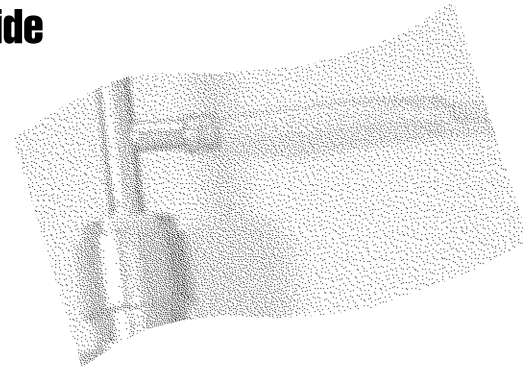
# Measurement of Carbon Monoxide in Diesel Engine Exhaust

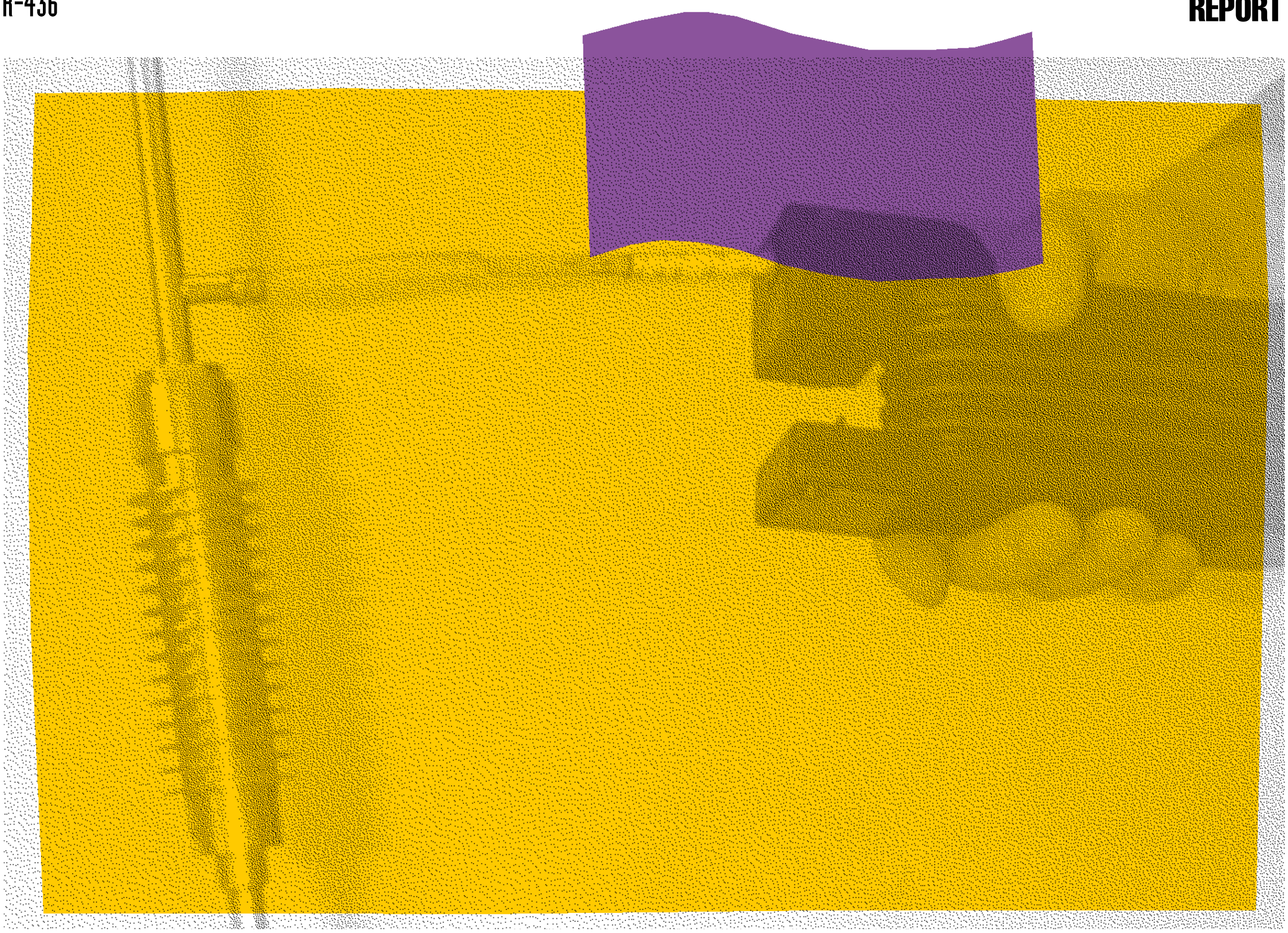


STUDIES AND RESEARCH PROJECTS

Michel Grenier

R-436

REPORT



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# Measurement of Carbon Monoxide in Diesel Engine Exhaust

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REPORT

Michel Grenier,
CANMET Mining and Mineral Sciences Laboratories



This study was financed by the IRSST. The conclusions and recommendations are those of the author.

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## EXECUTIVE SUMMARY

The measurement of carbon monoxide concentrations in the exhaust of diesel engines allows the identification of engines needing maintenance. Selecting the right instruments and the protocol to be followed is very important. The objectives of the work presented in this report are the selection and evaluation of the measuring instruments, as well as the selection of the protocol to be followed. The work related to the evaluation of the measuring instruments was carried out in the laboratory and underground, in order to identify the factors that could affect the measurement protocol.

The results demonstrate that colorimetric tubes can be used to measure carbon monoxide (CO) directly in the exhaust. Constraints related to the expected concentration range (100 – 1,000 ppm) and to health and safety are such that some of the colorimetric tube systems appear to be more advantageous than others. CO measurements can also be made with direct-reading instruments, but it is important to ensure that the technical personnel are well-trained and that the instruments are calibrated and maintained on a regular basis.

The protocol to be followed to measure CO is described in detail in this report. One of the most important questions at the protocol level is the operating parameters (speed and torque) of the engine during the test. Most countries where such measurements are made require that the engine be operated under dynamic load while the sample is being collected. This operating condition is the one that is most likely to reveal problems at the engine level. However, this raises several questions concerning the health and safety of operators and technicians. Moreover, the impact of this kind of test on the vehicle power train is unknown.

