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November 1993

REGIONAL NETWORK ON CONTROL AND REGULATORY MEASURES CONCERNING MOTOR VEHICLE EMISSIONS

DP/RAS/89/057

ASIA-PACIFIC REGION

Guidelines

on Consideration of Automotive Fuel Quality Standards and their Effect on Motor Vehicle Emissions in the Asia-Pacific Region

Prepared for countries of the Asia-Pacific Region
by the United Nations Industrial Development Organization
acting as Executing Agency for the
United Nations Development Programme

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EXECUTIVE SUMMARY

The Asia-Pacific region is experiencing the most rapid motor vehicle growth rate in the world, and in many urban areas, this is bringing with it commensurate increases in air pollution. In order to contain these increases, a comprehensive programme of effective vehicle emission reduction is necessary, and this needs to cover all aspects from the requirements for new vehicles to the provision of fuels and 2-stroke oils that will allow vehicles to operate at their optimum emissions performance.

The provision of fuels equivalent to those upon which vehicles are type-approved for emissions compliance, is likely to be an extremely expensive and lengthy process, as in many of the countries of the Region, the fuels quality is well below that of the major vehicle manufacturing countries, and thus of the homologation and reference fuels used for vehicle design and testing. For leaded motor gasolines, aimed largely at existing non-emission-controlled vehicle populations, this may be less important, as this situation already exists in many other countries, and the major emphasis should be on product consistency with a gradual improvement in quality over time. For unleaded motor gasolines however, destined for use in low-emission vehicles, there is a requirement to minimise emission deterioration over the target vehicle life (say 80 000 km), and this is best achieved by qualities close to the reference fuel properties. These factors are taken into account in these Guidelines by setting 'lowest' quality requirements for such motor gasolines, which are judged to achieve close to design emissions over the vehicle life. The introduction of low-emission vehicles should thus be timed to coincide with the availability of unleaded motor gasolines meeting at least these requirements.

For diesel fuels, the situation is more complex, as the US and Japanese reference fuels are at present rather less well defined than ECE-03-A-84, there is 'slippage' in the dates of implementation of lower sulfur limits into these reference fuels, and there are significant differences in volatility which make strict comparison difficult. The major determinant of choice however is quantity, and with high diesel/gasoline ratios, the European model, allowing a broader distillation range, is more appropriate to the countries of this Region.

Because of the low octane capacity in oil refineries in some countries, combined with older vehicle design manufacture and poor maintenance, the first priority may well lie in terms of tackling the problems of fuel consumption (CO_2 emissions) and toxic exhaust emissions rather than the control of regulated pollutants. However, a strategy for the introduction of at least a limited availability of adequate quality unleaded motor gasoline for low-emission vehicles is recommended. The early introduction of low quality unleaded motor gasoline, not meeting the 'lowest' quality specified in these Guidelines, (apart for use in 2-stroke engines) to fuel imported low-emission vehicles is not recommended.

There are improvements that can be made however, and a programme of octane quality upgrading should be embarked upon in many, if not most, of the countries of the Region. This will enable lead contents in leaded motor gasoline to be reduced, benzene contents to be controlled, and sulfur and volatility limits to be improved, and eventually, will lead to the introduction of unleaded motor gasoline in those countries at present unable to provide such a product at the required quality level.

For automotive diesel fuel, the situation may well be more difficult and expensive, largely because of the strong linkage between feedstock quality and final fuel quality. This is particularly true of the two major fuel quality precursors of regulated pollutants, namely ignition quality and density, where many of the feedstocks indigenous to the countries of the Region, do not provide adequate fuel quality through conventional oil refining. Sulfur contents are also high in many countries, leading to both high SO_x and PM emissions, and this is a problem that may be solvable alongside improvements in motor gasoline octane numbers, as increased catalytic reforming capacity, particularly in terms of the latest designs of continuous units, will automatically increase the availability of hydrogen, necessary for de-sulfurisation

Alongside all the recommendations for fuels quality included in these Guidelines, there is a need for an infrastructure of Standards and quality monitoring. This is considered in detail in the Guidelines, and recommendations on the structure and content of both Standards documents and quality monitoring systems are included.

