Identification of Fuel Oil in Absorbent and Non-absorbent Surfaces in a Site of Ammonium Nitrate-Fuel Oil (ANFO) Blast

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ABSTRACT: The investigation of explosion covers incidents ranging from accidents in the home or workplace to major terrorist attacks. In the scene of an explosion, the forensic scientists try identify the kind of explosion occurred, the materials involved and assists the police investigation. Legitimate explosives include fireworks and blasting materials used in quarrying. The current trend involves misuse of certain legitimate chemicals, widely available to the general public, as precursors to homemade explosives. ANFO on quarry explosives remains one of the most commonly used products in quarry blasting. The explosive is misused by the perpetrators for criminal activities such as blast fishing, Automated Teller Machine [ATM] bombings and terrorism. Another form of blasting activities wherein the unskilled perpetrators prepared IEDs with improper weight ratio of AN and FO to trigger explosions which caused ineffective explosions and damages that are reflected in the crime scene. The objectives of this ANFO blasting project were to identify the presence of oil residues on absorbent and non-absorbent surfaces in sites of blasts; to study the extent of fuel oil travels from the blast crater after the blast; and to study different ANFO blastings using different AN and FO mixing proportions. The result of controlled ANFO surface blasting study showed the possibility of identifying the fuel oil in different surfaces placed in different known distances. The formation of a fuel oil flash pattern in the crater reflected the improper fuel and oil combination that formed a valuable finding in the ANFO blast scene investigation.

Keywords: Forensic science, ANFO blast, absorbent & non-absorbent surfaces, flash pattern.

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Introduction

Fire and explosions are both the result of combustion reactions, where a fuel and oxygen react, sometimes violently and instantaneously, to give off large amounts of energy [1]. Fuels commonly found in commercial explosives include diesel fuel, carbon, PETN, TNT, smokeless powder, monomethylammonium nitrate, and monoethanolammonium nitrate [2]. The most common oxidizer used for explosion is ammonium nitrate, sometimes sodium nitrate and calcium nitrate [2]. Explosives are solid, liquid or gaseous substances which, when suitably initiated, suffer rapid decomposition with liberation of heat and production of large volumes of gas at high pressure. [3]. Explosives are used for a wide variety of purposes but their main applications lie in mining and quarrying and in construction and demolition work [4]. Ammonium Nitrate-Fuel Oil (ANFO) remains one of the most commonly used products in quarry blasting. ANFO, a mixture containing 94% AN and 6% fuel oil, is probably the most commonly used explosive material in the world today [5].When it is used illegally and to cause harm it is generally known as a bomb. The current trend is the problem of the misuse of widely available chemicals such as ammonium nitrate as precursors to homemade explosives.

Knowledge of preparing explosives from ammonium nitrate (AN) and common availability of ingredients are used by offenders and terrorists [6]. ANFO is inexpensive and safe to handle. The availability of AN in the form of fertilizers makes it a readily obtainable ingredient for homemade explosives [7]. Home-made explosives, in turn, are the tool most preferred by terrorists and other criminals to perpetrate attacks. While the majority of homemade bombs are still simple in their construction and functioning, the percentage of the more complex bombs employed has risen [8]. The analysis and detection of explosives continues to be a global issue of prime importance.

The forensic science community is interested in examining the blasting scenes and analyzing post-blast explosive residues, chemicals and materials associated with bomb making [9]. AN and FO are neither explosive by itself, but, is a high power explosive when mixed in the proper weight ratio. ANFO mixtures are a favourite of car and truck bombers. It was the explosive used and identified in 1993 the world trade centre bombing[1], 1995 bombing of the Murrah federal building in Oklahoma city[1], 2005 bombing of rush-hour London buses and trains, 2010,2011 serial bombings in India and so on. The aim of this pilot ANFO blasting project, the first kind in Malaysia was to identify the presence of fuel oil residues on absorbent and non-absorbent surfaces in a site of ANFO blasts, and to study the extent of fuel oil travels from the crater after the blasts and also to study ANFO blastings using different AN and FO proportions.

Materials and methods

Place of blasting exercises

The blasting exercises were conducted with the technical assistance from Tenaga Kimia Sdn Bhd campus, Batu Arang, Selangor (Fig 1) upon obtaining permission from the CEO and police.

