other hand, is inconsistent with ORF's 7% decrease and other scrubber work (Lawson and Vergeer 1977), and is thus likely an artifact.

Overall, the venturi scrubber has been shown, in both dynamometer and underground evaluations, to bring about a considerable reduction in diesel contaminants. In coal mining applications, the enhanced soot capture (double or triple current bath-type scrubbers) would contribute significantly to meeting coal dust standards (it is not possible, or perhaps desirable, to distinguish between coal dust and diesel soot contamination at present). In regions where only low grade diesel fuel is available, the venturi scrubber's capacity to remove soot as well as sulphur oxides could make it an attractive option for non-coal mines in which the attendant fogging does not create insurmountable problems.

Flameproofing a venturi scrubber package should not prove difficult: the scavenge pump and filter could be included in the flameproof package along with the manifold, exhaust pipe, venturi, and mist-eliminator. In-line flametraps in the supply and filtered water lines can isolate the largest component, the water tank, from the flameproof system. In those jurisdictions requiring an exhaust flametrap, the removal of most of the soluble fraction from the remaining soot could result in a significantly less onerous trap cleaning requirement.

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APPENDIX

Baseline and scrubbed exhaust contaminant levels for the heavy LHD cycle at Ontario Research Foundation's emission test facility.

Component	Baseline	Scrubbed exhaust
CO_2	6.5%	6.5%
Soot	98 mg/m^3	26 mg/m^3
NO	578 ppm	523 ppm
NO_2	25 ppm	39 ppm
SO_2	89 ppm	62 ppm
SO_4	0.30 mg/m^3	0.04 mg/m^3
CO	199 ppm	194 ppm
HC	191 ppm	154 ppm

Baseline and scrubbed exhaust contaminant levels for fixed point and on-board mine air samples from Michigan Technological University's experimental mine.

	Fixed Point		Onboard	
Component	Baseline	Scrubbed exhaust	Baseline	Scrubbed exhaust
CO_2*	0.31%	0.34%	0.12%	0.16%
Soot	5.82 mg/m^3	2.15 mg/m^3	2.83 mg/m^3	1.17 mg/m^3
NO	18.4 ppm	12.9 ppm	9.2 ppm	7.4 ppm
NO_2	3.8 ppm	2.5 ppm	2.1 ppm	1.5 ppm
SO_2	4.7 ppm	3.4 ppm	1.9 ppm	1.5 ppm
SO_4	0.45 mg/m^3	0.05 mg/m^3	0.18 mg/m^3	0.02 mg/m^3
CO	13.0 ppm	16.9 ppm	4.1 ppm	7.6 ppm

*minus background