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Mechanical and Explosive Properties of Plastic Bonded Explosives Based on Mixture of HMX and TATB

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ABSTRACT

This paper describes formulation of plastic bonded explosives (PBXs) compositions based on 2,4,6- triamino-1,3,5-trinitrobenzene (TATB), Octahydro l,3,5,7-tetranitro- 1,3,5,7-tetrazocine (HMX) by varying their relative amounts with Viton A as polymeric binder by slurry coating technique. These PBXs compositions are studied for mechanical and detonic properties. It has been observed that sensitivity and explosive performance of PBXs based on mixture of HMX and TATB were varied over a wide considerable range by varying relative amounts of TATB and HMX. The detonation study revealed there was increased in velocity of detonation (VOD) and detonation pressure with increasing amount of HMX from 10-80 % by weight. The sensitivity test results exhibited that insensitivity to impact for PBXs compositions was found to decrease with increasing HMX amount. Friction sensitivity study showed that no reactions were observed upto 36 kg load for PBXs compositions namely HT6030, HT5040, HT4050, HT3060, HT2070 and HT1080. The compressive strength of these PBXs compositions was found within the range of 9-11 MPa.

Keywords: High explosive, plastic bonded explosive, detonic, sensitivity, mechanical property

1. INTRODUCTION

Many researchers put their attention to develop new class of explosives known as plastic bonded explosives (PBXs) which are emerging in a big way in the field of high energy materials (HEMs). They are considered as potential replacement for conventional TNT based melt cast explosives due to high loading density, better mechanical strength, better thermal stability and better performance than normal explosive formulations. Among the important classes of PBXs, namely cast cured and pressable compositions are being studied for their applications in advanced weapons. PBXs compositions are based on HEMs such as octahydro l,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), hexahydro-l,3,5-trinitro-1,3,5-triazine (RDX), 2,4,6-triamino-1,3,5-trinitrobenzene (TATB), and hexanitro hexaazaisowurtzitane. HNIW, popularly known as CL-20 are extensively studied by researchers using various polymer binders such as Viton A, a vinylidene fluoride (VDF)-hexafluoropropylene (HFP) copolymer; Kel-F, a VDF-chlorotrifluoroethylene (CTFE) copolymer, polytetrafluoroethylene (PTFE), Estane 5703; a poly(ester urethane) block copolymer and hydroxyl-terminated polybutadiene (HTPB)[1-9].

PBXs are an explosive material in which explosive powder is bonded together in a matrices using 5-10 % by weight of synthetic polymer[10]. These compositions are widely used in military applications because of their high safety, processing ease and superior strength. PBXs compositions are embedded into polymer matrix in order to minimize their shock sensitivity and therefore make them less dangerous to handle. PBXs compositions serve important role in reducing sensitivity to hazardous stimuli such as shock, friction, impact etc. Of course, higher performance has always been a prime requirement in the field of research and development of explosives and the quest for the most powerful high explosives (HEs) still continues and this search seems to be never ending. Thus, in modern ordnance the primary requirements of futuristic weapon systems are high-energy output, good thermal stability, long storage life, improve performance as well as insensitivity to ensure material and personal safety in life cycle of ammunition[11-14]. However, these requirements are somewhat mutually exclusive. The explosives having good thermal stability and impact insensitivity usually exhibit poorer explosive performance and vice versa.

To address the requirement, pressable compositions are preferred over cast cured PBXs. Compositions based on energetic polymers and energetic plasticizers or binders such as HTPB, Estane and Hytemp with HMX or CL-20 as main explosive are reported in literature having more VOD and detonation pressure[15-18]. The data suggested that the CL-20 - based explosive compositions have considerably more energy than the analogous HMX compositions developed by Picatinny Arsenal, USA. They are developed PAX series of explosive compositions and also a series of insensitive munitions (IM) melt-cast explosives. The formulation, PAX-35, is less

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sensitive but of comparable performance to TNT-based melt-cast explosive formulation (Composition B) as it meets the IM requirements and also can be implemented on standard melt-pour equipment. The results of some researchers are indicated that CL-20 containing formulations are more sensitive to mechanical and shock stimuli than the RDX and HMX-based compositions[19].