Fig1: Tenaga Kimia Sdn. Bhd. factory campus, Batu Arang, Selangor, Malaysia

Absorbent and nonabsorbent surfaces used to collect post blast fuel oil residue

Selected absorbent surfaces like kitchen towel pieces, A4 paper, soil, dry leaves, cotton, plywood and nonabsorbent surfaces like aluminum sheets, PVC sheets, glass plates, rubber sheets, plastic sheets, ceramic tiles were used to obtain oil residue after the blasts. These surfaces were kept side by side in circular form around the centre point of explosion. The blasting exercises were conducted by keeping the surfaces from the centre point to distances of 5m, 7m and 9m radius as shown in figure 2.

The circle was divided into four parts and each part consists of six different types of absorbent surfaces. Hence, there were 24 non-absorbent surfaces in one circle or distance. Blasting exercises were conducted by keeping the absorbent and non-absorbent surfaces in intact around the crater point from a distances of 5 m, 7 m and 9 m respectively.

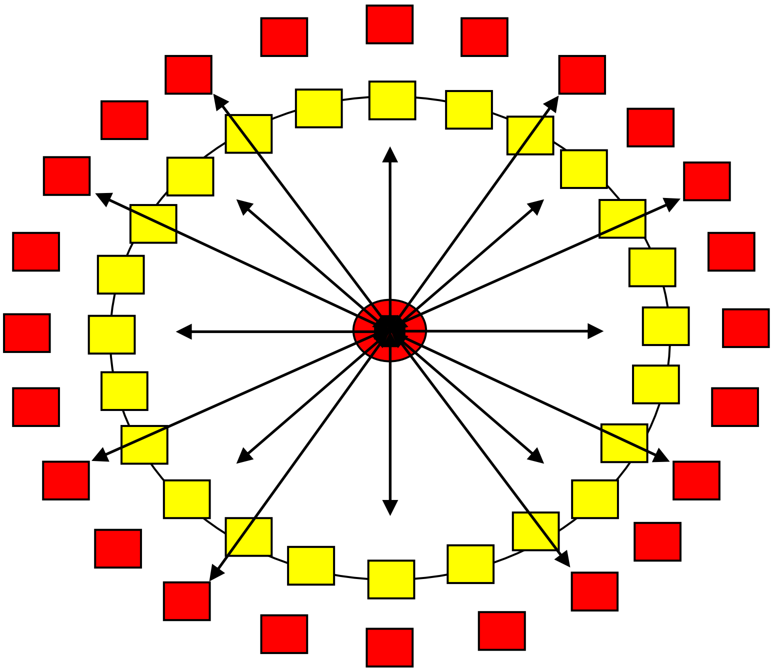

Fig 2: Arrangement of absorbent & non-absorbent surfaces around the blasting point

Chemicals used for blasting
Ammonium nitrate prills
Diesel oil
Emulsion explosive as booster [Emulux 150]
Electric detonator

Apparatus and other materials used
Measuring cylinder (10 mL)
Beaker (100mL)
Balance
Glass droppers
Measuring tape
Gloves
Rubber bands
Raffia ropes
Packing materials
Bricks to support

Preparation of ANFO
Since ANFO is a secondary high explosive, three-step explosive train was required to conduct the blasting exercises. In this study, three-step explosive train consists of electrical detonator, emulsion explosive and ANFO mixture. Instant electric detonators with No. 8 cap and Emulex® 150 (25x200 mm, 0.120 kg) as emulsion explosives were used for the blasting exercise as shown in figure 3. As per norms, ANFO comprises of explosive-based AN prills and commercial diesel fuel. As per the research requirement, ANFO mixtures were prepared in various proportions as shown in Table 1. Other devices used in this exercises were digital ohmmeter, blasting machine and connecting wires.

Table 1: Varying proportions of AN and FO

No.	Ratio of ANFO (by weight)	AN (kg)	FO (ml) (Diesel fuel)
1	94:6 (standard)	0.5	38.35
2	90:10	0.5	66.78
3	80:20	0.5	150.24
4	60:40	0.5	400.60
5	50:50	0.5	600.96

