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SPONTANEOUS-IGNITION TEMPERATURE LIMITS OF JET A FUEL IN RESEARCH-COMBUSTOR SEGMENT

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16. Abstract

The effects of inlet-air pressure and reference velocity on the spontaneous-ignition temperature limits of Jet A fuel were determined in a combustor segment with a primary-zone length of 0.076 m (3 in.). At a constant reference velocity of 21.4 m/sec (170 ft/sec), increasing the inlet-air pressure from 21 to 207 N/cm^2 decreased the spontaneous-ignition temperature limit from approximately 700 to 555 K. At a constant inlet-air pressure of 41 N/cm^2, increasing the reference velocity from 12.2 to 30.5 m/sec increased the spontaneous-ignition temperature limit from approximately 575 to 800 K. Results are compared with other data in the literature.

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SUMMARY

The effects of inlet-air pressure and reference velocity on the spontaneous-ignition temperature limits of Jet A fuel were investigated in an experimental combustor. Spontaneous ignition was defined in this study as the ability to ignite, within 10 seconds, the fuel injected into the combustor segment at a fuel-air ratio of 0.020. The rectangular combustor segment had a cross section at the diffuser inlet of 5.3 by 30.5 centimeters, a cross section at the combustor exit of 5.1 by 30.5 centimeters, and a maximum cross section of 15.3 by 30.5 centimeters. The combustor length was 45.6 centimeters, which included the diffuser. A snout open area of 40 percent of the combustor inlet area was used to admit air into the combustor primary zone.

Spontaneous-ignition temperature limits decreased markedly from 700 to 590 K when inlet-air pressure was increased by a factor of 2 from 21 to 41 newtons per square centimeter. However, increasing inlet-air pressure from 41 to 201 newtons per square centimeter reduced the temperature limit by only 35 K to a value of 555 K. These data were obtained at a constant reference velocity of 21.4 meters per second. Decreasing reference velocity from 21.4 to 12.2 meters per second gave a slight drop in the temperature limit (approximately 10 K), whereas increasing reference velocity from 21.4 to 30.5 meters per second increased the temperature limit from 590 to nearly 800 K (approximately 200 K) with an inlet-air pressure of 41 newtons per square centimeter.

At a reference velocity of 21.4 meters per second and an inlet-air pressure of 41 newtons per square centimeter, the spontaneous-ignition temperature limit (590 K) was approximately 100 K above the value given in the literature for crucible tests with JP-5 fuel. Spontaneous-ignition temperature limits were compared with other combustor data reported in the literature.

INTRODUCTION

A combustor segment was used to determine spontaneous-ignition limits of Jet A fuel over ranges of inlet-air pressure, temperature, and reference velocity. The problem of spontaneous ignition of fuel-air mixtures occurring in jet engine combustors (ref. 1) and afterburners (ref. 2) has been studied over a considerable period of time. In the case of combustors, spontaneous ignition may cause severe damage to a vaporizing type of fuel injector such as the "candy cane" injector (ref. 3) or to advanced premixing-prevaporizing combustors designed to reduce exhaust emissions. Previously, spontaneous-ignition temperature limits were determined for kerosene-air mixtures by using vitiated air, lean mixtures, and pressures equal to or below atmospheric (ref. 1). More recently, spontaneous-ignition data were obtained with kerosene-air mixtures by using unvitiated air, 4.1-centimeter-diameter burner tubes of different lengths, a range of equivalence ratios, and inlet-air pressures up to 110 newtons per square centimeter (ref. 4). However, most of the data were obtained at an inlet-air velocity of 65 meters per second, which simulates afterburner conditions and is considerably higher than that generally experienced in combustors. Thus, in the present investigation, spontaneous-ignition temperature limits were determined for Jet A fuel over a reference-velocity range of 12.2 to 30.5 meters per second. Inlet-air temperatures and pressures ranged from 550 to 783 K and 21 to 207 newtons per square centimeter, respectively. The combustor segment was 45.6 centimeters in length and had a maximum cross section of 15.3 by 30.5 centimeters.

