

A TECHNIQUE FOR MEASURING TOXIC GASES PRODUCED BY BLASTING AGENTS

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ABSTRACT

Traditional techniques for the experimental determination of toxic fumes produced by the detonation of high explosives are not applicable to blasting agents. To detonate properly, blasting agents require confinement, a significant booster, charge diameters of 3 inches (7.5 cm) or greater, and charge lengths greater than two times the charge diameter. Without these conditions, blasting agents will not detonate at full order, leading to a misrepresentation of the gaseous products.

A facility for detonating large, confined charges in a controlled volume has been constructed at the Pittsburgh Research Center's Experimental Mine. The facility consists of a portion of mine entry (once used for full scale mine explosion research and demonstrations) enclosed between two explosion proof bulkheads. Total volume of the chamber is 9,666 ft³ (274 m³). The chamber is equipped with an air circulating system and is vented using the mine's airflow. Up to 10-pound (4.5-kg) charges can be detonated in the chamber using a variety of confinements. For a typical test, the blasting agent is confined in a 4-inch (10-cm) schedule 80 steel pipe and initiated by a 3-inch (7.5-cm) diameter, 1-inch (2.5-cm) thick Pentolite booster. This combination of confinement and initiation yields a detonation velocity of about 4,000 m/sec for ANFO. This velocity is in line with that measured for blasting in the field. Twenty four 2-inch thick steel plates are suspended around the pipe bomb to stop shrapnel that would otherwise seriously damage the chamber. Following detonation of an explosive in the chamber, a circulating fan is run for about 10 minutes to uniformly mix the chamber atmosphere. Fumes samples are taken out of the chamber through 1/4-inch (0.6-cm) Teflon² or polyethylene tubes for analysis. The fumes are analyzed using bubblers or Vacutainers to collect samples for analysis by the analytical chemistry lab.

The technique described here has been employed to determine the fumes produced by the detonation of a variety of ANFO formulations and commercial explosives. This technique may be developed as a standard test to measure fumes produced by blasting agents or may be used to provide data with which to develop a computer model that will reliably predict the expected fumes production based on chemical composition.

INTRODUCTION

Over the years, extensive research has been done on the toxic fumes generated by the detonation of high explosives and many countries have test procedures and formal or informal requirements in place for the

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²Reference to Specific products does not imply endorsement by NIOSH.

maximum permitted fumes production^(1, 2)³. Typically, a hundred grams or so of high explosives are detonated in a chamber and the fumes collected for analysis. Measuring the fumes produced by the detonation of blasting agents is much more difficult. Any test to measure the fumes produced by blasting agents must take into account the fact that blasting agents require boosters, large charge sizes, and heavy confinement to detonate well and provide something close to a simulation of field use. At present there is no standard test for measuring blasting agent fumes. The lack of such a test has led to difficulties for blasters.

Some states in the U.S. have laws requiring that explosives used underground must be IME (Institute of Makers of Explosives) fume class 1. The IME fume classification is based on the poisonous gases produced by the detonation of a 1¼- by 8-inch (3.2- by 20-cm) cartridge of explosive in the Bichel Gauge; for IME fume class 1, poisonous gases produced must be less than 0.16 ft³ (4.53 liters). Blasters who wish to shoot blasting agents underground in a state requiring IME fume class 1 are faced with a dilemma. Blasting agents will not detonate at full order when initiated by a blasting cap as a 1¼- by 8-inch (3.2- by 20-cm) cartridge so it is impossible to determine IME fume class directly. In addition, the Mine Safety and Health Administration (MSHA) requires that exposure to airborne contaminants not exceed the threshold limit values adopted by the American Conference of Governmental Industrial Hygienists (3). Since airborne contaminants are not routinely monitored, the blaster needs to know the fumes class of the explosives in use so there will be a basis to decide if monitoring is necessary when a new explosive is used. If the IME fume class of the new explosive is the same as that of the old explosive, monitoring will probably not be necessary; if the IME fume class of the new explosive is higher than the old explosive, monitoring may be necessary. The blasting agent manufacturer can use a computer model to predict fumes production and thereby arrive at an expected IME fume classification but the validity of this technique is uncertain. It would be preferable to develop a test to either measure blasting agent fumes production or validate the various computer models that predict fumes production.

