

**PROCEEDINGS
OF THE
TWENTY-SIXTH ANNUAL CONFERENCE ON
EXPLOSIVES AND BLASTING TECHNIQUE**

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Volume I



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FACTORS AFFECTING ANFO FUMES PRODUCTION

James H. Rowland III and Richard Mainiero

ABSTRACT

For many years there have been small scale tests available for evaluating the toxic fumes production by cap-sensitive explosives (DOT Class 1.1), but these could not be used with blasting agents due to the large charge sizes and heavy confinement required for proper detonation. Considering the extensive use of blasting agents in construction and mining, there is a need to determine the quantities of toxic fumes generated by blasting agents. At the International Society of Explosive Engineers Twenty Third Annual Conference on Explosives and Blasting Technique in 1997, the authors reported on a facility for detonating large (4.54 kg), confined blasting agent charges in a controlled volume that had been constructed at the National Institute for Occupational Safety and Health's Pittsburgh Research Lab's Experimental Mine. Since 1997, this facility has been used to collect data on toxic fumes produced by the detonation of various ammonium nitrate/fuel oil (ANFO) mixtures and several cap-sensitive explosives.

ANFO composition ranging from 1 to 10 percent (pct) fuel oil have been studied. As expected from previous studies, with an increase in fuel oil content the carbon monoxide production increases, while nitric oxide and nitrogen dioxide production decrease. The detonation velocity varies from 3,000 to 4,000 m/sec for the 1 to 10 pct range of fuel oil content, suggesting that ANFO mixes with improper fuel oil content may appear to detonate properly, while their fume production differs significantly from optimum. The study also considers such factors as degree of confinement, water contamination, and aluminum content on blasting agent fume production. Results indicate that water contamination of the ANFO has little effect on carbon monoxide production, but causes significant increase in nitric oxide and nitrogen dioxide production. Decreasing confinement from Schedule 80 steel pipe to 0.4-mm thick sheet metal also has little effect on carbon monoxide production, but significantly increases nitric oxide and nitrogen dioxide production. Adding 5 and 10 pct aluminum to the ANFO had no clear effect on carbon monoxide, nitric oxide, or nitrogen dioxide production.

INTRODUCTION

In February of 1997 a paper entitled "A Technique for Measuring Toxic Gases Produced by Blasting Agents" was presented at the 23rd Annual Conference on Explosives & Blasting Technique in Las Vegas, Nevada. That paper discussed a method for measuring toxic fumes produced by detonation of blasting agents. The research reported here is a continuation of that work.

Detonating ANFO in steel pipe in the Pittsburgh Research Lab (PRL) mine fumes chamber yields a baseline for comparing relative fumes production for blasting agents, but is by no means a predictor of what will happen in the field. In actual blasting operations, the confinement of the detonating ANFO will probably be less than that offered by the 4-in, Schedule 80 steel pipe employed in most tests. Additionally the ANFO evaluated in the PRL mine chamber is carefully mixed the day before and care is taken to prevent contamination. In practice, ANFO may not be exactly the 94/6 ammonium nitrate/fuel oil ratio desired or may be loaded into boreholes weeks before it is shot, exposing the explosive to water seeping into loaded boreholes and possible fuel oil evaporation. The current research looks at these factors and others in an effort to determine how they affect fumes production. Fumes measurements in the mine chamber were carried out for ANFO mixtures other than 94/6, ANFO contaminated with up to 10 pct water, ANFO detonated with less confinement than that offered by Schedule 80 steel pipe, and ANFO contaminated with limestone rock dust. Additionally, several cap-sensitive explosives, as well as ANFO containing up to 10 pct aluminum were also studied to gain an understanding of how detonation behavior affects fumes production. In each case carbon monoxide, nitrogen oxides, and ammonia were the toxic gases of primary interest.

EXPERIMENTAL APPROACH

Detonating large blasting agent charges and confining the fumes requires a larger experimental chamber than was employed in past work on cap-sensitive explosives. Towards this end, a chamber was created in the experimental mine at PRL. The facility consists of a portion of mine entry 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 carbon monoxide 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 (4.54 kg) charges can be detonated in the chamber using a variety of confinements.

EXPERIMENTAL

A 28-inch (71-cm) length of 4-inch (20-cm) Schedule 80 seamless steel pipe was chosen to provide confinement in most tests of blasting agents and cap-sensitive 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 length¹. 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 2-inch (5-cm) diameter, 2-inch (5-cm) thick cast pentolite booster, initiated by a number 8 instantaneous electric

blasting cap. In conducting a test of a cap-sensitive explosive, the cartridge explosive is loaded into the pipe to a weight of about 10 lb (4.54 kg). Cap-sensitive 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 before 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 nitrogen oxides and ammonia 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, carbon monoxide, and carbon dioxide. Nitrogen dioxide, nitrogen oxides, and ammonia are not amenable to analysis by the Vacutainer technique and are instead absorbed in chemical solutions in bubbler trains using the technique described by Santis². 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 electrochemical carbon monoxide monitor was also employed to act as a backup to the analytical lab's carbon monoxide analysis of the Vacutainer and to allow monitoring of the mixing of the chamber atmosphere.

RESULTS

An ANFO mixture of 94 pct ammonium nitrate, 6 pct fuel oil is close to optimum from the perspective of minimum toxic fumes production. Previous research and theory show that the detonating ANFO will produce excessive levels of nitrogen oxides if the fuel oil content is too low and will produce excessive levels of carbon monoxide and ammonia if the fuel oil content is too high.^{3,4,5} This behavior is supported by data collected in the current research, as illustrated in Figures 2, 3, and 4.

