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TECHNICAL

REPORT

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On FORMATION OF MOVING AND STATIONARY DETONATION WAVES IN FLOWING COMBUSTIBLE MIXTURES

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Date November, 1967

DETONATION VELOCITIES AND INDUCTION DISTANCES IN MIXTURES OF LIQUID RP-1 AND GASEOUS OXYGEN

INTRODUCTION

Because of the importance of detonations of liquid fuel sprays in gaseous oxidizers, several experiments were undertaken to determine the detonation properties of liquid RP-1 sprays in gaseous oxygen under various conditions. RP-1 temperatures were varied from 20°C to 150°C while oxygen temperatures were varied from 20°C to 92°C in conjunction with stoichiometric, lean, and rich mixtures.

EXPERIMENTAL APPARATUS

The experiments were conducted in two vertical 4-ft sections of standard wall glass tubing, joined in the middle by a short brass section with the same ID as the tubing. Two different sizes of tubing (30 and 48 mm OD) were employed to determine the effect of diameter on the detonation properties.

A rotating drum strip film camera was employed to record direct-light traces of the flame front. The film employed in this camera was 70 mm wide, and produced an image of an eight-foot field of view.

The RP-1 and oxygen were mixed as they entered the first section of glass tubing by means of droplet shear mixing, using an injector with two concentric annuli. The exterior injection ports were of 0.018-inch diameter and passed the RP-1 into the glass tubing, while the interior ports, for the oxygen, were 1/32-inch in diameter.

Two different ignitors were employed during different experiments to determine their effect on the induction properties. However, the scatter of the induction data made it impossible to correlate the observed induction lengths with the type of ignitor.

The RP-1 employed was manufactured by Bell Oil and Gas Co., in accordance with military specification MIL-R-25576B. When employed, the two batches used were 24 months and 16 months old. Significant differences were noted between the results obtained from the two different batches showing that chemical changes had probably occurred in the 24-months-old-batch. This was confirmed when insolubles were found to have settled out in this batch.

The 16-months-old-batch was assumed to be close to the desired specifications of MIL-R-25576B, as no settling out was found to have occurred in that batch.

ANALYSIS

When both constituents were unheated, the data observed were not repeatable. The observed values of the detonation velocity in stoichiometric mixtures varied from 1100 to 1400 m/sec (Fig. 1). These values were 70% of the theoretical values calculated on the basis of the NASA program of Gordon and Zeleznik.[1] It was felt that the discrepancy between theory and experiment was caused by incomplete burning of the liquid droplets in the wave. The photographs revealed that after-burning took place in all examined cases.

An attempt was made to increase the amount of RP-1 vapor in the mixture by preheating the RP-1 to 100, 125, and 150°C. The heated RP-1 was injected into both hot and cold oxygen. When the oxygen was unheated, it was found that the mixture formed a fog because of condensation.

When the RP-1 was heated to 100°C and mixed with oxygen at room temperature, the detonation velocities varied from 1500 to 1750 m/sec. An increase of the RP-1 temperature to 125°C increased the detonation velocities to 1700-1850 m/sec. No further increase of the velocities was obtained when the RP-1 temperature was raised to 150°C. It was observed that the tube diameter and type of ignitor seemed to have no effect on the resultant detonation velocities.

When both the RP-1 and oxygen were at temperatures of 92°C, two modes of detonation, each with an associated stable velocity, were observed (Fig. 2). One mode was oscillatory with a velocity approximately 100 m/sec below that of the nonoscillatory mode in the same experiment. This difference is caused by the method of measurement, since only one-dimensional velocities are calculated from strip film traces. The one-dimensional, nonoscillatory detonations in the heated mixture ranged from 1600 to 1700 m/sec, over the examined range of mixture ratios.

Induction distances varied in each of the several experimental cases (Fig. 3), but were found generally to be shorter when a 3-grain squib ignitor was used, and longer when an exploding silver wire was employed. Induction distances also were much shorter when the two-year-old RP-1 was employed instead of the 16-month-old fuel. Higher temperatures appeared to decrease the induction distance significantly due to the presence of more RP-1 in the vapor phase. No significant effect of tube diameter on induction distance was observed.

