

LOW TEMPERATURE LIMITS FOR MIXING RECYCLED OIL, DIESEL FUEL, AND AMMONIUM NITRATE TO MAKE ANFO-TYPE BLASTING AGENTS

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ABSTRACT

The Bureau of Mines conducted research to determine the safe operating conditions for using recycled (used) lubricating oil from mining equipment as a partial replacement for diesel fuel to make ANFO-type blasting agents. The use of recycled oil (RO) saves energy, reduces oil imports, and reduces mining costs.

Low ambient temperatures may cause these recycled oils to become too viscous for proper absorption by ammonium nitrate (AN) prills and result in poor blast performance, safety hazards, and environmental problems. To help quantify and resolve these issues, viscosity, mixing, and performance tests were conducted at various temperatures. Diesel fuels No. 1 and No. 2 were studied separately and in blends with 25, 50, and 75% RO.

Good quality ANFO mixes (94-6) were produced with dry absorbent prills and blended fuel (No. 1 diesel plus RO) at temperatures as low as -40°F (-40°C) with 75% No. 1/25% RO, and at -20°F (-29°C) with 50/50. Diesel fuel No. 2 also made good mixes as low as -30°F (-34°C) with 75% No. 2/25% RO, and at 0°F (-18°C) with 50/50.

Reference detonation velocity tests were conducted in 1.4" (3.6 cm) diameter steel pipe at 70°F (21°C) on No. 1 diesel ANFO (94-6), giving an average value of 9722 ft/s (2964 m/s). Comparison tests showed good ANFO performance at low temperatures. Blended fuel ANFO (75% No. 1/25% RO) mixed, loaded, and tested at -40°F (-40°C), produced an average velocity of 9247 ft/s (2818 m/s). A 50/50 blend gave a velocity of 8083 ft/s (2464 m/s) at -20°F (-29°C).

Based on these results, a practical field method has been developed to help evaluate whether a specific oil blend will mix properly with AN at a low ambient temperature. This method will help to promote the safe and reliable use of RO ANFO at low temperatures, with adequate performance.

INTRODUCTION

The United States mining industry consumed about 4.1 billion pounds of AN-based industrial explosives in 1992.¹ Of these, about 3.2 billion pounds was ANFO and ANFO-type blasting agents. The usual ANFO formulation contains about 94% by weight ammonium nitrate and 6% diesel fuel oil. If recycled (used) lubricating oil could be safely substituted for the fuel oil, up to about 27 million gallons could be consumed. This use of recycled oil (RO) can save energy and reduce oil imports. Consumption of used oil (generated by mines) on site, by blending it with diesel fuel to make ANFO-type blasting agents, could offer considerable cost savings to the industry.

Recycled oil in ANFO may create blasting safety and performance problems, as well as health and environmental concerns.^{2,3,4,5,6,7} In order to help define, quantify, and resolve these issues, the US Bureau of Mines (USBM) is conducting a research project to generate relevant experimental data to present to the mining industry and MSHA. The goal is to promote the safe and efficient use of RO in blasting agents on a year-around basis. Currently, because of a lack of data and definitive methods, the use of RO in ANFO (mixed at the mine site) is discontinued when winter temperatures are low in the US. The concern is that the cold oil will be too viscous for proper absorption by the AN prills. However, the use of recycled oil to make blasting agents in a cold climate has been demonstrated in Canada by McDonald et al.⁸ The focus of this USBM study is to provide experimental data on oil viscosity, ANFO mixing, and performance at lower temperatures.

In the US, the oil is collected mainly from engine crankcases, machines, and hydraulic systems. Non-chlorinated degreasing solvents can also be a minor constituent. Only petroleum based fluids can be used. Water, emulsions, glycols (antifreeze), and other synthetics must be excluded.

Recycled oil which contains an excessive amount of undesirable contaminants can change the sensitivity of ANFO. For example, gritty particles, heavy metals with catalytic properties, or gasoline could make the blasting agent cap sensitive, especially at high ambient temperatures. A high water or heavy oil content could reduce the sensitivity, especially at low ambient temperatures. Excessive contamination in the form of heavy metals, chlorinated solvents, PCB's, or other synthetic materials, could cause health and environmental problems.