In Figure 5 the data from figures 2, 3, and 4 is presented in terms of oxygen balance. Figure 5 is a plot of carbon monoxide production versus oxygen balance for ANFO and several cap-sensitive explosives. As the oxygen balance is increased for ANFO the carbon monoxide production decreases. This would be expected since there is increasing oxygen to convert the carbon monoxide to carbon dioxide. ANFO mixed at 6 pct fuel oil produces approximately the same amount of carbon monoxide as cap-sensitive explosives of equivalent oxygen balance. The opposite is true when looking at nitrogen oxides production as a function of oxygen balance, as illustrated in Figure 6. When the oxygen balance is increased, the nitrogen oxides and nitrogen dioxide production increased. ANFO mixed at 6 pct fuel oil produced significantly more nitrogen oxides and nitrogen dioxide than cap-sensitive explosives. Figure 7 illustrates that as the oxygen balance for ANFO is increased the ammonia production decreases. With the exception of a couple data points that may be anomalous, ANFO mixed at 6 pct fuel oil produced about the same quantity of ammonia as cap-sensitive explosives of equivalent oxygen balance.

Figure 8 shows that adding water to an ANFO mixture of 94 pct ammonium nitrate and 6 pct fuel oil had little effect on carbon monoxide production for water percentages from 0 to 10 pct. However the nitrogen oxides and nitrogen dioxide increased dramatically when water is added to the ANFO mixture.

*Reference to specific products is for informational purposes and does not imply endorsement by NIOSH.

This is demonstrated in Figure 9. Figure 10 shows the effect of water on ammonia fumes production; adding water to the ANFO yields an erratic trend, indicating that further study is needed.

As mentioned earlier, shooting ANFO in 4-inch schedule 80 seamless steel pipe is probably much more confinement than seen in the field. To examine the effect of reduced confinement on fumes production, ANFO was tested in sheet metal and PVC pipe. As seen in Figure 11, reduced confinement doesn't have much effect on carbon monoxide production. Carbon monoxide production for ANFO shot in the PVC pipe was much higher than that for the steel or sheet metal pipe. The high carbon monoxide might be attributed to burning of the PVC pipe. The degree to which the PVC pipe reacted was not studied in detail, but it is safe to assume that at least some of the PVC burned during the ANFO detonation. The high carbon monoxide production would be consistent with the earlier observation that the higher the fuel content of the explosive, the higher the carbon monoxide production.

Explosive packaging is an important consideration relative to toxic fumes production. For example, a blast pattern may contain a number of boreholes that are contaminated with water and the blaster may decide to insert sleeves into the boreholes contaminated with water to keep the ANFO dry. If the sleeves are made of a combustible material they could add to the carbon monoxide production. Figure 12 shows that the production of nitrogen oxides and nitrogen dioxide increases dramatically with lower confinement, while Figure 13 shows that with less confinement ammonia decreases.

Limestone rock dust (approximately 73 pct through 200 mesh) was added to the ANFO mixture to simulate drill cuttings being mixed with the ANFO as it was loaded into a borehole. The rock dust had little effect on the carbon monoxide production, as illustrated in Figure 14. Figure 15 shows that the addition of the rock dust led to an increase in nitrogen oxides production and a decrease in nitrogen dioxide production. Since the nitrogen oxides consist essentially of nitric oxide and nitrogen dioxide, this indicates that nitric oxide production increased significantly. Figure 16 shows that adding rock dust to the ANFO caused a significant increase in ammonia production.

Aluminum is sometimes added to ANFO to increase the velocity and the output energy. Figure 14 illustrates that the aluminum added to the ANFO mixture has little effect on the production of carbon monoxide. From Figure 15 it is not clear whether or not the nitrogen oxides and nitrogen dioxide production is affected by the added aluminum. The ammonia increased with the added aluminum, as illustrated in figure 16. It should be noted that the addition of aluminum had no clear effect on the ANFO's detonation velocity. The aluminum added to the ANFO mixture was Fine Aluminum Paint Pigment Powder, Alcoa # 422 flake. This type was used to give the fastest possible burning rate for experimental purposes. For commercial explosives, the lowest and least expensive grade of aluminum is typically used, consisting of ground scrap aluminum of various particle sizes.

DISCUSSION

Several factors that may effect the fumes production of ANFO have been investigated. Probably the easiest to control is the fuel oil content. To minimize toxic fumes production, the ANFO should be mixed at 6 pct fuel oil. Deviating from the 6 pct will lead to excessive fumes. Water contamination may not have an affect on carbon monoxide production, but it increases the production of nitrogen oxides and nitrogen dioxide. At the present time in our research it is not clear how the production of ammonia is

affected. The confinement of ANFO doesn't appear to make a difference in the production of carbon monoxide, but it makes a difference in the production of nitrogen oxides, nitrogen dioxide, and ammonia. In the case of nitrogen oxides and nitrogen dioxide the fumes production will increase, while the ammonia fumes production will decrease.

Adding aluminum or rock dust to ANFO does not affect the fumes production of carbon monoxide. The addition of aluminum does not have a significant effect on nitrogen oxides and nitrogen dioxide production, but the addition of rock dust leads to an increased production of nitrogen oxides. Additionally, the rock dust appears to have an effect on the ratio of nitric oxide to nitrogen dioxide. The addition of aluminum and rock dust increased the production of ammonia. The effect of rock dust on fume production was based on limited data and requires further study to look at the effect of particle size and dust type.

It's important to understand that the data reported here applies only to the test conditions under which the data was collected. For example, the schedule 80 steel pipe may provide more confinement than many field blasts. The research reported here shows that the confinement will affect the quantity of toxic fumes produced. In the field the toxic fumes released from a blast will differ significantly from the data reported here. There is a need to collect data from the field to develop an understanding of how data from the PRL fumes chamber compare to fumes production in the field. This, in return, will help in developing improved tests for evaluating fumes production.

