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A Study on Influence of Density and Viscosity of Emulsion Explosive on Its Detonation Velocity

*Hemant Agrawal, **Arvind Kumar Mishra

*Assistant Manager, Coal India Limited, India (hemant.ism@gmail.com)
**Professor, Department of Mining Engineering Indian School of Mines, Dhanbad 826004 India (arvmishra@yahoo.com)

Abstract

Blast optimization and its study have become more important in mining scenario and attract more attention than before due to overall increasing economic pressures. Besides environmental hazards, inadequate and poor blast designs results in reduced efficiencies in various mining functions such as loading, hauling, crushing and grinding cycles and lead to increase in the unit cost of overall operation. Evaluation of a blast design is carried out with the assumption that the explosives have performed as per the specifications, which may not be true in all cases. A reduction in the VOD will produce a reduction in the detonation pressure as well as in the availability of the shock energy of the explosive. It is important that the explosive detonates at its optimum rate and induces sufficient detonation pressure leading to good fragmentation. The VOD of an explosive can, therefore, be used as one of the indicators of its performance. In other words, VOD of an explosive can be used to evaluate the performance of the explosive used in mines, under specific rock and test conditions. Since VOD is a direct measurement of the source function, it provides valuable information with respect to shock, stress waves, kinetics, ground vibration, air blast, fragmentation and undesirable noxious fumes. Blasting performance is directly related to the characteristics and efficiency of the explosives used. Hence a good knowledge on the influence of explosive parameters on VOD is necessary.

In this project, out of various method available, resistance wire technique, a continuous VOD measurement system has been being used for evaluation of in-hole VOD of emulsion explosive. The instrument VODmate from Instantel Inc., Canada made has been used.

This paper deals with monitoring of VOD of explosives at different mines in different geological conditions using VODmate and study the effect of explosive properties specifically

Density and viscosity on VOD of explosives. This work will help the manufacturer and consumer to design and choose the Density and viscosity of explosive to get the desired performance results in terms of VOD of explosive.

Key Words

Velocity of detonation (VOD), density of explosive, viscosity, emulsion explosives.

1. Introduction

Blasting plays a very significant role in mining and any other construction work, it is a very important parameter while designing and for Economics. Blasting is an expensive technique and also it makes the growth faster. Out of all these benefits it is very danger if not exercised properly in controlled manner, to maintain its efficiency continuous monitoring and proper study on different explosives at different condition are very necessary. Lot of work has been done before to improve the efficiency and to reduce the cost of blasting.

Blast optimization and its study have become more important in mining scenario and attract more attention than before due to overall increasing economic pressures. Besides environmental hazards, inadequate and poor blast designs result decreased efficiencies in various mining functions such as loading, hauling, crushing and grinding cycles and lead to increase in the unit cost of overall operation. If site-specific blast design is implemented in mines, the objective of decrease in overall operation cost with provision of safety and elimination of environmental hazards can be ensured. Evaluation of a blast design is carried out with the assumption that the explosives have performed as per the specifications, which may not be true in all cases. A reduction in the VOD will produce a reduction in the detonation pressure as well as in the availability of the shock energy of the explosive. It is important that the explosive detonates at its optimum rate and induces sufficient detonation pressure leading to good fragmentation. The VOD of an explosive can, therefore, be used as one of the indicators of its performance. In other words, VOD of an explosive can be used to evaluate the performance of the explosive used in mines, under specific rock and test conditions. Since VOD is a direct measurement of the source function, it provides valuable information with respect to shock, stress waves, kinetics, ground vibration, air blast, fragmentation and undesirable noxious fumes. If VOD is not monitored and an explosive product is assumed to perform as specified, the interpretation of other measurements (if any) could be erroneous when product malfunction occurs. Thus, it is important to correlate the product’s VOD characteristics to the rock environment, blast design, and other measurements.

Blasting performance is directly related to the characteristics and efficiency of the explosives used.

2. Literature Review

The velocity of detonation (VOD) is one of the most important properties of explosives. It is essential that the explosive in the field condition detonates at its optimum rate and induces sufficient detonation pressure leading to good fragmentation. As the explosive pressure is directly proportional to the VOD of an explosive, VOD measurements indicate the performance of explosive in real time.

Given that the VOD is the only measurable magnitude related to an explosive that can be given a number with certainty, it is easy to comprehend why it has been overemphasized as an indication of explosive strength. VOD is a function of the explosive properties, explosive configuration, hole diameter and confinement. Explosive configuration as explained by Cudzilo et al (2002) emulsion matrix prepared with pure ammonium nitrate as an oxidizer had the highest performance. Partial substitution of nickel nitrate (AN-NiN) /calcium nitrate (AN-CaN)/sodium nitrate (AN-NaN) caused a substantial decrease in the VOD or the explosive performance, also it was observed that the confinement of a charge considerably influences the production of NOx and CO; this is due to the oxidation of NO to NO2, that depends mainly on the initial concentration of NO in the environment [1]. Hole diameter and confinement are generic environment variables for any given blast [2]. The same explosive in different environments will manifest different VODs. In their literature, manufacturers usually quote the unconfined VOD of a small sample of explosive in a small diameter. Rather than strength, VOD gives a relative indication of the energy partitioning between shock and heave. The higher the VOD, the higher the shock component in relation to the total energy [4]. While low VOD explosives will shift the energy partition towards a higher proportion of heave. In any case, the VOD would have to be measured in a real borehole situation in order to be meaningful [5]. In-hole VOD measurements differ greatly from the values quoted in standard manufacturers literature. [7][8] [9]

Many researchers have earlier studied the effect of various properties of explosives on VOD of explosives such as, Svensk et al in 2004 [10] studied the impact of diameter on detonation velocity, Pradhan 2009 studied Effect of charge temperature on the detonation velocity of bulk emulsion explosives, Pradhan 2010 [11] studied the effect on sleep time on VOD explosives, Dobrilovic et al in 2014 [12] also studied the effect of explosive charge temperature on VOD of ANFO explosive, Žganec et al 2016 [13] studied the influence of type primer on VOD of explosive, Mishra et al 2017 studied Influence of Gassing Agent and Density on Detonation Velocity of Bulk Emulsion Explosives [14].

Here in this paper efforts have been made to understand the influence of density and viscosity of emulsion explosive on its VOD.

3. Factors Affecting the Performance of Explosives

The selection and evaluation of explosive performance depends on the properties of the explosive. The important properties of explosives include [3].

