

Novel Experimental Approach to Studying the Thermal Stability and Coking Propensity of Jet Fuel

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ABSTRACT: An experimental apparatus was designed and built to conduct studies on the thermal stability and carbon deposition leading to coking in the fuel injection nozzles of small gas turbine engines. The apparatus is a simplified but controlled representation of an aircraft fuel system consisting of a preheating section and a test section. The preheating section simulates the heating of the fuel when it is used as a coolant on board an aircraft, and the test section simulates the geometry, temperature, pressure, and flow rates of the fuel injection nozzles. Proof-of-principle experiments were performed to verify the functionality of the apparatus and the repeatability of measurements. The pressure drop across the test section was used during experiments to monitor deposit buildup, and the effective reduction in the test-section diameter due to deposit blockage was calculated. The deposition rate was validated further using a carbon-burnoff apparatus. The experimental results showed that the pressure drop increased significantly with increasing testing time, as expected, and that measuring the pressure drop is an effective method of monitoring and quantifying deposit buildup.

■ INTRODUCTION

In addition to powering aircraft, one very important function of jet fuel is its use as a heat sink. Many aircraft systems generate large quantities of heat and require cooling.¹ Modern engines operate at relatively high combustion temperatures for better thermal efficiency, and their lubrication systems require cooling as well.^{2,3} In addition, ever more avionics and electronic equipment generate excessive amounts of waste heat that must be removed.⁴ Using the fuel system as a heat sink offers several advantages as compared to other arrangements in which engine bleed air⁵ or ram air⁶ is used as the cooling medium. Jet fuel has a greater heat-sink capacity under a wider range of operating conditions than air. The disadvantage of the air as a coolant is that, as flight speeds increase, the stagnation temperature of the air rises as well, thus decreasing the effectiveness of the heat sink. Jet fuel, on the other hand, is not as restricted by operating conditions. Fuel temperatures in aircraft fuel tanks stay relatively cool, ranging from about -40 to 50 °C.⁷ Another advantage of fuel cooling is that it is weight-saving. Air cooling requires relatively heavy equipment to be installed and can incur drag penalties.^{4,8} With jet fuel, the cooling infrastructure can be designed into an aircraft's fuel system and does not require a separate system, reducing weight penalties.

Although jet fuel is an effective cooling medium, its heat-sink capabilities are limited, primarily by the property known as thermal stability. When fuel is heated to high temperatures, which is referred to as being thermally stressed, chemical reactions take place in the fuel that break it down and form solid precipitates that are eventually deposited onto the walls of the fuel passages in a process called coking. If left unchecked, such coking could not only result in severe damage to engine components but also reduce the effectiveness of heat transfer in the heat exchangers between the fuel and engine components.⁷

The thermal stability and coking of jet fuel affect all parts of an aircraft's fuel system. One particular area of interest is how deposits form in the passages of fuel-injector nozzles. In fact, fuel-injector coking in small gas turbine engines has been identified as the most widespread problem in the thermal stability of jet fuel.⁷ The passages of injector nozzles differ from the rest of the fuel system in two major ways. First, fuel-injector passages are small in diameter and short in length compared to the tubing in the rest of the system. The injector nozzle diameters can be as small as 0.25 mm.⁹ Second, because injector nozzles are located inside the combustion chamber, they are subject to much higher temperatures. The combustion temperatures will increase the wetted-wall temperatures of the nozzles to greater than 250 °C.¹ At these temperatures, significant coking is observed in standard engine operations. Coking can block the passages and affect spray patterns, thus affecting combustion performance.

Approaches that could be used to mitigate coking in injector nozzles include the following:

- (1) designing the injectors such that the jet fuel flowing through the injector nozzles does not get heated to temperatures that would induce coking,
- (2) limiting the cooling load of the fuel so that its temperature just before the injector is low enough that the fuel will not reach temperatures that would induce coking while it is passing through the injector,
- (3) coating the injector fuel-flow surfaces with material that delays/reduces coke deposition,^{10,11} and
- (4) manufacturing coking-resistant jet fuels.