To attempt to cover recommendations for fuels quality across the Asia-Pacific region in a harmonised manner, a long-term strategy is required providing step-wise improvements in individual countries towards an overall target quality for each fuel grade for the Region. Such a policy allows individual countries to introduce parallel improvements in vehicle design and emissions performance. There is scope for regional co-operation in the setting of limiting values for a range of properties in both intermediate and target qualities, but most importantly, in the manner in which fuel standards are prepared, and the test methodology used for the definition of fuels properties.

These Guidelines set out the principles behind the setting of fuels standards for the Region, and provide information on the relationship of fuels quality parameters with engine design and with socio-economic factors. The extent of co-operation between the countries of the Region, in implementing these recommendations as part of their air quality strategies is to be determined at the Expert group Meeting.

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1. INTRODUCTION.

These present Guidelines dealing with the contribution of fuel qualities to motor vehicle emission control in the Asia-Pacific region, were prepared in the framework of UNDP/UNIDO Project DP/RAS/89/057 'Regional network on control and regulatory measures concerning motor vehicle emission'. The following countries of the region have declared their participation or interest in the Project: Peoples Republic of China, Hong Kong, Iran, India, Indonesia, Republic of Korea, Malaysia, Philippines, Singapore, Sri Lanka and Thailand.

The main objectives of the Project are as follows:

- to initiate, develop and promote the cooperation among participating countries in the area of motor vehicle emission control, to establish working contacts between organisations dealing with motor vehicle emission control in these countries and to set up the nucleus of the operational regional network, which would develop recommendations for common standards and policy in the mentioned area;

- to lay down terms for the introduction of common standards and control procedures for motor vehicle emission control, at least for certain groups of countries within the region.

For this purpose, a series of Guidelines for vehicle emission related issues requiring a common approach within the region, will be prepared to assist the individual governments to address motor vehicle emission problems. These Guidelines will take into account region-specific conditions which affect potential solutions of common problems, such as vehicle design, vehicle population structure and density, road traffic, vehicle maintenance, economic conditions, current air quality, fuel quality, etc.

At the 'Expert Group Meeting on Control and Regulatory Measures Concerning Motor Vehicle Emission in the Asia-Pacific Region', held in Seoul form 21st to 24th August, 1990 during the preparatory phase of the Project, the following issues to be dealt with by a common regional approach were identified:-

- emissions standards for new vehicles,

- procedures for inspection of in-use vehicles,

- fuel quality standards,

- practical policies to improve the maintenance of vehicles.

These present Guidelines constitute the third in the series of four Guidelines to be prepared under the Project. The draft was prepared by a UNIDO consultant on the basis of, and taking account of:

i) reports of the Expert Group Meetings held under the Project [1], [2], [3], in particular, Country Papers included in the above reports,

ii) two other Guidelines already prepared under the Project [4], [5],

iii) results of fact-finding missions to the region and comments of concerned organisations in visited countries to suggestions and recommendations with regard to new motor vehicle emission control, and in-use motor vehicle inspection and maintenance in the region, and strategy for improving fuel quality,

iv) experience of countries conducting comprehensive and effective motor vehicle emission reduction programmes, and practices being followed in those countries,

v) experience of participation in the generation of pan-National fuel Standards and associated petroleum test methods.

2. SCOPE AND OBJECTIVES.

2.1 Scope. The scope of these Guidelines covers considerations regarding the compilation of standards for the quality of:

-gasolines for spark-ignition (SI) engines,

-diesel fuels for compression-ignition (CI) engines,

-oils for blending with fuel for 2-stroke engines.

The scope only covers on-highway applications of these fuels.

2.2 Objectives. The major objectives of these Guidelines can be summarised as:

-to provide the information necessary to formulate effective standards for automotive fuel quality,

-to lay down the outline of a strategy for the improvement of automotive fuel quality,

-to indicate a route for the gradual harmonisation of automotive fuel quality standards within the region,

-to indicate, where necessary, vehicular modifications needed to take advantage of improved fuel quality,

-to prioritise, where possible, the automotive fuel quality aspects contributing to air quality standards in participating countries.

The objectives take into account that the situation and conditions are different in each country, and thus the starting point in any harmonisation process will be different. Some of these aspects will be dealt with in more detail in 3.4.