** Density of FO (Diesel) = 0.832 kg/L

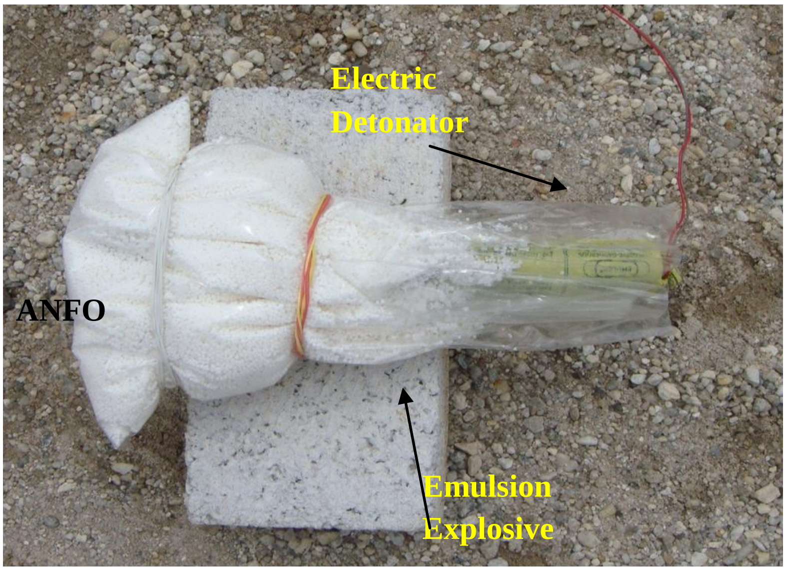

Fig 3: Three-step explosive train used in the blasting exercises.

Blasting procedure and sample collection

The plastic bag containing ANFO mixture (mixing ratio of 94:6 by weight for standard) was connected to detonator through booster was placed on a designated centre point in the blasting site surrounded by absorbent and non-absorbent surfaces placed at known distances as shown in Figure 2 and Table 2.

The leg wires of the instant electric detonator were connected to the blasting machine through the firing cable forming an electric circuit. The distance between the blasting point and the blasting machine was about 60 meter.
A digital ohmmeter was used to test the electric circuit to ensure that there was no open or short circuit.

The blastings were initiated using the capacitor blasting machine (exploder). This blasting machine was hand-activated generator that charged a bank of capacitors. When fully charged, a neon light glown and reached high potential of 1200 V. By pressing the firing button, the capacitors discharged the potential into the firing circuit and ignited the detonator and thereby an explosion occurred.

This procedure was repeated with different ANFO mixing ratios of 94:6, 90:10, 80:20, 60:40 and 50:50, keeping the absorbent and nonabsorbent surfaces at a distance of 5 m , 7m and 9 m (Table 2) from the center point.
All blasting exercises were conducted by an authorized licensed shot firer and the post blast residue on absorbent and nonabsorbent surfaces were collected and preserved as suggested by PDRM and JKM . The post blast residues collected from the ANFO mixing ratios of 94:6, 90:10 and 80:20 were analyzed in GC-MS at Chemistry Department Malaysia, PJ, Selangor and the mixing ratios of 60:40 and 50:50 were analyzed at Fire Investigation Laboratory, Fire and Rescue Department Malaysia, Kuala Terengganu, with the assistance of JKM and fire department staff as per their standard operation procedure and then recorded the findings.

Table2: Different mixing ratios of AN and FO and the interdistance between the centre blasting point and absorbent, nonabsorbent surfaces placed around with known distances.

No.	ANFO mixing ratio (by weight)	Distances between blasting point and surfaces
1	94:6	5m, 7m, 9m
2	90:10	5m, 7m, 9m
3	80:20	5m, 7m, 9m
4	60:40	5m, 7m, 9m
5	50:50	5m, 7m, 9m

Results

The controlled surface ANFO blast study indicated that the fuel oil could travel to a distance of 9m and found in the absorbent and nonabsorbent surfaces after the blast when the AN and FO mixing ratios were 94:6, 90:10 and 80:20. When the AN and FO mixing ratios were 60:40 and 50:50, the fuel oil could travel up to 5m only (Table 3) and also observed characteristic FO flash pattern in the crater (Fig 4-5), a novel finding in this controlled blast exercises. Selected mass chromatograms (Fig 6-10) and the hydrocarbon presence and retention time are presented here (Table 4-6).

Table 3: Varying ANFO mixing ratios: Detection of fuel oil in post-blast residue and formation of fuel oil flash pattern

ANFO mixing ratio (by weight)	Soil samples collected at the seats of explosion	Detection of oil residue collected in post blast residues in absorbent and nonabsorbent surfaces at the distance between blasting point and absorbent , nonabsorbent surfaces (m)		
		5	7	9
94:6	Detected FO	Detected FO	Detected FO	Detected FO
90:10	Detected FO	Detected FO	Detected FO	Detected FO
80:20	Detected FO	Detected FO	Detected FO	Detected FO
60:40	Detected FO and FO flash pattern	Detected FO	Undetected FO	Undetected FO
50:50	Detected FO and FO flash pattern	Detected FO	Undetected FO	Undetected FO