The results of this study show that, in theory, the use of colorimetric tubes based on a measurement protocol, where the engine is maintained under dynamic pressure, would be ideal. However, some questions remain regarding the health and safety of the sampling personnel and potential damage to the vehicles that are being tested.

Consequently, the use of a measurement protocol without dynamic load is recommended in this report. The choice of colorimetric tubes or continuous-reading electronic instruments is left to the discretion of mining operators. The protocol is described in detail in this report.

## FOREWORD

Within the scope of the application of the Regulation respecting occupational health and safety in mines, the Commission de la santé et de la sécurité du travail (CSST) Standing Review Committee for this Regulation requested from the IRSST the development of a carbon monoxide measurement protocol in the exhaust gas of diesel vehicles. This protocol must take into account the actual situation in the mines with regard to the profile of the fleet presently in operation. It must therefore be a tool that the mining industry can use immediately. The mandate for the development of this protocol was given to CANMET-MMSL.

## INTRODUCTION

The extraction of mining deposits is largely dependent upon the efficient use of diesel-powered vehicles. It is a known fact that diesel exhaust represents a health risk (1). Therefore, diesel engines must be maintained at regular intervals. The importance of maintenance with respect to engine performance is well known and the majority of Quebec mines carry out maintenance on production engines in accordance with a fixed schedule. Moreover, it is presently recognized that engines, which are not well maintained, can be an important source of contamination. Laboratory tests have shown increases of the order of 300% to 1,000% in diesel particulate matter (DPM) and exhaust gas concentrations due to poorly maintained engines (2).

New regulations are presently being developed to limit the exposure of workers to DPM from diesel engines. The direct impact of poor maintenance practices was observed in the concentrations of DPM (3). Unfortunately, there is no simple and accurate method for the measurement of DPM directly in the exhaust. However, carbon monoxide is a good substitute because it is much easier to measure in the exhaust. CO is also a good indicator of the maintenance condition of an engine. In fact, maintenance problems, which have a negative impact on CO levels, are also responsible for the increase in DPM (2).

There are many ways of measuring the concentration of carbon monoxide in the exhaust. This gas can be measured with direct-reading instruments or even with colorimetric tubes.

Direct-reading instruments are expensive ($2,000 - $15,000), delicate and must be calibrated at regular intervals. However, the accuracy (closeness of the measurement to the true value) and the precision (level of variability of repeated measurements) of these instruments, when they are properly calibrated, are by far superior to those of colorimetric tubes. On the other hand, colorimetric tubes are less expensive and, although they are not as effective as far as precision and accuracy are concerned, they do not require any calibration.

This report provides a summary of the research results directed at developing and evaluating a simple and efficient method for the measurement of CO in the exhaust of diesel vehicles in a mining environment.

## OBJECTIVES

The objectives of this research project were:

1. Selection of a simple approach for the sampling of CO in the exhaust. Although direct-reading instruments are more accurate than colorimetric tubes, the latter are less delicate, do not require any calibration and, therefore, may be better suited for use in a mining environment.

2. Selection and evaluation of two measurement systems with colorimetric tubes. The Dräger and Gastec systems were evaluated in three phases. The initial phase consisted in evaluating the measurement of various concentrations of CO diluted with pure nitrogen, using both systems. In this case, it was a matter of ensuring that the performance of both systems would meet the standards described in their respective technical documentation.

   The second phase was similar to the first one, except that the measurement of CO was made in the exhaust of a diesel engine, by using an in-laboratory test bench. As in the first phase, in addition to the precision and accuracy criteria, the target was to evaluate the impact of the exhaust heat and of the gases that could cause some interference during the measurement of CO.

   The third and final research phase consisted in evaluating the equipment and the method in a mining environment in order to highlight any problem related to their use in a mining environment, whether it be at the method, equipment or underground environment level.

3. Development of a measurement protocol that can be used immediately by the mining industry.

## EQUIPMENT AND MATERIAL

<u>Colorimetric tubes</u>

The colorimetric tubes are sealed glass ampules of approximately 12 centimetres in length and 0.5 cm in diameter. They contain chemical reagents that change colour in the presence of the target gas, in this case CO. Although this type of instrument is generally used for measurements in ambient air, it can also be used for measurements in the exhaust (4). The tubes manufactured by Dräger (5) and Gastec (6) have been selected for evaluation purposes. The characteristics of these two systems are summarized in Table 1. These data show that the two systems are quite similar.

Photographs of the Gastec and Dräger systems are presented in Figures 1 and 2, respectively. All figures and graphics are displayed in the Appendix. The Gastec system, including the pump, a high-temperature gas-sampling probe and a box of 10 tubes, costs approximately $420.00. The comparable Dräger instruments cost approximately $750.00. Although the Gastec probe is longer and more effective than the smaller Dräger probe, neither of them is really adequate for the sampling of CO in the exhaust of vehicles. It is therefore recommended to use the specialized Dräger probe that is shown in Figure 3. It costs approximately $650.00, but it allows samples to be collected without accidentally pressurizing the pump. This is due to the fact that the sampling port is perpendicular to an overflow exhaust gas outlet.

| Parameter | Gastec | Dräger |
|---|---|---|
| Concentration range / 1 stroke (ppm) | 25 – 1,000 | 100 – 3,000 |
| Sampling time / 1 stroke | 1 minute | 20 seconds |
| Change in colour | Yellow to dark brown | White to brown/green |
| Accuracy * | 25% | 10 - 15% ** |
| Temperature (ºC) | 0 - 40ºC | 0 - 50ºC |
| Interferences | None | None *** |

* According to the manufacturer

** Standard deviation – precision measurement

*** Discussions with the manufacturer – application in the diesel exhaust only

Table 1. Characteristics of the Gastec and Dräger colorimetric tubes

<u>Additional equipment</u>

The Brüel & Kjær (B&K) analyzer, model 1302 (Figure 4) was used to evaluate the performance of both of the colorimetric tube sampling systems. This instrument operates according to photo-acoustic principles. It was calibrated beforehand and has an accuracy of 5% on a scale from 0 to 2,000 ppm, which is equivalent to ± 100 ppm in the range used.

