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Cellulose Acetate Binder-Based LOVA Gun Propellant for Tank Guns

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ABSTRACT

Cellulose acetate (CA) binder-based low vulnerability ammunition (LOVA) gun propellant formulations with varying percentages of fine RDX as energetic ingredient have been studied. RDX percentage varied from 76 to 80 in these formulations. An optimised composition with 78 per cent RDX was then studied exhaustively. Ballistic data determined by closed vessel (CV) evaluation and vulnerability aspects obtained by safety tests were then compared *vis-a-vis* the properties of standard triple base NQ composition. Theoretical prediction and CV test results indicated that the CA binder-based LOVA gun propellant could satisfactorily meet the ballistic requirements for gun application.

1. INTRODUCTION

Presence of nitric esters as energetic ingredients makes the conventional propellants more sensitive to impact, friction and heat. In the LOVA concept, nitric esters are replaced by inert binders and more energetic cyclic nitramines to make the propellant least sensitive, meeting the ballistic requirements satisfactorily. Cellulose derivatives like cellulose acetate (CA), cellulose acetate butyrate (CAB), cellulose acetate propionate (CAP) and ethyl cellulose (EC) are reported[1,2] as promising binders for LOVA gun propellant. Cyclic nitramine like RDX in fine particulate form is the most commonly used energetic ingredient. Propellant composition designated XM-39 and its modified version designated NL-001 are the two LOVA propellants widely reported[3-5] in literature. In both these compositions, CAB is used as inert binder. The CAB, CAP and EC are all imported items and not easily available, whereas CA which is indigenously available was selected for feasibility study of LOVA gun propellant.

Burning behaviour of RDX-based propellant is dependent on the particle size of RDX used in the formulation[6]. Cohen and Strand[7] explained the combustion of RDX by melt layer combustion mechanism which follows unconventional combustion. According to Taylor[8], the apparent higher burn rate for bigger particle size of RDX is due to convective combustion. Pillai[6], *et al.* have shown that fine RDX of about 5 μm average particle size is the right choice for gun propellant application.

Theoretical prediction using the Therm[9] programme developed at the High Energy Materials Research Laboratory (HEMRL), Pune and the experimental evaluation of propellant formulations using CA as binder with varying percentage of fine

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RDX are presented. Performance of an optimised composition has been compared *vis-a-vis* existing triple base NQ composition currently in application for many gun ammunition.

2. EXPERIMENTAL PROCEDURE

Cellulose acetate of Mysore Acetate Ltd., having molecular weight (weight average) of 67,000 and acetyl value of 54.5 per cent as acetic acid was used as LOVA gun propellant binder. Fine RDX particle size was used as energetic ingredient. Triacetin (TA) was used as the plasticiser for CA. As in the case of propellant formulation reported in literature using CAB as binder, nitrocellulose (NC) of lower nitrogen content (12.2 per cent) was incorporated in the present formulations to the extent of 4 per cent along with CA as additional energetic binder. The propellant compositions with fine RDX varying from 76 to 80 per cent were then formulated. Chemical compositions formulated and their thermochemical properties calculated are presented in Table 1. All the propellant formulations shown in Table 1 were manufactured in heptatubular geometry using solvent process.

Pressure (P) versus rate of rise of pressure (dp/dt) and log r versus log P profiles were obtained by closed vessel (CV) firing in a 700 cc vessel at 0.2 g/cc density of loading as shown in Figs 1 and 2. Force constant (F), linear burning rate coefficient (β_1) and pressure exponent ($\propto$) were computed as per internal ballistic solutions[10-11]. Results of CV evaluation are presented in Table 2.

Based on the experimental data obtained, propellant formulation with 78 per cent RDX was then selected as an alternative to existing conventional triple base NQ propellant. The pilot scale (10 kg batch) manufacturing and evaluation of LOVA propellant were then carried out to confirm the ballistic aspects determined on experimental scale processing (2 kg batch).