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The last option is not viable for civil aviation because of the excessive costs involved in the manufacturing of fuels with reduced coking propensities. The third approach involves coating the wet surfaces of the injectors with a thin layer of a material such as ceramic that would reduce the coke deposition. The second solution leads to a small but measurable increase in fuel burn due to the power consumption of other on-board cooling systems. The first solution requires injector design modifications, as well as more comprehensive information on the relationship between coking and parameters such as fuel residence time, temperatures, nozzle geometry, and fuel chemical composition. The experimental approach described herein makes it possible to pursue parametric studies to provide a better understanding of the relationship between coking propensity and parameters related to operating conditions, flow geometries, coating materials, and the chemical structure of the fuel. ASTM standard D3241 for the thermal stability of aviation jet fuel describes the testing methodology to be used with a jet fuel thermal oxidation tester (JFTOT) for fuel certification.¹² This simple test offers a pass/fail procedure but does not yield any quantitative assessment of the coking process. Further, it is not known whether the JFTOT test can be used for biojet fuels.

REVIEW OF EXISTING TEST RIGS

Experiments on the thermal stability of jet fuel are usually divided into two main categories: continuous-flow dynamic tests and pressurized static tests. Dynamic tests usually consist of single-tube heat-exchanger experiments, but there are also full-scale gas-turbine fuel-system simulators and engine nozzle testers for the use in specifications and research testing.^{7,13} Static tests are mainly research experiments performed in pressurized reactor vessels or flasks to study the chemical mechanism of thermal oxidative stability.^{7,14–18}

The most prolific single-tube heat-exchanger test rig is the jet fuel thermal oxidation tester (JFTOT). It is based on the Coordinating Research Council (CRC) coker that was developed in the 1950s and accepted as the ASTM D1660 standard in 1959. The CRC coker consists of a 330-mm-long double-annulus aluminum chamber that is heated internally by a cartridge heater and followed by a heated filter housing. The fuel flows on the surface of the inner tube in laminar flow while being heated to a specified temperature of 149 °C, and the filter housing is kept at 205 °C. The flow rate is maintained at 60 mL/min for 5 h at a system pressure of 1.0 MPa, which provides a fuel residence time of 10 s. The fuel is given a pass/fail rating based on two criteria: the discoloration of the inner tube and the pressure drop across the filter. The JFTOT was selected as the device for use in ASTM D3241 in 1973 to provide remedies for some of the drawbacks of the CRC coker, such as reducing the amount of fuel required from 19 to 0.6 L by reducing fuel flow rate to 3 mL/min for 2.5 h and increasing the system pressure to 3.45 MPa using nitrogen to allow for a higher wetted-wall temperature of 260 °C. The double-annulus design remains, with the length reduced to 60 mm and the residence time decreased to about 13 s. However, the JFTOT still relies on the same two criteria as the CRC coker and is mainly to assess qualitative specifications, so it does not provide a quantitative tool for comparing different fuels or test conditions.^{7,13}

Several other experimental rigs with single-tube heat-exchanger configurations have been reported in the literature, for example, the Shell Development Company Heat Transfer Test Rig,⁵ the NASA Glenn Research Center Heated Tube

Facility,¹⁹ the Phoenix rig of the U.S. Air Force (USAF),^{20–22} the near-isothermal flowing test rig (NIFTR),^{23–27} the Australian Defence Science and Technology Organisation (DSTO) Thermal Stability Rig,^{28,29} the flow reactor of the Pennsylvania State University (PSU) Energy Institute,^{30,31} various designs from United Technology Research Center (UTRC),^{4,8,32} and the single-tube heat-exchanger apparatus of the University of Toronto Institute for Aerospace Studies (UTIAS).^{13,17,18} The test sections of these test rigs employ different methods for heating. For example, the Phoenix, NIFTR, and UTRC rigs embed the test section into a copper block and conductively heat it with an external electrical heater to achieve isothermal heating.^{20,23,32–34} Test sections are also heated directly by flowing electrical current through them to achieve pyrolytic temperatures and constant heat flux in the Shell Heat Transfer Test Rig⁵ and others.^{35–37} A fluidized sand bath is used to heat the submerged test section in the DSTO rig,^{28,29} whereas the PSU and UTIAS rigs use radiative heating of the test section by electrical tube furnaces.^{31,38,39}