1. Santis, L. D. and R. A. Cortese, A Method of Measuring Continuous Detonation Rates Using Off-the-Shelf Items, Proceedings of the Twenty-Second Annual Conference on Explosives and Blasting Technique, Orlando, FL, February 4-8, 1996.
2. Santis, L. D., J. H. Rowland, III, D. J. Viscusi, and M. H. Weslowski, The Large Chamber Test for Toxic Fumes Analysis for Permissible Explosives, Proceedings of the Twenty-First Annual Conference on Explosives and Blasting Technique, Nashville, TN, February 5-9, 1995.
3. Mainiero, R.J., A Technique for Measuring Toxic Gases Produced by Blasting Agents, Proceedings of the Twenty Third Annual Conference on Explosives and Blasting Technique, Las Vegas, NV, February 2-5, 1997.
4. Blaster's Handbook, Sixteenth Edition, E.I. du Pont de Nemours and Company, 1977, p. 59.
5. Explosives and Rock Blasting, Atlas Powder Company, 1987, p. 25-27.

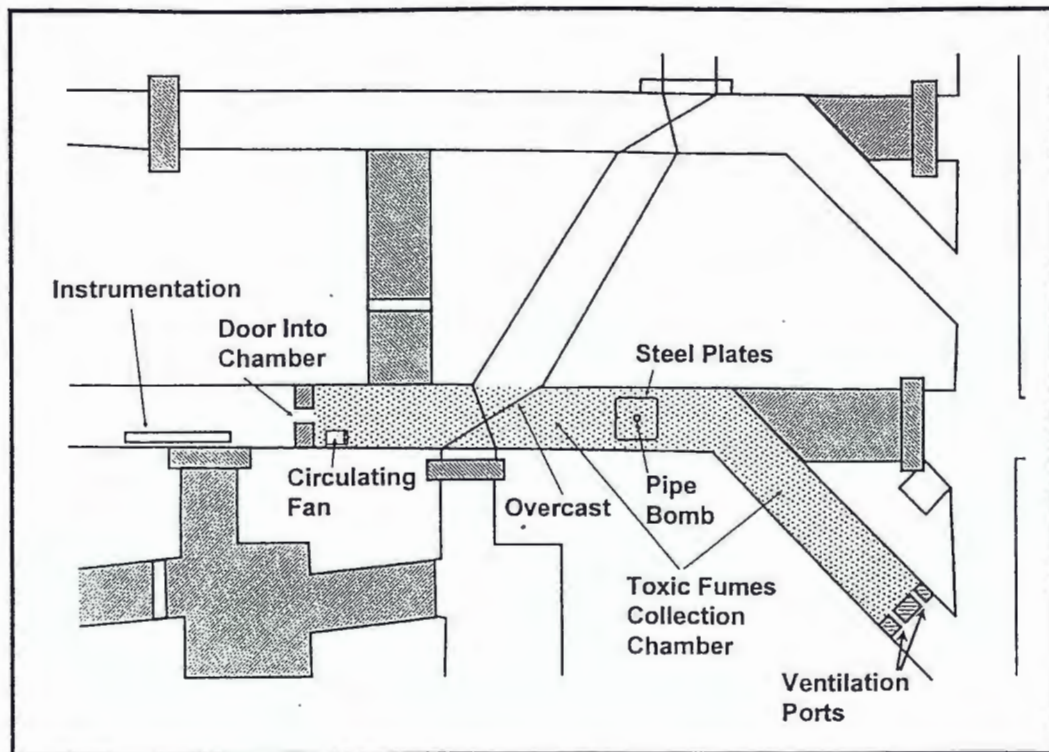


Figure 1. Research was conducted in a chamber created in the underground mine at the Pittsburgh Research Lab.

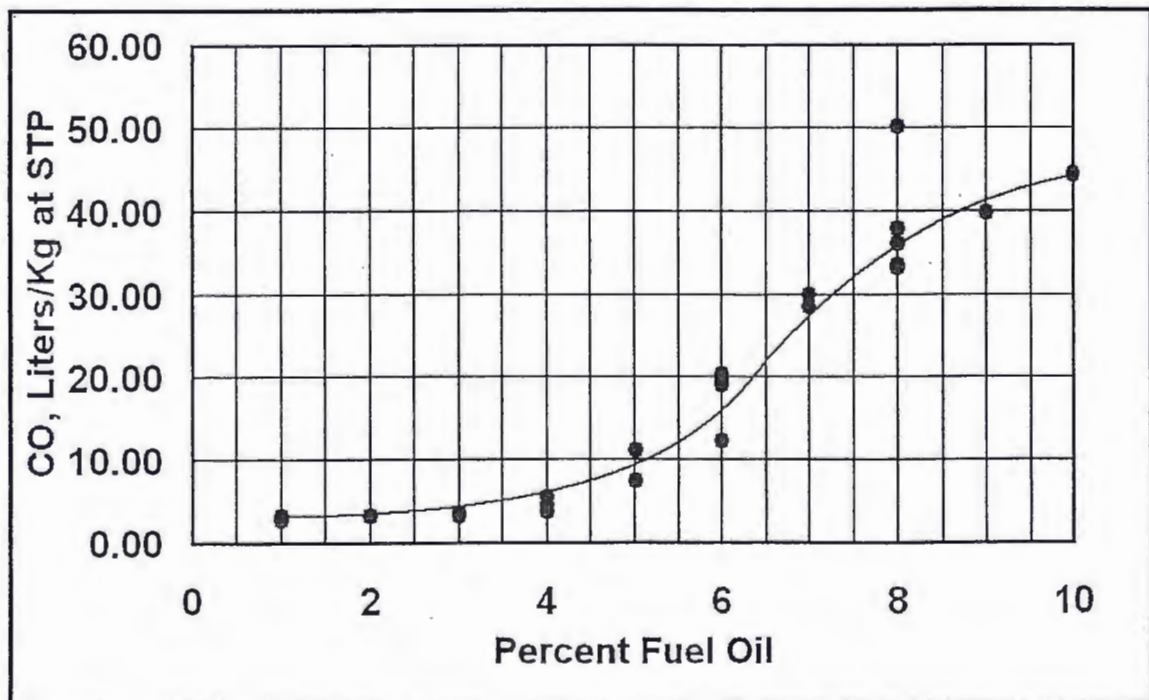


Figure 2. Effect of ANFO fuel oil content on carbon monoxide production. In all figures, the line is a polynomial fit to the data; it is included for illustrative purposes and does not represent a fit of theoretical results.