Currently the permitted use of recycled oil in ANFO and heavy ANFO in the United States requires compliance with all applicable governmental agency regulations. This includes the Mine Safety and Health Administration (MSHA)⁹, the Environmental Protection Agency (EPA)¹⁰, and for nonmining uses the Occupational Safety and Health Administration (OSHA) has such jurisdiction (29 CFR 1905). MSHA regulations [30 CFR 57.6309(b) & 77.1304(a)] currently prohibit the use of crankcase oil in making ANFO. Only through the Petition For Modification (PFN) procedures presented in 30 CFR Part 44⁹ can these regulations be modified for the petitioning mine. MSHA issues a guide (to the PFN) called the "Generic Petition." It lists 20 detailed technical requirements covering the selection, treatment, storage, analysis, blending, and record keeping for the use of RO in ANFO. The full text is included in the Appendix of this paper (at the request of MSHA).

EXPERIMENTAL WORK

Preliminary Tests

Part of item 6 of the Generic Petition specifies: "The blend of recycled oil and diesel fuel (hereinafter called blended oil) shall not exceed 50 percent (by volume) recycled oil." In preliminary tests, the USBM found that blended oil containing up to 83% RO can be absorbed by AN prills at moderate temperatures to make ANFO (1% No. 2 diesel + 5% RO + 94% AN), which gives good detonation velocities at temperatures in the range of 59° to 86° F (15° to 30° C). See Table 1. However, there are a number of reasons why it may not be advisable to use more than 50% RO in blended oil. Due to the possibly higher carbon content of RO, the oxygen to fuel balance of the ANFO may be shifted (if 6% oil is used - as per Petition item 11). This could produce excessive levels of carbon monoxide. In addition, the concentrations of lead (and other heavy metals) in the blasting fumes would be increased. The ANFO may become cap sensitive due to increased levels of impurities from the RO, especially in hot conditions. Likewise, the water in RO may reduce sensitivity at some low temperatures (such as winter ambient conditions at northern mines).

Specifications of Oils and Ammonium Nitrate Used

The Bureau obtained two analyzed samples of RO (A and B) from a mine approved by MSHA to use ANFO made from RO on site. Sample A was used only for the preliminary tests (Table 1). Sample B was used for all other tests. These oils both met the EPA requirements for allowable levels of heavy metals (lead etc.), halogens (chlorinated solvents, and PCB's), and minimum flash point as listed in the Appendix (Generic Petition - item 4).

The oils are black in color, and a fine black residue settled out on standing. The residue is presumed to be a combination of carbon, graphite, and other insoluble materials. Because of this, all containers were shaken well before any sample was withdrawn. The particle size of this residue is controlled by item 3 of the MSHA Petition, which requires a 100 mesh (147 micron) filter.

Diesel fuels No. 1 and No. 2 are designated herein after as #1 and #2. Three different diesel fuel samples were bought. A locally obtained #2 was used only for the preliminary tests listed in Table 1. To insure proper specification fuel for the other work in this USBM study, certified, analyzed samples of #1 and #2 were purchased directly from a refinery. These were dyed dark red to help observe the mixing with AN prills.

Standard bulk blasting agent grade AN prills were purchased from a local explosive supplier. The bulk density is about 0.85 g/cc at room temperature. To maintain dry storage conditions, the prills were transferred to plastic buckets with two sealed inner plastic bags and lids.

Viscosity Measurements

To help evaluate the mixing of ANFO at low temperatures, viscosity measurements were made in the range of 70° to 5° F (21° to -15° C) on the following oils: RO, #1, #2, mixtures of #1 with 25, 50, and 75% RO, and mixtures of #2 with RO. The results are listed in Table 2. The viscosity measurements were made with a Brookfield * model LVDV II + (rotary spindle) digital readout viscometer, with UL Adapter attachment, except for the RO viscosities from 30° to 5° F (-1° to -15° C), which were made with the Small Sample

Adapter attachment. The temperature was controlled to within 0.1° C by an attached cooling jacket, connected to a bath circulating antifreeze solution. Each viscosity reading was checked at several different speeds. The values compared closely, indicating Newtonian behavior.¹¹ The 5° F (-15° C) values are at the lower operating temperature limit of the bath.

Obtaining accurate viscosities at lower temperatures would be impractical in the field and difficult in the laboratory. According to reference 11, many mineral oil- based automotive fluid lubricants are non-Newtonian at low temperatures, because they develop shear-rate-sensitive wax or wax-polymer gels. Accurate viscosity measurements on such gels would only allow for minimum stirring action, to avoid breaking down their structure. However, the RO used must be well stirred to put its carbon sediment in suspension.

