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Recycled Fuel Performance in the SR-30 Gas Turbine

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Abstract

An SR-30 gas turbine engine has been run with biodiesel fuel (referred to henceforth as biodiesel) to broaden the educational experience of the engineering students in various classes. The preparation of biodiesel from new and used vegetable oil and pre-testing of the fuel is also described.
Basic characteristics and operation of the engine have not been covered here since they are very well presented in the TTL publications and in Dr Callinan's ASEE paper[1].

Background
John Brown University (JBU) purchased an SR-30 gas turbine engine in 1999. Two years later we purchased the cutaway version since our use was for classroom and laboratory applications. The first applications of the engine were done with no deviations from the Turbine Technologies suggested practice. We found the engine to be an excellent device for demonstration and a definite morale builder. In the fall of 2000 we were making biodiesel from unused cooking oil for testing in piston diesel engines and decided to try that fuel in our SR-30. Based on that success, in 2001 we prepared SR-30 fuel from used cooking oil.

A variety of fuels are specified by Turbine Technologies Ltd. , manufacturer of the SR-30 Turbojet Engine®. Throughout the history of the gas turbine one of the most interesting features has been the theoretical ability for them to use a variety of fuels. Some early authors even anticipated performance independent of fuel type. In the extreme, Tickell [2] reports applications for piston engines using used cooking oil 'straight', after a startup period with conventional fuel.

Commercial airplane engines do not have the liberty of using compounded vegetable fuels, due mainly to their auxiliary equipment, temperatures and pressures, standards and guaranteed performance, Mattingly [5]. The university laboratory is not bound by these considerations and we continue to explore the diversity of vegetable oil based fuels to broaden the engineering students' design mindset.

The John Brown University TTL MiniLab® System has been left as shipped, with no inlet

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or exhaust modifications. The unit is always operated in a large laboratory in front

of a garage door opened to the outside. Incidentally, as several SR-30 operators have modified the intake and exhaust flow paths in a custom fashion, a study of the effects of suction and back pressure from those ductworks would be essential to the exchange of operating data. Velocity profiling of the free exhaust plume shows that it stays essentially horizontal and 'gaussian' as far from the building as it is accurately measurable with our anemometer; about 25 ft, Sewall [3]. It also shows that centerline velocity falls off as the inverse of the distance from a virtual source point.

Safety and human comfort precautions and equipment are always used as mentioned in Callinan [1] and the TTL publications. The JBU turbine is rarely run longer than 15 minutes and never for over 30 minutes.

The first use of a different fuel in the John Brown University SR-30 gas turbine was in the fall of 2000. At that point the turbine had been used for one year and there was about two and a half-hours of operating time on the turbine using only JET-A fuel. The first batch of biodiesel that was prepared was made with unused canola oil, directly out of the gallon jugs from the University's food service.

Commercial biodiesel product is available from several sources as listed in the *Resources* section of Tickell [2]. However, since the intention in these tests was to support an undergraduate engineering educational endeavor, the full fuel production process added plausibility and certainly stimulated the students' interest. The 'in-house' production also provided a 'control' for the later experiments with fuel produced from 'used' oil.

Testing Procedure

The biodiesel was prepared using the suggested chemistry from Tickell [2] for unused oil.: 1 liter methanol, 5 liters vegetable oil, 17.5 grams lye. The fuel is prepared in two stages, first the lye is carefully dissolved in the methanol. Then the oil is added and stirred vigorously for an hour then slowly for eight hours. Caution and safety equipment must be used during this process as very caustic compounds are involved and (hopefully) the final product is combustible. The indications in the resulting fuel were specific gravity, 0.88, and glycerin residual fraction, 15%, just as predicted for a quality biodiesel. The fuel was first compared qualitatively with commercial diesel from the University's bulk tank in ignition and open flame comparison tests. The only notable difference was the odor of the combustion products. The odor of the biodiesel smoke was much more pleasant than the diesel. The fuel was then used in the University's piston diesel engined 'Grasshopper'® lawn machine to test the fuel. The mower was first started with the conventional fuel then the engine was stopped. Bypasses were connected to the fuel supply and return lines and put into a plastic tank containing the biodiesel. The engine was immediately restarted. Performance was excellent. The engine ran smoothly and responded quickly to the throttle. The exhaust gases were noticeably less offensive than those emitted while using diesel fuel. The tractor was run about five minutes in the first test and ten minutes during a second test run for the thermodynamics class. Short excursions around the lawn were made but no extensive or load or duration tests were