3. BACKGROUND/OVERVIEW.

3.1 Overall emission strategy. An emission strategy is only one tool of a number of tools available for the maintenance or improvement of ambient air quality in urban areas. Air quality is thus the focus, emission strategy one tool, and vehicular emission strategy, including fuel standards and quality control, only one part of this tool. It is essential that an inventory of those harmful contributors to ambient air quality, together with their sources, is clearly defined before such a strategy is embarked upon. A coherent vehicular emission control strategy is inordinately expensive, impacting not only on the capital and revenue expenses of both the motor and oil industries, but also on the capital and revenue necessary to set up and maintain and infrastructure that ensures continued compliance. In addition, although not directly part of this Project, care must be taken that there is not a swop of one type of harmful gaseous emission for another, in particular, the increase in greenhouse gases (energy) used in the vehicle manufacturing and oil processing industries, exceeding the efficiency gains by the end users.

Most important of all are the socio-economic implications of a vehicular emissions regime of any potential impact. Many factors contribute to this, and some will be highlighted further in these Guidelinest, but two appear to be of overwhelming importance in several, but not all, countries involved in this Project.

3.1.1 **Composition of the 'private' vehicle parc.** To achieve a reduction in vehicular emissions from the privately owned sector of the vehicle parc in a reasonably short time period, is not so dependent on the emission strategy for new vehicles, or even the maintenance of these emission standards, as on the strategy for the worst emitters amongst the existing vehicles. The Unocal 'SCRAP' programme[6] in the US showed that even in the relatively affluent and sophisticated environment of California, about 3% of the private car parc was pre-1971, and did not have any forms of pollution control equipment fitted. Examination of a reprentative portion of this sector showed that these cars emitted between 10 and 100 times the three key pollutants, than current cars. Extrapolating these results to the whole car parc, showed that this 3% of vehicles could account for 30% to 50% of the total emissions from private vehicles.

If we look at this in the context of the region involved in this Project, where the proportion of gross emitters is obviously much higher, including a vast population of two-and three-wheeled vehicles powered by two-stroke engines, we need to apply a different strategy to maintain, or improve, the emission performance of this sector, recognising that enforced, or even incentivised, removal is an impracticable solution. The options lay only in the maintenance and fuels quality areas, and to some extent these can be enforced through regulations on fuels Standards, and in-use testing, but the effect will be relatively moderate. The real improvement is unlikely to exceed 10 %, with the maximum potential only 20 %.

Unfortunately, the poorest maintained vehicles are generally owned by the poorest sector of the community able to afford any form of personal mobility, and thus prone to the least maintenance, and the cheapest fuel/lubricant options available. Before adding to this sector's costs, a cheap reliable alternative (mass transit) is probably necessary. Allowing this population to continue, or even to grow, in an uncontrolled manner, could more than negate any emission control strategy applied to other vehicle sectors. This will be a particular problem for three or four of the countries involved in this Project.

In urban areas of high concentrations of 2- and 3-wheeled vehicles running on 2-stroke engines, there is no doubt that they are disproportionate contributors to the decline in ambient air quality. As such, they demand high priority for control. As discussed earlier, it would be difficult to eliminate, or even reduce, the worst offenders in the short term, although that would be the the approach to show real gains in air quality. It will be necessary to 'contain' the existing population by the regulation of fuel/lubricants used in the vehicles, and by in-use inspections, and to 'control' the emissions performance of new vehicles (of course, also with regulations on the fuel/lubricants). The current difficulty is the choice of emissions limits for these engines. The requirements specified in ECE Regulation 40/01 are lenient, and exert only limited control. If more stringent emission limits are required to address the air quality problems, then those currently applied in Austria, Switzerland or the US could be considered. Details of these are given in 'Guidelines for New Motor Vehicle Emission Control in the Asia-Pacific Region' prepared under this Project [5].

3.1.2 **Contribution of the heavy vehicle parc.** For the large majority of countries involved in this Project, the consumption of diesel fuel is considerably higher than that of gasoline. With the exception of Singapore and China, the ratio of diesel fuel consumption to gasoline was generally in the range of 3:1 to 6:1. This of course means that vehicular emissions of particulate matter (PM) and NO_x are largely from the heavy duty sector, since apart from taxis, and some vans and minibuses, there are few passenger car diesel engines. The taxis themselves may be a particular problem in a few urban areas. Many of the heavy duty vehicles observed were ancient, both in design and longevity, and badly maintained.