3.1 Density

Density is defined as the mass per unit volume, expressed in g/cc. Density affects sensitivity and performance of the explosive. An explosive sensitivity can be reduced by too much increase in density. If the density of explosive exceeds the critical density even a good primer may not detonate it. A useful expression of density is loading density, which is the weight of the explosive per unit hole length. This helps in determining the weight of the explosive loaded per running meter of the blast hole. The density of most explosives varies between 0.8 to 1.35 gm/cc

3.2 Velocity of Detonation (VOD)

Velocity of Detonation Velocity of Detonation is the rate at which the detonation front travels through a column of explosive. Every explosive has an ultimate or ideal detonation velocity known as steady state velocity of the explosive. VOD of any explosive is influenced by its chemical composition, diameters of the blast hole, confinement, temperature, degree of priming etc. VOD of emulsion explosive falls in the range of 4500 – 5500 m/s.

3.3 Detonation Pressure

Detonation Pressure It is the pressure in the reaction zone behind the detonation front, at the Chapman - Jouquet (C-J) plane, expressed in kilobars. Detonation pressure is a function of charge density, VOD and the particle velocity of the explosive material. Detonation pressure is different from explosion pressure, which is the pressure after the adiabatic expansion back to the original explosive volume. The explosion pressure is theoretically about 45% of the detonation pressure.
The detonation pressure can be approximated as follow:

$$P = 2.5 \times 10^{-6} \times \rho \times V^2 \qquad (1)$$

where P is detonation pressure (kilobars), V = velocity of detonation (m/s) & ρ = density (gm/cc).

The values of detonation pressure help in blast design to attain desired fragmentation. It is also important in priming for effective and reliable initiation that the primer exceeds the detonation pressure of explosive charge.

Detonation pressure is a function of density and VOD of explosive.

3.4 Sensitivity

Sensitivity of an explosive is its ability to propagate through air at which a primed half cartridge (donor) will detonate an unprimed half cartridge (receptor), under unconfined conditions. It is expressed in several forms such as hazard sensitivity, performance sensitivity, initiation sensitivity, propagation sensitivity, gap sensitivity, etc.

3.5 Energy Output/Strength

Strength / Energy Output The strength of an explosive is related to the theoretical available chemical energy in the explosive composition. It is a measure of its ability to do useful work. Different explosive manufacturer uses different expression to indicate their explosive strength. The terms used to express explosive strength are Absolute Weight Strength. (AWS), Absolute Bulk Strength (ABS), Relative Weight Strength (RWS) & Relative Bulk Strength (RBS).

Absolute Weight Strength (AWS) is the measure the absolute amount of energy (in calories) available in each gram of explosive.

Absolute Bulk Strength (ABS) is the measure of the absolute amount of energy (in calories) available in each cubic centimeter of explosive. ABS is the product of AWS & density of the explosive.

Relative Bulk Strength (RWS) is the measure of the energy available per unit volume of explosive as compared to an equal volume of bulk ANFO at 0.81gm/cc density.

3.6 Water Resistance

Water Resistance It is the ability of the explosive to withstand water penetration without losing sensitivity or efficiency. The liberation of brown nitrogen oxide fumes from a blast often indicates inefficient detonation caused by water deterioration and implies need for better water-resistant explosives. Water resistance is expressed as the number of hours a product may be submerged in static water and still be detonated reliably. The water resistance property depends not only on inherent ability of explosive to withstand water but also on the water condition. Static water at low pressure will not affect as quickly as dynamic fast-moving water, specially at high pressure. All slurry and emulsion explosives are having good water resistance. ANFO is having no water resistance. By mixing emulsion, ANFO is made water resistant.

3.7 Thermal Stability

Thermal Stability The temperature at which explosive is stored and used may have a detrimental effect upon its ultimate performance during the use. The explosives used in below freezing temperatures are specially formulated so that they do not lose their characteristics. For example, dynamite will freeze and become hazardous to tampering, slurries become stiff and insensitive and fail to detonate. All types of NG - based explosives are prohibited to be used in hot holes. Only slurries and emulsions are permitted to be used in hot hole having maximum temperature up to 80o C.

3.8 Fume Characteristics

Fume Characteristics The explosion gases consist mainly of carbon dioxide, oxides of nitrogen, carbon mono-oxide etc. The explosive composition is balanced when the oxygen contained in the ingredients reacts with the carbon and hydrogen. If there is negative oxygen balance (insufficient oxygen) then the tendency to form carbon monoxide is increased. If there is positive oxygen balance (excess oxygen), oxides of nitrogen are formed. Emulsion matrix prepared with pure ammonium nitrate as an oxidizer had the highest performance. Partial substitution of nickel nitrate (AN-NiN) /calcium nitrate (AN-CaN)/sodium nitrate (AN-NaN) caused a substantial decrease in the VOD or the explosive performance, also it was observed that the confinement of a charge considerably influences the production of NOx and CO; this is due to the oxidation of NO to NO2, that depends mainly on the initial concentration of NO in the environment [1].The excessive liberation of toxic fumes are due to insufficient charge diameter, inadequate priming, water deterioration, reactivity of the product with rock or other material being blasted, incomplete product reaction etc.

In all the factors explained above, density and VOD of explosive plays an important role while choosing emulsion explosives. Also, here in this paper it is tried to study the effect of viscosity of explosive on its VOD.

4. VOD Measurement System Used for Study

4.1 Resistance wire continuous VOD measurement systems (Microtrap, VODSYS-4 from MREL, Canada and VODmate from Instantel, Canada)

The continuous resistance wire method was developed in the early 1960s by the United States Bureau of Mines (USBM). Operation is based on the basic Ohm's law, (E = RI), where E = Voltage, R = Resistance and I = Current. When the current is held constant against a shortened (i.e. detonated) wire of known resistance per unit length, a voltage drop can be measured instantaneously at any point in time. The voltage drop is equivalent to the length of resistance wire consumed in the detonation. Resistance wire probes actually consist of two wires which must be physically shorted out by the detonation through ionization. Some resistance wire probes consist of just two insulated wires twisted together and other probes consist of one coated wire placed inside of a small metal tube which acts as the second wire.