APPARATUS AND PROCEDURE

Test Facility

The combustor segment was mounted in the closed-duct test facility shown in figure 1 and is described in more detail in reference 5. Combustion air drawn from the laboratory high-pressure supply system was indirectly heated to 811 K in a counterflow U-tube heat exchanger at combustor inlet-air pressures up to 207 newtons per square centimeter. The temperature of the air flowing out of the heat exchanger was automatically controlled by mixing the heated air with varying amounts of bypassed air.

Test Combustor

The test combustor, shown in detail in figure 2, was a rectangular segment which simulated an annular combustor. The overall combustor length of 45.6 centimeters included a diffuser length of 14 centimeters and a burner length of 31.6 centimeters, the latter consisting of a primary zone 7.6 centimeters long and a secondary zone 24 centimeters long. The combustor cross section was 5.3 by 30.5 centimeters at the diffuser inlet and 5.1 by 30.5 centimeters at the combustor exit. The maximum cross section was 15.3 by 30.5 centimeters. The inlet snout open area was 40 percent of the combustor inlet area. A detailed description of the airflow in the primary and secondary mixing zones is given in the discussion of combustor model 3 in reference 5.

Fuel injection. - Jet A fuel having an average hydrogen-carbon ratio of 0.161, a lower heating value of 43 000 joules per gram (18 600 Btu/lb), and a boiling range of 447 to 561 K was used in all the tests. One of the four simplex pressure-atomizing nozzles used to inject the fuel is shown in figure 3 along with the air swirler and fuel-tube mounting assembly. Each nozzle produced a fuel-spray angle of approximately 90° at a flow rate of 0.0152 kilogram per second (120 lb/hr) with a pressure drop of 40 newtons per square centimeter.

Instrumentation. - Inlet-air temperature was measured in the diffuser section with eight Chromel-Alumel thermocouples. Inlet-air total pressure was measured at the same location with four stationary rakes consisting of three total-pressure tubes connected to differential-pressure strain-gage transducers balanced by wall static-pressure taps located at the top and bottom of the duct.

Test conditions. - Fuel was injected into the combustor at a fuel-air ratio of 0.020 for 10 seconds. Inlet-air total pressure and reference velocity are given in table I.

RESULTS AND DISCUSSION

To determine spontaneous-ignition limits of Jet A fuel injected into the combustor with pressure-atomizing fuel nozzles at a fuel-air ratio of 0.020, tests were made over a range of inlet-air pressures, temperatures, and reference velocities. A maximum time of 10 seconds was allowed for spontaneous ignition to occur. Ignition was verified by steady flame propagation observed through the combustor window and an accompanying temperature rise at the combustor exit. Spontaneous-ignition temperature limits were determined as a function of inlet-air pressure and reference velocity. Also, experimental values were compared with results reported in the literature.

Effect of Inlet-Air Pressure on Spontaneous-Ignition Temperature Limits

As shown in figure 4, the spontaneous-ignition temperature limit decreased markedly from approximately 700 to 590 K when inlet-air pressure was increased from 20.3 to 40.5 newtons per square centimeter. However, increasing inlet-air pressure to 201 newtons per square centimeter only slightly decreased the temperature limit to 555 K. To obtain these data, inlet-air temperature was decreased in steps of 25 to 50 K at constant inlet-air pressure and reference velocity until spontaneous ignition could no longer be obtained in 10 seconds; this condition is indicated by the solid symbols in figure 4. Open symbols indicate the minimum inlet-air temperature at which spontaneous-ignition could be obtained. Included in figure 4 for comparison are data obtained from the literature showing the limiting values of spontaneous-ignition temperature as a function of air pressure as determined from crucible tests using JP-5 fuel (ref. 6). This comparison shows that the spontaneous-ignition temperature for Jet A fuel was approximately 200 K above the minimum spontaneous-ignition temperature obtainable with JP-5 fuel at a pressure of 21 newtons per square centimeter and only 100 K above the minimum value at a pressure of 90 newtons per square centimeter.

