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U.S. DEPARTMENT OF ENERGY
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Summary

Conditions were determined in a continuous-flow, premixing-prevaporizing duct in which autoignition occurred. Test conditions were representative of an advanced, regenerative-cycle, automotive gas turbine. The test conditions were inlet air temperatures from 600 to 1250 K (a vitiated preheater was used), pressures from 170 to 600 kPa, air velocities of 10 to 30 m/sec, equivalence ratios from 0.3 to 1.0, mixing lengths from 10 to 60 cm, and residence times of 2 to 100 ms. The fuel was diesel No. 2. The 12-cm-inside-diameter duct was insulated. Three fuel injectors were used: one was a single simplex pressure atomizer, and the other two were multiple-source injectors. The data obtained with the simplex and one of the multiple-source injectors agreed satisfactorily with the literature and correlated with an Arrenhius expression, $\tau \propto e^{E/RT}/\tau$, where τ is the autoignition delay time, E and R are constants, T is the absolute temperature, and p is the pressure. The data obtained with the other multiple-source injector, which used multiple cones to improve the fuel-air distribution, did not correlate well with residence time.

Introduction

In support of the DOE Gas Turbine Highway Vehicle Systems Project, experimental conditions were determined for autoignition to occur in a premixing-prevaporizing fuel preparation duct.

Lean premixed-prevaporized combustion systems are being considered for gas turbines to reduce pollutant emissions, in particular nitrogen oxides. Essential to such a system is the prevention of autoignition before the fuel is mixed and vaporized so as not to generate nitrogen oxides or cause physical damage.

Autoignition has been studied by several investigators. Mullins, Ducourneau, Marek, et al., and Spadaccini and TeVelde (refs. 1 to 5) have conducted continuous-flow autoignition experiments that are representative of gas turbine combustor conditions. The results from these studies are satisfactorily correlated by an Arrhenius type expression. However, the results differ in important respects, for example, in the value of ignition delay time, the effect of equivalence ratio, and the value of the pressure exponent. These differences demonstrate the importance of the test hardware configuration and, in particular, of fuel injector design.

Recently, autoignition tests were performed (ref. 6) with a multiple-source fuel injector designed to premix and prevaporize the fuel for use with a catalytic reactor. Considerable scatter occurred in the data of that study. A possible cause of the scatter is that the fuel was injected at the surface of the throat of each of the 21 venturi-shaped air passages and that the fuel could have collected on the surface in an unsteady way. Another possible cause for the data scatter is the placement of the thermocouple used to detect autoignition at the wall. Small changes in overall conditions could produce large changes in conditions at the wall. In this study, to avoid these possible problems, fuel was injected into the center of the air venturi passages, and five thermocouples, located at various radial depths in the ducts, were used to detect autoignition. To evaluate the effect of fuel injector type and, therefore, spatial fuel-air distribution on autoignition limits, three different fuel injection systems were used. One single-source and two multiple-source fuel injectors were used to see if the fuel-air mixing had any effect on the autoignition limits. Of the two multiple-source fuel injectors, one had an array of conical tubes at the fuel injection plane, and the other did not. Test conditions were representative of those found in an advanced, regenerative-cycle automotive gas turbine.

Apparatus

Test Rig

A schematic drawing of the test rig is shown in figure 1(a). The experiment was performed in a 12-cm-inside-diameter, insulated tubular duct. The duct was constructed from 15.2-cm-inside-diameter (6-in., schedule 40) stainless-steel pipe. Carborundum T30R Fiberfrax tube insulation, 1.5 cm thick, was placed inside the pipe to minimize heat losses. A 0.1-cm-thick stainless-steel liner was placed inside the insulation to minimize erosion of the insulation and provide a flow diameter of 12 cm. The air was preheated using a hydrogen burner to temperatures up to 1250 K. Six Chromel-Alumel thermocouples and a static-pressure transducer located 10 cm upstream of the fuel injector were used to measure inlet-air conditions (see fig. 1(b)). The fuel was diesel No. 2 (see table I for properties) and was supplied to the injector at ambient temperature. The fuel injector was inserted in a spool piece that was changed to vary the mixing-vaporizing length. Located downstream of the premixing-prevaporizing section were five Chromel-Alumel thermocouples (see fig. 1(b)) and a pressure transducer. Four of these thermocouples were used for data acquisition, and the other was used to trigger a fuel shutoff when ignition in the premixing-prevaporizing section was detected. Downstream of the five thermocouples, a flameholder and a hydrogen enriched afterburner were used to burn the unreacted fuel. The flameholder was water cooled and contained 62, 0.63-cm-diameter holes that resulted in a 75-percent blockage. The afterburner was 61 cm long, and the liner was air cooled. A water-cooled orifice downstream of the afterburner was used to control back pressure. Varying the orifice

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size controlled the level of back pressure. Water was injected downstream of the orifice to cool the gases before going to the atmospheric exhaust.