The pilot scale batch propellant was exhaustively evaluated by static firing in CV at normal density of loading (0.2 g/cc). Performance was evaluated based on the theoretically-predicted

Table 1. Chemical composition and thermochemical properties

Type of binders	Composition I	II	III	IV	V	VI
CA	12.0	12.0	12.0	12.0	12.0	16.0
NC (N_2 % 12.2)	4.0	4.0	4.0	4.0	4.0	–
RDX	76.0	77.0	78.0	79.0	80.0	80.0
TA	7.8	6.8	5.8	4.8	3.8	3.8
Carbamite	0.2	0.2	0.2	0.2	0.2	0.2

Theoretical thermochemical values at 0.2 g/cc loading density

Parameter	I	II	III	IV	V	VI	NQ
Flame temperature (K)	2733	2803	2874	2945	3014	2802	2780
Force constant (J/g)	1061	1081	1100	1119	1138	1082	1034
P_{max} (MPa)	266	270	275	279	284	271	256
Co-volume (ml/g)	1.0057	1.0080	0.9961	0.9913	0.9866	1.0020	0.9571
n value (moles/g)	0.04668	0.04636	0.04604	0.04572	0.0454	0.04642	0.04473
Ratio of specific heats	1.2646	1.2635	1.2624	1.2613	1.2602	1.2664	1.2513

Composition NQ

NC (13.1 %) 20.8, NG: 20.6, picrite: 55.00, carbamite: 3.6, potassium cryolite: 0.3 (parts)

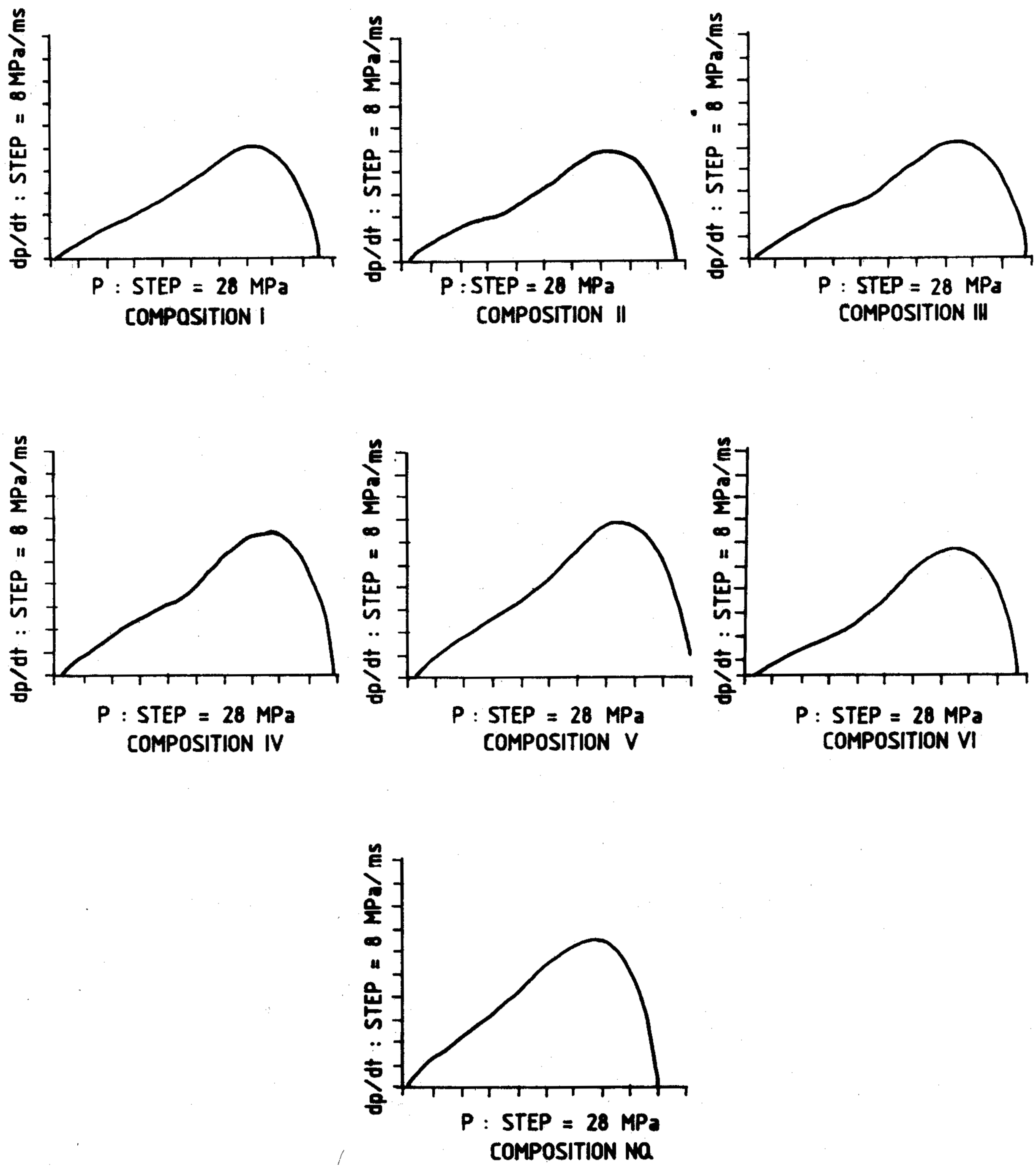

Figure 1. Pressure versus rate of rise of pressure profile of compositions

and experimentally-determined values in comparison to standard NQ/M 119 propellant.