Also shown in figure 4 for comparison are data from combustor tests using a kerosene fuel similar in properties to Jet A fuel and JP-5 (ref. 4). Spontaneous-ignition temperature limits are considerably above those obtained in this study because of the relatively high reference velocity (65 compared with 21.3 m/sec). A more direct comparison with the data of reference 4 is made in the next section.

Effect of Reference Velocity on Spontaneous-Ignition Temperature Limits

Each data point shown in figure 5 was obtained at an inlet-air pressure of 41 newtons per square centimeter by holding reference velocity constant and gradually decreasing inlet-air temperature until spontaneous ignition no longer occurred. Increasing reference velocity from 12.2 to 21.4 meters per second increased the spontaneous-ignition temperature limit slightly, by approximately 10 K. However, increasing reference velocity from 21.4 to 30.5 meters per second increased the temperature limit by more than 200 K.

The spontaneous-ignition temperature data of figure 5 are shown in figure 6 as a function of the reciprocal of the combustor residence time (reference velocity divided by primary-zone length) at several inlet-air pressures. Crucible data, with an assumed reference velocity of zero, are included for comparison. Data obtained in this study using Jet A fuel fell considerably below those given in reference 4 for kerosene fuel. Enhanced mixing of the fuel spray and air in this study by the use of air swirlers, which were not used in reference 4, and the use of a different type of pressure-atomizing fuel nozzle may have contributed significantly to the difference shown in figure 6.

SUMMARY OF RESULTS

Spontaneous-ignition temperature limits of Jet-A fuel were determined in a combustor segment over a range of inlet-air pressures and reference velocities. Fuel was injected into the combustor at a fuel-air ratio of 0.020 for a maximum of 10 seconds to test for spontaneous ignition. Test conditions included inlet-air pressures from 21 to 207 newtons per square centimeter and reference velocities from 12.2 to 30.5 meters per second. The following results were obtained:

1. The spontaneous-ignition temperature limit for Jet A fuel decreased from approximately 700 to 555 K when the inlet-air pressure was increased from 21 to 207 newtons per square meter at a constant reference velocity of 21.4 meters per second.

Increasing reference velocity from 12.2 to 30.5 meters per second increased the spontaneous-ignition temperature limit from approximately 575 to 800 K at a constant inlet-air pressure of 41 newtons per square centimeter.

2. At a reference velocity of 21.4 meters per second and an inlet-air pressure of 41 newtons per square centimeter, the spontaneous-ignition temperature limit was approximately 100 K above the value given in the literature for crucible tests with JP-5 fuel.

3. Spontaneous-ignition temperature limits for Jet A fuel were somewhat below those reported in the literature for combustor tests with kerosene fuel. This difference may have been due to enhanced fuel-air mixing obtained in this study by the use of air swirlers and the use of a different type of pressure-atomizing fuel nozzle.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 10, 1974,
501-24.

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TABLE I. - COMBUSTOR TEST CONDITIONS

Inlet-air total pressure		Reference velocity	
N/cm^2	psia	m/sec	ft/sec
21	30	21.4	70
41	60	12.2	40
41	60	21.4	70
41	60	27.4	90
41	60	30.5	100
104	150	21.4	70
152	220	21.4	70
207	300	21.4	70