The evaluation of the colorimetric tube systems was done in a laboratory during the first phase, in an artificial atmosphere produced using commercially available cylinders of nitrogen and carbon monoxide. The concentration of CO from Praxair is certified at 3050 ppm ± 0.006%. The nitrogen, which was used to dilute the CO, is manufactured by Matheson and certified at 99.998%. The gas mixtures were collected by means of laminated sampling bags.

## METHOD – PERFORMANCE OF COLORIMETRIC TUBES

### Phase 1 – Laboratory measurement, CO mixed with nitrogen

During the first phase, the measurement of CO in a mixture of nitrogen was performed using the Dräger and Gastec systems. The CO was diluted with nitrogen in order to obtain mixtures in a concentration range between 100 and 3,000 ppm of CO. The device is presented in Figure 5. The gas mixture was collected in a sampling bag and, for each concentration, two samples were collected by means of colorimetric tubes from each manufacturer. Three technicians then proceeded to read each tube in a dark room with a mine lamp in order to simulate the reading in an underground environment. Each mixture was also analyzed with the B&K instrument (Figure 6).

### Phase 2 – Laboratory measurement, CO in the diesel exhaust

During the second phase, the CO was measured in the exhaust of a diesel engine on a test bench. This equipment (dynamometer system) is also used for the certification of mining engines. It allows the diesel engine to be operated at different levels of speed and torque in order to produce various conditions of exhaust compositions and temperature profiles.

In addition to the precision and accuracy criteria measured in the first phase, the objective here also included the evaluation of the impact of exhaust heat and of other exhaust gases that could cause some interference during the measurement of CO. To do so, a sampling port was installed, as shown in Figure 7. A sample can be collected through this port with the colorimetric tubes directly in the exhaust and it is also possible to collect a sample in a laminated bag to make another measurement with colorimetric tubes at room temperature. As in phase 1, the B&K analyzer was used to measure the concentration in each bag in order to compare with the reading made with the tubes.

Phase 3 – Measurement in a mining environment, CO in the diesel exhaust

The third and final research phase consisted in evaluating the equipment and the method in an underground mining environment. In this case, different types of vehicles in the hauling/production categories, together with service and maintenance vehicles were targeted. This part of the research project has allowed, among other things, to determine the concentration ranges of CO in relation to the type of vehicle and engine speed. The problems related to sampling in a mining environment were also identified.

## RESULTS – PERFORMANCE OF COLORIMETRIC TUBES

Phase 1 – Measurement of CO mixed with nitrogen

The results of the evaluation are summarized in Table 2 and in the graphics of Figures 8 and 9. The values in question were calculated, based on the readings of two tubes by three technicians. The average of those readings will be compared with the results of the B&K analyzer to evaluate their accuracy, while the calculated standard deviation, based on the readings of a single tube by three technicians, will be used to establish a precision measurement.

On average, there is a difference of 17.6% between the B&K analyzer and the readings with the Dräger system. As for the Gastec system, it shows a difference of 13.8%. The standard deviation also confers a slight advantage to the Gastec system, with a value of 10.2% for the Dräger system and of 6.0% for the Gastec system. According to the technicians, the reading of the Gastec tube is easier in view of the length and clarity of the scale.

The graphic in Figure 8 shows the linear relationship between the results obtained with the Dräger tubes and the B&K analyzer. In this graphic, a slight break in the data can be observed between the results obtained on the 300 ppm scale (10 strokes) and the 3,000 ppm scale (1 stroke). In a more rigorous analysis, it would perhaps have been necessary to examine the linear relationship in two segments, one for each measurement scale. The correlation coefficient ($R^2 = 0.98$) shows a high level of linearity between the B&K and Dräger results. The high value of the y-intercept (-206) is caused, in part, by the break in continuity between the low and the high measurement scale.

| Characteristics | Dräger | Gastec |
| --- | --- | --- |
| Measurement zone (1 stroke) | 100 – 3,000 ppm | 25 – 1,000 ppm |
| Standard deviation * (Phase 1, pure CO) | 10.2% | 6.0% |
| % Difference ** (Phase 1, pure CO) | 17.6% | 13.8% |
| % Difference ** (Phase 2, CO/diesel) | 11.4% underestimated | 22.6% overestimated |
| $NO_2$ interference | None | None |
| $SO_2$ interference | None | None (< 10% of the CO concentration) |
| Temperature effect < 100ºC | Not noticeable | Not noticeable |

* Mean standard deviation calculated based on readings by at least three technicians

** Mean difference (%) between the B&K analyzer and the colorimetric tubes

Table 2. Performance of the Dräger and Gastec colorimetric tubes during the laboratory testing phases (Phases 1 and 2)

The graphic in Figure 9 provides the results with the Gastec system. These results also show a high level of linear relationship. A value of -41 ppm can also be observed on the y-intercept, which seems to show a better transition between the two measurement scales, i.e. at 1,000 ppm.

Phase 2 – Laboratory measurement of CO in the diesel exhaust

The results of the work carried out on a test bench in the diesel exhaust are summarized in Table 3, as well as in Figures 10 and 11. After discussions with the manufacturers, it would appear that the other gases, such as $NO_2$ or $SO_2$, should not cause any interference during the measurement of CO in the diesel exhaust. According to the Dräger manufacturer, the measurement of CO in the diesel exhaust should be done without any problem as long as the temperature is less than 50ºC. Based on the test bench results, there does not seem to be any relationship between the presence of $SO_2$ or $NO_2$ and the performance of the Dräger system (Table 3).

The information provided by the Gastec manufacturer states that the presence of $NO_2$ should not affect the accuracy of the CO measurement. However, the presence of $SO_2$ in concentrations of

10% or more of the CO concentration could cause an overestimation. The $SO_2$ values measured in the exhaust were less than 11 ppm, which is well below 10% of the assumed value of CO (Table 3).

The results in Table 2 show that the Dräger system has a superior performance to that of the Gastec system in the diesel exhaust. The Gastec system overestimates by 22.6%, whereas the Dräger system underestimates by 11.4%. This is not necessarily a serious problem, depending on the approach that will be selected to evaluate the maintenance condition of the engines.