A series of new explosive compositions (PBXs) are developed with promising blend of insensitivity and performance and thermal stability[20,21]. TATB is the most attractive insensitive high explosive (IHE) for modern ordnance and space applications because of exceptional insensitivity and thermal stability, which are greater than that of any other known material of comparable energy[22]. Several compositions based on TATB have been reported as main-charge explosives. PBX-9502 (TATB 95% and Kel- F 800 5%) is a main-charge explosive formulation with comparatively lower performance but very low shock sensitivity; RX-26-AF (HMX 49.3%, TATB 46.6% and Estane 4.1%) is another main-charge explosive formulation with comparable performance but increased shock sensitivity; PBX - 9503 (TATB 80%, HMX 15% and Kel-F 800 5%) was developed as a booster formulation for PBX-9502. TATB/Kel-F 800 and TATB/Viton compositions are most stable and attractive for long-term use[23,24]. To improve performance of TATB-based PBXs compositions, HMX and TATB mixture based PBX formulations are attempted to find a favourable compromise between prime properties of explosive safety and its excellent performance. For this purpose, HMX which has an excellent power performance but more sensitive to impact is mixed with IHE TATB. Some explosive formulations based on HMX and TATB and KeL-F are characterized for density, VOD, initiation sensitivity, ignition temperature and other explosive properties[25]. Few studies on PBXs compositions based on mixture of TATB and HMX with Kel-F, a vinylidene fluoride-chlorotrifluoroethylene copolymer are also covered under patents[26,27].

In this study, authors describe formulation of PBXs compositions based on mixture of TATB and HMX by varying their relative amounts with Viton A as polymeric binder by slurry coating technique. These compositions are investigated for mechanical and explosive properties to understand influence of HMX amounts on performance and safely of PBXs compositions.

2. EXPERIMENTAL

2.1 Materials

The HE like HMX prepared in our laboratory was taken for PBX formulations. The purity was analysed by HPCL (MERK La Chrome 7000 model) containing >99.5% HMX having β polymorph free form α and γ polymorph (FTIR Nicolet Avtar 360 model). The particle size was 180 μm mean diameter (analysed using Malvern Mastersizer). The TATB received from HEMRL Pune, India was used as received for PBX formulations. The analysis report mentioned purity of > 99.0 % and particle size 32 μm mean diameter. The polymeric binder Viton A; vinylidene fluoride (VDF) and hexafluoropropylene (HFP) copolymer is manufactured by DuPont Corporation was used as received having fluorine content of 66 %. Mehtyl ethyl ketone (MEK) and acetone LR grade procured from MERCK and SD Chem Ltd. Pvt. India were used as received respectively.

2.2 Process for Preparation of PBX Moulding Powder

In this process, the slurry coating was conducted in 5000 ml round-bottomed reaction vessel fitted with mechanical stirrer and a condenser. The experiment setup was assembled with steam jacketed stainless steel vessel containing water for uniform steam heating to reaction vessel. In this process, HMX and TATB at varying ratios (10:80, 20:70, 30:60, 40:50, 50:40, 60:30, 70:20 and 80:10 respectively) were dispersed with 3000 ml distilled water with continuous stirring at 60 °C. At this stage, the lacquer of Viton A (10 g Viton A dissolved in 200 ml of MEK) was added drop wise through dropping funnel which was further followed by dispersion the resulting slurry with stirring at 700 rpm in order to maintain uniform dispersing of polymeric binder over crystalline HEs at temperature 90 ± 1 °C for 1 h. A series of PBX compositions prepared at different HMX and TATB ratios of 10:80, 20:70, 30:60, 40:50, 50:40, 60:30, 70:20, and 80:10 by weight percentage were designated as HT1080, HT2070, HT3060, HT4050, HT5040, HT6030, HT7020, and HT8010 respectively.

2.3 Evaluation of PBX Compositions

2.3.1 Particle Density

One property of the PBXs which helps in evaluating an explosive's performance is its particle density. In this study, particle density of PBXs moulding powder was determined by using Ultrapycnometer 1000 instrument (from M/s Quantachrome, USA) which is measured volume of PBXs moulding powder. This method is based on Archimedes' principle of fluid displacement and Boyle's law for determining volume by comparing the change in pressure when the sample is introduced in the measurement chamber which has a reference standard having pre-determined volume. The displaced fluid is an inert gas (Helium) that can penetrate all but the finest pores, thereby assuring maximum accuracy. Here, Helium gas was used due to its small atomic dimensions approaching 0.25 mm in diameter. The volume of the samples was calculated using the following equation:

$$V_s = V_c - \frac{V_{exp}}{\frac{p_1}{p_2} - 1}$$

where V_s is volume of the sample, V_c is sealed cell volume, V_{exp} is expansion volume, P_1 is the initial pressure and P_2 is the pressure after expansion.

