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FACT FINDING INVESTIGATION

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REPORT ON THE INTERCHANGEABILITY OF B5 BIODIESEL BLEND WITHIN RESIDENTIAL OIL-BURNER APPLIANCES INTENDED FOR USE WITH NO. 2 FUEL OIL

National Biodiesel Board
Jefferson City, MO

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SUMMARY

In consideration of the fact-finding character of this investigation, this Report is to be construed as information only and should not be regarded as conveying any conclusion or recommendations on the part of Underwriters Laboratories Inc. regarding the acceptability of the construction or performance of the product for UL Listing or Recognition, acceptance by any code, standard, Authority Having Jurisdiction (AHJ) or for any other purpose.

This Fact Finding Investigation was conducted to determine the interchangeability of B5 biodiesel blend with No. 2 fuel oil, as defined in the Objective Section of this Report. Test samples were considered and selected to represent fuel oil heating systems installed over the last twenty years (new and used), as indicated in the Test Sample and Fuel Selections Section. The test program was developed based upon the safety requirements contained in UL 296 "Oil Burners" and UL 157 "Gaskets and Seals" for No. 2 fuel oil burning components and appliances, as indicated in the Burner-Appliance System Investigation Section of this Report. Using B5 biodiesel blend fuels, components and / or heating appliances intended for use with No. 2 fuel oil, yielded acceptable results when tested as required by the scope of the UL Standards referenced in the Burner-Appliance System Investigation Section of this Report. It should be noted that the duration of the testing contained in the UL Standards referenced above is limited and does not reflect the useful life span of the equipment.

There is increased risk of material incompatibility with increasing percentage of biodiesel blend. Therefore, the results of this Fact Finding Investigation are limited to biodiesel blends of up to 5% and are not considered representative of higher concentrations of biodiesel (greater than B5).

ASTM D6751 specification biodiesel fuel (B100) was used to create the B5 biodiesel blend used for most tests. An exception to this was that a synthetic aggressive fuel denoted as "UL B5 biodiesel blend" fuel blend was used for gasket and seal testing and endurance testing. This latter fuel was chosen for its more aggressive properties (increased acidity and moisture content). The No. 2 fuel oil used to create the biodiesel test fuels was ASTM D396 specification. The investigation did not consider any base fuels or biodiesel blends outside specifications, as noted above.

While much of the available public literature for biodiesel impacts on diesel engine emissions indicate the potential to generate higher NO_x levels burning biodiesel, the test data did not confirm this assertion with fuel oil burning appliances. The results observed showed typically lower levels of NO_x were measured firing B5 biodiesel blend in comparison with firing No. 2 fuel oil.

The endurance portion of this investigation covered 250 hours of operation with selected burner / appliance combinations. This was consistent with current requirements of the product safety standards. A typical heating season operation may be more than five times that timeframe.

During the endurance investigation, filtration was observed with three varieties of oil filter assemblies, 1) spin-on type with paper filter element, 2) metallic mesh screen filter integral to the oil pump, and 3) spin-on type filter with plastic filter element, as shown in the Test Record Section. At approximately 198 hours of operation with UL B5 biodiesel blend, the paper media filters were observed to be clogged to the point the primary safety control of the heating appliances signaled shutdown and lockout. This observation was made for three separate heating appliances utilizing the exact same paper filter media. An analysis was not conducted on the residue collected on the paper filter media to determine the root cause of the clogging. The other filter technologies did not exhibit clogging.

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As described in the Test Record Section, burner flame luminosity was affected by flame shape and method of propagation within the combustion chamber, as opposed to the type of fuel being fired. These results are considered to apply to residential "gun type" oil burners only, utilizing cadmium sulphide combustion detectors. This Fact Finding Investigation did not address the use of ultraviolet and / or lead sulphide type combustion detectors.

Combustion test data was unaffected by the presence of a nozzle line heater (30°F rise).

Oozing of a caulking-like compound, also referred to as "boiler paste," was observed from the joint between the sections of a cast iron boiler operated with B5 biodiesel blend. This Fact Finding Investigation did not address the composition (unknown) of the boiler paste or its long-term properties when exposed to B5 biodiesel blend. Further investigation of boiler paste(s) may be warranted to determine the significance of this observation.

The results of this investigation are limited to the range of materials and samples identified in the Burner-Appliance System Investigation of this Report.

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GENERAL

OBJECTIVE

This Fact Finding Investigation was performed to develop data on

a) Material compatibility of B5 biodiesel blend[1] with materials employed in residential oil-fired heating appliances[2] (including metals, refractory / combustion chamber liners, thermosets, thermoplastics and elastomers),

b) B5 biodiesel blend combustion characteristics, and

c) General performance comparisons between B5 biodiesel blend and No. 2 fuel oil[3].

It is understood that the National Biodiesel Board (NBB) will seek to use this data to determine the interchangeability of the specified B5 biodiesel blend and No. 2 fuel oil in the residential heating appliances.

The investigation focused on examining relevant safety and performance criteria for B5 biodiesel blend only. It does not address biodiesel blends over 5%, or blends with other ASTM D396 fuel grades (Nos. 1, 4, 5 or 6), nor does it investigate blending with other similar Class II Combustible Liquids such as ASTM D975 diesel fuel oils or ASTM D3699 kerosene.

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[1] *When referred to in this Report, "B5 biodiesel blend" is comprised of five percent by volume ASTM D6751 (Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels) and ninety five percent ASTM D396 (Standard Specification for Fuel Oils) No. 2 fuel oil. Note: for the purposes of this Report, "B5 biodiesel blend" and "UL B5 biodiesel blend" are two distinct fuels.*

[2] *UL defines residential oil-fired appliance as an appliance with volumetric fuel flow burn rate of less than 3 gallons per hour (gph).*

[3] *When referred to in this Report," No. 2 fuel oil" is as defined by the Standard Specification for Fuel Oils, ASTM D396.*

TEST SAMPLE AND FUEL SELECTIONS

Fuel Oil Heating Systems – General

The product safety standards associated with oil-fired heating systems address the risk of explosion, fire, fuel leaks / spills, and toxic gas generation among other potential hazards. The standards are applicable to individual components of the system (burners, filters, storage tanks) as well as collectively to their use in combustion equipment. The requirements consider the effects of operation on materials that comprise these components, both from a short-term and long term perspective. They therefore can serve as a relevant basis for comparison of the performance of test fuels on test samples.

The requirements of these standards are periodically revised as field experience, science and technology dictate. This is also the case for the materials, components and equipment of the heating system.

Selection of Components for Testing

The components of a fuel oil heating system that would be affected from a safety perspective by exposure to B5 biodiesel blend in lieu of unblended No. 2 fuel oil were identified. A documentation review of UL Listed oil-fired burner assemblies, boiler assemblies, water heaters, and warm air furnaces was conducted to further identify materials, used in the components of these products, that are exposed to the fuel. The review looked at current as well as past designs to ensure selection of representative test samples. It revealed that the typical designs of today are very similar to oil heating systems of the past (up to 20 year look-back) with the exception of the functionality of electric safety and operating controls.

The *Standard for the Installation of Oil-Burning Equipment* (NFPA 31) specifies the materials acceptable for use in fuel piping systems and components. These materials remain unchanged throughout the look-back period.

Independent research and testing of materials relevant to the fuel tanks of the heating system is largely available and was reviewed by UL for this Report. Fuel tanks and integral components thereof were not further investigated.

Byproducts of combustion have the potential to affect vent and chimney materials. The safety standards for these components address this concern. Literature review indicates that biodiesel fuel results in reduced carbon dioxide and diesel particulate matter emissions, while slightly increasing NO_x. Sulfur content is reduced proportionate to the percent blend, reducing potential acidity of emissions. At a B5 blend, the byproducts of combustion are not considered to be significantly different from No. 2 fuel oil and ventilation components of the heating system were not further investigated.

Figure 1 illustrates typical construction of a fuel train for a residential fuel oil burning appliance, with the components labeled.

FIGURE 1

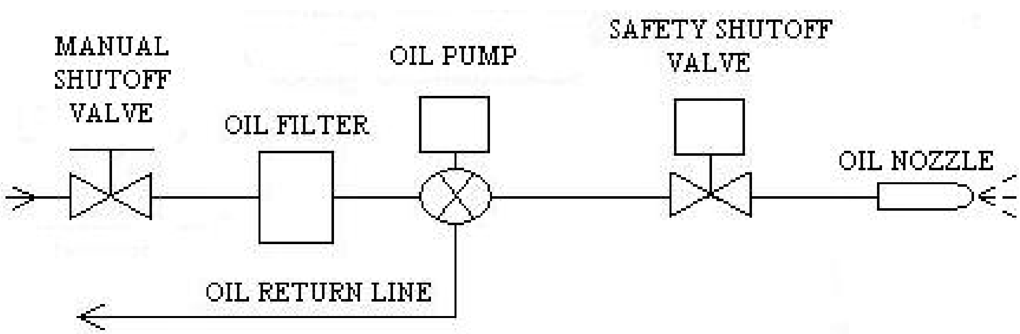
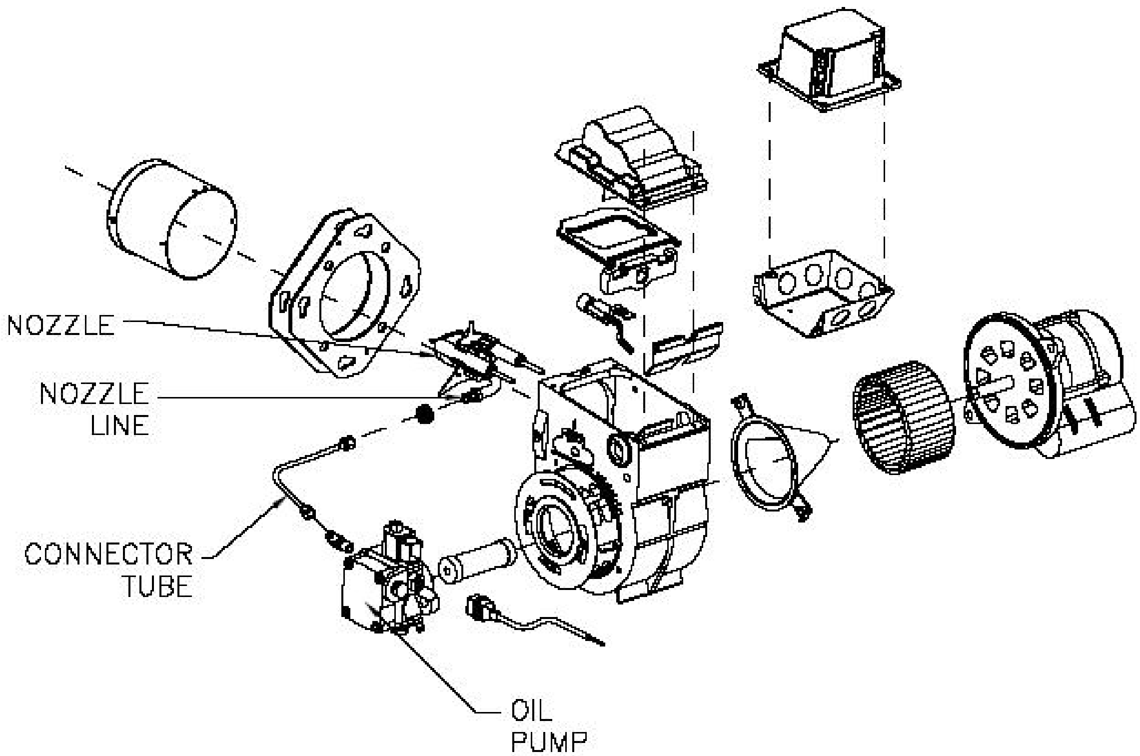


Figure 2 shows an exploded view of a typical flame retention fuel oil burner, which is representative of the residential oil burner market. Each burner component that would contact the fuel is labeled. Note, the flame retention head is not shown, it is located within the firing head assembly.

FIGURE 2



Details on the specific components chosen for testing are provided below.

Burners

All oil-fired burner assemblies selected and utilized in generating this Report are UL Listed for use with No. 2 Fuel Oil.

Three prominent residential oil burner suppliers to the North American market agreed to participate in the testing portion of the Fact Finding Investigation. In total, twelve burner-appliance combinations were identified and selected for testing. The burner-appliance combinations selected were both new and used and chosen to address the variables of age and equipment performance characteristics. With input from the oil burner suppliers confirming the documentation review described previously, these combinations were considered representative of the past (approximately 1 to 20 years) and present residential oil heating residential appliance market.

See the Test Record Section for specific details, with respect to the test sample appliances in which the burners were installed. All oil burner assemblies selected and utilized in generating this report are UL Listed for use with No. 2 fuel oil.

Carlin Combustion Technologies, Inc.

Discussions with Carlin Combustion Technologies resulted in the following burner test sample selections:

- Model EZ-1.
- Model 99FRD.

The burners are constructed primarily of commercial grade steel and may utilize copper and brass fuel containing components. According to Carlin's management, these two burners are representative of approximately 95% of residential oil burners shipped by Carlin Combustion Technologies over the last decade. The remaining 5% of Carlin's residential oil burners are constructed with different configurations of burner firing heads, blowers, and other application specific components. However, the construction, materials and fuel containing parts and components are similar to the selected test samples and therefore considered represented.

The oil pumps tested and supplied with the oil burner selections are as follows and were considered to represent approximately 99% of Carlin's pump usage over the last decade:

- Model EZ-1 burner - Suntec A2VA3006 fuel unit with an integral electric safety shutoff valve.
- Model 99FRD - Suntec A2VA7116 fuel unit and Carlin M8 electric safety shutoff valve.

Burner Model EZ-1 was equipped with a nozzle line heater of the non-contact type. Fuel oil is not in direct contact with the oil heater element(s); oil is heated by conduction through the oil nozzle line. Approximately one-half of all residential burners that Carlin Combustion Technologies manufactures are constructed with nozzle line heaters.

R.W. Beckett Corporation

Discussions with R.W. Beckett Corp. resulted in the following burner test sample selections:

- Model AFG.
- Model NX.

The Model AFG residential oil burner represents approximately 80% of current annual burner volume. This burner represents performance of other similar burners in the Beckett product portfolio, specifically, the Model S and AF burners.

The Model NX residential oil burner represents similar burners in the Beckett product portfolio, specifically, the AFII burner.

These two burner models were considered representative of R.W. Beckett's current residential burner product line as well as those units produced for the past twenty years. The burners are constructed primarily of commercial grade steel and may utilize aluminum, copper, and brass fuel containing components. Fuel-train components were additionally varied to provide representative exposure to components used over the past twenty plus years in the construction of residential oil burners by R.W. Beckett Corp.

The oil pumps tested and supplied with the oil burner selections are as follows and were considered to represent Beckett's pump usage over the last decade.

- Model AFG burner - Suntec A2VA7116 and Combu E7-LUS electric safety shutoff valve.
- Model AFG and NX burner - Suntec A2EA6520 with an integral electric safety valve.
- Model AFG burner - Danfoss BFPH with integral electric safety shutoff valve.

Burner Model AFG (equipped with the Suntec oil pump) was equipped with a nozzle line heater of the non-contact type. Fuel oil is not in direct contact with the oil heater element(s); oil is heated by conduction through the oil nozzle line.

Riello Burners – North America

Discussions with Riello Burners, North America resulted in the following burner test sample selections:

- Model R40-F3
- Model 40-BF3
- Model 40-F5

The models selected represent 95% of Riello – North America's residential oil burners distributed over the last decade. The remaining 5% of residential oil burners are represented for the purposes of this investigation due to the similarities of construction, materials, fuel containing parts and components. The burners are constructed primarily of commercial grade steel and may utilize aluminum, copper, and brass fuel containing components.

The oil pumps tested and supplied with the oil burner selections were model RBL 6807-0215 and were considered to represent Riello – North America's pump usage over the last decade. The pumps are manufactured by Riello specifically for use with their oil burners.

Oil-Fired Heating System Components

Metallic and non-metallic materials are used in the construction of valves, switches, pumps, burners, and other oil-fired fuel conveying and containing components.

