Kerosene Lamps and Cookstoves - the Hazards of Gasoline Contamination

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Abstract

Gasoline contamination of kerosene has been implicated in accidental fires associated with the use of kerosene illumination lamps and cook stoves. We have investigated potential causes of accidental fires in lamps and lanterns filled with contaminated fuel through controlled tests using typical appliances and varying amounts of contamination. Studying reports of accidents, it is apparent that a common cause of fires is filling hot appliances that are in operation or close to an open flame. The role of contaminated fuel vapor in creating a hazardous situation is shown to be crucial. We evaluate miscibility assumptions and quantify the hazard through flashpoint measurements for mixtures of kerosene and gasoline as a function of the amount of gasoline (up to 10%). A simple model for predicting the flashpoint of an arbitrary mixture is presented.

1. Introduction

One-third of the world's population, or about 1.6 billion people, live without electricity (World Bank 2000). A recent study (Mills 2002) indicates that a substantial fraction of the energy budget in rural areas goes toward liquid fuel for illumination. As discussed by Mills (2005), implications of this dependence are far-reaching in terms of living conditions that contribute to the cycle of rural poverty, the generation of greenhouse gases, depletion of non-renewable resources, and hazardous waste disposal issues, e.g., dry cell batteries. In this article, we examine another aspect of this problem, the safety hazards associated with fuel-based lighting and cooking. Children are entrusted with filling and lighting lamps or stoves without any oversight or awareness of the hazards. Accidents with overturned lamps or stoves and spilled fuel are commonplace, in some cases causing burns and death.

Bizzo et al. (2004) suggest that replacing liquid fuels with gases is the preferred short-term solution from the viewpoint of improving safety and reducing health risks associated with indoor air pollution. A promising alternative (Economist 2006, Mills 2005) to fuel-based lighting is the use of low-power white-light LEDs powered from batteries charged by solar cell arrays. On the other hand, in some regions, switching from firewood or other biomass fuel to kerosene is viewed as the first priority (Alberts et al 1997) in improving the quality of life. Given the magnitude of the problem, liquid fuel-based lighting and cooking will be in use for some time to come and accidental fires will continue to be an issue.

Precise figures and the total cost of such accidents are hard to come by, but in one country, Sri Lanka, the problem of household lamp fires is so severe that a physician has devoted his life to developing an improved lamp and to fire safety education. Dr. Wijaya Godakumbura has developed (Rolex 2005) a simple lamp with a heavy base and screw on top that almost eliminates the problem of lamps tipping over and spilling. Since 1992, he has led the Safe Bottle Lamp Project to develop, manufacture, and distribute inexpensive but safe lamps. He has estimated that 40% of the burns in Sri Lankan homes are due to kerosene bottle lamps, that between 150 to 200 lives are lost each year, and that the cost of treating burn injuries is over 1 million dollars per year to the Sri Lankan government. His efforts have attracted international attention and the Rolex Award for Enterprise in 1998 (Rolex 1998). Dr. Godakumbura's goal is to ultimately replace millions of unsafe lamps in Sri Lanka. The problems of Sri Lanka, a country of 18 million, are unfortunately typical, and the use of kerosene lamps for household illumination is wide spread among the billions of rural poor.

2. Fuel Contamination

Even with the development of better lamps and implementation of fire safety education, there remains the rather serious problem of fuel contamination. Kerosene is universally used to fuel lamps and stoves because of its intrinsic safety – the flash point of kerosene is greater than 38^{o}C (100^{o}F) and the vapor pressure is rather low at normal temperatures. This means that at normal temperatures and pressures, a pool of kerosene evaporates very slowly; the concentration of vapors above the pool is well below the lower flammability limit; and it is extremely difficult to ignite a pool of kerosene with a single match. In contrast, gasoline has an extremely low flash point, -40^{o}C (-40^{o}F) and a high vapor pressure. A pool of gasoline will evaporate quickly, the vapors above the pool mix with air to form a flammable region of large extent, and the fuel-air cloud will ignite readily with a single match. Contaminating kerosene with even a small percentage of gasoline will cause a decrease in the flash point, will increase the vapor pressure, and creates a much more hazardous situation for the consumer overall (Lentini 1990). The problem of contamination is particularly serious when it is combined with a lack of fire safety awareness and carelessness in handling fuels. Many of the accidents we have examined could have been avoided, even if the fuel was contaminated, by following basic fire safety practices. A common situation is the spillage of fuel on garments and accidental ignition of the fuel-soaked clothing, which is possible by the wicking action of cloth even if the fuel is not contaminated. In some cases, such as poorly designed barometric (bottom-fed) kerosene heaters (Henderson and Lightsey 1986, Lentini 1989), fuel spillage can be created by the high vapor pressure of contaminated fuel. This is the cause (Brabauskas 2003, p. 866) of numerous fires and fire-related deaths each year.

Contamination of kerosene occurs for several reasons. The most common reason is switch loading of transport trucks (fuel tankers): delivering a load of gasoline from a fuel tanker on one delivery and a load of kerosene from the same tanker on the next delivery. Unless the tank and delivery lines are carefully purged of gasoline, contamination of the kerosene will be inevitable due to residual gasoline in the lines and tank. The problem of contamination is well known in the fuel industry, and suppliers have strict procedures that have to be followed whenever switch loading is practiced. Improper switch loading of a tanker may contaminate the entire batch of kerosene and everyone using fuel from this batch is at risk. A common indication of improper switch loading is widespread reports of increased fires and explosions[1] from a village or region that is served by a single fuel depot or service station. In the last decade, such news

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[1] The term explosion is often used in newspaper reports and government investigation of these events but in all the events we have studied, accidental or unexpected fire appears to be the correct technical description since there is no evidence of pressure or blast waves.

reports can unfortunately be found from many places such as Papua New Guinea (43 burn victims in February 2001, Mokono 2001), Nigeria (134 cases in February 2001, WHO Nigeria 2001), and Micronesia[2] (Pohnpei FSM 1992). Contamination also results from the use of unmarked containers by the end consumers, often milk jugs or 2-liter soda bottles that may be used for gasoline as well as kerosene storage. In Nigeria during 2001, illegal fuel sales (Bizzo et al 2004) and substandard transport tankers were blamed after an emergency was created by the failure of a kerosene pipeline that was normally used for fuel distribution in Lagos.