CONCLUSIONS

One of the more significant results of the presented work is shown in Fig. 2, in which two different stable modes of detonation were observed in the same experiment. The first detonation mode was nonoscillatory in the first four-foot section of glass tube, but after passing

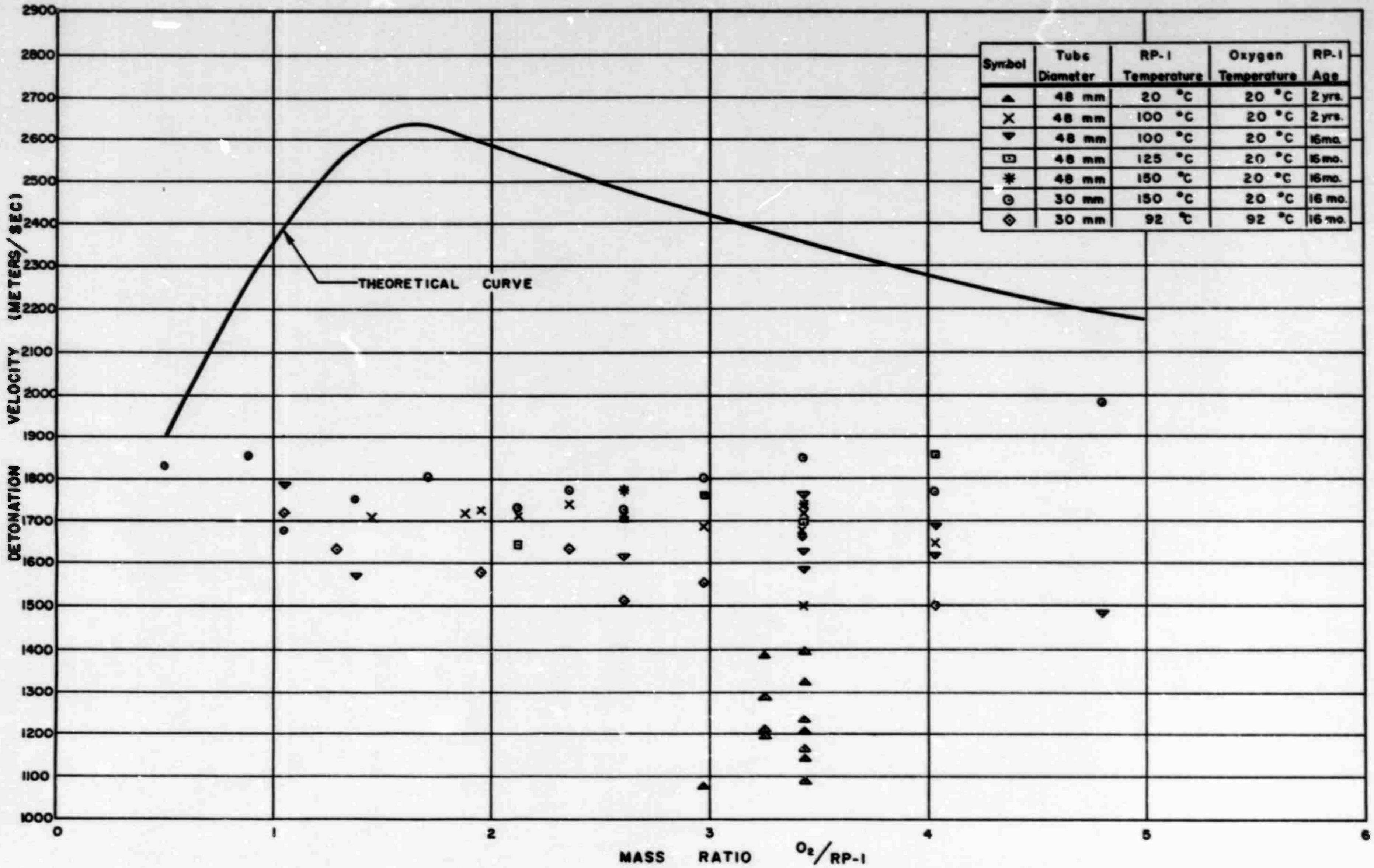