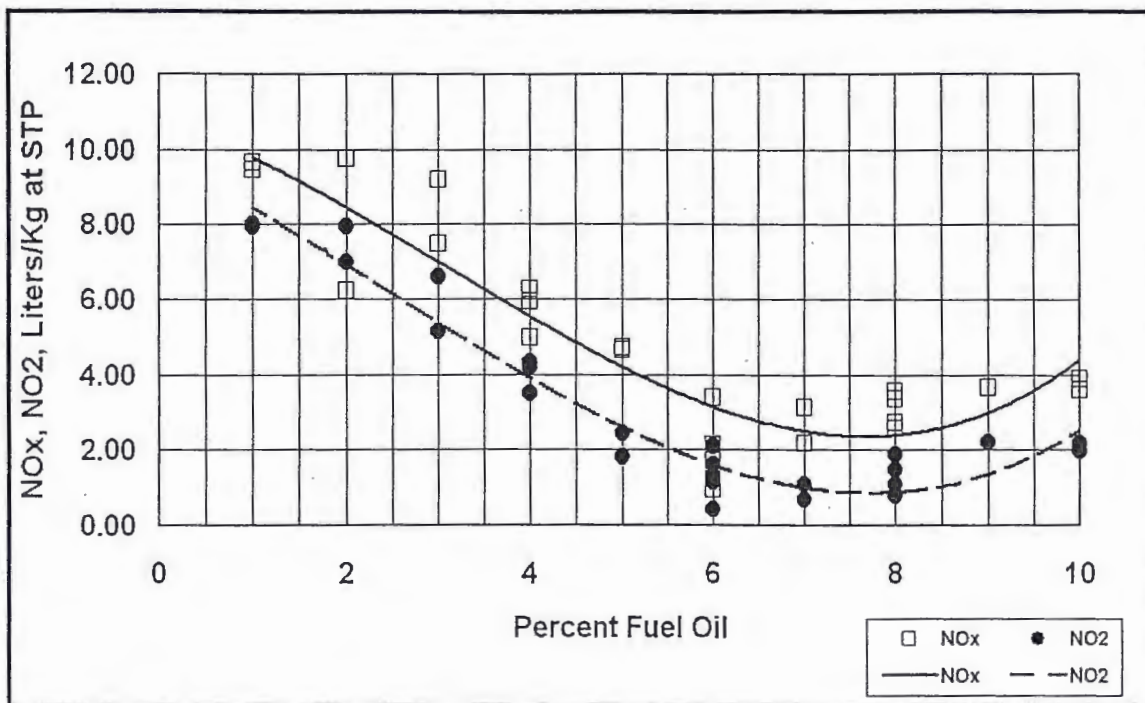


Figure 3. Effect of ANFO fuel oil content on nitrogen oxides and nitrogen dioxide production.

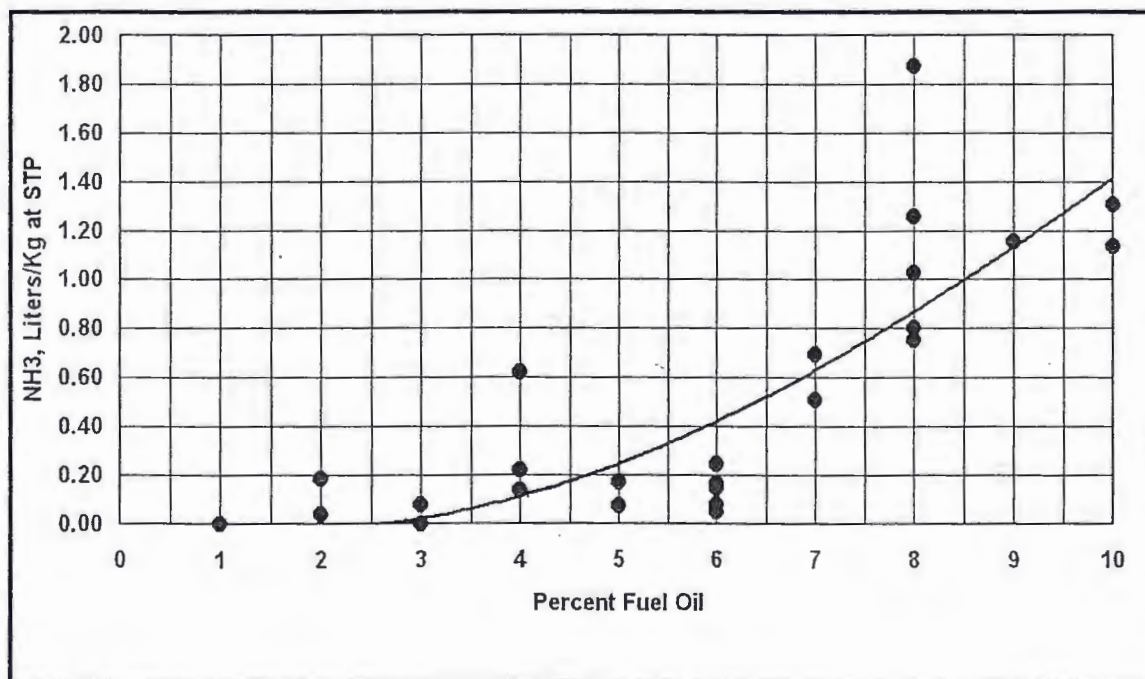


Figure 4. Effect of ANFO fuel oil content on ammonia production.