Providing that the wires are adequately shorted during the detonation, the resistance wire method does provide a truly continuous VOD along the explosive column due to the high sampling rates ranging from 1.25 MHz to over 10 MHz If the wires are not adequately shorted in a continuous and reliable fashion, erroneous results, excessive electronic noise and severe drop outs are the norm.

a) **VODmate by Instantel:**

The VODmate analyses the performance of an explosive's velocity of detonation and helps optimize blasting efficiency. [3][4]

- Affordable, Easy-to-Use, and Highly Accurate
- Records multiple holes; measures up to 1 000 ft. (300 m) of VOD measuring cable
- Compatible with coaxial resistive VOD measuring cable from other manufacturers
- Up to 2 MHz Sampling Rate and 14 Bit Resolution – for precise recording
- Minimum trigger level of just 0.4% of cable length
- Automatic Setup – adjusts to sensor cable length
- Easy Cable Connecting – with self-test to ensure reliability
- Small, Portable, Rugged, and Lightweight
- Timer Mode – to record only when you want.
- Multiple Event Storage – in 4 MB permanent memory

Fig. 1. VODmate by Instantel

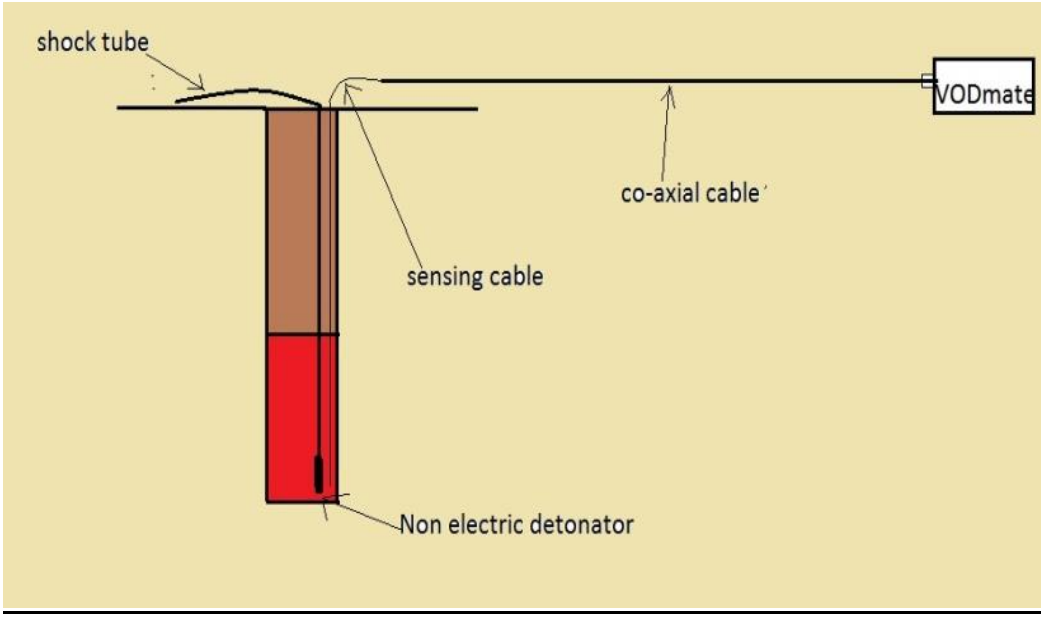

Fig. 2. VODmate Setup in a Single Hole Kept for the Continuous Monitoring

5. Vod Measurements at Different Conditions

5.1 Rajapur Mine

Rajapur opencast project is a coal production project of BCCL India.

1. **Coordinates**: 23°45'9"N 86°25'11"E

Fig. 3. Location of Rajapur mines on google map

2. Blast design parameters

- No. of holes: 10
- Diameter: 150 mm
- Depth of hole: 7.0 m
- Burden x Spacing : 3 m x 3.5 m
- Stemming: 4 m
- Charge per hole: 68 kg
- Explosive make: Star gel Black diamond pt. Ltd.
- Temperature of Emulsion while charging: 58°C
- Viscosity (As given by manufacturer): 54400 CPA
- Detonator: non-electric detonator with shock tube

