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HIGH ENERGY MATERIAL TECHNOLOGIES FOR DEFENCE APPLICATIONS

Technology Focus focuses on the technological achievements in the organization covering the products, processes and technologies.

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Laboratory Correspondents

From the Desk of Guest Editor

High Energy Materials (HEMs) form an integral part of almost all weapon systems. High Energy Materials Research Laboratory (HEMRL), Pune has made outstanding contribution in the field of various HEMs such as high explosives, gun and rocket propellants, pyrotechnics, battlefield protection systems, explosive detection systems, etc. This edition of Technology Focus brings out the salient features of different systems and technologies related to HEMs developed by HEMRL.

Recent conflicts have seen increased use of thermobaric weapons which are particularly effective in enclosed spaces such as tunnels, buildings, fortified structures, etc. Thermobaric explosive compositions are capable of generating higher blast impulse and long duration thermal effects than conventional HE compositions. HEMRL has developed and demonstrated the thermobaric explosives for various bombs/ammunitions for Indian Air Force (IAF) and Indian army. Further, to reduce vulnerability of warheads to accidental stimuli, insensitive munition compliant high explosive compositions are developed for torpedoes and naval rockets.

New Generation Explosive Reactive Armor (NGERA), a breakthrough technology in the field of ERA has been developed for defeating tandem shaped charge warheads and long rod penetrators. In addition, significant developments have been carried out in the field of explosive ink technology, which is an emerging technology for realising miniaturised armament systems.

In the field of gun propellant, indigenous Bi Modular Charge System (BMCS) providing universal solution to all 155 mm artillery guns of Indian Army has been successfully developed. BMCS was extensively evaluated in 39 cal Bofors gun and its utility has been demonstrated in 45 cal Soltam gun. After successful development, ToT has been given to private industries.

Active binder-based high energy propellant is a game changer in the field of solid rocket propellants with higher specific impulse and density compared to conventional HTPB-based composite propellants. This high energy propellant offers advantage of improved missile performance in terms of range, payload, and design flexibility. HEMRL has developed raw materials ingredients, propellant formulation, and processing technology for high energy propellant and demonstrated delivered specific impulse > 252 s for 2- ton class rocket motor. Further, HEMRL has also developed segmented mandrel technology for safe processing of intricate grain configuration for large size solid rocket motors. This technology would make our indigeneous missiles more effective in the coming decade.

Detection of explosives has become a forefront priority for security agencies worldwide. In this regard, HEMRL has developed a hand-held trace explosive detector OPX-Revilator which is extremely useful for detection and identification of explosives in post-blast scenario. Further, RaIDer-X, a portable, hand-held device for stand-off detection of bulk explosives is also developed in association with IISc, Bangalore. These explosive detectors are highly useful for para-military and police forces. This technology is expected to be available for public use within a year.

It is my sincere belief that the technologies developed in the field of high energy materials will help in achieving self reliance in the relevant area and achieving the goal of Atma Nirbhar Bharat.

Jai Hind..

Dr AP Dash
Scientist 'G' & Director, HEMRL

HIGH ENERGY MATERIAL TECHNOLOGIES FOR DEFENCE APPLICATIONS

High Energy Materials Research Laboratory (HEMRL), Pune, an ISO 9001–2015 certified laboratory, is one of the premier laboratories under Armament and Combat Engineering systems (ACE) cluster of DRDO. HEMRL was established as a full-fledged DRDO laboratory (ERDL, Pune) in the year 1960. It was renamed as High Energy Materials Research Laboratory (HEMRL) on 1 March 1995.

HEMRL is working on entire gamut of high energy materials starting from ammunition for small arms, mortars, pyrotechnics, to high explosives for warheads and bombs in addition to high energy solid propellant for gun, rocket, and missiles. The important technologies developed by the HEMRL are:

- High energy propellant (HD 1.1 class) with delivered specific impulse > 252 s
- High density (> 1.79 g/cc) composite propellant (HD 1.3 Class) with delivered specific impulse> 243 s
- High burning rate (> 40 mm/s at 70 kgf/cm^2) composite propellant
- Pressure casting and curing technology for solid propellant rocket motors
- Segmented mandrel technology for high volumetric loading grain configuration
- Nitramine rich high-performance gun propellant (FC > 1000 J/g)
- Thermobaric high explosives compositions with TNT Equivalent > 2.0
- Hot pressing and warm iso-static pressing technology for realizing high density and high precision explosive charges
- Explosive ink technology for armament applications
- Less sensitive high explosive compositions (melt cast, pressable and plastic bonded) for insensitive munitions
- Blast-based hard kill counter measures for protection of tanks against incoming threats
- Various types of Igniter technologies like head-end igniters, throat-based igniters, Nozzle-cap based igniters, retainable igniters, etc.
- Scale-up technologies for various HEMs such as TATB, FOX-7, TNSTAD, RS-RDX, etc.
- Strategic Nano materials like Nano-Boron, Nano-Aluminium, Nano metal oxides , etc.

HEMRL has been at the forefront in transferring critical technologies to PSU's/private industries to encourage private participation in development and production activities. ToTs include various products, sub-systems, processes, etc. and till date HEMRL has successfully transferred 195 Nos of ToTs to various public sector and private industries. In last five years, more than 90 LAToTs have been signed with industry partners. Further, HEMRL has made significant contributions in academics. HEMRL is a recognized post graduate centre of Pune University for MSc and PhD degree in Chemistry and Environmental Science.

THERMOBARIC AMMUNITIONS

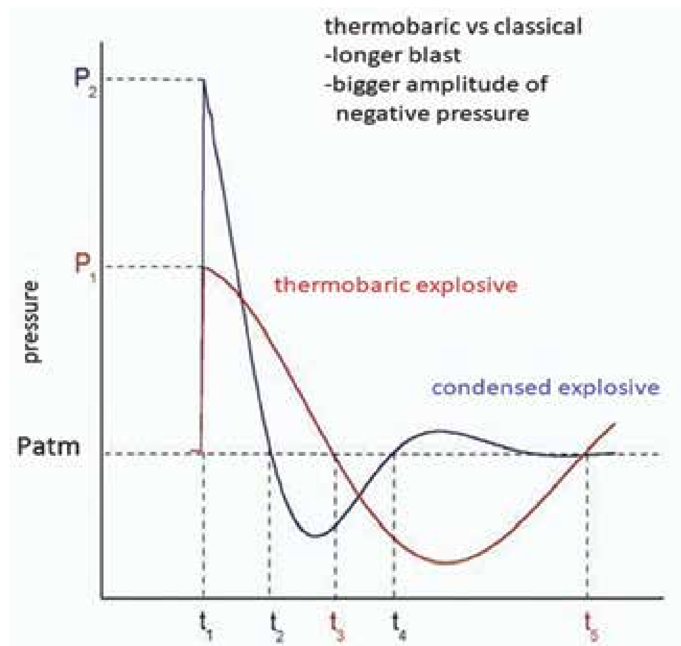
The changing nature of warfare has necessitated development of ammunitions suitable for use in urban or confined environment where target defeat can be achieved without undue collateral damage. In view of this, Thermobaric Explosives (TBE) are one of the recent advances in the field of high explosives which has gained interest in scientific community for maximising the lethality of warheads. Therefore, to modernise the existing ammunitions, HEMRL has developed the technology of TBE which is a critical milestone in the path of development of advanced futuristic weapon systems. TBE compositions are capable of generating not only high blast impulse but also high thermal impulse with a duration varying from a few hundreds of milliseconds to few seconds. This nature of output is made possible by using precise combination of metal fuel and high explosive in the composition. Generally, TBE compositions consist of metal fuel in excess of 30 per cent by weight along with high explosive and polymeric binder. The nature and size distribution of metal fuel are the deciding factors to achieve the enhanced blast and thermal effects. TBE compositions are oxygen deficient in nature and require additional oxygen from atmosphere to achieve complete combustion of fuel. Hence, these explosive formulations are optimised to partition energy release in multiple stages (anaerobic and aerobic reactions) leading to the total energy output significantly higher than conventional high explosive compositions.