Whatever the source of contamination, a common issue faced by fuel distributors and government authorities is determining the extent of contamination. This problem of fire hazards from kerosene contamination was important from the very beginning of the petroleum industry in the 1860s and motivated the first measurement methods and regulations on flash point (Totten 2004). Since then, the concept has been well known to fire investigators (Lentini 2006) but there are only a few (Lentini 1990) quantitative studies available. The present study provides data and a simple mathematical model for quantifying the effect of contamination by predicting the flashpoint of an arbitrary mixture of gasoline and kerosene. The methods used in the present study are based on previous work with pure substances (Affens and McLaren 1972) that are applicable for fuel blends that can be considered as ideal solutions. We do not consider the important but much more challenging problem of the prediction of flash point for non-ideal solutions (French and Malone 2005) such as mixtures of ethanol or dimethyl ether with gasoline or kerosene.

3. Gasoline and Kerosene

Kerosene and gasoline are commodities with certain minimum specifications rather than precise properties. As products of distillation of crude oil, these fuels are a mixture of hydrocarbon molecules with a range of molecular structures and masses. Several hundred distinct molecular species can be identified in a given sample of fuel. Scientific characterization of a fuel requires determining the relative amounts of each species by a method such as gas chromatography-mass spectrometry (GC-MS), and the results of such an analysis are commonly referred to as the fuel composition. One of the difficulties in carrying out testing

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[2] Mentioned in the case of Lebehn v. Mobil Oil Micronesia, Inc.

with these fuels is that the composition varies by region and season. The composition, the exact type and amount of each molecule in the mixture, is unique to each batch of kerosene or gasoline. The makeup of the fuel depends on the source of the petroleum, the operation of refinery, and other factors like mixing of batches in bulk storage tanks.

Each species is defined by the numbers of carbon and hydrogen atoms and the geometrical arrangements of the carbon backbone, which can be linear, branched, or ring-like. The ratio of hydrogen to carbon atoms is closely related to the geometrical configuration. The number of carbon atoms range from 4 to 20 per molecule and many of the same species are present in both fuels. The key difference in the composition is that, on the average, gasoline molecules are smaller than kerosene and gasoline is slightly less dense than kerosene. The average number of carbon atoms per molecule in liquid gasoline is about 7 and the average number in liquid kerosene is about 12. At room temperature, the composition of the vapor is lighter than that of the liquid since the larger molecules do not evaporate as readily as the smaller ones. The chemical composition of the vaporized fuel depends strongly on the temperature, flashpoint, amount of liquid, and the exposure of the fuel to the atmosphere (Woodrow 2003, Shepherd et al 1999, Shepherd et al 1997).

One of the most common industrial uses of kerosene is as fuel for jet airplanes. Fuel certified for aviation use is known worldwide as either Jet A or Jet A1. For the purposes of combustion properties, Jet A and Jet A1 are identical (CRC 2004) and we will just refer generically to Jet A in the following points. The only difference in the specification is that Jet A1 has a minimum freezing point of -47^{o}C as opposed to -40^{o}C for Jet A. In some rural areas, such as the islands of the western Pacific, Jet A is sold to consumers for the purposes of home lighting and heating. In the United States, kerosene used for home heating or lighting is designated 1-K or 2-K. The present study was carried out using samples of Jet A but the results should be applicable to kerosene, whatever the source. Gasoline is used for fueling vehicles such as cars, motorcycles, and boats and also portable power generators, compressors, farm or yard implements. It is never used directly for illumination or cooking. There are some lanterns and appliances that operate from light petroleum distillates commonly known as Coleman Fuel, but these are expensive and fragile devices that are not commonly found among the rural poor.

Like kerosene, the composition of gasoline varies between refiners and in many countries is regulated. Additives such as MTBE or alcohol fuels are blended with the gasoline to boost octane and to control emissions of pollutants. For the purposes of the present evaluation, we will not consider the effect of these additives on flammability but examine the case of a generic product with the standard treatments to maintain a minimum octane level.

The gasoline and kerosene used in this study were characterized using a Hewlett-Packard 5890 gas chromatograph (GC) and 5989 mass spectrometer (MS) combination. About 0.1 microliter of the liquid sample was injected into the GC inlet which was at a temperature of 250^{o}C. A Hewlett-Packard HP-5 capillary column (30 m x 0.32 mm x 0.25 μm) with a (5%-Phenyl)-methylpolysiloxane stationary phase and helium carrier gas was used for the separations. The column oven temperature program was 30^{o}C for 3 minutes followed by an increase to 250^{o}C in 10^{o}C per minute increments. The total data acquisition time was 28 minutes for the MS and the scan range was 35-300 *m/z*. The output of the GC-MS (total ion chromatogram or TIC) for Jet A and gasoline are shown in Figure 1 as a function of retention time within the gas chromatograph column. The large number of individual peaks in the TIC, which blend together in a continuous hump for Jet A, is an indication of the many species that are present in these liquids. In general, each peak represents a particular molecular species or set of species with a common molecular mass with larger retention times corresponding to larger masses, although there are exceptions to this rule (Grant 1996). The species that correspond to a particular peak were determined by the instrument software which compares the MS ion fragment distribution with a database of patterns previously determined from known compounds.

