GENERAL JONAS ŽEMAITIS
MILITARY ACADEMY OF LITHUANIA

THE DIESEL ENGINES RELIABILITY IN THE DIFFICULT CONDITIONS OF AFGHANISTAN

PART IV

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Agenda

Object: JET FUEL F-35/F-34 BURNING PROCESS SINGULARITY IN THE INTERNAL COMBUSTION ENGINE IN VARIED CONDITIONS

4.1. Introduction

4.2. III class of supply on the battlefield , advantages and disadvantages to use kerosene type of fuel

4.3. Influence of fuel fractional composition on engines

4.4. Summary

Jet fuel F-35/F-34 burning process singularity in the internal combustion engine in varied conditions

Introduction

In 2004 ”NATO Pipeline Committee” adopted the concept of NATO general policy of unified fuel. All NATO countries, including Lithuania, have ratified STANAG 4362 document. Value of this policy is to substitute the diesel fuel for diesel engines of military land vehicles and equipment for the fuel F–34 (F–35).

Different countries are involved in providing humanitarian aid under extreme climatic and geographical conditions of mountainous desert. Different transport means are used for this purpose. Diesel fuel (DF) will be replaced by F-34, F-35 in compression ignition engines; both fuels have lower lubricity and viscosity. Since F-34, F-35 is a more highly refined fuel than DF-2.

Introduction

The tribological requirements of fuel-lubricated components in the injection system were unknown for The Lithuanian Armed Forces. As a result, no widely approved lubricity test or standard exists. Similar problems are currently faced in commercial applications where low-sulfur/aromatic fuels are being introduced.

However, increased failure rates are being reported on a number of fuel-sensitive components during Military Operation in Afghanistan for the period of summer 2005 to autumn 2008.

MAP OF GEOGRAPHICAL LOCATION OF AFGHANISTAN. REGIONS OF DESERTS

- Oxus basin Amu Darja (1A), Kara-Kum Garagum, Badghyz and Karabil (1B). Clay deserts: Seistan, Dasht-e-Margo and Dasht-i-Arbu South, South-West Afghanistan desert (1C), Registan, South-East Afghanistan Sandy Desert (1D). Regions of semi-deserts: Khorassan (2A), part of Persian Iran) desert (2B), valleys of semi-deserts of the Afghan Mountains (2C). Regions of hills, semi-deserts and lower mountains that can be passed through: regions of Safedhok and Circum Oxiani-Hill (3A), and Siahkok (3B). Mountainous regions: Chorat (4A), Paropamiz and Hazarajat Mountains (4B), alpine plain surface Hindu Kush (4C), Pamir high-mountainous region (4H). (Michael A. Mares 1999, 2003).

III class of supply on the battlefield, advantages and disadvantages to use kerosene type of fuel

Introduction

The NATO Pipeline Committee adopted the Single Fuel Concept as NATO Single Fuel Policy in 2004.

All NATO nations, including Lithuania, have ratified and are implementing STANAG 4362.

Logistical benefits of a single fuel are related to a variety of technical, operational, economical and environmental factors, but the major advantage is simplification of the fuel supply chain tasks and the supporting static or deployable infrastructure as described in Directive for the NATO Petroleum Supply Chain.

Introduction

Different countries are involved in providing humanitarian aid under extreme climat and geographical conditions of mountainous desert. Different transportation means are used for this purpose. It foresees the replacement of diesel fuel (F-54) with F-34, F-35 in land-based vehicles and equipment with compression ignition or turbine engines deployed on the battlefield.

Both fuels have lower lubricity and viscosity. The tribological requirements of fuel-lubricated components in the injection system were unknown for The Lithuanian Armed Forces.

13 ADVANTAGES TO USE KEROSENE TYPE OF FUEL

1. simplification of the fuel supply chain tasks
2. Illuminate mistakes during refueling
3. Reduced engine combustion-related component wear.
4. Reduced nozzle fouling/deposit problems in both diesel and gas turbine engines.
5. Reduced potential for fuel system corrosion problems.
6. Increased fuel filters replacement intervals.
7. Reduced exhaust emissions and signature.