FIG. I DETONATION VELOCITIES IN MIXTURES OF LIQUID RP-1 AND GASEOUS OXYGEN

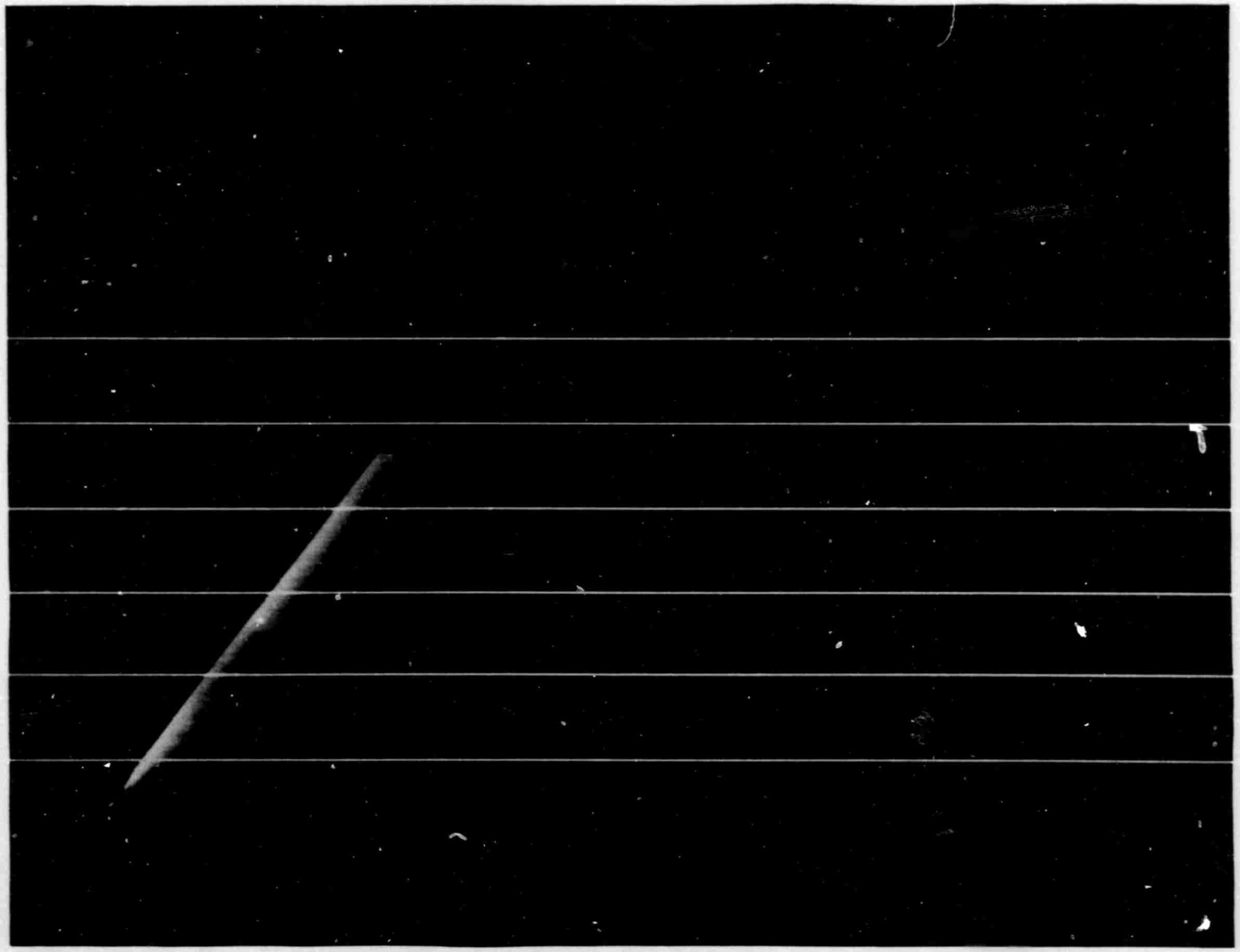
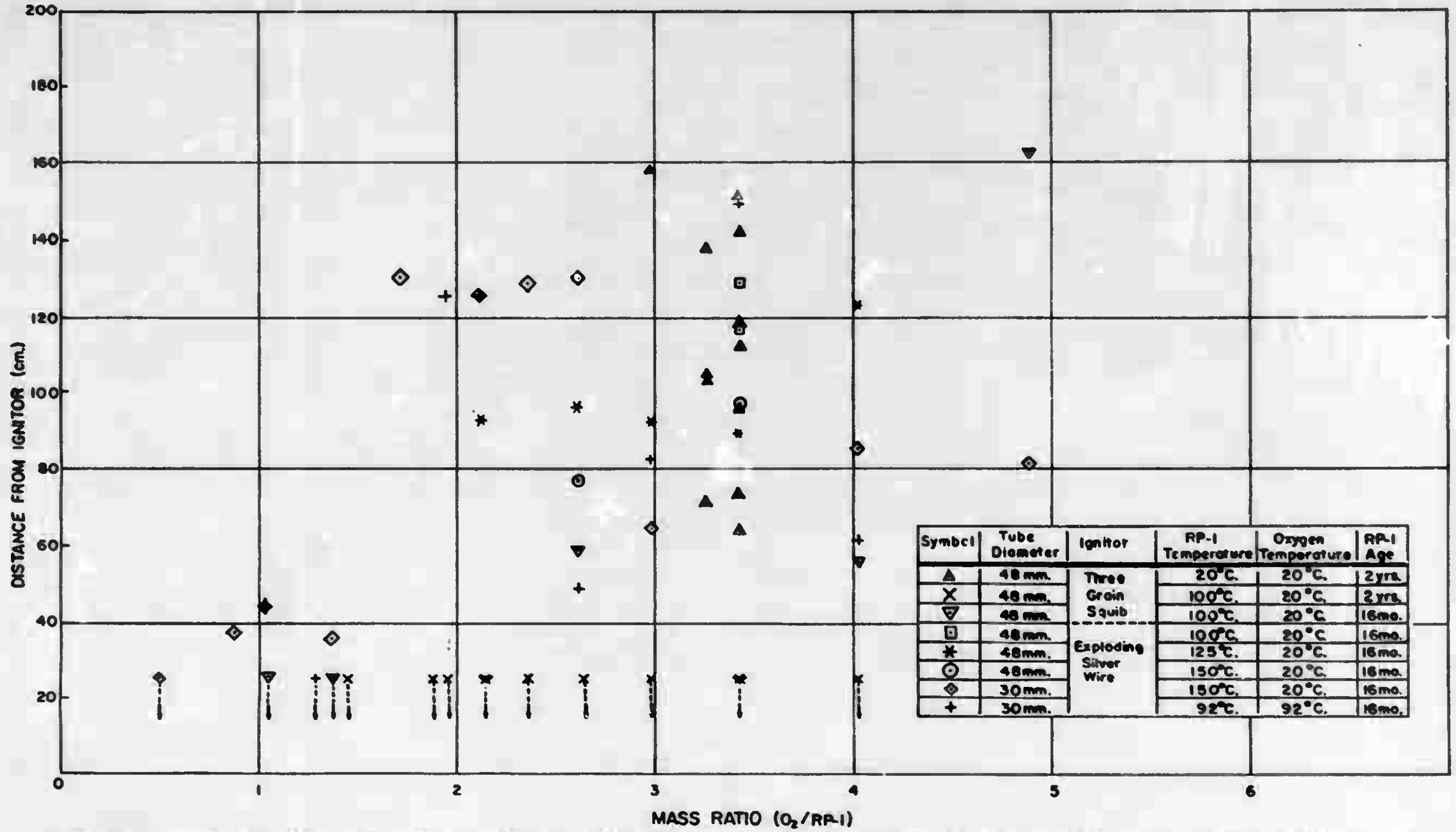