The enhanced blast and thermal output makes TBE more effective against soft targets especially in enclosed spaces like tunnel, bunker, field fortifications, underground structures, buildings, machine gun posts, etc. When a thermobaric explosive is initiated, the detonation is simultaneously accompanied by the dispersal of the explosive detonation products and metal fuel in air. The heat generated during detonation ignites the metal fuel mixed with the compressed hot air behind the shock front which leads the blast wave.

The hot and compressed environment helps in fuel combustion with detonation products and atmospheric oxygen resulting in a sustained blast wave and a thermal output as a fireball for extended time duration which damages the target. The wide dispersion of the metal fuel in the atmosphere before its combustion makes the combustion zone very large in comparison with a standard high explosive blast.

Thermobaric Explosive Detonation

In confined environment, the reflections of blast waves from various surface boundaries enhance the blast pressure and impulse and, in addition, also provide kinetic support for fuel combustion. Conventional High Explosives (HE) typically produce very high overpressure for a short duration; whereas TBEs produce a moderate overpressure for a longer duration with an added thermal effect. A typical blast profile of a thermobaric explosion compared to that of conventional HE is shown in Figure. TBE compositions are capable of generating high temperature output greater than 1500 °C sustaining for hundreds of milliseconds duration.



Typical Blast Pressure Profiles from TBE and Conventional HE Detonations

HEMRL has developed the TBE technology using indigenous resources which enabled the development of thermobaric ammunitions successfully. The indigenous efforts have resulted in development of thermobaric explosive compositions, establishment of process parameters and performance evaluation test methods.

The effect of various parameters like nature and proportion of metal fuel and explosive ingredients was studied for maximizing performance parameters.

Aircraft Bombs

HEMRL has developed TB explosive formulation for converting existing TNT filled conventional bombs into TB bombs. The TB bombs developed have met the requirement of performing satisfactorily during carriage, safe separation, safe jettisoning, flight and impact functioning trials.

The TB bombs generate higher blast impulse (>30%) and long duration thermal effects than conventional HE bombs.

The salient features of TB bombs are:

- TB bomb warheads on detonation create high blast impulse blast and fireball effects which are suitable for defeat of soft and medium hard targets in open/confined environments.
- TB explosive filling has got higher thermal stability than TNT-based conventional filling (Composition is stable upto 150°C as compared to 80°C for TNT).
- The TBE filled bombs has got advantages with respect to insensitivity, storage life and performance in terms of high impulse blast effects.

Thermobaric Bombs

TB Ammunition for Infantry Mortar

The infantry mortar weapon is a light smooth bore, muzzle loading weapon having high angle of fire and capable of a high degree of accuracy. The existing TNT filling was replaced with TB explosive formulation which produced enhanced blast, thermal and fragmentation effects during static performance evaluation trials. The mortar bomb filled with TB explosive composition has qualified in the various environmental and dynamic trials.

The salient features of TB ammunition for infantry mortar are:

- Higher blast impulse, fireball temperature and duration than TNT filled shells
- Improved fragmentation effects in terms of hit density and perforation against steel plates (1.5 mm /3 mm/6 mm thick) simulating anti-personnel and anti- material damage capability.
- Can be deployed without any additional change in weapon logistics as well as ballistic property of ammunition.
- TB composition is having higher thermal stability and low vulnerability thereby enhancing the ammunition safety.

Mortar TB Ammunition

TB Ammunition for IFG

TB explosive formulation has been developed for the IFG HE shell to replace the existing TNT filling. The TB ammunition was suitably designed for the existing Range Tables without any change. The TB ammunition gave enhanced performance during various static and dynamic trials. DGQA associated environmental trials for safety in storage, transport, handling and operational use of the TB ammunition has also been successfully completed.

105 mm TB Ammunition

The salient features of the TB ammunition are given below:

- The observed blast impulse for TB shell is about double to that of TNT shells with comparable blast overpressure.
- The number of effective fragments generated is higher than that of TNT filled shells leading to a higher damage capability.

HEMRL, in association with TBRL and PXE, has demonstrated the enhanced lethality of TB ammunitions for aircraft bombs, mortar and gun ammunition.

The ongoing research efforts in this area focus on use of new reactive fuels, innovative designs like surround (layered) charges, and energetic binders to achieve TNT equivalence more than 2. The enhanced lethality of the improved class of thermobaric explosives has been demonstrated for different class of mortar and artillery ammunitions. The development of thermobaric explosive technology is one of the critical milestones in achieving self-reliance in the field of advanced warhead technology. It provides a cutting edge to Indian Armed Forces over the contemporaries in terms of lethal fire power.

HIGH EXPLOSIVES FOR INSENSITIVE MUNITIONS

One of the important thrust areas of research in the field of high explosives is aimed at reducing vulnerability of warheads to accidental stimuli. Secondary explosives possessing a lower sensitivity are highly crucial for the development of insensitive munitions (IM). The transition towards IM compliant category is required to reduce the risk of munitions in accidental and hostile environments. Controlling the sensitivities and response of high explosives towards thermal or mechanical stimuli is one of the key criteria in achieving IM compliance in addition to the suitable design features of the system.

These new class of explosive materials exhibit higher thermal stability, lower sensitivity to bullet fragment impact and minimize the unintended (sympathetic) detonation due to explosion of a nearby munition or excessive heat generated by fuel fires in the vicinity. These characteristics can

Thermobaric Ammunition of IFG Breaching a Brick Wall of 400 mm thickness be achieved by employing inert polymer binders like hydroxyl terminated polybutadiene (HTPB), Nitrile butadiene rubber (NBR), etc. as ingredients of explosive compositions in place of trinitrotoluene (TNT). IM compliant systems not only improve the safety and survivability for personnel and assets but also maximize the storage capabilities and improve flexibility in logistics. Moreover, safety during processing, handling and operation provides high confidence level to production teams and soldiers during operations. Although such compositions were considered as prime requirement of ship/submarine borne torpedoes, their application will proliferate to missile, rocket and bomb warheads with the increasing emphasis on low sensitive/insensitive munitions.