An ideal measurement of toxic fumes production would involve sampling the post blast atmosphere for a typical blast (4,5,6,7). Collecting this type of data would be prohibitively expensive and would not be very useful. In order to measure fumes production, the fumes released after a blast must be confined long enough for sampling to take place; this would be very difficult for a large underground blast and impossible for a surface blast. There is also no such thing as a typical blast. Research has shown that the degree of confinement of an explosive charge and the material being blasted both have a significant impact on fume production^(1,8,9). Measurements of fumes produced by blasts in one mine tell us little about the fumes that would be produced for a different blast pattern in different material at another mine. A practical approach is to devise a test that reports fumes production under a well defined set of conditions. Such a test may be used to qualitatively rank the toxicity of fumes produced by commercial blasting agents. For example, an acceptable level of toxic fumes production for a given mining situation may be set based on reference to explosives that have been used successfully in the past; if explosive A has been used for many years without a problem then any new explosives that are used must not produce more toxic fumes than Explosive A, as measured in the standard test.

This paper describes a blasting agent fumes test being developed at the Pittsburgh Research Center. Some

³ Italic number in parenthesis refer to items in the list of references at the end of this report.

preliminary results will be presented but further research must be done to evaluate the validity of the data being reported, compare the results to those obtained by other researchers, and compare the results to those predicted by computer models. Future work will also look at the effects of confinement, moisture content, and composition on fumes production. These results will be presented in later papers.

EXPERIMENTAL APPROACH

Detonating large blasting agent charges and confining the fumes requires a larger experimental chamber than was employed in past work on high explosives. Towards this end, a chamber was created in the experimental mine at the Pittsburgh Research Center. The facility consists of a portion of mine entry (once used for full scale mine explosion research and demonstrations) enclosed between two explosion proof bulkheads. Each bulkhead is 40 inches (1 m) thick, constructed of solid concrete block hitched 1 foot (30 cm) into the roof, ribs, and floor. On the intake side, the bulkhead is fitted with a submarine mandoor and a small port for control and sampling lines. On the return side, the bulkhead is fitted with two sealed ventilation ports. Total volume of the chamber is 9,666 ft³ (274 m³). The chamber volume was determined by releasing a known quantity of CO into the chamber and sampling the atmosphere after it had mixed. Following the shot, a fan mounted at one end of the chamber mixes the chamber atmosphere at 3,500 ft³/min, after which the chamber is vented using the mine's airflow. The layout of the chamber is illustrated in Figure 1. Up to 10 pound (4.5 kg) charges can be detonated in the chamber using a variety of confinement.

As discussed above, the fumes produced by blasting agents are dependent on the conditions under which they detonate. Preliminary work was devoted to finding a way to detonate the blasting agent that would result in a velocity of about 4,000 m/sec, a typical velocity for blasting in the field. Initially, attempts were made to shoot blasting agents in steel pipes placed in a hole in the floor of the mine or in a concrete cannon; the former method caused too much damage to the chamber and the latter required excessive preparation and cleanup. The possibility of shooting the explosive in a suspended steel pipe was then explored. The ANFO detonated at about 4,000 m/sec when confined in 4-inch (10-cm), schedule 80 seamless steel pipe. Without protection, the shrapnel would severely damage the test chamber. The shrapnel problem was addressed by hanging 8-ft by 1-ft by 2-inch (2.4-m by .3-m by 2.5-cm) steel plates from the roof in the form of a 6-ft (1.8-m) square surrounding the charge. These plates stopped the shrapnel and prevented damage to the chamber. The steel plates were damaged by the shrapnel, but this was not a serious problem since they could be replaced when they were damaged to the point of being unuseable. After 20+ shots it has been found that there is a need to replace, on average, one plate per shot. The pipe bomb and the steel plate enclosure are illustrated in Figures 2 and 3.