Figures 10 and 11 show once more a good linear relationship between the values measured with the colorimetric tubes and the B&K analyzer. Two graphics are presented in these Figures, one with results derived from samples collected directly in the exhaust (temperatures ranging between 27ºC and 90ºC) and another with results derived from samples collected in a laminated sampling bag, at room temperature. For both systems, i.e. Gastec and Dräger, the graphical data seem to indicate that temperatures below 100ºC do not appear to affect CO sampling.

| % Difference – comparison with the B&K analyzer | | Temperature (ºC) | $NO_2$ (ppm) | $SO_2$ (ppm) |
|---|---|---|---|---|
| Dräger | Gastec | | | |
| 17 | -26 | -- | 35 | 10.5 |
| 18 | -29 | -- | 70 | 7.9 |
| 5 | -28 | 65 | 19 | 10.9 |
| 0 | -29 | 46 | 100 | 10.9 |
| -12 | 4 | -- | 56 | 7.5 |
| 14 | -19 | 27 | 71 | 1 |
| -11 | -25 | 90 | -- | -- |

Table 3. Observations, effects of $SO_2$, $NO_2$ and the temperature

Phase 3 – Evaluation in a mining environment

The results of the measurements in a mining environment are summarized in Table 4. Samples were taken from four vehicles: a Kubota tractor (vehicle #688) that is used to transport the engineers, a scooptram (production vehicle #339), a personnel carrier (vehicle #649) and a truck that is used for ore transportation (production vehicle #414). In all cases, these vehicles were tested at two different operating speeds, one at reduced speed and the other at approximately 3/4 of the maximum operating speed, without loading the engine. As for the scooptram, a measurement was also made by loading the engine at high rpm by means of the hydraulic system (by forcing the bucket). For each test, the exhaust temperature was stabilized before taking any reading. The CO measurement was made ahead of any treatment device through Swagelok Quick-Connect sampling ports. The sample was collected by means of a high-temperature Dräger probe. This probe allows to cool down the exhaust gases and also to collect samples through a 90° opening in relation to the gas movement axis, thereby preventing the accidental pressurization of the sampling system (Figure 3).

| **Vehicle** | **Speed** | **Gastec** | **Dräger** | **B&K** |
|---|---|---|---|---|
| | | CO concentration, ppm | | |
| Kubota tractor #688 | Reduced speed/without load | 212 | 167 | --- |
| | 3/4 operating speed/without load | 408 | 442 | --- |
| Scooptram #339 | Reduced speed/without load | 210 | 191 | --- |
| | 3/4 operating speed/without load | 456 | 333 | 315 |
| | 3/4 operating speed/dynamic load | 200 | 127 | --- |
| Carrier #649 | Reduced speed/without load | 325 | 273 | 208 |
| | 3/4 operating speed/without load | 312 | 197 | --- |
| Truck #414 | Reduced speed/without load | 208 | 138 | --- |
| | 3/4 operating speed/without load | 167 | 100 | 96 |

Table 4. Performance of colorimetric tubes – exhaust in a mining environment

The results in Table 4 show that, in the first place, all the collected samples are well below the 750 ppm value, which is under discussion for production vehicles. This is true of both the values measured with colorimetric tubes and the B&K analyzer. The highest measured value is 456 ppm for the scooptram operating without load, at high speed, as measured by the Gastec system. These observations suggest that the recommended values of 750 ppm and 900 ppm for production and service vehicles, respectively, are definitely in the range of values that can be encountered in practice.

The results also support the observations made in the laboratory on a test bench, to the effect that the Dräger system is more accurate than the Gastec system with respect to sampling in the diesel exhaust. This is noticeable when observing three cases where a sample was collected in a laminated bag and measured with the B&K analyzer, for comparison purposes. The readings with the Dräger system range between 4% and 31%. This range is between 45% and 74% for the Gastec system. The reasons that could explain those differences are not known at this time.

Another observation seems to indicate that the measurements at high speed, without load, appear to double the CO concentration for vehicles #688 and #339, compared to the measurements made at reduced engine speed. As to the other two vehicles, it appears that concentrations are more or less the same, regardless of the operating mode.

## DISCUSSION

Colorimetric tubes vs. continuous-reading instruments

It is generally recognized that continuous-reading instruments are usually superior to colorimetric tubes (2,3,7). This is true, provided that the continuous reading instruments are rigorously and regularly maintained and calibrated. In view of the fact that some of these instruments are complex and fragile, it is preferable that the tests be performed by trained mechanics or technicians in a maintenance shop.

If all those conditions cannot be met, it is preferable to use colorimetric tubes. The results have also shown that colorimetric tubes have an accuracy that can be as high as 74% when used in the diesel exhaust. If the measured concentrations are close to the values targeted by the regulations, it is recommended to collect more than one sample in the exhaust of the diesel vehicle.

Colorimetric tubes also have certain advantages, given that they are ready for use and do not require any calibration. A minimum of training is required and they are generally easy to use in the field as well as in the workshop.

To encourage mines that already use more sophisticated instruments, operators should also be allowed to carry out evaluation tests in the exhaust with direct-reading instruments. However, it is recommended that mines, which choose to use these instruments, prove that the technicians have been adequately trained, that the instruments are regularly maintained and calibrated, and that records to that effect are kept on file. Furthermore, it is also recommended that these instruments, which are often fragile and more or less portable, be kept in the workshop and that the analysis be performed at that location.

Selecting the colorimetric tube system

The selection of the colorimetric tube system will depend upon the accuracy and the precision of the instrumentation, as well as the restrictions at the sampling protocol level and the expected concentration ranges. On the accuracy level, the Dräger system seems to be superior to the Gastec system, especially as far as the measurement in the diesel exhaust is concerned. However, the specific application favors the Gastec system, for two reasons:

1. the measurement scale for 1 stroke (100 ml) for the Gastec system covers concentrations from 25 to 1,000 ppm, which is the expected concentration range for the present application. As for the Dräger system, it cuts this concentration range in half at 300 ppm. The lack of linearity at that critical point could cause problems.

2. the sampling time must be minimized, firstly, for health and safety reasons for the personnel collecting the sample. Moreover, the measurement must be made while the engine is hot and running at high speed; although this is not harmful for the engine over short periods of time, it is not recommended to let it run needlessly under those conditions. If the Dräger tubes are used and the 300 ppm scale is necessary as a result of the low CO concentrations (see the data for truck #414), the sampling time could take 4 minutes in view of the fact that the sampling will require 10 pump strokes. The Gastec system can make the measurement in 1 stroke of less than 45 seconds.