HEMRL has taken lead in this direction and developed RDX and HMX based low vulnerable cast cure explosive compositions and productionised for warhead fillings of Heavy Weight Torpedo Varunastra, Sea Mine MIGM, RGB-60 and RL-140 naval rockets with TNT equivalence of 1.2 to 1.8. These warheads were found to qualify in IM tests for thermal stimuli during cook off tests and mechanical stimuli during bullet/fragment impact. The high explosives compositions based on Polymer Bonded Explosive (PBX) technology have been productionised through DPSU to meet the user requirements.

Varunastra Warhead

RGB 60 Rocket Warhead

RL 140 Rocket Warhead

Multi Influence Ground Mine (MIGM)

Heavy Weight Torpedo Varunastra

EXTREMELY INSENSITIVE DETONATING SUBSTANCES

To bridge the technological gap in the field of low sensitive and insensitive munitions, HEMRL has undertaken a program to develop high explosive compositions qualifying the Extremely Insensitive Detonating Substances (EIDS) criteria. To meet the requirements, intrinsically less sensitive explosives like NTO, RS-RDX, FOX-7 and TATB are synthesized and productionised through ToT. Ongoing developmental work has established the feasibility of development of EIDS category formulations for melt cast, cast cure and pressed type of explosives. Further, experimental set-up for EIDS tests has been established at HEMRL.

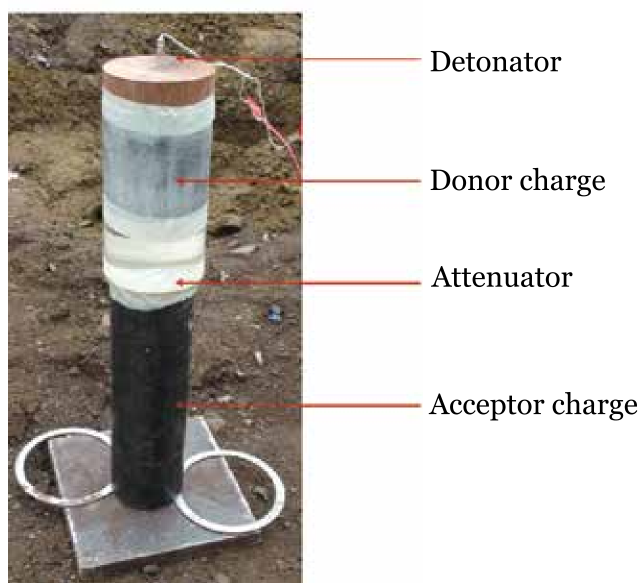
Melt cast compositions based on NTO/DNAN and NTO/TNT having equivalent performance to conventional explosive compositions have been developed and characterized for their performance and insensitivity. Pressed explosive charges based on Reduced Sensitivity RDX (RS-RDX), TATB and HNS and cast cure PBX compositions using RS-RDX and NTO have also been developed and evaluated for EIDS compliance. The developed compositions have passed the Gap test, Cap test and Friability tests to meet the EIDS standards. Further, these formulations have been tested and found to have high shock insensitivity (> 53 kbar). Typical characteristic of few compositions are presented in Table 1. These inherently insensitive explosive fillings decompose more mildly, resulting in less probability of violent reaction during fast cook-off, slow cook-off and mechanical stimuli. The development of weapon systems filled with EIDS compositions will lead to reduction in vulnerability, thereby remarkable reduction in the hazards during processing, handling and transportation of explosives as well as the explosive filled devices.

Table 1. Characteristics of EIDS Compositions

Compositions	Shock sensitivity, kbar	VOD, m/s	Density, g/cc
Melt Cast HE (TNT/NTO)	70	6960	1.81
Cast Cure HE (RS-RDX/NTO/Al/HTPB)	57	6300	1.80
Pressed HE (TATB/PU)	58	7000	1.73

Sample for Fribility test Mass:9±0.1g Dia. 18 mm

Launcher Gun for Friability Test



Test Setup for EIDS Gap Test

Test Setup for EIDS Cap test

NEXT GENERATION EXPLOSIVE REACTIVE ARMOUR (NGERA)

HEMRL has successfully developed ERA Mk-I and ERA MK-II. ERA Mk-I is fitted on T-72 tanks, whereas ERA MK-II is likely to be inducted for fitment on MBT Arjun Mk-I A and import substitute for T-90 tank. Further to develop ERA capable of defeating anti-tank missiles equipped with tandem shaped charge warheads in addition to mono shaped charges and kinetic energy projectiles, HEMRL has taken up development of NGERA.

The technology is based on a newly developed less sensitive explosive composition, which contains two types of explosives along with other ingredients. The composition and thickness of explosive sheet were finalized based on large number of optimization experiments. Outer size of panels was kept same as ERA Mk-II and only internal configuration was modified. To meet the requirement for reduced sensitivity and performance, the number of reactive elements in each module was also optimized based on experimental studies.

NGERA comprises modules of reactive elements housed in metallic panels, which are either welded or bolted on surface of the tank. The internal shock attenuator in the reactive elements prevents sympathetic detonation of adjacent modules inside the panels. The explosive being insensitive as compared to that used in previous versions of ERA, it is more safe in handling, storage and operation.

NGERA has been developed in association with DMRL and CVRDE as per the protection requirements of NGMBT and it can be adaptable to any tank as per the requirement. NGERA has been evaluated against two types of in-service tandem shaped charge warheads and tank fired 125mm FSAPDS ammunition. NGERA has consistently been able to reduce the penetration of tandem shaped charge warheads by more than 50 per cent and kinetic energy projectiles by more than 30 per cent. Further, mockup fitment of NGERA on T-72 tank was carried out at CVRDE to finalise the fitment aspects.