The Jet A TIC shows a broad peak centered at 16 minutes with superimposed spikes corresponding to the major straight chain alkane (saturated hydrocarbons of the form C_nH_{2n+2}) species. Identification of species was carried out using the MS, and the peak corresponds to a median carbon number of 12 and hydrocarbon species between 4 and 18 carbon atoms were observable in the TIC. The gasoline TIC has fewer species and the majority are unsaturated or ring compounds with less than 11 carbon atoms and the median carbon number is between 5 and 6. Our results are consistent with those of other researchers (Woodrow 2003, CRC 2004) who have carried out more detailed analysis of fuel composition and used GC/MS methods in the analysis of ignitable liquid residues (Lentini 2006). The variation of the peak amplitude with carbon number is not as regular as observed by some researchers (Lentini 2006), this may be due to a low scan rate in the MS resulting in not completely resolving the highest amplitude peaks.

4. Flammability, vapor pressure and flash point

The flammability of gaseous fuels is determined by testing to find the concentration range of fuel vapor in air that will support combustion with a specified ignition source, usually a strong electric arc (see Chapter 4 of Babrauskas 2003). For example, the flammability range of gasoline is 1.3 to 7.1% by volume of gasoline in gasoline-air mixtures (Kuchta 1986). Reporting flammability for gasoline in terms of concentration is quite reasonable for gasoline, which readily vaporizes at room temperature. Gasoline does so because the vapor pressure (partial pressure of gasoline vapor in equilibrium with a liquid layer in a container) is quite high, between 35 and 60 kPa at 25^{o}C. The actual vapor pressure will depend on the processing to meet local regulations and is specified in terms of a standardized test, the Reid Vapor Pressure (RVP) method (ASTM D323), discussed below.

As a consequence of the high vapor pressure, a small amount of gasoline liquid in a container (about 1 cc for 2 liters) will almost (a small residue of heavy components may remain in the liquid state) completely vaporize and create a flammable mixture. The vapor pressure is a strong function of liquid temperature and molecular composition of the fuel. For kerosene, the vapor pressure at 25^{o}C is only on the order of 1/100 of that of gasoline. This means that the vapor above uncontaminated kerosene liquid will not be ignitable at room temperature. In contrast to the situation with gasoline, even a large volume of room temperature liquid kerosene will not produce a flammable mixture inside a container. The liquid kerosene temperature has to be increased to at least 38^{o}C before there is sufficient vapor (at least 0.7% according to Kuchta 1986) for a flammable mixture to be created. The large difference between kerosene and gasoline vapor pressure is the key reason why contamination of kerosene by small amounts of gasoline is such a significant fire hazard.

For liquid commodity fuels with low vapor pressures, such as kerosene, the ignition hazard of vapor created above a pool of liquid is conventionally measured by the flash point. The flash point is the temperature at which there is enough fuel vapor to just make a brief flash of light when an open flame is introduced into a small volume filled with fuel vapor and air. A special device known as a flash point test apparatus is used by fuel suppliers and refineries to measure flash point. Historically, two of the most common standardized methods for measuring flash point are the Tag closed-cup apparatus (ASTM D56) and the Pensky-Martins method. The D56 test requires a 50 cc sample of fuel and an experienced operator. In the last decade, new standards and completely automated methods for measuring flash point have been introduced but older methods are still accepted and in wide use throughout the world.

When the flash point of a fuel is significantly less than the ambient temperature, there is a danger of fire when this fuel is improperly handled and fuel-air vapors are exposed to ignition sources like open flames. The specification of Jet A and Jet A1 requires that the flash point be above 38°C (100°F). This is just a minimum specification and the actual flash point varies world wide from a low of 100°F up to a high of 150 to 160°F. The value of 100°F for the minimum flash point of Jet A is somewhat arbitrary. In part, it was chosen so that Jet A can be shipped as a *combustible liquid* – defined as having a flash point above 100°F – rather than as a *flammable liquid* – defined as having a flash point less than 100°F. These definitions are historical in origin and used by the NFPA and the US DOT to classify liquid fuels for the purposes of shipping and handling. [3]

There is no minimum flash point requirement for gasoline. Gasoline is so volatile, that the flash point is -40°C (-40°F) or lower and flash point is not used to characterize the flammability of the vapor. Instead the vapor is characterized by measuring the vapor pressure at 38°C – known as the Reid Vapor Pressure or RVP. Typical values of the RVP range from 40 to 60 kPa (6 to 9 psia). The RVP of gasoline is regulated to be within maximum and minimum values that depend on the season of the year and the stringency of the

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[3] Recently the boundary between flammable and combustible liquids has been changed worldwide to harmonize regulations with the UN classification of Dangerous Goods that places the boundary at 141°F (60.5°C) although an exception is made in the US in the case of fuels like kerosene. See NFPA 30 (2003) and the UN website http://www.unece.org/trans/danger/danger.htm on Dangerous Goods for clarification.

environmental quality regulations in a region. Vapor pressure is a strong function of temperature and during the summer months, the RVP is reduced in order to decrease vaporization losses and prevent vapor lock.

5. Measured Flashpoint of Kerosene-Gasoline Mixtures

The flash point of mixtures of Jet A and gasoline was measured using the ASTM D56 Tag Closed-Cup method. Two sources of Jet A and gasoline were used at the time of testing in 2000. Source A fuels were from southern California refineries. Jet A had a flashpoint of 44.6^{o}C (114^{o}F) and the gasoline was a low RVP formulation (less than 7 psi) based on the Air Resources Board requirements. Source B was from the island of Pohnpei, Federated States of Micronesia. The Jet A had a flashpoint of 41.8^{o}C (107 ^{o}C) and the gasoline RVP was on the order of 8–9 psi.[4]

Approximately 50 cc of liquid were prepared by volumetric measurement and placed in the test apparatus. The ASTM procedure was followed to determine the flash point. The results, which are given in Table 1 and Figure 2 and Figure 3, show that there is a dramatic decrease in the flash point with small amounts of gasoline addition. For source A, linear regression of the measured flash point vs. gasoline percentage yields a reduction of 4.1^{o}C (7.4^{o}F) per each percent addition of gasoline (correlation coefficient $R^2 = 0.99$) . For source B, linear regression of the measured flash point vs. gasoline percentage yields a reduction of 5.9 ^{o}C (10.6^{o}F) per each percent addition of gasoline (correlation coefficient $R^2 = 0.95$). Lentini (1990 and p. 42 of 2006) has also measured the reduction in flashpoint of kerosene with increasing amounts of gasoline and obtained even larger reductions for 10% gasoline addition than found in the present study. His results are comparable with the present data at low concentrations (Figure 4) but at higher concentrations show a larger decrease in flashpoint which may be due to a higher RVP for the gasoline used in his mixtures.