2.3.2 Explosive Detonation Parameters Measurement

The performance evaluation including velocity of detonation (VOD) and detonation pressure of PBXs compositions was determined by high speed streak photography technique. The PBXs moulding powder predried at 60 °C was pressed into cylindrical pellets using warm Isostatic press. The predried PBX moulding powder composition was filled in rubber mould which was further evacuated and sealed. These

PBXs moulding powder were pressed at 90 °C under applied pressure of 170 MPa. These pellets were machined and have a dimension of Φ 50 mm × 150 mm. Some of PBXs charges after machining are shown in Figure 1. The densities of the pellets were measured gravimetrically after machining.

Streak camera was directly used for measuring detonation velocity of PBX charges. It was used in velocity measurement mode, i.e. the slit was kept along the charge length and perpendicular to the camera optical axis. The streak camera was recorded distance time history of detonation wave propagation along the charge surface[28,29]. Detonation pressure of high explosives is determined by applying aquarium techniques[29].

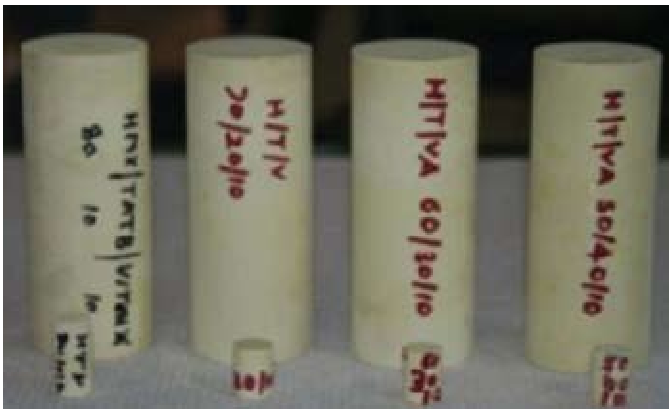


Figure 1. Photographs of some PBX compositions based on mixture of HMX and TATB.

2.3.3 Sensitivity Test

The impact sensitivity of PBX compositions was determined by fall hammer apparatus (BAM) using Bruceton staircase method[30] using a 2 kg drop weight. The results reported in terms of height for 50 % probability of explosion of the sample was determined. The friction sensitivity of PBX compositions was determined using a standard Julius Peter's apparatus operating upto 36 kg load[31].

2.3.3 Mechanical Stength Measurement

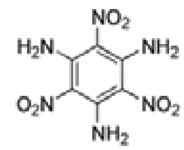
Compressive strength of PBX compositions was determined by benchtop tester model universal testing machine (UTM) having capacity of 100 kN at room temperature and humidity of 55%. Speed of the load cell was adjusted to 10 mm/min. The pellets were compressed to its breaking point and from the graph of load versus change in height, compressive strength was calculated. Two samples were tested for each composition.

3. RESULTS AND DISCUSSION

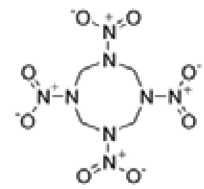
3.1 Particle Density

The molecular structure of TATB, HMX and Viton A are given in Scheme 1. The particle density of PBXs moulding powder was measured by 25 g weighing for each composition. The results of particle density for PBXs moulding powder were summarized in Table 1. It was observed that particle density of PBXs moulding powder was found within range of 1.902 - 1.913 gcm^{-3}.

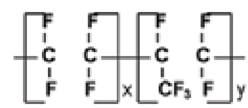
Scheme 1



TATB



HMX



Viton A

Table 1. Particle density of PBXs compositions using Ultrapycnometer instrument

PBX compositions	Compositions (HMX/TATB/Viton A)	Particle density (g/cm^3)
HT1080	10/80/10	1.912
HT2070	20/70/10	1.911
HT3060	30/60/10	1.912
HT4050	40/50/10	1.904
HT5040	50/40/10	1.903
HT6030	60/30/10	1.907
HT7020	70/20/10	1.905
HT8010	80/10/10	1.904

3.2 Detonation Properties of PBXs Compositions

The velocity of detonation (VOD) and detonation pressure are two most important properties for measuring explosive performance. The results of VOD and detonation pressure of mixture of HMX and TATB based PBXs compositions are shown in Table 2. The results indicated that VOD was found to increase from 7.4 km/s - 8.24 km/s, and detonation pressure was increased from 24.5 GPa - 31.2 GPa when amount of HMX was varied from 10 % to 80 % by weight. Sikder[32], *et al*. also studied detonation properties such as detonation velocity and Chapman-Jouguet (C-J) pressure of some organic energetic compounds especially on nitroaromatic and nitramines. The PBXs based on TATB, HMX and Kel -F800 were reported, having more VOD due to 95 % loading of explosives in composition[33,34]. A large number of CL-20 -based PBXs were also reported in the literature having 12 % - 15% higher energy potential compared to compositions HMX based compositions.