This sector poses severe socio-economic problems because of the direct relationship between the costs of transportation, either for the distribution of goods, or for the carriage of people, and the consumer price indices. The ability of carriers to generate capital for the replacement of obsolete vehicles, and to maintain their condition throughout their working life, must be addressed as part of the overall air quality strategy.

In addition, it is the emissions from these vehicles (particularly smoke) that are most sensitive to traffic speed, and thus most affected by traffic management decisions.

In some urban areas visited, the contribution of vehicular emissions to the total ambient air particulate content was less than 10%, although this does not take account of the relatively more hazardous nature of diesel particulate matter in particular. Their complete elimination would result in a barely measurable decrease in ambient air particulate burden. In such cases, a much lower priority to the inordinate expense required, would seem to be warranted. A similar argument may be put forward for SO_x emissions, where it would seem unreasonable to drive automotive fuel sulfur contents down to very low levels, even below 0.01 %(m/m), whilst allowing industry and off-highway applications to continue with uncontrolled emissions from fuels as high as 4 %(m/m) sulfur content. Smoke however is another matter. It is emitted from vehicles at low level, it is visible, and it is generally unpleasant, and may even be harmful.

3.2 The Contribution of Fuel Quality. The dominant factor which determines the emission of the 'controlled' pollutants (CO, HC, NO_x, PM) is the engine design and condition, and, as for the assessment of octane requirement for new vehicles, differences between individual vehicles of the same make and model often exceed the differences between makes and/or models. Fuel quality does play a role however, which becomes more critical as new vehicles are produced to meet tighter emissions limits. The relationship of fuel quality to controlled emissions on older, poorly maintained vehicles is more tenuous. Annex G gives detailed information on the relationships of engine design and operational features that interact with fuel quality options, and a brief synopsis only is given here of some of the major implications. The recommendations of this summary are incorporated into the 'target' fuel qualities given in tables 1, 2, 6, 7 and 9 of these Guidelines.

There are some features of fuel quality however, that do have a direct impact on emissions, irrespective of the vehicular contribution, and these relate to the composition of the fuel, both hydrocarbon and non-hydrocarbon. There is thus a direct and fairly immediate, benefit to air quality obtainable by regulating these constituents.

3.2.1 **Fuels for SI Engines.** It is vital that all future production of SI engines has suitable metallurgy to accommodate the use of unleaded motor gasoline, irrespective of the time-scale envisaged for the introduction of catalytic converters to meet more stringent controlled emission limits. These engines, without converters, can still accommodate leaded fuel, where unleaded fuel is not available, but delays in their introduction put back any potential phase-out of leaded motor gasoline by the turnover life of vehicles in a given market.

For leaded motor gasolines, every effort should be made to reduce the maximum lead content to 0,15 gPb/l at the earliest opportunity. Apart from the direct effect on the lead burden in ambient air, this will stimulate the first stage of 'clear octane' enhancement in refineries.

For all motor gasolines, the benzene content should be controlled at a maximum of 5 %(V/V), and in the longer term, perhaps even lower.

There will be benefits to the emission of regulated pollutants from tighter control of limits, and particularly tolerances, on a number of other fuel properties and constitution and for new engines, these benefits may be considerably enhanced by a close matching of fuel quality with engine design features. These properties include:

i) **Density**-closer tolerances will contribute to lower HC and CO emissions,

ii) **Volatility**-closer tolerances lead to better driveability '(lower HC), and controlled maximum volatility also reduces evaporative losses,

iii) **Composition**-the use of oxygenates has a beneficial, but small, effect on CO emission,

iv) **Additives**-there are many effective engine system cleanliness additives available. The main objective of this type of additive is to maintain the engine in 'as-new' condition, and thus not increase in emissions with time and the malfunctions associated with deposits.

3.2.2 **Fuels for CI Engines.** A major contributor to both particulate matter (PM) and SO_x emissions is, of course, the sulfur content of the fuel, and this needs to be regulated. The level chosen should be part of a coherent strategy of sulfur and particulate emissions from all fuels, and the specific contribution of vehicular emissions to this total. Maximum levels of between 0,50 %(m/m) and 0,20 %(m/m) would seem to be reasonable in the short to medium term, with lower levels down to 0,05 %(m/m) being considered only when both the environmental and economic circumstances dictate and/or allow.