Nevertheless, the use of the larger Dräger cooling probe is recommended in view of the fact that it is more solid and should be able to cool down the exhaust gases more easily. The Dräger probe should be modified in order to add a Swagelok Quick-Connect adaptor. It should be possible to fasten it to another Swagelok connector that will be permanently installed on the exhaust pipe of the vehicle, as described below. It will have to be a type of connector that shuts automatically when it is disconnected.

Measurement protocol

All experts agree that the best way of checking the integrity of a diesel engine is to perform the test while the engine is under dynamic load, i.e. by loading the engine by means of the torque converter (2,7,8). This is possible only if the targeted vehicles are equipped with torque converters and automatic transmissions. Such a protocol cannot easily be used on vehicles equipped with standard or manual transmissions.

Moreover, testing the engine under dynamic load, as described above, is not done routinely in Canada. It was important to obtain the opinion of experts regarding the safety aspects of the procedure. Consequently, the Pennsylvania method (dynamic load) was reviewed by experts from the Ontario Ministry of Labour. The opinion of the Ministry representatives is summarized in the Appendix.

Some concerns were brought up with regard to the dynamic load of the engine, both for the health and safety of the sampling personnel, as well as for engine protection.

Because of those concerns, the tests under dynamic load are not recommended at this time. Moreover, until the risks of damages to vehicles are evaluated, it would be preferable to carry out the tests at high speed, without load. It will thus be possible for the mining industry to immediately apply this measurement protocol while the research along that line continues.

The CO measurement tests must be performed ahead of any treatment device, but as far downstream as possible to allow the exhaust gas to cool down. The sampling personnel must be afforded a safe and comfortable access to the sampling port. The measurement protocol is as follows:

1. Check the integrity of the Gastec/Dräger pump by inserting a new (unopened) tube. Then, activate the pump and ensure that it remains under pressure for at least 10 minutes. This can be done at the beginning of the work shift and it allows to verify that the sampling pump bellows is not damaged or otherwise leaking.

2. Before sampling begins, the operator and the technician must wear the required personal protective equipment, i.e. gloves (for heat protection), safety glasses and respiratory protection (for DPM).

3. The vehicle must be parked in a well-ventilated area, the emergency brakes must be engaged and wheel chock blocks must be used. It is necessary to ensure that the transmission remains securely in neutral position throughout the test.

4. Fasten the cooling probe to the Swagelok sampling port on the exhaust pipe.

5. If the engine is cold, let it run slowly for 1 minute.

6. Gently press on the accelerator for 2 minutes so as to slightly increase the engine speed.

7. Prepare the sampling equipment so as not to let the engine run needlessly.

8. When the sampling equipment is ready, ask the operator to press on the accelerator to maintain the speed at three quarters of the maximum rpm of the engine.

9. Connect the sampling equipment and collect the sample. During the test, if the operator believes that there is a risk to the health/safety of the workers or that damage may be caused to the vehicle, he must release the accelerator, let the power train components cool down and consult a mechanic, as required.

10. When the sampling is terminated, the accelerator must be released. It is advisable to let the power train components cool down before returning to normal activities. If the measured CO value is close to the value targeted by the regulations, the test must be repeated.

This procedure is a combination of steps suggested in various protocols (2,4,7). However, it has not been tested rigorously by the author of this report and should be tested in a mining environment in order to answer any other questions raised with regard to health and safety.

CO measurements in the exhaust should be made at regular intervals and after every regular engine maintenance. This will ensure that the maintenance work has actually improved engine performance.

## Regulations

Table 5 provides a summary of the national and international regulations of various jurisdictions where CO tests are made in the exhaust. In all cases, except for Ontario, it is recommended that tests be performed while the engine is running at full speed and under dynamic load. In Pennsylvania, it is recommended to carry out the maintenance when the CO base value doubles.

| Country/Province | Acceptable CO concentration in the exhaust |
|---|---|
| Ontario | 1,500 ppm, engine at 3/4 operating speed, without dynamic load |
| Pennsylvania | 2X the baseline concentration, dynamic load of the engine |
| Australia | 1,500 ppm, dynamic load of the engine |
| MSHA | 2,500 ppm, dynamic load of the engine |

Table 5. Regulations respecting CO concentrations in the exhaust

## CONCLUSIONS

Although there is no general consensus about the use of colorimetric tubes for the measurement of CO in the exhaust, they are presumably adequate for the present application, which is not the case for the measurement protocol itself. It is recommended, for the time being, to perform the tests without dynamic load, while keeping in mind that they are less likely to detect the presence of problems at the maintenance level. Additional research should be carried out in a mining environment in order to evaluate the health-related problems (emissions) and safety-related problems (heat and immobilization of the vehicle), as well as the risks of engine and/or vehicle breakdown or damages during the tests performed under dynamic load.

In order to allow the immediate application of this procedure in a mining environment, the protocol without load, as described above, is recommended. The choice of colorimetric tubes or direct-reading electronic instruments is left to the discretion of mining operators.