- Copper and copper alloys in contact with fuel oil in the components above were considered. The UL review of publicly available information indicated copper and copper alloys have compatibility issues at higher blend percentages. Although the risk of leaks using a B5 biodiesel blend was considered minimal at the material thicknesses in heating equipment components, potential long term gum or film formation on fuel passage surfaces could affect equipment performance.

- Use of aluminum is typically limited to pump housings and impellers. Aluminum parts are considered compatible with B5 biodiesel blends but, could experience long term gum or film formation on fuel passage surfaces if the B5 biodiesel blend ages to a point of degradation. As with copper alloys, material thickness minimizes the risk of leakage. Depending upon the grade of aluminum, accelerated mechanical / chemical wear of an impeller could affect equipment performance (e.g. clogged filter or orifice).

- Steel parts are considered compatible with B5 biodiesel blends but, could also experience gum or film formation on fuel passage surfaces if the B5 biodiesel blend ages to a point of degradation.

For the indicated reasons, inspection of these metallic components was conducted throughout the testing phase of this Fact Finding Investigation (see Test Record Section) and, after the testing was concluded, the parts were examined for corrosive effects and improper operation due to the introduction of the B5 biodiesel blend.

Research indicated that non-metallic gasket and seal materials were most vulnerable to degradation from the introduction of B5 biodiesel blend, the consequence of which could be an oil leak / spill or equipment performance issue.

Documentation review of current UL Listed and / or Recognized Component oil-fired components[4] confirmed a survey of the manufacturers and users of oil-fired heating system components. It was concluded that two non-metallic materials were in widespread use in the construction of the gasket and seals of fuel train components. The materials identified were nitrile and fluorocarbon elastomer compounds.

To represent the range of elastomer compounds used, two samples of each compound were selected based on the material hardness (65 to 90 durometer). Gasket and seal materials chosen were new Recognized Components[5]. This evaluation resulted in four total gasket and seal material test samples, two nitrile and two fluorocarbon, as shown below:

Parker Seal Co., Division of Parker Hannifin Corporation, O-Ring Division

Compound Designation: N1499 (nitrile), N1500 (nitrile)
VA151 (fluorocarbon), V1163 (fluorocarbon)

In addition, a preformed combustion chamber liner was tested. The material identified for testing was a Sid Harvey Model SH633-70 vacuum formed alumina-silica combustion chamber liner.

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[4] *UL categories; KYXZ "Oil Burners", MEGR "Power Operated Pumps", METZ "Oil Burner Strainers", MHKZ "Manual Valves", YIOZ "Electrically Operated Valves", and YRBX "Flammable Liquid Shutoff Valves."*

[5] *The component manufacturer signifies compliance with the requirements of the applicable product safety standard by applying UL's Recognized Component marking in accordance with an agreement with UL.*

Test Fuels

The following fuels[6] were utilized for performance and material compatibility testing.

No. 2 fuel oil –	100% ASTM D396 No. 2 fuel oil
ASTM D6751 B5 biodiesel blend –	95% ASTM D396 No. 2 fuel oil 5% ASTM D6751 B100 biodiesel
UL B5 biodiesel blend –	95% ASTM D396 No. 2 fuel oil 5% UL B100 biodiesel formula

[6] *The UL B100 was prepared by Brookhaven National Laboratory, Upton, NY, and distributed to the test facilities in order to maintain consistency in the UL B5 test fuel. The ASTM D6751 B100 was obtained by each manufacturer from a local supplier of their choice.*

BURNER-APPLIANCE SYSTEM INVESTIGATION

Investigating the Storage of Fuel

The Attachment of this Report includes data and research developed for the investigation of biodiesel storage and was considered representative for the purposes of this Fact Finding Investigation.

Investigating Burner/Appliance Performance

To investigate the performance of the B5 biodiesel blend in an oil burner, combustion safety tests required by the UL *Standard for Safety for Oil Burners*, ANSI/UL 296 were performed. The First Edition of UL 296 was published in May 1927 and currently is in its Tenth Edition of publication dated September 11, 2003. UL 296 scope includes oil burners designed to utilize any hydrocarbon oil as defined by Specifications for Fuel Oils, ASTM D396. In the creation of a testing program for this Fact Finding Investigation, the methodology of conducting the tests remained the same. However, specific revisions were made with respect to parameters and observations[7]. The performance (test) requirements of ANSI/UL 296 were considered appropriate to investigate the operational safety concerns of the B5 biodiesel blend due to its similar application and chemical makeup as compared to No. 2 fuel oil.

To provide a controlled comparison of No. 2 fuel oil and B5 biodiesel blend, the appliance testing was conducted consecutively utilizing both fuels. The following tests are from UL 296 – Tenth Edition:

1. Combustion – Section 50.1.
2. Mechanical Atomizing Burner endurance – Section 50.2[8].
3. Combustion Air Failure – Section 5.1
4. Undervoltage – Section 53.
5. Power Interruption – Section 54.
6. Temperature – Section 55.
7. Ignition Tests, Electric High-Tension, Reduced Voltage – Cold Oil – Section 57.1.

In general, the testing included observations for carbon monoxide (CO) generation, carbon dioxide (CO_2) generation, smoke generation, general flame characteristics, flame luminosity, build-up of carbon, soot, ash, etc., appliance stack (flue gas) and burner surface temperatures and ignition properties at normal and abnormal conditions. The tests were conducted and repeated utilizing three combustion air settings (trace point, factory setting and full air / last stable ignition). The settings were established while burning No. 2 fuel oil and the exact settings were utilized for B5 biodiesel blend testing. These general observations and the separate combustion air settings established a balanced, repeatable matrix representing normal and abnormal operating conditions of an oil burner installed "in the field."

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[7] *Observations were added for flame shape and luminosity to determine the primary safety control's flame sensor effects during the conduct of the Combustion Test. Observations for excessive burner nozzle drip (drool) or leakage during post purge during the conduct of the Combustion Air Failure Test to determine effects on burner operation such as delayed ignition, excessive smoking, and odor, were considered a priority.*

[8] *To obtain a "worst case" condition from a material compatibility standpoint, UL B5 biodiesel blend was utilized in the conduct of the 250-hour evaluation during the Mechanical Atomizing Burners Test, Section 50.2. Observations were made with respect to observable physical changes of fuel handling parts, leakage of fuel, etc. within the fuel train during and at the conclusion of the test. A 50-hour "pre-conditioning" test with No. 2 fuel oil was performed before the 250-hour operation UL B5 biodiesel blend test.*

Investigating the Material Compatibility of the Fuel

To investigate the compatibility of the polymeric materials in contact with the B5 biodiesel blend, UL *Standard for Safety for Gaskets and Seals*, ANSI/UL 157 was utilized. The First Edition of UL 157 was published in February of 1991 and currently is in its Second Edition of publication with revisions dated June 30, 1999. For the polymeric material testing program for this Fact Finding Investigation, the methodology of conducting the tests remained the same as a standard investigation with the addition of visual observations of the test samples for appearance changes, sloughing, volume change, etc. ANSI/UL 157 was considered to represent B5 biodiesel blend applications due it the test methods being independent of the fuel utilized. UL B5 biodiesel blend was utilized for the test program. The test program consisted of the following ANSI/UL 157 tests:

1. Tensile Strength, Elongation and Volume Change “As Received” – Section 8.
2. Tensile Strength, Elongation and Volume Change After Immersion – Section 11.

The test samples were assembled as ASTM slabs per UL 157, consisting of 65-90 durometer grades of nitrile and fluorocarbon elastomers, resulting in four test materials.

In the creation of a combustion chamber liner material testing program for this Fact Finding Investigation, the methodology of conducting the tests remained the same with that of the established test program for similar fuel oil compatible products. The test program consisted of the following tests from the UL Recognized Component category, Refractory Liners (MENQ2):

1. Oil Saturation
2. Flame Impingement

TEST RECORD

General

The burner / appliance performance testing specified in the Burner-Appliance System Investigation Section was conducted at the following facilities:

1. R. W. Beckett Corp., Elyria, OH
2. Carlin Combustion Technology Inc., East Longmeadow, MA
3. Riello Burners of North America, Mississauga, Ontario

Data generated at these sites complied with the requirements of Underwriters Laboratories Inc. Data Acceptance Program[9] and was conducted and developed in accordance with UL's Guidelines and General Practices of Combustion Laboratories[10].

The gasket / seal material testing was performed at Underwriters Laboratories Inc. Northbrook, IL facility.

The preformed combustion chamber liner testing was conducted at Brookhaven National Laboratories, Upton, NY.

Samples

Oil Burners:

All the oil burners were forced draft, gun type flame retention burners with the oil pump direct driven from the combustion air motor shaft. Oil was pressure atomized in a single 'Simplex' nozzle using a single pipe. A mid-point grounded ignition module provided direct spark ignition of the atomized oil supply. A cadmium sulphide combustion detector proved flame.

Test Appliances: (All dimensions are nominal)

Armstrong Furnace Model 80 upflow warm air furnace having a 10 in. ID refractory lined combustion chamber installed with Beckett Model AFG oil burner.

Bock Corp. vertical storage water heater Model 71E formed alumina-silica soft wall combustion chamber liner installed with Carlin Model EZ-1 oil burner.

Buderus cast iron five (5) section Model G215/5 hot water boiler having a 13.25 in. dia., 26.25 in. long unlined combustion chamber with Carlin Model 99FRD oil burner.

Buderus cast iron section four (4) Model G115/4 how water boiler having a 11.5 in. wide by 19 in. long by 11.5 in. high unlined combustion chamber with Riello Model R40-F3 oil burner.

Burnham Corp. cast iron three (3) section Model V83 hot water boiler having a combustion chamber 14.125 in. wide by 10 in. long by 14 in. high with an alumina-silica flame target wall and refractory blanket on floor installed with Beckett Model AFG oil burner and L1 firing combination.

International Comfort Products upflow warm air furnace Model AMP-1E2-105 with unlined formed steel combustion chamber 13 in. wide, 21 in. long by 15 in. high with Riello Model 40-F3 oil burner.

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[9] *The UL Data Acceptance Program (DAP) is a defined UL process that provides a uniform policy for the validation of standard testing methods by an external laboratory.*

[10] *UL's Guidelines and General Practices of Combustion Laboratories establishes a uniform process to ensure all combustion laboratories utilized by UL have adequate facilities to provide supporting test data for combustion equipment.*

Peerless cast iron four (4) section Model WVB-04 hot water boiler having a 14 in. wide, 13 in. long by 15.25 in. high combustion chamber with rear flame target wall and refractory blanket on floor installed with Riello Model 40-F5 oil burner.

Weil-McLain cast iron three (3) section Model P-WGO-3 hot water boiler having a 14.25 in. wide, 11 in. long by 15.5 in. high combustion chamber with an alumina-silica flame target wall and refractory blanket on floor installed with Beckett Model NX oil burner.

Weil-McLain cast iron three (3) section Model P-WGO-3 hot water boiler having a 14.25 in. wide, 11 in. long by 15.5 in. high combustion chamber with an alumina-silica flame target wall and refractory blanket on floor installed with Beckett Model AFG oil burner and L1 air tube combination.

Weil-McLain cast iron three (3) section Model P-WGO-3 hot water boiler having a 14.25 in. wide, 11 in. long by 15.5 in. high combustion chamber with an alumina-silica flame target wall and refractory blanket on floor installed with Beckett Model AFG oil burner and F3 air tube combination.

Weil-McLain cast iron four (4) section Model GO4 hot water boiler having a 14.125 in. wide, 13.625 in. long by 15.5 in. high combustion chamber with an alumina-silica flame target wall and refractory blanket on floor installed with Carlin Model EZ-1 oil burner.

Unidentified cast iron three (3) section hot water boiler having a 11.75 in. wide, 10.875 in. long by 12.5 in. high, unlined combustion chamber. The burner was fitted with a direct vent kit installed with Riello Model 40-BF3.

General Comments on Data

Manufacturer specific references have been removed to keep the data empirical, where possible, and not application dependant. In some instances, portions of a test were not subjected to all combinations. In these instances, it was considered probable that all combinations would manifest similar findings.

The density (specific gravity @ 60ºF) of each fuel was measured using ASTM Test Method D 1298-99 (Reapproved 2005) and found to be within the range of compliance with No. 2 fuel oil.

Supplemental NO_x and / or SO_2 values were recorded when the combustion analyzer used had such capability. When recorded, the values were the actual load, not converted to 3% O_2 or other.

Smoke spot(s) were pulled during the Combustion, Undervoltage and Mechanical Atomizing Burner endurance tests. Care was taken to assure the Smoke spot papers did not become smudged.

- Each spot having an observed stain was subjected to having the density measured, in accordance with ASTM D2156-94 (Reapproved 2003), by a reflection gloss meter. A 100 Photovolt reading = 0 Smoke, 90 PV = No. 1 Smoke, 80 PV = No. 2 Smoke, etc.

- Each Smoke paper was to be loaded in the Smoke pump with sufficient tightening pressure on the knurled collar such to make a slight impression on the paper, thus making it possible to readily identify where the spot was in the event a Zero Smoke was pulled.

- Smoke spots obtained with the Bacharach True Spot® smoke test pump, each of ten (10) strokes was to consist of a slow and steady pull taking between 7 to 10 s from full close to full pull.

APPLIANCE TESTING

COMBUSTION TEST:

METHOD

The test was conducted in accordance with UL 296, Tenth Edition, Section 50.1, issued September 11, 2003.

The burners were installed in the indicated test appliances and arranged for operation according to the instructions provided by the burner manufacturer. Each burner was fired until steady-state combustion conditions were obtained with No. 2 fuel oil and the air-fuel ratio adjusted in accordance with the burner manufacturer's instructions.

This test was repeated firing B5 biodiesel blend.

The performance of the burner during this test was to be observed for the following:

A. Automatic ignition obtained each cycle within the intended period of time without backfire, flash, or puff.
B. Burner flames not to flash outside the heating appliance being fired, and combustion shall be complete and stable.
C. Observed smoke at all firing rates not to exceed that indicated by a No. 1 spot firing a distillate fuel on the Shell-Bacharach scale.
D. Observed carbon dioxide, carbon monoxide and oxygen concentrations.
E. Surfaces of the firebox, nozzles, electrodes, igniters and their insulators free from detrimental formation of carbon, soot, and tar.
F. No tar or flocculent soot deposited on surfaces of heat exchanger, flue passages, or the flue pipe of the heating appliance.
G. Observed combustion characteristics, including flame shape and luminosity.

RESULTS

The smoke spot in the flue gases was not in excess of a No. 1 for all equipment and fuel combinations and all air settings, except for Trace Point measurement firing No. 2 oil in Furnace 2 (actual No. 1.1 Bacharach Smoke) and a Trace Point measurement firing B5 biodiesel blend in Boiler 6 (actual No. 1.48 Bacharach Smoke). At the time the data was taken, the density of the smoke spot was identified as exceeding a No. 1. It was considered appropriate to record the data producing heavy smoke spots at the adjusted settings, as they represented a minimum air shutter setting for the application. Additional test data demonstrated that with minor adjustment to the air shutter, the smoke density was reduced to less than a No. 1 Bacharach Smoke by increasing the air shutter opening.

Performance of the burner was such that automatic ignition was obtained on each cycle within the intended time period without backfire, flash, or "puff," at all air settings, except that Boilers 1, 3 and 6 were observed to ignite with a puff at the minimum air shutter setting firing B5 biodiesel blend. Firing No. 2 oil at the same setting, there was no observed “puff”.

Water heater 1 was observed to ignite with a slight “puff” at the barometric damper at the minimum air shutter setting firing No. 2 oil. Firing B5 biodiesel blend at the same setting, there was no observed “puff.”

Stable combustion was maintained for all equipment and fuel combinations and all air settings without flashout of flames from the heating appliance being fired, and no excess amount of soot, carbon, or tar was deposited on surfaces of the burner or heating surfaces of the test appliance.

Electrical ratings were consistent at high fire for the components employed.

The luminosity of the flame and the flame characteristics could not be predicted from one fuel to the other, nor from one appliance to the other, except for the propensity of the flame to lift, curl and / or break towards the coldest section of the cast iron boiler. In certain combinations, the flame shape / color remained unchanged from one fuel to the other; while in other combinations, the flame would shorten, narrow and / or feather. In certain combinations with other than factory settings firing No. 2 oil and B5 biodiesel blend, the flame was observed to have traces of feathery, blue finger flames. Cad cell resistance was not deleteriously affected from one fuel to the other. The measured resistance was affected most by the shape of the flame, and how the flame cone carried within in the combustion chamber as it extended beyond the burner flame retention head.