The salient features of NGERA are:

- Capable of protection against tandem shaped charge warheads and KE projectiles.
- Reduction in penetration
  - Tandem shaped charge warheads: >50 %
  - KE projectiles (FSAPDS) :>30 %
- New low sensitivity explosive with long shelf life (>15 years)
- Immune to detonation against small arms ammunition
- No sympathetic detonation of adjacent modules of reactive elements
- Common size of reactive element for all the panels on tank imparting flexibility for fitment.
- Additional weight on tank: ~1.65 T

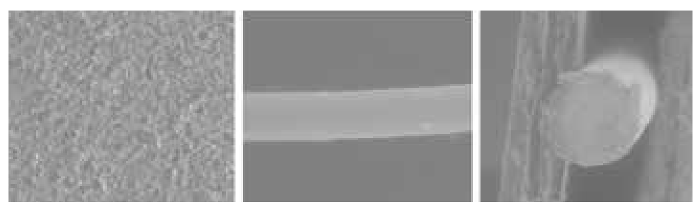
Evaluation NGERA Against Tandem Shaped Charge Warhead

Mockup fitment on Tank T-72

EXPLOSIVE INK TECHNOLOGY FOR EMERGING ARMAMENT APPLICATIONS

Explosive ink (Xink) is a burgeoning technology that offers breakthrough for architecting energetic materials in the form of sub-millimeter charge of explosives for miniaturized armament systems. The technology comprises novel flowable explosive compositions and its printing methodology. A unique direct printing method is a versatile additive manufacturing tool for dispensing the explosive inks. It allows precise deposition of an energetic fills with small volumes into the sub-millimeter explosive tracks where conventional methods for filling of these explosive materials are not possible due to their inherent limitations. Explosive inks along with its printing methodology will dictate the future of armament systems in variety of domains such as Micro-scale Explosive Fire (MSF) trains of MEMS-based Safety arming mechanisms, multipoint initiation system for directional warheads, plane wave generators, explosive lens, miniaturized detonators, devices for self-destruction electronic circuits, etc. HEMRL has developed secondary and primary explosive inks along with their printing methodology for armament applications.

First Generation Secondary Explosive Inks: Secondary explosive inks undergo detonation at sub-millimeter sized tracks. Achieving such kind of detonations at extremely narrow channels even under semi-confinement conditions is a real challenge. HEMRL has developed low critical thickness explosive compositions using judicious choice of explosives as well as its particle size. CL20 (Xink1) and PETN (Xink2) based explosive inks have been developed by tweaking their particle size and dispersing it in polymeric binder resulting in desired flow characteristics and stable performance.



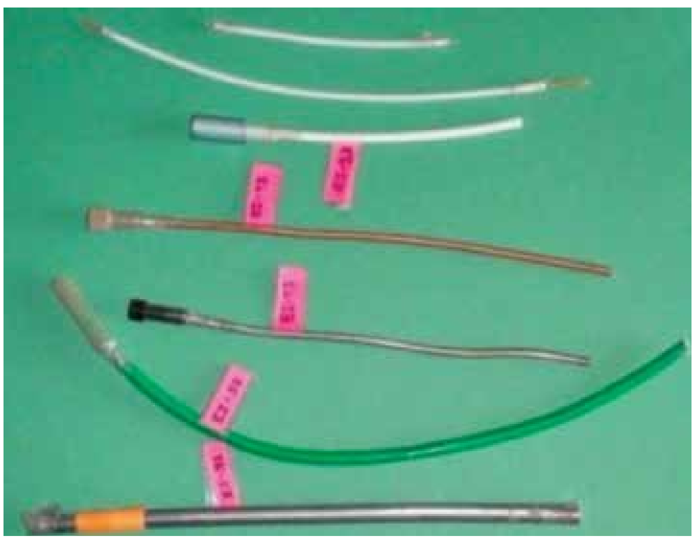
SEM of Xink Formulation (Bulk surface, Exp. wire & its cross view)

Table 2. Characteristics of Explosive Inks

Parameter	Xink-I	Xink-2
Explosive Filler	CL-20	PETN
Explosive Loading	95-98%	95-98%
Particle Size	~5µm	~5µm
Filling Density	1.2-1.3 g/cc	1.0 g/cc
Filling Method	Direct Write	Direct Write
Filling Dimensions	0.5 x 0.5 mm	0.5 x 0.5 mm
Detonation Velocity	6600 m/s	5900 m/s
Critical Thickness	120µm	160µm

Primary Explosive Inks: Miniaturized armament device based on secondary explosive based ink requires compact initiation mechanism. HEMRL has developed environmentally benign, lead-free primary explosive ink. It has the capability to deposit as spot charge and able to initiate consistently the secondary explosive ink even at a few milligram level.

Second Generation Explosive Inks: Unlike, first generation Xinks, second generation explosive inks are self-curable, do not use diluent and thus resulting in higher densities. These inks are the building blocks of 3D printing of explosive/propellant structures. Energetic materials/additives embedded in energetic/non-energetic polymeric binders bring the advantage of filling them in closed channels like tubes/pipes and also the construction of multi-layered energetic structures.



2nd Gen Xinks Filled in Tubes

Printing Methodology: The power of explosive inks technology relies on its printing methodology. Capability of patterning explosive inks is enabled by the automated pneumatic direct write printing method. A device which is used for electronic device fabrication is successfully tuned to handle sensitive explosive compositions with capability of patterning complex structures. The maneuverability of dispensing mechanism is achieved by controlling rheological characteristics of explosive inks.

Automated Pneumatic Dispenser | Patterning of Complex Structures | Complex Structures prior & post detonation

Printing of complex pattern using Xinks

APPLICATION OF EXPLOSIVE INKS IN ARMAMENT

Explosive Inks for Directional Warhead Applications

Symmetrical warheads with single point initiation systems generate a fixed, isotropic fragment distribution. Efforts have been made to improve warhead kill efficiency by directing the fragment pattern on detonation. Multipoint initiation through explosive line tracks can be used for directing the fragmentation pattern of warhead and maximize the number and energy of fragments impacting a target.

Such designs require explosive fills in extremely narrow channels with in-plane and out of plane bending. This unique structure of plane wave initiators greatly simplifies the warhead and makes it cheaper and lighter. However, their filling cannot be done in the trivial ways of explosive compaction methods.

The current development of novel explosive ink technology offers the precise filling of explosive tracks of multi-point initiation device with single initiation point and simultaneous multiple outputs. PETN explosive ink (Xink 2) in very small quantity was filled in the micro-tracks of the device. On suitable initiation, all the outputs of the device were observed using high speed camera wherein all simultaneous outputs were recorded in a single frame with a time delay difference of less than 2μs. Thus, explosive ink technology with just few milligrams of explosives enabled to overcome conventional Combined Detonating Fuzes (CDF) improving its cost, weight and reliability.

Explosive Ink Technology for Future MEMS-based S&A Devices

Micro Electro-mechanical Mechanisms (MEMS) based Safety-and-Arming (S&A) devices find application in smart weapon systems. Such MEMS S&A devices typically use a combination of mechanical mechanisms, which only under the extreme physical conditions of firing or launch create an alignment of firing train comprising very small explosive charges with other explosive components.

MEMS S&A devices are preferably fabricated on a die approximately one square centimeter or less in area, wherein the very small explosive charges (micro-liter volumes) must to be precisely deposited within a series of holes and channels that comprise the firing train.