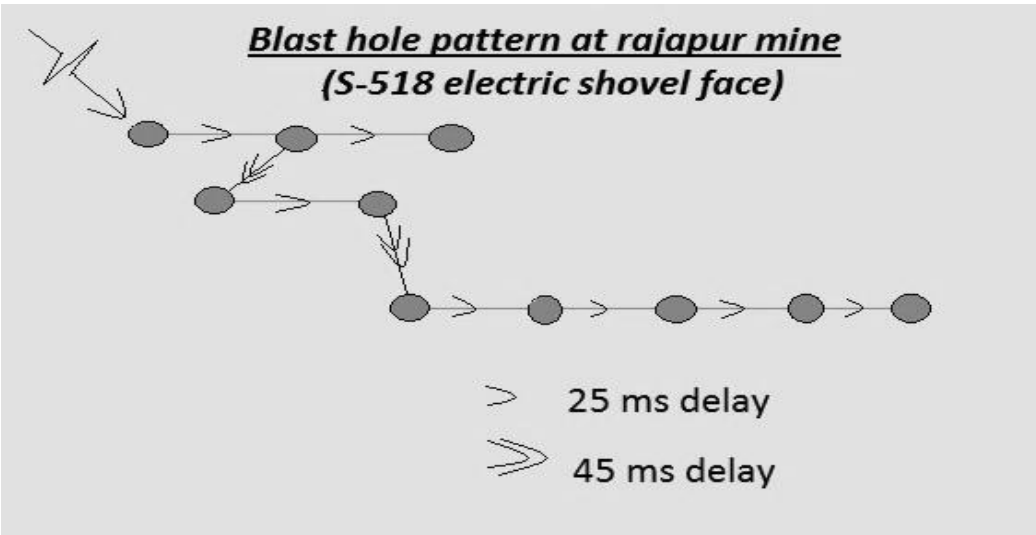

Fig. 4. Blast Design at Rajapur Mines

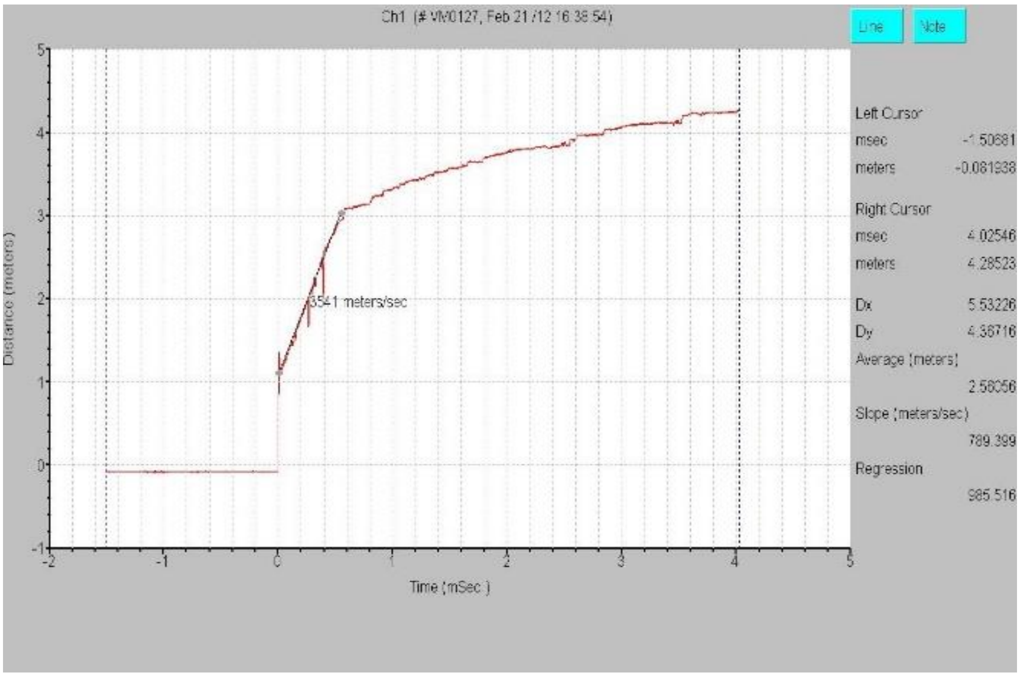

Fig. 5. Analysis on Blast Ware

3. Condition of blasting patch:

- The patch was watery and holes were wet.
- Presence of cracks and voids.

Table 1. Details of Blast Conducted at Rajapur Mines with VOD, Density and Viscosity of Emulsion Explosive

Sl No	Diameter of hole (mm)	Blast design parameters (m)			Explosive per hole (Kg)	Density (gm/cc)		Charging Temperature (ºC)	Viscosity (CPA)	VOD (m/s)
		Spacing	**Burden**	**Depth**		**Before gassing**	**After gassing**			
1	150	3.5	3.0	7.0	68	1.34	1.24	58	54400	3541
2	150	3.5	3.0	7.1	70	1.30	1.15	59	55200	3900
3	150	3.5	3.0	6.8	65	1.35	1.05	59	54600	3760
4	150	3.5	3.0	6.8	65	1.30	1.20	59	54900	3791
5	150	3.5	3.0	6.2	60	1.30	1.01	58	54200	3720

4. Result:

- The in-Hole VOD of explosive used in Rajapur mine found to be 3541 m/s.
- The initial density and final density of explosives was as following:

Initial – 1.34 g/cc

Final (after gassing) – 1.24 g/cc

- The gassing of emulsion was not sufficient resulting into insufficient oxygen supply for proper reaction in explosive. Hence, lesser VOD than standard VOD of emulsion (4500-5500m/s).

Similarly, total 5 number of blasts were monitored at Rajapur mine and the VOD of emulsion explosive at different densities and viscosities were calculated using VODmate and Blastware III software. The data collected is as shown in Table 1.

5.2 Jamunia Mines Visit

It's an opencast coal mine under block II of BCCL India.

1. **Coordinates:** 23°46'39"N 86°12'13"E

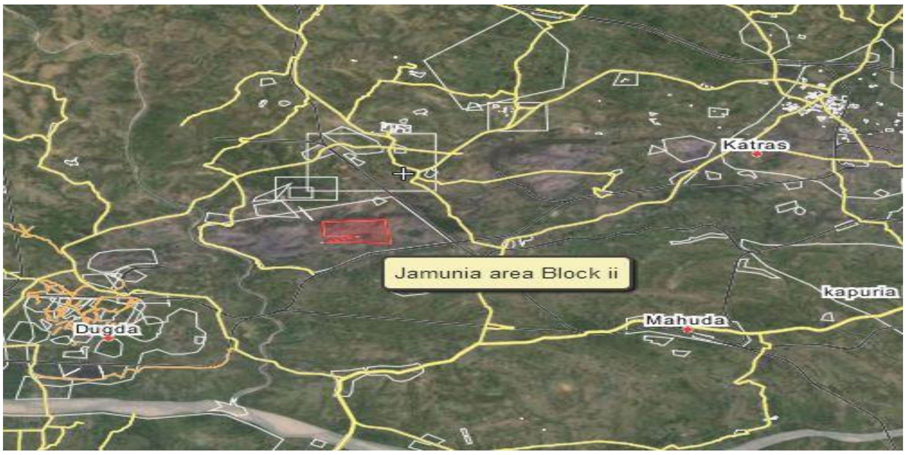

Fig. 6. Location of Jamunia Mines on Google Maps

2. Blast design parameters

- Hole depth: 6m
- Hole diameter: 150 mm
- Detonator: Macpentolite cast booster (35mm Dia X 100gms, Sua explosives)
- Explosive used: Emulsions (IBP)
- Temperature of Emulsion while charging: 58^{o}C
- Viscosity (As given by manufacturer): 54900 CPA
- Burden x Spacing: 2 x 2.5
- Stemming length: 3.5 m

3. Conditions of mine:

- The strata around was hard and competent.
- Cracks were very less.
- Patch was dry with dry hole condition.