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13 ADVANTAGES TO USE KEROSENE TYPE OF FUEL

8. Extended oil change intervals and filter replacement intervals.
9. Reduced fuel related low temperature operability problems; eliminate fuel waxing.
10. Reduced potential for microbiological growth problems in fuel tanks.
11. Reduced water entrainment/emulsification problems in vehicle fuel tanks.
12. Increased storage stability capability.
13. Improved fuel/lubricant related cold starting.

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DISADVANTAGES TO USE KEROSENE TYPE OF FUEL

1. Reduction in horsepower occurred due to the lower volumetric heat content of kerosene type of fuel
2. Fuel consumption rates were increased (approx. 1-5%)
3. Changes in the fuel viscosity alter the fuel injection process. Most of the injection changes are caused by the internal leakage from the high pressure regions of the pump and injection nozzle.
4. Kerosene type of fuel more flammable fuel compare to diesel fuel.
5. Smoke equipment does not work.

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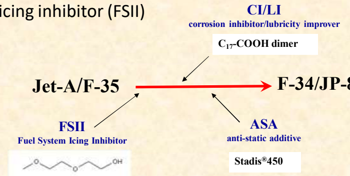
FUEL PROPERTIES

- F-34/Jet-A & F-35/JP-8 are mixtures of several hundred different compounds, most at low concentrations
- JP-8 is similar to Jet-A, with the addition of
  - a corrosion inhibitor/lubricity improver
  - an anti-static additive
  - fuel system icing inhibitor (FSII)



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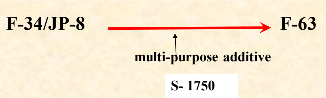
FUEL PROPERTIES

- F-35/F-34 & F-63 are mixtures of several hundred different compounds, most at low concentrations
- F-63 is similar to F-35/F-34, F-34 is treated with 0.1% by volume of multi-purpose additive, S- 1750 which, in the context of the Single Fuel Policy, is used to enhance the lubricity and ignition performance of F-34 when required. S-1750 is a combined lubricity and ignition improving additive for ground fuels
- **F-63 is intended for land equipment only and <u>must not be used for aircraft.</u>**



AVERAGE CHEMICAL FORMULA FOR KEROSENE FUEL

The average chemical formula	Kerosene F-34 and F-35 is a complex mixture of	Information source
$C_{12}H_{23}$	Kerosene F-34 and F-35 is a complex mixture of **alkanes** (50-65% vol.), **mono-and poly-aromatics** (10-20% vol.) and **cycloalkanes or naphtenes (mono- and poly-cyclic,** 20-30% vol.) widely used in aircraft engines.	Gracia-Salcedo et al.. NASA Tech. Memorandum 101475, 1988
$C_{11}H_{2l}$		Edvards and Maurice, J. Propulsion and Power, 17,461-466, 2001
		Edwards, T. "Kerosene" Fuels for Aerospace Propulsion-Composition and Properties. In Proceedings of the 38thAIAAI'ASMEI SAEIASEE Joint Propulsion Conference and Exhibit, July 7-10,2002, Indianapolis, IN; AIAA Paper No. 2002-3874, pp 1-11.
		Sinor, J.E., Investigation of Byoproduct Application to Jet Fuel. Final Report NREL/SR- 510-30611 October 1,2001
$C_{11}H_{22}$		Gueret,C., Thesis University of Orleans (in French), 1989
$C_{11}H_{23}$	The compounds identified in kerosene at the highest levels of concentration are n-alkanes	Nguyen and Ying, AIAA-90-2439. 1990
$C_{11.6}H_{22}$		Martel,C.R,AFWAL/POSF Report. July 15. 1988
$C_{11.5}H_{22.4}$		Chickos James S., Hui Zhao, Measurement of the Vaporization Enthalpy of Complex Mixtures by Correlation-Gas Chromatography. The Vaporization Enthalpy of RP-1, JP-7, and JP-8 Rocket and Jet Fuels at T = 298.15 K., Energy & Fuels, 2005