Table 2. Denotation parameters of PBXs compositions using streak photography

PBX compositions	Charge density (g/cm^3)	VOD (km/s)	P (GPa)
HT1080	1.84	7.40	24.5
HT2070	1.84	7.41	25.3
HT3060	1.82	7.64	26.0
HT4050	1.83	7.73	27.8
HT5040	1.83	7.91	29.0
HT6030	1.83	8.12	30.0
HT7020	1.83	8.19	30.4
HT8010	1.84	8.24	31.2

3.3 Sensitivity Test

The sensitivity is the degree of response to external stimulus. The results of impact and friction sensitivity for PBX compositions are listed in Table 3. It was observed from Table 3. that insensitivity in respect to impact sensitivity was found to decrease with increasing the weight % of HMX. The impact sensitivity of PBX compositions was found to increase from 32 cm to 116 cm when amount of HMX was varied from 80 % to 10 % by weight. As far as impact sensitivity is concerned, no reactions were observed upto 36 kg load for PBXs compositions HT6030, HT5040, HT4050, HT3060, HT2070 and HT1080. This indicated that these compositions were insensitive to friction upto 36 kg load. Sensitivity data reported on TATB/HMX/Kel-F based PBXs clearly show that insensitivity rapidly decreases with increasing HMX content, even at relatively low levels of HMX. Evidently, some trade-off must be made between VOD and sensitivity[33]. Further, sensitivity data also indicated that TATB-based formulations rank as the most insensitive explosive formulations[34]. In literature, much interest was generated on how to reduce the sensitivity of high explosives. It was reported that crystal size, shape, morphology, purity, internal and external defects, and the microstructure of inter crystalline voids play a vital role in the sensitivity of high explosives[35-37]. Recently, some empirical calculation methods were reported for performance evaluation of explosive compositions and sensitivity of high energetic materials[38-43].

Table 3. The sensitivity and compressive strength of PBX compositions

PBX	Impact sensitivity H_{50} (cm)	Friction sensitivity* (kg)	Compressive strength (MPa)
HMX	26	24	---
TATB	127	> 36 [a]	…
HT1080	116	> 36 [a]	9.7
HT2070	108	> 36 [a]	10.1
HT3060	92	> 36 [a]	9.6
HT4050	78	> 36 [a]	9.7
HT5040	56	> 36 [a]	10.0
HT6030	43	> 36 [a]	9.8
HT7020	34	36	10.2
HT8010	31	36	9.6

*Insensitive upto 36 kg

[a]No reactions were observed upto 36 kg load.

3.4 Mechanical Strength

As weapons system are exposed to range of thermal and mechanical environments, it is important to characterize PBXs compositions for mechanical properties. The mechanical strength of PBXs compositions depends to many variable which includes particle size and its distribution, polymer characteristics, processing method, compaction density, pressing conditions, relative humidity of storage environment, deformation strain rate, thermal history, storage and test temperature[44-48], etc. In these experiments, all other constituent parameters were kept same and mechanical strength of the PBX charges was assumed to depend on mixture of TATB and HMX in the PBX compositions. After drying, PBXs moulding powder were pressed at same conditions as mentioned above for detonation parameters study. The PBXs charges were further machined into dimension (Φ 15 mm × 30 mm) as shown in Fig. 1. The compressive strength for PBX compositions measured by UTM at ambient temperature is given in Fig. 2 and results obtained are listed Table 3. It was observed that compressive strength of PBXs compositions was found within a range of 9-11MPa, which is more and less same as reported in literature[49,50].

4. CONCLUSIONS

In present study, PBXs compositions based on mixture of TATB and HMX and Viton A have been formulated and investigated for mechanical and explosive properties. The detonation and explosives properties can be tailored by varying amount of HMX and TATB for their application of insensitive explosive components. The sensitivity study reveals that PBXs compositions become comparatively less sensitive toward impact and friction forces with reducing amount of HMX. One of the important conclusions of PBX compositions based on mixture of HMX and TATB is that the favourable combinations can be achieved between the extreme sensitivity and modest detonation performance of TATB and the modest sensitivity but excellent detonation performance of HMX. These studies clearly indicates that some PBXs compositions may be considered as a potential replacement for conventional melt cast explosives based on TNT and pressed explosive components based on wax for combat safe military applications requiring IM compliance.

