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FACTORS AFFECTING FUMES PRODUCTION OF AN EMULSION AND ANFO/EMULSION BLENDS

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ABSTRACT

In previous conferences the authors have reported on toxic fumes generated by the detonation of ANFO. The research reported here extends the earlier work to include an emulsion blasting agent and ANFO/emulsion blends. Explosive mixtures were shot in 4-inch Schedule 80 steel pipe (outer diameter 4.50 in (11.43 cm), inner diameter 3.83 in (9.72 cm)) in a chamber in the experimental mine at the Pittsburgh Research Laboratory (PRL). Following each shot, the fumes in the chamber were analyzed using on-line instrumentation.

A major goal of the research was to gain a better understanding of the factors that lead to the generation of toxic fumes in blasting operations. Earlier studies have suggested that the high nitrogen dioxide and nitric oxide concentrations in product clouds might be the result of the poor confinement provided by relatively weak ground strata or the exposure of the explosive to ground water prior to shooting the shot.

Various mixtures of ANFO and emulsion were detonated in 4-inch schedule 80 steel pipe (outer diameter 4.50 in (11.43 cm), inner diameter 3.83 in (9.72 cm)) and 4-inch galvanized sheet metal pipe (outer diameter 4.0 in (10.16 cm), inner diameter 3.97 in (10.08 cm)) to evaluate the effect of confinement. Explosive mixtures were also allowed to soak in water for one to two hours, one week, one month, and two months to determine which explosive mixtures would be degraded and observe what effect this degradation had on fume production. Results indicated that the production of nitrogen dioxide increased with low confinement of the detonating explosive and with exposure of the explosive to water.

INTRODUCTION

In February 1997 the authors presented a paper entitled "A Technique for Measuring Toxic Gases Produced by Blasting Agents" 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. In February of 2000 the authors followed up with a paper entitled "Factors Affecting ANFO Fumes Production" which investigated the effects of confinement and water contamination on ANFO's production of toxic fumes. The research reported here extends this study to include an emulsion blasting agent and ANFO/emulsion blends.

The generation of carbon monoxide and nitrogen oxides in blasting operations is a concern to blasters. Some mines have encountered problems with the generation of excessive nitrogen dioxide. Two causative

factors that have been suggested are poor confinement of the blasting agent when blasting in poorly consolidated soils and allowing the blasting agent to soak in water for an extended period prior to the blast. The research reported here centers on these two factors.

In 1996 Schettler and Brashear¹ conducted a study of the water resistance of ANFO/emulsion blends. They found that an ANFO/emulsion blend had to contain at least 40 pct emulsion to be considered water resistant, and suggested that 50 pct may be required to insure a water-proof product. In that research, all products were tested *after* immersion in water for at least one hour. In reality, blasting agents in the field may be loaded into wet boreholes up to a month or two prior to detonation. Further research is needed to determine whether the “water-proof” 50/50 ANFO/emulsion blend and other blends can resist the effects of degradation by water for a month or more.

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 in (1 m) thick, constructed of solid concrete block hitched 1 ft (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 (99050 liters/min), after which the chamber is vented using the mine’s airflow. The layout of the chamber is illustrated in Figure 1. Up to 1 O-lb (4.54-kg) explosive charges can be detonated in the chamber using a variety of confinements.

EXPERIMENTAL PROCEDURE

A 28-in (71-cm) length of 4-inch Schedule 80 seamless steel pipe (outer diameter 4.50 in (11.43 cm), inner diameter 3.83 in (9.72 cm)), and a 28-in (71-cm) length of 4-inch galvanized sheet metal pipe (outer diameter 4 in (10.16 cm), inner diameter 3.97 in (10.08 cm)) were chosen to provide confinement of the blasting agents. Prior to loading the pipe with explosives, a continuous velocity probe 30 in (76 cm) in length is secured to the inner surface of the pipe along its length, as described by Santis². The test fixture is water-proofed by sealing one end with plastic and caulking, after the velocity probe is secured. To expose the explosive to water, 1.36 liters of water is poured into the 4-inch Schedule 80 steel pipe, after which 10 lb (4.54 kg) of the commercial blasting agent minus its wrapper, or premixed ANFO/emulsion blend, is loaded into the pipe. The same procedure is used for the galvanized sheet metal pipe with the exception that 1.68 liters of water is poured into the pipe before loading the blasting agent; the quantity of water was chosen such that the explosive plus the water filled the pipe. Initiation was provided by a 2-in (5-cm) diameter, 2-in (5-cm) thick cast pentolite booster, initiated by a number 8 strength instantaneous electric detonator. The majority of the tests were done in duplicate, however there were a few tests that were not due to experimental difficulties.