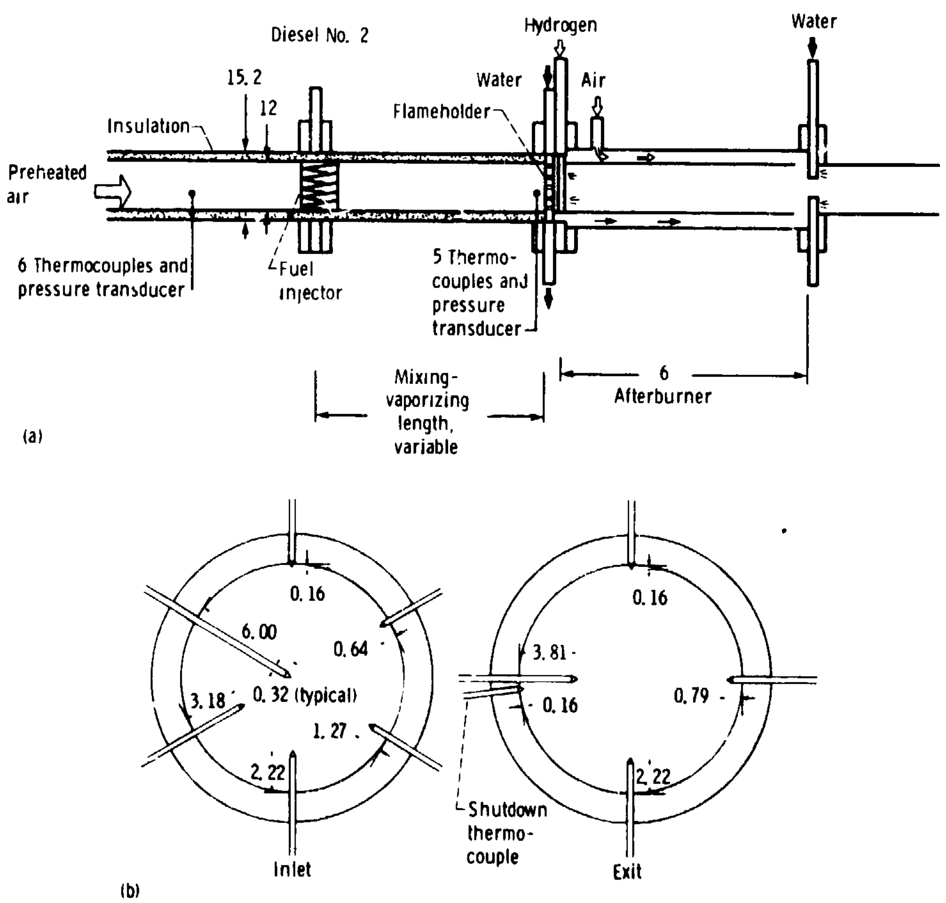
Fuel Injectors

A single-source, simplex, pressure-atomizer fuel-injection system and two multiple-source fuel injection systems were used for this study.

The single-source simplex pressure atomizer was a commercially available Monarch nozzle, 2.27×10^{-2} m^3/hr at 690 kPa pressure drop (6 gal/hr at 100 psi) with a 70° hollow cone angle.

One of the multiple-source fuel injection systems had 41 fuel sources discharging into an equal number of diffusing air passages (fig. 2). The purpose of the diffusing air passages was to meter equal amounts of air flow to each fuel source and to provide higher velocity air for better atomization. Each air passage entrance was 1.27 cm in diameter with a diffuser half angle of 3.5°. The open airflow area was 41.4 percent. Each fuel tube had a 0.069-cm inside diameter. Around each fuel tube was a second, concentric tube with a 0.155-cm inside diameter. Air at ambient temperature flowed through the annular gap to provide cooling of the fuel tubes and additional atomization of the fuel. The supply pressure for the cooling airflow was fixed; thus the cooling airflow varied as the test section pressure varied. The cooling airflow was always less than 4 percent of the total airflow and was not included in the velocity and residence time calculations.

The second multiple-source fuel injection system, the 19-source fuel injector (fig. 3(a)), consisted of 19 fuel injector modules (fig. 3(b)). In each module, fuel was injected downstream through a center tube (0.024 cm i.d.), and ambient temperature air flowed through the outer four tubes (0.051 cm i.d.) to assist in the atomizing and mixing of the fuel. The supply pressure for the air assist was fixed; thus the airflow for the air assist varied as the test-section pressure varied. The airflow for the air assist, always less than 2 percent of the total airflow, was



(a) Rig schematic.
(b) Location of thermocouples.

Figure 1. - Fuel injector test rig. (Dimensions are in centimeters.)

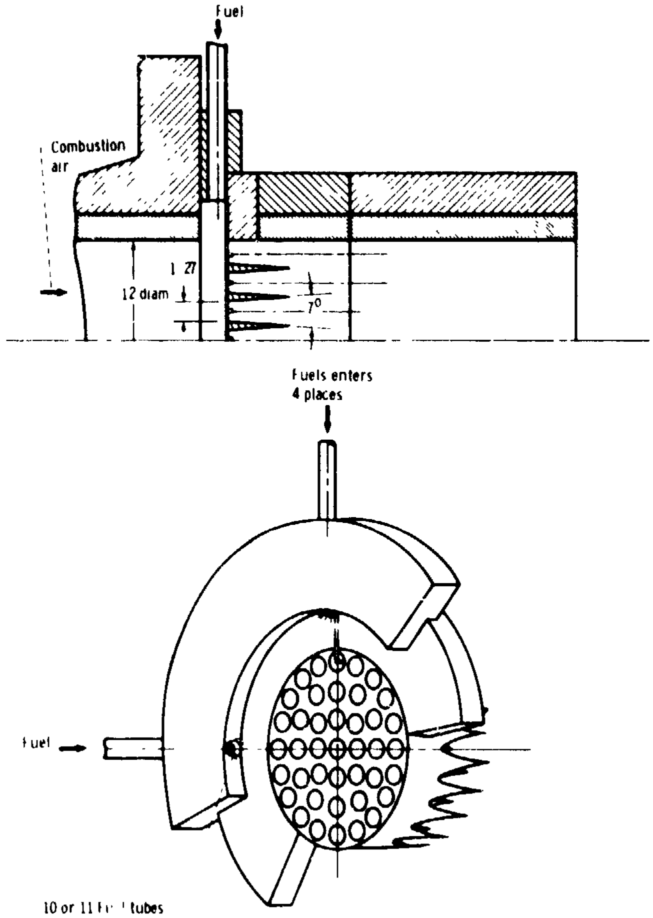
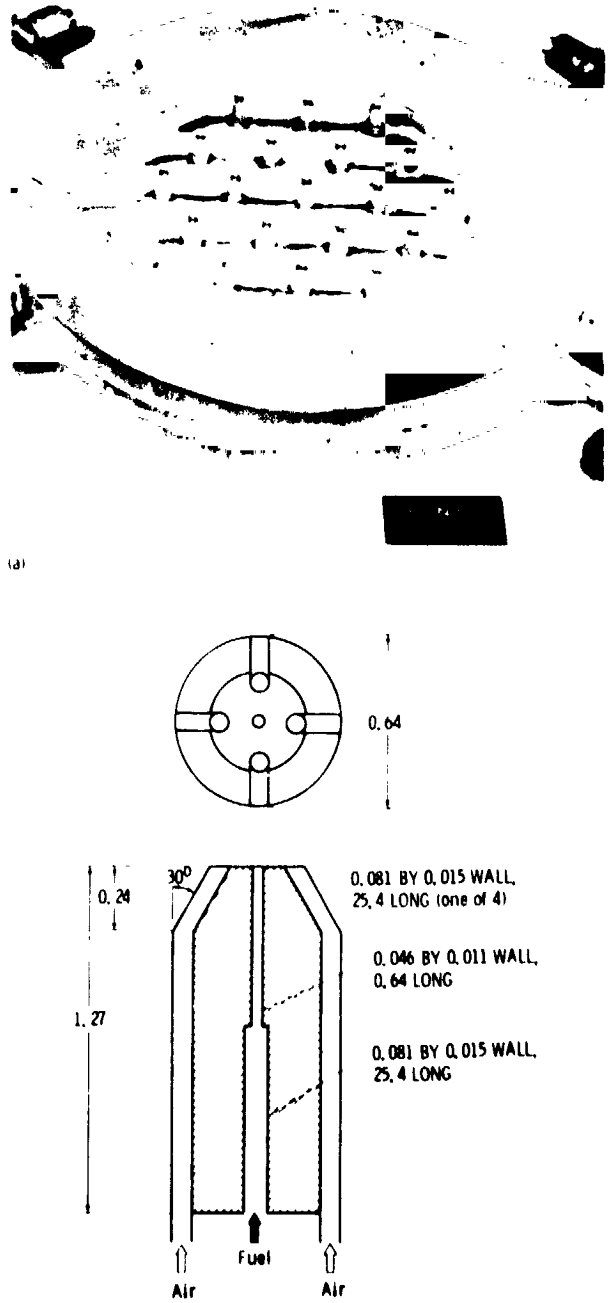