There is potential for very good matching of engine design features and fuel quality in CI engines, but only limited advantage can be taken of this. The key to the matching is tight tolerances on some of the fuel properties, enabling engine settings to be optimised, e.g.smoke stops and fuel pump settings, but the natural variations in these qualities from a variety of feedstocks, makes the imposition of extremely tight tolerances impracticable in most instances.

The most noticeable emissions from CI engines are smoke, both white on start-up and warm-up, and black during running. The dominant contributor to white smoke is ignition quality, and to eliminate this completely, higher ignition qualities than any specified in any market are probably needed (European diesel manufacturers estimate a cetane number of 52 to 54 is required). Significant reductions do start above about 48 cetane number, and that recommended in the 'target' quality is the same as the present European limit of 49 minimum. For black smoke, the prime contributor is density, with ignition quality again being a strong influence. Density maxima are being reduced world-wide in response to increasing evidence that values above 865 kg/m^3 dramatically increase smoke and particulate emissions. Higher densities also increase CO emissions.

Other fuel properties that influence emissions and performance include:

i) **Viscosity**-minimum to protect fuel pumps from lubricity failure, and maximum to ensure good droplet formation and fuel/air mixing,

ii) **Volatility**-front-end to ensure ignition, and back-end to reduce CO and HC (and to restrict the availability of PAH in the fuel, which may be directly related to PAH in particulates),

iii) **Carbon residue/ash**-to control injector/port/valve deposits which may lead to erratic combustion,

iv) **Additives**-a similar range of additives to those for SI engines is available.

3.3 Fuel Qualities and Trends. In most of the highly industrialised countries, there has been considerable activity over the past 5 years on automotive fuel quality, driven by proposed increasingly severe emissions limits for controlled pollutants. This is particularly noticeable for the motor gasoline engined vehicles, where this has meant that now in all of Europe, Japan and North America, new vehicles have to be fitted with catalytic converters, fuel injection and engine management systems, and thus can only run on unleaded motor gasoline. Japan has already discontinued the sale of leaded motor gasoline, and the US will complete this process by 1997, and other countries are close to a similar conclusion. Europe has produced 'common' specifications for unleaded motor gasoline (EN 228) and automotive diesel fuel (EN 590) which are legally binding in 19 countries, but largely because of climatic variations, these do appear to be rather complex, rather in the manner that ASTM D4814 has complexities when applied to the US. Unfortunately, both in Europe and the US, there is a trend to 'environmental' grades of fuel (particularly automotive diesel fuel) being specified in sub-areas, encouraged by fiscal incentives/penalties, which confuses the issue still further. This trend has already had severe market disturbing effects in some areas, to the extreme that in California, four of the major marketers (BP, Shell, Mobil, Texaco) have withdrawn from the automotive diesel fuel market, creating a severe shortage. A similar situation is developing in Sweden.

The major benefit of the mainstream activity has been the gradual harmonisation of both emissions limits and more particularly, homologation fuels and reference fuels for type-approval testing, giving the multi-national motor producers at least some scope for rationalisation, and the oil refiners a basis for upgrading facilities abeit often on an unrealistic time-scale.

There are considerable uncertainties over the next steps in these industrialised countries, and this makes predictions beyond 2000 rather dependent upon both the perceived impact of current changes on ambient air quality as the vehicle/fuel parc homogenises, and the world-wide economic climate enabling vastly expensive further changes to be accomplished. It is likely that evaporative emissions, both vehicular and distributional, will receive more attention, and this will be applied to vehicles, infrastructure, and fuels, and that more attention will be given to the **nature** of emissions, rather than their quantity (this particularly applies to PM from CI engines, and aldehydes from SI engines). The danger is that having achieved limited harmonisation, we may see fragmentation in the future, with the most environmentally active legislatures pushing severe emissions strategies on the sole basis of achievable technology, rather than of air quality and cost-effectiveness.

Changes in fuel quality in these industrialised countries between now and 2000 are, of course, already known, and are relatively minor, apart from the reduction in sulfur content in **both** motor gasoline and automotive diesel fuel to 0,05 %(m/m) maximum at some time (1994 in US, 1995/7 in Europe and possibly 1998 in Japan). There is likely, during this period, to be some form of official 'accreditation' of additives which already occurs by some motor manufacturers, motoring organisations or independent bodies, in some countries.