Following detonation of an explosive in the chamber, the fan was turned on to uniformly mix the chamber atmosphere before fumes samples were taken out of the chamber through 1/4-in (0.6-cm) Teflon or polyethylene tubes for analysis. Teflon sample lines were used for nitrogen oxides and ammonia to minimize loss of these constituents to absorption on the tube surface. Vacutainer* samples were taken and sent to the analytical laboratory for analysis; this technique was appropriate for components that were stable in the Vacutainer, namely hydrogen, carbon monoxide, and carbon dioxide. Nitrogen oxides and ammonia were not amenable to analysis by the Vacutainer technique and were instead monitored with a chemiluminescence analyzer for nitrogen oxides, and a Chillgard Analyzer* for ammonia. Test samples were taken for seventy-three minutes after detonation of the explosive. 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

Figures 2, 3, 4, and 5 report on the generation of carbon monoxide and nitrogen oxides for a 70/30 ANFO/emulsion blend shot in steel and galvanized sheet metal pipes following immersion in water for one to two hours, one week, one month, and two months. For comparison, the blend was also tested in steel pipes and sheet metal galvanized pipe that contained no water. Results for shots in steel pipe indicate that, in most cases, the blend failed to detonate when loaded in the pipe with water for one week or longer. For the shots in galvanized sheet metal pipe, immersion of the blend in water for one to two hours was sufficient to cause detonation failure. One cause for failure of the blend to detonate can be understood by examination of Figure 6, a photo of the blend loaded in a 4-in (10-cm) diameter plexiglass tube with water. The 70/30-blend floats on top of the water, leaving a 5½-in (14-cm) layer of water between the booster and the explosive. The blend shot in the steel pipe without water yielded a velocity of 3,985 m/s, while the corresponding shot in galvanized sheet metal yielded a velocity of 2,857 m/s. The 3,985-m/sec velocity in steel pipe agrees well with the 4,230-m/s velocity reported by Schetler and Brashear for this blend. The lower velocity in the galvanized sheet metal pipe is to be expected since the confinement is insufficient to provide for good detonation.

The shots of 70/30 ANFO/emulsion blend in steel pipe produce about the same quantity of CO, 17-20 l/kg, when shot dry and immersed in water for one to two hours. Immersion of the blend in water had a detrimental effect as evidenced by the lower detonation velocity, 3,394 m/s versus 3,985 m/s, and the higher NO_x production, 14 l/kg versus 8.5 l/kg. Only the dry blend shot in the galvanized sheet metal pipe, yielding a velocity of 2,860 m/sec, CO of 27 l/kg, and NO_x of 9.5 l/kg. It is surprising to note that the blend immersed in water for one to two hours yields a higher velocity than the dry blend shot in galvanized sheet metal, while at the same time producing more NO_x. Normally one would expect that a higher velocity would represent better detonation reaction, hence less NO_x. Apparently the water has more of an effect on the blend than just lowering its velocity.

Figures 7, 8, 9, and 10 report on the generation of carbon monoxide and nitrogen oxides for a 50/50 ANFO/emulsion blend shot in steel and galvanized sheet metal pipes following immersion in water for one

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

to two hours, one week, one month, and two months. For comparison, the blend was also tested in steel pipes and sheet metal galvanized pipe that contained no water. Figure 7 shows that the 50/50 blend yielded identical velocities and fumes when shot in a steel pipe without water or exposed to water for one to two hours. When the 50/50 blend was loaded in the steel pipe containing water for a week or more, the results were mixed. In some cases the explosive detonated at a low velocity and in others no detonation was observed. In cases where no detonation was observed, the steel pipe was in one piece following the shot but the bottom section was bulged out from detonation of the booster. The question arises as to whether the measured fumes were produced by the booster alone, or were a combination of those from the booster and fumes from deflagrating explosive. Previously, tests shots were conducted to measure the fume production of a single booster; the fumes produced were much less than those measured after the shots of blasting agent. The booster by itself could not have produced the observed fumes. Detection of significant CO and NO_x fumes following each blasting agent shot indicated that the explosive burned, even if it did not detonate. Similar results were observed for the corresponding shots in sheet metal pipe. These results were significantly different from those for the 70/30 blend. The 70/30 blend either detonated, yielding CO and NO_x or it failed to detonate, yielding little CO and NO_x. Figure 11 shows the 50/50 blend loaded in a plexiglass tube with water for four weeks.