Evaluation of ANFO Mixing Versus Temperature

To determine how well the oils and blends listed in the viscosity table would actually mix with AN prills, individual absorption test trials were performed at temperatures in the range of 70° F (21° C) to -40° F (-40° C). The results from 40° F (4° C) to -40° F (-40° C) are listed in Table 3. The methods used for cooling and mixing the oils and AN and evaluating the ANFO "quality of mix" are described in the Appendix.

Low Temperature Detonation Velocity

To evaluate the actual performance of ANFO at low temperatures, selected mixes from Table 3 were prepared cold. All ingredients and components of the explosive charge were precooled. The ANFO mixing and loading, into an insulated primed steel tube, was done inside a freezer. The tubing size was 1.88" o.d. (1.44" i.d.) x 16" long [4.77 cm (3.65 cm) x 40.6 cm]. A continuous velocity probe was mounted inside, and a 1/3 lb (165 g) cast pentolite primer was attached. This is the USA Gap Test For Solids (run at zero gap).¹² The charge temperature was monitored via an imbedded thermocouple. Reduced scale charges were made because all items had to be transferred in and out of a freezer through a 4" (10 cm) diameter opening, to maintain the low temperature and keep frost out. The cold assembled charges were transported in dry ice, and fired in a bunker at the temperatures listed in Table 4.

RESULTS

The absorption tests (Table 3) showed that blended oils will give good stable mixes with prills at quite low temperatures. After the brief one minute mixing time, and six hour standing time in the freezer, there was no noticeable unabsorbed oil draining to the bottom. In all tests, out of 6.00 g of oil originally weighed into each mixing jar, the maximum amount drained was 0.07 g (see Appendix for details). With dry absorbent prills good quality ANFO mixes were made at temperatures as low as -40° F (-40° C) with 75% #1/25% RO, and at -20° F (-29° C) with 50/50. Diesel fuel #2 also made good mixes as low as -30° F (-34° C) with 75% #2/25% RO, and at 0° F (-18° C) with 50/50. It should be noted that RO from other mines may have a higher viscosity than this sample. If so, a lower percentage of other RO (in the blended oil) may be necessary to obtain equal absorption at these temperatures.

Table 4 lists the detonation velocity values obtained from the reduced scale 1.4" (3.6 cm) diameter charges. Standard #1 diesel ANFO (94-6), which shot at an average of 9722 ft/s (2964 m/s) at 70° F (21° C), was

used as a reference. In comparison, the blended fuel ANFO 75% #1/25% RO, which was mixed, loaded, and shot at -40°F (-40°C), produced an average velocity of 9247 ft/s (2818 m/s). This was 95% of the reference value. A 50% #1/50% RO blend gave an average velocity of 8083 ft/s (2464 m/s) at -20°F (-29°C). This was 83% of the reference value. It should be noted that MSHA restricts the use of RO ANFO to surface mining only, and in holes with a minimum diameter of 6 inches (see Appendix, Generic Petition items 17 and 18).

RECOMMENDATIONS

Item 11 of the MSHA Petition states in part: "When low temperatures cause the blended oil to become too viscous for proper absorption (at least 6 percent fuel by weight) in the ammonium nitrate prills, use of the blended oil shall be suspended." To judge if a specific oil blend will mix properly with AN at a current ambient temperature, the following practical field method is suggested.

Use two sizes of glass jars, with screw lids having an inner seal. To prevent spillage when pouring the AN, one jar should fit inside the other (with the lids removed). Inside a building weigh 94.0 grams of AN or more (94%) into the smaller jar, and 6.0 grams of well-mixed oil (6%) into the larger jar. Seal the jars and place them outside (but under cover) along with a thermometer for at least four hours. Lay the oil jar on its side. When ready to mix, carry the jars (keeping oil jar horizontal) into an unheated shed or truck cab. Rotate the oil jar to see if it flows, and coat the jar wall as much as possible. Remove the caps, pour the AN into the oil jar, reseal, and shake for one minute. While shaking, swirl the prills so they tend to rub the oil off the jar wall. The prills should not crumble when frozen or when cooled and mixed with oil, if they do, the moisture content is probably too high. Rate the final mix as good, fair, or bad, as described in the Appendix and listed in Table 3.