Fig 4: FO flash pattern formation the in the crater (60:40)

Fig 5: FO flash pattern formation the in the crater (50:50)

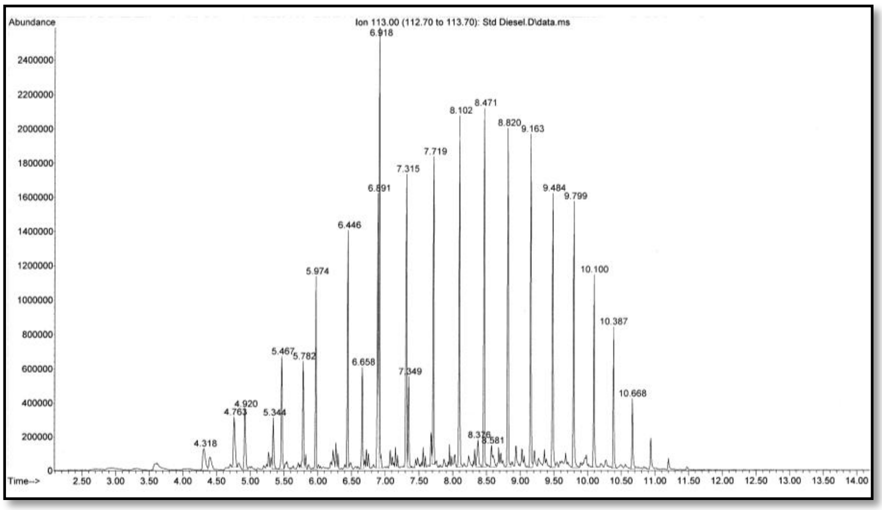

Figure 6: Mass chromatogram for m/z 113 of standard of fresh diesel fuel

Table 4: Identification of hydrocarbons present in the fresh diesel standard and its retention time (min)

No. of carbon atoms	Compound name	Retention time (min)
C12	Dodecane	4.318
C13	Tridecane	4.920
C14	Tetradecane	5.467
C15	Pentadecane	5.974
C16	Hexadecane	6.446
	Pristane	6.891
C17	Heptadecane	6.918
C18	Octadecane	7.315
	Phytane	7.349
C19	Nonadecane	7.719
C20	Eicosane	8.102
C21	Heneicosane	8.471
C22	Docosane	8.820
C23	Tricosane	9.163
C24	Tetracosane	9.484
C25	Pentacosane	9.799
C26	Hexacosane	10.100
C27	Heptacosane	10.387
C28	Octacosane	10.668

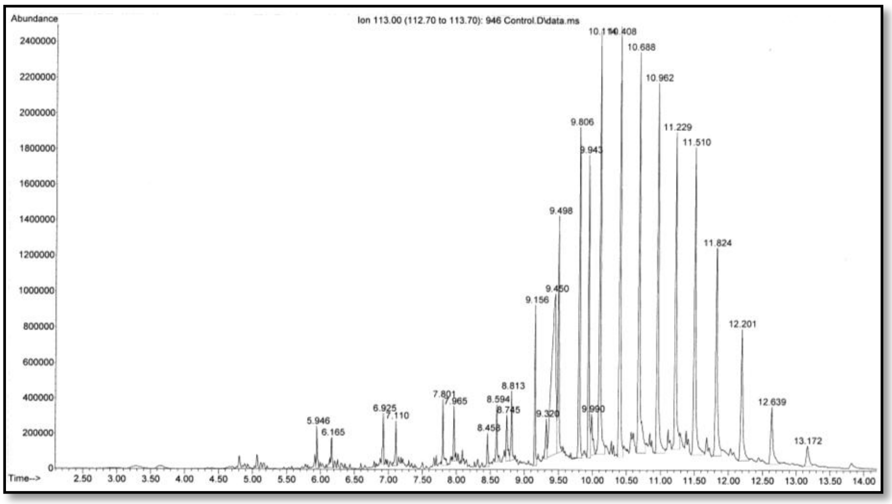

Figure 7: Mass chromatogram for m/z 113 of 94:6 soil sample collected at the seat of explosion.