Figure 2. - 41-Source-conical-tube fuel injector. (Dimensions are in cm.)

not included in the velocity or residence time calculations. Placed 5 cm upstream of the 19-source fuel injector was an array of hexagonal tubes (see fig. 4) arranged so that the centerline of a hexagonal tube corresponded to the centerline of a fuel injector module. These tubes metered an equal amount of air to each fuel injector module to provide a spatially uniform fuel-air distribution.

Procedure

Data are presented and correlated for the conditions where the fuel spontaneously ignited in the mixing-vaporizing duct. The method used to obtain autoignition data was to establish air flow and fuel flow, then increase inlet air temperature to obtain ignition. The data points in the plots (data are also tabulated in table II) are those taken just before autoignition occurred. An autoignition was defined for this study as at least a 200 K increase in mixture temperature for a small (less than 20 K) increase in inlet temperature. The inlet temperature for autoignition is the maximum of the six inlet thermocouples. This temperature was at the center of the duct and was as much as 50 K above the average and 100 K above the temperature at the wall.



(b)

(a) Upstream view.
(b) Air assist module.

Figure 3. - 19-Source fuel injector.

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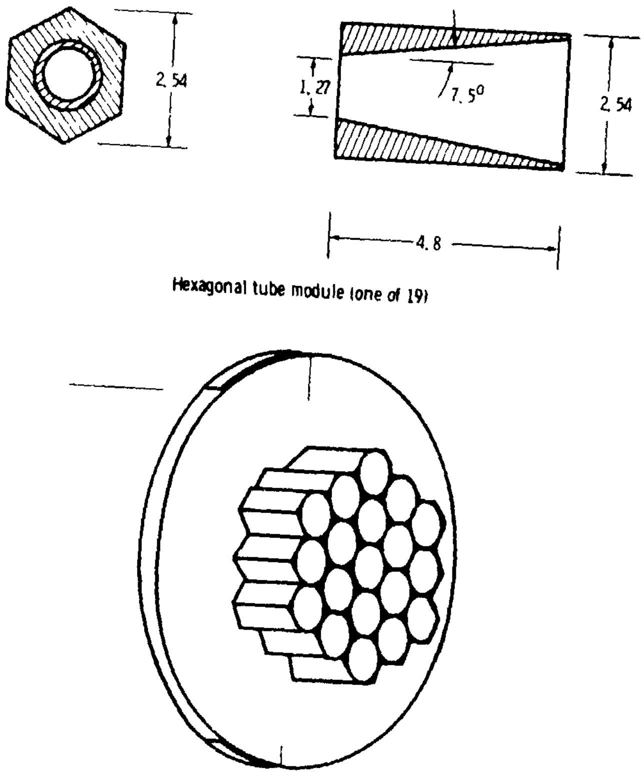
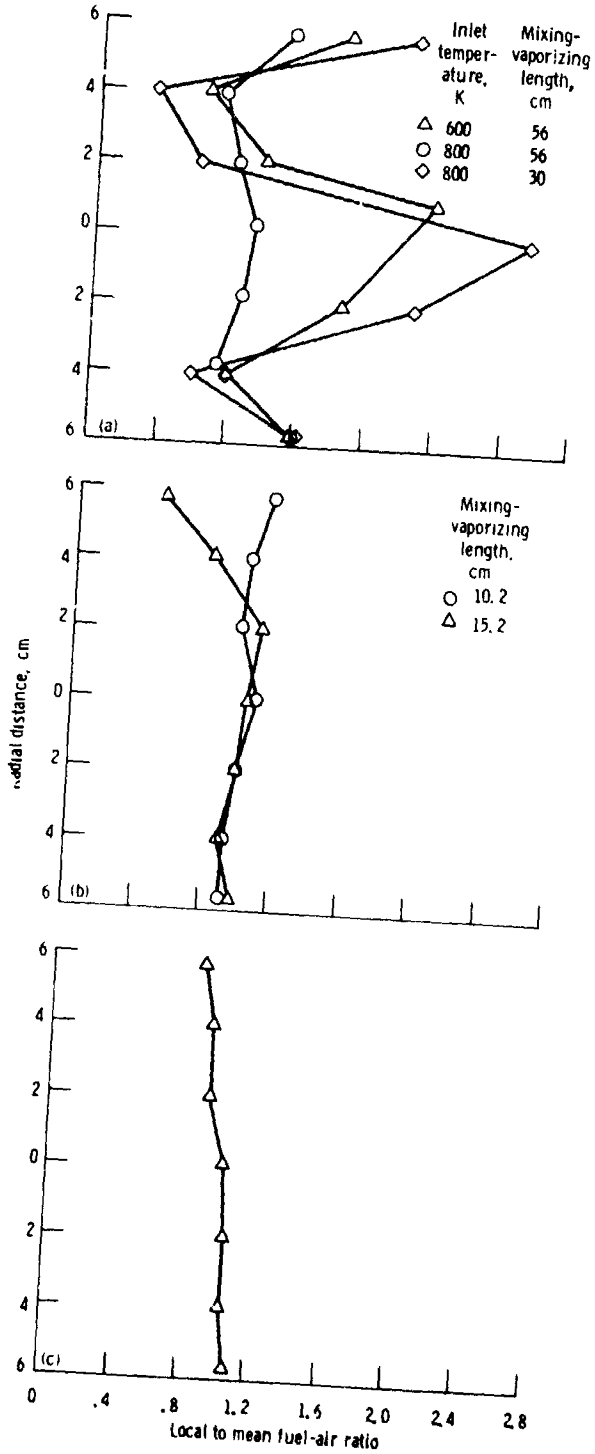


Hexagonal tube module (one of 19)

Hexagonal tube array

Figure 4. - Hexagonal tube module and array.



