Defence Science Journal, Vol 45, No January 1995, pp 25-30

Developmental Studies on Metallised UDMH and Kerosene Gels

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ABSTRACT

The influence of particulate and hydrocolloid gellants and different surfactants on gellation of metallised stable gels of unsymmetrical dimethyl hydrazine (UDMH) and kerosene containing 30 per cent 15 micron *Al* was studied. Metallised UDMH and kerosene gels were characterised with respect to pseudoplasticity, thixotropy, consistency and yield stress using Contrave's rheometer. The effect of shear rate and temperature on the viscosity of these gels was determined. Thermal stability, hypergolicity tests and flow rate studies were also conducted. Metallised UDMH and kerosene gels are found to be stable, thixotropic and pseudoplastic and easily flowing like a liquid under shear force.

1. INTRODUCTION

Gel propellant is a new class of storable liquid propellants which can give higher energetics than those of conventional storable liquid propellants[1,2]. The other merits of the system are higher density impulse, minimisation of storage/handling and slosh problems and reduced vapourisation[3]. However, gel propellant poses the technological challenge of converting the gel to easily flowable liquid in the combustion chamber.

2. THERMODYNAMIC EVALUATION

Thermodynamic calculations using equilibrium flow method show a vacuum specific impulse of 316.7 s for 30 per cent aluminised unsymmetrical dimethyl hydrazine (UDMH) gels and 320.9 s for 30 per cent aluminised kerosene gel with N_2O_4 system at the optimum oxidiser-fuel ratio of 1.5 and 2, respectively. The effects of *Al*-loading on I_{sp} of UDMH and kerosene gels with N_2O_4 are shown in Table 1.

Table 1 Effect of *Al*-loading on I_{sp} of UDMH and kerosene gels

UDMH-*Al* with N_2O_4			Kerosene-*Al* with N_2O_4		
O/F ratio	*Al* (%)	V.I_{sp} (s), 70 KSC	O/F ratio	*Al* (%)	V.I_{sp} (s), 70 KSC
1.5	0	287.6	2	0	293.2
	20	311.2		20	315.5
	30	316.7		30	320.9
	40	316.2		40	320.5

3. GELLATION EXPERIMENTS

Gellation is a physical process which involves swelling of gellant particles with the liquid fuel and metal powder, followed by three-dimensional network formation. UDMH is highly volatile and toxic and hence gellation experiments were done in a sealed reaction kettle fitted with high speed emulsifier and cooled to 15-20 °C by immersion cooler. The liquid fuel was charged to the kettle and then cooled to 15-20 °C. This was followed by slow addition of gellant for 10 min under agitation; and then agitation was continued further for 30 min. Surfactant was added which was followed by sequential addition of metallic powder. All these processes were carried out under agitation over a period of 45-60 min.

Received 04 October 1994

Table 2. Details of gellation experiments

Gel system	Gellant (%)	Kettle type	Bath temp (°C)	Observations
KRS+Cab	0-7.5	open	RT	Partial gellation at 7.5 %
KRS+Cab+PG	0-7.5	open	RT	Partial gellation at 7.5 %
KRS+AA	0-7.5	open	RT	No gellation
KRS+MC	0-7.5	open	RT	No gellation
KRS+OPC	0-7	open	RT	Gellation at 6-7 % partial separation
KRS+OPC+PG	6-7	open	RT	Good gel, no separation
KRS+OPC+PG+ 30 % *Al**	7	open	RT	Good gel, no separation
KRS+OPC+PG+ 40 % *Al**	6	open	RT	Good gel, no separation
UDMH+AA	2	open	RT	Heavy loss of UDMH
UDMH+AA	2	closed	RT	Partial gellation with separation loss of UDMH
UDMH+AA	0-12	closed	15-20	Partial gellation at 12 %
UDMH+EC	0-17	closed	15-20	Very thin gel at 17 %
UDMH+CMC	0-14	closed	15-20	No gellation
UDMH+HMC	0-7	closed	15-20	Good gel at 7 %
UDMH+MC	2-4	closed	15-20	Thin-thick gel
UDMH+MC+30 % *Al*	3	closed	15-20	Good gel, no separation
UDMH+MC+30 % *Al**	3	closed	15-20	Good gel, no separation

* – 500 g batch size

KRS - kerosene, Cab - cabosil, PG - propylene glycol, AA - agar agar, OPC - organophilic clay complex, EC - ethyl cellulose, CMC - carboxymethyl cellulose, HMC - hydroxymethyl cellulose, and MC - methyl cellulose.