The conventional methods for loading explosive materials into munitions are not suitable for these systems. Explosive ink Technology is the only viable technology for such microscale fire trains (MSF). HEMRL has tested capability of filling Xinks in such narrow channels and reliable functioning with compact initiation mechanism.

Explosive Inks for the Development of Miniaturized Detonators

The initiating devices basically employ primary explosive, which when subjected to heat, flame, impact, friction/electric spark generates a detonation shock wave and initiates the secondary or booster explosive. Most commonly used primary explosives are lead azide/styphnate. The devices based on these primary explosives involve compaction of spot charge, transfer charge and output charge over the heating element for providing the confinement and to achieve required shock levels.

This compaction process is hazardous and also results in reasonably larger configuration of final detonator/initiators. Towards realisation of miniaturised armament systems, compact and safe detonator development is essential and in specific, micro detonators are vital in MEMS fuses.

Tape and Cup-type Detonators-based on Xinks

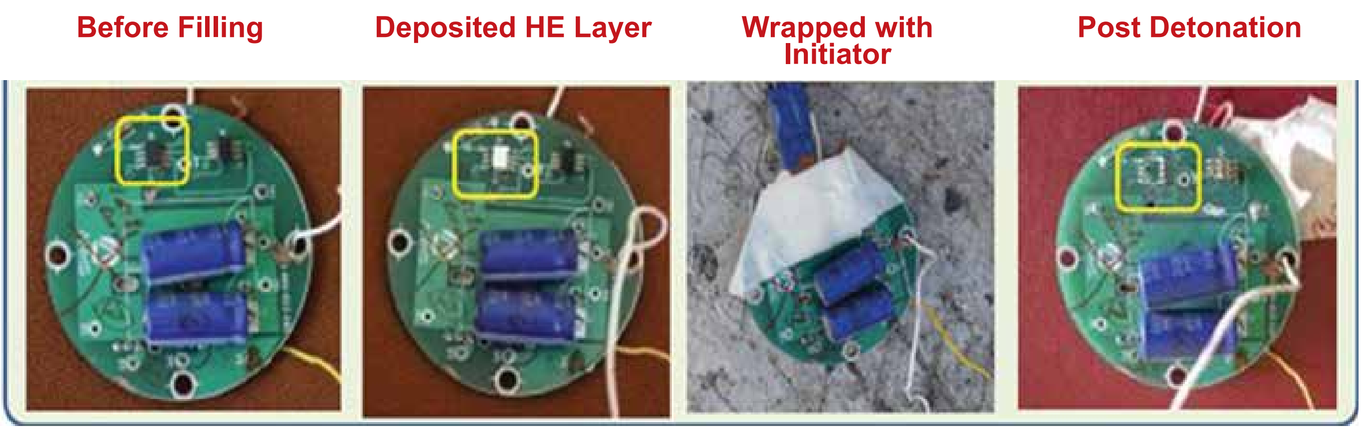
HEMRL has developed miniaturized detonators based on environmentally benign, lead-free primary explosive ink. Novel flexible tape type detonator and compact cup-type detonators are the different variants realized with just a few milligrams of relatively safe primary explosive ink. Both these detonators are proven to initiate the secondary explosive ink tracks (Xink 1 & 2). Further, flexibility offered by this detonator created an avenue for sandwich type explosive devices where-in heating element, primary explosive ink layer and secondary explosive ink are possible to stack.

Explosive Ink Technology for Self-destruction of Electronic Memory Devices

The protection of classified information of national security is important to prevent from enemy use when captured or from unauthorized access. Explosive devices based on Xink finds application in the destruction of electronic storage media/memory chips to a maximum state of damage that makes it impossible to recover the information.

The explosive device with suitable composition is required complete destruction of IC chip structure. For such application, metallic substrate patterned with secondary explosive ink and initiator based on thin layer of primary explosive ink was established and initiation was demonstrated.

Destruction of IC Chip Using Xink



Destruction of Memory Devices Using Xink

BI-MODULAR CHARGE SYSTEM FOR 155 MM ARTILLERY GUNS

155 mm Bofors ammunition adopted by Indian Army consists of nine cloth bag charges, each differing in size, shape, weight and propellant type. These bagged charges often require removal of an increment in the charge for achieving required range. Charge increment so removed poses a problem of disposal, which is a major concern from safety point of view. Moreover, precious time is lost in removing the charge increments which affects the rate of fire from the gun and also adds to the cost of ammunition.

With the advancement of combustible cartridge case technology, the Bi-Modular Charge System (BMCS) has been developed globally. Army imported BMCS with ToT to OFB. It is based on two types of combustible modular charges employed as lower and higher zones. Lower zones are for shorter ranges and higher zones for longer ranges. Considering the likely dependence on foreign vendors for critical/ key ingredients/processes, HEMRL was mandated to develop BMCS technology with indigenous raw materials and processes.

HEMRL has designed and developed indigenous BMCS for 155 mm Artilery Gun. BMCS developed by HEMRL with suitable range tables, can provide a universal solution, to all 155 mm guns (39/45/52 cal) of Indian Army as well as create an export potential. For 155 mm 39 caliber (cal) gun, Lower Zone (LZ) consists of zone-1 (one module) and zone-2 (two modules) whereas Higher Zone (HZ) consists of zone-3 (three modules), zone-4 (four modules) and zone-5 (five modules). In 45 caliber Soltam & 52 caliber Vajra, additional zone-6 (six modules) are used. Apart from primary ammunition like ERFB-BT and ERFB-BB, secondary ammunition like HE, illuminating or smoke can also be fired with BMCS.

The BMCS technology has been developed with indigenous raw materials, equipment and processes to suit for various guns like 39 cal Bofors, 39 cal ULH, 45 cal Soltam, 45 cal Dhanush and 52 cal Vajra after making the requisite range tables. For ease of identification, LZ modules are made green in colour while HZ modules are White. The top surface of LZ module has notches for night identification. They have different locking system to avoid mixing of LZ and HZ modules during any assembly. Combustible case (CC) with requisite colour code and locking notches/grooves comprises cup shaped main body, closing disc and igniter tube.

LZ modules are filled with fast burning single base propellant (SBP) containing NC as a major ingredient for achieving sliver-free combustion at lowest zone. SBP grains used have cylindrical hepta-tubular shape and smaller size (3.6 mm diameter x 5.7 mm length), whereas, HZ white modules contain slow burning cool triple base propellant (TBP) containing additional nitro-glycerine (NG) and nitroguanidne (NQ) for higher energy. Organized filling is adopted with bigger size (11 mm diameter x 22 mm length) hepta-tubular grains having rosette shape to achieve maximum loading.

HEMRL has developed an automated propellant filling and assembly machine in which assembly of higher zone modules can be completed in about 10 minutes as against about 50 minutes required in manual assembly.