EXPERIMENTAL APPROACH

Rationale for the Current Rig Design. On an aircraft, as the fuel travels from the fuel tanks to the combustion chamber, it flows through several heat exchangers that expose the fuel to different temperature ranges.⁷ The residence times of the fuel in these various heat exchangers also vary greatly, depending on several factors such as the size of the aircraft, the location of the fuel tanks, the geometry and arrangement of the fuel lines, and the operating conditions of the aircraft. Because the focus of the present project is coking in fuel-injector passages, it is important to ensure that the fuel flowing through the passages have conditions that are representative of real-world fuel systems and operating conditions. Furthermore, because the fuel is exposed to different temperatures, the experimental apparatus must be able to maintain different temperatures in different parts of the fuel flow path. Because of the low power settings applied under idle and descent conditions, the corresponding fuel flow rates are relatively low compared to those under takeoff and cruising conditions. Thus, descent and idle present favorable conditions for fuel-system coking and are of great interest in thermal stability research.

However, short of constructing an exact replica of a fuel system, it is difficult and impractical to build a test rig to simulate all of the different temperatures seen in the fuel system. Therefore, for the present project, the complex and varied temperatures and residence times in the many fuel-system components were simplified. Specifically, the “fuel system” was simplified and represented by two sections in the fuel flow path: the “preheating section” and the “test section”. The preheating section represents the heat exchangers through which the fuel flows before it reaches the injector. The test section is a fuel passage designed to simulate the narrow passages of a fuel injector. The temperatures in each of these two sections could be controlled independently; as a result, two temperatures and associated time scales were identified as the primary parameters of interest.

The temperature of the fuel in the preheating section, T_p , is limited to about 100–150 °C. This is the temperature of the fuel when it enters the test section. The wetted-wall temperature in the test section, T_w , is the temperature of the wet metal wall to which the fuel is exposed within the passage. This temperature could be as high as 300 °C. These two temperatures combined with the three time scales are the main parameters in the experiments. The first time scale is related to the residence time of the fuel during which it is used as a heat sink in the heat exchangers before reaching the combustor. This residence time typically is on the order of 1 min. It represents the duration of the period during which the fuel is subjected to thermal stress before it reaches the injection passage. The second time scale is the residence time of the fuel through the injector flow passages, which is on the order of a small fraction of a second. The most important time scale is the third one, on the order of hours, which is the duration of engine

operation during which the coking process can continue and deposits can accumulate, predominantly in the injector passages and exits. These three time scales and two temperatures should be controlled independently in the experimental apparatus, along with the pressure and flow rate of the fuel, as well as the diameter and length of the test section.

Description of the Experimental Setup. The experimental rig was designed and built in accordance with the rationale explained in the previous subsection. As shown in the schematic in Figure 1, the

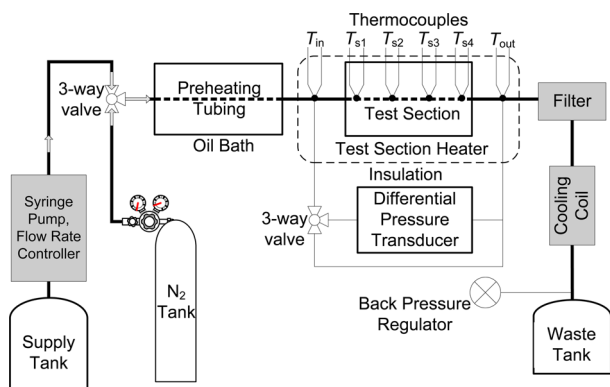


Figure 1. Schematic of the experimental setup.

experimental rig consisted of a syringe pump, a preheating oil bath, a test-section assembly, a differential pressure transducer, a filter, a cooling coil, and a back-pressure regulator.

The fuel was drawn from the supply tank by a Teledyne Isco A500 dual syringe pump, which provided continuous fuel flow with a flow set-point accuracy of $\pm 0.5\%$ and a pressure set-point accuracy of $\pm 0.5\%$. The fuel was first heated in the preheating oil bath (Mettler model ONE 45), which had a maximum set-point temperature of 200 °C and a usable heated space of 45 L. The oil bath was chosen because of the advantages of a stable and uniform heating temperature and the flexibility of changing the preheating residence time by simply changing the geometry of the submerged tubing. This preheating tubing had a length of 1 m, an outer diameter of 6.35 mm ($1/4$ in.), and a wall thickness of 0.889 mm (0.035 in.) and was type-316 stainless steel tubing that was bent into a rectangular S-shape to fit inside the oil bath. The residence time for this preheating section was about 50 s. The temperature of the fuel in the preheating section (T_p) was monitored with a K-type thermocouple at the inlet to the test section, as shown in Figure 2, in which the oil-bath temperature was set accordingly to reach the desired fuel set-point temperature. The maximum achievable value of T_p for the 1-m preheating length was about 163 °C, which is the maximum fuel temperature allowed at the