Combination	Furnace 1									
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.75	0.75	0.75	0.75	0.75	0.75	0.76	0.80	0.78	0.78
Test Pressures, psig										
Oil Pump Supply	140	140	140	140	140	140	138	135	135	135
Oil Temp. at Nozzle, °F	102	110	89	108	111	108	105	101	103	107
Products of Combustion										
Smoke - Bacharach No.	0	0	Trace	1	0	0	0.12	0.07	0.7	0.08
Smoke - Photovolt							98.8	99.3	93	99.2
O_2 in Flue, %										
CO_2 in Flue, %	9.37	10.46	10.33	10.46	6.9	7.03	9.05	8.52		6.8
CO in Flue, ppm							0	0		0
NO_x in Flue, ppm							80	78		58
Temperatures - °F										
Flue Gas	540	549	532	534	590	612	550	545	571	594
Room Ambient	71	68	74	69	73	73	72	68	71	72
Primary Air Shutter Position Open	7.5/0	7.5/0	6/0	6/0	10/4	10/4	7.5/0	7.5/0	10/4	10/4
Cad Cell Resistance - Ω	57	57	48	49	104	110	89		152	
Draft Over Fire, in.WC	-0.01	-0.01	-0.01	-0.01	+0.03	+0.03	-0.01	-0.04		+0.01
Draft in Flue, in.WC	-0.035	-0.035	-0.03	-0.035	-0.01	-0.01	-0.04	-0.01		-0.035
Electrical Inputs at High Fire										
Burner Motor V	120						120	120		
Burner Motor A	1.3						1.37	1.4		
Burner Motor rpm	3401									
Control Circuit V	120									
Control Circuit A	1.4									
Observation Note	1	1	1	1	1	1	1A	1B	1A	1B

Note 1: Good light off and stable flame observed.
Note 1A: Test performed with nozzle line heater installed and energized.
Note 1B: Rate was measured without allowing burner temperature to stabilize. The cooler the nozzle, the slower the oil will flow through the nozzle resulting in a mathematically higher flow rate.

Test not observed at Trace Point on Furnace 1.

Combination	Furnace 2					
	Factory Setting		Trace Point		Maximum Air Shutter Setting	
	Observed Data					
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.76	0.74	0.76	0.74	0.76	0.74
Test Pressures, psig						
Oil Pump Supply	171.6	160.4	171.6	160.6	172	160.1
Oil Temp. at Nozzle, °F	68.7	67.4	72.2	73.2	73.7	72.5
Products of Combustion						
Smoke - Bacharach No.	0.1	0.15	**1.1**	0.41	0.14	0.09
Smoke - Photovolt	99	98.5	89	95.9	98.6	99.1
O_2 in Flue, %	4.1	4.5	2.3	3.0	5.2	5.7
CO_2 in Flue, %	12.23	11.97	13.57	13.10	11.39	11.00
CO in Flue, ppm	0	0	1	0	0	0
SO_2 in Flue, ppm	62.8	61.2	69.5	64.4	58.2	54.6
NO_x in Flue, ppm	102.5	97.9	108.4	108.6	92	87.5
Temperatures - °F						
Flue Gas	600.8	605.3	557	569	600	603.5
Room Ambient	76.4	76.4	76	76.8	75.8	77.6
Primary Air Shutter Position Open	3.5	3.5	2.75	2.75	6.0	6.0
Cad Cell Resistance - Ω	5.56k	6.0k	4.87k	4.77k	6.57k	7.28k
Draft Over Fire, in.WC	+0.01	+0.01	+0.01	-0.03	+0.01	+0.03
Draft in Flue, in.WC	-0.03	-0.03	-0.01	-0.03	-0.03	-0.01
Electrical Inputs at High Fire						
Burner Motor V	120	120				
Burner Motor A	1.38	1.38				
Burner Motor rpm						
Control Circuit V	120	120				
Control Circuit A	1.48	1.48				
Observation Note	2	2	2A	2A	2B	2B

Note 2: Some lifting of the flame at the tip, solid color at factory setting.
Note 2A: Flame observed to be looser and have a wider shape.
Note 2B: Flame was very short flat.

Combination	Water Heater 1						Boiler 1					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	1.27	1.22	1.27	1.26	1.27	1.26	1.55	1.49	1.56	1.54	1.56	1.54
Test Pressures, psig												
Oil Pump Supply	115	115	115	110	115	110	160	160	160	160	160	160
Products of Combustion												
Smoke - Bacharach No.	0.19	0.05	0.26	0.11	0.12	0.12	0.28	0	0.2	0.22	0.18	0.19
Smoke - Photovolt	98.1	99.5	97.4	98.9	98.8	98.8	97.2	100	98	97.8	98.2	98.1
O_2 in Flue, %	4.7	5.3	2.4	3.1	8.3	8.8	6.4	6.5	2.6	2.5	7.3	7.7
CO_2 in Flue, %	12.1	11.7	13.8	13.3	9.4	9.1	10.8	10.8	13.7	13.7	10.2	9.9
CO in Flue, ppm	10	5	10	6	3	2	4	4	4	5	8	10
NO_x in Flue, ppm	126	121		144	82	74	80	81	94	99	76	72
Temperatures - °F												
Flue Gas	745	734	689	686	724	725	415	398	398	355	420	364
Room Ambient	78	78	71	71	72	72	79	80	70	73	74	75
Primary Air Shutter Position Open	70%	70%	55%	55%	100%	100%	70	70	40	40	95	95
Cad Cell Resistance - Ω	222	266	150	158	325	399	603	348	408	355	388	364
Draft Over Fire, in. WC	-0.005	0.00	-0.02	-0.02	+0.03	+0.025	+0.06	+0.06	+0.02	+0.02	+0.07	+0.08
Draft in Flue, in.WC	-0.04	-0.03	-0.04	-0.035	-0.03	-0.03	-0.04	-0.04	-0.05	-0.04	-0.04	-0.04
Electrical Inputs at High Fire												
Burner Motor V	120	120					120.6	120.6				
Burner Motor A	1.59						1.76	1.86				
Burner Motor rpm	3467	3453	3490		3480		3449	3436				
Control Circuit V	120	120					120.6	120.6				
Control Circuit A	1.59						1.83	1.92				
Observation Note					3	3A	4	4C	4A	4B	4B	4D

Note 3: Slight barometric puff.
Note 3A: No barometric puff.
Note 4: Orange-yellow flame with slight right hand break at rear of flame. Flame not solid, has some feathering.
Note 4A. Flame dark orange-yellow has with a hard right hand break.
Note 4B: Flame length shortened considerably with a right hand break.
Note 4C: Flame has significant lift up and to the right at the rear that was not observed firing No. 2 oil.
Note 4D: Flame shape, size and color similar to that for No. 2 oil. Burner ignites with audible puff not present during No. 2 oil tests.

Combination	Boiler 2						Boiler 3					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.80	0.79	0.80	0.79	0.80	0.79	0.94	0.95	0.94	0.95	0.94	0.95
Test Pressures, psig												
Oil Pump Supply	197	184.4	197	186.2	197	185.6	140	135	138	134	139	135
Oil Temp. at Nozzle, °F	71.7	64	72.3	67.2	72.5	66.7	88	88	90	89	88	83
Products of Combustion												
Smoke - Bacharach No.	0.57	0.59	0.65	0.61	0.63	0.55	0.11	0.02	0.29	0.05	0.09	0.04
Smoke - Photovolt	94.3	94.1	93.5	93.9	93.7	94.5	98.9	99.8	99	99.5	99.1	99.6
O_2 in Flue, %	3.9	4.8	3.7	4.4	5.2	5.8						
CO_2 in Flue, %	12.38	11.84	12.59	12.14	11.43	11.00	11.65	11.61	13.64	13.65	8.96	9.0
CO in Flue, ppm	13	15	14	17	13	15	1	0	10	2	0	0
SO_2 in Flue, ppm	63	57.9	62.2	59.3	57.4	53.8						
NO_x in Flue, ppm	92.7	86.3	94	85	82.5	77.2	115	111	165	166	61	58
Temperatures - °F												
Flue Gas	328.3	327.3	326.9	293	332	335	587	581	545	544	626	612
Room Ambient	72.6	69.1	71.9	69.7	73.9	70.2	69	71	70	70	69	68
Primary Air Shutter Position Open	4	4	3.75	3.75	6	6	8.5/0	8.5/0	4.25/0	4.25/0	10/10	10/10
Cad Cell Resistance - Ω	10.2k	10.0k	9.8k	10.2k	10.5k	10.9k	623	682	600	594	1012	1217
Draft Over Fire, in.WC	+0.01	+0.01	0.0	+0.01	0.0	0.0	-0.0125	-0.015	-0.01	-0.01	+0.028	+0.03
Draft in Flue, in.WC	-0.03	-0.01	0.0	-0.01	-0.03	-0.03	-0.03	-0.035	-0.02	-0.02	0.0	0.0
Electrical Inputs at High Fire												
Burner Motor V	120	120					120.1					
Burner Motor A	1.33	1.4										
Burner Motor rpm							3477					
Control Circuit V	120	120					120.1					
Control Circuit A	1.42	1.44					1.48					
Observation Note	5	5C	5A		5B	5D			6	6		6A

Note 5: Yellow-orange flame with slight lift at upper right corner of flame.
Note 5A: Flame not as bright, and break to right not as distinct. Some lifting of flame upwards towards right rear.
Note 5B: Shorter flame; a few feathers lift at upper right corner; flame cone is smaller.
Note 5C: Flame appears to be slightly narrower that No. 2 oil flame with slight lift at top right corner of flame.
Note 5D: Flame narrower and shorter than No. 2 oil flame.
Note 6: Flame length increased with few feathers of flame.
Note 6A: Main body of flame is short with a trailing flame having a distinct blue tinge. With combustion chamber in fully heated condition, turning burner off/on immediately resulted in a hard relight with a smoke puff visible at the observation port. No flame flashout or damage to the burner or boiler.

Combination	Boiler 3						Boiler 3	
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.95
Test Pressures, psig								
Oil Pump Supply	140	140	140	140	140	140	138	136
Oil Temp. at Nozzle, °F	89	90	89	89	90	90	89	86
Products of Combustion								
Smoke - Bacharach No.	0	0	Trace	Trace	0	0	0.1	0.05
Smoke - Photovolt							99	99.5
O_2 in Flue, %								
CO_2 in Flue, %	11.66	11.59	14.62	14.6	8.51	8.45	11.55	11.53
CO in Flue, ppm							0	0
NO_x in Flue, ppm							111	112
Temperatures - °F								
Flue Gas	565	567	531	526	596	594	583	562
Room Ambient	73	73	71	72	75	74	72	70
Primary Air Shutter Position Open	7/0	7/0	3/0	3/0	10/10	10/10	8.5/0	8.5/0
Cad Cell Resistance - Ω	579	600	506	519	600	1292	641	646
Draft Over Fire, in.WC	-0.01	-0.01	-0.01	-0.01	+0.01	+0.01	-0.015	-0.01
Draft in Flue, in.WC	-0.03	-0.03	-0.02	-0.02	-0.025	-0.025	-0.035	-0.025
Electrical Inputs at High Fire								
Burner Motor V	120						120.3	
Burner Motor A	1.3							
Burner Motor rpm	3481						3477	
Control Circuit V	120						120.3	
Control Circuit A	1.4						1.58	

Stable combustion was observed at all settings. It was observed the nozzle line heater generates 108-111ºF on heater block and the oil temperature at nozzle did not increased significantly.

Combination	Boiler 4						Boiler 5			
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	1.25	1.245	1.25	1.245	1.25	1.245	0.91	0.93	0.91	0.94
Test Pressures, psig										
Oil Pump Supply	196	193	197	192	197	192	185	182	189	182
Oil Temp. at Nozzle, °F	67.2	70.1	66.9	70.5	67.3	71.3	95	93	94	93
Products of Combustion										
Smoke - Bacharach No.	0.22	0.05	0.43	0.44	0.06	0.1	0.1	0.1	0.32	0.1
Smoke - Photovolt	97.8	99.5	95.7	95.6	99.4	99	99	99	96.7	99
O_2 in Flue, %	4.0	4.0	3.3	3.2	6.4	6.3				
CO_2 in Flue, %	12.44	12.28	12.84	12.85	10.49	10.4	10.35	10.31	13.37	13.07
CO in Flue, ppm	1	1	6	5	0	0	2	0	9	3
SO_2 in Flue, ppm	63.6	61	66.7	63.4	52.3	51				
NO_x in Flue, ppm	96.9	93.5	97.2	96.1	76.4	74.7	68	73		88
Temperatures - °F										
Flue Gas	384	382	374	374.3	417	412	464	453	424	418
Room Ambient	71.5	73	70.8	78.6	71.4	75	74	71	70	70
Primary Air Shutter Position Open	3.5	3.5	3.25	3.25	6.0	6.0	2.75	2.75	1.9	1.9
Cad Cell Resistance - Ω	6.987k	7.3k	10k	6.7k	11.7k	12k		870	736	757
Draft Over Fire, in.WC	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.015	-0.0125	-0.035	-0.035
Draft in Flue, in.WC	-0.03	-0.03	-0.04	-0.03	-0.04	-0.04		-0.04	-0.045	-0.06
Electrical Inputs at High Fire										
Burner Motor V	120	120					120.5	120.6	120.6	
Burner Motor A	1.45	1.46					1.74	1.74		
Burner Motor rpm							3499	3453		
Control Circuit V	120	120								
Control Circuit A	1.55	1.59								
Observation Note	7						8	8A		8B

Note 7: No trailing flames observed.
Note 8: Bright yellow flame with tight flame cone. Only a few feathers of flame at sides and rear.
Note 8A: Flame shape and length resembles the No. 2 oil flame but with a slightly darker yellow color.
Note 8B: Flame is slightly darker yellow in color and flame shape is slightly bushier at this setting. The barometric damper was not readjusted.

Test not observed at minimum air shutter setting on Boiler No. 5.

Combination	Boiler 5					
	Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.93	0.93	0.93	0.93	0.93	0.93
Test Pressures, psig						
Oil Pump Supply	175	175	175	175	175	175
Products of Combustion						
Smoke - Bacharach No.	0	0	Trace	Trace	0	0
CO_2 in Flue, %	11.3	11.3	13.1	13.2	7.36	7.4
Temperatures - °F						
Flue Gas	399	405	381	380	452	445
Room Ambient	65	66	65	65	66	65
Primary Air Shutter Position Open	2.5	2.5	1.9	1.9	5	5
Cad Cell Resistance - Ω	624	620	570	580	881	892
Draft Over Fire, in.WC	-0.01	-0.01	-0.01	-0.01	+0.015	+0.015
Draft in Flue, in.WC	-0.025	-0.025	-0.02	-0.02	-0.015	-0.015
Electrical Inputs at High Fire						
Burner Motor V	120					
Burner Motor A	1.6					
Burner Motor rpm	3455					
Control Circuit V	120					
Control Circuit A	1072					

Stable combustion was observed at all settings.