The major changes in the definition of fuel quality will be the full introduction of new test methodology for vapour pressure of motor gasolines, and for low temperature operability of automotive diesel fuels. Both of these will have some small impact on limiting values for these properties.

3.4 Outline Strategy for Improving Fuel Quality. The overall strategy for individual countries wishing to improve their fuels quality and/or control system will be obtainable from the whole of these Guidelines, but a summary of some of the key points is included here.

For a number of countries, the investment and organisational changes required will not be forthcoming in the short term, in order to produce any form of 'harmonised' fuel specifications. Furthermore, the lead times for major changes to both vehicle and oil manufacturing facilities, imply at least a 5-year delay before the process can even start in some countries. This is inevitably going to lead to some very significant pressures for change from environmental lobbies, vehicle importers, or external bodies, and could well lead to expensive and unwelcome interim measures. Unless the overall direction of the air quality and emission policies are coherently de vised, then many of these interim measures will need to be revised, or even reversed, as the strategies evolve. At best then, these Guidelines should provide a series of integrated fuel and emisssion standards, directionally trending from almost the worst in existence towards a judgement of the harmonised position required in say 10-15 years time, and allow individual countries to choose their position and rate of progress.

In the initial stages, these Guidelines cannot include consideration of all possibilities, and therefore can only look at the optimum solutions **within** countries, with the aspiration that the progress of countries along a quality improvement route will gradually eliminate barriers to harmonisation.

In summary, the minimum requirements necessary to implement an effective automotive fuels quality strategy should include the following major elements:

i) A National Standard, which may be the National implementation of a Regional Standard, of which at least the properties of fuels contributing directly to environmental air quality degradation, are legally binding.

ii) An infrastructure for the monitoring of automotive fuels quality for conformance to the National Standard.

iii) A standardised regime for the monitoring of automotive fuels quality, including a focal point, sampling regimes for various types of outlet, and testing regimes for both random and programmed compliance testing.

The approach of individual countries towards a 'harmonised' or 'target' fuels quality will be to determine their position between 'lowest' and 'target' qualities, and to plan a structured route and time-scale, dependent upon their individual capacity for change. For vehicles with SI engines, the major priority is to ensure the correct metallurgy (see 3.2.1), and then introduce some, if only limited, availability of unleaded motor gasoline at the earliest opportunity. The introduction

of low-emission vehicles recommended in Guidelines for New Motor Vehicle Emission Control in the Asia-Pacific Region [5] can only be integrated with the availability of these fuels.

4. STANDARDS CONSIDERATIONS.

4.1 General. In the creation of consensus petroleum product standards for the main tranche of products (fuels and lubricants), a balance needs to be achieved between the petroleum product supplier, the equipment manufacturer (in this case the engine manufacturer), the end-user, and the regulator. This balance, when achieved, is often extremely fragile, and in the best cases, wholly satisfies no party (the principle of 'equalisation of misery'). In an exercise such as this Project, it is obviously not possible to enter into protracted discussions in 11 countries to achieve this balance (if it were a realistic aim in any case), and therefore an approach is needed which will inevitably include some form of imposition, unwelcome though it may be to some of the parties, although already a de facto position in some countries.

An attempt has been made to assess the major sensitivities to change by the various parties, and to gauge the economics, and thus cost-effectiveness, of such changes. The missing factor is of course, the potential air quality impact of the changes, and this can at best only be roughly gauged from forecast vehicle population data, both by numbers and by type, in combination with parallel changes in fuel quality. Of course, in many countries, it is this vehicle population, together with inspection and maintenance regimes, and traffic management, that will have the greatest impact on air quality in the short to medium term, and thus there needs to be a series of concurrent strategies dealing with both the current vehicle parc, and particularly the older part of this, and new vehicles, together with their projected life. Depending on the vehicle factors, will be the fuel types needed, and following from that, the logistics and rationalisation to a realistic grade structure for each individual market.

4.2 Petroleum fuel standards. The published, widely available, normally National (or pan-National), fuel Standard, is only the visible tier of three standards, and this helps to explain the long lead times in implementation of radical changes to existing standards.