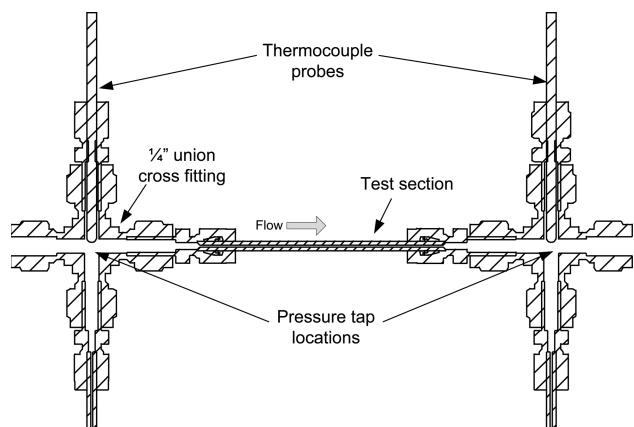


Figure 2. Cross section of the test section with pressure taps shown.

inlet of the fuel nozzles by the USAF and the engine manufacturers.^{28,40–42} The test section was a 82.55-mm- (3.25-in.-) long piece of type-304 stainless steel tubing with a nominal outer diameter of 3.175 mm ($1/8$ in.) and a nominal wall thickness of 1.27 mm (0.05 in.). It was connected to two Swagelok $1/4$ -in. union cross fittings that also served as the thermocouple probe ports and the pressure taps for the differential pressure transducer [Omega MMDWU001 V5P3A0T1A1, 0–1 pounds per square inch differential (psid)], as shown in Figure 2. Measurement of the pressure drop provided the means to calculate the effective reduction in the test-section diameter when deposits built up in the test section. The outer-wall temperature profile and the heating of the test section were provided by a brass heater block assembly (Figure 3) that consisted of

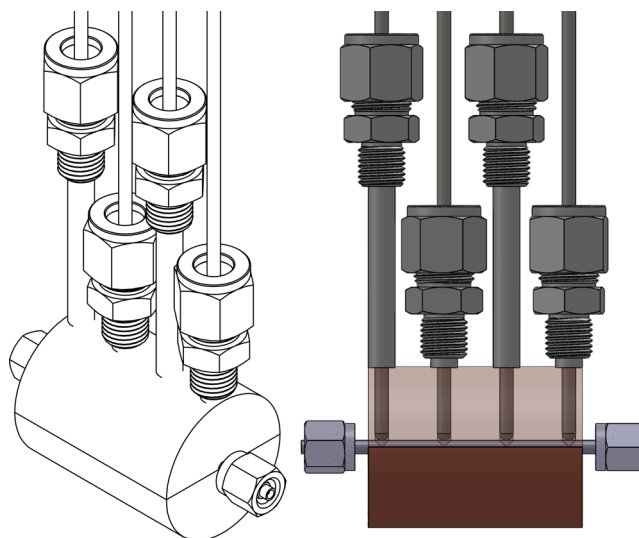


Figure 3. Isometric and side views of the design of the test-section heater block. The upper half of the heating block houses four thermocouple probes.

two halves of a cylindrical block with a diameter of 38.1 mm (1.5 in.) and a length of 50.8 mm (2 in.); thus, the heated length was 50.8 mm. The center of the block had a 3.175-mm ($1/8$ -in.) through-hole to accommodate the test-section tubing, and the upper half of the block also had four equally spaced holes for the 3.175-mm ($1/8$ -in.) thermocouple probes to be mounted on the surface of the test section. The whole assembled heater block was then clamped in place by a 300-W nozzle band heater that is used for injection molding machines. These four thermocouples provided the outer temperature profile and the means for controlling T_w . The 0.5- μm filter was used to collect contaminants in the fuel and to prevent the clogging of downstream equipment. The fuel finally passed through the cooling coil, which was used to quench any deposit-forming reactions within the heated fuel, and the back-pressure regulator (Swagelok KPB1N0G425P2000), which kept the system pressure at about 689.5 kPa (100 psig).