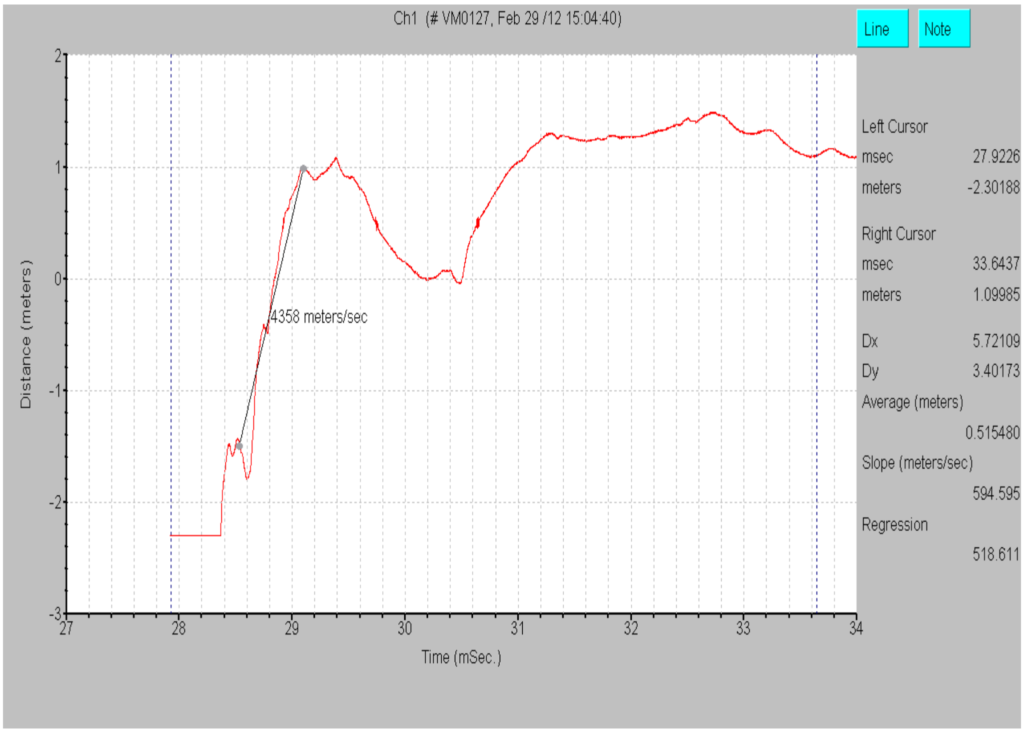

Fig. 7. Analysis on Blastware for Jamunia Mines

4. Result:

- The In-hole VOD of explosive used in Jamunia mine found to be 4358 m/s.
- The gassing was good as the densities were:

Density Before gassing: 1.30 gm/cc

Density After gassing: 1.07 gm/cc

- The gassing was sufficient resulting in VOD at range of emulsion explosive which is 4500-5500m/s.

Table 2. Details of blast conducted at Jamunia mines with VOD, Density and Viscosity of emulsion explosive.

Sl No	Diameter of hole (mm)	Blast design parameters (m)			Explosive per hole (Kg)	Density (gm/cc)		Charging Temperature (°C)	Viscosity (CPA)	VOD (m/s)
		Spacing	Burden	Depth		Before gassing	After gassing			
1	150	2.5	2.0	6.0	60	1.30	1.07	58	54900	4358
2	150	2.5	2.0	5.8	55	1.28	1.13	59	54700	4401
3	150	2.5	2.0	5.9	55	1.35	1.1	59	54600	4330
4	150	2.5	2.0	6.0	53	1.35	1.2	59	54400	4021

Similarly, total 4 number of blasts were monitored at Jamunia mine and the VOD of emulsion explosive at different densities and viscosities were calculated using VODmate and Blastware III software. The data collected is as shown in Table 2.

5.3 Chasnalla Colliery

1. **Coordinates:** 23°39'33"N 86°27'2"E

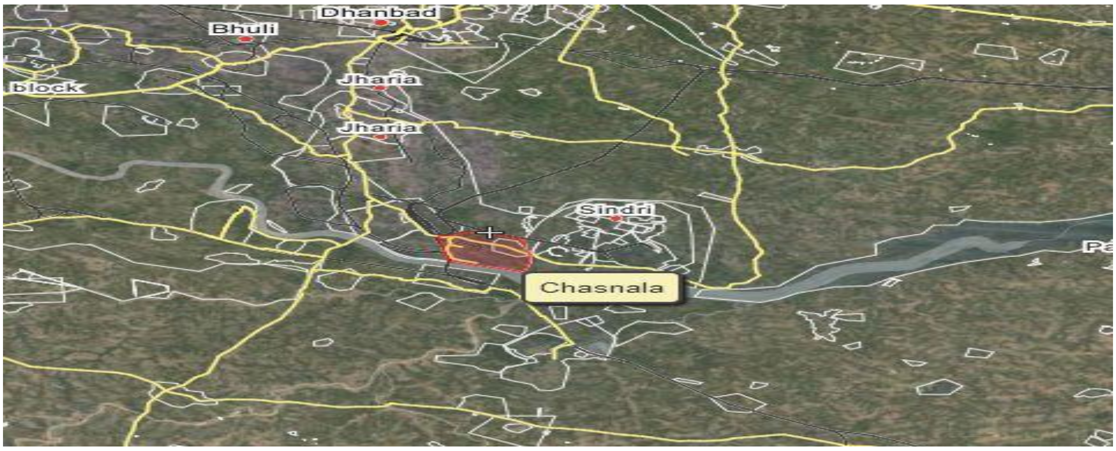

Fig. 8. Location of Chasnalla Project on Google Map

2. Blast design parameter

A. Blast-I

1. Blast design parameter

- Hole depth: 9.70m
- Hole diameter: 100mm
- Burden x Spacing : 3 x 4
- Stemming: 2.9m
- Explosive type: Emulsion (IDL explosives) Star Gel
- Temperature of Emulsion while charging: 56^{o}C
- Viscosity (As given by manufacturer) : 54700 CPA
- Total charge: = 47.2 kg

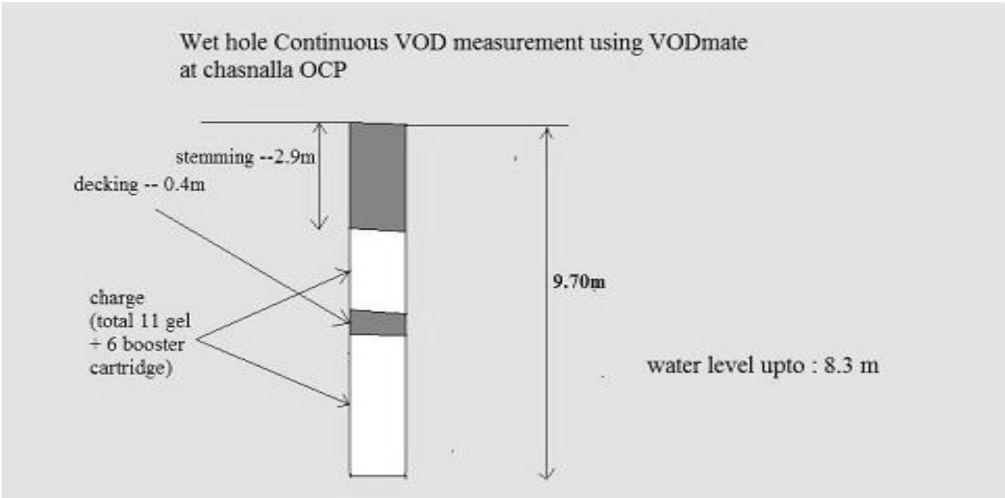

Fig. 9. Wet hole VOD Measurement using VODmate at Chasnalla OCP

3. Conditions of patch

- Watery patch with wet holes.
- Weak Strata condition.