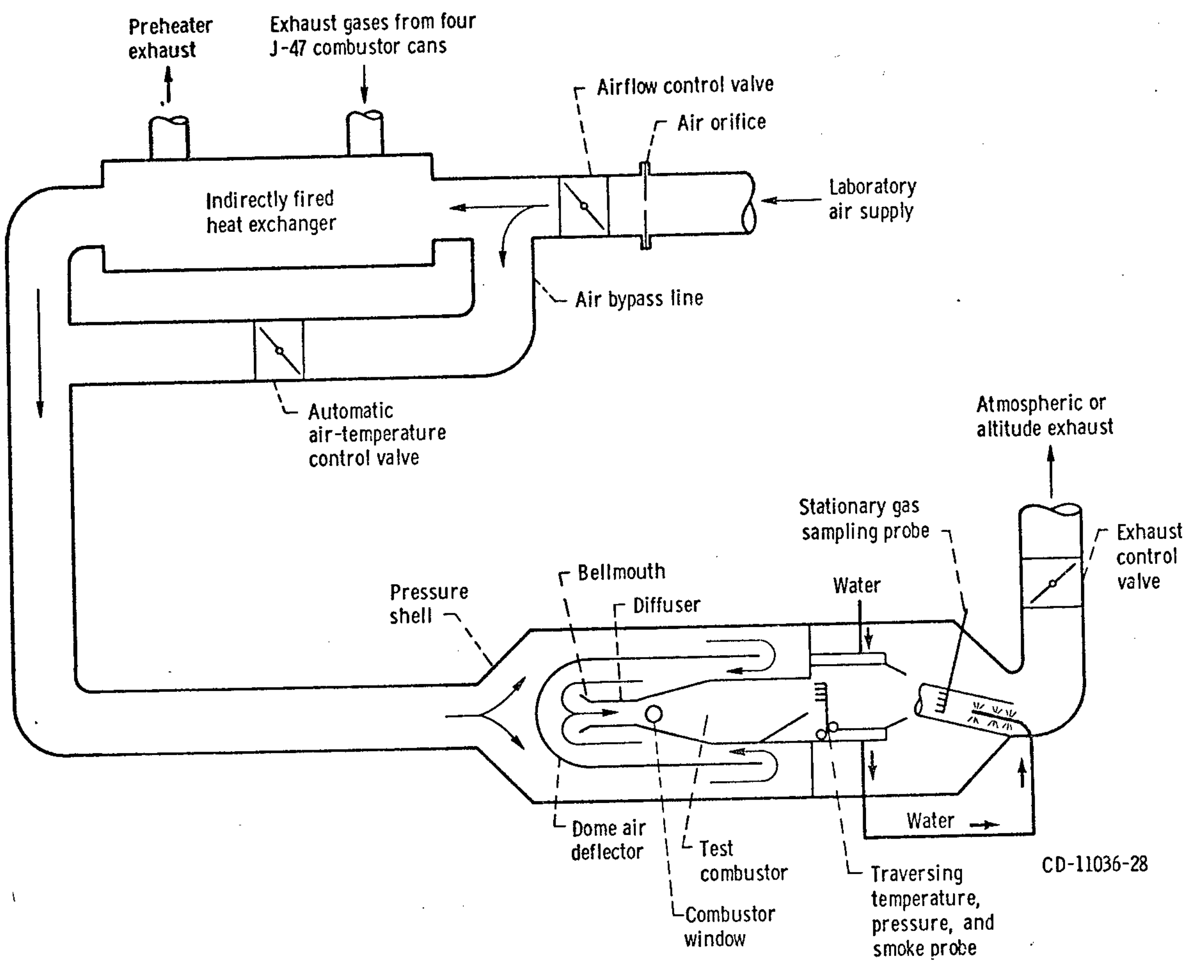


Figure 1. - Test facility and auxillary equipment.