conducted. After each test, the intake tube was shifted from the accessory tank to the regular tank allowing the diesel fuel to refill the system. The engine was immediately restarted causing the diesel fuel to refill the system. After allowing adequate time to flow all the biodiesel out of the fuel system's filter, the drain line was replaced into the regular tank. The system was allowed to run for several minutes to complete the purge.

The tests outlined above were performed to assure that what was to be used as fuel in the SR-30 was indeed biodiesel. The same procedure outlined above was used for changing the fuel supply for the tests with the SR-30. Biodiesel was never left in the tank, filter or piping system and no additives to prevent bio-fouling or to stabilize the fuel were added.

The second round of tests was performed a year later in the fall of 2001. In the interim the turbine had been run several times using Jet-A fuel. The total operating time on the engine at the beginning of the second biodiesel testing was about three and a half hours. This batch of biodiesel was based on 'used' cooking oil from the University's food service deep fryers. The oil was nominally the same commercial product as had been used with the 'unused' biodiesel production. The indications for the 'used' fuel biodiesel were very similar to that obtained for the 'unused' oil. The chemistry was changed as described by Tickell based on a series of test mini-batches with different lye contents. The most favorable batch was one with a lye increase factor of 1.75, that is 75% more lye.

Viscosity of the fuels was tested on a relative basis with drain time apparatus. The viscosities were represented as drain times in ‘seconds’. The viscosity apparatus used was a 100[ml] cylinder-funnel with a 2 [mm] diameter drain hole. Multiple measurements were made with each sample but temperature dependence was tested for the biodiesels only. Testing was done with the two biodiesels, the Wesson® canola oil as purchased, water and Jet-A fuel. Repeatability was within +/- 0.3 seconds on all the measurements.

The viscosity of the fuel used is pertinent in the SR-30 for the performance fuel delivery system. The positive displacement pump and the spray nozzles are affected as well as the pressure drops in the fuel lines, filter, and dump valve. The pump being positive displacement should be immune to small changes in viscosity due to temperature or fuel type, or to viscosity related increases in induced pressure drops in the delivery system.

Specific gravities were measured with a hydrometer with a range of 0.79 to 0.91. The vegetable oil (canola) was actually beyond the marked range on the hydrometer, but at 15 [C] was readable as 0.92 just as expected. Apparently all vegetable based cooking oils have specific gravity greater than 0.9 at 15[C]. The specific gravities of the biodiesels produced were measured over a range of temperatures from 15 to 35 [C]

No claim is made for precision in the results for our history of tests, beyond accuracy of the instrumentation, and placement of the transducers. First, there is almost no

control in the vegetable oil used as source, either of production method or vegetable components. Second, the quality of a used oil depends on the condition of its use, primarily the duration and temperature but also on the other foods that have been cooked in the oil. Third, the diesel bulk tank has various ages and compositions of diesel fuel depending on use and source. And fourth, engine performance is not independent of other factors like ageing, carbon deposit, fuel variety, and oil temperature. However, 'head to head' comparisons of JET-A fuel and biodiesel are valid for the educational point at hand. These studies indicate that the laboratory prepared biodiesel from new or used grocery quality vegetable oil compares favorably with the JET-A fuel purchased at the local airport.