Figures 12, 13, 14, and 15 report on the generation of carbon monoxide and nitrogen oxides for the emulsion blasting agent shot in steel and galvanized sheet metal pipes following immersion in water for one to two hours, one week, one month, and two months. For comparison, the emulsion was also tested in steel pipes and sheet metal galvanized pipe that contained no water. In all cases, for loading in steel and galvanized sheet metal pipes without water and containing water, the emulsion detonated with a velocity in excess of 5,500 m/s, ie the emulsion detonated well under all test conditions. The emulsion shot in steel pipe consistently produced CO in the neighborhood of 13 l/kg, while the shots in galvanized sheet metal yielded 14 to 21 l/kg. Examination of the results for production of NO, NO₂, and NO_x yields very interesting results. The shots of emulsion loaded in steel pipe without water and loaded in the pipe with water for one to two hours yielded NO_x production at the low level of 1% l/kg. Similarly, the shots of emulsion loaded in galvanized sheet metal pipe without water and loaded in the pipe with water for one to two hours yielded NO_x production at the relatively low level of 3 l/kg. The emulsion loaded in steel pipe and galvanized sheet metal pipe with water for a week or more produced much higher levels of NO_x, about 6 l/kg for both. This result is very surprising when considering that the velocities for all shots of emulsion were about the same, in the neighborhood of 6,000 m/s (see Figure 17), and examination of the emulsion loaded in the plexiglass tube with water showed no apparent degradation of the emulsion.

DISCUSSION

Some of the results of this study are expected and some are unexpected. Schettler and Brashear had reported that 30 percent emulsion was not sufficient to make an ANFO/emulsion blend water resistant; they reported that a minimum of 50 pct emulsion was needed to make the blend water resistant; in their study, "water resistant" meant that the blend was unaffected when immersed in water for an hour. The study of 70/30 ANFO/emulsion blend reported here indicated that the blend would not detonate in the steel pipe when exposed to water for more than a day and would not detonate in the galvanized sheet metal pipe when exposed to any water. Consistent with the results of Shettler and Brashear, the 50/50 blend is water resistant for short exposures, but is not resistant for exposures of a week or more.

The results for shots of the emulsion are very surprising. When the emulsion was loaded in a pipe with water for up to 2 months, there was no visible effect on the emulsion and the detonation velocity looked very good, yet the NO_x production was very high. Normally, one would expect that if an explosive detonates well, its NO_x production will be low; excessive NO_x production is normally associated with blasting agents that do not detonate properly, either through degradation by water or some other mechanism. A blaster who normally loads blastholes with ANFO or a blend may switch to loading with 100 pct emulsion when wet boreholes are encountered, in the belief that the water won't degrade the emulsion. The emulsion in the wet holes will detonate at the expected velocity, leading the blaster to believe that the water exposure had no effect. However, the water may have degraded the emulsion such that it produces higher NO_x without the blaster realizing it. This could explain why blasts loaded with emulsion may perform well from shot to shot without regard to the presence of water in the blastholes, yet occasionally produce excessive NO_2 .

1. Schettler, L and S Brashear, Effect of Water on ANFO/Emulsion Blends in Surface Mine Blasting, Proceedings of the Twenty-Second Annual Conference on Explosives and Blasting Technique, Orlando, FL, February 4-8, 1996.
2. 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.