4. Results:

- The In-hole VOD of cartridge explosive comes out to be 3701m/s.
- The gassing was improper as the densities were:

Density Before gassing: 1.35 gm/cc

Density After gassing: 1.20 gm/cc

- Less gassing and less final density resulting in VOD lesser than standard VOD of emulsion (4500-5500m/s).
- Presence of water may be the reason of lesser final density.

B. Blast- II

1. Blast design parameter

- Hole depth: 9.50m
- Decking: 0.8 m
- Hole diameter: 100mm
- Burden: 3 m
- Spacing: 4m
- Stemming: 3.0 m
- Explosive type: Emulsion (IDL explosives) Star Gel
- Temperature of Emulsion while charging: 56^{o}C
- Viscosity (As given by manufacturer) : 56100 CPA

- Total charge = 52.8 kg.

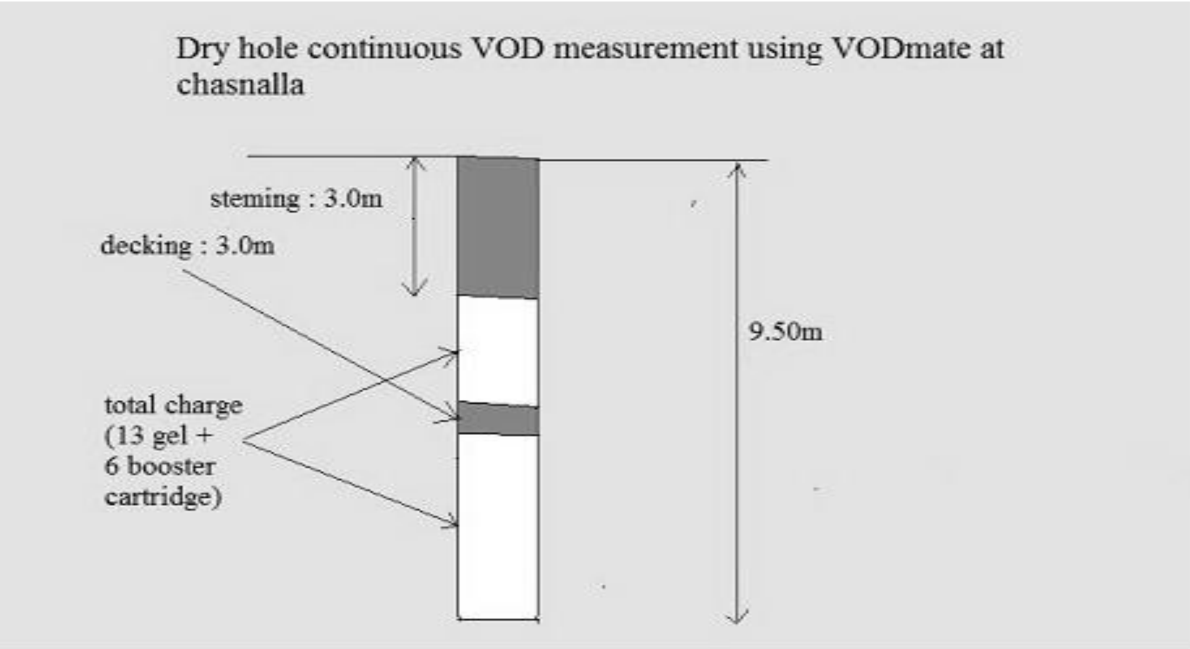

Fig. 10. Dry hole VOD Measurement Using VODmate at Chasnalla OCP

2. Conditions of patch.

- The holes were dry.
- The strata were compact with less crack and voids.
- The charging was good due to absence of water.

3. Results:

- The In-hole VOD of cartridge explosive found to be 4343m/s.
- The gassing and the densities were:

Density Before gassing: 1.30 gm/cc

Density After gassing: 1.05 gm/cc

- VOD found to be better than the wet holes and near to standard which is 4500-5500/s.
- Cracks were less and better confinement also contributed in better gassing resulting in higher VOD.

Similarly, total 5 number of blasts were monitored at Chasnalla mine and the VOD of emulsion explosive at different densities and viscosities were calculated using VODmate and Blastware III software. The data collected is as shown in Table 3 below:

Table 3. Details of Blast Conducted at Chasnalla Mines with VOD, Density and Viscosity of Emulsion Explosive

Sl No	Diameter of hole (mm)	Blast design parameters (m)			Explosive per hole (Kg)	Density (gm/cc)		Charging Temperature (ºC)	Viscosity (CPA)	VOD (m/s)
		Spacing	Burden	Depth		Before gassing	After gassing			
1	100	4	3	9.70	47.2	1.35	1.20	56	54700	3701
2	100	4	3	9.50	52.8	1.30	1.05	56	56100	4343
3	100	4	3	9.50	46.0	1.35	1.12	58	55200	4390
4	100	4	3	9.70	48.5	1.30	1.10	59	55300	4358
5	100	4	3	9.60	47.0	1.35	1.22	57	55000	3906

5.4 HCC Crude Oil Storage - Underground Cavern at Padur, Karnataka (ISPRL project)

It is an underground crude oil storage project from Indian strategic petroleum reserves limited and the project is being taken by Hindustan construction corporation (HCC). It is located at Padur near Mangalore in Karnataka.

1. **Coordinates:** 13°13'40"N 74°47'22"E

Fig. 11. Location of ISPRL Project on Google Maps

2. Blast design parameter

- Hole depth: 4m
- Diameter of shot hole: 45.00mm
- Explosive Charged: 30kg
- Type of Explosive: Emulsions

- Temperature of Emulsion while charging: 60°C
- Viscosity (As given by manufacturer): 55100 CPA
- Manufacturer: Keltech Explosive Limited

3. Conditions of face:

- High joints and cracks were present.
- Holes were horizontal.
- No stemming was done.