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**APPENDIX**

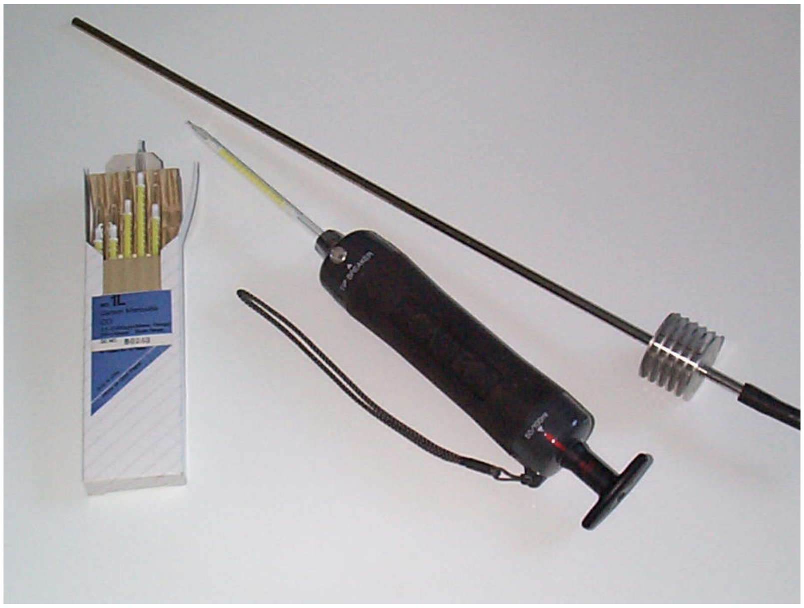

Figure 1.  Gastec sampling system, carbon monoxide measurement

Figure 2.  Dräger sampling system, carbon monoxide measurement

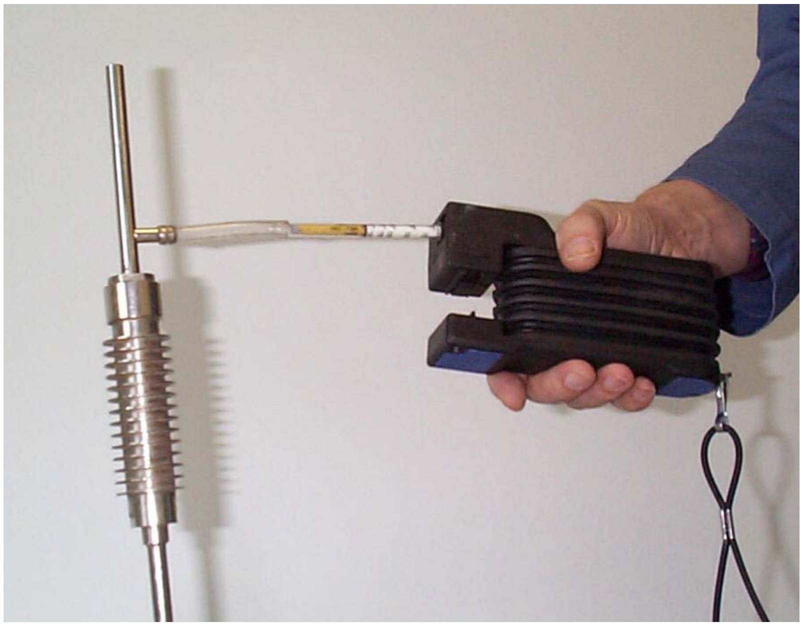

Figure 3.  Dräger sampling probe for high-temperature application


Figure 4.  B&K photo-acoustic gas sampler (model 1302)