6. Modeling the Flashpoint of Gasoline-Jet A Mixtures

A method for predicting mixture flash points was developed using a simple model (Shepherd et al 2000) based on the concept that the vapor concentration above the liquid at the flash point is at the lower flammability limit concentration. We assume that the lower flammability limit composition for a mixture can be estimated using L'Chatelier's mixture flammability rule (Kuchta 1985) to combine the component flammability limits

$$1 = \frac{X_K}{L_K} + \frac{X_G}{L_G} \tag{1}$$

where the mole fractions X are equal to the ratio of the vapor pressures of kerosene (subscript K) and gasoline (subscript G) in the kerosene-gasoline mixture to the ambient pressure P_{amb}

$$X_K = \frac{P_{vap,K}}{P_{amb}} \quad X_G = \frac{P_{vap,G}}{P_{amb}} \ . \tag{2}$$

and the parameters L_K and L_G are the mole fractions of kerosene and gasoline vapor at the lower flammability limits. We assume that the vapor pressure P_{vap} of the fuels in the mixture is related to the individual component vapor pressures P_σ by Raoult's law assuming that the mixture can be treated as an ideal solution

$$P_{vap,K} = Y_K \cdot P_{\sigma,K} \quad P_{vap,G} = Y_G \cdot P_{\sigma,G} \quad Y_K = 1 - Y_G \tag{3}$$

where Y_K is the mole fraction of the kerosene component in the liquid fuel mixture and Y_G is the mole fraction of the gasoline component. These ideas were used by Affens and McLaren (1972) to successfully model binary mixtures and extended to kerosene mixtures by Shepherd et al (1997, 2000). The individual component vapor pressures were represented by the approximate formula

$$P_\sigma = C_1 \exp(-C_2/T) \tag{4}$$

where the temperature is in Kelvin. The coefficients C_1 and C_2 were determined for Jet A at Caltech (Shepherd et al. 1997, 2000) and values for gasoline were fit to the vapor pressure correlation given by Kuchta 1985. To account for differences between the reference and test fuels, the pre-exponential constant C_1 was adjusted to give the measured flash point for kerosene and the measured RVP for gasoline. Values of the coefficients used for the reference fuels are given in Table 2. Combining Eqs. 1-4, we obtain an expression for the mole fraction of gasoline Y_G as an explicit function of the flashpoint temperature.

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[4] The fuel was shipped from Singapore to Guam, then to Pohnpei. The RVP was tested in Guam but some reduction is expected due to evaporation during shipping.

Predictions are shown in Figure 2 and Figure 3 for several values of the RVP consistent with the range to be expected for each source of fuel. The uncertainty associated with each datum is derived from the discussion in the ASTM D56 standard. The degree of agreement between the model and the measurements is reasonable given that the vapor pressure and flammability limit of the gasoline was not actually measured but only estimated. The comparison shown in Figure 4 indicates that the Lentini data is consistent with a RVP of 13 psi, within the range that is possible for the winter season. The RVP is higher in the winter than in summer, so that all other factors being the same, contamination with gasoline purchased in the winter will result in a lower flash point than for gasoline bought in the summer.

7. Miscibility of Jet A and Gasoline

The miscibility of Jet A and gasoline was examined by making measurements with a GC/MS on samples withdrawn from vials filled with mixtures of Jet A and gasoline. Five 20 ml vials were used with contents as specified in Table 3. The Jet A gasoline mixtures all had a nominal gasoline concentration of 10% by volume. In mixtures 30 and 31, the fuels were not stirred after being carefully placed in the vials with a pipette. The Jet A was introduced first into vial 30 and the gasoline was introduced first into vial 31. No systematic changes were observed for the samples taken at 3 and 10 days. There was no evidence of separation of the different components in either the parent fuels or in the mixtures of Jet A and gasoline. Visual examination of the vials indicated that no meniscus or variation of color (the gasoline and kerosene contained different color dyes) could be observed in any of the vials.

The vials were sampled with a 1 microliter syringe at top, middle and bottom locations 3 days and 10 days after the samples were prepared. About 0.1 microliter of the sample was injected into the GG-MS combination as described previously for the tests on Jet A and gasoline. The syringe was cleaned with cetane between samples. Statistical analysis of the TICs for samples 30, 31 and 32 show no systematic differences with either time or sample location with a correlation coefficient of 0.94 or higher for a linear regression analysis on peak areas obtained at 3 and 10 days after mixing. The loading process and natural processes (diffusion, thermal convection) within the vials ensured that complete mixing occurred without any active stirring. Two sets of TIC results are shown in Figure 5 for samples taken 10 days apart from vial 32. The presence of the gasoline in the mixtures is manifested by the characteristic TIC peaks at retention times earlier than 11 min, which are observed in the gasoline TIC (Figure 2) but not the Jet A TIC (Figure 1). In particular, the alkyl benzene peaks at about 8.5 min are considered (ASTM E1618) to be key indicators of gasoline. Quantitative analysis of the area under each peak (proportional to the abundance of that species) reveals that the relative abundance of these species changed less than 4% in 10 days based on a sample of 60-70 peak areas for each of the samples shown in Figure 5. Differences in individual peak heights are apparent in these graphs but some care must be taken in drawing conclusions about relative abundance since the scales are different in each case.