Vulnerability aspects of the propellant under consideration were then checked by determining the impact and friction sensitivity as well as ignition temperature. Impact sensitivity was determined by calculating the height for 50 per cent explosion with 2 kg falling weight. Friction sensitivity and ignition temperature were determined using Julius Peter apparatus. These results are presented in Table 3.

Table 2. Results of closed vessel evaluation

Parameter	Composition						
	I	II	III	IV	V	VI	NQ
Web size (mm)	1.12	1.10	1.12	1.10	1.05	1.02	1.19
Density (g/cc)	1.630	1.647	1.653	1.652	1.654	1.630	1.675
P_{max} (MPa)	267	272	274	277	280	271	252
Force constant (J/g)	1066	1085	1097	1112	1125	1083	1033
Linear burning rate coefficient (β_1) cm/s/MPa	0.0869	0.0820	0.0870	0.1000	0.0980	0.0840	0.1400
Pressure exponent (α)	0.89	0.84	0.86	0.87	0.85	0.97	0.78
Specific energy (KJ/kg)	4029	4118	4180	4256	4324	4065	4110

All results are presented without cooling correction and hence actual values are expected to be slightly more than what is reported.

Table 3. Results of vulnerability tests

Parameter	Composition	
	For LOVA propellant composition (I-VI)	For NQ propellant
Impact sensitivity [(Height for 50% explosion, (cm)]	55-67	29
Friction sensitivity (insensitive up to) (kg)	36	19
Ignition temperature (°C)	>220	<175

Relative humidity : 55-58 per cent,
Relative temperature : 29-30 °C
LOVA propellant does not ignite even at 350 °C. At 220 °C, it starts producing yellow fumes.

Table 4. Results of mechanical properties

Parameter	For LOVA propellant composition (I-VI)	For NQ propellant
Compression strength (kg/cm^2)	310 - 430	280 - 320
Percentage compression	3 - 6	10 - 15

Compression strength and percentage compression of the propellant sample prepared as per ASTM standard were determined using Instron universal testing machine (Model No. 1185). The results are shown in Table 4.

Propellant was tested for deflagration-to-detonation transition (DDT) test also[12]. The pattern of DDT tube burst for LOVA gun propellant *vis-a-vis* standard NQ/M propellant is presented in Figs 3, 4 and 5.

3. RESULTS & DISCUSSIONS

Results presented in Table 1 indicate that the isochoric flame temperature (T_o) of the propellant formulation varied from 2733 to 3014 K, while the force constant varied between 1061 and 1138 J/g as per theoretical predictions. As seen from the data given in Table 2, the force constant determined experimentally is in close agreement with the theoretically-predicted values. It is also seen from the results that for every one per cent increase in RDX content at the cost of plasticiser (TA), the improvement in force constant is about 20 J/g.

Force constant realised for CA binder-based LOVA gun propellant with 78 per cent RDX (composition No. III) was 1097 J/g. Specific energy of this propellant works out to about 4180 KJ/kg which is marginally superior to conventional NQ composition currently in use with tank gun ammunition.

Pressure exponent of this propellant in heptatubular geometry was well within the acceptable level for gun application. The linear burning rate coefficient (β_1) for the formulation is about 0.09 cm/s/MPa at 0.2 g/cc loading density which is lower than that of NQ composition whose