BMCS has many advantages over conventional charge system. The major advantages of modular concepts for artillery propelling charge are:

- Facilitates full range of ballistic mission i.e. multiple zoning by adding incremental rigid modular charge proportional to the increase in range required
- Facilitates auto loading resulting in increased rate of fire
- Smooth ignition propagation through the propellant charge
- Simultaneous ignition of all the modules by centrally placed ignition tube containing gunpowder, resulting in uniform ignition of propellant charge
- Reduced flash, blast, smoke signature

Indigenously Developed BMCS for 155 mm cal Artillery Guns

- Superior moisture resistance.
- Enhanced gun barrel life
- Better logistics, combat effectiveness & reduced weight
- Eliminates wasteful removal and disposal of bagged charge
- Operating temperature -30 to +55°C
- IM compliant

BMCS has been extensively evaluated in 39 cal Bofors gun and provisional range tables are prepared. Its utility has been demonstrated in 45 cal Soltam gun also. Debris-free burning is achieved at wide range of service temperatures (-30°C to +55°C) considering the weather conditions of Siachen to Rajasthan. After successful development of BMCS, technology was transferred to two Private firms; M/s Economic Explosives Limited, Nagpur & M/s Bharat Explosives Limited, Lalitpur.

HIGH ENERGY PROPELLANT

Hydroxy terminated polybutadiene (HTPB) based composite propellants have been workhorse propellant in present-day solid rocket motors worldwide. However, HTPB-based propellant compositions have reached a saturation level in terms of specific impulse and density impulse. In the quest for higher performance, HEMRL has developed a new class of high energy composite propellant based on active binder system, which is capable of providing at least 10s higher specific impulse than conventional HTPB/Al/AP based composite Solid Propellants. High energy propellant composition will enhance missile performance in terms of range, payload and design flexibility.

The high energy propellant is based on active binder system where the energetics of the polymeric binder is significantly enhanced with the addition of energetic plasticizers. Active binder preparation involves plasticization of high molecular weight Nitrile Butadiene Rubber (NBR) plasticized with energetic nitrate ester plasticizers viz. diethylene glycol dinitrate (DEGDN) and triethylene glycol dinitrate (TEGDN) and other additives.

HEMRL has established active binder preparation technology based on specially designed anchor blade mixer and solvent recovery system and the processing facility has been established to cater the production requirements of strategic missile systems. A dedicated high energy propellant processing facility has been created for processing of high energy propellants.

High Energy Propellant Facility comprises advanced process equipment like bladeless rotary mixer and 2-blade vertical planetary mixers -15 L and 50 L for mixing of high energy propellant, remotely operated feeding systems for liquid and solid ingredients, fully automated casting set-up, confined and pressurized curing set up and other utilities like vacuum pump, hot and cold-water circulation system, air compressor, etc.

All the operations of processing of high energy-based propellant are carried out remotely using a SCADA-based control system.

High energy propellant compositions have been developed with a burning rate ranging from 9 to 17 mm/s at 70 kgf/cm^2.

The details of ingredients used in propellant composition and characteristic of propellant are presented in Table 3 and Table 4 respectively.

High energy propellant has many advantages compared to conventional HTPB based composite propellant which are listed below:

- Higher delivered specific impulse (252-254 s) and density (> 1.8 g/cc)
- Longer pot life of propellant thus improving processibility
- Excellent low temperature strain capability
- Lower levels of toxic and corrosive combustion products (HCl <5-7 %) making it less detrimental to environment compared to conventional composite propellant
- Less variations of mechanical properties with temperature

HEMRL has successfully developed indigenous sources for all the raw materials/ingredients and

Table 3. High Energy Propellant Composition

Ingredients	Function
Active binder+ curing agent+ bonding agent	Binder/Fuel+ Cross-linker for Structural integrity of propellant
Aluminum powder (Al)	Metallic Fuel
RS-RDX/HMX	Secondary Oxidiser/Energetic ingredient
Ammonium Perchlorate (AP)	Oxidizer

Table 4. Characteristics of High Energy Propellant

End of Mix Viscosity, Poise, 50°C	11000-13800
Spreadability co-efficient	70-90 %
Pot life	>24 hrs
Tensile strength	8-10 kgf/cm²
E-Mod	20-25 kgf/cm²
Tensile bond strength (Propellant and Liner)	> 5 kgf/cm²
% Elongation	50-55 %
Density	1.785-1.825 g/cc
Shelf life, years	>15
Delivered Specific Impulse (Isp) s, 70:1	252-254
Characteristic velocity (C*), m/s	1615-1625
Pressure index ('n'- value)	0.37-0.45


Anchor Blade Mixer and Rotary Mixer for Processing High Energy Propellant

40 kg BEM and Upper Stage Motor Processed with High Energy Propellant

their quality control methods. Further, propellant processing facility for processing of high energy propellant has been established. Propellant processing was carried out initially at sub-scale levels (10-50 kg) and later at large scale levels (up to 2 ton). Propellant performance has been demonstrated in number of static tests at 2 kg BEM, 40kg BEM, as well as 1T class, and 2T class rocket motors.

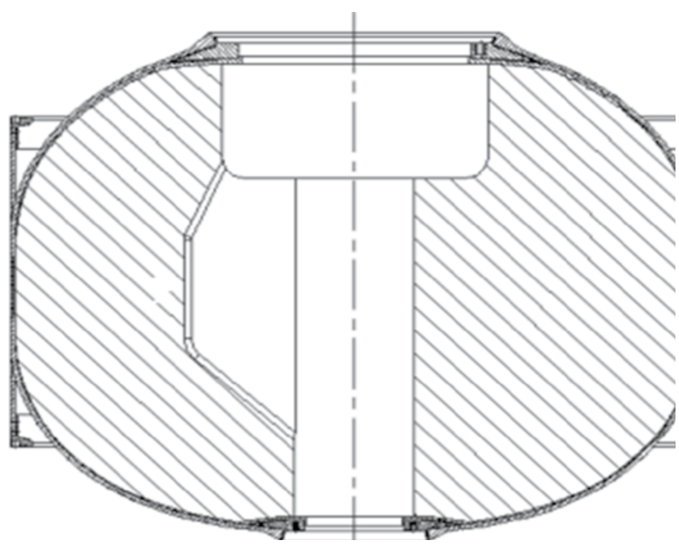
SEGMENTED MANDREL TECHNOLOGY

Advanced solid propulsion system demands intricate propellant grain configuration to cater higher volumetric loading and incorporation of high energy propellant where machining needs to be avoided. Various intricate propellant configurations in a Solid Propellant Rocket Motor (SPRM) have been designed to meet the mission requirements. The most promising propellant configuration is deep fin-o-cyl configuration with volumetric loading of propellant > 92 %.

For such grain configuration, conventional mandrel cannot be used as assembly and de-coring of mandrel is not possible during propellant processing because motor opening diameter is less than maximum fin diameter and constraint on propellant port diameter. Moreover, achieving such grain configuration by propellant machining operation is highly unsafe operation. In order to achieve the desired propellant grain configuration, segmented mandrel technology has been established successfully which can be assembled *in situ* in the rocket motor prior to casting.