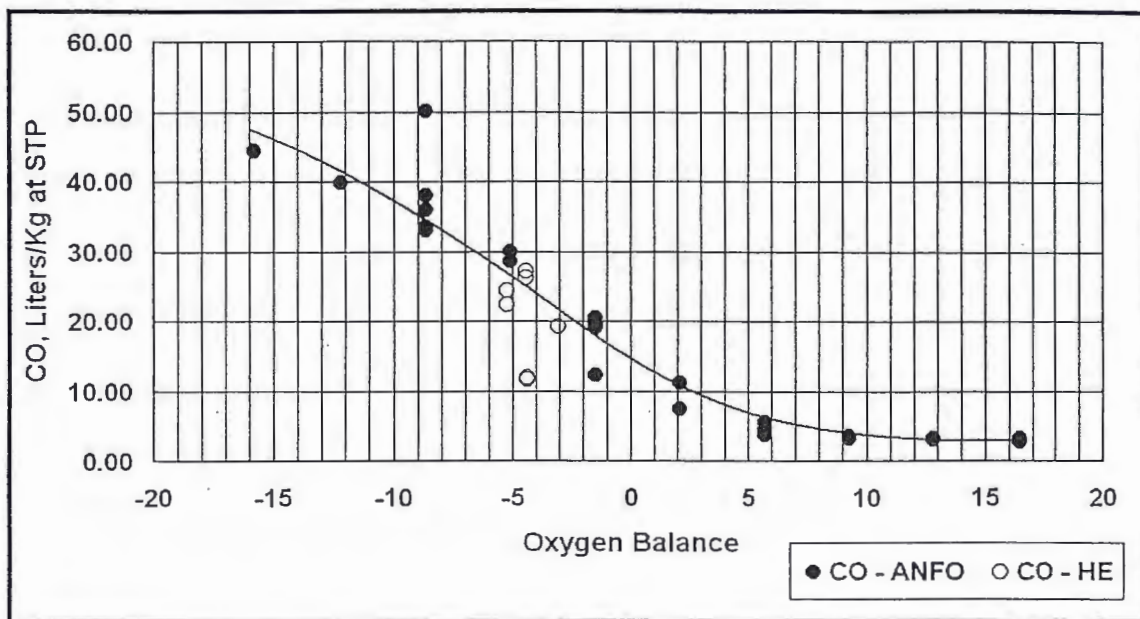


Figure 5. Effect of Oxygen Balance on carbon monoxide production for 94/6 ANFO and high explosives (cap-sensitive explosives).

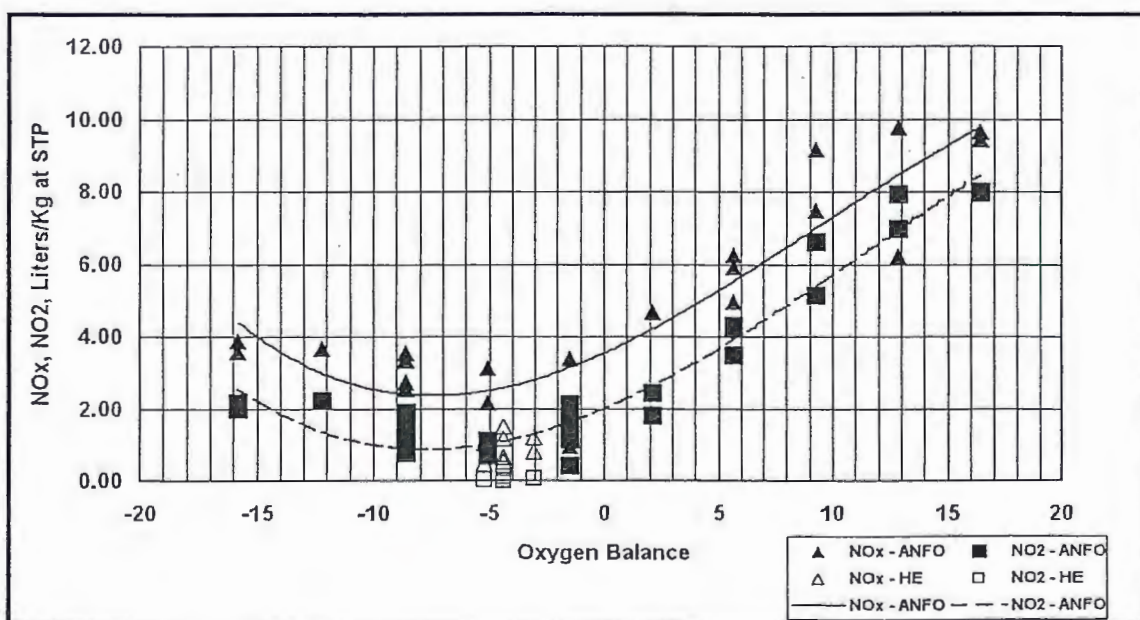


Figure 6. Effect of Oxygen Balance on nitrogen oxides and nitrogen dioxide production for 94/6 ANFO and high explosives (cap-sensitive explosives).