Same Oil Names

- **Brent Blend** is the name for oil from 15 European oil fields
- **Ural** - oil extracted in Russia
- **West Texas Intermediate (WTI)** - North American oil
- **Dubai** is predominantly Middle Eastern oil
- **Tapi** - Malaysian Oil
- **Minas** - Indonesian oil
- **Arab Light** - Saudi Arabian Oil
- **Bonny Light** - Nigerian Oil
- **Fateh** - Dubai region oil
- **Isthmus** - Mexican Oil
- **Saharan Blend** - Algerian oil
- **Tia Juana Light** - Venezuelan oil

THE AVERAGE PROPERTIES OF A JET AND A DIESEL FUELS

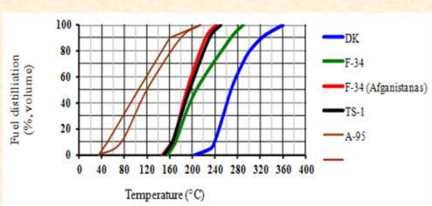
Property	F-34 & F-35[5]	F-63	DF grade E (Lithuania)	F-34 (Afghanistan)
Acidity, Total (mu KOH/IOO cm3) Max.	0.015	0.015	N/A	0.012
Aromatics (wt %) Max.	25	25	11	18
Sulphur. Total (wt %) Max.	0.3	0.3	0.035	0.20
Sulphur. Mercaptan (wt %) Max.	0.003	0.003	N/A	0.003
Flash Point (°C)	Min. 38	Min. 38	55	42
Density (a) 15°C (kg/m³)	775-840	775-840	820- 845	761.7
Freezing Point (°C) Max.	-47	-47	-15	-54.6
Viscosity (a) 20°C (cSt)	0.97-1.2	1.7	1.9-4.5	1.25
Net Heat of Comb. (MJ/kg) Min	42.8	42.8	43.1	42.9
Celane number average	40-42	47.3±	Min 51	Min 38

Kerosene F-34 and F-35 is a complex mixture of alkanes (50-65% vol.), mono-and poly-aromatics (10-20% vol.) and cycloalkanes or naphtenes (mono- and poly-cyclic, 20-30% vol.) widely used in aircraft engines. The compounds identified in kerosene at the highest levels of concentration are n-alkanes.

PROPERTIES OF FUELS

- In Afghanistan Lithuanian troops, much of the aviation kerosene that initially was procured had characteristics close to Russian TS- 1 aviation kerosene because the neighboring refineries produce aviation kerosene as TS-1 instead of F-34 or F-35. The Russian TS-1 aviation kerosene is similar to Jet-A1, but it is more volatile because it has a lower flash point and the same low viscosity. While all piston engine fuels have the same volatility but differ in combustion characteristics, jet fuels differ primarily in volatility and differences in their combustion qualities are minor. Measured of several grades of a diesel and a jet fuels fuel distillation behavior was shown. For fuels in which the Reid Vapor Pressure is too low for accurate measurement, the flash point is given. This is the temperature to which a fuel must be heated to generate sufficient vapor to form a flammable mixture in air.

A DIESEL AND A JET FUELS FUEL DISTILLATION BEHAVIOR



For fuels in which the Reid Vapor Pressure is too low for accurate measurement, the flash point is given. This is the temperature to which a fuel must be heated to generate sufficient vapor to form a flammable mixture in air.