A limiting factor in mixing blended oil and AN at low temperatures at mine sites is the suspended carbon in the oil settling to the bottom of the oil storage tank in the ANFO mix truck. To keep the blended oil uniformly mixed, a plumbing modification could be made. A recirculation loop could be added to mix the contents of the oil storage tank, just before spraying is started. Even at very low temperatures, if the blended oil can be sprayed uniformly onto dry absorbent prills, a good ANFO mix should be produced. Such a mix should give good performance when properly primed and loaded.

CONCLUSIONS

Recycled oil ANFO can be safely and successfully mixed and used at low ambient temperatures to give acceptable blasting performance. This is best accomplished by following the MSHA recommendations and regulations. Small scale mixing trials, using the suggested field method, will determine if a specific oil blend will mix properly with AN at a particular ambient temperature. If the blended oil and AN produce a good ANFO mix at low temperature, it should shoot properly in large, dry, well-primed holes.

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APPENDIX

Footnote: * Reference to specific brand names does not imply endorsement by the Bureau of Mines.

Refrigeration Equipment and Frost Control Method

To provide stable temperature conditions (within about $\pm 3^\circ\text{F}$ (1.7°C), two cooling units were employed. A Lab-Line Instruments, Inc.* model 3566, explosion-proof, upright refrigerator-freezer (in a single compartment) was used down to 20°F (-6.6°C). To control temperature and minimize frosting, the refrigerator door opening was covered with clear plastic. Two small flaps were cut to allow hand and arm access. In addition, the tests were done in winter with the room door open to the outdoors. Temperatures were monitored with thermocouples.

A Revco Scientific * model ULT-1050-5A chest freezer with digital set point temperature control was used from 10°F (-12°C) to -40°F (-40°C). The opening was fitted with cross support bars to hold up a flexible sheet of transparent cellulose acetate plastic (8 mil or 0.2 mm thick), which was taped in place. Two arm holes were cut out, and water proof plastic sleeves (cut from chemical splash coveralls) were sealed on with vinyl tape. The sleeves had elastic cuffs to seal at the wrists. For clear viewing, a small electric hot air blower was used to remove frost, and a 6 volt flashlight bulb (hanging from a wire) was installed inside. Since the freezer is 27" (69 cm) deep and mixing was done near the bottom, stable low temperatures could be maintained, with the room cold.

ANFO Mixing and Evaluation Method

To cool and mix the oils with AN, and observe the ANFO for oil separation, a three- jar procedure was used. At room temperature, 94.0 grams of AN was weighed into a 4 oz (125 cc) jar, 6.00 grams of oil in an 8 oz (250 cc) jar, and 6.00 grams of absorbent cotton in a quart (1000 cc) jar. These were tall-form, wide-mouth glass jars selected to fit inside of each other. Each was sealed with a screw cap (with an inner seal), and put in the freezer to cool over night. The oil jar was laid on its side. An additional 8 oz jar cap was made into a retaining ring by cutting out a 1.5" (4 cm) hole. This was used to hold an 80 mesh (175 micron) brass filter screen.

For each test the oil jar was first rotated in the horizontal position to observe if the oil would flow at the test temperature and to coat the jar wall as much as possible. The AN was then poured into the oil jar, and it was capped and shaken vigorously for one minute. In comparison the mixing time in an ANFO truck is about 30 to 45 seconds total for the vertical and horizontal augers. The degree of mixing (in the jar) was judged approximately as good, fair, or bad, depending on the number of prills which remained stuck on the glass by the oil. In a good mix the prills had "rubbed" most of the oil off the glass, and only a few prills and the AN fines remained stuck. In a fair mix up to about two square inches (13 cm^2) of prills adhered. In a bad mix, more of the glass area remained covered, so that it was difficult to see inside the jar even with the light bulb held against the glass.

After mixing, the cut-out cap (with filter screen) was attached and the jar was inverted and put inside the quart jar, with the filter pressing against the cotton. This assembly was left in the freezer for six hours, to allow any unabsorbed oil to drain down and be absorbed by the cotton.