Table 5: Identification of hydrocarbons present in the post blast(94:6) soil sample collected at the seat of explosion and its retention time (min)

No. of carbon atoms	Compound name	Retention time (min)
C21	Heneicosane	8.458
C22	Docosane	8.813
C23	Tricosane	9.156
C24	Tetracosane	9.498
C25	Pentacosane	9.806
C26	Hexacosane	10.114
C27	Heptacosane	10.408
C28	Octacosane	10.688

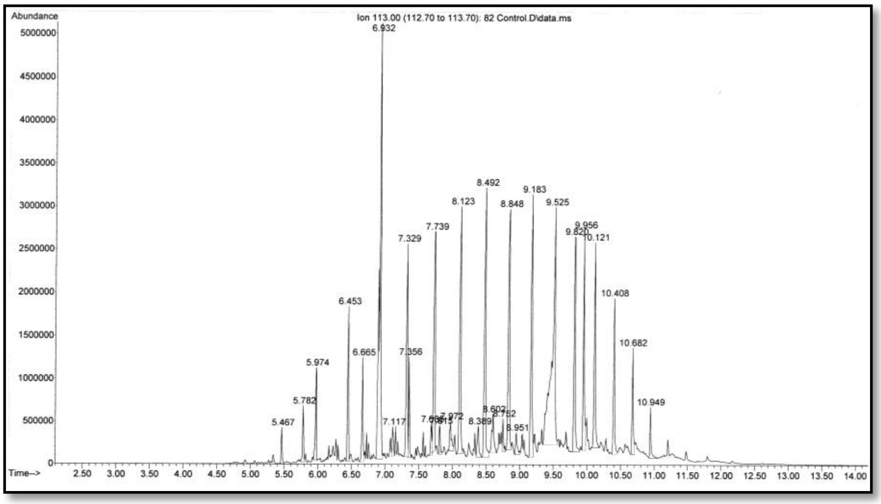

Figure 8: Mass chromatogram for m/z 113 of 80:20 soil samples collected at the seat of explosion

Table 6: Identification of hydrocarbons present in the post blast (80:20) soil sample collected at the seat of explosion and its retention time (min)

No. of carbon atoms	Compound name	Retention time (min)
C17	Heptadecane	6.932
C18	Octadecane	7.329
	Phytane	7.356
C19	Nonadecane	7.739
C20	Eicosane	8.123
C21	Heneicosane	8.492
C22	Docosane	8.848
C23	Tricosane	9.183
C24	Tetracosane	9.525
C25	Pentacosane	9.820
C26	Hexacosane	10.121
C27	Heptacosane	10.408
C28	Octacosane	10.682
C29	Nonacosane	10.949

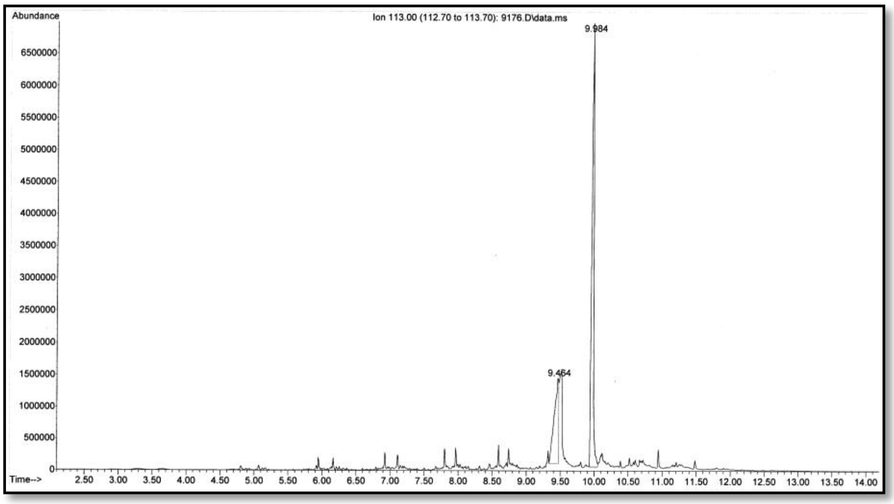

Figure 9: Mass chromatogram for m/z 113 of 90:10 dry leaf samples at 7 m distance.