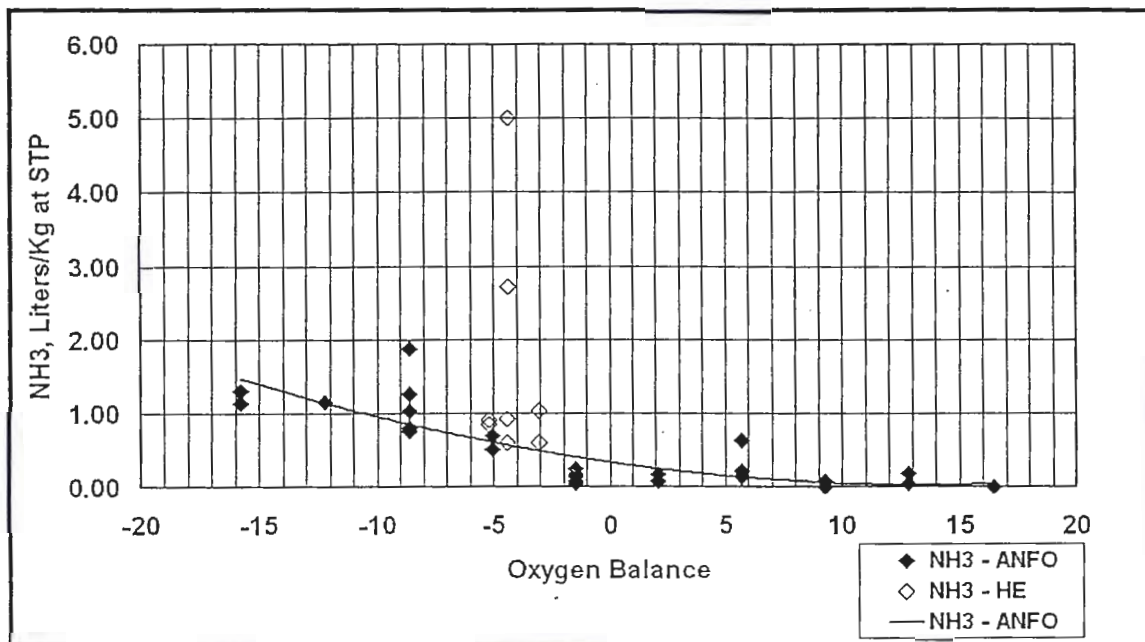


Figure 7. Effect of Oxygen Balance on ammonia production for 94/6 ANFO and high explosives (cap-sensitive explosives).

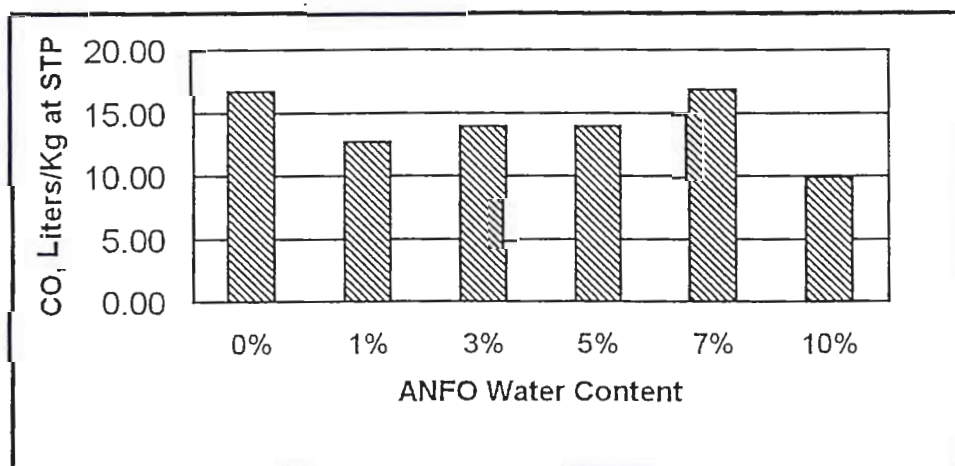


Figure 8. Effect of ANFO water content on carbon monoxide production for a 94/6 mix.

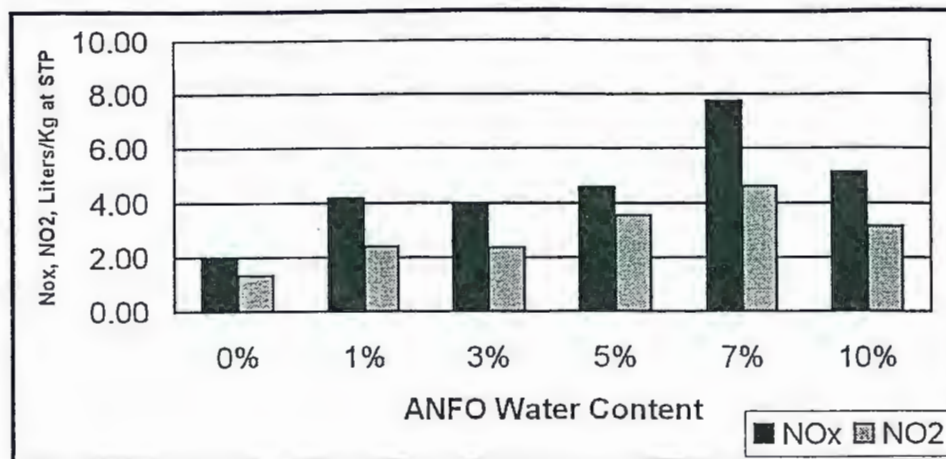


Figure 9. Effect of 94/6 ANFO water content on nitrogen oxides and nitrogen dioxide production.