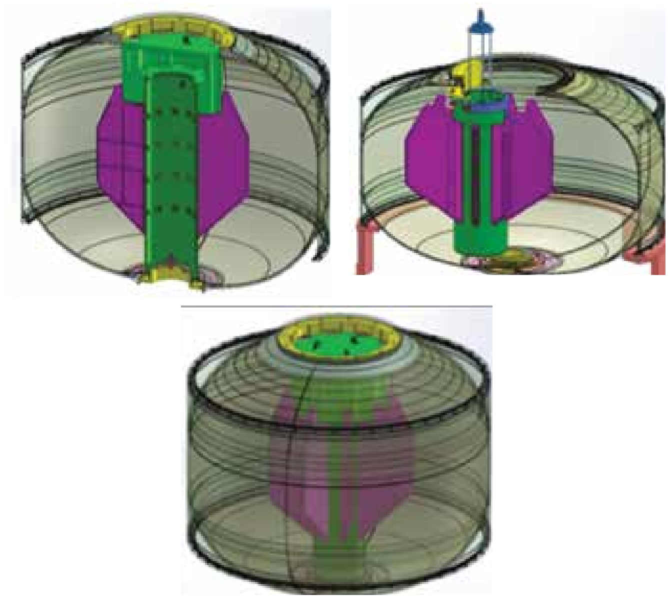
The advantages of the developed segmented mandrel technology are:

- Processing of solid propellant rocket motors with intricate grain geometries with higher volumetric loading
- Elimination of hazardous propellant machining operation
- Remote assembly and do-coring of mandrel
- Offers flexibility to propellant grain designers
- Reduction in overall processing time
- Reproducibility of grain geometry



Deep Fin-o-cyl Grain Configuration in a Solid Rocket Motor

The developed segmented mandrel consists of central core pipe and required numbers of fins. An innovative and noble approach is used for eccentric assembly of fins with central core pipe which is having *in-situ* fasteners and both end alignment features with graflon rollers. One fin is assembled to central core pipe at eccentric position. For assembly of subsequent fins, centre core is rotated with the help of graflon roller provided in the bottom cup and the support roller provided at the top of rocket motor. After assembly of all fins, full mandrel assembly is lifted and aligned with the motor axis by bottom cup provided at the bottom of rocket motor.



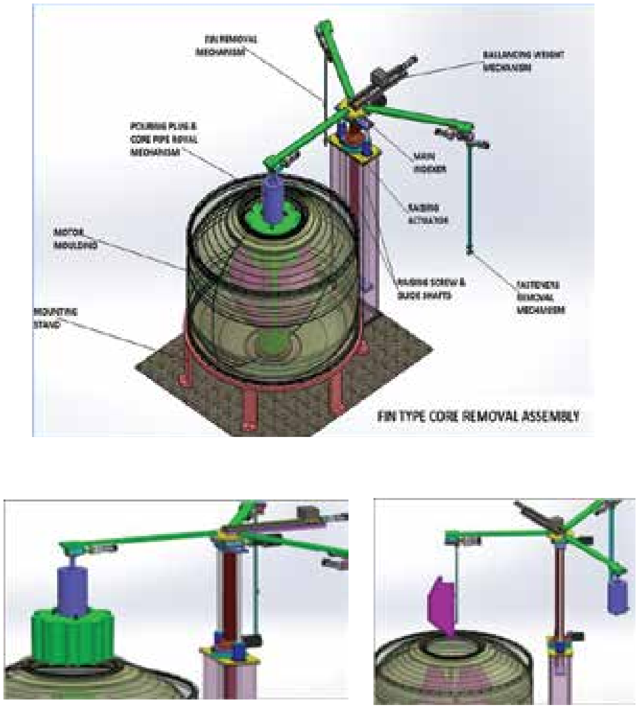
Segmented Mandrel Assembly in a Solid Rocket Motor

The leak-proof interfaces between central core and fins have also been designed and developed using contoured Teflon sheet as gasket to prevent leakage of propellant during casting and curing of propellant. The entire mandrel assembly is carried out inside the rocket motor and special tooling is developed for ease in assembly. All the components of segmented mandrel are Teflon coated. A pouring plug is also designed and assembled at the top of rocket motor which provides the shape to the propellant grain as well as flow path for propellant slurry casting.

Pouring Plug

For removal of segmented mandrel (de-coring operation), an automated remote de-coring mechanism is also developed and realized with in-built safety features. The automated de-coring mechanism consists of three arms for removal of segmented mandrel assembly. These three arms are used for removal of pouring plug and central core pipe, removal of fasteners and removal of fins. All the mechanisms are remotely controlled and various parameters like loads, linear movement, radial movement, motor torques, etc. are monitored during de-coring operations for safe removal of segmented mandrel assembly.

Extensive trials have been conducted with table top model, prototype motors with dummy materials using developed segmented mandrel and its de-coring mechanism. The assembly and dis-assembly procedures were finalised by conducting trials on proof motors having end features same as actual rocket motor. Further, trials have been conducted with live propellant in class rocket motor with the developed segmented mandrel and remote de-coring system and desired deep fin-o-cyl configuration was achieved. The rocket motor with deep fin-o-cyl configuration is ready for evaluation.



Remote De-coring System for Removal of Segmented Mandrel Assembly

EXPLOSIVE DETECTION SYSTEM

Detection of explosives for security has been an area of global concern since decades. Concerted efforts have been focused on the detection of explosives which is a challenging task, as the criminal use of explosives and Improvised Explosive Devices (IEDs) by anti-social elements for the destruction of public life and property is increasing day by day. The threat of IEDs has proliferated to civilian areas in addition to military installations. IEDs are used for large scale destruction causing tragic casualties.

OPX-Revilator Trace Explosive Detector

HEMRL, Pune has designed and developed OPX-Revilator-an Optronic Trace Explosives Detector for the detection and identification of explosives in the pure form, in compositions or mixtures as well as in traces with contaminants like mud, sand, sugar, salt, diesel oil, etc. The device works on the principle of Colorimetry and Computer Vision Technology. Revilator is designed to uniquely identify an explosive by processing the images obtained during the reaction between an explosive and the reagent to detect colour patterns. Once the mixture is inserted into the device, it analyses its colour and also its pattern, which in turn is cross checked from a data library.

OPX-Revilator, an embedded microcontroller based handheld explosive identification device, is useful in the pre and post blast analysis for identification of explosives. The OPX-Revilator explosives detector utilises a set of chemical reagents in a pre-defined sequence for the detection and identification of explosives.

The suspected sample for test is collected directly or by swabbing, its solution is placed in four test trays and subsequently reagents are added as directed. Colours obtained on the four trays are then processed by the device. A user friendly, in-built algorithm guides the operator at every step, to obtain the name of explosive constituents on the LCD display screen of the device within three minutes.