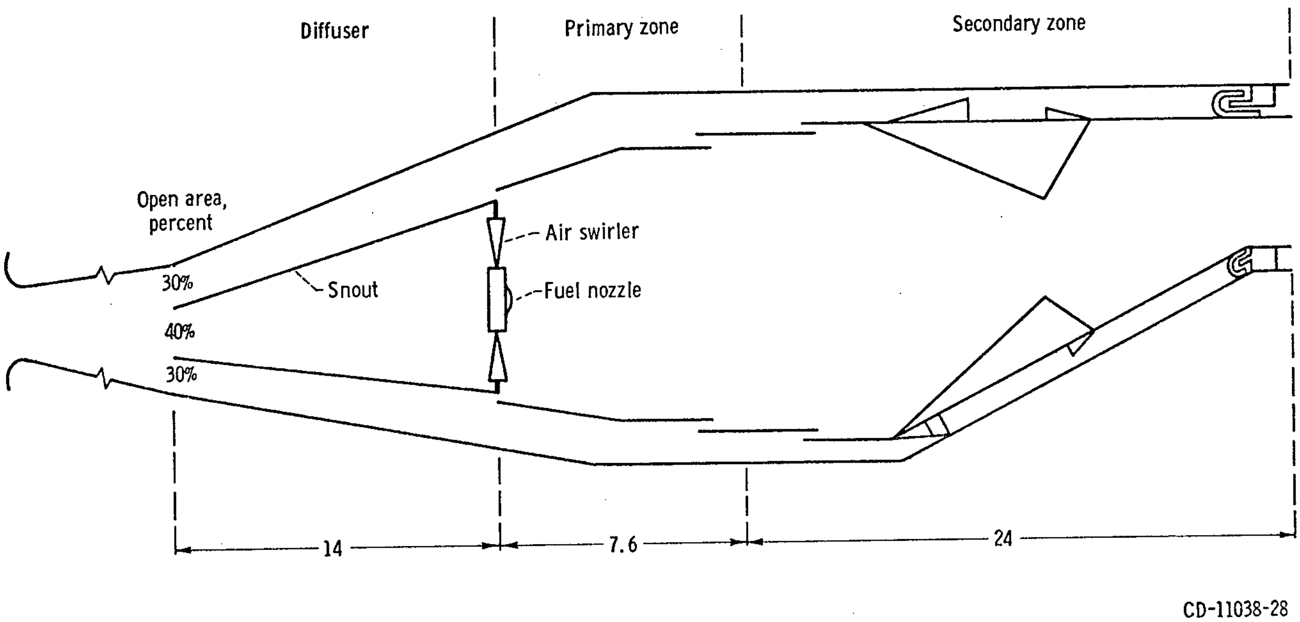
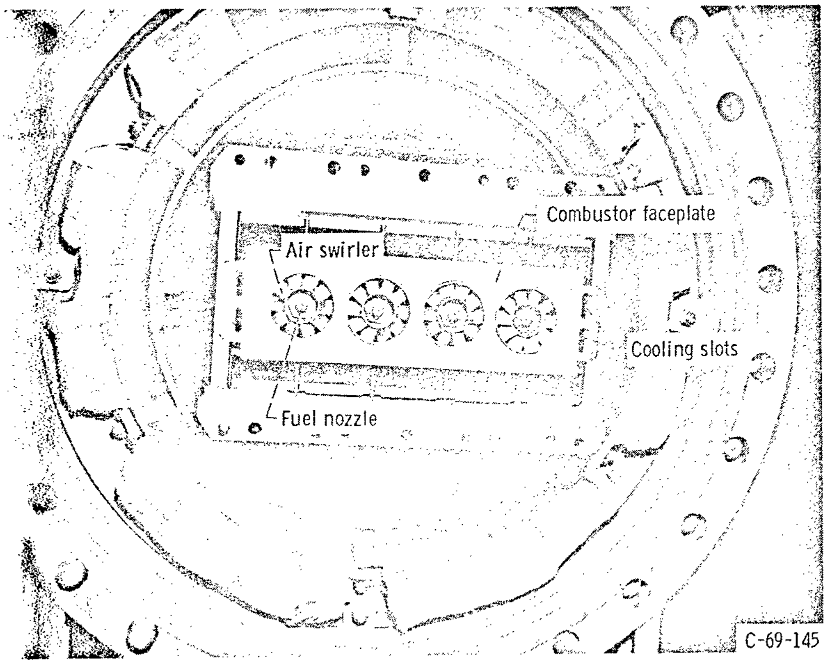
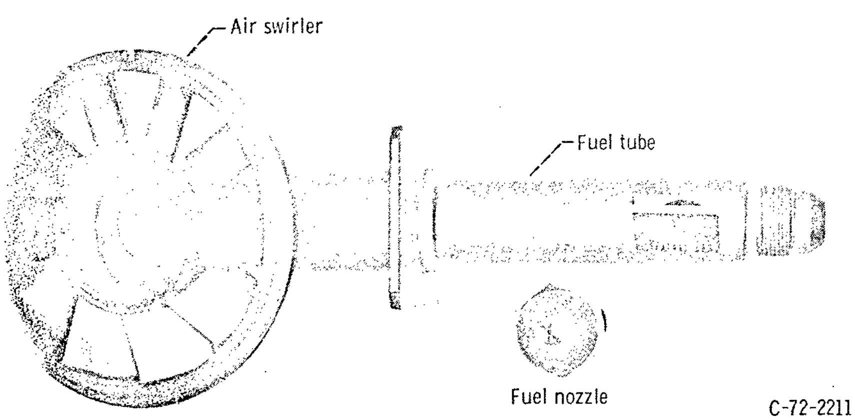