Experimental Procedure. Studies of the thermal stability of jet fuel are separated into three regimes corresponding to differences in the bulk fuel temperatures.^{33,43} The autoxidation regime starts at 150 °C and goes to 350 °C, the transition regime is in the range of 350–400 °C, and the pyrolytic regime is above 400 °C. Practical gas turbines usually operate in the lower range of the autoxidation regime,⁷ which has a much lower deposit rate than the pyrolytic regime.³² The experimental procedure was designed for long multisession test runs that would be able to run for up to 100 h. Each test run was conducted in 5-h sessions with complete startup and shutdown similar to that used in the study by Faith et al.⁵ System startup for each session involved the heating of the oil bath to the desired preheat temperature. Fuel flow was then started, and the system was pressurized. Pressure-drop data were recorded for 15 min after the outer-wall temperature had reached the target temperature, which was set for each T_p . This

target outer-wall temperature was to ensure that the thermal expansion of the test section was the same for each session, to reduce the variability of the pressure-drop measurements. The test-section heater was set to the desired value of T_w . The data acquisition for the 5-h coking test was then started when the outer-wall temperature reached a specified target temperature, which was the same as T_w . Temperature data were also collected throughout the whole test session. When the 5-h test session was finished, the oil bath and the test-section heater were turned off, the system was depressurized, and the fuel flow was shut off. The 15-min pressure-drop data were used to account for the session-to-session changes in the amounts of deposits on the inner wall of the test section, which were then used to calculate the effective deposit radius. The 5-h pressure-drop data were mainly used to monitor transient changes inside the test section and the test rig. Two recent endothermic fuel studies^{35,36} in the pyrolytic regime had similar experimental procedures, although those studies compared the pressure-drop changes in cold flow and the test-rig heating time was much shorter than in the current study.

RESULTS AND DISCUSSION

Deposit Analysis Method. Pressure-drop measurements were used to monitor the amount of blockage by measuring the changes in the total pressure drop across a length of cylindrical test section in laminar flow. This is known as Hagen–Poiseuille flow,^{44,45} or the hydraulic resistance method,^{35,36} and is evaluated according to the equation

$$\Delta P = \frac{8\mu QL}{\pi R^4} \quad (1)$$

where ΔP is the pressure drop across the test section of length L , μ is the dynamic viscosity of the fluid, Q is the volumetric flow rate, and R is the inner radius of the test section. This equation relates the reduction of the cross-sectional area to the pressure drop, which is inversely proportional to the fourth power of the inner radius of the test section. In terms of measurements of the pressure drop before and after each test session, eq 1 can be rearranged to yield

$$R_f = R_i \sqrt[4]{\frac{\Delta P_i}{\Delta P_f}} \quad (2)$$

where ΔP_i and ΔP_f are the initial and final pressure-drop values, respectively, and R_i and R_f are the initial and final inner radii, respectively, of the test section. This expression allows an effective, or average, deposit radius to be calculated that assumes a uniform distribution of deposits.^{35,46} According to Liu et al.,³⁶ this assumption would result in a deviation of about 0.7% if the deposit thickness were about 50 μm at the exit of the test section. Equation 2 was used to analyze the pressure-drop data of the 15-min tests to provide a measure of the deposit thickness.

Carbon burnoff was used to measure the amounts of the deposits on the test sections. After the pressure-drop measurements, the test sections were removed from the rig and drained overnight, and the central heated section was cut into four 12.7-mm (0.5-in.) sections, whereas the two unheated ends were about 15.875 mm (0.625 in.) in length. These smaller sections were then rinsed with hexane and dried in a vacuum oven at 120 $^\circ\text{C}$ for 3 h. An ELTRA SC-800 surface carbon determinator was used to measure the amounts of carbon deposits on the inner surfaces of the test sections by measuring the amounts of carbon dioxide produced during a controlled carbon burnoff at a set-point temperature of 700 $^\circ\text{C}$. This analyzer has a dynamic range from 5 to 50000 μg of carbon per sample with an accuracy of $\pm 1\%$ of the measured value. The

total carbon mass and the deposit profile were evaluated using the known test-section inner surface area.