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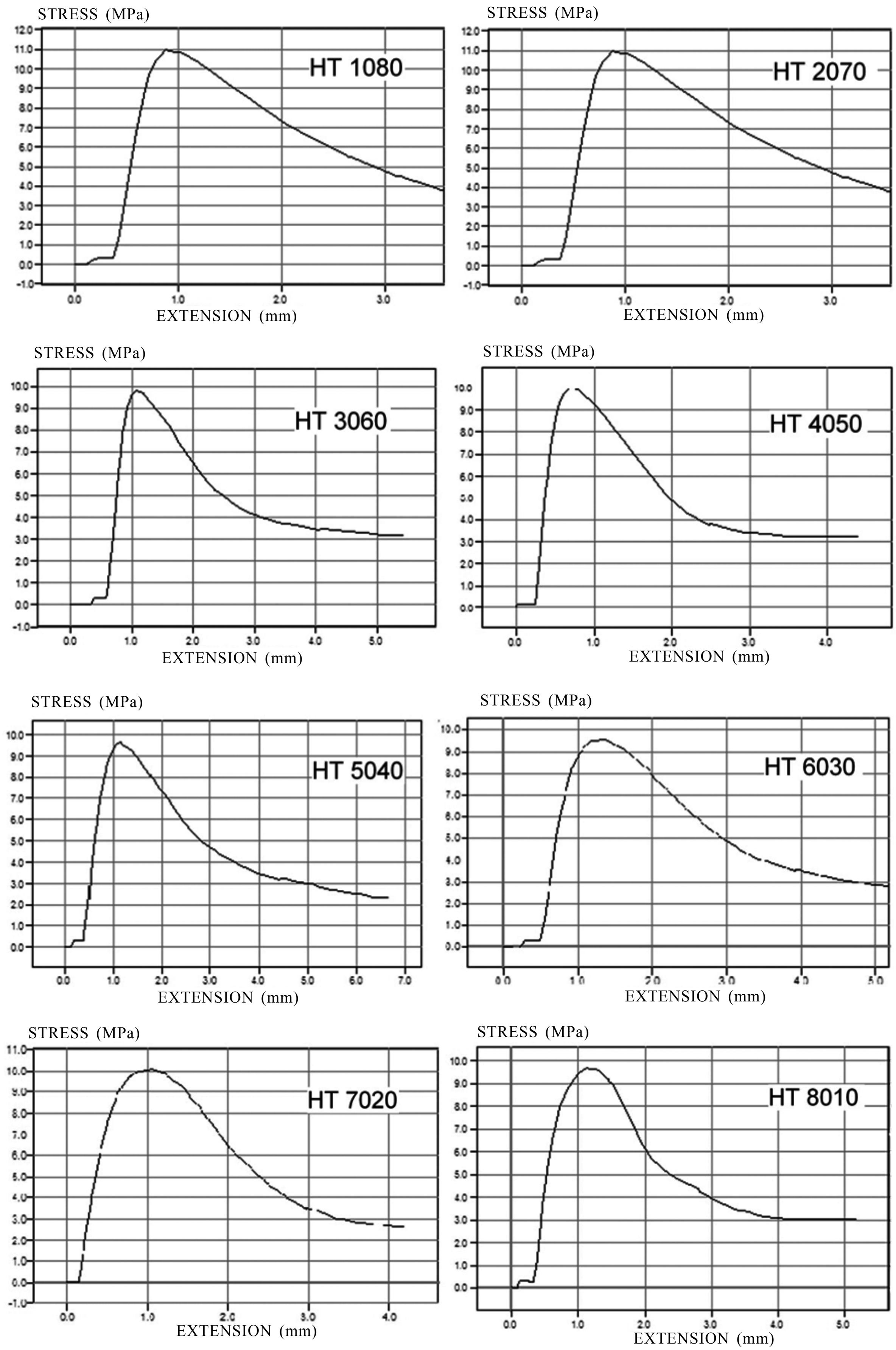

Figure 2. The compressive strength for PBX compositions based on mixture of HMX and TATB.

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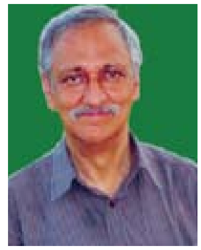

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