Combustion of Pig Lard in an Industrial Boiler

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INTRODUCTION

The changing or loss of markets for lard and grease is a major concern for the hog processing industry. The U.S. capacity for the daily processing of hogs in July 1999 was 389,820 hogs per day [1]. After rendering, each hog will produce an average of 2.60 gallons of choice white grease (CWG) and 1.43 gallons of lard [2]. This equates to nearly 600 million gallons of combined products a year. Of the total animal product entering the slaughterhouses and meat processing and packing plants, some 60% leaves as appropriate for human use; the remaining 40% goes to the rendering plant, and 80% of the rendered material returns to animal feedstuffs [3]. Should legislative action prohibiting feeding animal by-products to animals consumed by humans occur, lard and CWG will then have to compete with the other non-food markets. It should be noted that not all of the lard and grease is currently used in the animal feed industry; hog by-products are sources of chemicals that are used in the manufacture of a wide range of products, e.g., cosmetics, insecticides, weed killers, lubricants, etc. [1].

In the study Penn State worked closely with Hatfield Quality Meats and Lehigh University. Although Hatfield currently has markets for the lard and CWG, they wanted to explore options should they lose their current markets through the changing demographics of lard consumers, or legislative action banning the use of animal by-products in animal feed for animals that are consumed by humans. Should these occur, then Hatfield will have a potentially massive and difficult disposal problem.

One option is to use the lard and the CWG as boiler fuels. Hatfield has three No. 6 fuel oil boilers in their main processing plant. The watertube boilers are of D-type design with one rated at 800 Hp and two rated at 650 Hp. Cleaver Brooks manufactured the 800 Hp boiler while the 650 Hp boilers were manufactured by Keeler Dorr-Oliver. Typically, when the 800 Hp boiler and one 650 Hp boiler are in operation they consume about 35,000 gallons of No. 6 fuel oil per week. Therefore, should lard and/or CWG prove to be an adequate fuel for firing industrial boilers, Hatfield would produce enough products in-house to meet their weekly fuel quota.

The objective of this study was to perform the analysis of CWG, semi-finished lard, finished lard and No. 6 fuel oil, and to compare the firing and handling characteristics of semi-finished lard, finished lard and No. 6 fuel oil in Penn State's research boiler. Should lard and CWG be candidates for boiler fuels, then they could be utilized in Hatfield's boilers and marketed to other boiler operators, both industrial and utility. From the utility perspective, the lard and CWG could be used as the start-up fuel in coal-fired boilers as a direct replacement for No. 6 in oil-fired boilers [4].

EXPERIMENTAL

Fuel Characterization

Ultimate analysis was performed on all feedstocks using a LECO CHN-600 instrument for total carbon, hydrogen, and nitrogen contents, and a LECO SC-132 sulfur determinator was used for total sulfur determination. As-fired heating values (in Btu/lb) were determined using a Parr Adiabatic Calorimeter. Viscosity measurements were taken using a Brookfield DVIII viscometer with a #21 spindle, at 100, 120, 140 and 160°F for the No. 6 fuel oil, CWG, and lard samples. Spindle speed rate was varied to establish whether the samples exhibited Newtonian or non-Newtonian fluid characteristics. Simulated distillation gas chromatography (SimDis GC) was performed on all samples using a Hewlett Packard 5890 plus gas chromatograph fitted with an FID and a Restek MXT-500 Sim Dist column (6 meter x 0.53 mm ID x 0.15μm df).

Research Boiler and Ancillary Components

The design and operation of the research boiler used in this study has been described previously [2]. The typical operating procedure of the boiler involved preheating the system with natural gas until the refractory-lined quarl (divergent burner throat) reached a predetermined temperature. This took approximately four hours. The natural gas flow was then reduced, and the No. 6 fuel oil and lard flow increased until the required thermal input was obtained with satisfactory flame appearance. Tests were conducted for three, six, and three hours, firing No. 6 fuel oil, finished lard, and semi-finished lard, respectively. Approximately 100 gallons (2 drums) of the finished lard and 100 gallons of the semi-finished lard were used during the testing.