The system was kept undisturbed and gellation was found to occur within 30-60 min. Nitrogen gas was purged in the initial and final phases of gellation to avoid air oxidation. The experimental set-up for the preparation of virgin and metallised UDMH gels is shown in Fig. 1. All the gellation experiments were done in 100 g batch level and the promising composition was scaled up to 500 g batch.

The influence of various gellants, such as hydrocolloid and particulate gellants and of different surfactants on gellation of kerosene and UDMH was studied. Incorporation of 0-30 per cent 15 micron *Al* in both UDMH and kerosene gels was successfully done and their gel stability was tested at 8-50 °C. Pseudoplasticity, thixotropy and yield stress of these gels were studied using Côntrave's rheometer. Effect of shear rate on the viscosity of these gels was found using rheometer and Brookfield viscometer. Flow rate studies were initiated using fabricated pressure vessel of 500 ml capacity using single die hole of 1 and 2 mm at N_2 pressure of 0.5-2 KSC. Spraying of aluminised kerosene gel was done using a spray gun under N_2 pressure.

4. RESULTS AND DISCUSSION

The gellation experiments showed that organophilic clay complex (OPC) in combination with propylene glycol (PG) as surfactant gave proper consistency to kerosene gel at 6-7 per cent. A kerosene gel having good storage stability was achieved by successfully incorporating 0-40 per cent 15 micron *Al* (Table 2).

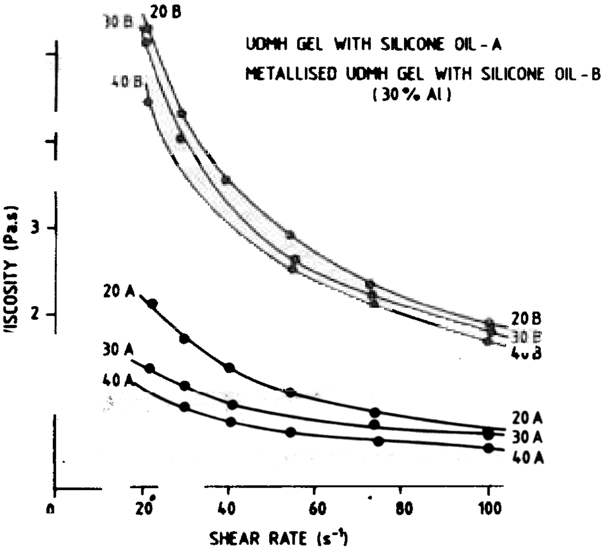

Figure 4. Effect of shear rate on viscosity of virgin and metallised UDMH gels with silicone oil.

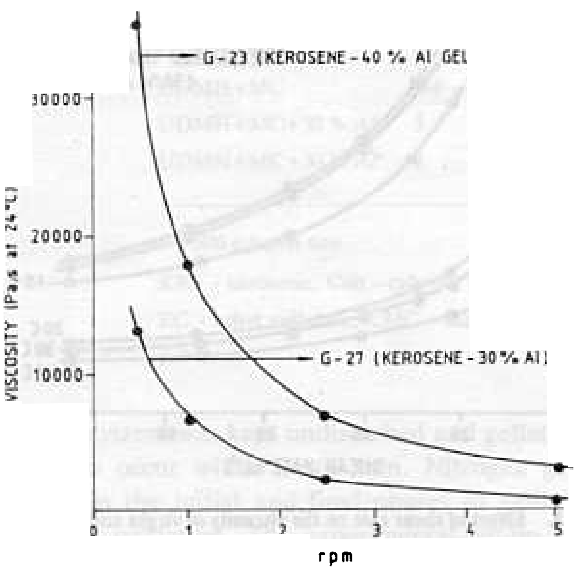

Figure 5. Brookfield viscosity vs rpm (Brookfield viscometer data).

stress is found to increase with metal loading and decrease with temperature. Addition of silicone oil surfactant reduces the yield stress whereas lecithin increases it.

4.1.3 *Pseudoplasticity*

The pseudoplasticity index (n) deduced from the rheogram for different UDMH gels (Fig. 8) shows only marginal decrease with increase in temperature. A

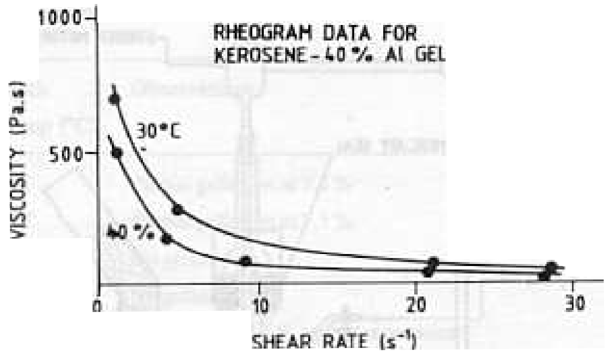

Figure 6. Effect of shear rate on the viscosity of metallised kerosene gel (rheogram data).