Acknowledgments

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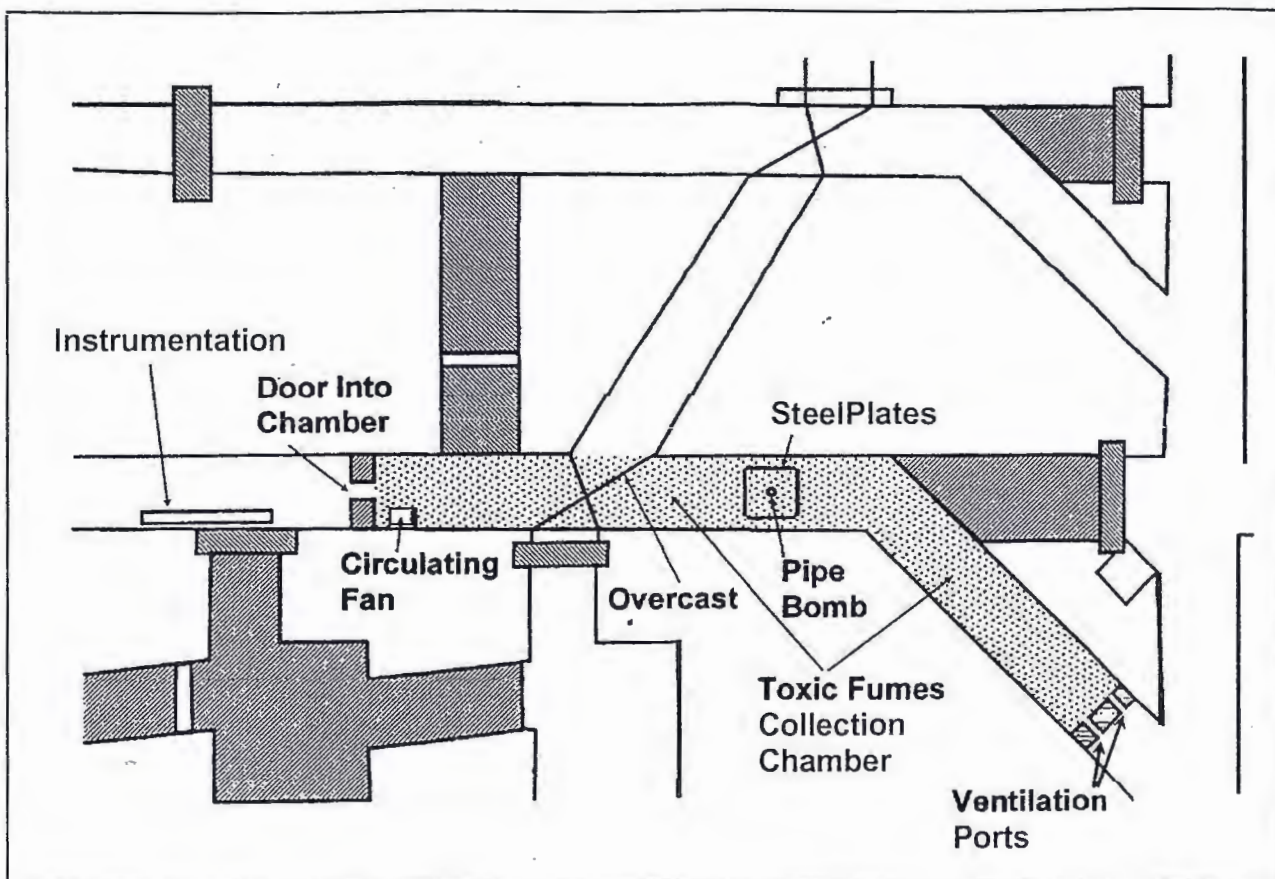


Figure 1. Research was conducted in a chamber in the underground mine at the NIOSH Pittsburgh Research Lab.

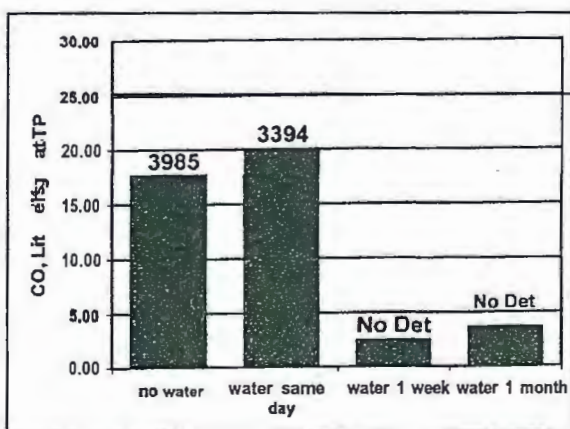


Figure 2. Carbon monoxide production of 70/30 ANFO/emulsion blend shot in steel pipe following exposure to water for up to a month. Numbers above bars are detonation velocity in m/s. "Water same day" means that the explosive was shot one to two hours after it was loaded.