Influence of fuel fractional composition on engines

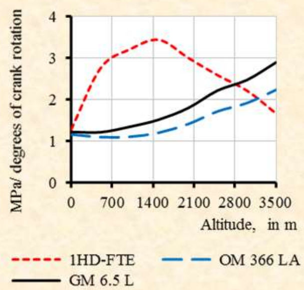
INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- Diesel engine operation nature depends on the used fuel **fractional composition and cetan number.** For burning fuel of lighter fractional composition, less air is required; less time is required for preparing a flammable mixture, also.
- Such combustion of a mixture causes the **loud diesel engine work** – this can be explained as: at the moment of fuel ignition a significant amount of fuel vapor is in engine cylinder, the combustion of it is accompanied by an **excessive pressure increase rate for 1° of engine crankshaft rotation during combustion process** and specific knock in the engine.

INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- The main indicator of **noisy engine working** is rate of maximum $(dP/d\varphi)_{max}$ and average $(\Delta P/\Delta\varphi)$ pressures increase rate during the engine fuel combustion process in diesel engine cylinders.
- Rate of **pressure** of many of these **engines must not exceed the standard numbers** $(dP/d\varphi)_{max}$**<1,5…2,0** ***MPa*** **and** $(\Delta P/\Delta\varphi)$**<0,4…0,6** ***MPa*****.**
- Influence of **fuel fractional composition on engines of different types is different.** It is observed when investigating the three types of diesel engines 1DH–FTE, GM 6.5L, OM 366LA.

Dependence of combustion cycle of maximum pressure growing



Compared with the engine 1DH–FTE with direct fuel injection, having a bulk combustible mixture preparation, the engine GM 6.5L with the swirl chamber and the engine OM 366 LA with axial and radial air turbulence for combustible mixture preparation are less sensitive to fuel with the light fractions.

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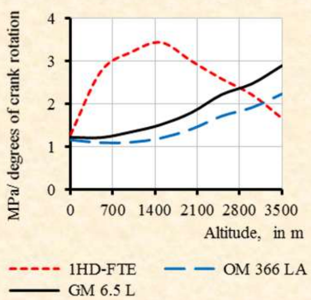
Dependence of combustion cycle of maximum pressure growing



Two factors **– excess air ratio (λ_H) and air pressure (P_C)** in the engine cylinder – define change of optimal fuel parameters of fuel high–pressure pump (fuel supply angle and injection start–up of fuel pressure). With the unchanged fuel high–pressure pump factory settings fuel ignition delay period τ_1 and fuel combustion process period φ_2 increases, fuel combustion process expands into the expansion cycle and increases in time.

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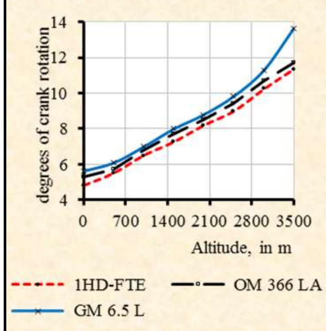
Dependence of fuel ignition delays on altitude above sea level



Lower viscosity of the fuel increases the fuel penetration between the ram and cylinder bushings, which in turn reduces the amount of fuel injected into the engine combustion chamber during the cycle; the pressure of fuel injection decreases in high-pressure pipelines of the engine fuel injection system – this in turn increases the fuel injection delay period to the angle of 2–4° turn of the crank.

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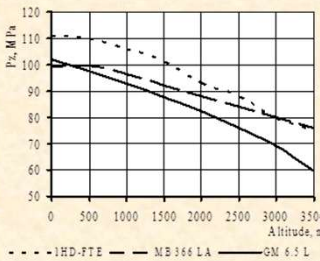
Dependence of combustion cycle of maximum pressure on altitude above sea level



Rising in the mountains above sea level preparation of fuel mixture and combustion processes are more complicated. In the mountains the air pressure (P_{AH}) at the beginning of the compression cycle is significantly reduced and accord ingly the air pressure in the compression cycle (P_C) in the engine cylinder becomes less. This decrease in pressure negatively affects the quality of fuel injection and preparation of the combustion mixture.