The first tier of these is the 'homologation' fuels, which are those upon which engine design is based. Although not full Standards, they contain the essential features for the engine designer to optimise his configuration for thermal efficiency and durability, and thus needs to be known at least 5 years in advance of the implementation of new National Standards. Of course, the choice of existing homologation fuels eliminates this lead time, but it must be realised that this implies that the final National Standard will meet, or exceed, these design properties when it is implemented.

The second tier is the 'reference' fuels, upon which both type approval and in-use testing for performance and emissions will be based. These specifications are slightly fuller than the homologation fuel specifications, but normally have the same limiting values, albeit with different tolerances, for the critical properties. These reference fuels are those quoted in the emissions regulations, and as such are the key to successful emissions strategy. If they differ markedly from the marketed fuels, then so will the emissions, and therefore it is no use accepting type-approvals (perhaps with no local checking) based on one series of reference fuels, and expecting corresponding emissions performance from lower quality fuels on the market. There is no acceptable translation or correlation between the quantities of the individual pollutants emitted, and the key fuel quality items. This will be a function of the sensitivity of each individual engine type. Theoretically, it is possible to have 'local' reference fuels, and to adjust the emissions limits accordingly, but the above-mentioned factor of engine sensitivity makes such an approach difficult and potentially unfair.

The final tier, the National Standards, will be dealt with in more detail later in these Guidelines, and this is both the starting and finishing point of the process. It is sufficient to say at this stage, that it is not simply a table, or tables, of limiting values, but describes an organised means of reproducible checking for compliance, as well as a coherent description of market requirements for the benefit of end-users.

4.3 Considerations in the content of fuels standards.

4.3.1 **Motor gasoline.** Examination of the situation in various countries makes it clear that some at least, will have only a minimal short-term requirement for unleaded gasoline, possibly only for tourists, but there is considerable benefit to be gained in air quality terms by improvements in the quality of leaded gasoline (see 3.2.1). Some attention has therefore been given to this aspect. The judgement of the timing of the introduction of full emission controlled gasoline-engined passenger cars, with catalytic converters, knock-sensors, and electronic engine management systems, is of course, a matter for each regulatory authority, and will undoubtedly vary with the balance between locally produced and imported vehicles. The engine metallurgy to run on unleaded gasoline is the first priority (see 3.2.1).

Most of the countries involved in this Project have small seasonal variations in temperature, although some (e.g. China, Iran, Korea) have regions where seasonal variations are much greater. The application of seasonal grades, in terms of volatility, has largely been neglected in these Guidelines, concentrating mainly on a mainstream 'summer' quality, which would be generally applicable within the temperature range of 25 °C to 35 °C. Lower temperatures would allow some relaxation of volatility limits, whereas higher temperatures would demand some further restriction. The limits suggested are for vehicular losses only, with evaporative losses during storage and distribution (and local regulations on these) left as a purely environmental consideration.

The most difficult area possibly, is the incorporation of oxygenated compounds. The use of alcohols as whole fuels is not considered. There are strong arguments for the use of such compounds, both economic (octane enhancement), and environmental (CO, HC, CO_2 emission reduction). However, there are drawbacks, especially in the use of alcohols, even in fairly small proportions. The drawbacks include toxicity (methanol) and water-leaching (all), and the latter of these demands a totally clean and dry distribution system, with no possibilities of leached product reaching either inland or marine water environments. In the short term, this seems an unlikely possibility for most of the countries involved in this Project, and therefore the use of alcohols as fuel components is not recommended in these Guidelines. However, ethers (MTBE, ETBE, TAME) are considerably more attractive. They provide the benefits of alcohols, with few of the drawbacks, do not significantly leach from gasoline blends when used in reasonably small proportions, they utilise readily available refinery components and generally surplus alcohols in their manufacture, and provide an octane enhancement/volatility ratio more suited to modern gasolines. The use of ethers therefore, in proportions up to 15 %(V/V), can be allowed, or even recommended for the higher octane grades and for their contribution to emission reduction (see annex G), but in these Guidelines, they are not mandatory.