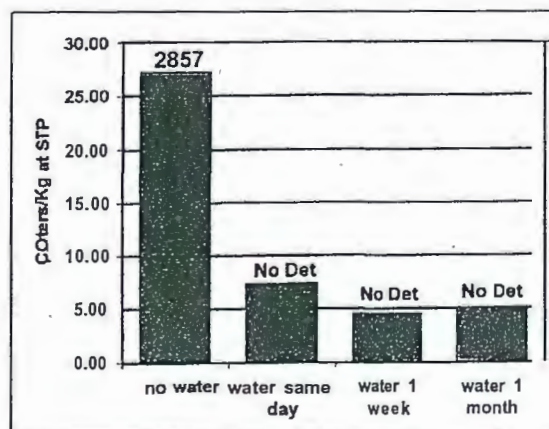


Figure 3. Carbon monoxide production of 70/30 ANFO/emulsion blend shot in galvanized sheet metal pipe following exposure to water for up to a month. Numbers above bars are detonation velocity in m/s.

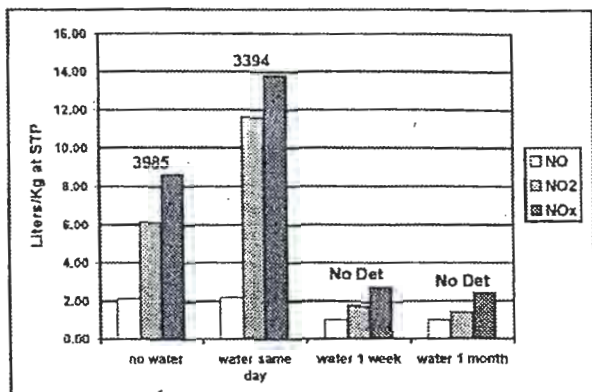


Figure 4. Nitrogen oxides production for 70/30 ANFO/emulsion blend shot in steel pipe following exposure to water for up to a month. Numbers above bars are detonation velocity in m/s.

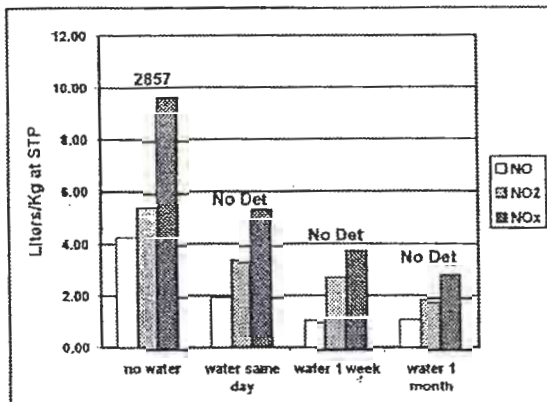


Figure 5. Nitrogen oxides production for 70/30 ANFO/emulsion blend shot in galvanized sheet metal pipe following exposure to water for up to a month. Numbers above bars are detonation velocity in m/s.

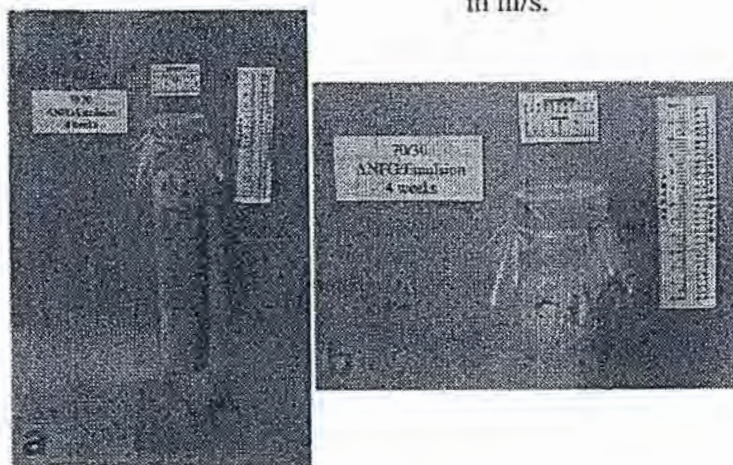


Figure 6. Figure shows the 70/30 ANFO/emulsion blend loaded in a 4-in (10-cm) diameter plexiglass tube following exposure to water for four weeks.