The lard was heated and mixed before being transported to the feed tank where it was heated continuously to maintain a temperature of ≈130°F. The following information was collected:

- Fuel firing rate;
- Fuel pressure;
- Combustion air flow and temperature;
- Atomizing air mass flow rate and pressure;
- Flame character, stability, and quality (quantitative;)
- Boiler and system operating temperatures and pressures;
- Steam flow rate and pressure; and
- Continuous stack gas composition (O_2, CO_2, CO, NO_x, and SO_2).

RESULTS AND DISCUSSION

Fuel Characterization

The data from the determination of the fuel characteristics are shown in Table 1. The lard samples contained less carbon and more oxygen than the No. 6 fuel oil. In addition, the lard samples contained essentially no sulfur. The heating value of the lard samples was ≈16,900 and 17,000 Btu/lb for the semi-finished and finished lard samples, respectively, compared to ≈18,500 Btu/lb for the No. 6 fuel oil sample.

The CWG sample contains slightly more sulfur than the lard samples (0.2% vs. ≤0.1%) but much less than the No. 6 fuel oil. The heating value of the CWG is similar to the lard samples.

Table 1. Fuel Analysis

	Semi-Finished Lard	Finished Lard	Choice White Grease	No. 6 Fuel Oil
Ultimate Analysis (%, as fired)[a]				
Carbon	77.7	77.4	77.9	85.8
Hydrogen	12.0	11.5	13.6	12.1
Nitrogen	0.4	0.6	0.2	0.6
Sulfur	0.0	0.1	0.2	1.5
Oxygen (by difference)	9.9	10.4	8.1	-
Heating Value (Btu/lb, as fired)	16,941	16,990	16,977	18,454
Viscosity (cSt)[b]				
100°F	70	97	91	1,357
120°F	23	25	26	520
140°F	17	17	17	232
160°F	-	-	13	128
Boiling Points (°C)[c]				
<260	0.7	0.8	0.5	8.9
280 to 450	5.1	1.9	20.9	29.3
450 to 540	1.8	1.1	11.6	12.5
540 to 700	91.6	95.3	65.6	38.3
>700	0.3	0.3	0.9	9.8

[a] Fuel oil analysis normalized to 0% oxygen because oxygen, by difference, was –0.6%

[b] Measured using a Brookfield DVIII viscometer, a #21 spindle.

[c] Measured using a Hewlett Packard 5890 plus gas chromatograph fitted with a FID and a Restek MXT-500 Sim Dist column.

Figure 1 is a plot of viscosity (in centistokes) as a function of temperature for the samples analyzed in this study. For comparison, the viscosities of Nos. 4 and 5 fuel oils at 100°F are also shown [5]. The CWG and lard samples became very fluid over a small temperature rise and exhibited signs of being shear-thinning fluids, i.e. when more force is applied (faster spindle speed), the lower the measured viscosity. Semi-finished lard exhibited the lowest viscosity values; however, the viscosities for the CWG and lard samples fell in a narrow range. The differences in measured viscosity were mainly due to the relative concentrations of the components, e.g. the finished lard had proportionately more of the higher boiling constituents than the semi-finished lard

(95.3% to 91.6% in the 540-700°C boiling range). This is due to the fact that higher boiling constituents are usually more viscous than the lower boiling constituents. The viscosities of the lard and CWG samples indicate that they should handle and atomize easier than No.6 fuel oil and are probably more like No. 5 fuel oil.

SimDis GC was performed on each of the samples to determine their boiling point distributions (see Figure 2). This was done to compare the boiling characteristics of the lard and CWG samples with No. 6 fuel oil. The SimDis GC of the semi-finished lard shows that 91.6 wt.% of the sample boils between 540-700°C, and that there is a smaller proportion (5.1 wt.%) boiling between 260-450°C. Further refining to produce the finished lard reduces the quantity of constituents that boil below 540°C by 50% from 7.6 to 3.8 wt.%. Consequently, the proportion of 540-700°C boiling constituents increases to 95.3 wt.%.