Combination	Boiler 6						Boiler 7					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	1.23	1.21	1.23	1.20	1.23	1.24	0.51	0.49	0.51	0.49	0.51	0.49
Test Pressures, psig												
Oil Pump Supply	140	140	140	140	140	140	214	203	212	202	215	201
Oil Temp. at Nozzle, °F	92	90	96	98	82	83	72.4	72.3	73.9	73	74.5	73.2
Products of Combustion												
Smoke - Bacharach No.	0.0	0.13	0.75	**1.48**	0	0.32	0.32	0.3	0.84	0.53	0.78	0.75
Smoke - Photovolt	100	98.7	92.5	85.2	100	96.8	96.8	97	91.6	94.7	92.2	92.5
O_2 in Flue, %	5.5	5.1	4.5	3.8	10.5	10.4	3.4	4.1	2.1	2.9	6.7	7.2
CO_2 in Flue, %	11.5	11.8	12.4	12.8	7.8	7.9	12.63	12.35	13.66	13.25	10.09	10.00
CO in Flue, ppm	6	6	8	11	16	12	5	5	5	2	18	24
SO_2 in Flue, ppm							63.8	60.3	67.1	64.4	49.6	47.8
NO_x in Flue, ppm	115	115	116	117	65	69	106.7	108	118.5	109	78.8	77.2
Temperatures - °F												
Flue Gas	449	450	436	430	490	494	410	415	404	409	448	450
Room Ambient	74	75	78	81	73	74	75.9/93	74.9	77.9/96	75.5	77.9/93	75.7
Primary Air Shutter Position Open	54%	54	45%	45	95%	95	3.1	3.1	2.9	2.9	4.5	4.5
Cad Cell Resistance - Ω	219	212	215	219	462	428	4.7k	4.6k	4.79k	4.66k	4.75k	4.79k
Draft Over Fire, in.WC	-0.02	-0.01	-0.03	-0.03	+0.01	+0.01	+0.03	+0.03	+0.03	+0.01	+0.03	+0.03
Draft in Flue, in.WC	-0.04	-0.035	-0.04	-0.045	-0.04	-0.045	-0.01	+0.01	0.0	0.0	+0.01	+0.03
Electrical Inputs at High Fire												
Burner Motor V	120	120					120	120				
Burner Motor A	1.7	1.74					1.25	1.22				
Burner Motor rpm	3466	3466										
Control Circuit V	120	120					120	120				
Control Circuit A	1.89	1.83					1.25	1.22				
Observation Note	9	9C	9A	9D	9B	9E	10		10		10	

Note 9: Somewhat narrow, slightly darker orange flame.
Note 9A: Flame width is more defined with some feathering at extreme edges of flame. Some left hand trailing flames with lift to the upper right.
Note 9B: Flame narrows and flattens with blue tinges on feathers.
Note 9C: Flame is wider and fuller than that firing No. 2 oil. Flame pushes to left with somewhat of a longer tail at the end.
Note 9D: Flame is fuller than that firing No. 2 oil.
Note 9E: Main body of flame on right hand side appeared to impinge on the rear wall. Top feathers of flame lift to top of combustion chamber. Barometric dampers swings upon ignition of main flame with an audible thump, but no puff or flashout of flame.
Note 10: Temperatures observed at room ambient / combustion air temperature at burner inlet from direct vent.

Combination	Boiler 8						Boiler 9					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.95	0.95	0.95	0.95	0.95	0.95	0.90	0.90	0.90	0.90	0.90	0.90
Test Pressures, psig												
Oil Pump Supply	140	140	140	140	140	140	140	140	140	140	140	140
Oil Temp. at Nozzle, °F	99	103	103	103	98	96	108	109	109	110	102	102
Products of Combustion												
Smoke - Bacharach No.	0	0	Trace	Trace	0	0	0	0	Trace	Trace	0	0
CO_2 in Flue, %	12.0	12.09	13.88	13.80	8.97	9.10	10.7	10.8	12.7	12.7	7.0	7.2
Temperatures - °F												
Flue Gas	416	419	395	393	456	455	421	425	396	405	460	466
Room Ambient	74	74	74	73	73	75	71	71	72	71	71	72
Primary Air Shutter Position Open	8/0	8/0	4.5/0	4.5/0	10/10	10/10	6/0	6/0	3.5/0	3.5/0	10/5	10/5
Cad Cell Resistance - Ω	250	254	211	219	420	461	150	149	124	127	376	396
Draft Over Fire, in.WC	-0.01	-0.01	-0.01	-0.01	+0.01	+0.01	-0.01	-0.01	-0.01	-0.01	+0.035	+0.035
Draft in Flue, in.WC	-0.03	-003	-0.02	-0.02	-0.025	-0.025	-0.025	-0.025	-0.02	-0.02	-0.01	-0.01
Electrical Inputs at High Fire												
Burner Motor V	120						120					
Burner Motor A	1.25						1.6					
Burner Motor rpm	3494						3445					
Control Circuit V	120						120					
Control Circuit A	1.6						1.85					
Observation Note	11						12					

Note 11: Stable combustion observed at all settings.
Note 12: Stable combustion, ignition and flame retention observed at all settings

COMBUSTION TEST- MECHANICAL ATOMIZING BURNER ENDURANCE:

METHOD

The test was conducted in accordance with UL 296, Tenth Edition, Test No. 1, Mechanical Atomizing Burners, Section 50.2, issued September 11, 2003.

A burner was installed in a thoroughly cleaned test appliance and adjusted for operation firing No. 2 fuel oil as described in Combustion Test. The automatically-ignited on-off burner was fired in successive cycles, each cycle consisting of 10 min "on" and 10 min "off" for a total "on" time of 50 h.

Daily observations were made of the draft over-fire, ignition and combustion characteristics, including flame shape and luminosity, combustion chamber condition, fuel leakage of components / pipe connections and fittings, and for any abnormal performance. After every 50 h of operation, smoke, draft over-fire, carbon dioxide and carbon monoxide concentrations and fuel input rate were measured.

This test was repeated firing UL B5 biodiesel blend for a total "on" time of 250 h. After completion of the test, the internal surfaces of the oil piping and oil handling components were observed for changes in physical properties.

RESULTS

The results of tests firing both No. 2 fuel oil and UL B5 biodiesel blend indicate ignition was obtained during each cycle, flames did not flash outside the heating appliance, the observed smoke was less than a No. 1 on the Shell-Bacharach scale, and no tar or flocculent soot buildup was observed on heat exchanger or burner surfaces.

There was no observed leakage of the oil train and its components resulting from 250 hr. of operation firing UL B5 biodiesel blend.

Upon dismantling the oil train and its components for burners mounted on Water Heater 1 and Boilers 1 and 6, there was an apparent[11] reduction of the piping ID / volume as described in the table below. Seals and gasket materials did not appear to be degraded.

Combination	Water Heater 1			Boiler 1			Boiler 6		
Oil train part:									
	Before	After	% Change	Before	After	%Change	Before	After	% Change
Combustion head mass, g	2.50	2.41	-3.6	2.44	2.20	-9.8	2.45	2.29	-6.5
Nozzle line mass, g	1.06	1.01	-4.7	1.02	1.02	0.0	0.140	0.138	-1.4
Flared end of combustion head, in.	0.122	0.122	0.0	0.122	0.122	0.0	0.119	0.118	-0.8
Nozzle line @ pump end orifice, in.	0.116	0.116	0.0	0.116	0.116	0.0	0.121	0.121	0.0
Nozzle line @ combustion head orifice, in.	0.116	0.116	0.0	0.116	0.116	0.0	0.121	0.121	0.0
Fitting @ pump NPT end, in.	0.216	0.215	-0.5	0.216	0.215	-0.5	0.218	0.218	0.0
Fitting @ pump flared end, in.	0.117	0.115	-1.7	0.117	0.115	-1.7	0.120	0.119	-0.8

[11] *The dimensional change(s) were at the precision limits of the measuring instruments.*

Supply oil piping to Water Heater 1 and Boilers 1 and 6 was fitted with a spin on type oil filter considered typical of those found in residential installations. At approximately 198 hr total "on" time, the primary safety control on each burner was found to be 'locked out' signifying a flame failure. Vacuum at the inlet to each oil filter was observed to be 6 in. WC[12], indicating the filter media was clogged. Each oil filter was replaced with a clean (new) oil filter of the same type and the test continued. Observed vacuum at the inlet of each new filter was 0 in. WC.

The three (3) oil filters were subjected to physical inspection following the test. The pleated paper media of each filter was thoroughly coated with a congealed substance (See Fig. 3), The substance produced a sour odor. Disassembly of the oil pumps did not reveal a similar build-up in the internal filter screens, nor was any debris observed. Internal parts of the oil pumps did not show signs of pitting, galling or unusual wear. It was noted a new tank was utilized for distribution of the B5 biodiesel blend for testing.

FIGURE 3

Filtration issues were not observed during the tests on Furnaces 1 and 2 and Boilers 2, 3 and 5. Furnace 1 and Boilers 3 and 5 did not utilize an external spin on type filter. They utilized a mesh screen filter that was integral to the oil pump. Disassembly of the oil pumps did not find any build-up in the integral filter screens, except that the integral filter screen in the Suntec pump was observed (See Fig. 4) to have a small amount solid debris (vs. congealed, as shown in Figure 3) not exceeding 1 in. in length in two filter pleats adjacent the oil inlet port. There was no observed pitting, galling or unusual wear on the internal parts of the pump. Some discoloration was observed on machined portions of an oil pump piston that appeared related to different types of metal finishing processes used. These were judged to not have any impact on oil pump performance.

FIGURE 4

Discoloration of relieved portions of the piston and on another internal part observed during teardown was believed to be the red fuel dye. The red dye effect was fairly strong and, where these parts supported a heavier film of oil (i.e., where the surface is rougher), it was noticeably red-brown. (See Fig. 5).

FIGURE 5

Furnace 2 and Boiler 2 utilized an external oil filter having a sintered plastic element. There was no observed degradation of the filter media and no build-up of solids. (See Fig. 6)

FIGURE 6

Upon disassembly of the oil pumps for Furnace 1 and Boiler 2, there was no observed abnormal wear nor discoloration of parts. The integral filter (Fig. 9) was observed to have a few loose strands that resembled the filter media. This was not considered excessive. (See Figs. 7, 8 and 9)

FIGURE 7

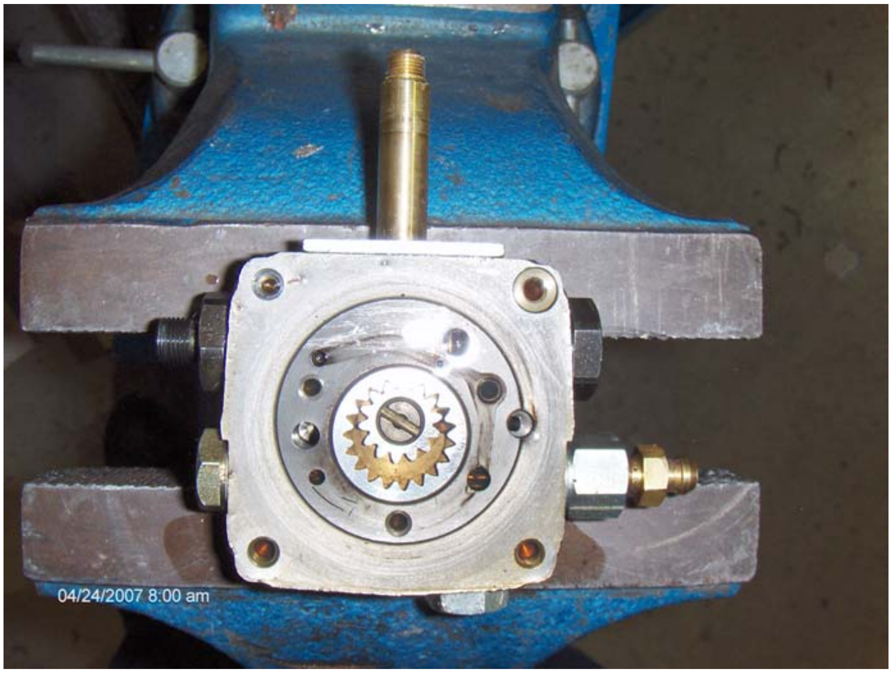
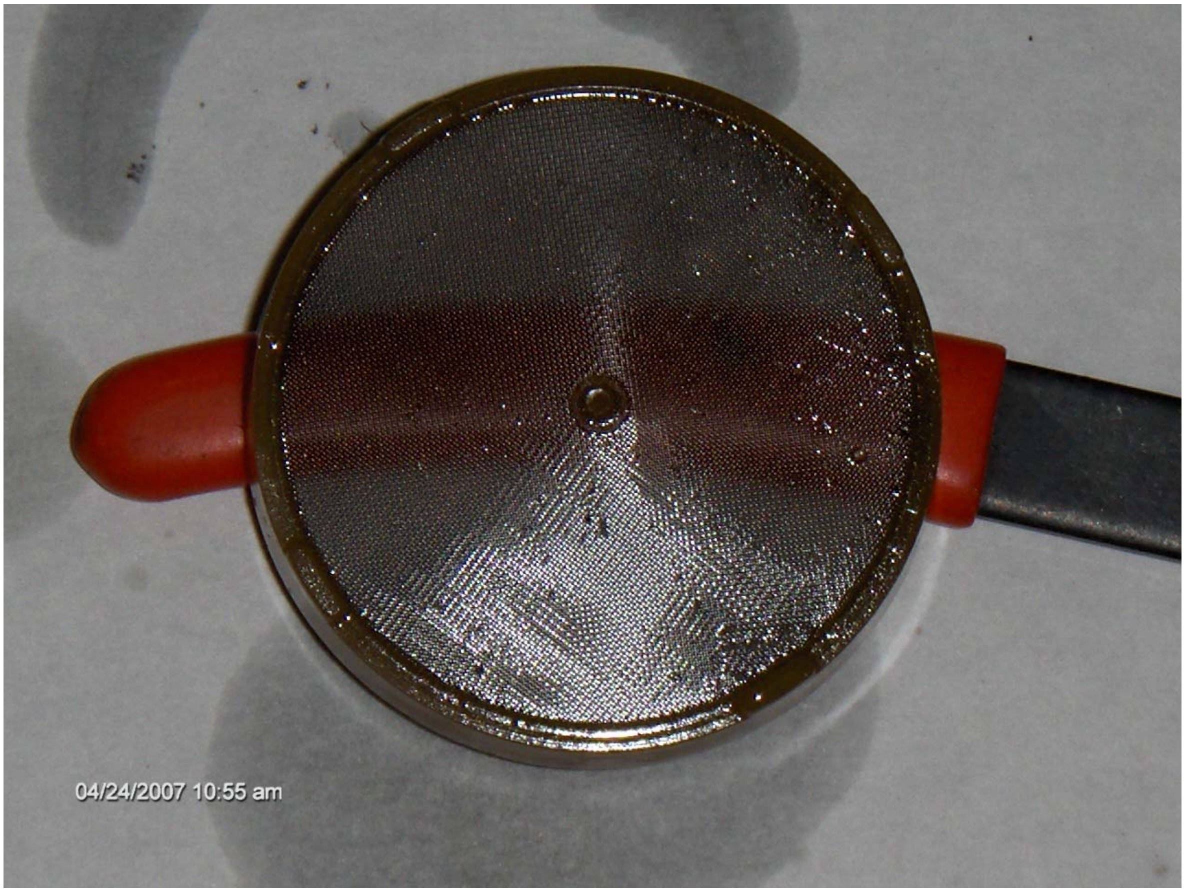


FIGURE 8

FIGURE 9



Fireside surfaces were observed at the end of 50-hour firing No. 2 oil, cleaned and then observed again following 250-hour firing UL B5 biodiesel blend. After the 50-hour operation on No. 2 fuel oil, the flue pipe and turbulator within Water Heater 1 was observed to have a light build-up of light gray colored residue attributed to sulphur contained in the No. 2 fuel oil. After the 250-hour operation on UL B5 biodiesel blend, the build-up of light gray residue was significantly thicker and all surfaces were covered. It was readily dislodged by light finger pressure. (See Figs. 10 and 11).

FIGURE 10
Water Heater 1 at conclusion of 50-Hour No. 2 fuel oil operation

FIGURE 11
Water Heater 1 at conclusion of 250-Hour UL B5 biodiesel blend operation

After the 50-hour operation on No. 2 fuel oil, the fireside surfaces between sections of Boiler 1 were observed to have a minimum build-up of identical material as Water Heater 1. (See Figs. 12 and 14). The combustion chamber of Boiler 1 was free from this residue. After the 250-hour operation on UL B5 biodiesel blend, a similar increase in build-up, as noted for Water Heater 1, was observed on fireside surfaces between sections of Boiler 1 and resembled a substance similar in appearance to spores. (See Figs. 13 and 15).