These tests clearly show that even though gasoline is less dense (density of about 0.74 g/cc) than kerosene (density of about 0.82 g/cc), complete mixing takes place without any tendency to separate out of solution. This is an important aspect of the gasoline contamination issue – once kerosene has been contaminated by gasoline, it is impossible to separate the gasoline from the kerosene by physical methods and contamination cannot be detected by simple visual examination. This is a consequence of the identical nature of the hydrocarbon molecules that make up gasoline and the lighter (lower molecular mass) components of kerosene.

8. Summary

The flash point of aviation kerosene (Jet A) is dramatically reduced by contamination with even small amounts of gasoline. Measurements of flash point for gasoline-kerosene mixtures with up to 10% gasoline showed a substantial reduction of flash point with gasoline addition. For the two sources of fuel examined in this study, an initial reduction in flashpoint of 4 to 6^{o}C (7 to 11^{o}F) per percent of gasoline added was observed. The relationship between flash point and concentration is linear only for small amounts of gasoline addition. The data and our model predict a decreasing rate of reduction with increasing gasoline concentration for large amounts of gasoline addition. Gasoline and kerosene were observed to be miscible and remain mixed over a period of weeks without any visible or measured fractionation despite the large initial differences in density. Contrary to some popular misconceptions, it is not possible to detect contamination by simple visual inspection and contaminated fuel will not spontaneously separate into gasoline and kerosene components.

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Table 1. **Measured flashpoint of kerosene with small amounts of added gasoline.**

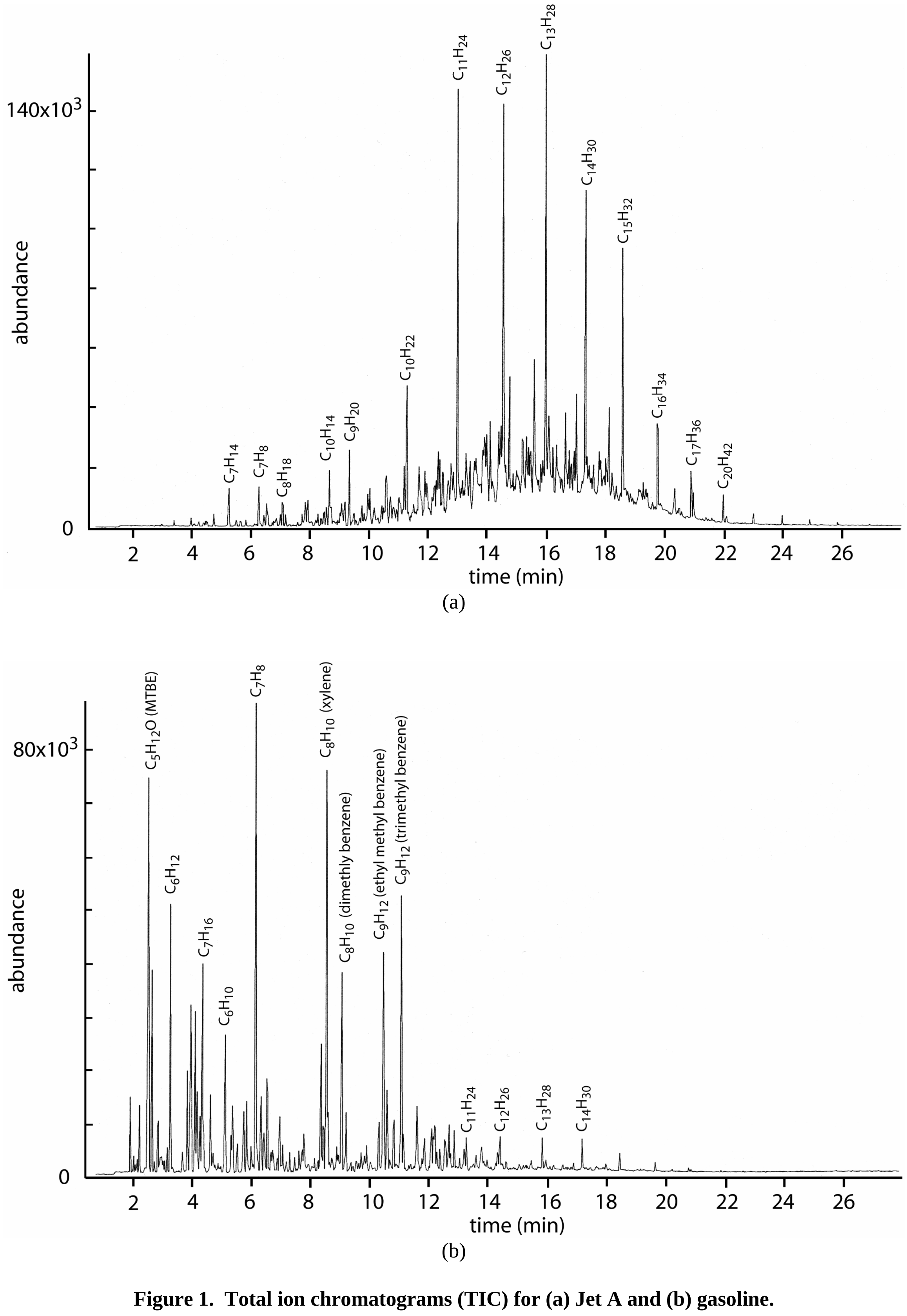
% Gasoline in mixture	Flash point
Source A	
0	44.9°C (113°F)
1	40.8°C (105°F)
2	35.2°C (95.4°F)
3	32.8°C (91.0°F)
10	3.5°C (38.3°F)
Source B	
0	41.7°C (107°F)
1	33.1°C (92°F)
2	25.6°C (78°F)
3	19.4°C (67°F)
4	15.0°C (59°F)
6.5	5.0°C (41°F)

Table 2. Coefficients used in the flammability model.

Substance		L	C_1 (kPa)	C_2 (K)
Gasoline	(RVP = 6.5 psi)	.013	3375000	3489
Kerosene (Jet A)	(FP = 113°F)	.007	575000	4191

Table 3. Samples used in miscibility study.