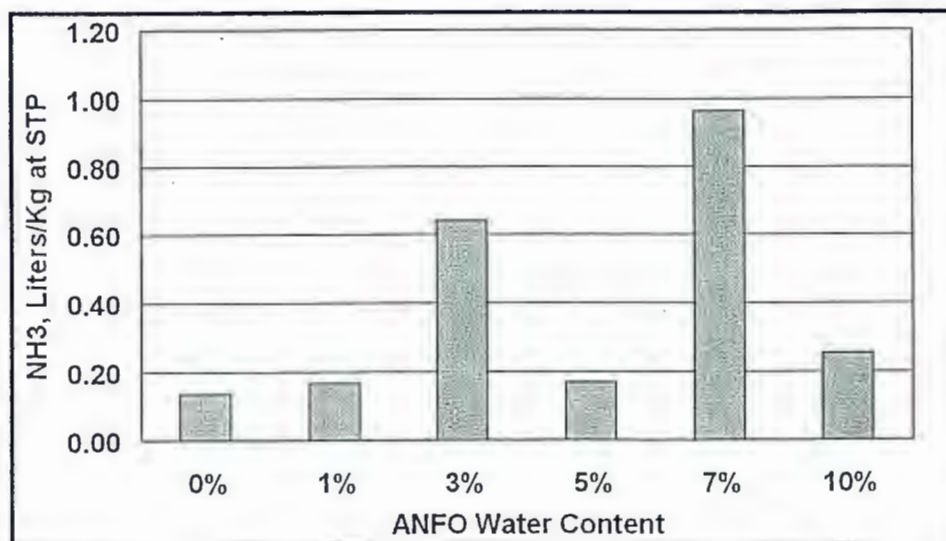


Figure 10. Effect of 94/6 ANFO water content on ammonia production.

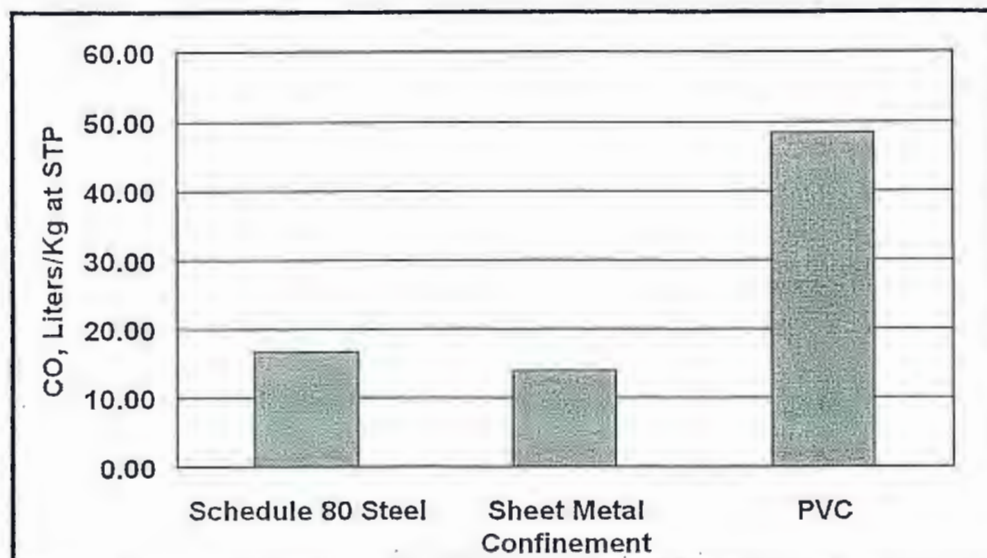


Figure 11. Effect of 94/6 ANFO confinement on carbon monoxide production.

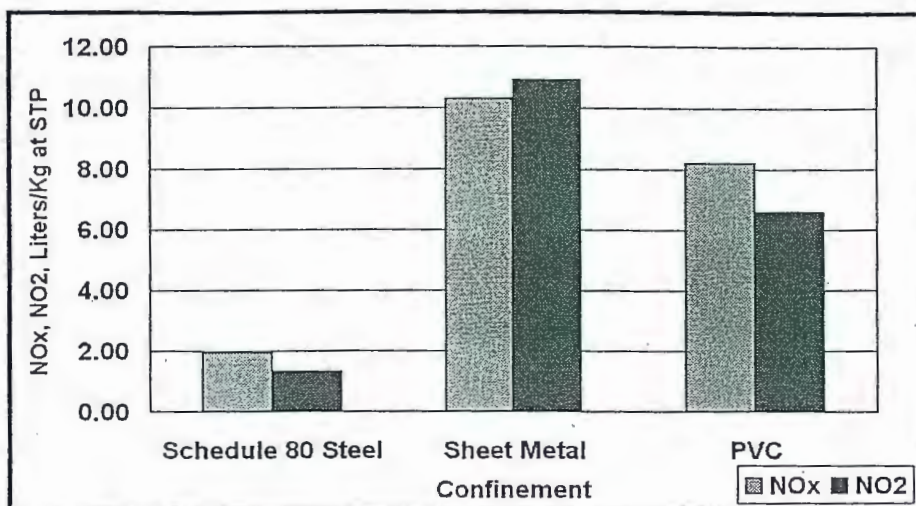


Figure 12. Effect of 94/6 ANFO confinement on nitrogen oxides and nitrogen dioxide production.