The CWG has two distinct regions with different boiling points (see Figure 2a). Two thirds of the sample boils between 540-700°C. The majority of the rest boils between 300-540°C, while the entire sample boils below 750°C.

Figure 2d shows that No. 6 fuel oil has constituents that cover a wide range of boiling points. Over 50 wt.% boils below 540°C, and almost 10 wt.% boils above 700°C (for the lard and CWG samples < 1 wt.% boiled in the +700°C range). In addition 1 wt.% of the No. 6 fuel oil did not elute from the column, and thus had a boiling value of +770°C.

It is the presence of the very high boiling material and their physical interactions with the lower boiling constituents, that causes the high viscosity in the No. 6 fuel oil.

Materials Handling and Combustion

No. 6 fuel oil

The No. 6 fuel oil was heated to 130°F in the feed tank before firing in the boiler. Although No. 6 fuel oil is typically preheated to 200°F [5], it was heated to 130°F in order to have a direct comparison with the lard tests.

The research boiler was fired on natural gas for a period of four hours before switching over to the No. 6 fuel oil. The transition from natural gas to No. 6 fuel oil occurred over approximately a 20-minute period until the desired air and fuel flow rates were obtained. The No. 6 fuel oil was burned for a period of three hours. During this period, the operating conditions were varied to establish the lowest O_2 level the boiler would operate at without adverse impact on CO emissions. This was found to be ≈ 2.0%; consequently, the lard tests were then conducted at similar O_2 levels. The combustion data listed for the No. 6 fuel oil in Table 2 are for a 0.65 hour period of steady-state testing with 2.0% O_2 in the flue gas. No problems related to the handling or combustion of the No. 6 fuel oil were encountered.

Finished and Semi-Finished Lard

Both the finished and semi-finished lard had similar handling characteristics. The samples were heated to above ≈105°F, in order to 'melt', and homogenize them into a consistent liquid mixture. The lard samples were then transported into the feed tank where the temperature was maintained at ≈130°F. Except for heating, no processing of the lard was needed before combustion.

When firing the lard samples (which were done on separate days) the boiler was fired on natural gas for 4-4.5 hours before switching over to the lard. The transition from natural gas to lard required approximately ten minutes until the desired air and fuel flow rates were obtained. The finished lard was burned for six hours and the semi-finished lard was burned for three hours. No problems related to the handling or combustion of the lard samples was encountered.

The lard flames can best be described as having a small initial blue 'natural gas-like' flame followed by an 'oil-like' bright, central jet, surrounded by a grayish flame. The distinct separations in the flame are likely a result of the combustion differences of the discrete constituents of the lard.

The lard flames were well anchored during the tests. There was no change in the flame character over the time each fuel was tested. The lard flames were significantly longer than either the natural gas or No. 6 fuel oil flames, and were self-sustaining.

The emissions remained fairly steady throughout the tests. Interestingly, the NO_x and SO_2 emissions from the lard tests were lower than when firing the No. 6 fuel oil. The nitrogen content of the lard samples is similar to that of the No. 6 fuel oil; hence, the lower NO_x emissions are likely due to the presence of water or other constituents in the fuel, which resulted in a different flame structure (i.e., longer flame), and possibly a lower flame temperature. No flame measurements were taken during the tests. There is no appreciable sulfur in the lard samples; therefore, no SO_2 emissions were observed. The CO emissions when firing the lard were slightly higher than when firing the No. 6 fuel oil. This is because the O_2 level was not optimized for the lard tests. Instead the O_2 levels were kept to that of the No. 6 fuel oil test.

SUMMARY

In comparison with No. 6 fuel oil, the lard samples evaluated in this study possess very good materials handling and combustion characteristics. During combustion, the lard samples produced no sulfur emissions, and two thirds less NO_x than No. 6 fuel oil. With the correct firing system reconfigurations, lard and possibly CWG could be used as fuels for industrial-scale boilers, or as start-up fuel for utility boilers.