FIGURE 12
Boiler 1 at conclusion of 50-Hour No. 2 fuel oil operation

FIGURE 13
Boiler 1 at conclusion of 250-Hour UL B5 biodiesel blend operation

FIGURE 14
Boiler 1 (Combustion Chamber) at conclusion of 50-Hour No. 2 fuel oil operation

FIGURE 15
Boiler 1 (Combustion Chamber) at conclusion of 250-Hour UL B5 biodiesel blend operation

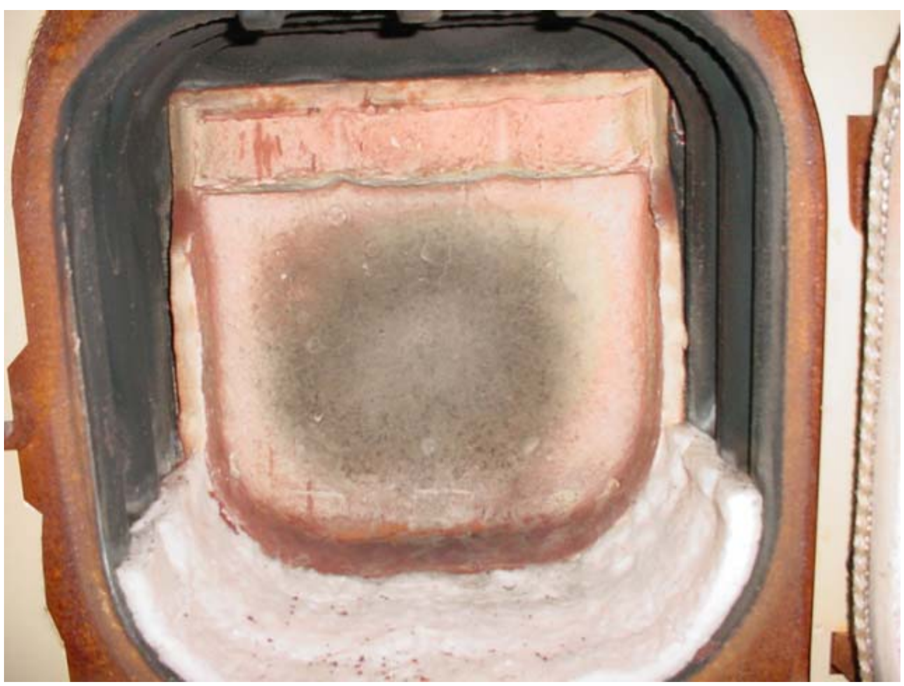
The rear wall (end opposite the burner) from the 6 to ~9 o'clock position as viewed from the front of Boiler 6 was observed to have a 'dusting' of this light gray colored residue, and at 11 and 1 o'clock on the rear wall, the dusting was slightly more pronounced. (See Figs. 16 and 17). The rear wall of Boiler 6 contained an increased build-up at 11 and 1 o'clock of what appeared to be ash. It was flakey to touch and dislodged easily. The right wall of the combustion chamber was observed to have a flame impingement pattern on it that was attributed to the rope gasket used to mount the burner to the boiler having dislodged further. (See Figs. 18 and 19) Burner firing heads were free from heavy solid carbon build-up and were observed to have some sooting around the periphery of the vanes that was attributed to the oil filter being blocked during the test.

FIGURE 16
Boiler 6 at conclusion of 50-Hour No. 2 fuel oil operation

FIGURE 17
Boiler 6 at conclusion of 250-Hour UL B5 biodiesel blend operation

FIGURE 18
Boiler 6 (Combustion Chamber) at conclusion of 50-Hour No. 2 fuel oil operation

FIGURE 19
Boiler 6 (Combustion Chamber) at conclusion of 250-Hour UL B5 biodiesel blend operation



Fireside surfaces of Boilers 3 and 5 were observed around the 200 h mark with similar observations with respect to light gray residue noted previously. At the end of 250 h, the burner firing heads were observed to be clean.

After 50 hours of operation on No. 2 fuel oil, the floor of the combustion chamber and second and third flue passes of Boiler 2 were observed to have a build-up of red and faint yellow deposits. The red deposits were attributed to the sulphur content in the oil. The yellow deposits were not identified. (See Fig. 20) After 250-hours of operation on UL B5 biodiesel blend, an increase in the build-up of the red and yellow deposits was observed. An additional red deposit, exhibiting an "oozing" effect, was observed where the boiler sections contacted one another. The substance carried into the flue pass. These deposits were considered to be the boiler paste used to assemble the sections. (See Figs. 21 and 22).

FIGURE 20
Boiler 2 at conclusion of 50-Hour No. 2 fuel oil operation

FIGURE 21
Boiler 2 at conclusion of 250-Hour UL B5 biodiesel blend operation

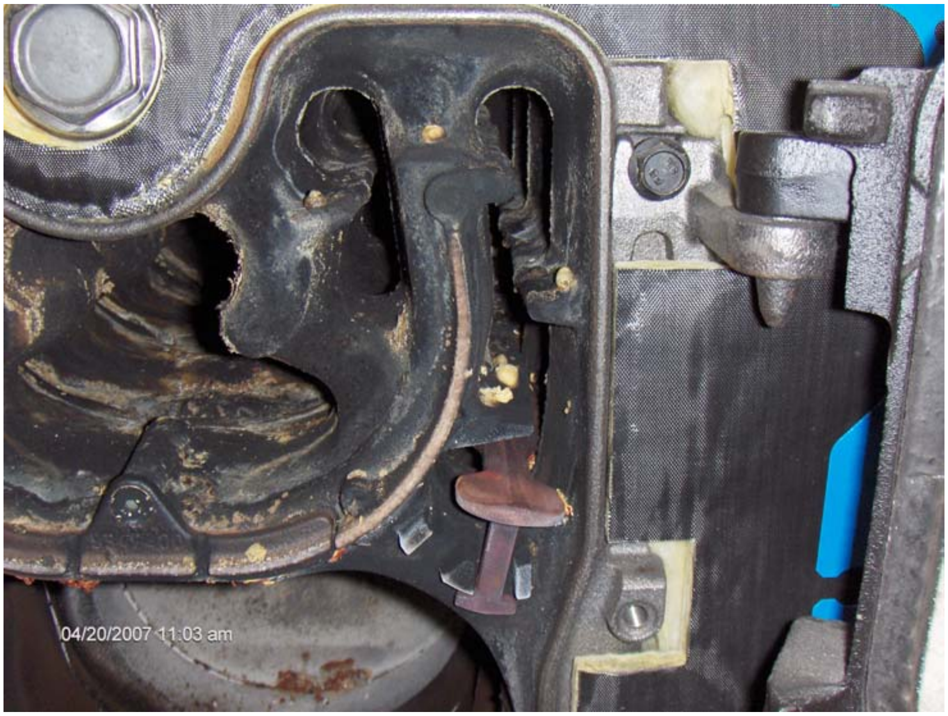
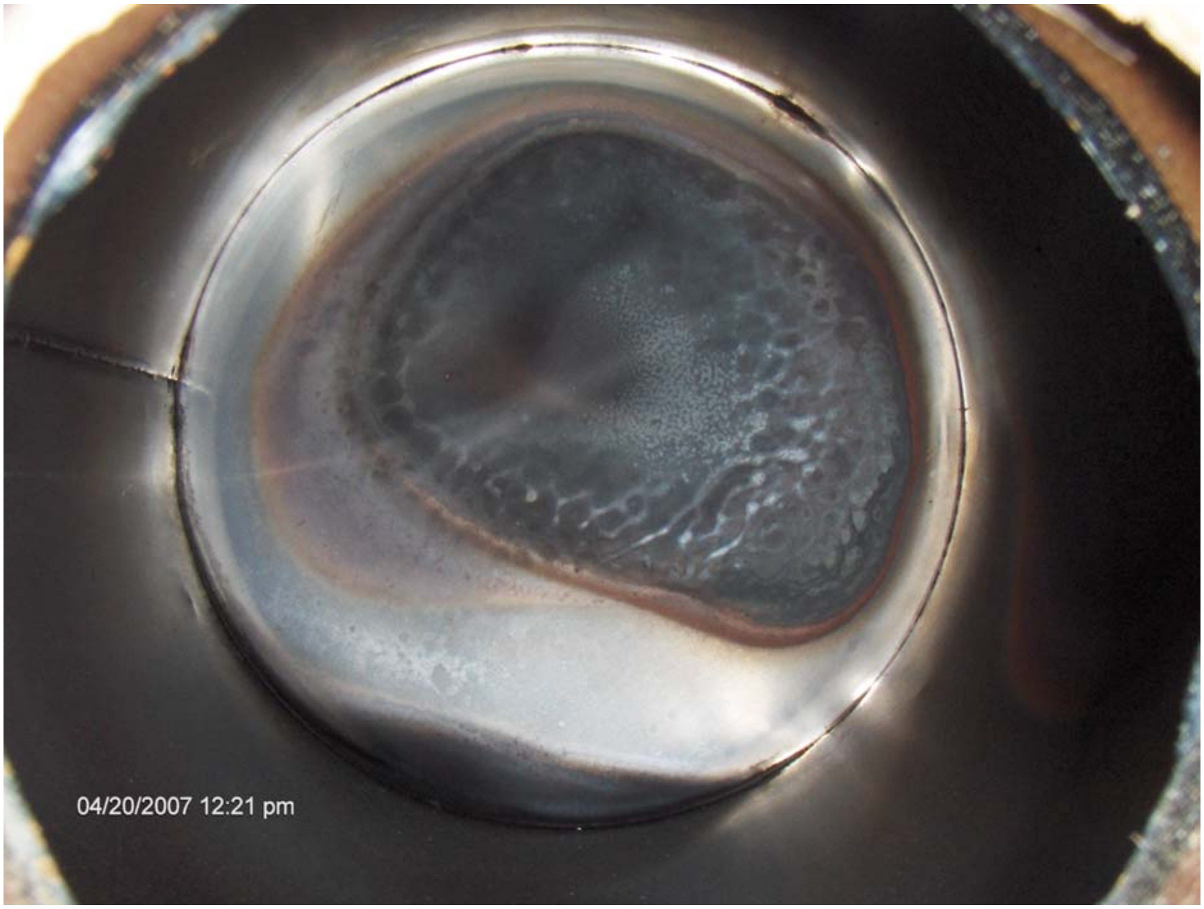


FIGURE 22
Boiler 2 (Combustion Chamber) at conclusion of 250-Hour UL B5 biodiesel blend operation

After 50 hours of operation on No. 2 fuel oil, the combustion chamber of Furnace 2 was observed to be free from any build-up or sooting. After the 250-hour operation on UL B5 biodiesel blend,, the combustion chamber remained clean and free from any debris. (See Figs. 23 and 24.)

FIGURE 23
Furnace 2 at conclusion of 50-Hour No. 2 fuel oil operation

FIGURE 24
Furnace 2 at conclusion of 250-Hour UL B5 biodiesel blend operation



COMBUSTION AIR FAILURE TEST:

METHOD

The test was conducted in accordance with UL 296, Tenth Edition, Test No. 3, Section 51, issued September 11, 2003.

The mechanical draft burner was installed and adjusted for operation firing No. 2 fuel oil as described in Combustion Tests. While the burner was being fired, the fan supplying combustion air was stopped by disconnecting the fan motor from the electrical circuit. The consequences to the burner were then observed. If combustion continued, the equipment was operated for up to 48 hours.

This test was repeated firing B5 biodiesel blend.

During the coast down of the combustion air motor and prior to interruption of fuel flow, the amount of oil discharged from the nozzle and observations were made of flame shape, any dripping or pooling in the combustion chamber.

After the main flame was extinguished following interruption of the combustion air supply, reignition was observed upon restoration of the air supply.

RESULTS

The results of tests firing both No. 2 fuel oil and B5 biodiesel blend for each combination indicate fuel to the main burner flame was shut off immediately, clean nozzle cutoff occurred without drool or excessive spitting and, upon restoration of the air supply, the burner restarted automatically, completely and without backfire, flash or puff.

UNDERVOLTAGE TEST:

METHOD

The test was conducted in accordance with UL 296, Tenth Edition, Test No. 5, Section 53, issued September 11, 2003.

The burner was installed and adjusted for operation firing No. 2 fuel oil as described in Combustion Tests, except that the test voltage was reduced to 85% rated voltage of the burner. Each burner was fired until steady-state combustion conditions were observed. Observations were made to determine the performance of the burner.

This test was repeated firing B5 biodiesel blend.

The performance of the burner during this test was observed as follows:

A. Automatic ignition obtained each cycle within the intended period of time without backfire, flash, or puff.
B. Burner flames not to flash outside the heating appliance being fired.
C. Observed smoke at all firing rates not to exceed that indicated by a No. 1 spot firing a distillate fuel on the Shell-Bacharach scale.
D. Observed carbon dioxide, carbon monoxide, and oxygen concentrations.
E. Observed combustion characteristics, including flame shape and luminosity.

RESULTS

The smoke spot in the flue gases was not in excess of a No. 1 for all equipment and fuel combinations and all air settings, except for the following combinations/conditions.

Combination	Fuel	Condition	Bacharach Smoke
Furnace 2	B5	Trace Point	No. 1.38
Boiler 6	No. 2	Trace Point	No. 1.39
Boiler 6	B5	Trace Point	No. 1.85

The density of the smoke spot was identified as exceeding a No. 1. However, it was considered appropriate to record the data producing heavy smoke spots at the adjusted settings, as they represented a minimum air shutter setting for the application. Additional test data demonstrated that with minor adjustment to the air shutter, the smoke density was reduced to less than a No. 1 Bacharach Smoke by increasing the air shutter opening.

Performance of the burner was such that automatic ignition was obtained on each cycle within the intended time period without backfire, flash, or "puff," at all air settings, except that Water heater 1 was observed to ignite with a slight “puff” at the barometric damper at the minimum air shutter setting firing No. 2 oil and B5 biodiesel blend.

Stable combustion was maintained for all equipment and fuel combinations and all air settings without flashout of flames from the heating appliance being fired.

The luminosity of the flame and the flame characteristics could not be predicted from one fuel to the other, nor from one appliance to the other, except for the propensity of the flame to lift, curl and / or break towards the coldest section of the cast iron boiler. In certain combinations, the flame shape / color remained unchanged from one fuel to the other; while in other combinations, the flame would shorten, narrow and / or feather. In certain combinations with other than factory settings firing No. 2 oil and B5 biodiesel blend, the flame was observed to have traces of feathery, blue finger flames. Cad cell resistance was not deleteriously affected from one fuel to the other. The measured resistance was affected most by the shape of the flame, and how the flame cone carried within in the combustion chamber as it extended beyond the burner flame retention head.

Combination	FURNACE 1								
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Maximum Air Shutter Setting
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	B5
Fuel Input, gal/h	0.75	0.75	0.75	0.75	0.75	0.75	0.76	0.75	0.78
Products of Combustion									
Smoke - Bacharach No.	0	0	Trace	Trace	0	0	0.12	0.06	0.07
Smoke - Photovolt							98.8	99.4	99.3
CO_2 in Flue, %	9.4	9.4	10.3	10.3	7.24	7.3	9.11	8.66	6.83
CO in Flue, ppm	0	0					0	0	0
NO_x in Flue, ppm							80	80	57
Cad Cell Resistance - Ω							88	89	150
Voltage to Burner Motor	102	102	102	102	102	102	102	102	102
Burner Motor rpm	3411	3406	3411	3409	3400	3390	3420		
Draft Over Fire, in.WC	-0.01	-0.01	-0.01	-0.01	-0.01	+0.035	-0.015	-0.015	0.0
Draft in Flue, in.WC	-0.03	-0.03	-0.025	-0.025	-0.01	-0.01	-0.035	-0.04	-0.04
Observation Note									1

Note 1: Smooth ignition trials.

Combination	Furnace 2					
	Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.75	0.73	0.75	0.73	0.75	0.73
Products of Combustion						
Smoke - Bacharach No.	0.19	0.14	0.82	1.38	0.07	0.1
Smoke - Photovolt	98.1	98.6	91.8	86.2	99.3	99
O_2 in Flue, %	4.0	4.5	2.1	2.7	5.1	5.5
CO_2 in Flue, %	12.31	11.94	13.75	13.32	11.50	11.16
CO in Flue, ppm	0	0	1	0	0	0
SO_2 in Flue, ppm	62.5	60.9	70.9	67	52.7	54.9
NO_x in Flue, ppm	103.7	99.1	110	108.2	94.4	89.2
Cad Cell Resistance - Ω	5.4K	5.87k	4.67k	4.88k	6.39k	7.05k
Voltage to Burner Motor	102	102	102	102	102	102
Draft Over Fire, in.WC	+0.01	+0.03	+0.01	+0.01	+0.01	+0.03
Draft in Flue, in.WC	-0.03	-0.03	-0.03	-0.04	-0.03	-0.04
Observation Note	2	2	2A	2A	2B	2B

Note 2: Some lifting of the flame at the tip, solid color at factory setting.
Note 2A. Flame observed to be looser and have a wider shape.
Note 2B: Flame was very short and flat.