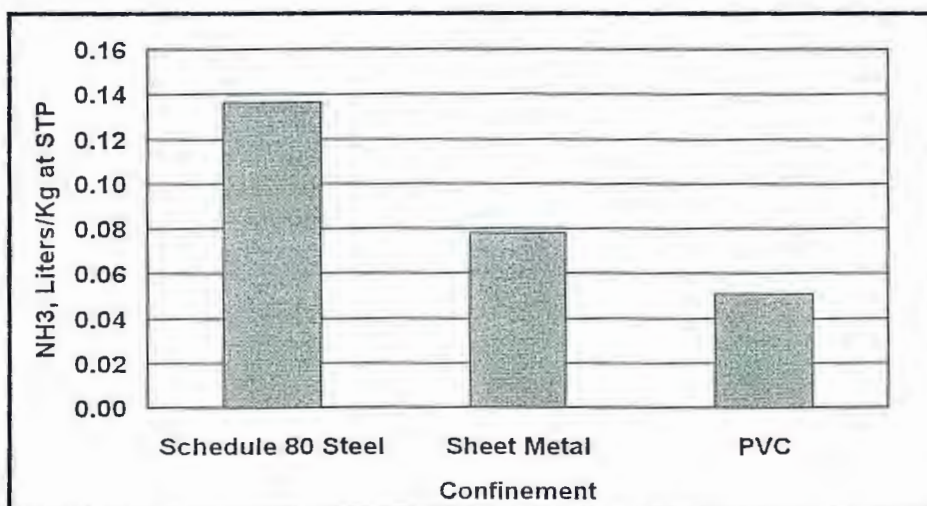


Figure 13. Effect of 94/6 ANFO confinement on ammonia production.

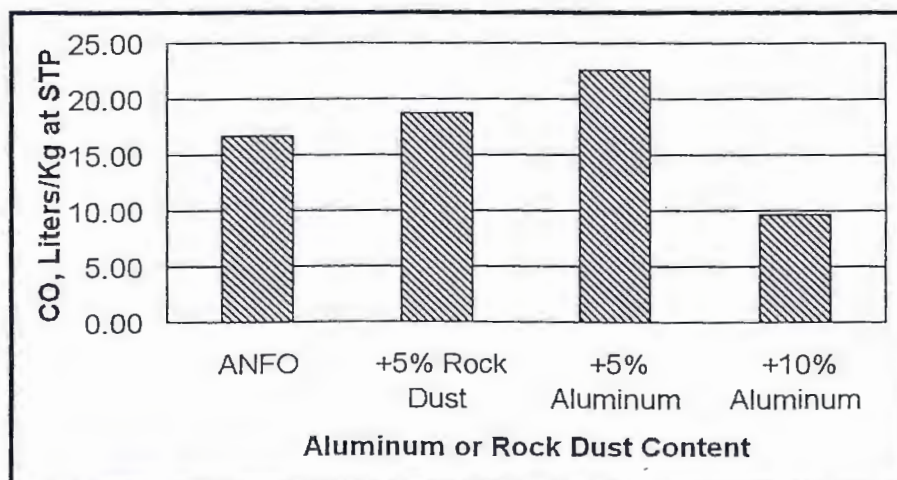


Figure 14. Effect of aluminum and rock dust content on carbon monoxide production.

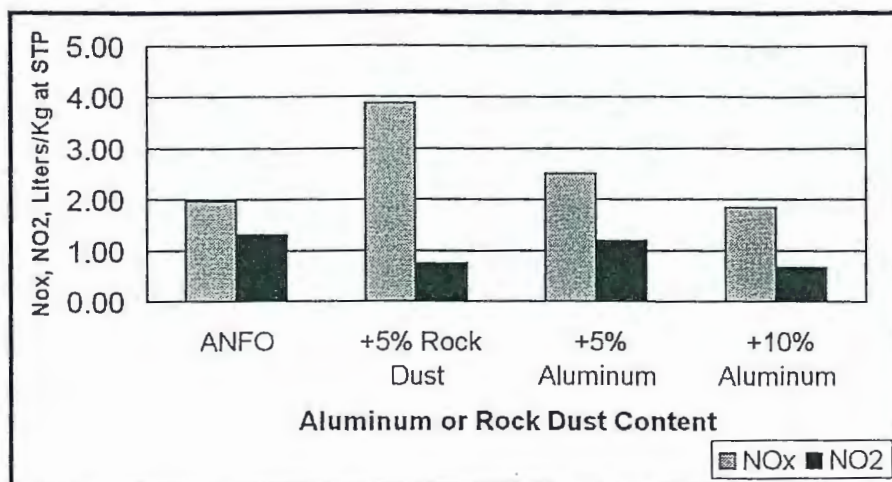


Figure 15. Effect of aluminum and rock dust content on nitrogen oxides and nitrogen dioxide production.

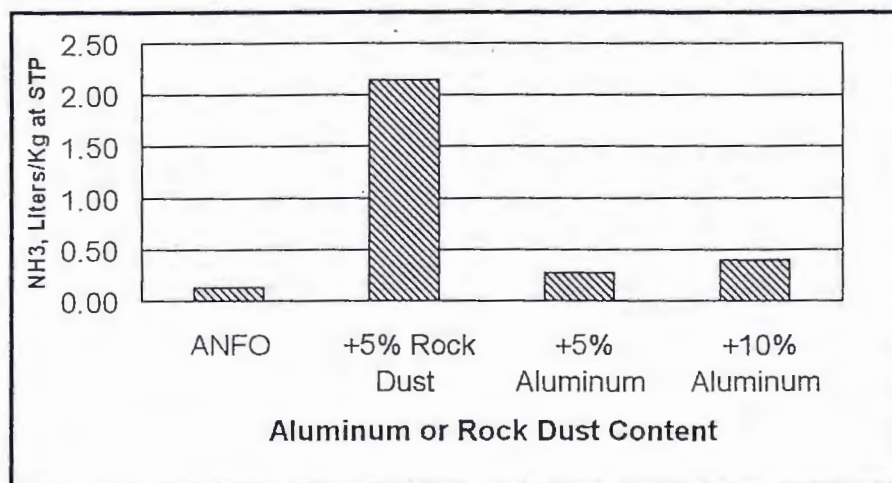


Figure 16. Effect of aluminum or rock dust content on ammonia production.