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INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- During Military Operation in Afghanistan for the period of summer 2005 to autumn 2010, **certain families of engines that used fuel-lubricated, rotary-distribution, fuel-inject ion pumps experienced some operational problems that resulted in to restarting a vehicle while its engine is still hot hot-starting difficulty and gradual loss of power up to 10% at high fuel temperature, the fuel consumption increased of 25% however, the increases take place of Afghan mountains impact, significant ashy deposits were found in the pre-combustion chamber of the 4-cycle diesel engines.** The most common problems were the General Motors 6.5-liter engines, which use the commercially manufactured Stanadyne fuel-injection pump. These engines power smaller tactical wheeled armor vehicles high-mobility, multipurpose, wheeled vehicles (HMMWVs).

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INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- Causes of the problems with the engines included— **sustained operation during high temperatures, improperly manufactured replacement parts, the injection pump delivery valve seats and the nozzle valve and body showed evidence of cavitation erosion, unauthorized oils and fluids added to F-35 fuel, use of F-35 that did not contain corrosion inhibitor and lubrication-enhancing additives, also some malfunctions in fuel-injection systems occurred because of unqualified work of maintaining personnel.** The viscosity of the F-35 fuel being supplied by contractors under a host nation support agreement was very low, as was the sulfur content, which further compounded the hot- starting problems.

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INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- Actually all differences in vehicle's work between F-34 and diesel fuel comes from engine fuel injection system's reaction to fuel physical changes. The injection pump delivers accurately measured amount of fuel to every cylinder, pressure during this process is from 34,5 MPa to 165,5 MPa. The moment of beginning and whole injection process is accurately regulated according to the crankshaft's rotation.

INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- **F-34 has lower density than diesel fuel.** This has influence to engine performance and injection process. That is because injection system measures amount of fuel injected depending on its volume and combustion is regulated according to the mass of fuel which is injected. So different density of fuel means different mass of fuel injected during one injection stroke. Although less mass of F-34 than diesel fuel is injected, pressure during injection process remains the same, becaus these fuels actually have the same compressibility.

INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- As we can see F-34 fuel has 1,25 cSt viscosity at 20°C, when the recommendation for fuel's viscosity is at least 1,3 cSt at 20°C, diesel fuel's viscosity is 1.9-4.1 cSt at 20°C. So F-34 has lower viscosity. Changes in the fuel viscosity alter the fuel injection process. Most of the injection changes are caused by the internal leakage from the high pressure regions of the pump and injection nozzle.
- F-34 and diesel fuel have different ignition delay periods and different pressure rise rate. Due to different F-34 and diesel fuel evaporation rate (F-34 evaporation rate is 15-40% faster than diesel fuel) pressure rise rate changes.

INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- Internal leakage reduces the mass of fuel delivered into the combustion chamber during the injection process. Designers of injection pump alter seal length to fit lower viscosity fuels. For low viscosity fuel use, the length of seal between the barrel and plunger is the only physical dimension that practically can be altered to reduce fuel leakage. Viscosity has another effect in fuel-lubricated injection pumps that use fuel to provide the hydrodynamic film in a journal type bearing. Using lower viscosity fuel decreases hydrodynamic film thickness. This causes increased wearing of the surfaces covered by that film .

Fuel Injection System Mass Variations Due to Viscosity and Density

Property	F-34 Afghanistan	F-34/ F-35	F-63	DF grade E Lithuania
Mass fuel metered relative to DF	0.93	0.94	0.95	1.0
Mass leak rate relative to DF	2.83	2.33	1.83	1.0
Mass fuel injected relative to DF	0.93	0.94	0.95	1.0

INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- Fuel's ignition delay period has a big influence for whole work process of diesel engine. This period depends on some factors, such as temperature and pressure of the air, physical and chemical features of fuel, size and shape of combustion chamber, pressure of injection. Fuel's ignition temperature, which also influences its delay period, depends on the environment pressure. If the pressure rises in the combustion chamber rises, the temperature of fuel ignition becomes lower.