MSHA Generic Petition (revised 9-1-94)

Compliance with MSHA regulations and the terms of an MSHA Proposed Decision and Order (PDO) does not necessarily constitute compliance with the regulations of other government agencies. For example, the practice of using used oil is subject to regulation in Title 40 Code of Federal Regulations which are administered by the U.S. Environmental Protection Agency (EPA). These regulations may impose more stringent or different requirements than required by MSHA. Therefore, Companies using used oil should ensure that they are in compliance with EPA and other applicable governmental agency regulations.

1. Only petroleum-based lubrication oil, which is recycled from equipment at the _____ Mine, shall be used for the purpose of blending with fuel oil in the creation of ANFO. Provisions shall be in place to ensure that the used oil is not contaminated with PCB's.

2. The used oils shall be recycled by filtering and then stored in a storage tank used exclusively for this purpose. The contents of the storage tank shall, after testing and meeting specifications as provided in item 4 below, be considered a batch and no additional oil or other products, with the exception of diesel fuel, shall be added until the contents of the tank have been fully depleted.

3. The two filters used in the filtering system shall be 60 mesh and 100 mesh arranged in series. These filters shall be cleaned/replaced on a regularly scheduled basis, and whenever the filter becomes clogged to the extent that a pressure of 50 psi exists at the pump outlet. The pump will regulate flow such that no oil passes into the tank when 50 psi occurs at the pump outlet. Records, including the dates, of all filter cleaning/replacing activities shall be kept on the mine property and made available to MSHA upon request for a period of at least three years.

4. Tests or analyses shall be conducted on each storage tank of recycled oil after the entire contents of the storage tank are thoroughly mixed and before blending with fuel oil to ensure that the used oil meets the following specifications:

(1) Arsenic	5 ppm maximum
(2) Cadmium	2 ppm maximum
(3) Chromium	10 ppm maximum
(4) Lead	100 ppm maximum
(5) Total Halogens	1,000 ppm maximum
(6) Flash point	100° F minimum

These specifications were derived from Table 1 in 40 CFR 279.11.

Flash point shall be verified using either a closed-cup ASTM D3941-90 test or open-cup ASTM D1310-86 (Reapproved 1990) test.

Any test result on the contents of a storage tank which is outside these specifications shall have the contents retested immediately. Any two consecutive test results on the same contents of a storage tank which are outside these specifications shall be reported to MSHA, and the contents of the storage tank shall not be blended with diesel fuel for use in making ANFO unless prior authorization is obtained from MSHA. The contents of the storage tank shall be considered a batch of recycled oil after it is proven to be within these specifications. Prior to filtering the oil in the storage tank, the oil shall be considered "used oil."

The frequency of testing and analyses for these specifications may be reduced upon the adequate submittal of records to the MSHA District Manager showing a demonstrated record of meeting the specifications, and a written authorization from the MSHA District Manager allowing the reduction in testing frequency.

5. The recycled oil shall be checked for water and ethylene glycol in the sight tube of the recycled oil storage tank prior to blending with diesel fuel. If either is observed, it shall be drained from the batch prior to blending.

High viscosity oils of 90W or above shall be restricted to less than 10 percent of the total quantity of recycled oil in the storage tank.

6. The blend of recycled oil and diesel fuel (hereinafter called blended oil) shall not exceed 50 percent (by volume) recycled oil. When blends exceeding 30 percent recycled oil are to be used, an absorption test on the recycled oil shall be performed prior to blending with fuel oil to determine the proper mixing ratio.

7. The recycled oil shall be mixed continuously while being blended with diesel fuel or immediately after adding the diesel fuel. Mixing shall ensure recirculation of at least three times the total volume of diesel fuel and recycled oil.

The blending date, blend mix ratio of diesel fuel to recycled oil for each batch, and the quantity in gallons of each ingredient in the blended oil batch shall be recorded. The gallons of each grade of diesel fuel shall also be recorded. These records shall be maintained at the mine property and made available to MSHA upon request for at least three years.

8. The recycled oil and blended oil shall not be modified by heating, adding additives (with the exception of diesel fuel), or in any other way that could change the relevant properties of the recycled oil.

9. The blended oil shall be remixed within 24 hours of being drawn into any bulk mixing vehicle. This remixing shall either recirculate at least 25 percent of the total volume of blended oil remaining in the storage tank or at least two consecutive viscosity samples, taken at least 5 minutes apart, shall be within 10 percent of each other immediately before loading into the bulk mixing vehicle.