Combination	Water Heater 1						Boiler 1					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	1.26	1.24	1.26	1.22	1.26	1.24	1.55	1.50	1.55	1.49	1.55	1.55
Products of Combustion												
Smoke - Bacharach No.	0.07	0.1	0.35	0.09	0.08	0.33	0.21	0.02	0.28	0.18	0.19	0.19
Smoke - Photovolt	99.3	99	96.5	99.1	99.2	96.7	97.9	99.8	97.2	98.2	98.1	98.1
O_2 in Flue, %	4.6	5.1	2.2	2.9	8.2	8.7	6.1	6.4	2.1	2.3	2.0	7.4
CO_2 in Flue, %	12.2	11.8	14.0	13.4	9.5	9.1	11.1	6.4	14.0	2.3	10.4	7.4
CO in Flue, ppm	8	4	1	6	2	2	4	10.8	7	13.9	6	10.1
NO_x in Flue, ppm	127	122	148	142	84	76	82	78	102	97	77	75
Cad Cell Resistance - Ω	220	253	146	159	314	369	624	343	422	363	396	360
Voltage to Burner Motor	102	102	102	102	102	102	102	102	102	102	102	102
Burner Motor rpm	3424	3404	3458	3445	3458	3445	3402	3399	3417	3399	3416	3385
Draft Over Fire, in.WC	0.00	0.00	-0.02	-0.02	-0.03	+0.025	+0.055	+0.07	+0.02	+0.02	+0.07	+0.07
Draft in Flue, in.WC	-0.04	-0.04	-0.035	-0.04	-0.04	-0.04	-0.045	-0.05	-0.04	-0.045	-0.045	-0.04
Observation Note					3	3	4	4C	4A	4D	4B	

Note 3: Slight barometric puff.
Note 4: Orange flame with slight right hand break at rear of flame.
Note 4A. Flame dark orange-yellow has with a hard right hand break.
Note 4B: Flame length narrower and shorter; flame trails to the right with an upwards break.
Note 4C: Flame has tendency to break to the right with very little lift.
Note 4D: Loose, dark orange flame with a hard right hand break with upwards lift.

Combination	Boiler 2						Boiler 3					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.80	0.78	0.80	0.78	0.80	0.78	0.94	0.95	0.94	0.94	0.94	0.95
Products of Combustion												
Smoke - Bacharach No.	0.73	0.65	0.83	0.7	0.65	0.7	0.07	0.04	0.41	0.09	0.16	0.11
Smoke - Photovolt	92.7	93.5	91.7	93	93.5	93	99.3	99.6	95.9	99.1	98.4	98.9
O_2 in Flue, %	3.8	4.7	3.5	4.2	5.0	5.7						
CO_2 in Flue, %	12.46	11.95	12.71	12.2	11.55	11.11	11.94	11.3	13.82	13.73	9.06	9.11
CO in Flue, ppm	12	15	14	15	14	16	0	0	16	7	0	0
SO_2 in Flue, ppm	63.4	58.3	63.4	59.4	56.7	53.1						
NO_x in Flue, ppm	93	86.4	94.8	87.9	83.6	77.2	121	110	164	165	62	57
Cad Cell Resistance - Ω	9.9k	9.8k	9.7k	9.68k	10.35k	10.67k	628	693	585	606	980	1201
Voltage to Burner Motor	102	102	102	102	102	102	102	102	102	102	102	102
Burner Motor rpm							3448			3457		
Draft Over Fire, in.WC	0.0	0.0	0.0	0.0	+0.01	+0.01	-0.01	-0.01	-0.01	-0.01	-0.025	+0.025
Draft in Flue, in.WC	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.025	-0.02	-0.02	-0.025	0.0
Observation Note	5	5C	5A		5B	5D		6B	6	6C	6A	

Note 5: Yellow-orange flame with slight lift at upper right corner of flame.
Note 5A: Flame not as bright, and break to right not as distinct. Some lifting of flame upwards towards right rear.
Note 5B: Shorter flame; a few feathers lift at upper right corner; flame cone is smaller.
Note 5C: Flame appears to be slightly narrower that No. 2 oil flame with slight lift at top right corner of flame.
Note 5D: Flame narrower and shorter than No. 2 oil flame.
Note 6: Fuller flame cone with slight lifting at end.
Note 6A: Flame extremely short.
Note 6B: Flame feathers have blue tinge at top of flame.
Note 6C: Flame narrows with slight curling (lifting) at 2:00 position.

Combination	Boiler 3						Boiler 3	
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.94	0.94	0.94	0.94	0.94	0.94	0.93	0.94
Products of Combustion								
Smoke - Bacharach No.	0	0	Trace	Trace	0	0	0.05	0.08
Smoke, Photovolts							99.5	99.2
CO_2 in Flue, %	11.5	11.4	14.75	14.8	0	0	11.8	11.3
CO in Flue, ppm	0	0	70	38	0	0	0	0
NO_x in Flue, ppm							117	116
Cad Cell Resistance - Ω							622	664
Voltage to Burner Motor	102	102	102	102	102	102	102	102
Burner Motor rpm	3452	3450	3461	3463	3444	3444		
Draft Over Fire, in.WC	-0.01	-0.01	-0.01	-0.01	+0.01	+0.01	-0.03	-0.01
Draft in Flue, in.WC	-0.03	-0.025	-0.02	-0.02	-0.025	-0.025	-0.0125	-0.025

Stable combustion was observed at all settings. The data was observed with the nozzle line heater energized.

Combination	Boiler 4						Boiler 5			
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	1.25	1.24	1.25	1.24	1.25	1.24	0.91	0.92	0.91	0.92
Products of Combustion										
Smoke - Bacharach No.	0.42	0.12	0.99	0.52	0.39	0.24	0.1	0.12	0.45	0.66
Smoke - Photovolt	95.8	98.8	90.1	94.8	96.1	97.6	99	98.8	95.5	93.4
O_2 in Flue, %	3.3	3.6	2.7	2.9	6.1	6.8				
CO_2 in Flue, %	12.82	12.57	13.3	13.06	10.71	10.69	10.51	10.43	13.54	13.10
CO in Flue, ppm	3	3	15	10	0	0	1	0	11	5
SO_2 in Flue, ppm	66.5	61.4	69.6	63.9		49.4				
NO_x in Flue, ppm	98	95	97.8	96.4	78.3	79.7		76		88
Cad Cell Resistance - Ω	6.7k	6.9k	6.3k	6.5k	11.1k	11.4k	812	867	739	758
Voltage to Burner Motor	102	102	102	102	102	102	101.2	102	102	102
Burner Motor rpm							3393	3406		
Draft Over Fire, in.WC	-0.04	-0.03	-0.04	-0.03	-0.03	-0.03	-0.01	-0.015	-0.04	-0.03
Draft in Flue, in.WC	-0.03	-0.04	-0.03	-0.03	-0.04	-0.03	-0.04	-0.045	-0.05	-0.06
Observation Note	7		7		7A			8A	8	8B

Note 7: No trailing flame; tinge of darkness at rear of flame.
Note 7A: No darkness; flame shape, size, and color is intense.
Note 8: Flames are harder with more length than No. 2 oil flame. They appear to be slightly longer with curl up at the end towards the target wall.
Note 8A: Flame strength and shape similar to No. 2 oil flame with a slightly darker yellow color.
Note 8B: Flame color is lighter yellow than that observed at rated voltage. Flame does not appear to be as hard. Slight lifting at right hand side but overall flame shape not affected deleteriously.

Test not observed at minimum air shutter setting on Boiler No. 5.

Combination	Boiler 5					
	Factory Setting		Trace Point		Maximum Air Shutter Setting	
	Mfr. Data					
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.93	0.93	0.93	0.93	0.93	0.93
Products of Combustion						
Smoke - Bacharach No.	0	0	Trace	Trace	0	0
CO_2 in Flue, %	11.06	10.81	12.86	12.95	8.7	8.6
Voltage to Burner Motor	102	102	102	102	102	102
Burner Motor rpm	3396	3397	3405	3400	3391	3408
Draft Over Fire, in.WC	-0.0-	-0.01	-0.01	-0.01	0.0	0.0
Draft in Flue, in.WC	-0.025	-0.025	-0.02	-0.02	-0.025	-0.025

Stable combustion was observed at all settings.

Combination	Boiler 6						Boiler 7					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	1.19	1.20	1.2	1.20	1.2	1.24	0.50	0.50	0.50	0.50	0.50	0.50
Products of Combustion												
Smoke - Bacharach No.	0.25	0.14	**1.39**	**1.85**	0	0.32	0.39	0.3	0.78	0.74	0.71	0.73
Smoke - Photovolt	97.5	98.6	86.1	81.5	100	96.8	96.1	97	92.2	92.6	92.9	92.7
O_2 in Flue, %	5.4	4.9	4.0	3.6	11.0	10.2	3.1	4.2	1.9	2.6	6.6	7.0
CO_2 in Flue, %	11.6	12.0	12.6	12.9	7.4	8.0	12.96	12.25	13.84	13.46	10.21	10.09
CO in Flue, ppm	7	6	9	11	20	9	5	4	5	2	16	21
SO_2 in Flue, ppm							64.2	60.3	69.5	65.7	50.6	49.4
NO_x in Flue, ppm	115	118	117	117	59	72	108.6	100.9	119.5	112	79.7	76.9
Cad Cell Resistance - Ω	216	214	215	224	0.5k	417	4.6k	4.56k	4.67k	4.51k	4.67k	4.77k
Voltage to Burner Motor	102	102	102	102	102	102	102	102	102	102	102	102
Burner Motor rpm	3436	3423	3436		3414	3414						
Draft Over Fire, in.WC	-0.02	-0-015	-0.03	-0.03	+0.01	+0.005	0.0	+0.03	-0.01	+0.03	+0.01	+0.03
Draft in Flue, in.WC	-0.035	-0.04	-0.035	-0.04	-0.045	-0.04	+0.03	+0.01	+0.03	0.0	+0.03	+0.01
Observation Note	9	9C	9A	9D	9B	9E		10		10		10

Note 9: Somewhat narrow, slightly darker orange flame.
Note 9A: Flame width is more defined with some feathering at extreme edges of flame. Some left hand trailing flames with lift to the upper right.
Note 9B: Flame narrows and flattens with blue tinges on feathers.
Note 9C: Flame is fuller with a longer feather towards the top of the heat exchanger than that firing No. 2 oil. Flame pushes to left and rear of flame appears to be closer to the rear of the combustion chamber.
Note 9D: Flame is looser and fuller. Similar lift as seen at the factory setting, but a shorter flame.
Note 9E: Flame is short, body of flame not as full with several feathers of flame around the periphery. Relight attempts resulted in smoke puff visible at the observation port. Audible thump was observed at the barometric damper. No flame flashout or damage to the burner or boiler.
Note 10: Smooth ignition; no noise.

Combination	Boiler 8						Boiler 9					
	Factory Setting		Trace Point		Maximum Air Shutter Setting		Factory Setting		Trace Point		Maximum Air Shutter Setting	
Type of Fuel	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5	No. 2	B5
Fuel Input, gal/h	0.95	0.95	0.95	0.95	0.95	0.95	0.90	0.90	0.90	0.90	0.90	0.90
Products of Combustion												
Smoke - Bacharach No.	0	0	Trace	Trace	0	0	0	0	Trace	Trace	0	0
CO_2 in Flue, %	11.5	11.5	14.45	14.4	9.1	9.1	10.55	10.7	12.1	12.2	7.6	7.7
CO in Flue, ppm	2	2	29	34	2	3	0	0	0	0	8	9
Voltage to Burner Motor	102	102	102	102	102	102	102	102	102	102	102	102
	3468	3464	3460	3468	3461	3455	3410	3409	3410	3408	3397	3391
Draft Over Fire, in.WC	-0.01	-0.01	-0.01	-0.01	0.0	0.0	-0.01	-0.01	-0.01	-0.02	+0.025	+0.02
Draft in Flue, in.WC	-0.03	-0.03	-0.02	-0.02	-0.03	-0.03	-0.025	-0.025	-0.02	-0.02	-0.015	-0.02
Observation Note	11						12					

Note 11: Stable combustion observed at all settings.
Note 12: Stable combustion observed at all settings.

POWER INTERRUPTION TEST:

METHOD

The test was conducted in accordance with UL 296, Tenth Edition, Test No. 6, issued September 11, 2003.

The burner was installed and adjusted for operation firing No. 2 fuel oil as described in Combustion Test. While the burner was being fired at any firing rate, the power supply was interrupted. The consequences to the burner were then observed. If combustion continued, the equipment was operated for up to 48 hours.

Power was restored after being interrupted for any period of time. The burner was to require manual restart, or an automatically-lighted burner was to restart automatically provided reignition was obtained.

This test was repeated firing B5 biodiesel blend.

RESULTS

The results of tests firing both No. 2 fuel oil and B5 biodiesel blend for each combination indicate conformance with applicable requirements since fuel to the main burner flame was shut off immediately following interruption of the power supply and, upon restoration of the power supply, the burner restarted automatically.

TEMPERATURE TEST:

METHOD

The test was conducted in accordance with UL 296, Tenth Edition, Test No. 7, issued September 11, 2003.

With the burner installed and adjusted for operation firing No. 2 fuel oil as described in Combustion Test, the burner was allowed to operate at the maximum fuel input until equilibrium temperatures were attained on the burner firing head assembly.

Upon attaining equilibrium, firing of the burner was terminated and maximum temperatures were observed with the burner off. Room temperature was measured by a shielded thermocouple located directly opposite and 18 in. in front of the burner centerline.

This test was repeated firing B5 biodiesel blend.

RESULTS

The results of tests firing both No. 2 fuel oil and B5 biodiesel blend for each combination indicate the maximum temperature rises observed did not exceed the temperature limits of the materials and components used. Immediately upon terminating firing of the burner, temperatures on or about the firing head were observed to decrease without overshoot. Temperatures recorded firing B5 biodiesel blend were lower than those of No. 2 fuel oil in every case but one. (Firing head for Boiler 5).

Combination	Furnace 1	Furnace 2	Water Heater 1	Boiler 1	Boiler 2	Boiler 3
Thermocouple Location	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF
No. 2 fuel oil						
Firing Head						
12:00 position	704	935	Test Waived			357
3:00 position	851	862				
6:00 position	937	948				
9:00 position	787	1005				
B5 biodiesel blend						
Firing Head						
12:00 position	671			683.4		343
3:00 position	834			631.4		
6:00 position	910			486		
9:00 position	760			620		

Combination	Boiler 4	Boiler 5	Boiler 6	Boiler 7	Boiler 8	Boiler 9
Thermocouple Location	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF	Maximum Rise ºF
No. 2 fuel oil						
Firing Head						
12:00 position	594	240	812.2		352	676
3:00 position	759.2		676.2			562
6:00 position	999.2		1096.6			618
9:00 position	848.4		655.8			420
Shroud		800				
B5 biodiesel blend						
Firing Head						
12:00 position	585.8	359	819.4		338	670
3:00 position	743.8		741.8			358
6:00 position	990.4		1109.8			604
9:00 position	846.6		637.4			410
Shroud		791				

IGNITION TEST, ELECTRIC HIGH-TENSION REDUCED VOLTAGE - COLD OIL:

METHOD

The test was conducted in accordance with UL 296, Tenth Edition, Test No. 8, issued September 11, 2003.

The burner was installed and adjusted for operation firing No. 2 fuel oil as described in Combustion Test. With 85 percent of normal test voltage applied to the primary safety control and 70 percent of normal test voltage to the ignition transformer, five trials for ignition of main flame were initiated. For this test, the spark gap was adjusted to the maximum recommended by the manufacturer, but not less than 1/8 in.