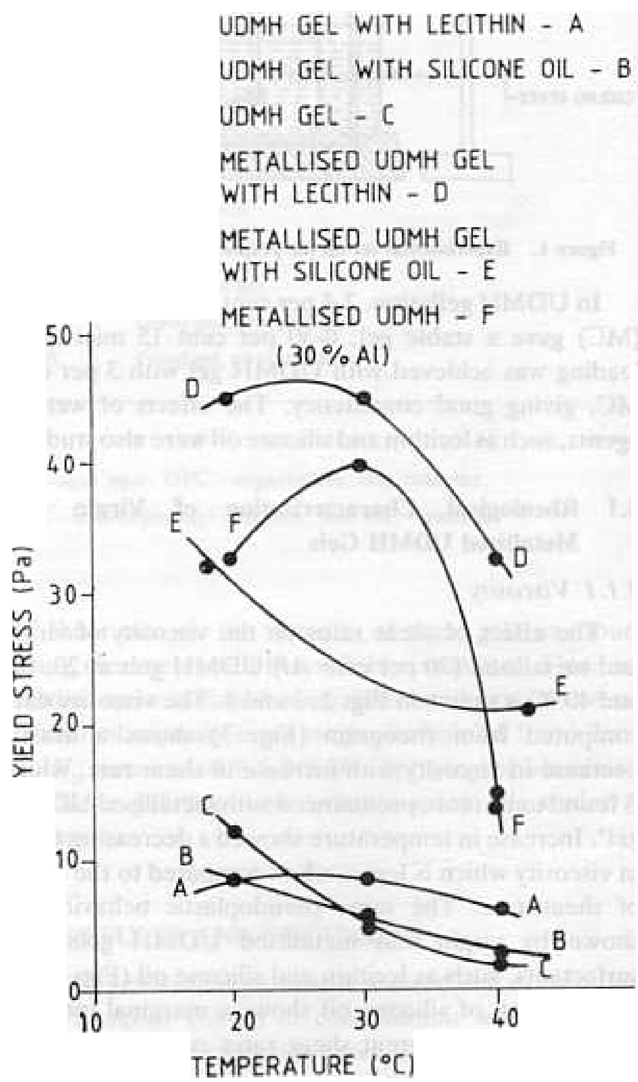

Figure 7. Effect of temperature on yield stress of virgin and metallised UDMH gels.

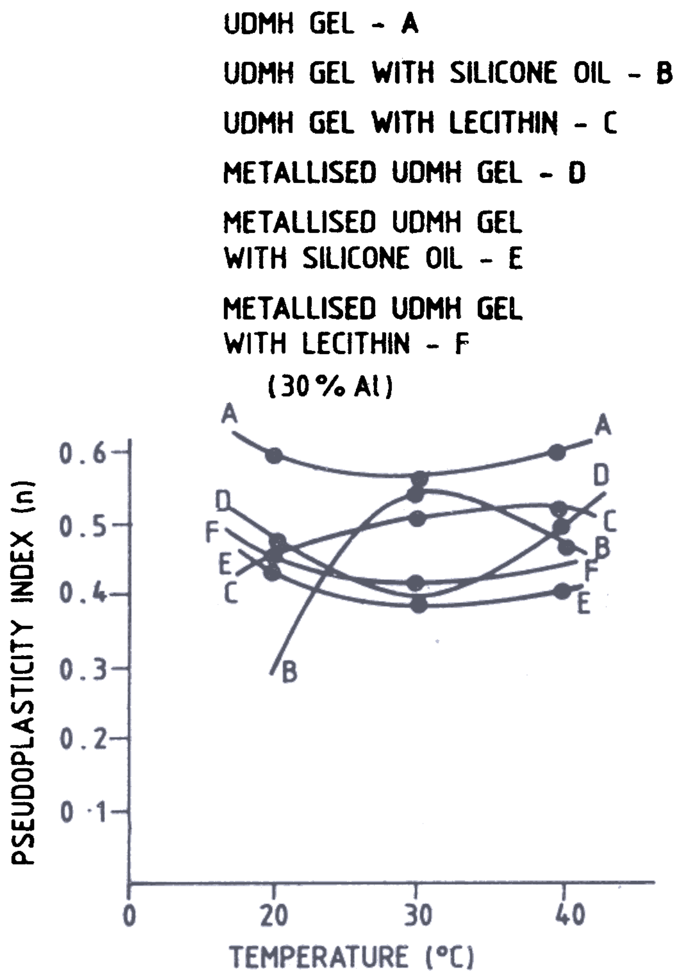

Figure 8. **Effect of temperature on pseudoplasticity index (*n*) of virgin and metallised UDMH gels.**