Test Conditions. The measurement conditions for a typical test run are summarized in Table 1. The objective of the test

Table 1. Summary of the Test Parameters

parameter	conditions
inlet fuel temperature, T_p	162.8 $^\circ\text{C}$
wetted-wall temperature, T_w	315.6 $^\circ\text{C}$
outer-wall temperature	335.0 $^\circ\text{C}$
oil-bath temperature	193.0 $^\circ\text{C}$
preheater residence time, t_p	50 s
fuel flow rate, Q	20.408 mL/min
fuel pressure, P	910.1 kPa
test-section residence time, t_t	0.055 s
Reynolds number, Re	1670
mean velocity through test section, V	0.92 m/s
test-section material	stainless steel 304

runs described in Table 1 was to run the experiments until about 10% blockage of the flow cross-sectional area, or a radial deposit thickness of about 18 μm for the inner diameter of 0.686 mm, was reached. Three tests were run for 35 h in succession with the same batch of fuel to assess the repeatability of pressure-drop measurements with this setup. Jet A-1 fuel, which had passed the JFTOF test, was left in the supply tank to aerate overnight before each test session.

T_p was controlled by setting the oil-bath temperature, whereas T_w was controlled by the outer-wall temperature. Because it was not possible to measure T_w , a two-dimensional heat-transfer simulation was performed to iterate the required outer-wall temperature to achieve T_w . This iteration was based on the numerical simulation of the jet-fuel autoxidation code developed by Liu.⁴⁷ The Reynolds number (Re) was based on T_p and the test-section geometry, which indicated that the flow remained in the laminar flow regime. Note that the pressure and temperature stated in Table 1 are below the critical conditions of jet A fuel and that the fuel did not go through a phase change.⁴⁸

Sample Data. The pressure-drop measurements for the 15-min tests are shown in Figure 4. An increase of between 28%

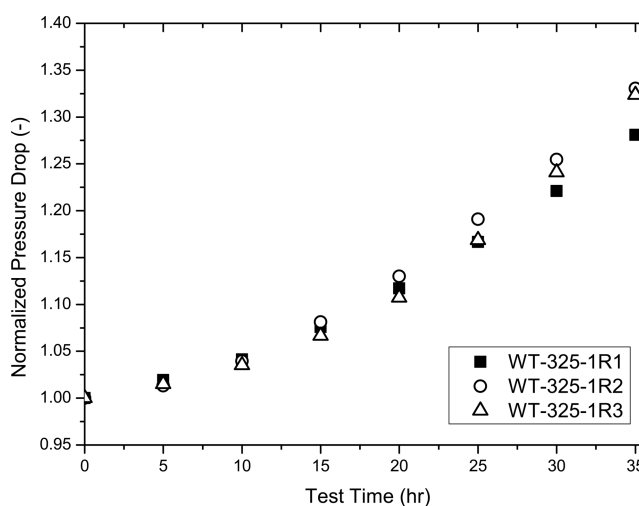


Figure 4. Normalized pressure-drop ratio for the 15-min tests. R1, R2, and R3 denote duplicate tests performed to evaluate the repeatability.

and 33%, with an average of about 31%, was observed after 35 h of heating, which was much higher than the accuracy of the differential pressure transducer of $\pm 0.08\%$. This means that the current setup was able to measure the pressure-drop increase induced by deposit formation and that the data were repeatable across the three test runs. The radial deposit thickness, as shown in Figure 5, was calculated from eq 2. It varied between

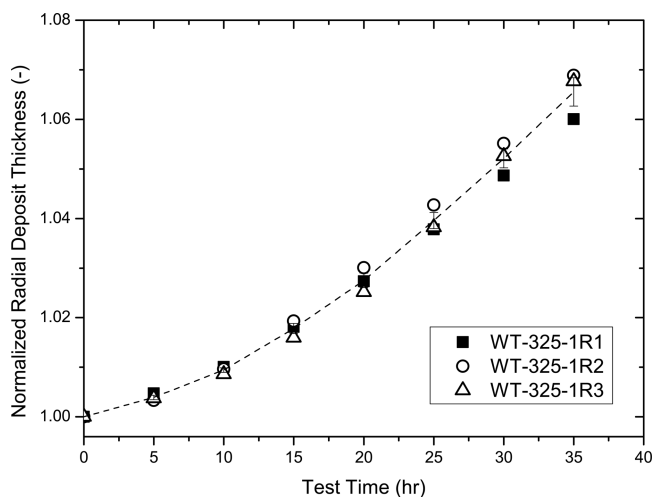


Figure 5. Radial deposit thickness calculated from the 15-min pressure-drop data and normalized by the tube radius. The dashed line is the curve fit to the average data from three repeats.