Vial Number	Mixture
28	Jet A
29	Gasoline
30	18 ml Jet A + 2 ml gasoline, not stirred
31	2 ml gasoline + 18 ml Jet A, not stirred
32	18 ml Jet A + 2 mil gasoline, stirred



(a)

(b)

Figure 1. Total ion chromatograms (TIC) for (a) Jet A and (b) gasoline.

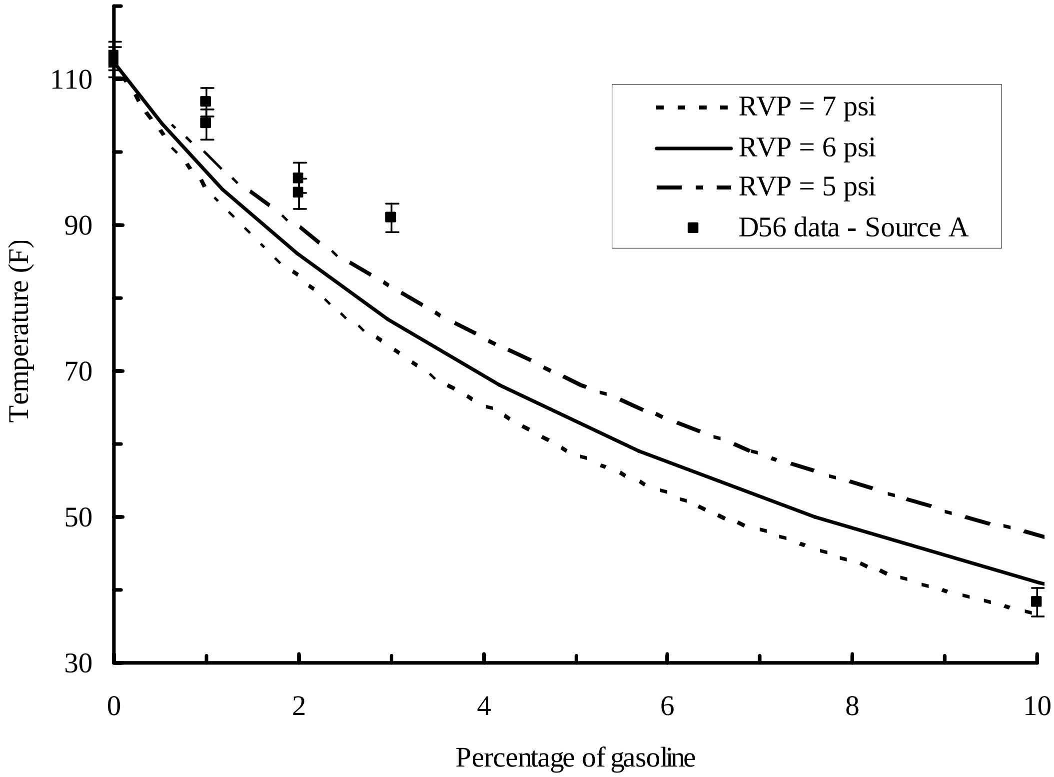


Figure 2. Measured and predicted flashpoint for Source A fuels.

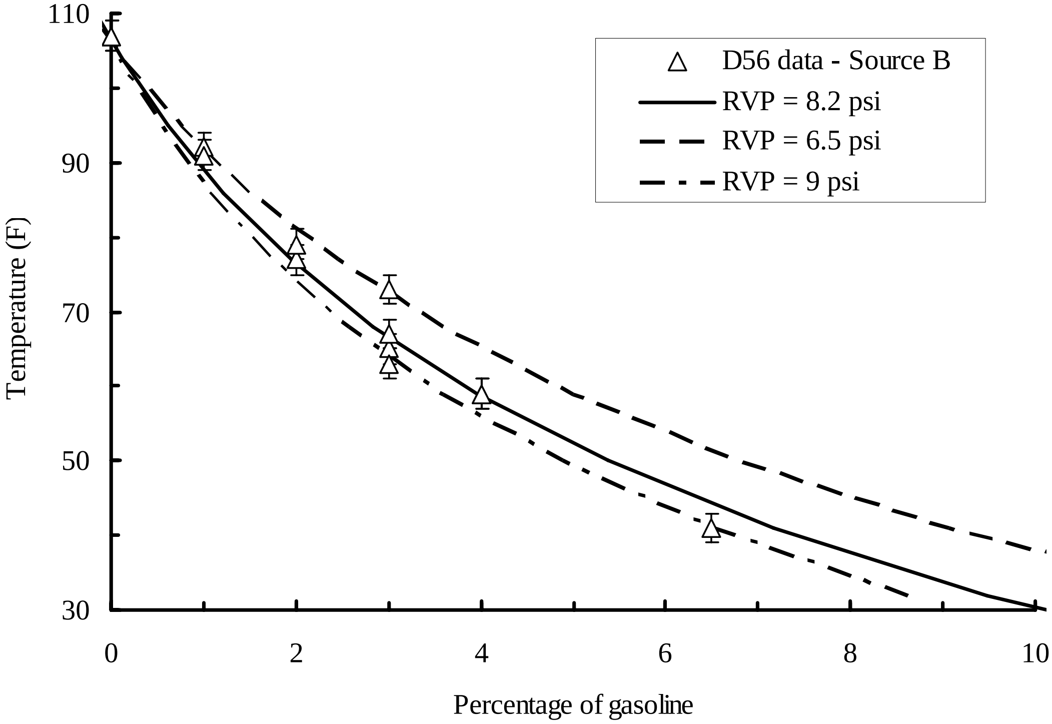


Figure 3. Measured and predicted flash points for Source B fuels.