Figure 2. - Test combustor. (Dimensions are in centimeters.)



(a) Combustor primary-zone inlet (looking upstream).



(b) Pressure-atomizing nozzle with air swirler and fuel tube.

Figure 3. - Fuel nozzles.

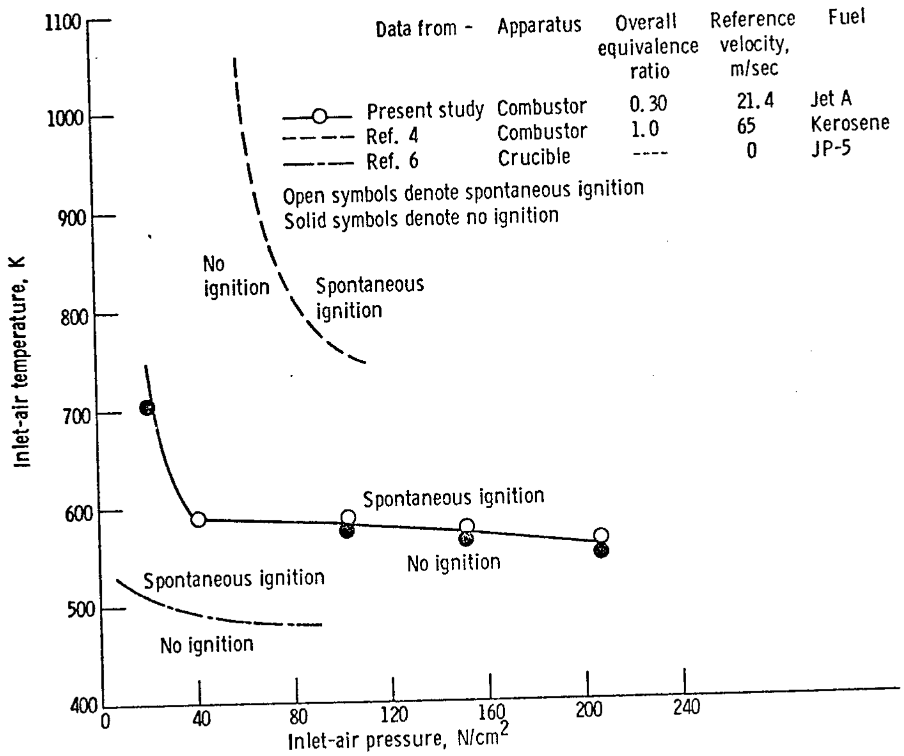


Figure 4. - Comparison of variations of spontaneous-ignition temperature limits with inlet-air pressure. Fuel-air ratio, 0.020; primary-zone equivalence ratio, 0.75.