(a) Simplex fuel injector. Pressure, 250 kPa; air velocity, 20 m/s.
(b) 19-Source fuel injector. Inlet temperature, 700 K; pressure, 420 kPa; air velocity, 10 m/s.
(c) 41-Source-conical-tube injector. Inlet temperature, 600 K; pressure, 210 kPa; air velocity, 15 m/s; mixing-vaporzing length, 15.2 cm.

Figure 5. - Spatial fuel-air distribution. Equivalence ratio, 0.3.

No correction was made to the autoignition delay time because the inlet air was vitiated. Vitiation changes the fuel-to-oxidant ratio (and adds water vapor and carbon dioxide), but the literature differs on whether there is an effect of fuel-to-oxidant ratio on autoignition delay time; so for this study no correction was made.

Data were taken over a range of equivalence ratios, but data at equivalence ratios below 0.28 are not reported because there was no well-defined ignition point at the low ratios.

The spatial fuel-air distribution for the three fuel injectors is shown in figure 5. The method for obtaining the fuel-air distributions is described in reference 8. The distribution from the 41-source-conical-tube fuel injector was very uniform; from the 19-source fuel injector moderately uniform; and from the simplex the distribution, nonuniform. With the simplex nozzle at an axial distance of 30 cm, the hollow cone spray produced a distribution with rich zones near the wall and in the center. At a mixing length of 56 cm, the profile was more uniform. Increasing inlet air temperatures also increased the uniformity of the fuel-air distribution for the simplex nozzle.

Autoignition Correlation

Effect of Pressure and Temperature

A convenient form for presenting autoignition data is

$$\tau = ke^{E/RT}/p^n$$

(refs. 3 and 5) where τ is the autoignition delay time, k is a constant for a constant equivalence ratio, E is the activation energy, R is the universal gas constant, T is the inlet air temperature, p is the pressure, and n is a constant determined experimentally. The equation is derived from chemical reaction theory and does not include a mixing and vaporization time, even though it affects the actual autoignition delay time. Thus, the actual data may not be of this form, although it is still a useful way to present the data. The value of n found in the literature varies: Spadaccini and TeVelde (ref. 3) used a value of 2.0; Ducourneau (ref. 2), 1.0; and Stringer, Clarke, and Clarke (ref. 7), 0.83. In this report a value of 1.0 was used.

The autoignition data for the three fuel injectors are plotted in figure 6 as log τp as a function of $1/T$, where τ is the residence time, p is the pressure, and T is the maximum of the six inlet air temperatures. The data for the simplex injector correlate well; the data for the 19-source fuel injector correlate moderately well; and the data from the 41-source-conical-tube injector correlate poorly.

Some of the data points to the far right on the plots (at $T = 702$ K for the simplex fuel injector and at $T = 733$, 753, and 810 K for the 41-source-conical-tube fuel injector) do not correlate with the rest of the data and were possibly caused by a flashback. In this experiment there was no way to discriminate between flashback and autoignition.

The data from the simplex and 19-source fuel injectors, plotted in figure 6(d), agree well. In figure 6(e) the data from all three of the fuel injectors are plotted. Because of the large data scatter of the 41-source, conical-tube fuel injector, the data only correlate within an order of magnitude.

Effect of Equivalence Ratio

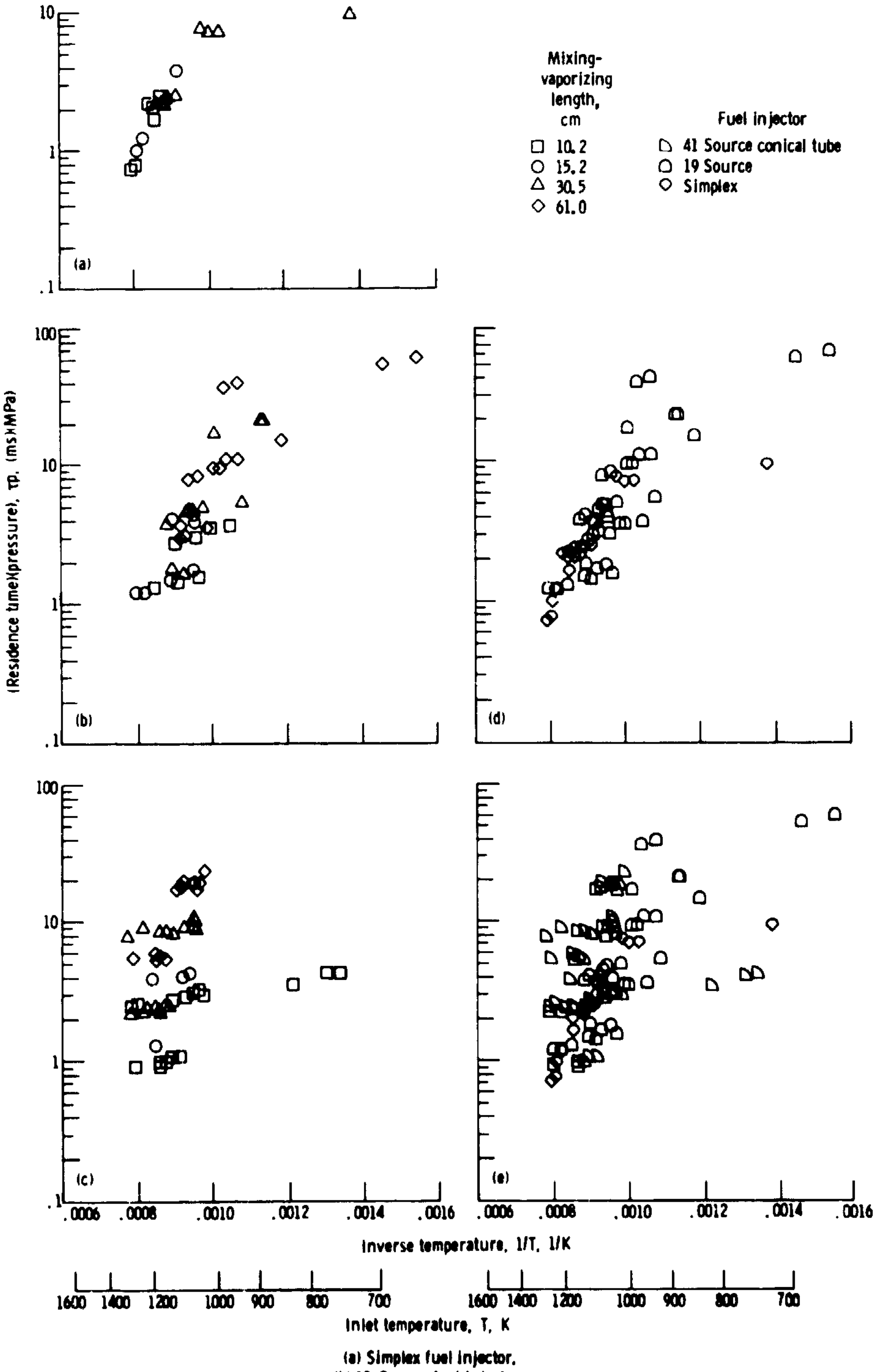
In a completely premixed-prevaporized experiment, the equivalence ratio and pressure determine the concentration term in the reaction rate expression. Previous experimenters have reported conflicting results on the effect of equivalence ratio. Mullins (ref. 1) found no effect, Spadaccini and TeVelde (ref. 3 and 4) showed only a slight effect, and Ducourneau (ref. 2) reported a strong effect. An explanation for the differences may be that, with liquid fuel injection, one can only approximate a premixed-prevaporized system; thus, the effect of equivalence ratio is dependent on the rate of mixing and vaporization of the fuel.