INFLUENCE OF FUEL FRACTIONAL COMPOSITION ON ENGINES 1DH–FTE, GM 6.5L, OM 366LA.

- F-34 evaporation is bigger than diesel fuel because higher pressure rate occurs. Higher rates can lead to premature engine failures. When the fuel vaporizes and ignites late, the associated higher burning rates lead to higher combustion pressures thus a larger impact. Parts being eroding, due to higher pressure rise rates in the vicinity of the piston bowl edge, which leads to greater bigger damage engine failure. There are number of suggestions which can help to reduce engine wear. First, redesign the piston bowl to control spray over-penetration by increasing the diameter and modifying the bowl entry angle. Then reduce the injector nozzle hole sizes to control spray over-penetration. Finally, consider using high pressure common rail fuel system in parallel with suggestion two for both controlling overpenetration and improving power density

Problems of Diesel Engines

1. To restarting a vehicle engine while its engine is still hot hot-starting difficulty.
2. Gradual loss of power up to 10% at high fuel temperature.
3. The fuel consumption increased of 25% however, the increases take place of Afghan mountains impact.
4. Significant ashy deposits were found in the pre-combustion chamber of the 4-cycle diesel engines.

Problems of Diesel Engines

5. The injection pump delivery valve seats and the nozzle valve and body showed evidence of cavitations erosion.
6. Unauthorized oils and fluids added to F-35 fuel.
7. Rate of pressure growth per 1º of engine crankshaft rotation during fuel combustion process in diesel engine cylinders, $dPz/d\varphi$.

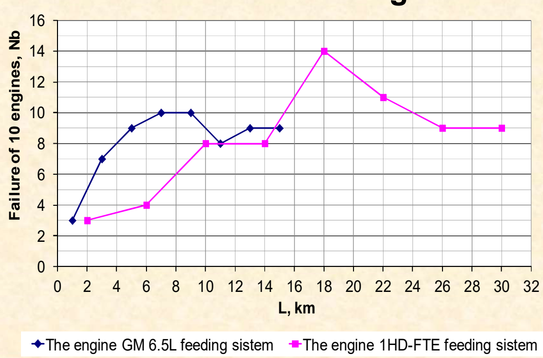
Problems of Diesel Engines

8. Engine oil dilution with fuel.

9. Increased failure rates are being reported on a number of fuel-sensitive components.

10. Some malfunctions in fuel-injection systems occurred because of unqualified work of maintaining personnel.

Problems of Diesel Engines



Summary

- Following the theoretical assessment of combustion rate of the fuel F–34 (F–35) substitute in diesel engines in high–altitude conditions, we can state that its use is complicated, the engines work is accompanied by too fast fuel combustion, occurring in loud engines work, an increase of delayed fuel ignition period, and a decrease in effective pressure of combustion cycle.
- Minimum factors, able to improve engine performance, is changing of diesel power system, i.e. changing of fuel high–pressure pump factory settings: fuel injection angles, cyclic fuel and air intake volume.
- The engines in which this fuel will be used must be developed and designed exactly for that type of fuel or have adaptation possibility if such changes occur, as the engines operated in Afghanistan react differently to changes in the mountain climate and physical and chemical fuel properties.

Summary

- The lecture presents a theoretical study of combustion rate of the fuel “Afghanistan fuel ", as a substitute for the military fuel F–34 (F–35), used in the diesel engines 1DH–FTE, GM 6.5L, the OM 366 LA operated in the mountains of Afghanistan, with unchanged the factory fuel supply system regulation settings. Fuel assessment showed that the fuel caused many problems, associated with diesel engine fuel combustion process; it leads to deterioration of conditions of fuel ignition and fuel combustion with the excessive pressure increase rate for 1° of engine crankshaft rotation and strong combustion cycle pressure drop. These changes are the result of mountain climate and the physical and chemical properties of the fuel used.