EXPERIMENTAL

As mentioned above, a 27-inch (69-cm) length of 4-inch (20-cm) Schedule 80 seamless steel pipe was chosen to provide confinement in tests of blasting agents and high explosives. Prior to loading the pipe with explosive, a continuous velocity probe of the type described by Santis is taped to the inner surface of the pipe along its length(10). In conducting a test of a blasting agent, the commercial blasting agent minus its wrapper or premixed ANFO are loaded into the pipe to a weight of 10 lb (4.54 kg). Initiation is provided by a 3-inch (7.5-cm) diameter, 1-inch (2.5-cm) thick cast pentolite booster, initiated by a number 8 instantaneous electric blasting cap. In conducting a test of a high explosive, the cartridge explosive is loaded into the pipe to a weight of about 10 lb (4.54 kg). High explosives are initiated by a number 8 instantaneous electric blasting

cap.

Following detonation of an explosive in the chamber, the fan is run for about 10 minutes to uniformly mix the chamber atmosphere. Fumes samples are taken out of the chamber through 1/4-inch (0.6-cm) Teflon or polyethylene tubes for analysis. Teflon sample lines are used for the oxides of nitrogen (NO_x) and ammonia (NH_3) to minimize loss of these constituents to absorption on the tube surface. Vacutainer samples are taken and sent to the analytical laboratory for analysis; this technique is appropriate for components that are stable in the Vacutainer, namely hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2). NO , NO_x , and NH_3 are not amenable to analysis by the Vacutainer technique and are instead absorbed in chemical solutions in bubbler trains using the technique described by Santis (11). That method was modified by eliminating the purging of the system with helium and using a gas meter to measure the volume of fumes bubbled through the solutions rather than measuring gas flow rate.

An Ecolyzer electrochemical CO monitor was also employed to act as a backup to the analytical lab's CO analysis of the Vacutainer and to allow monitoring of the mixing of the chamber atmosphere. In most cases, the electrochemical CO monitor and the lab analysis for CO agreed to within 10 percent. The CO concentration reported by the lab was chosen as the more reliable value since the CO electrochemical cell responds to H_2 as well as CO and was therefore yielding slightly erroneous results.

Bubbler trains are an accepted technique for measuring NO , NO_x , and NH_3 concentrations in fumes samples but the technique is time consuming to set up and it can take several weeks to get results back from the analytical lab. To simplify the fumes analysis, a series of National Draeger electrochemical cells have been set up to measure CO , NO , NO_2 , NH_3 , H_2 , SO_2 , H_2S , and HCl . Currently only CO , NO , NO_2 , NH_3 , and H_2 are of interest, but the SO_2 , H_2S , and HCl cells may be employed in the future if explosives that contain sulphur or chlorine are tested. As Persson mentioned in his work, calibration of electrochemical cells and correction for cross sensitivity can be difficult(9). Each of the cells must be carefully calibrated and corrections have to be applied to account for the fact that each cell responds not only to the constituent it is supposed to, but to others as well. Although installed, the electrochemical cells were not employed in the work reported here because all of the necessary calibrations and corrections have not been completed; once this is done, both the bubbler trains and electrochemical cells will be employed for an indefinite period to compare the results. The sampling systems are illustrated in Figures 4 and 5. Cylinders of pure gases have also procured for the purpose of creating toxic atmospheres of known composition in the chamber. By sampling these tailor-made atmospheres, it will be possible to determine how close the measured composition agrees with the known composition and in this way verify that the analytical techniques are working properly.

RESULTS AND DISCUSSION

Data for tests conducted with ANFO are presented in Table 1. The detonation velocities were on the order of 4,000 m/sec, which meant that the ANFO detonated in a manner similar to that measured in the field. Data for toxic fumes generation were corrected to remove the contribution of the 3-inch diameter, 1-inch thick pentolite booster used to initiate the shot. Figures 6, 7, and 8 present plots of CO , NO_x , and NO_2 generation as a function of fuel oil content in the ANFO. For comparison, data reported by Persson(9) and Chaiken(12), and values predicted for an ideal detonation as reported by Chaiken(12) are also presented. Persson's data were based on ANFO detonated in a 40-mm diameter steel tube with a 12 mm thick wall, and Chaiken's were based on ANFO detonated in a steel cannon. Despite the different test conditions, the

author's CO data agree reasonably well with the predicted values and trends, and that measured by Persson. The author's NO₂ and NO_x data also agree reasonably well with those measured by Persson and Chaiken. The NO₂ data of Persson, Chaiken, and that reported here do not agree with the predicted values but follow the predicted trend and are all similar in magnitude, suggesting that the difference between the measured and predicted NO₂ is a matter of the model not fitting the chemistry of the explosion products rather than an error in the measurement technique.