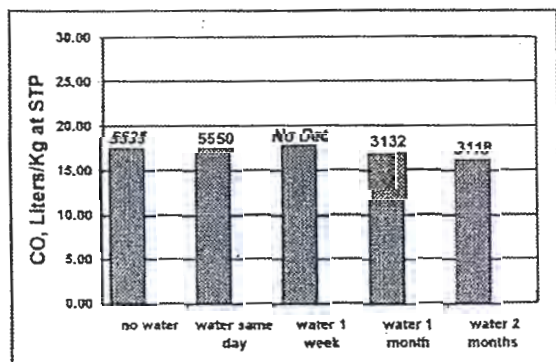


Figure 7. Carbon monoxide production of 50/50 ANFO/emulsion blend shot in steel pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.

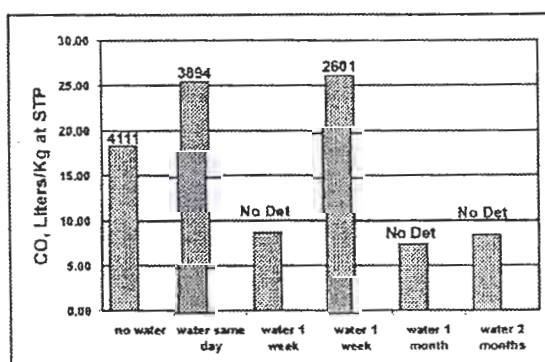


Figure 8. Carbon monoxide production of 50/50 ANFO/emulsion blend shot in galvanized sheet metal pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.

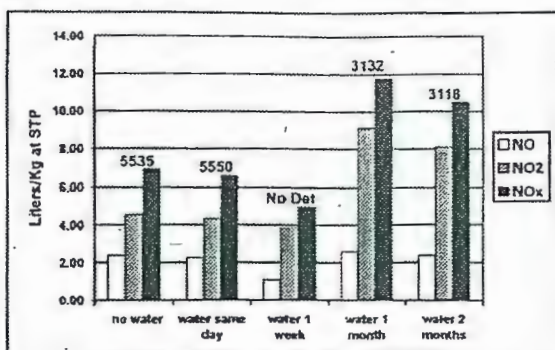


Figure 9. Nitrogen oxides production for 50/50 ANFO/emulsion blend shot in steel pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.

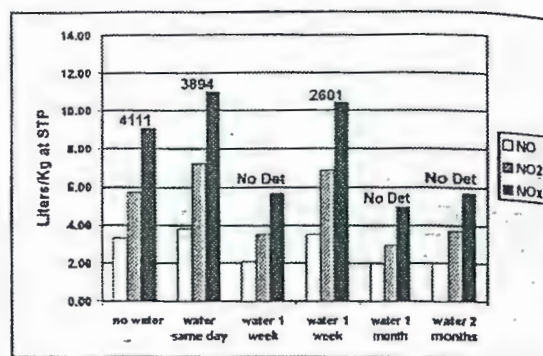


Figure 10. Nitrogen oxides production for 50/50 ANFO/emulsion blend shot in galvanized sheet metal pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.



Figure 11. Figure shows the 50/50 ANFO/emulsion blend loaded in a 4-in (10-cm) diameter plexiglass tube following exposure to water for four weeks.

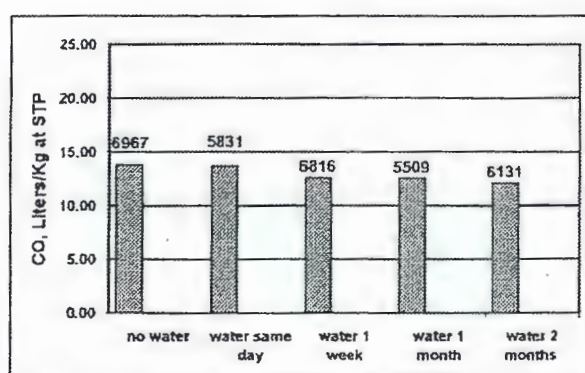


Figure 12. Carbon monoxide production of emulsion shot in steel pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.