The data of figure 7 are plotted with the pressure term multiplied by the equivalence ratio. The effect of equivalence ratio on the autoignition delay time for the three fuel injectors seems to vary with the uniformity of the spatial fuel-air distribution. The spatial fuel-air distribution for the simplex fuel injector was very nonuniform (fig. 5(a)), and overall equivalence ratio had no apparent effect on the autoignition delay time (fig. 7(a)). The 19-source and 41-source-conical-tube fuel injection systems both produced nearly uniform spatial fuel-air distributions (figs. 5(b) and (c)). Including the overall equivalence ratio considerably improved the data correlation for autoignition delay time (figs. 7(b) and (d)). Note that the data from the 41-source-conical-tube fuel injector segregate with the mixing-vaporizing length. In figure 7(d) the data taken with the simplex and 19-source fuel injectors are plotted, and the data agree well. The data of figure 7(e), wherein data from all three fuel injectors are plotted, correlate better with the equivalence ratio term included, but there is still significant scatter due to the 41-source-conical-tube fuel injector data.

The data from reference 6 are compared with the data from the present study in figure 7(f). The data from reference 6 span the data from this report and show the considerable scatter that may be present in autoignition data. The fuel injector of reference 6 had 21 venturi-shaped air passages with fuel injected at the surface of the throat of each passage. As discussed in the introduction, a possible cause of the data scatter in reference 6 was that the fuel was injected from the wall of the individual air tubes and fuel could have collected on the surface in an unsteady way. There was no air cooling of these fuel tubes. Another possible cause of the data scatter was that only one thermocouple located at the duct wall was used to detect whether autoignition had occurred. Since at the wall there are usually large gradients in conditions such as temperature and velocity, possibly small changes in overall conditions could produce large differences in conditions at the thermocouple and thus account for the data scatter. In the present experiment the center thermocouples were usually the first to indicate a temperature rise, and the fuel would be shut off before the two thermocouples nearest the wall indicated a temperature rise.

Effect of Mixing-Vaporizing Length

As previously noted, the data with the 41-source-conical-tube fuel injector separate according to the mixing-vaporizing length. This is not surprising, since the data of Spadaccini and TeVelde (ref. 3) and Ducourneau (ref. 2) also show a length effect (see discussion in ref. 6). Figures 7 (a) to (c) show that as mixing-vaporizing length



(a) Simplex fuel injector.
(b) 19-Source fuel injector.
(c) 41-Source-conical-tube fuel injector.
(d) Simplex and 19-source fuel injectors.
(e) Simplex, 19-source, 41-source-conical-tube fuel injectors.

Figure 6. - Autoignition as function of temperature, pressure, and delay time.