The techniques developed for measuring toxic fumes produced by blasting agents look promising. Further development should result in a standard technique, either through testing or computer modeling, for estimating the toxic fumes produced by blasting agents.

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Table 1. Summary of data for shots of ANFO.

Pct. Fuel Oil	Velocity, m/sec	CO l/kg	NO _x l/kg	NO ₂ l/kg	NH ₃ l/kg
5	4,420	9.65	4.26	2.31	0.03
5	3,830	6.5	4.44	1.77	0.13
6	3,900	18.93	1.88	1.25	0.01
6	4,340	19.23	1.17	1.52	0.04
6	4110	17.24	0.77	1.22	0.1
7	4,340	28.03	1.93	0.65	0.46
7	4,160	27.31	2.92	1.07	0.65

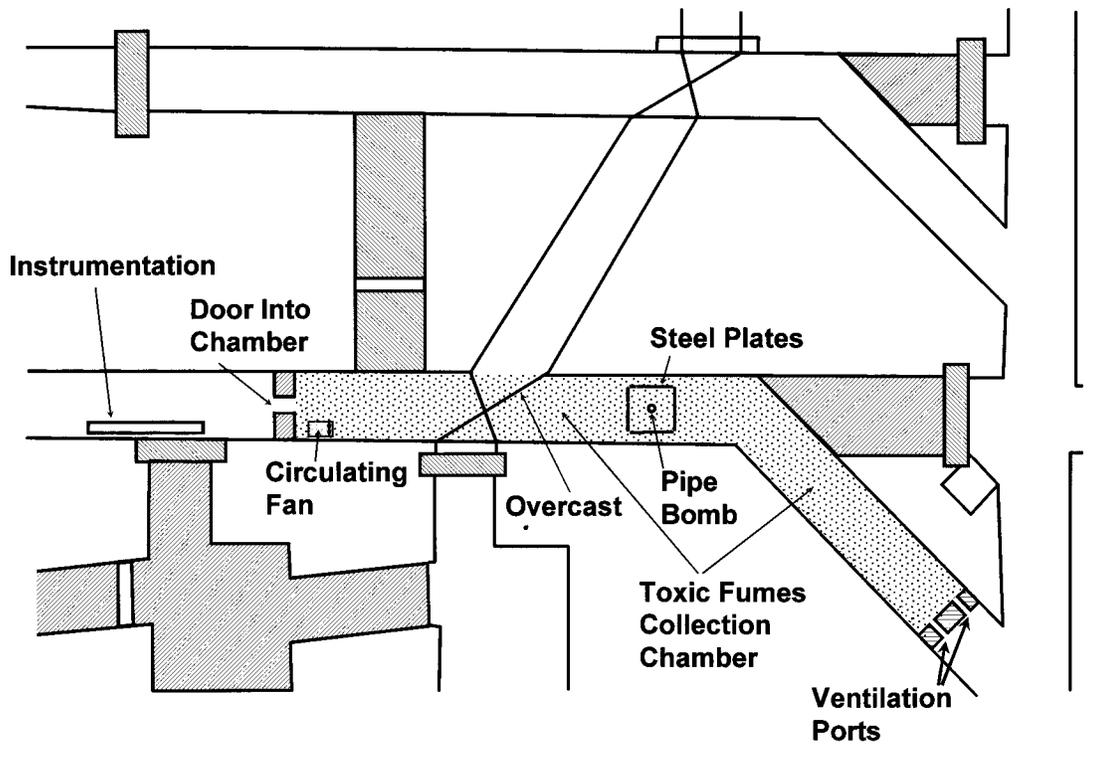


Figure 2. Research was conducted in a chamber created in the underground mine at the Pittsburgh Research Center.