Table 2. Combustion Data

	#6 Fuel Oil	Finished Lard (Overall)	Semi-Finished Lard (Overall)
Length of Test (h)	0.65	5.90	2.53
Fuel Injection Temperature (°F)	140	130	130
Fuel Firing Rate (million Btu/h)	1.74	1.74	1.72
% O_2	2.2	2.0	2.2
% CO_2	14.4	14.7	14.6
ppm CO @ 3% O_2	111	145	147
ppm NO_x @ 3% O_2	395	137	135
ppm SO_2 @ 3% O_2	784	0	0

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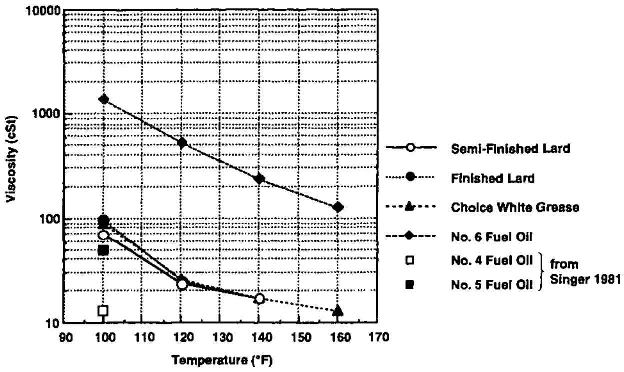

Figure 1. Viscosity as a function of temperature using a Brookfield DVIII viscometer with a #21 spindle.

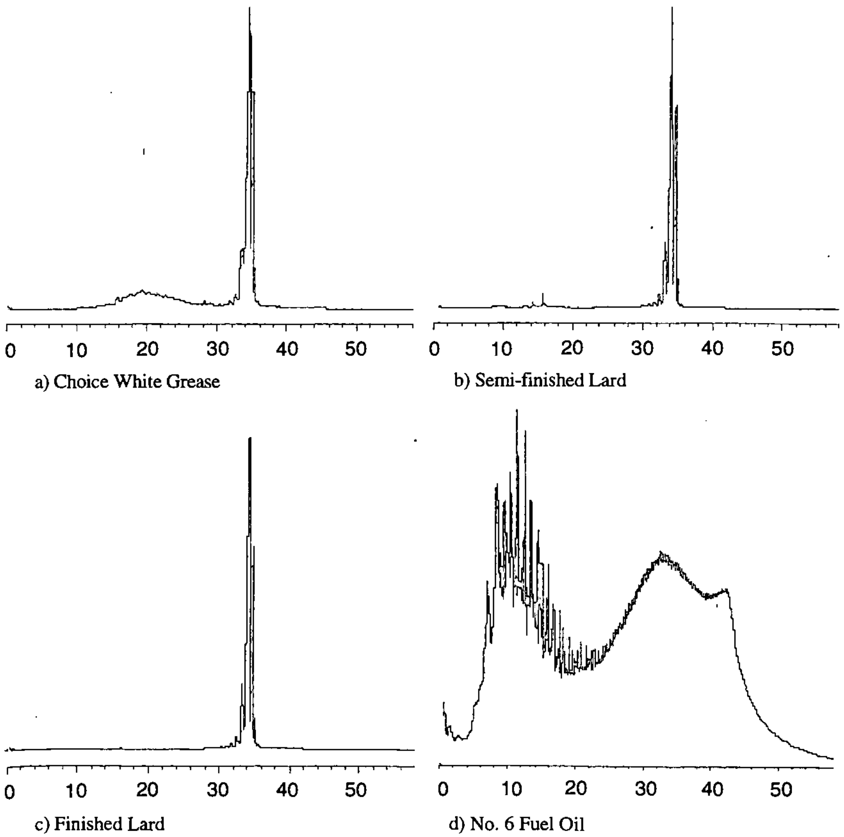

Figure 2. Simulated distillation chromatograms of samples evaluated in this study