10. Each new batch of blended oil shall be tested for sensitivity of the blended oil and ammonium nitrate prills to a No. 8 strength detonator prior to their loading in any holes. For each new batch of blended oil, this test shall be performed on at least 3 samples, each having minimum dimensions of 3-3/8 inches in diameter and 6-3/8 inches long. Each detonator shall be placed near the center of each sample. Each sample container must be non-rigid, such as paper products, to minimize confining effects upon initiation. Records of whether or not each sample detonated shall be maintained on the mine property and made available to MSHA upon request for at least 3 years.

11. When low temperatures cause the blended oil to become too viscous for proper absorption (at least 6 percent fuel by weight) in the ammonium nitrate prills, use of the blended oil shall be suspended. Viscosity tests and absorption tests at various temperatures may be performed to obtain their correlation with temperature. Once these correlations are obtained, in the field viscosity tests of the blended oil, at temperatures which are the same or below the temperature at which the holes are to be loaded, can be performed to verify proper absorption.

In the event proper absorption cannot be obtained as a result of high viscosity, additional diesel fuel may be added to the blended oil and thoroughly mixed. However, records of the blend date, blend mix ratio, and quantity of each ingredient as required by item 8 shall be maintained and made available for inspection by MSHA for at least three years. Retesting for sensitivity to a No. 8 blasting cap, as specified in item 10, shall not be required for this new blend.

12. The blended oil shall be transported and used in a closed system which prevents skin contact, inhalation of vapors, and ingestion of the ANFO products.

13. Blasting records for each shot employing the blended oil shall be maintained and identified as a specific blended oil batch. The records shall include the dates(s) of loading and blasting, weather conditions, type of initiation system(s), primer type(s) and size(s), size and depth of all borehole(s), number and location within the shot of all borehole(s) and all misfires, quantities of ANFO used in the shot, and quantities, as well as type, of emulsions (heavy ANFO) employed in the shot. The use of any plastic hole liners shall also be recorded. These records shall be maintained on the mine property and made available to MSHA upon request for at least 3 years.

Emulsions (heavy ANFO) shall not be used with the blended oil unless the manufacturer of the emulsion certifies compatibility of the emulsion and the blended oil. This compatibility certification shall be maintained on the mine property and made available to MSHA upon request.

14. Misfires which are reasonably suspected to have been caused by the blended oil shall be reported to the MSHA District Manager immediately.

15. Material Safety Data Sheets for the recycled oil and diesel fuels shall be maintained on the mine property and made available to MSHA upon request.

16. The oil blending facility shall not be put into operation until an on-site inspection is conducted by MSHA and detailed drawings of the entire used oil and blending facilities, including product flow directions, are submitted and approved by MSHA.

17. The prill/blended oil mixture shall not be used in blasting operations in confined spaces or underground.

18. The prill/blended oil mixture shall be used only on the _____ Mine property. Mixing of the blended oil and ammonium nitrate prill is intended for immediate use in loading holes and is not allowed to be stored as a mixed product. The prill/blended oil mixture shall be used in minimum hole diameters of 6 inches.

19. A lockout system shall be provided on the oil storage tank facilities to prevent unauthorized tampering. Only properly trained authorized personnel shall have keys to operate the lockout system.

20. Within 60 days after the petition is granted, revisions to the mine's approved 30 CFR Part 48 training plan shall be submitted to the District Manager. These proposed revisions shall include initial and refresher training regarding compliance with the petition for modification.

TABLE 1 - DETONATION VELOCITY OF 94-6 ANFO MIXTURES VERSES TEMPERATURE
Made With No. 2 (#2) Diesel Fuel, and Mixtures With Recycled Oil (RO)
Shot In 4" (10.2 cm) diam. Steel Pipe, With a 1/2 lb (255 g) Primer,
At a Loading Density of 0.83 to 0.86 g/cc.

OIL(S) IN ANFO (94% AN + 6% TOTAL OIL)	DETONATION VELOCITY		TEMPERATURE	
	ft/s	m/s	° F	° C
6% #2 Diesel Fuel (100% #2)	12,200 ¹	3,730 ¹	59	15
3% #2 + 3% RO (50 - 50)	10,800	3,280	68	20
2% #2 + 4% RO (33 - 67)	12,500	3,810	77	25
1.5% #2 + 4.5% RO (25 - 75)	12,300	3,750	68	20
1% #2 + 5% RO (17 - 83)	13,000	3,970	86	30

¹ Explosive Co. advertising literature velocity values for ANFO, shot in the ground (in 4" diam./10.2 cm holes), vary from 12,500 to 12,900 ft/s (3810 to 3930 m/s), at a loading density of 0.85 g/cc.