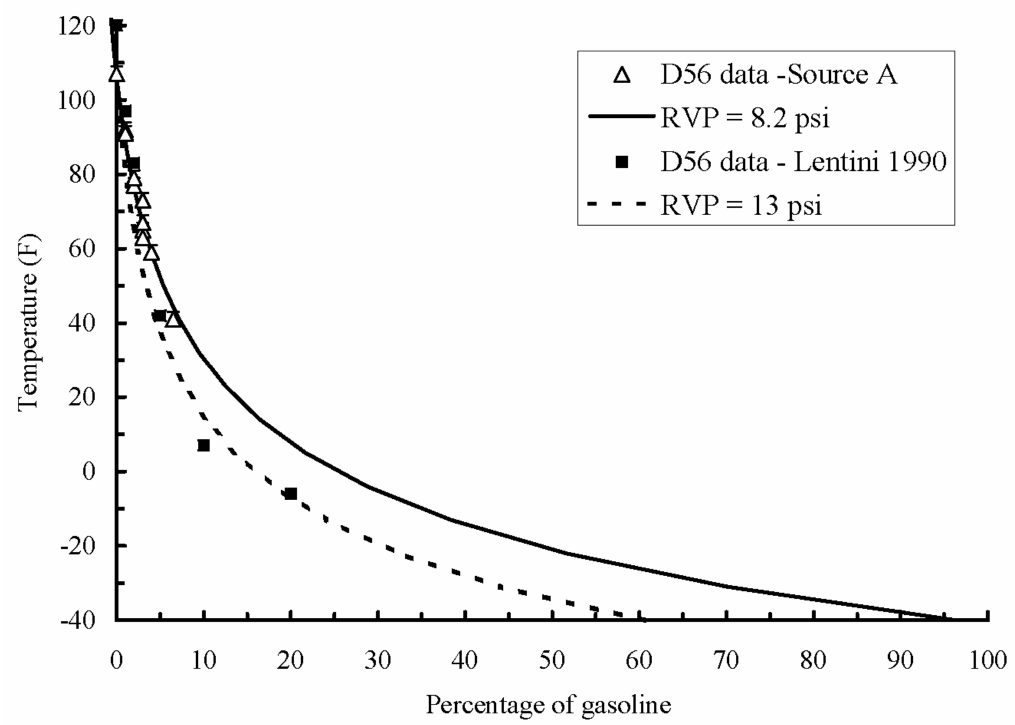
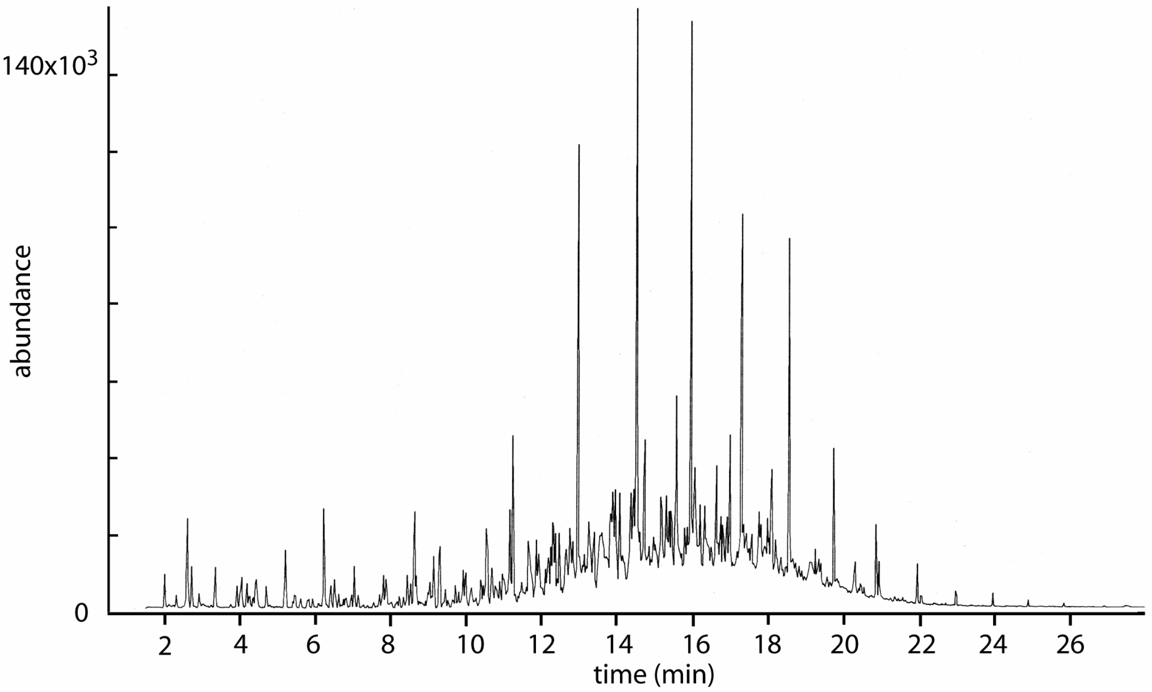
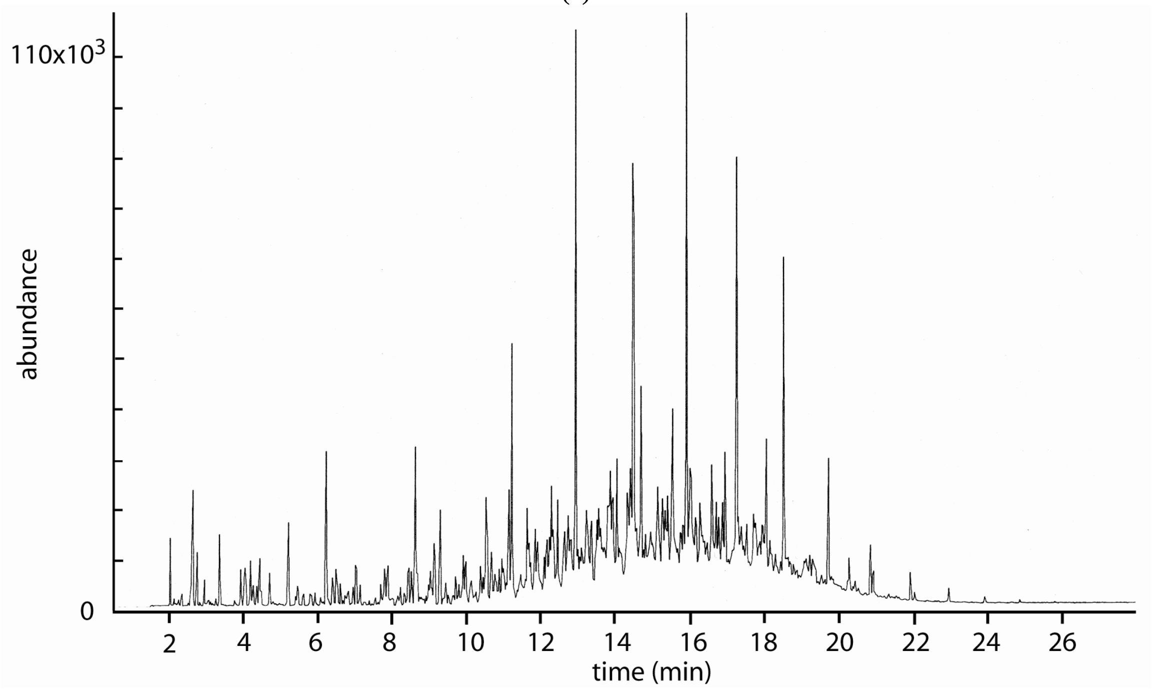