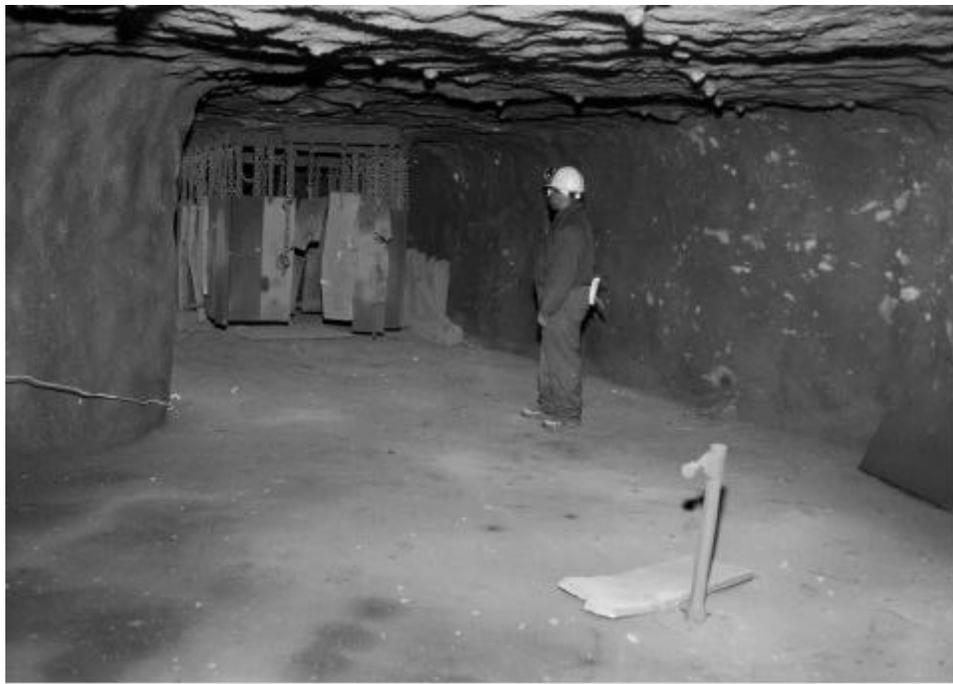


Figure 2. Chamber in the mine where toxic fume measurements were conducted. The steel plates protected the chamber from shrapnel produced by the detonation of the pipe bomb.



Figure 3. Blasting agents were confined in a 27-inch (69-cm) length of 4-inch (10-cm) Schedule 80 steel pipe.



Figure 4. A series of bubblers were used to collect toxic gas components (NO_x , NO_2 , and NH_3) that could not be collected in Vacutainers.



Figure 6. In the future, electrochemical cell will be used to give real time readout of toxic fumes composition.

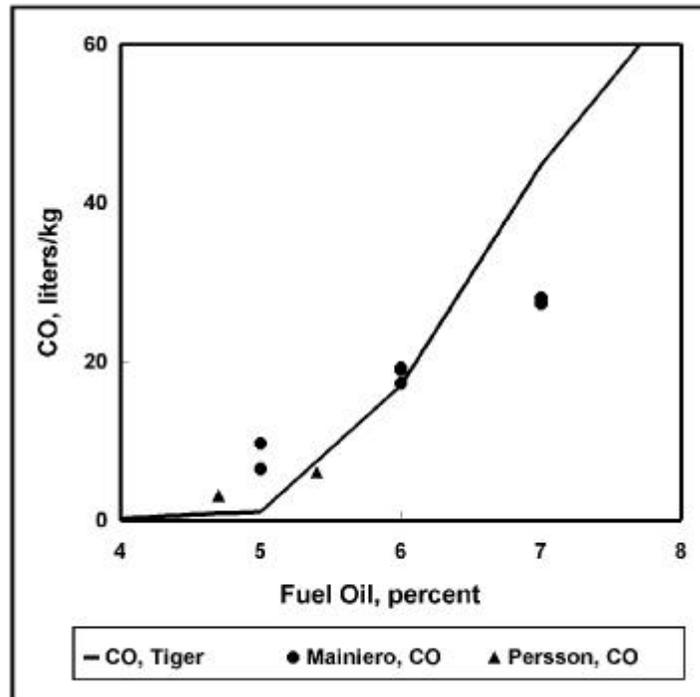


Figure 6. Plot of CO production versus fuel oil content of ANFO. The Tiger prediction is that reported by Chaiken(12).