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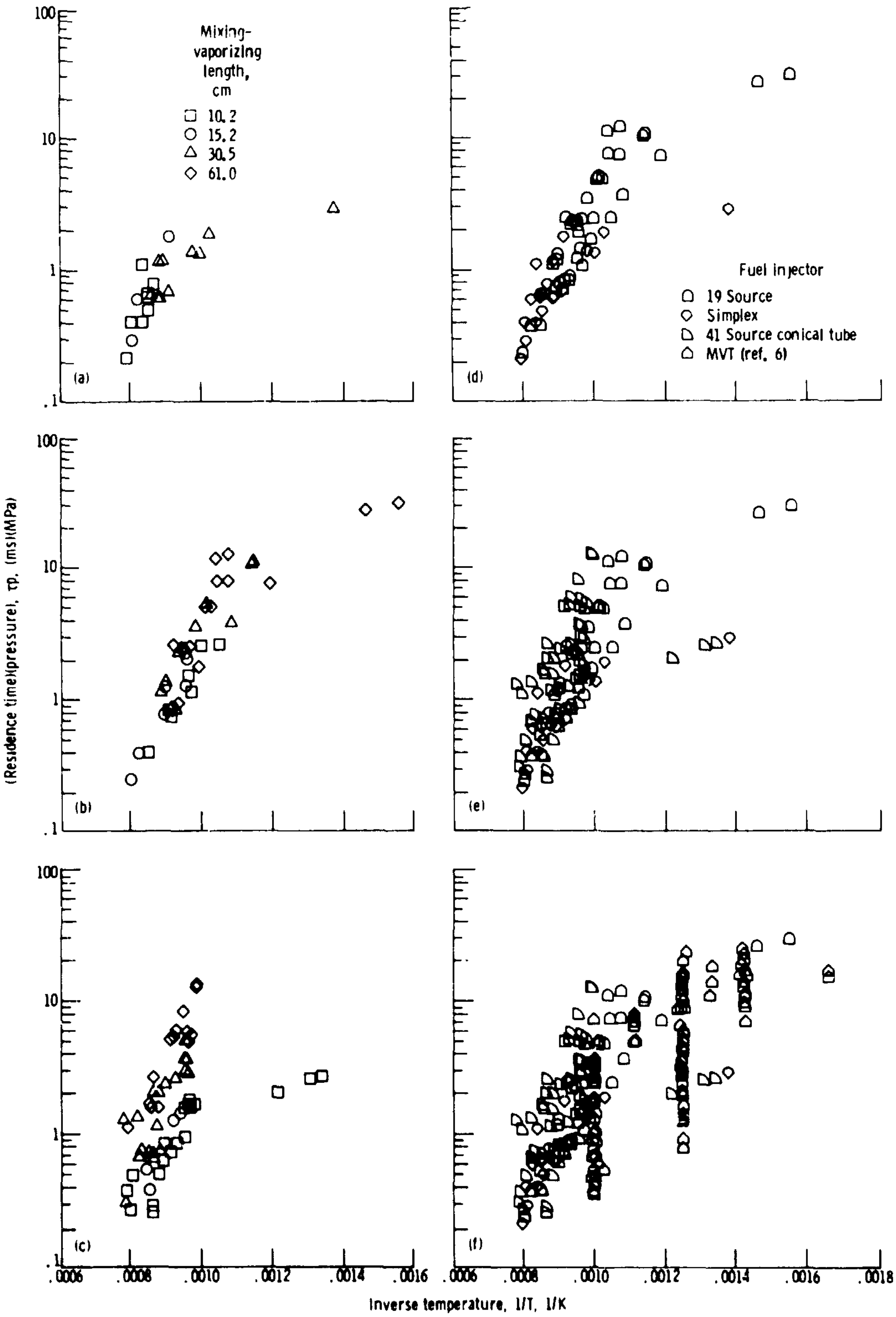
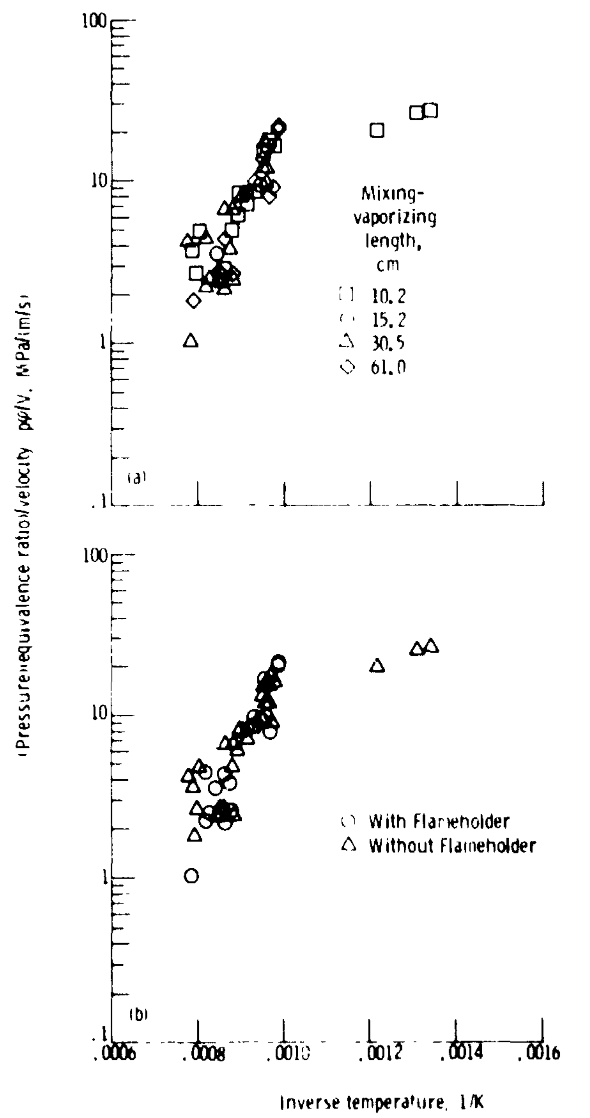


(a) Simplex injector.
(b) 19-Source fuel injector.
(c) 41-Source-conical-tube fuel injector.
(d) Simplex and 19-source fuel injectors.
(e) Simplex, 19-source, and 41-source-conical-tube fuel injectors.
(f) Simplex, 19-source, 41-source-conical-tube, and multiple venture tube (MVT) fuel injectors.

Figure 7. - Autoignition as function of temperature pressure, equivalence ratio, and residence time.

increases, the autoignition delay time also increases (pressure and equivalence ratio held constant). A plot of $p\varphi/V$ as function of $1/T$, where V is the upstream air velocity, was made for the 41-source-conical-tube, fuel-injector data. The data correlated very well (fig. 8(a)). One possible explanation of the ignition conditions being independent of bulk flow residence time is that there were local recirculation zones at the fuel injector that provided the time for ignition. The data of Ducourneau (ref. 2) and Spadaccini and TeVelde (ref. 3) do not show such a strong effect of length.

Data were also taken without the afterburner flameholder (still with downstream burning, however) to determine if this would affect the results. As shown in figure 8(b) no noticeable difference between the data taken with and without the flameholder occurred.



(a) Length as parameter.
(b) Data with and without afterburner flameholder.

Figure 8. - Independence of autoignition data on bulk flow residence time for 41-source-conical-tube fuel injector.

Comparison with References

In figure 9 the data taken with only the simplex fuel injector are compared with the data from Mullins (ref. 1), Ducourneau (ref. 2), Spadaccini and TeVelde (refs. 3 and 4), Marek, et al., (ref. 5), and Stringer, et al., (ref. 7). The data were plotted as log τp as function of $1/T$.

Since differences in data may be a result of differences in experimental hardware and test conditions, a brief description of the reference experiments is given here. Probably, the most important difference between the various experiments is in the mixing and vaporization rates which resulted from the difference in fuel injectors. Spadaccini and TeVelde used a multiple-source injector similar to the 41-source, conical-tube injector but with a much higher blockage. Ducourneau used a multiple-source fuel injector that consisted of a number of fuel tubes with multiple holes that sprayed the fuel cross-stream into the airflow (25 injection points in a 42-mm-diam duct). Mullins used a single simplex pressure atomizer, which sprayed fuel downstream. Marek also used a single simplex pressure atomizer but sprayed the fuel upstream. Stringer's data were obtained from a diesel engine application so that the fuel was pulsed into a slow moving air stream from a single fuel tube.

The fuels used by other researchers were all kerosene type fuels. Stringer, TeVelde, and Spadaccini used diesel No. 2, Marek used Jet A, and Ducourneau and Mullins used kerosene. Spadaccini, who tested Jet A, diesel No. 2, and JP4, showed that there is little difference in the autoignition results with these kerosene type fuels. The diesel No. 2 data from Spadaccini is plotted.