TABLE 2 - VISCOSITY VERSES TEMPERATURE OF OILS USED IN MAKING ANFO
Recycled Oil (RO), No. 1 (#1) and No. 2 (#2) Diesel Fuel, and Mixtures

TEMPERATURE		VISCOSITY IN CENTIPOISE								
° F	° C	RO	#1	75% #1+ 25% RO	50% #1+ 50% RO	25% #1+ 75% RO ¹	#2	75% #2+ 25% RO	50% #2+ 50% RO	25% #2+ 75% RO ¹
70.0	21.1	156 ²	1.52	3.19	7.92	26.9	2.59	5.29	12.6	37.3
60.0	15.6	217	1.67	3.61	9.39	34.1	2.93	6.14	15.3	47.9
50.0	10.0	312	1.86	4.13	11.2	44.2	3.35	7.31	19.1	63.8
40.0	4.4	471	2.08	4.70	13.5	56.0	3.85	8.80	24.2	87.2
30.0	-1.1	680	2.37	5.53	16.9	76.6	4.55	10.6	31.8	121
20.0	-6.7	1092	2.69	6.52	21.4	106	5.41	13.2	41.8	173
10.0	-12.2	1822	3.07	7.80	27.4	148	6.45	16.6	56.4	254
5.0	-15.0	2379	3.27	8.51	30.9	174	7.07	18.8	65.9	313

¹ Currently the MSHA maximum permitted % of RO is 50% in mixed oil.

² Comparison values of new vehicle lubricating oils at 70° F (21.1° C):
 SAE 30 HD motor oil = 236 cP, SAE 40 HD motor oil = 451 cP

**TABLE 3 - ABSORPTION VERSES TEMPERATURE OF OILS BY AN PRILLS
IN MAKING 94-6 ANFO
No. 1 (#1) and No. 2 (#2) Diesel Fuel, and Mixtures With Recycled Oil (RO)**

TEMPERATURE		QUALITY OF MIX (94-6 ANFO)							
° F	° C	#1	75% #1+ 25% RO	50% #1+ 50% RO	25% #1+ 75% RO ¹	#2	75% #2+ 25% RO	50% #2+ 50% RO	25% #2+ 75% RO ¹
40	4	Good	Good	Good	Good	Good	Good	Good	Good
30	-1	Good	Good	Good	Good	Good	Good	Good	Good
20	-7	Good	Good	Good	Good	Good	Good	Good	Fair
10	-12	Good	Good	Good	Fair	Good	Good	Good	Bad
0	-18	Good	Good	Good	Bad	Good	Good	Good	--
-10	-23	Good	Good	Good	--	Good	Good	Fair	--
-20	-29	Good	Good	Good	--	Good ²	Good ³	Bad	--
-30	-34	Good	Good	Fair	--	Good ⁴	Good ³	--	--
-40	-40	Good	Good	Bad	--	Good ⁵	Fair ³	--	--

¹ Currently the MSHA maximum permitted % of RO is 50% in mixed oil.

² Waxy skin formed on top of oil, but oil flowed when jar rotated.

³ Oil flows when jar rotated.

⁴ Waxy, oil would not flow unless jar shaken.

⁵ Waxy, oil would not flow when jar shaken, but did flow and was absorbed when shaken with AN prills.

**TABLE 4 - DETONATION VELOCITY OF 94-6 ANFO MIXTURES VERSES TEMPERATURE
Made With #1 and #2 Diesel Fuel and Mixtures With Recycled Oil (RO)
Shot In 1.4" (3.6 cm) diam. Steel Pipe, With a 1/3 lb (165 g) Primer,**

OIL(S) IN ANFO (94% AN + 6% TOTAL OIL)	DETONATION VELOCITY		TEMPERATURE OF MIXING, LOADING, AND SHOOTING	
	ft/s	m/s	° F	° C
#1 Diesel Fuel	9763 9682	2976 2951	+70	+21
#2 Diesel Fuel	9997 9865	3047 3007	+70	+21
50% #1 + 50% RO	8036 8130	2449 2478	-20	-29
75% #1 + 25% RO	9259 9235	2822 2815	-40	-40