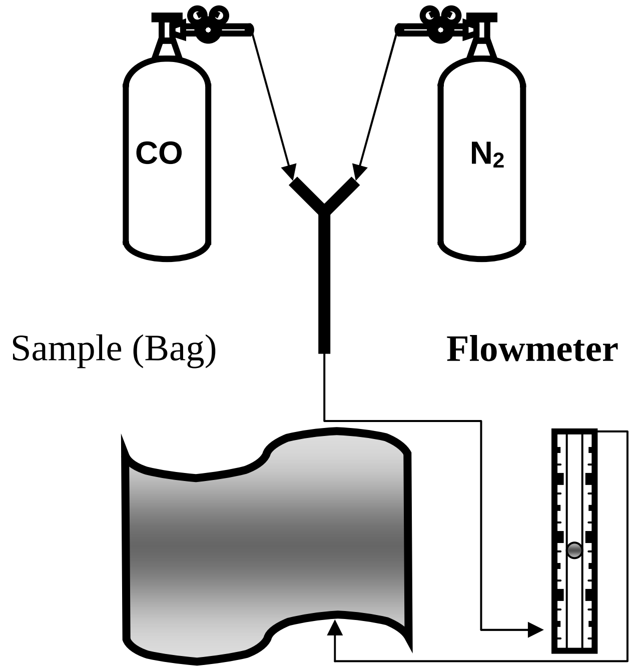


Figure 5. Preparation of $CO/N_2$ gas mixture

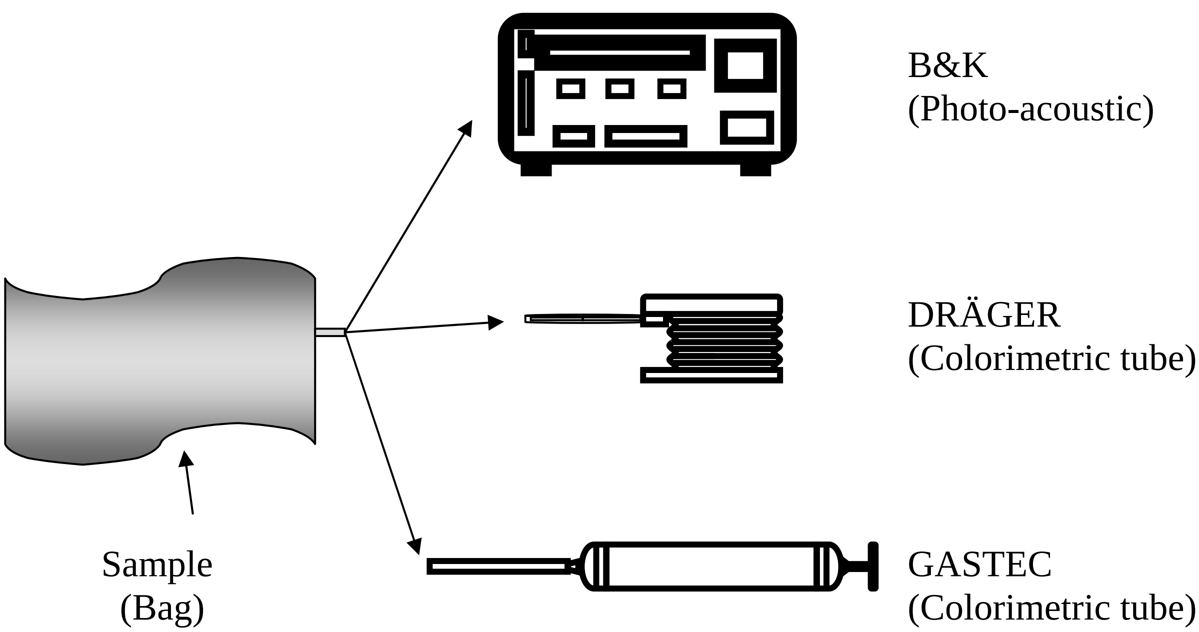


Figure 6. Carbon monoxide sample collected in a bag

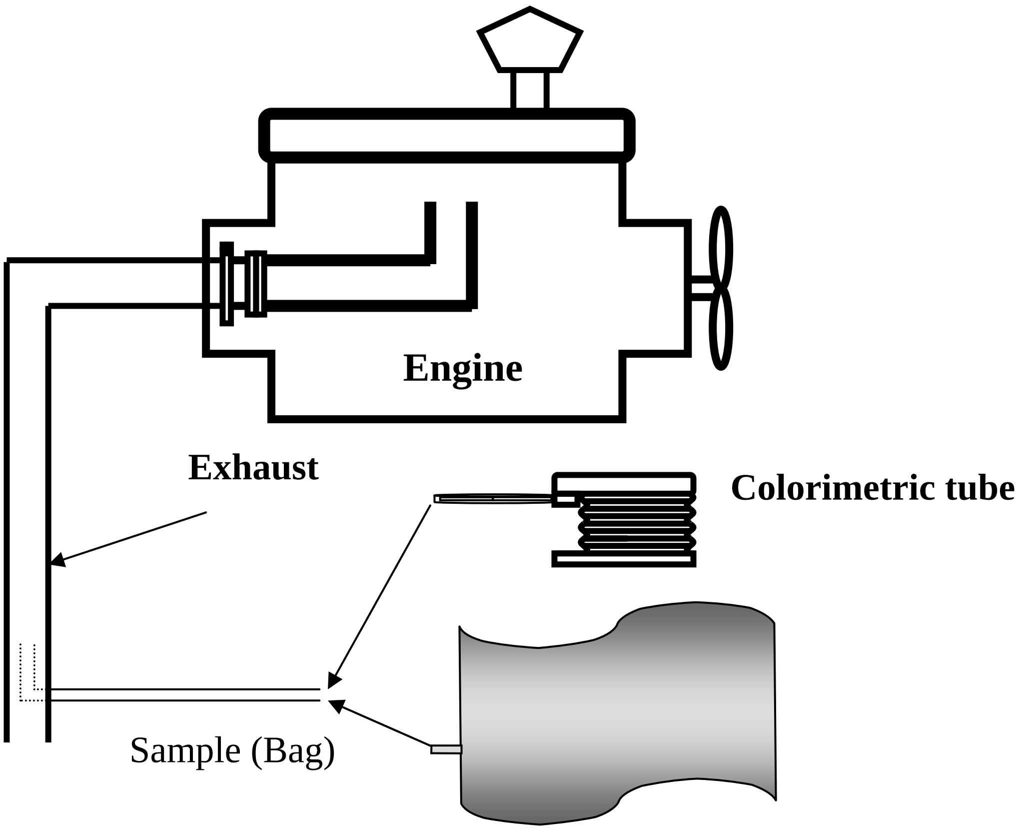


Figure 7.  Evaluation instrumentation on a diesel test bench

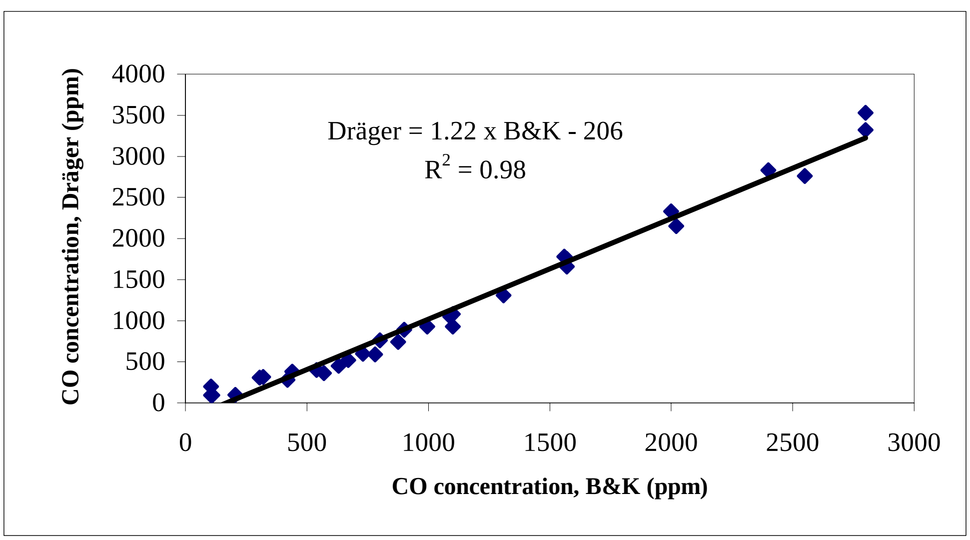


Figure 8.  Comparison Dräger vs. B&K – $CO/N_2$ mixture

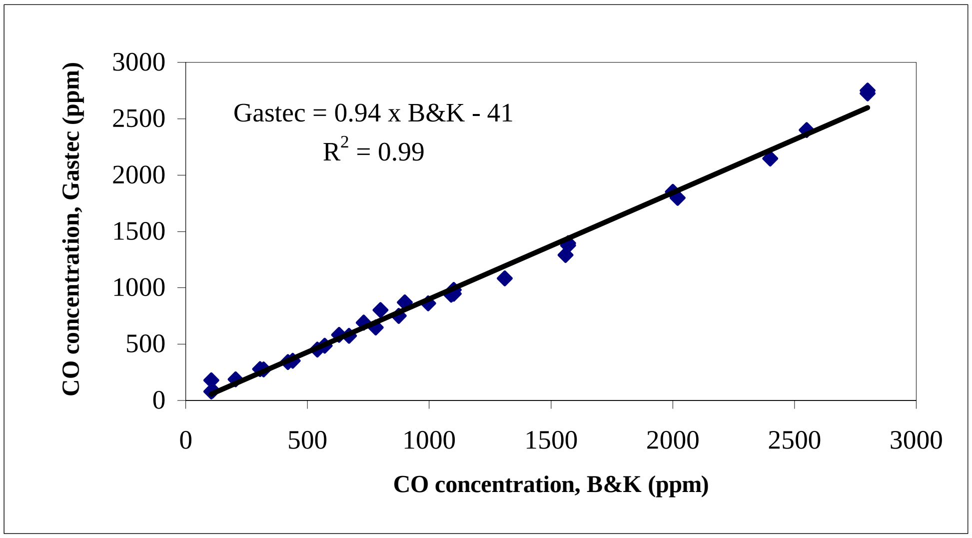


Figure 9. Comparison Gastec vs. B&K – $CO/N_2$ mixture

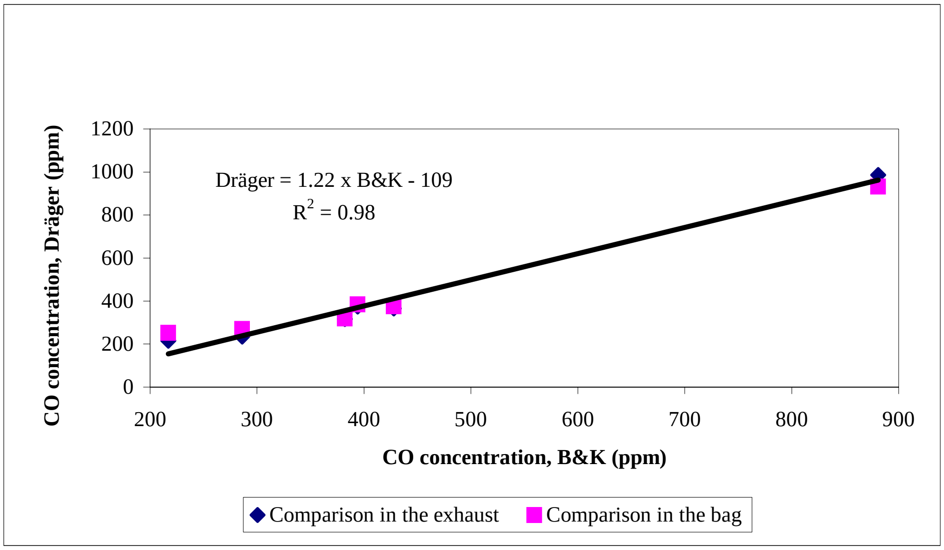


Figure 10. Comparison Dräger vs. B&K – Diesel test bench

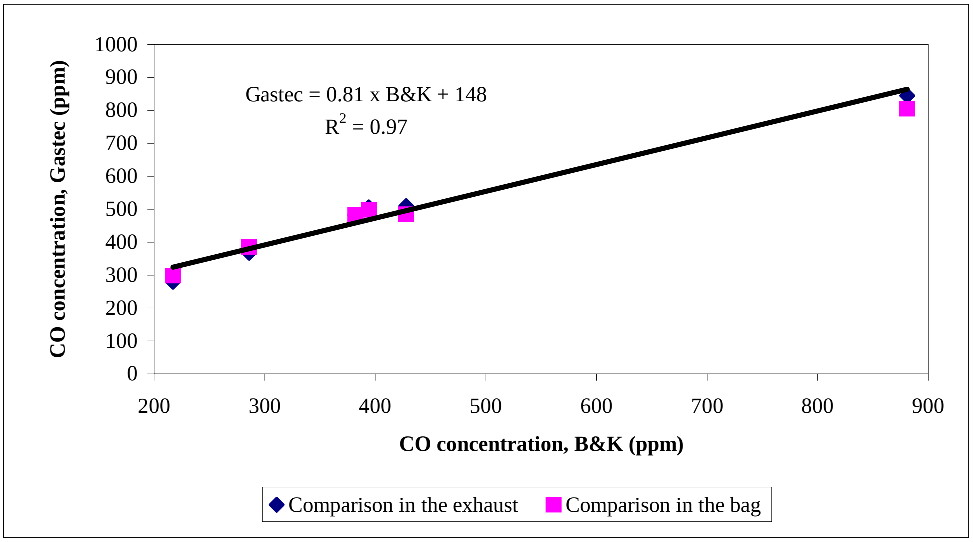


Figure 11.  Comparison Gastec vs. B&K – Diesel test bench

Ontario

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|---|---|
| **Ontario Ministry of Labour** | **Ministère du Travail de l'Ontario** |

Date: November 3, 1998

Michel Grenier
Program Manager
CANMET
1079 Kelly Lake Road
Sudbury, Ontario
P3E 5P5

Dear Michel,

## Re: Undiluted Carbon Monoxide Testing - Pennsylvania

I received your fax on the rules for testing undiluted CO in the Commonwealth of Pennsylvania by the Bureau of Deep Mine Safety (Diesel-Powered Equipment, Act 182 of 1996).

I found the procedure very interesting and very detailed. I see that Pennsylvania requires the use of particulate filters. To summarize their procedure for testing undiluted CO in the exhaust:

**(A)** These tests must be conducted when a diesel unit first enters the mine:

- test the brakes
- place equipment into an intake entry (not in shop)
- set brakes and chock the wheels
- install a portable CO sampling device into the untreated exhaust gas coupling provided in the operator's cab (they require a permanent setup)
- allow the engine to warm up to operating temperature