Equivalence ratio was another variable in the references. Mullins varied equivalence ratio but found no effect; on the other hand, Ducourneau reported a large effect. The Ducourneau data are plotted for a equivalence ratio of 1.0. The data of Spadaccini and TeVelde (ref. 3) showed only a slight effect of equivalence ratio and are also plotted for an equivalence ratio of 1.0. The effect of equivalence ratio was not determined in the follow-on work of TeVelde and Spadaccini (ref. 4); the data for a range of equivalence ratios from 0.2 to 1.0 are plotted. The data of Marek were taken at a single equivalence ratio of 0.7.

The data differ by an order of magnitude. The dependence on temperature as seen by the slopes of the curves are quite different. The data of Spadaccini and TeVelde (ref. 3) agree very well with those of Stringer. Their data show a strong dependence on temperature at low inlet-air temperatures, and this dependence decreases as inlet-air temperature increases. The high inlet-air temperature data of Mullins (ref. 1), TeVelde and Spadaccini (ref. 4), and the data of this report show a strong dependence on temperature. The data of Ducourneau (ref. 2) show the least dependence on temperature, with the data of Marek (ref. 5) falling between the two extremes.

Length was a variable (to change residence time) in the experiments of Ducourneau (ref. 2) and Spadaccini and TeVelde (ref. 3). In figure 9 it can be seen that their data separate according to mixing-vaporizing length as did the data with the 41-source-conical-tube fuel injector. The longest mixing-vaporizing lengths have the highest value of autoignition delay time (for a fixed pressure). Note that the data of Spadaccini and TeVelde (ref. 3) at the two longest lengths agree very well but that the data at the shorter lengths separate.

In conclusion despite large differences in the autoignition data, the data show general agreement and trends. The differences in data result from differences in mixing and vaporization rates of the fuel, which are dependent on the interaction of the fuel injector and operating conditions.

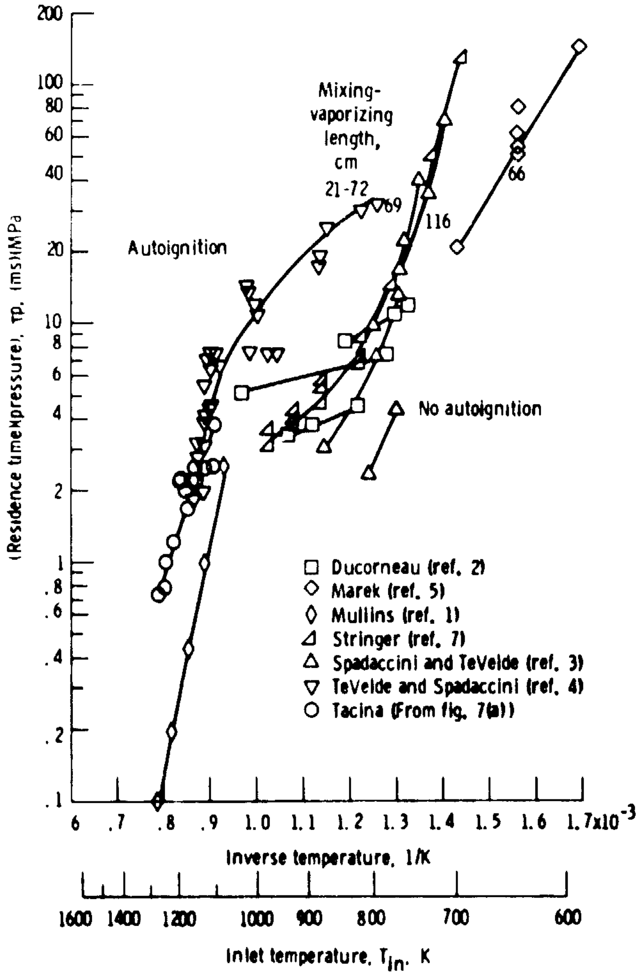


Figure 9. - Comparison of autoignition data with refere...

Summary of Results

Data were obtained for the conditions where autoignition occurred in a premixed-prevaporized fuel preparation duct. Test conditions were representative of an advanced, regenerative-cycle automotive ga[s turbine]. High inlet temperatures, up to 1250 K, were of particular interest. The test conditions were inlet-air temperatures from 600 to 1250 K (vitiated preheat), pressures from 170 to 600 kPa, air velocities of 10 to 30 m/sec, equivalence ratios from 0.3 to 1.0, mixing-vaporizing lengths from 10 to 60 cm, and residence times of 2 to 100 ms. The fuel was diesel No. 2. Three fuel injectors were used to study the effect of fuel injector type on autoignition limits. A simplex pressure atomizer, a 19-source fuel injector, and a 41-source-conical-tube fuel injector were used. The results of this study were as follows:

1. There was a significant effect of fuel-injector type on the autoignition data. The autoignition delay time for the simplex and 19-source fuel injectors showed good agreement as a function of temperature and pressure, but the autoignition delay time for the 41-source-conical-tube injector did not.

2. The autoignition delay time was a function of equivalence ratio for the 19-source and 41-source-conical-tube fuel injectors, but was not for the simplex fuel injector. The difference in equivalance ratio effect is attributed to the difference in spatial fuel-air distribution. The spatial fuel-air distribution with the 19-source and 41-source-conical tube fuel injectors was uniform, but the fuel-air distribution was not uniform with the simplex fuel injector.

3. The autoignition delay time data separated as a function of mixing-vaporizing length for the 41-source, conical-tube fuel injector. However, the data correlated well when ignition was plotted as $p\varphi/V$ as a function of $1/T$ where T is temperature, p is pressure, V is velocity, and φ is equivalence ratio.