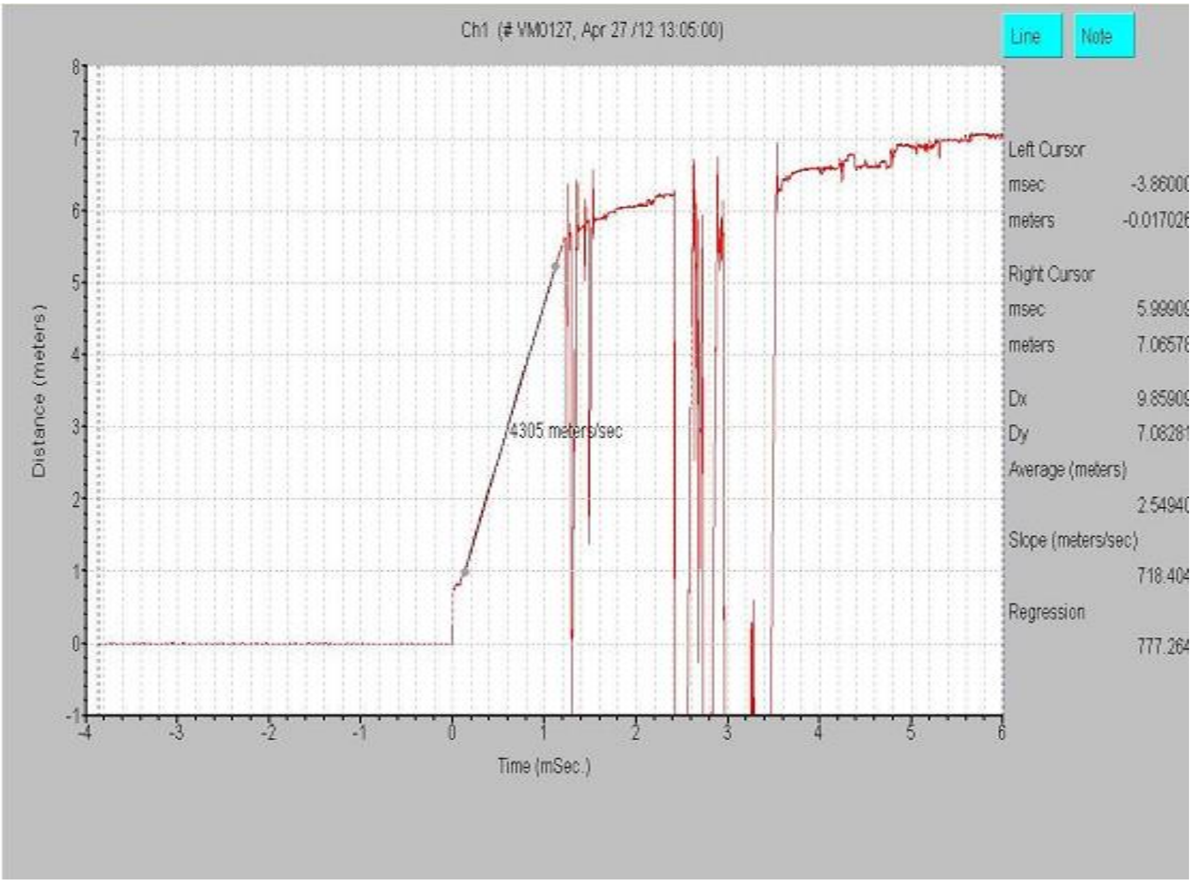

Fig. 12. VOD Analysis on Blastware for Padur Project

4. Results:

- The VOD found to be 4305 m/s.
- The gassing and the densities were:

Density Before gassing: 1.51 gm/cc

Density After gassing: 1.15 gm/cc

- Final density of 1.15 with sufficient gassing lead to VOD of 4305 m/s .

Similarly total 6 number of blasts were monitored at Underground cavern at Padur, Karnataka (ISPRL project) and the VOD of emulsion explosive at different densities and viscosities were calculated using VODmate and Blastware III software. The data collected is as shown in Table 4 below:

Table 4. Details of at Blast Conducted Underground Cavern at Padur, Karnataka (ISPRL Project with VOD, Density and Viscosity of Emulsion Explosive

Sl No	**Diameter of hole (mm)**	**Depth of hole (m)**	**Explosive per hole (Kg)**	**Density (gm/cc)**		**Charging Temperature (ºC)**	**Viscosity (CPA)**	**VOD (m/s)**
				Before gassing	After gassing			
1	45	4.0	30.0	1.51	1.15	60	55100	4305
2	45	3.8	28	1.35	1.05	61	55350	4270
3	45	3.9	28	1.42	1.20	61	54980	4108
4	45	4.1	32	1.38	1.22	60	54900	4256
5	45	3.6	26	1.45	1.25	59	54210	3980
6	45	4.0	31	1.50	1.10	61	54700	4100

6. Analysis

Data collected at four different mines/geology is analyzed and compared on the same scale to know the pattern of variation of VOD with the density and viscosity of explosive.

6.1 Comparison of VOD of Explosive with Its Final Density at 4 Different Mines/Geology

The measured VOD at different densities of emulsion explosive of all 4 mines/geology were plotted on a same graph below (Figure 13).

All the data collected from 4 different mines is plotted on a same graph and it can be observe that, in all the cases the VOD of emulsion explosive increases up to the density range of 1.12-1.18 gm/cc and then start decreasing with the increase in density of emulsions. Hence It can be concluded that the highest VOD is found where the density of emulsion explosive is in range of 1.12 to 1.18 gm/cc