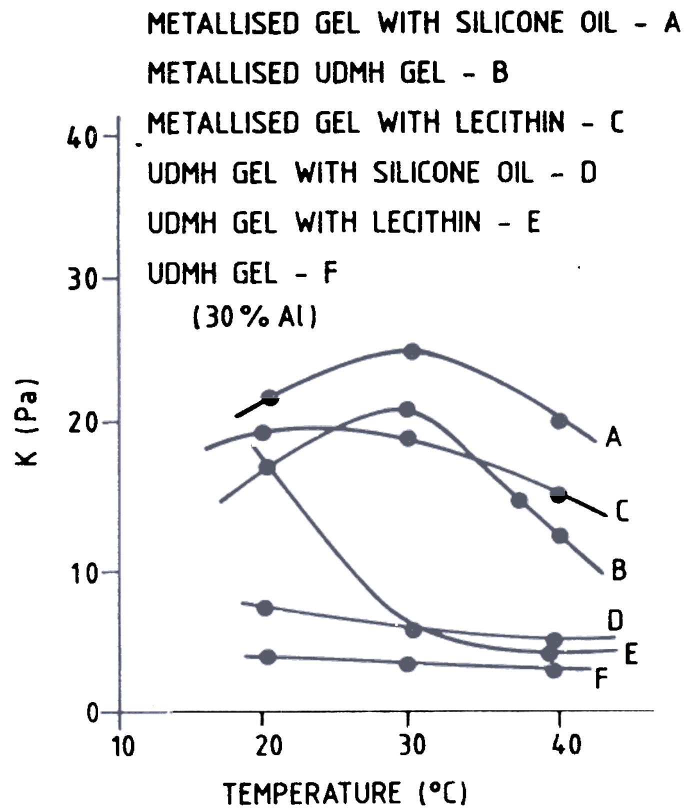

Figure 9. **Effect of temperature on consistency index (*k*) of virgin and metallised UDMH gels.**

decrease in *n* is found with metal loading of UDMH gel. Addition of silicone oil (0.7 per cent) decreases the *n* value of virgin and metallised UDMH gels whereas lecithin gives only marginal decrease in *n* value.

4.1.4 Consistency Index (k)

Consistency index (*k*) values show a drastic increase with metal loading of UDMH gel. The effect of temperature on *k* values is only marginal. Addition of silicone oil increases the *k* value (Fig. 9).

4.1.5 Metallised Kerosene Gels

The viscosity values deduced from Brookfield viscometer and from rheogram against shear rate or rpm are shown in Figs 5 and 6, respectively. Metallised kerosene gels containing 30 and 40 per cent *Al* show a drastic decrease in viscosity with increase in shear rate or rpm. Viscosity values show a decreasing trend with increase in temperature, though not so marked.

4.1.6 Stability and Hypergolicity Tests

Metallised UDMH and kerosene gels were found to be stable at ambient conditions for long periods. Thermal stability tests done in sealed glass containers for 90 min at 8, 20, 30, 40 and 50 °C did not show any separation, showing its stability over a wide temperature range. Hypergolicity tests showed that aluminised UDMH gel is hypergolic with N_2O_4 whereas kerosene gel is non-hypergolic. A mixture of both was found to be hypergolic with N_2O_4.

4.1.7 Flow Rate Studies

Flow rate studies[5] were initiated using a fabricated 500 ml pressure vessel. Continuous flow through a single die of 1 mm dia at 0.5 to 1 KSC N_2 pressure was noticed for metallised UDMH and kerosene gels.

5. CONCLUSION

Metallised stable gels of UDMH and kerosene containing 30 per cent 15 micron *Al* powder have been prepared and characterised with respect to rheology, thermal stability, hypergolicity and flow rate studies.

These gel propellants are found to be pseudoplastic and thixotropic stable gels which flow easily like a liquid under shear force.

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