Experimental Results

The Loyola thrust measurements reported by Callinan [1] are different than those from the John Brown SR-30 turbine. The turbine minilabs were delivered within a few months of one another in 1999. (The JBU serial is '342'). However, this thrust difference is perhaps not surprising since the Minilab delivered to John Brown University does not have the strain gauge based load cell described by Callinan. On the JBU unit, the thrust readout is supplied directly from the combustion pressure, 'P3', line. Numerically the thrust and P3 values taken during all test runs, are close, averaging;

$$T(\omega) = 0.78 * P3(\omega) \quad \{Lbf, psi\} . \qquad -1$$

The coefficient implying an effective area of about 0.78[in^2]. There is no direct way to calibrate this type of thrust determination. Reading only in whole pounds of force, the thrust indicator has a least count of 1 [Lbf] and the pressure gauge varying by 0.5[psi]. Equations 2 & 3 show a typical set of JBU readings using JET-A compared with the data given by Callinan (unknown fuel). Angular velocity varying by +/-1 % during a measurement.

$$T(\omega) = 0.0025(\omega - 45000) \quad \{N, RPM\} \qquad -2$$

$$T(\omega) = 0.0040(\omega - 55000) \quad \{N, RPM\} \qquad -3$$

Thrust with the biodiesel fuels was proportionately less than the JET-A for all engine speeds. The thrust difference amounted to about 8 [N] (8%) less at 84 [kRPM]. As mentioned above, the uncertainty in the measurements also would be at least 8 [N]. The results are given as equations {4} for new biodiesel and {5} for used biodiesel.

$$T(\omega) = 0.0024(\omega - 45000) \quad \{N, RPM\} \qquad -4$$

$$T(\omega) = 0.0025(\omega - 45000) \quad \{N, RPM\} \qquad -5$$

Ignition in the engine with either of the biodiesels was not detectably different from that with the JET-A. A visual observation of the exhaust jet color and size indicated no difference. There was a difference in the odors of the exhausts. Exhaust Gas Temperature (EGT) was very similar with the three fuels. The used biodiesel exhaust seemed somewhat smoky at engine speed below 60 [kRPM] , but at higher speeds the exhaust was indistinguishable from the other two fuels.

In an attempt to have a measure of fuel performance which included factors like volatility, droplet formation and ease of ignition in situ, an acceleration test was run. In this test the engine was timed while the engine speed increased at its fastest rate. The throttle was quickly advanced from one setting to a higher setting as the timer was started. The angular acceleration was measured over a range roughly from an equilibrium speed of about 60 [kRPM] to a speed of about 80[kRPM] . The JET-A fuel averaged an angular acceleration of 4.50+/- 0.20 [kRPM/s] and the biodiesel from unused oil averaged 3.50 +/- 0.44 [kRPM/s]. The engine acceleration using biodiesel from used oil was about 15% less than that of biodiesel made from unused oil, but unfortunately the fuel was depleted before the formal tests were run.

Conclusions

TTL includes in their operations manual [4] a variety of acceptable fuels; JET-A, A-1, B, 4,5,8, heating fuel oil, diesel kerosene and ‘gaseous fuel system’. The JBU tests have extended the fuel menu to biodiesel made from unused or lightly used vegetable based cooking oils. The extension to themenu of fuels for the SR-30 engine is to develop a broader educational experience. Beyond the testing herein, some other fuel varieties that are diverse enough to stimulate attention are wood (or refuse) smoke [8], natural gas, hydrogen[10], powdered coal, gasohol[9] and fuel oils[7]. Ehrenman [11] mentions ‘e-diesel’ in reference to a mixture of petroleum diesel with ethanol. Biodiesel can also be made with ethanol as a purely vegetable-derived fuel candidate.

Strangely, the ignition and open flame comparison tests were more convincing for the students than either the piston or turbine engine demonstrations that a usable engine fuel can be easily made from waste cooking oil. Similarly the ‘cutaway’ SR-30 was really more effective for educational points about turbine operation. However the fundamental interest and plausibility come from a screaming high RPM gas turbine running on recycled foodstuffs producing power and exhausting a nearly smokeless jet.

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