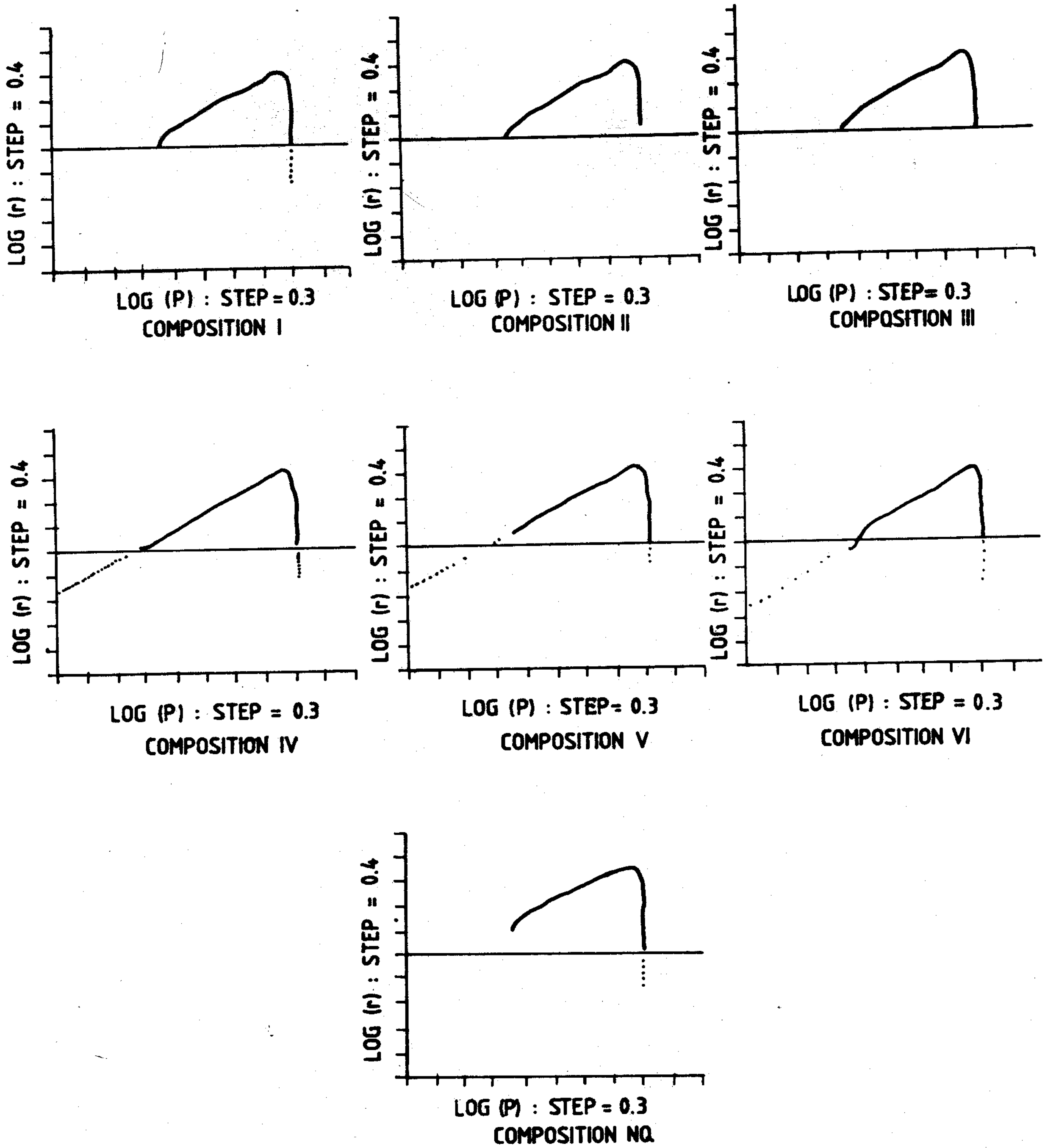

Figure 2. Log *r* versus log *P* profiles of compositions

(β_1) value realised under similar condition was 0.14 cm/s/MPa. The lower burning rate of this propellant is expected to be beneficial for the gun pressure control. It will only necessitate the manufacture of propellant in suitable lower web size. A careful analysis of the burning behaviour of different formulations with the help of *P* versus *dp*/*dt* and log *r* versus log *P* profiles indicated that as the inert plasticiser percentage increased, the combustion was not smooth. Irregular combustion was more prominent beyond 6 per cent plasticiser. However, increase in RDX percentage at the cost of

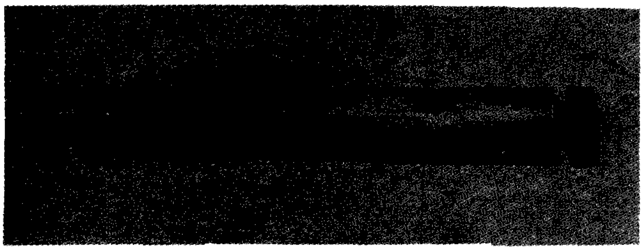

Figure 3. DDT tube before test

plasticiser TA made the propellant brittle and also led to processing difficulty. It was found that CA and TA in the ratio of 2:1 with 78 per cent RDX is promising and offers a feasible alternative to existing NQ composition for gun application.