4. A comparison of the data from the simplex fuel injector reported herein with data from the references showed fair agreement.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, December 8, 1982

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TABLE I. - FUEL PROPERTIES

Distillation temperature, K:	
Initial boiling point	433
5	469
10	489
20	505
30	516
40	525
50	533
60	543
70	551
80	567
90	587
Final boiling point	6[illegible]
Specific gravity at 289 K	0.8534
Viscosity at 295 K, cS	3.54
Surface tension, dyne/cm	30.6

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TABLE II. - DATA

Fuel injector	Mixing-vaporizing length, cm	Inlet temperature, K		Pressure, kPa	Air velocity, m/s	Equivalence ratio	Residence time, ms
		Average	Maximum				
41-Source conical tube, with afterburner flameholder	15.20	1144	1174	228	26.6	0.294	5.714
		1035	1058	441	15.[illegible]	.337	9.682
		1055	1082	425	16.0	.314	9.500
		1161	1186	44[illegible]	17.4	.140	8.736
	30.50	1088	1110	440	16.4	0.295	18.598
		1061	1075	430	14.4	.291	21.181
		[illegible]	1040	411	12.6	.291	24.206
		1028	1043	386	11.6	.299	26.293
		1191	1221	455	15.3	.150	19.935
		10[illegible]8	1046	372	10.6	.475	28.774
		1130	1165	208	27.2	.308	11.213
		1166	1216	210	28.4	.305	10.739
		1169	1206	220	27.7	.317	11.011
		1131	1157	232	31.1	.293	9.807
		1187	1220	236	32.2	.30[illegible]	9.472
		1113	1143	203	24.7	.468	12.348
		1250	1273	224	30.9	.143	9.871
	61.00	1104	1137	235	26.9	0.297	22.677
		1144	1170	237	27.4	.302	22.263
		1119	1158	202	[illegible]	.470	27.982
		1020	1034	402	14.7	.292	41.497
		1083	1096	413	14.9	.301	40.940
		1025	1042	427	13.8	.307	44.203
		1060	1075	438	13.9	.310	43.885
		987	1012	380	10.1	.568	60.396
		981	1011	377	10.0	.549	61.000
41-Source conical tube, without afterburner flameholder	10.20	1024	1048	417	13.7	0.305	7.445
		1022	1047	422	13.6	.289	7.500
		1006	1044	402	13.	.509	7.556
		810	821	391	11.4	.592	8.947
	20.50	1108	1132	228	27.5	0.298	11.091
		1156	1176	232	28.4	.295	10.739
		1037	1040	346	12.0	.420	25.417
		1031	1047	353	11.7	.404	26.068
		1141	1158	432	15.5	.243	19.677
		1127	1134	430	15.4	.243	19.805
		1238	1284	426	16.6	.167	18.373
	61.00	1010	1026	424	13.9	0.295	43.885
		1058	1081	422	14.6	.299	41.781
		1028	1051	347	11.5	.445	53.043
		1155	1175	252	26.4	.289	23.106
		1247	1263	253	28.4	.206	21.479
41-Source conical tube, without afterburner flameholder	10.70	1006	1020	411	14.0	.552	7.286
		1022	1036	411	14.0	.552	7.286
		1052	1073	415	14.7	.298	6.939
		1092	1117	413	15.1	.304	6.755
		1003	1033	418	13.5	.501	7.556
		753	764	418	10.2	.628	10.000
		1009	1033	426	13.3	.555	7.669
		1020	1034	431	13.6	.565	7.500
		733	745	422	10.0	.633	10.200
		1205	1243	420	16.5	.193	6.182
		1236	1268	414	17.2	.154	5.930
		1122	1160	238	26.9	.292	3.792
		1104	1136	248	25.4	.505	4.016
		1086	1120	256	24.2	.582	4.215
		1036	1093	251	23.6	.671	
		1112	1160	283	29.7	.301	3.434
		1208	1253	289	31.8	.297	3.208
19-Source	10.20	1045	1106	405	15.1	0.298	6.755
		987	1041	411	13.9	.493	7.338
		887	953	428	11.8	.689	8.644
		932	1001	426	12.2	.702	8.361

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TABLE II. - Concluded.

Fuel injector	Mixing-vaporizing length, cm	Inlet temperature, K		Pressure, kPa	Air velocity, m/s	Equivalence ratio	Residence time, ms
		Average	Maximum				
19-Source	10.20	959	1096	287	20.2	.503	5.050
		1002	1033	[illegible]3	18.9	.696	5.397
		1127	1180	288	22.3	.300	4.574
	15.24	1150	1217	231	28.8	0.318	5.292
		1064	1122	247	25.1	.510	6.072
		1191	1252	239	29.6	.200	5.149
		990	1050	261	22.0	.690	6 927
		1071	1117	425	15.7	.298	9.707
		1000	1050	429	14.7	.497	10.367
		1000	1045	385	14.8	.503	10.297
	30.50	1093	1134	283	22.6	0.298	13.496
		1020	1052	309	19.7	.496	15.482
		1037	1071	304	20.3	.499	15.025
		893	923	304	16.9	.692	18.047
		981	1020	303	18.3	.702	16.667
		1015	1063	298	18.7	.494	16.310
		843	879	532	7.5	.491	40.667
		837	875	516	7.4	.517	41.216
		949	988	500	8.8	.298	34.659
		1011	1080	176	31.6	.501	9.652
		1063	1115	196	32.2	.718	9.472
	61.00	1011	1073	173	33.7	0.295	18.101
		1047	1091	173	35.5	.291	17.183
		950	1010	181	30.9	.487	19.741
		1042	1088	190	31.6	.692	19.304
		955	1037	284	20.8	.298	29.327
		1023	1064	279	21.7	.302	28.111
		930	976	288	18.4	.519	33.152
		943	992	287	18.5	.526	32.973
		911	932	310	17.2	.698	35.465
		939	960	310	17.2	.698	35.465
		816	841	406	16.5	.495	36.970
		883	931	577	8.8	.306	69.318
		909	964	565	9.3	.308	65.591
		625	644	601	5.9	.499	103.390
		660	684	587	6.5	.495	93.846
Simplex	10.20	1076	1177	348	15.9	0.309	6.415
		1126	1195	344	15.8	.517	6.456
		1062	1195	342	16.1	.194	6.335
		1245	1261	235	32.5	.304	3.138
		1232	1242	225	29.0	.529	3.517
		1158	1177	363	17.8	.312	5.730
		1158	1171	277	16.7	.303	6.108
		1141	1152	320	13.1	.327	7.862
	15.20	1137	1238	202	30.2	0.301	5.033
		105	1215	215	26.2	.500	5.802
		032	1095	363	14.5	.488	10.483
	30.50	702	725	336	10.5	0.311	29.048
		939	999	352	14.7	.192	20.748
		1038	1133	199	27.8	.297	10.971
		1031	1132	203	25.5	.504	11.961
		1023	1098	252	30.4	.286	10.033
		1070	1162	200	27.6	.313	11.051
		1045	1122	208	25.6	.493	11.914
		1067	1138	217	29.2	0.283	10.445
		927	973	348	14.5	.270	21.034
		951	1020	362	14.3	.187	21.329