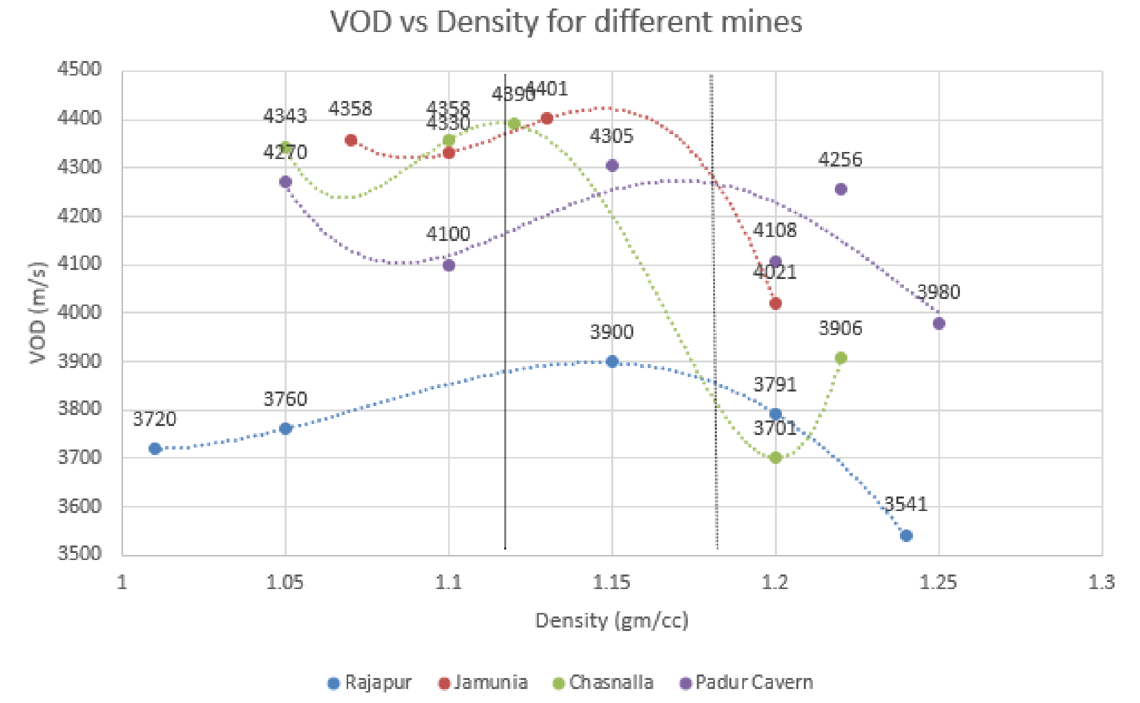

Fig. 13. VOD Plotted Against Density of Emulsion for 4 Different Mines/Geology

6.2 Comparison of VOD of Explosive with Its Viscosity at 4 Different Mines/Geology

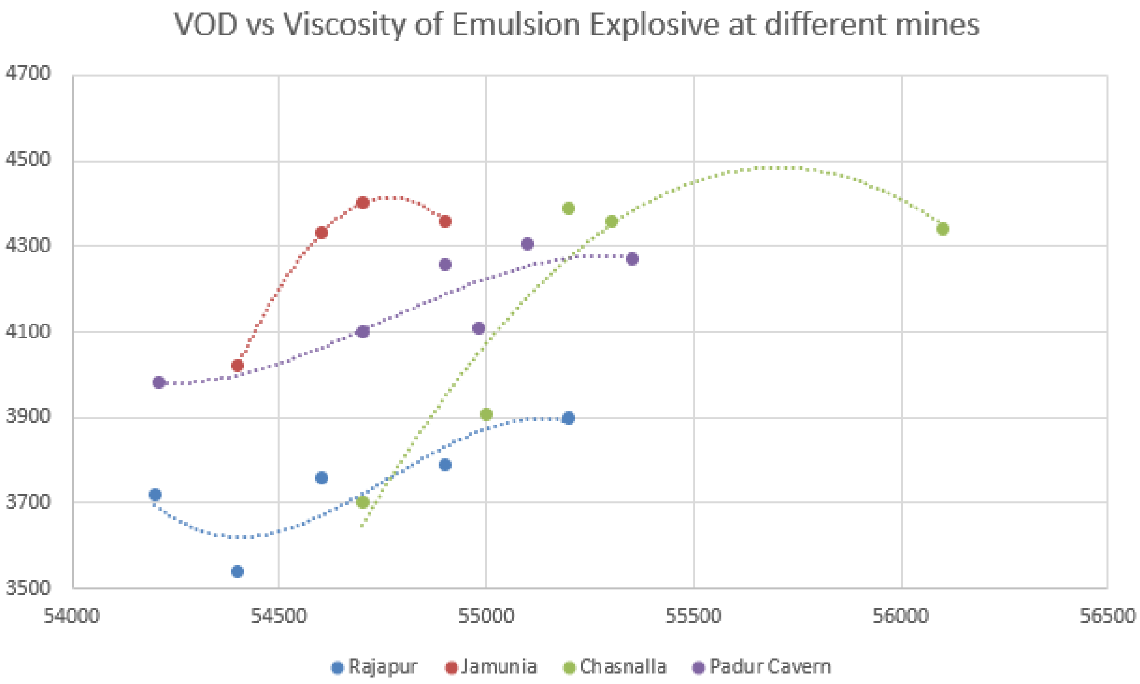

Figure 14: VOD of Emulsion Explosive Plotted Against Viscosity for 4 DifferentMines/Geology

The viscosity of the emulsion determines the rate of Movement of micro balloons through the emulsion, as, in time, the low-density micro balloons would begin to separate out. The behavior of the emulsion under shock loading, to a certain degree, is also determined by the viscosity of the emulsion.

The measured VOD at different viscosity of emulsion explosive of all 4 mines/geology were plotted on a same graph below (Figure 14).

It can be observed that in all the 4 conditions/mines the curve between VOD and viscosity of emulsion explosive is showing similar pattern, the VOD of explosive is increasing with the increase in viscosity but certainly after the value of viscosity increases to a high the VOD will not change significantly.

Conclusion

In this study, monitoring of velocity of detonation (VOD) of the explosives have been done using in-hole continuous resistance wire technique of VOD measurement to evaluate the performance of the explosives. The field trials have been conducted at Rajapur mines, Jamunia mine (Block II), Chasnalla OCP and HCC Padur crude oil storage project at Mangalore, Karnataka. Monitoring and analysis of VOD of explosive have been done using VODmate and Blast ware series III software with varying density and Viscosity of emulsion at almost constant charging temperature.

The study conducted with emulsion explosives at different sites of different density and viscosity. The following conclusion have been made from above study:

- The VOD of an emulsion explosive is maximum when the density of emulsion explosive lies in the range of 1.12 to 1.18 gm/cc and then start reducing with higher densities. Therefore, for optimum result the density of bulk explosive should be kept between 1.12 to1.18 gm/cc to achieve highest velocity of detonation.
- The VOD of emulsion increases with its viscosity but certainly after the value of viscosity increases to a high the VOD will not change significantly.

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