Fig. 2 Two Modes of Detonation Propagation in a Stoichiometric RP-1 Oxygen Mixture at 92°C Showing Point of Onset of Detonation, One-Dimensional Propagation, and Spinning Propagation



Symbol	Tube Diameter	Ignitor	RP-1 Temperature	Oxygen Temperature	RP-1 Age
▲	48 mm.	Three Grain Squib	20°C.	20°C.	2 yrs.
×	48 mm.		100°C.	20°C.	2 yrs.
▽	48 mm.		100°C.	20°C.	16 mo.
⊡	48 mm.	Exploding Silver Wire	100°C.	20°C.	16 mo.
✱	48 mm.		125°C.	20°C.	16 mo.
⊙	48 mm.		150°C.	20°C.	16 mo.
◈	30 mm.		150°C.	20°C.	16 mo.
+	30 mm.		92°C.	92°C.	16 mo.

FIG. 3 DISTANCE FROM IGNITOR TO POINT OF ONSET OF DETONATION IN MIXTURES OF LIQUID RP-1 AND GASEOUS OXYGEN (SYMBOL WITH ARROW DENOTES UNMEASUREABLE INDUCTION DISTANCE OF LESS THAN 25 CENTIMETERS)

through the brass junction between the glass tubes, the detonation attained a different constant velocity in a spinning mode of propagation.

Induction properties were unrepeatable and random for the most part, leading to little basis for correlation of induction properties with tube diameter, or type of ignitor. The induction distances generally decreased with a temperature increase.

The large discrepancy found between theoretical and experimental wave speeds shows a need for theoretical work concerning droplet burning in a detonation wave.

TABLE I - ROCKET FUEL RP-1*

Test	Specification	Results	
Gravity, °API	42-45	44.9	
Gravity, Specific	0.801-0.815	0.8022	
Existent Gum, M_G/100 M_L Max	7	0.3	
Potential Gum, 16 M_R Aging M_G/100 M_L Max	14	1.0	
Sulfur, Total, Pct Wt, Max	0.05	0.05	
Mercaptan Sulfur, Pct Wt, Max	0.005	0.0005	
Freeze Point, °F, Max	-40	-40	
Thermal Value: Mean of Combustion, Net BTU/lb, Min	18,500	20,910	
Viscosity, Centistokes at -30°F, Max	16.5	14	
Aromatics, Vol Pct, Max	5.0	4.7	
Olefins, Vol Pct, Max	1.0	0.65	
Smoke Point, MM, Min	25.0	31.5	
Copper Strip Corrosion, ASTM Classification, Max	1	1 B	
Water Reaction	(1.0)(1 B)	0.0 (1)	
Flash Point, Min, °F	110	172	
Aniline Point, °F	Record	165.5	
Distillation		°F	°C
Initial Boiling Point, °F	Record	374	190
Fuel Evaporated, 10% at °F	365-410	400	205
Fuel Evaporated, 50% at °F	Record	431	222
Fuel Evaporated, 90% at °F	Record	470	243
End Point, Max °F	525	506	263
Residue Vol Pct, Max	1.5	1.0	
Distillation Loss, Vol Pct, Max	1.5	1.0	

*Bell Oil and Gas Company, Ardmore, Oklahoma.

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13. ABSTRACT

This report summarized experiments undertaken to determine the detonation properties of liquid RP-1 sprays in gaseous oxygen as a function of fuel and oxidizer temperature and mixture ratio. One of the more significant results observed was that when both the RP-1 and oxygen were tested to 92°C, two different stable modes of detonation, each having a steady speed, occurred in the same experiment. The first detonation mode was non-oscillatory; the second mode was a spinning oscillatory detonation mode with a different constant velocity approximately 100 meters/second below that of the non-oscillatory mode. Induction properties were unrepeatable and random for the most part, leading to little basis for correlation of induction properties with tube diameter or type of igniter. Tube diameter and type of igniter seemed to have little effect on the resultant detonation velocities. The induction distances generally decreased with temperature increase. The large discrepancy found between theoretical and experimental wave speeds were thought to be caused by incomplete burning of the liquid droplets in the detonation wave front.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Detonation Wave Propagation						
Multiphase Detonations						
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Spinning Detonation						
Oscillatory Detonation						
Combustion Instability						
Supersonic Combustion						
Shock-Initiated Supersonic Combustion						
Moving Detonation Waves						
Stationary Detonation Waves						
Stable Detonation						
Unstable Detonation						

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