Figure 4. Comparison of the present data with that of Lentini (1990) and model results for two values of the RVP. The value of 13 psi for the RVP was chosen to give a reasonable match to the 5, 10, and 20% gasoline data of Lentini.



140x10^3
0
abundance
2
4
6
8
10
12
14
16
18
20
22
24
26
time (min)

(a)



110x10^3
0
abundance
2
4
6
8
10
12
14
16
18
20
22
24
26
time (min)

(b)

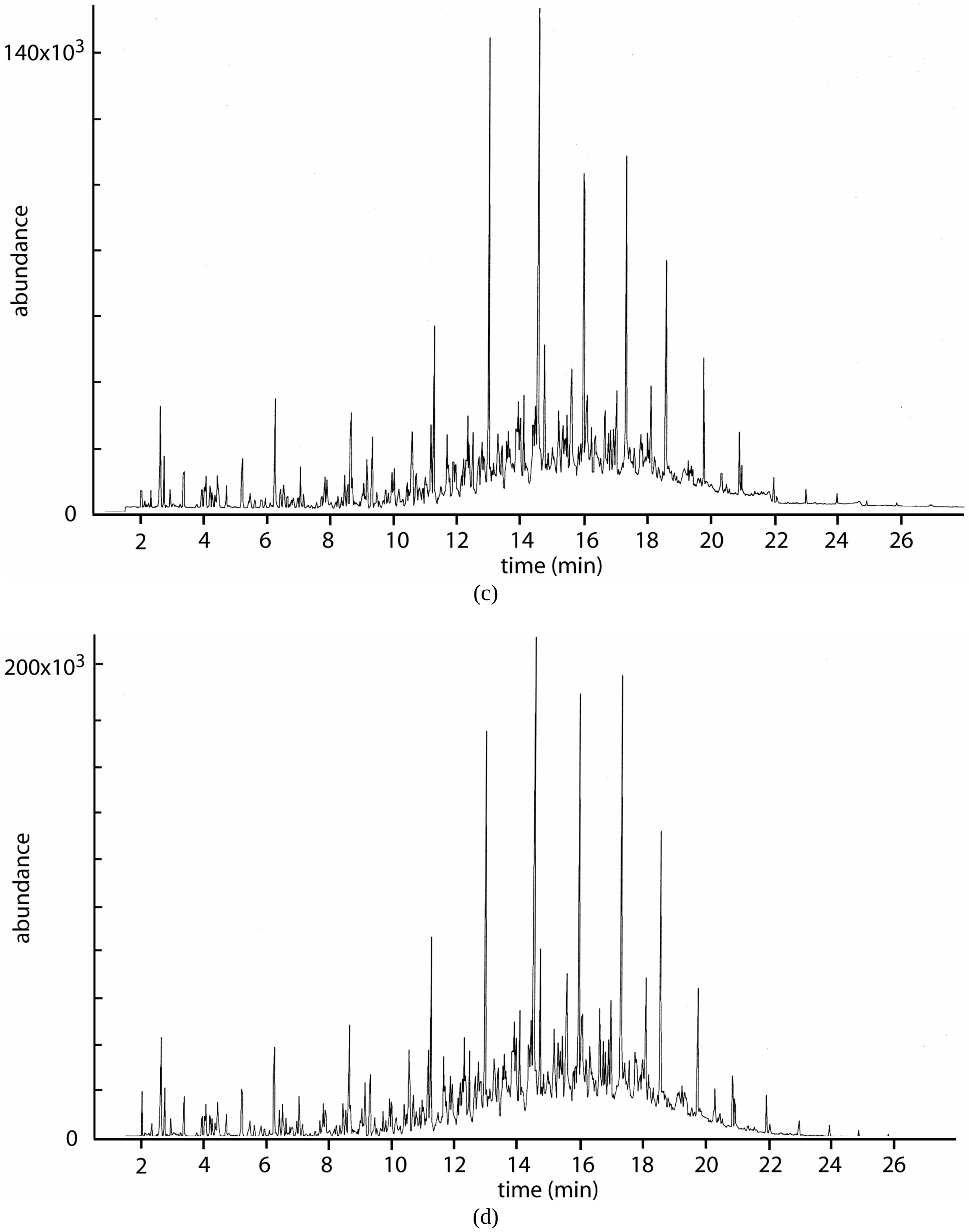


Figure 5. TIC results for samples of 10% gasoline – 90% Jet A, taken 10 days apart. (a) from bottom of vial, immediately after preparation, (b) from bottom of vial, 10 days later, (c) from top of vial, immediately after preparation, (d) from top of vial, 10 days later.