1.06 and 1.07 μm with a mean value of 1.065 μm and a sample standard deviation of 4.2% at 35 h. The time required to reach 10% area blockage was found by fitting a third-order polynomial to the data, and the fitted equation was used to calculate the time required to reach 17.6 μm . This time varied between 28.4 and 31.2 h, with a mean of 29.7 h. The temperature and pressure-drop data from the 5-h test are shown in Figures 6 and 7. The fluctuations in the outer-wall temperatures over the whole 35-h test run were less than ± 1 $^{\circ}\text{C}$, which means that the test section was kept in a stable state. The outlet fuel temperature decreased throughout the test run as the pressure drop increased. This signals that the amount of

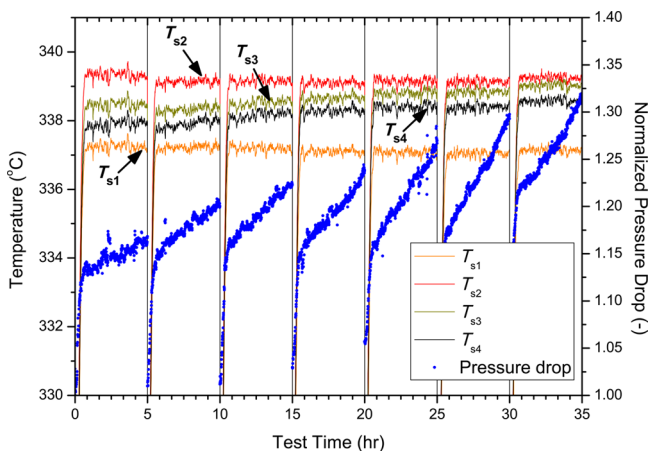


Figure 6. Outer-wall temperature and pressure-drop data during seven sessions of 5-h coking test. Temperature measurement locations on the test section are indicated in Figure 1.

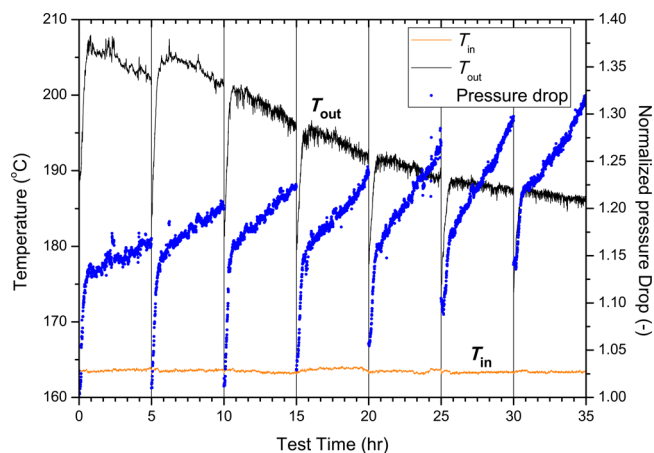


Figure 7. Fuel temperatures at the test-section inlet and outlet during each 5-h test session.

heat transferred from the test section to the fuel decreased as the deposit accumulated inside the test section.

Carbon-burnoff measurements of the two repeat tests, WT-325-1R1 and WT-325-1R2, were performed to provide profiles of the carbon deposit along the test sections as well as the total carbon mass. The carbon-deposit profiles are shown in Figure 8. The repeatability of the experimental setup and the

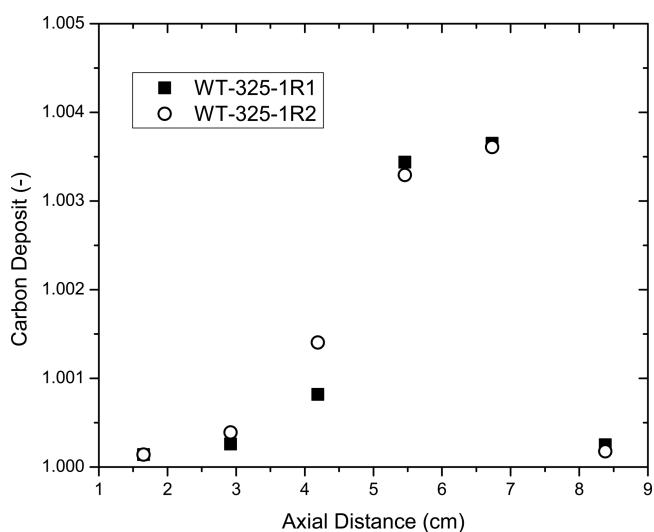


Figure 8. Profiles of the carbon deposits along the length of the test section. The mass of the carbon deposit was normalized by the mass of the corresponding piece of the test section.