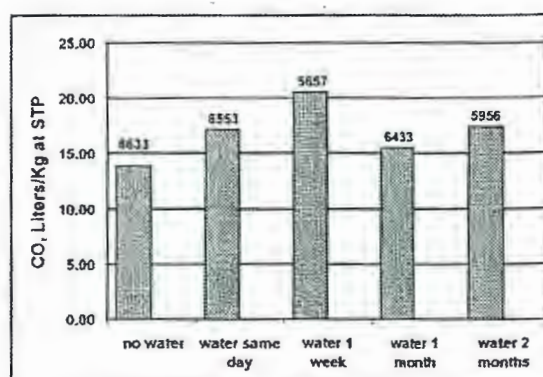


Figure 13. Carbon monoxide production of emulsion shot in galvanized sheet metal pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.

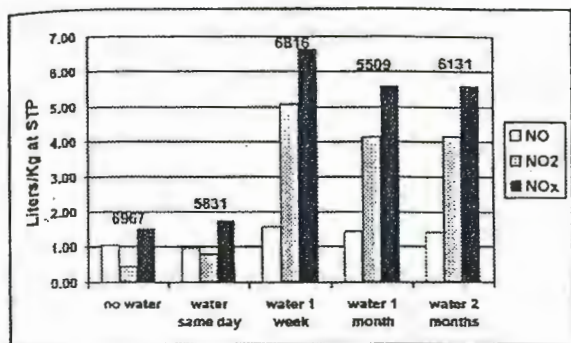


Figure 14. Nitrogen oxides production for emulsion shot in steel pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.

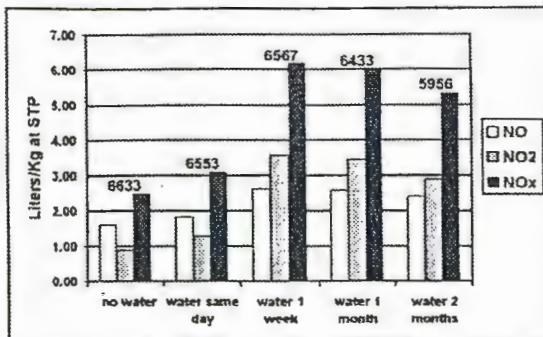


Figure 15. Nitrogen oxides production for emulsion shot in galvanized sheet metal pipe following exposure to water for up to two months. Numbers above bars are detonation velocity in m/s.

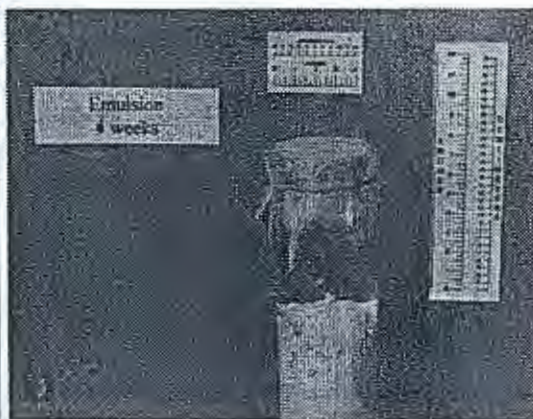


Figure 16. Figure shows the emulsion loaded in a 4-in (10-cm) diameter plexiglass tube following exposure to water for four weeks.

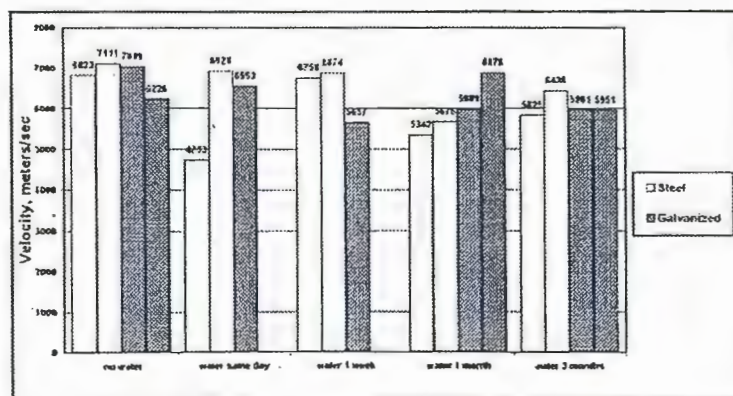


Figure 17. Detonation velocities for emulsion in steel pipe and galvanized sheet metal pipe.