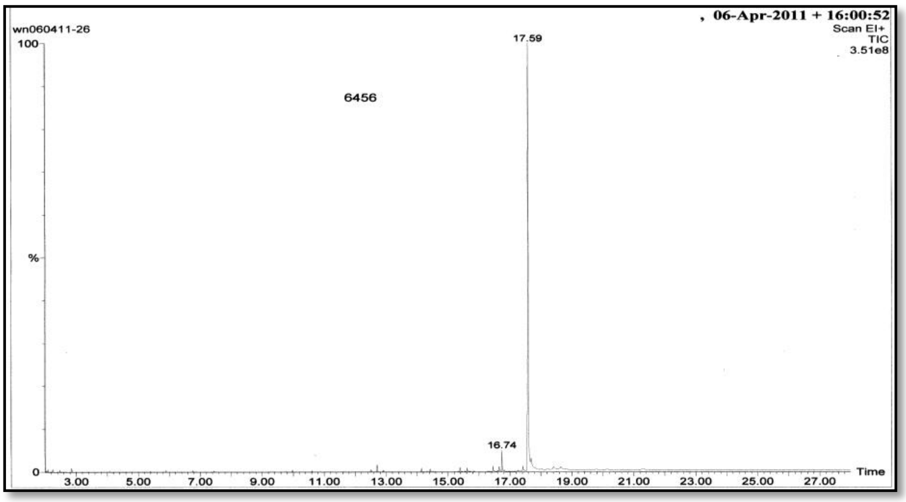

Figure 10: Mass chromatogram of 60:40 dry leaf sample at 5 m distance.

Discussion

The role of Forensic Scientists in examining explosives and their debris both in the crime scene and forensic science laboratory is largely concerned with those explosives that are illegally used. Legal or legitimate use of explosive is mainly by military and certain industries. The explosives used in industries like quarries for example, ammonium nitrate and fuel oil, are not generally termed as bombs since they are used for legitimate mining purposes only. In contrast with the above two types of explosives, there is another category generally known as Improvised Explosive Devices (IED). These are bombs manufactured illegally by miscreants and these do not conform to any specifications.

During this surface blasting exercise, the weather condition was fine with moderate temperature without rain and wind. The environmental conditions such as weather patterns, rain, and wind may be considered [10] during the blast which influence the effects of blast and the travelling distance of oil residue. The controlled ANFO surface blasting study [11] here using 500g of AN indicated that the fuel oil could travel to a distance of 9m and found in the absorbent and nonabsorbent surfaces when the ANFO mixing ratio was standard 94:6 or nearly standard proportion viz. 90:10 and 80:20. When the ANFO mixing ratios were deviated from the standard mixing ratio to improper mixing proportions viz. 60:40 and 50:50, the fuel oil could not travel beyond 5m. But invariably the post blast fuel oil residue could be detected in all the blast crater marks irrespective of the mixing proportions used for blastings. Another interesting feature observed was the formation of FO flash pattern with varying diameter. That is, the flash diameter formed from 50:50 mixing ratio is smaller than the flash diameter formed from 60:40 mixing ratio.

According to the theory of ANFO energy output, as the percentage of fuel oil increases from the standard ANFO proportion 94: 6, the energy output would decreases [12] as shown in Fig 11 and hence fuel oil could not be detected beyond 5m i.e. when the fuel oil proportions were 40 and 50. In these two fuel oil proportions, variations in size of the flash pattern were observed i.e. higher the fuel oil proportion, smaller the diameter of the fuel oil flash pattern. These findings would form a base for the crime reconstruction and be a clear lead to the forensic investigators to solve the crime in the ANFO blasting scenes.

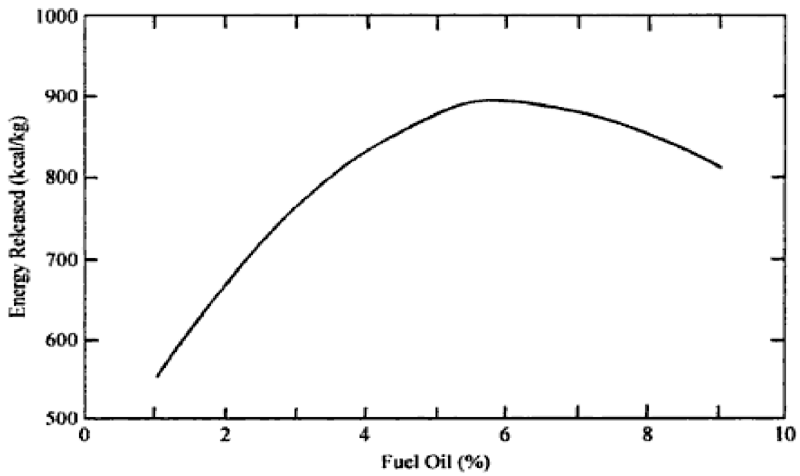

Fig11: Relative ANFO energy as a function of the percent fuel oil used

Conclusions

Further ANFO blast research is needed in future for the detailed study on fuel oil flash pattern formation in the crater for application in blast scene investigations. The environmental conditions during the blast such as weather patterns, rain, and wind should also be taken into consideration.

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