Vulnerability test results presented in Table 3 indicate that the CA binder-based LOVA gun propellant is considerably insensitive wrt all the three parameters, viz., impact sensitivity and friction sensitivity as well as ignition temperature. Improvement in ignition temperature level to > 220 °C as against < 175 °C for NQ propellant is a clear advantage in achieving the nonvulnerability characteristics.

Mechanical properties of this propellant presented in Table 4 indicate slight superior performance in compression strength, but the percentage compression for LOVA propellant is inferior to standard NQ. This calls for improvement in the formulation for improved compressibility of propellant grain. Results of DDT test for LOVA gun propellant with 78 per cent RDX *vis-a-vis* standard NQ/M 119 propellant indicate that the LOVA gun propellant does not show the tendency to DDT. This is evident from the fragmentation pattern of both the DDT tubes as given in Figs 3, 4 and 5. The number of fragments recovered after the test were less for LOVA propellant than for standard NQ/M 119.

Theoretical prediction of the ballistic performance of CA binder-based LOVA gun propellant indicates that this can meet marginally superior ballistics for gun ammunition than that of

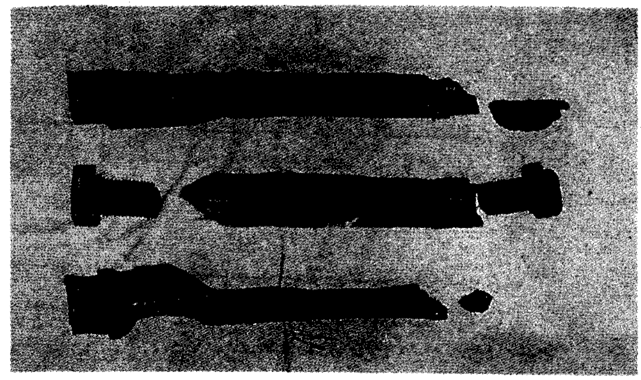

Figure 4. DDT tube fragments with LOVA propellant with 78 per cent RDX.

existing conventional triple base NQ composition (Table 5). Internal ballistic computation reveals a muzzle velocity of 1453 m/s at 425 MPa for 105 mm kinetic energy (KE) ammunition.

4. CONCLUSION

In comparison to the existing triple base NQ propellant, CA binder-based LOVA gun propellant incorporating 78 per cent fine RDX gives marginally higher compression strength, better

Table 5. Internal ballistic computation

Parameter	Value
Calibre of gun (mm)	105
Shot travel (mm)	4750
Chamber volume (cm^3)	6550
Projectile mass (kg)	6.33
Shot start pressure (MPa)	85
Charge mass (kg)	5.35
Propellant force constant (J/g)	1100
Co-volume (cc/g)	0.9961
Propellant density (g/cc)	1.640
Gamma	1.262
Web size (cm)	0.090
Linear burning coefficient (β_1 cm/s/MPa)	0.100
Form factor	- 0.172
P_{max} (MPa)	425
Muzzle velocity (m/s)	1453

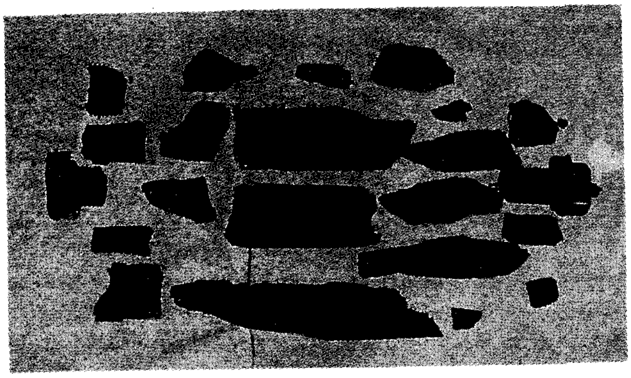

Figure 5. DDT tube fragments with propellant NQ

nonvulnerability properties and superior ballistic performance. This propellant can serve as a feasible alternative to the conventional triple base NQ propellant for gun ammunition.

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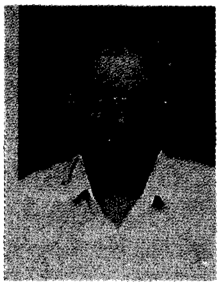

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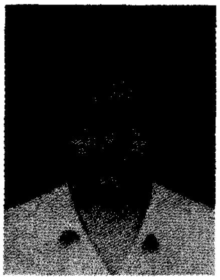

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