procedures of the developed pressure-drop method were confirmed by the two closely matching carbon-deposit profiles. Possible sources of the noticeable discrepancy in carbon deposition between the two experiments at the axial distance of about 4 cm in Figure 8 include the relatively poor repeatability at low levels of deposition and the uncertainty involved in cutting the test tube into pieces of exact dimensions. The deposition profiles were found to be highly nonlinear, as most of the carbon deposit formed in the second half of the test section. It was not possible to derive the actual deposit thickness from the carbon-burnoff data without knowledge of the variation in the density of the carbon deposit along the test section. However, assuming a constant density,⁴⁹ it would be possible to estimate the variation in the deposit thickness along

the test section. The data on the total carbon mass are reported in Table 2, along with the percentage pressure-drop increases

Table 2. Summary of Coking Test Results

test ^a	total carbon mass (μg)	pressure-drop increase (%)	radial deposit thickness (normalized)
WT-325-1R1	3801	28.1	1.06
WT-325-1R2	4133	33.0	1.07

^aR1 and R2 denote repeat tests under the same operating conditions.

and radial deposit thicknesses after 35 h of heating. The pressure-drop method and carbon-burnoff method both indicated that the WT-325-1R2 test produced more deposit than the WT-325-1R1 test. The pressure-drop method predicted a higher difference between the two tests, as the pressure-drop ratio was 17.4% whereas the total carbon mass ratio was only 8.7%. This could be due to a small region with a high amount of accumulated deposit, which would increase pressure drop significantly.

It should be noted that deposition by coking on the inner wall of the tube would affect the roughness of the inner wall and could lead to the differential pressure variations; however, we note that such effects occur only in the turbulent regime. For the laminar flow regime, in which the current experimental setup operates, roughness has no discernible effect on the friction factor. On the other hand, changes in the tube inner diameter by coking deposition would affect the friction factor, if the reduction in diameter with respect to the tube diameter were significant. In the laminar flow regime, the friction factor is given by $64/Re$, where Re is the Reynolds number. A deposition thickness of 0.02 mm, for example, would change the friction factor for an inner tube diameter of 0.686 mm by about 3%. As the deposit thickness increased, an iterative correction scheme could be developed to take the change in the diameter into account.

The objective of the ASTM D3241 JFTOT test is not to reproduce closely the formation of deposits in the jet-fuel system, but rather to differentiate between jet fuels of inferior and acceptable thermal stabilities and coking propensities. The JFTOT test provides information on thermal stability and coking propensity through a visual or metrological rating of the deposition on the surface of the heater tube and the increase in the differential pressure during a test. The system presented in this work, on the other hand, was designed and built to simulate thermal stress conditions close to those typically found in small gas turbine engines. This study has the potential to open a new perspective for a future more quantitative standard methodology for evaluating the thermal stability and coking propensity of fuels. Further, applicability of the described methodology to jet fuels produced from nonconventional feedstocks seems conceivable, and extensive experiments on the described test rig with synthetic aviation jet fuels manufactured from various biomass sources are in progress.

CONCLUSIONS

A study of the thermal oxidative stability of jet fuel was conducted on an experimental apparatus that was designed and built to simulate the conditions in the fuel-injector nozzles of small gas turbine engines. The apparatus was able to independently control different parameters, providing a platform for studying the thermal oxidative stability and coking propensity of jet and biojet fuels. Pressure-drop measurements

were used to monitor deposit buildup across the test section, and the Hagen–Poiseuille flow equation was used to calculate the effective reduction of the inner diameter of the test section as a result of this deposition. Three tests were conducted as proof-of-principle experiments. The experimental results showed that the pressure drop increased significantly with increasing heating time, as expected, and that the data were repeatable. These conclusions were verified by the carbon-burnoff results. The pressure-drop method is thus an effective and nondestructive method that would allow for continuous monitoring of deposit buildup for quantitative comparisons.

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Notes

The authors declare no competing financial interest.

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