- for mobile equipment, shift into second gear and put the engine at full throttle, or for stationary equipment, induce a load and put the engine at full throttle (their regulations are silent for the testing of stationary equipment)
- start the CO sampler and measure and record CO levels every minute for 5 minutes

**(B)** Every 100 hours [the life of a Paas filter] the tests are repeated.

After talking to various manufacturers as well as our own electrical/mechanical engineers, several concerns were raised:

1. Parking brakes are intended to hold the vehicle stationary when stopped and not intended to hold the vehicle under dynamic load. Performing this test with a parking brake could over stress and weaken the parking brake. Therefore the emergency brake must be used in this test. The emergency is designed to stop the vehicle under full speed/full load conditions.

2. Because the power train is locked in place, there is also a concern with the torque convertor overheating. The cooling system on a torque convertor is designed for normal operating conditions. Will damage to the torque convertor be covered by the manufacturer's warranty?

3. Equipment with a standard transmission can only be tested under high speed no load conditions.

4. To bring up the engine to normal operating temperature, using torque/hydraulic stall is not the best method. Drive the vehicle around to bring up the engine temperature.

5. Because the CO testing is carried out with an instrument in the operator's cab the procedure is safe enough, as long as the qualified person doing the testing is out of the way.

6. If the test is to be conducted with a standard hand held cooling probe, this test procedure is inherently dangerous in case the brakes slip. In addition, the person doing the manual testing would be directly exposed to the exhaust for five minutes or more.

Hope this helps.

John Vergunst, P.Eng., CIH

Provincial Mining Specialist
Ontario Ministry of Labour