The device can identify more than 20 types of explosives including almost all the explosive compositions being used by anti-social elements as well as explosive compositions in the contaminated condition of specimen. It identifies explosives across different classes like Nitramines, Nitro-aromatics, Nitrate esters and Inorganic Nitrates. With lighter weight, ease of operation and less dependence on human skill, the device comes handy for operation and getting a reliable result. The technical specifications of OPX Revilator are presented in Table 3.

The major advantages of OPX-Revilator trace explosive detector are as follows:

- OPX-Revilator can identify 20 commonly used Military explosives, their compositions and mixtures as well as Civil explosives across different classes like Nitramines, Nitro-aromatics, Nitrate esters and Inorganic nitrates

- It identifies by name a wide range of explosives as well as the individual explosive constituents in case of compositions and mixtures
- It can successfully identify trace explosives even in the presence of contaminants like mud, diesel oil, sugar, salt, wheat flour, etc.

Table 3: Technical Specification of OPX-Revilator

Parameter		Values/Description
Dimensions	:	185 mm (L) x 126 mm (W) x 75 mm (H)
Weight	:	480 g (including battery)
Power Requirement	:	Mains Adaptor/Rechargeable Battery
Display	:	LCD screen
Battery Backup	:	6-8 hours
Display of results	:	Name(s) of explosive(s) displayed on LCD
Form of explosive sample for identification	:	Pure or with Contaminants such as mud, diesel, sugar, wheat flour etc.
Classes of explosive identified	:	Nitramines, Nitro-aromatics, Nitrate Esters, Inorganic Nitrates
State of explosive for identification	:	Explosive in solid and liquid state
Time taken for identification	:	< 3 minutes
Suitability	:	Laboratory and Field
Adaptability	:	Extendable library for identification of more explosive
Usefulness	:	Identification of explosives for Pre or Post blast scenario
List of explosives identifiable	:	

- RDX
- HMX (seen as RDX)
- FOX-7
- CL-20
- ANFO (AMMONIUM NITRATE/FUEL OIL)
- NTO
- PETN
- TETRYL (CE)
- TNT
- AMATOL
- AMMONAL

- COMPOSITION A
- COMPOSITION B
- COMPOSITION C-4
- CYCLOTOL
- DENTEX
- LTPE (LOW TEMP PLASTIC EXPLOSIVE)
- OCTOL
- PENTOLITE
- PEK-I (PLASTIC EXPLOSIVE KIRKEE – I)
- TORPEX
- TRITONAL

- It is based on the highly reliable principle of colorimetry and computer Vision technology.
- It is highly suitable for the on site identification of suspect samples in the Pre and Post- blast scenarios within two to three minutes.
- It is handheld, light weight and battery operated for field applications.
- It provides a reliable result which is displayed on the LCD screen of the device.
- It is cost-effective, economical to use and deployable in large numbers.
- The device is ready for use immediately after testing with no dwell time required between two tests.
- It is microcontroller-based with a user-friendly single button operation.
- It can be continuously operated for six hours after a single charge.

OPX Revilator Trace Explosive Detector

After successful development, ToT for productionization of OPX-Revilator was given to two Private firms; M/s Secumatic Technologies LLP, Pune and M/s Krystalvision Image Systems Pvt. Ltd., Pune. ToT partners are ready to supply the product to meet the market requirements.

RAIDER-X BULK EXPLOSIVE DETECTION SYSTEM

HEMRL, Pune, in association with IISc, Bangalore has designed and developed a Raman Spectroscopy based Bulk Explosives Detector for detection and identification of explosives in the concealed condition. It is named as RaIDer–X (Rapid Identification Detector-Explosive). Raider-X is a state-of-the-art detection device which is capable of identifying explosives kept at a stand-off distance of up to half meter and concealed in translucent materials having a thickness up to 3 mm. Its operation is based on the Raman Spectroscopy technique. It can be used for the identification of suspect bulk military and civil explosives.

This portable device with a flexible point and shoot probe has been tested and evaluated for the detection and identification of fourteen pure explosives and two binary compositions from different classes of explosives. The results of the analysis are displayed onscreen within a minute. Data analysis and explosive identification are performed using the in-built Artificial Intelligence based identification algorithm.

The explosives which can be identified using Raider-X include TNT, RDX, HMX, Ammonium nitrate, CL-20, PETN, FOX-7, NTO, CE, TATB, HNS, Barium nitrate, Ammonium perchlorate, Potassium perchlorate, RDX/TNT and HMX/TNT. The library database can be extended for detection of newer explosives, hazardous chemicals, narcotics and contraband. It allows for non-invasive, non-destructive and label free sampling for stand-off applications in either the exposed or concealed condition. Extensive field trials are being conducted for the device evaluation.

The major advantages of Raider-X bulk explosive detector are as follows:

- Raider-X is portable device with a flexible point and shoot probe.
- It can detect explosives at a stand-off distance of up to half meter.
- It can identify fourteen pure explosives and two binary compositions across different explosive classes.
- It can identify explosives in the exposed and concealed condition without requirement of sample preparation.
- It can penetrate translucent containers up to 3 mm thick.
- It uses Laser with adjustable power for greater safety with explosives and flexibility of detection.
- Results of the tests are displayed onscreen within a minute
- The device is ready for use immediately after testing with no dwell time between samples.
- The library is extendable to newer explosives, toxic & hazardous chemicals, Narcotics, etc.
- It is also suitable for identification of liquid explosives and explosives in the solution form.

The explosive detection systems Revilator and Raider-X will be very useful for National Security applications in India and abroad. These systems will be useful at all strategic locations as well as Airports, Railway Stations, Shopping malls, Multiplexes, Schools, Colleges, Universities, etc.

HEMRL can demonstrate and train Indian Security forces from different states for the use of Revilator and Raider-X. Agencies like Paramilitary Forces (BSF), Army, Navy Air Force, Bomb Detection and Disposal Squad (BDDS), CISF and CRPF will find the explosive detection system useful.

Raider-X Explosive Detector

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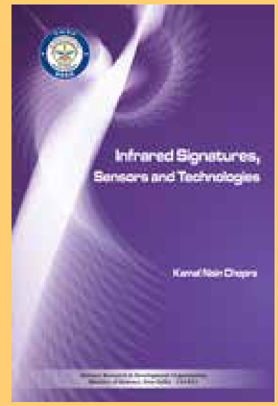

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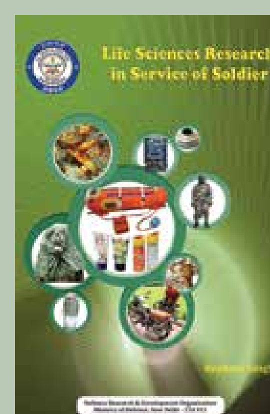

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