The temperature of the oil as supplied to any parts of the burner was 35 ± 5ºF.

Following the last trial-for-ignition, the burner was allowed to operate at the maximum rated fuel input for an additional 15 min.

This test was repeated firing B5 biodiesel blend.

RESULTS

Each burner and ignition circuit was energized and allowed to remain energized for the designed trial-for-ignition period. Voltage to the burner motor and primary safety control was 102 V except Furnace 1 and Boilers 2, 4 and 7, where voltage to burner motor and primary safety control was adjusted to 84 V. Reduced voltage to the primary safety control was 102 V except Furnace 1 and Boilers 2, 4 and 7, where voltage to the primary safety control was adjusted to 84 V. Reduced voltage to the ignition transformer for all appliance combinations was 84V. The spark gap was 0.125 in. to 0.158 in. depending on burner provided.

Results of tests firing both No. 2 fuel oil and B5 biodiesel blend indicate ignition of the main burner flame was established without flames being expelled from the burner or heating appliance being fired for test. Additionally, stable combustion was continued for 15 min following the last trial-for-ignition.

Boiler 1was observed to ignite cold oil with a slight puff without flash out firing No. 2 oil and an audible puff at the barometric firing B5 biodiesel blend.

Boiler 2 was observed to ignite cold oil smoothly firing No. 2 oil with an occasional slight puff in the barometric damper firing B5 biodiesel blend.

Boiler 5 was observed to ignite cold oil with an occasional smoke puff out the barometric damper. There was no flash out of flame and no damage to the burner or boiler.

Boiler 6 was observed to ignite cold oil with a visibly quick opening of the barometric damper and audible puff firing No. 2 oil. No movement of the draft damper was observed firing B5 biodiesel blend.

GASKET / SEAL TESTING:

TENSILE STRENGTH, ELONGATION, AND VOLUME CHANGE TESTS:

METHOD

The Tensile Strength and Elongation and Volume Change Tests before and after immersion were conducted in accordance with the Standard for Gaskets and Seals, UL 157, Sections 5 and 11 on two nitrile and two fluorocarbon compounds described elsewhere in this report.

RESULTS

Results of the tests indicate compliance with the test requirement of UL 157 since the tensile strength and elongation retained more than 60% of the unconditioned value and the volume change was within the required minus 1 to plus 25 percent.

As Received Tensile Strength and Elongation	Compound Nitrile 1	Compound Nitrile 2	Compound Viton 1	Compound Viton 2
Average tensile strength, psi	2901	1667	1849	2029
Average elongation, percent	265	198	171	196
After 70 hr. immersion in UL B5 biodiesel blend at 23°C				
Average tensile strength, psi	3090	1661	2049	2096
Percent of original	106	99	110	103
Average elongation, percent	286	193	175	206
Percent of original	108	97	102	105
Volume Change After 70 hr. immersion in UL B5 biodiesel blend at 23°C				
Average volume change, percent	0.9	-1.0	0.3	0.6

Lab Conditions	22.9 °C	48 % RH

COMBUSTION CHAMBER LINER MATERIAL TESTING:

OIL SATURATION TEST:

METHOD

The sample tested was a preformed vacuum chamber liner (Sid Harvey Model: SH633-70). A new combustion chamber liner was used during each test specified below.

The combustion chamber liner was installed in an open drum. The drum was sized to fit a Carlin Model: EZ-1 0.75 gph oil burner and properly vented to the outdoors.

The material was saturated with No. 2 fuel oil utilizing the oil burner operation with the ignition system deenergized. The material was considered saturated when the material was thoroughly soaked with fuel to the point just before fuel began to pool in the bottom of the drum. Upon saturation of the material, the burner ignition means was reenergized and the burner allowed to fire into the open drum for a period of one minute and then shut down for one minute. Five firing trials were conducted.

The combustion chamber liner material was examined for any noticeable effect from the conduct of the test.

The test was repeated utilizing B5 biodiesel blend. See Figures 25 through 31 for details.

FIGURE 25
Test Arrangement prior to the start of the Saturation Test

FIGURE 26
Observation During First Trial of Operation Following Saturation with No. 2 fuel oil

FIGURE 27
Observation During Fifth Trial of Operation Following Saturation with No. 2 fuel oil

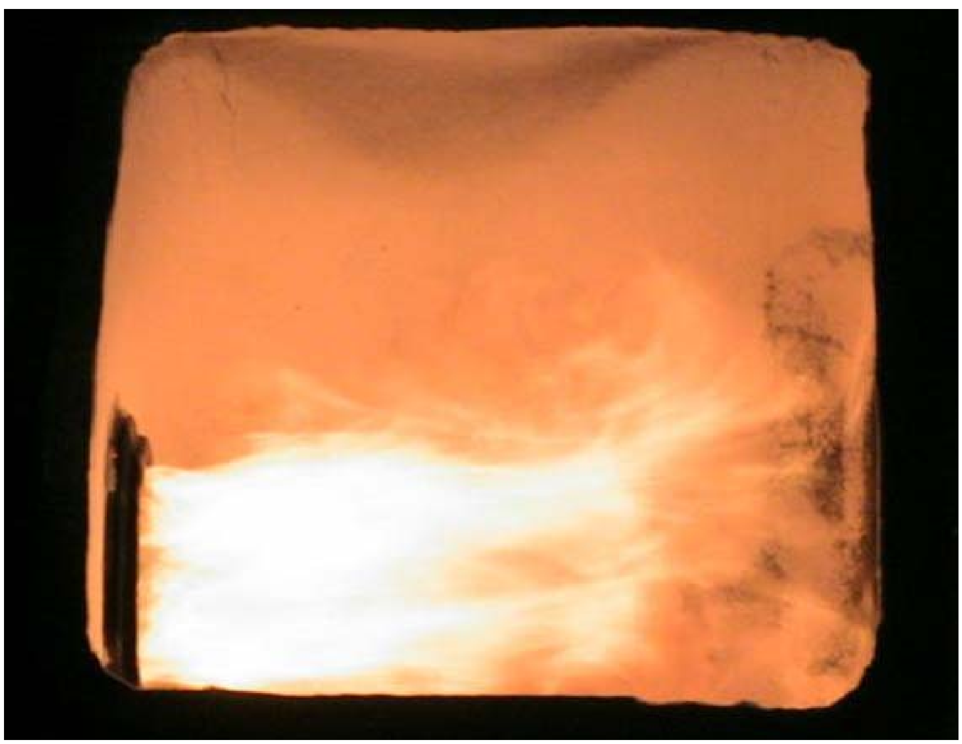


FIGURE 28
Post Test Observation after Conclusion of Fifth Trial of Operation with No. 2 fuel oil

FIGURE 29
Observation During First Trial of Operation Following Saturation with B5 biodiesel blend

FIGURE 30
Observation During Fifth Trial of Operation Following Saturation with B5 biodiesel blend

FIGURE 31
Post Test Observation after Conclusion of Fifth Trial of Operation with B5 biodiesel blend

RESULTS

The flame expanded outside of the combustion chamber after the first trial of operation with both the No. 2 fuel oil and B5 biodiesel blend. This condition was determined to be a result of the saturation of the chamber as described in the Method. By the fifth trial of operation, the flame was contained within the combustion chamber when fired with both No. 2 fuel oil and B5 biodiesel blend, the excess fuel being combusted. No liner degradation was observed for either fuel.

FLAME IMPINGEMENT TEST:

METHOD

The combustion chamber liner material was installed in an open drum. The open drum was sized for the oil burner and properly vented to the outdoors. The liner and burner combination were the same as for the Liner Oil Saturation Test.

The burner was operated with No. 2 fuel oil. The burner flame was directed to allow abnormally close flame impingement of the combustion chamber liner for one hour. Impingement was defined as a majority of the flame cone being in contact with the liner material.

After an hour of operation of abnormally close flame impingement, the burner was redirected to allow normal operation within the combustion chamber for one hour.

The combustion chamber liner material was examined for any noticeable effect from the conduct of the test.

The test was repeated utilizing B5 biodiesel blend. See Figures 32 through 39 for details.

FIGURE 32
Observation During Abnormally Close Flame Impingement Operation with No. 2 fuel oil

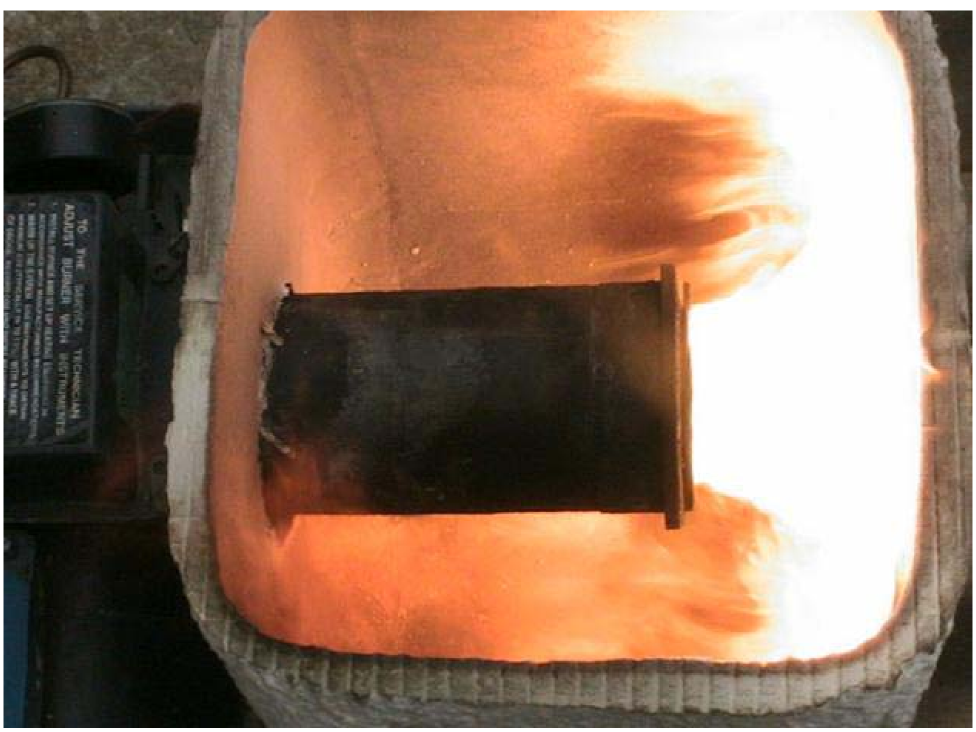


FIGURE 33
Observation Following One Hour Duration of Impingement with No. 2 fuel oil

FIGURE 34
Observation of During Normal Operation Following One Hour Duration of Impingement with No. 2 fuel oil

FIGURE 35
Observation Following Normal Operation at the Conclusion of Impingement Test with No. 2 fuel oil

FIGURE 36
Observation During Abnormally Close Flame Impingement Operation with B5 biodiesel blend

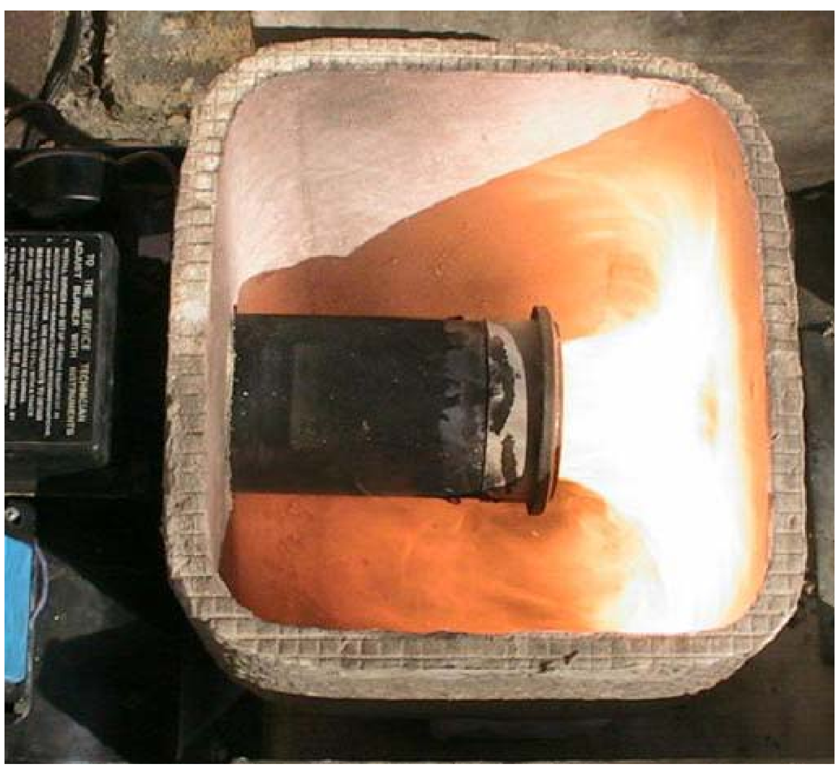


FIGURE 37
Observation Following One Hour Duration of Impingement with B5 biodiesel blend

FIGURE 38
Observation of During Normal Operation Following One Hour Duration of Impingement with B5 biodiesel blend

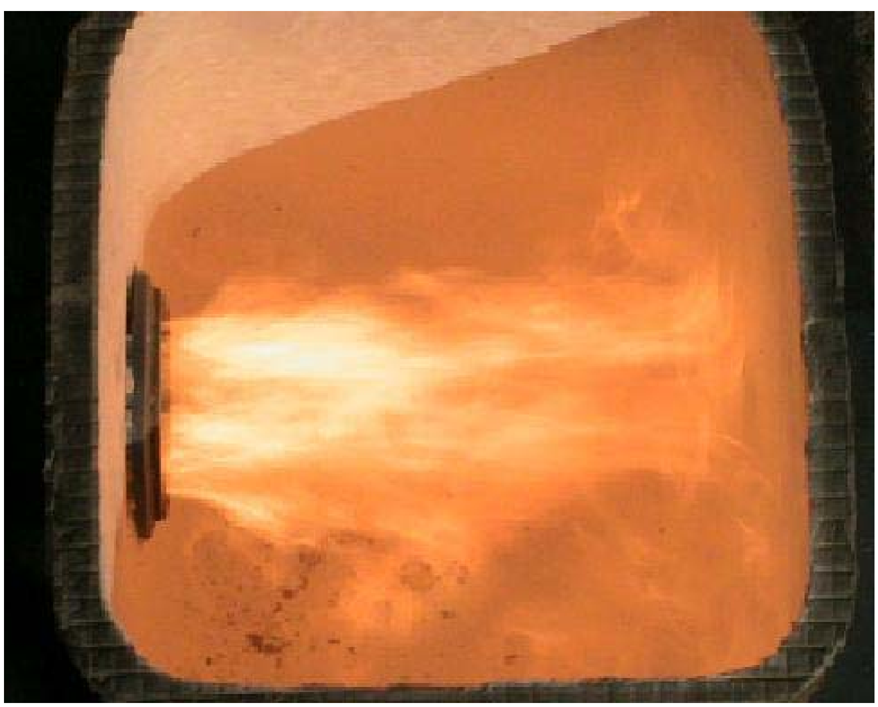


FIGURE 39
Observation Following Normal Operation at the Conclusion of Impingement Test with B5 biodiesel blend

RESULTS

There was no observed degradation of the combustion chamber liner material after testing.

ATTACHMENT

BACKGROUND: BIODIESEL AND OTHER BIOFUELS[1]

Biofuels are renewable fuel sources that are increasingly being considered as blending components or replacement for traditional petroleum fuels, primarily for use in internal combustion engines and heating appliances. Environmental, economic and geopolitical factors have created a market for the biofuels methanol, ethanol, butanol and biodiesel. They are being initially introduced as low blend percentages for use in engines and appliances designed for traditional fuels. As an expanding market, biofuel usage is expected to significantly increase as production capacity is brought on line and additional market incentives are made available.

This Fact Finding Investigation is focused on "B5 biodiesel blends[2]". For reasons outlined elsewhere in this report, the 5 percent biodiesel blend is being compared to No. 2 fuel oil when used in residential oil heating appliances to identify performance and/or compatibility issues.