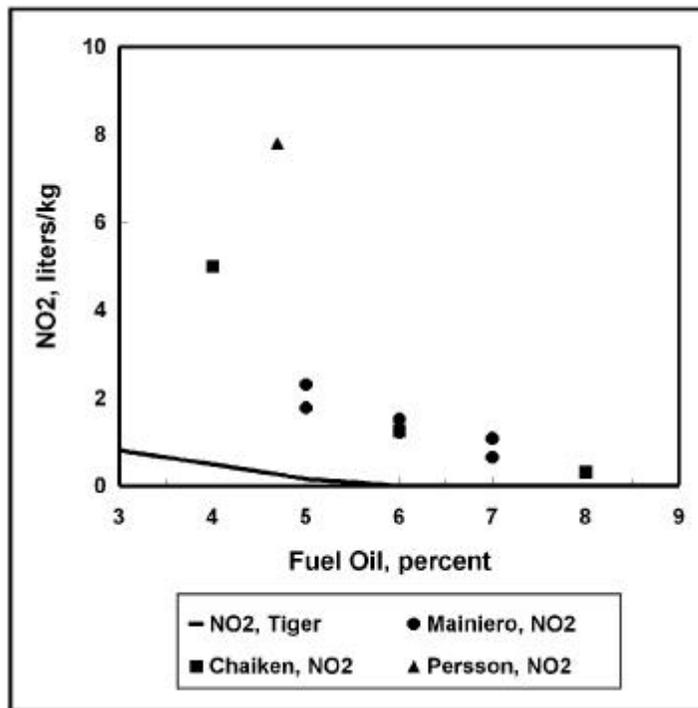


Figure 7. Plot of NO₂ production versus fuel oil content of ANFO. Tiger predictions are those reported by Chaiken(12).

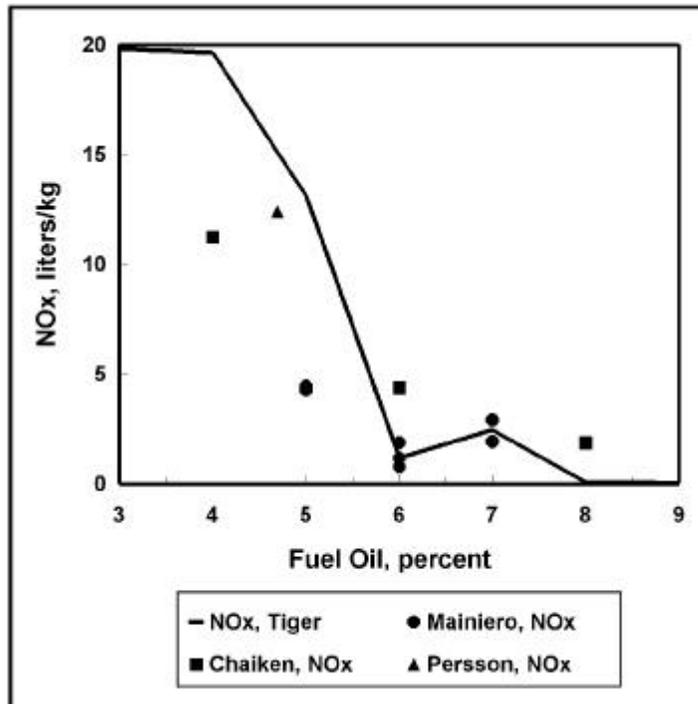


Figure 8. Plot of NO_x production versus fuel oil content of ANFO. Tiger predictions are those reported by Chaiken(12).