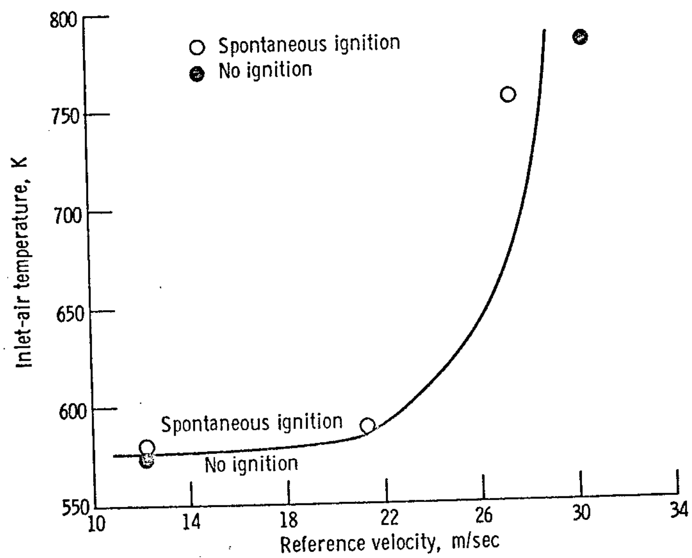


Figure 5. - Variation of spontaneous-ignition temperature limit with reference velocity. Inlet-air pressure, 41 newtons per square centimeter; fuel-air ratio, 0.020; primary-zone equivalence ratio, 0.75.

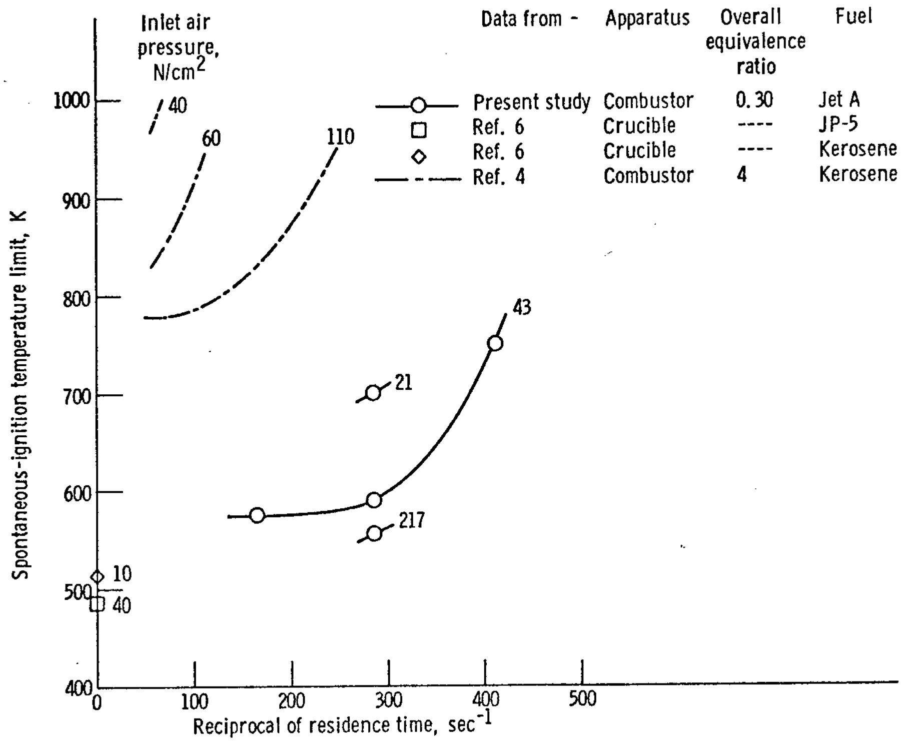


Figure 6. - Variation of spontaneous-ignition temperature limit with reciprocal of residence time. Fuel-air ratio, 0.020.

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