"Biodiesel" and "biofuels" are terms that are loosely used in the popular media. Therefore, the first step in this investigation was to define and describe what bioheat was, and what the appropriate components for blending were. The base petroleum fuel (No. 2 fuel oil) had been previously defined, and has been used for many years. However, the blend stock is specified on a performance-related property basis that is not prescriptive of the base stock. As with any other naturally occurring or naturally originated material, there is a range of properties to consider for the biodiesel blend stock. For the purposes of this investigation, it was therefore necessary to consider the fuel feedstock, processing variations and differences in chemical composition that could impact results.

For biodiesel blends, UL is assessing potential safety aspects, developing test procedures, and establishing guidelines. As part of this effort UL seeks to understand relevant property and performance differences with conventional fuels. This background section provides a summary of this UL effort and describes the resulting fuel composition set for use in test procedures.

Biodiesel Chemistry

"Biodiesel" is defined in ASTM D6751 as "a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100" and is otherwise generally known as fatty acid methyl esters (FAME). In simple chemical terms, biodiesel is a long chain fatty acid ester composed of a short chain alcohol (i.e., methanol) and a long chain fatty acid. Fats and vegetable oils are esters of long-chain fatty acids and glycerol (a molecule containing three functional alcohol groups). Fatty acids may be either saturated or unsaturated; that is, the long hydrocarbon chains that possess single (saturated) and/or double (unsaturated) covalent bonds. The term "saturation" refers to the ratio of carbon to hydrogen and the term "unsaturation" indicates that the carbon atoms do not have the maximum possible amount of hydrogen present. These functional differences relate to fuel feedstock and affect fuel processing and are important when selecting representative test fuels. They also dictate physical and chemical properties of the fuels and may affect chemical stability and performance over time.

[1] *The information is this section was drawn mainly from publicly available sources. In addition to those specifically cited in the narrative, the following documents served as principle sources; Biodiesel Handling and Use Guidelines – US Department of Energy & National Renewable Energy Lab, SAE J1681 Recommended Practice for Gasoline, Alcohol and Diesel Fuel Surrogates for Materials Tests, and ASTM D6496-04 Standard Guide for Microbial Contamination in Fuels and Fuel Systems, Organic Chemistry, J. B. Hendricks, D. J. Cram and G. S. Hammond, Petroleum Geology and Geochemistry, J. M. Hunt.*

[2] *When referred to in this Report, "B5 biodiesel blend" is comprised of five percent by volume ASTM D6751 (Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels) and ninety five percent ASTM D396 (Standard Specification for Fuel Oils) No. 2 fuel oil. Note: for the purposes of this Report, "B5 biodiesel blend" and "UL B5 biodiesel blend" are two distinct fuels.*

Biodiesel feedstocks are derived from three general organic sources: 1) vegetable oils (soy, corn, canola, rapeseed, sunflower, cottonseed, etc.) and tropical oils (palm, coconut, olive, etc.), 2) animal fats (yellow grease, white grease, beef tallow, chicken fat, fish oils, etc.) and 3) recycled fats & oils (any combination of the above from commercial restaurants and processing plants).

These fats and oils are commonly known as triglycerides; that is, chemical compounds with a three carbon-glycerin backbone to which individual fatty acids are covalently attached by ester linkages. Each bio-based feedstock is also composed of a mixture of different fatty acid carbon chain lengths that range from 12-22 carbons for the ten most common types but, of these, 90% have 16-18 carbons.

Biodiesel is produced through a reactive chemical process called transesterification. This process consists of reacting bio (oil or fat) feedstocks with short chain alcohols (typically methanol) and a catalyst (typically sodium or potassium hydroxide. In essence, the triglyceride ester is broken into glycerol and three alkyl esters by substituting three mono-functional alcohol molecules for the tri-functional glycerol. The biodiesel is refined by washing and filtration to remove excess unreacted alcohol, catalyst, and glycerol. A specification, ASTM D6751, exists for the purity and quality of the biodiesel product. As with petroleum-based fuels, biomass-based fuels have many sources and process variations. Biofuels are therefore typically batch manufactured to compensate for chemical variation and ensure consistent quality end fuel.

Fuel Composition

The introduction of biodiesel into the supply chain (production, distribution and consumption) can impact a number of factors such as fire, combustion, material compatibility and contamination. This impact can be assessed by comparing the physical and chemical (molecular) properties of petroleum and biomass fuels.

A basic comparison of the properties of No. 2 fuel oil and B100 biodiesel are provided below in Table 1

As a result of the higher flash point, B100 biodiesel is considered less of a fire risk than No. 2 fuel oil, but potentially could have low temperature operational issues due to the solidifying point of saturated fatty acids, process by-products or other organic contaminants. B100 biodiesel has some additional unique chemical differences arising from the ester functionality: a) higher electrical conductivity (4-5X), b) increased moisture sensitivity (approx 10X), c) increased polarity and solvency (due to the ester dipole moment), d) chemical reactivity (hydrolysis of the ester and reactivity of functional groups that may be present) and e) microbial sensitivity (metabolism of the ester fatty acids). Although B100 biodiesel is a minor component in the blended (B5 biodiesel blend) fuel makeup, understanding and evaluating how they would impact the performance of oil heating equipment is critical, even at low blends. Regarding the solvency question, according to Brookhaven National Laboratories a recent study has shown B100 does not have a measurable solvent behavior toward sludge deposits commonly found at the bottom of home heating storage tanks. The solubility limit of water in B100 biodiesel is 1000-1800 ppm as compared with petroleum fuel, which is 50-150 ppm. Both of these levels are considered very low. Temperature swings and contamination with physical and biological agents play a significant role in the process of acquiring and separating water from the fuel, which is also the case with petroleum fuels

Table 1[3]
Comparison of Typical Fuel Properties, No. 2 Heating Oil and Biodiesel

Property	No. 2 Heating Oil	Biodiesel (B100)
Standard	ASTM D396	ASTM D6751
Higher Heating Value (Btu/gal)	139,200	125,000
Kinematic viscosity (@ 40 F)	2.7	4.0 – 6.0
Specific gravity (kg/liter @ 60 F)	0.86	0.88
Density (lb/gal)	7.1	7.25
Water and Sediment (vol %)	0.001	0.05
Carbon (wt %)	86.6	77.0
Hydrogen (wt %)	13.6	12.0
Oxygen (wt %)	0.1	11.0
Sulfur (wt %)	0.1	0.0 – 0.0024
Flash Point (F)	120 – 210	210 - 350
Cloud Point (F)	-13 – 14	26 – 54
Pour Point (F)	-22 – 5	5 – 50

[3] *Table 1 was generated from the following sources:*
Baukal, C. E., and Schwartz, R.,. The John Zink Combustion Handbook CRC Press, 2001.
Stultz, S.C. and Kitto, J.B., Steam, Its Generation and Use, Babcock and Wilcox, 1992.
C-E Fuel Burning and Steam Generating Handbook, Combustion Engineering, Inc., 1973.
ASHRAE Handbook of Fundamentals, 2005
American Society of Heating, Refrigeration, and Air Conditioning Engineers, 2005.
Northrop Grumman, TRW, and NIPER, Heating Oils, 1998 through Heating Oils, 2006.
BDM Petroleum Technologies, TRW Petroleum Technologies, Northrop Grumman, 1998 through 2006.

Contamination

All fuels are susceptible to contamination at various points along the supply chain from the production (unrecovered processing residuals), transport (unclean pipes and vessels), storage (tank openings) and fuel aging and degradation. These contamination points primarily introduce water, “color-bodies” (short length polymers of the fuel molecules), salts, organic and inorganic acids and microbes into the fuels that may cause them to shift out of specification and negatively affect material compatibility and system performance. It is realized that these contaminants cannot be completely controlled, especially in residential heating systems that potentially are not inspected or maintained by homeowners.

Water contaminants are not uncommon in residential oil tanks from supply chain contamination or atmospheric condensation as the fuel level in the tank is lowered and displaced with outside air. Biodiesel is somewhat hygroscopic which may contribute to water contamination and possible water separation if the total water exceeds a level of 0.1%, which is only slightly higher than petroleum fuels. Salts may be introduced from salt air aerosols. Acids may come from residual process compounds during refining, ester hydrolysis, or microbial growth byproducts. ASTM fuel specifications for water limits do not address the postproduction environment, however they are of concern to the operation of heating oil equipment.

Microbes enter fuel from various terrestrial or atmospheric sources and may colonize water/fuel interfaces. Biodiesel may be more susceptible to microbial growth (fatty ester metabolism) as it is more hygroscopic and less toxic. Ester hydrolysis leads to the formation of free acids and alcohols, which accounts for the increased moisture sensitivity over time. The microbes may metabolize the hydrocarbon chains in water that migrates to the storage tank bottom, in thin films in phase separation or even top surface condensation. Residential heating fuels may have even higher potential for contamination from microbial flora in the tank due to the warmer, undisturbed breeding environment in the non-heating-season

Fuel decomposition is a natural consequence of microbial activity, hydrolysis, oxidation, heating or other chemical processes and can often be seen in the production of color bodies that darken the fuel. Biodiesel decomposition increases acidity (souring). It is currently unknown if the recent addition of a fuel stability minimum to the ASTM D6751 specification will mitigate this. However, it is likely that heating oil blends because of long storage times may be susceptible to fuel decomposition, and thus a B5 biodiesel blend may have an impact on appropriate storage life, but again, residential heating fuels are at increased risk due to long dormant off season periods.

General Material Compatibility

Significant research has been done on biodiesel compatibility with products and materials relative to diesel engines. This may or may not be entirely transferable to parts of residential heating equipment in direct contact with fuels. However, broad compatibility conclusions from diesel engine applications are instructive for basic engineering materials in common with heating equipment.

B100 biodiesel does not exhibit long-term compatibility with: a) certain soft metals (copper, brass, bronze, lead, tin and zinc), b) polymers (polyethylene, polypropylene), and c) elastomers (among them, buna-n, nitrile and non-oil resistant rubbers). Conversely, harder metals (steel), many, but not all fiber reinforced plastics (FRP’s), nylons, fluoropolymers and fluoroelastomers generally exhibit greater chemical resistance[4]. Assurance of material compatibility with biodiesel blends should be verified on a case-by-case basis to ensure long-term performance. The individual components and combination(s) of components in residential heating systems add complexity, especially where they differ from the diesel engine systems studied.

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[4] *Many automotive research projects have been undertaken to determine the effects of biodiesel on the physical properties of polymeric materials in fuel conveying systems, such as gaskets, seals, o-rings, etc. One study looked at the particular effects introducing soy-based biodiesel blends (20-100%,) into systems designed for petroleum fuel (diesel, fuel oils) can have on metals and elastomers. For details, reference should be made to Compatibility of Elastomers and Metals in Biodiesel Fuel Blends, Gary B. Bessee, Joseph P. Fey, Southwest Research Institute, 1997. ©Society of Automotive Engineers, Inc.*

Long-term material compatibility with fuels is typically concerned with retention of physical properties and resistance to material migration that may result in contamination of the fuel. Metallic corrosion and nonmetallic degradation are accelerated by fuel contamination or ‘out of specification’ fuel (described previously). Again, dormant residential heating systems may present increased risk.

For metals, there are a number of different corrosion mechanisms that can occur, however there are at least two that are significant to biodiesel: galvanic and pitting corrosion. Galvanic corrosion is driven by the electrochemical potential of dissimilar metals in the presence of conducting fluids. The hygroscopic susceptibility of biodiesel (moisture uptake), ester polarity and the presence of soluble ionic contaminants increase the conductivity of the fuel. The higher concentration of trace minerals, salts and acids, individually or in combination, will accelerate corrosion by attacking protective oxide films and / or increasing conductivity that promotes galvanic action more easily than fuel oil. Pitting corrosion occurs when there is localized damage to the protective oxide film that is exacerbated by ionic or conductive fluids in contact with the metal surfaces.

For non-metals (thermosets, thermoplastics and elastomers), the ester-based biofuels may initiate change by solvating and penetrating (i.e., swelling) the material followed by possible extraction (especially low molecular weight plasticizers and/or stabilizers and additives). The polarity of biodiesel increases its solvency and facilitates permeation and extraction. Solvation, swelling and/or extraction leads to changes in key physical properties of materials such as modulus, tensile strength, elongation, flexibility, impact and dimensional change. These changes, in turn, could lead to further permeation. Extraction alters the fuel chemistry and could increase degradation potential for other parts further along the fuel train. The chemical changes noted above could also accelerate degradation (hydrolysis, oxidation) of the material with the loss of additives and stabilizers.

Metallic corrosion and polymer degradation could potentially result in altered performance of equipment and could result in suspended solids in the system. The extent of the degradation, and the size of the particulates could affect the performance of filters and nozzles.

The physical and/or chemical changes noted above for metals and nonmetals could lead to malfunction, leakage or even failure of individual components in the system.

Representative Test Fuels

The compositional differences between biofuels may significantly affect material compatibility and equipment performance. For this investigation, the test fuels, along with key hydrocarbon components were selected to simulate “worst case” fuel conditions. That is, the properties exhibited by this representative test fuel composition could be achieved under certain realistic conditions in the field. This was the rationale for recent development and use of “aggressive” fuels by various SAE and UL technical committees that focus on evaluation of fuel containing or consuming products. The “UL B5[5] biodiesel blend” test fuel described in this Fact Finding Investigation was blended from UL B100 biodiesel stock, developed as described below.

This synthetic test fuel is considered more aggressive than B5 blend biodiesel because of the increased acidity and moisture content of the UL B100 biodiesel stock. Therefore, “UL B5 biodiesel blend” was utilized for selected material capability and endurance testing. For combustion and other testing, the standard B5 biodiesel blend, as defined by this Report, was considered sufficient.

Major fuel components include alkanes (aliphatics or paraffins), aromatics (naphthenes or naphthenearomatics), oxygenates (any molecule containing covalent oxygen) and additives (detergents, stabilizers, colorants, etc.). With respect to domestic heating systems fuels, petroleum hydrocarbons are divided between the alkane and aromatic fractions, and biodiesel represents the oxygenates (esters). Additives have typically not been included in test fuels, as they are in trace amounts and industry has not agreed on representative generic chemical additives.

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[5] *When referred to in this Report, “UL B5 biodiesel blend” is comprised of five percent by volume UL B100 and ninety five percent ASTM D396 (Standard Specification for Fuel Oils) No. 2 fuel oil.*

Major fuel contaminants include water arising from hygroscopic biofuels and external contamination), salts (typically sodium chloride), organic acids (arising from production, hydrolysis or microbial activity), inorganic acids (mineral acids, such as hydrochloric or sulfuric) and peroxides (arising from the reaction of oxygen with unsaturated compounds). With respect to the test fuels developed, such as UL B100 biodiesel, all these contaminants are reflected in the synthetic composition except for peroxides (there is no technical agreement on the amount or type yet). Sulfur compounds are represented in the base fuels and therefore considered represented.

The UL Standards Technical Panel (STP) responsible for the *Standard for Nonmetallic Underground Piping for Flammable Liquids*, UL 971, developed the UL B100 biodiesel test fuel formula. That STP convened specialized Work Groups, consisting of UL and industry experts, for the purpose of developing requirements for the containment of flammable liquids. Findings relevant to this Fact Finding investigation include the following.

- A 99.8% soy feedstock was selected as a worst case representative of all feedstock as it combined balanced composition percentages and low fuel stability.
- It was determined that the biodiesel chain length and saturation level were not as significant as the aggressive components in evaluating material compatibility. Therefore, a mixture of 0.2% acid water (decanoic acid and DI water) was used with Acid Number adjustment (additional biodiesel or decanoic acid to the final mix to reach a consistent 1.0% +/- 0.02).
- The water volume was tied to saturation levels in biodiesel, decanoic acid represented biodiesel decay byproducts and the Acid Number, based on the D6751 specification of max 0.5, is a 2-times (2x) safety factor.

Therefore, the final fuel component makeup of the B5 biodiesel blend test fuel used in this investigation consisted of approximately 95% petroleum, 5% oxygenate and trace aggressive salts and acids. Note that the addition of salt and, in some instances, deference to automotive fuel was not considered to invalidate the B5 biodiesel blend test fuel for residential heating equipment. However, the impact of these variables should be considered if future testing at higher blends is conducted with the test fuel.