Finally, there is the overwhelming economic decision on the choice of octane numbers for the various grades. Octane numbers, both RON and MON, are possibly the most cost-critical item to the oil product manufacturer, dictating both capacity and severity of secondary processing units of considerable sophistication. They are also critical to the engine manufacturer, since in general terms, the higher the octane numbers, the better the thermal efficiency, and thus economy (and to a lesser extent, performance). Exhaustive studies in Europe and the US in the late 1970's, established that there was a cross-over in energy terms between increased energy (CO_2) in the refinery for more intensive processing, and decreased energy, in terms of economy per km, by the end-user. This cross-over was established at about 95 RON/85 MON, and these values have been used by the motor industries of North America, Europe and Japan as the key homologation fuel properties for 'premium' requirement passenger cars since about 1982-3. Before this study, in the late 1960's and early 1970's, there was an 'octane race', with car manufacturers able to claim better and better performance and economy on ever increasing octane number fuels, even to over 100 RON. The fuels were of course, leaded (and increasingly so), totally hydrocarbon, and with little control on composition. With crude oil very cheap, it was the economy of the end-user that dominated.

The balance of the cross-over point is again under challenge by the motor industry, and the study of the late 1970's is being repeated. Although the results will not be known for some time, it seems unlikely that the point will have moved significantly (almost certainly less than 1 ON).

There is a case for maintaining a higher octane grade for that part of the car population that can take advantage of it. This may be leaded, if the metallurgy is unsuitable for unleaded fuels, or unleaded, or, as in most European countries, both. This enables motorists with environmental instincts, but unsuitable engine technology, to mix fuels of sufficient octane quality to maintain economy and performance, down to a minimum lead content to protect their engines (0.03 gPb/l to 0.05 gPb/l). These higher octane unleaded fuels are not homologation fuels, but there is disturbing evidence that some motor manufacturers are aiming at these fuels for 'maximum' performance, and tuning to a lower quality for conformance testing. In some countries, it is necessary to universally adjust the engine conditions to meet the marketed fuel octane qualities. It must be clearly realised that this procedure not only upsets the energy balances discussed above, but also can have a drastic effect on emissions performance.

4.3.2 **Automotive diesel fuel.** The design of automotive diesel fuels has historically been much simpler than motor gasoline with the major proportion of the product coming from atmospheric distillation, with or without de-sulfurisation, and smaller elements coming from secondary processing facilities. However, because of this simplicity, many of the key fuel performance parameters are directly related to the chemical composition of the crude oil processed, and although increased secondary processing has been introduced to greatly increase the quantity of diesel fuel (and other middle distillates), many of the adverse quality aspects are at best only maintained, or in many cases, worsened.

With emissions regulations increasingly focussing on the heavy duty diesel-engined vehicles, with their natural propensity to smoke and particulate emissions, the quality of both fuels and engines has come under pressure. It is here, on this interface, that the 'cutting-edge' technology of both industries is being tested. The problem is even more acute if the small (less than 2.5 l) direct-injection passenger car engine is being considered. In an attempt to match the performance of these vehicles with gasoline-engined vehicles of similar size, and to maintain the fuel economy advantage of the diesel engine (very largely to the end-user only), and to reduce NO_x and particulates, these vehicles demand a fuel quality well above the average of that marketed in most countries. It is perhaps worth mentioning that the introduction of significant numbers of passenger car diesels to the US, very much heralded in the late 1970's and early 1980's, foundered on the aspect of fuel quality.

Unfortunately, there are no current easy options in terms of high quality, non-hydrocarbon, components for diesel fuel as there are for motor gasoline. There are potentially small quantities of biomass substitutes, notably esterified vegetable oils, but these may well be both economically unattractive requiring a complex system of subsidies, and could be environmentally negative, particularly if nitrogenous fertilisers are used for growth. More attractive, are processes to produce a new generation of hydrocarbon components from natural gas (synthetic middle distillates), but these also have economic penalties, and severe quantity limitatiohs. Since the development and production of these is likely to be entirely within the oil industry, they will undoubtedly fulfill a small but increasing role as components, but are likely to be directed primarily at the highest added-value markets.

Severe secondary processing, such as hydrogenation, does show some gains in quality, but the fundamental chemical transformation, that of ring-opening, has not yet reached commercial implementation. With many of the crude oils local to countries involved in this Project yielding rather poor middle distillate fractions, the balance between achievable emissions performance and fuel costs will inevitably be disturbed. The logistics and economics of crude oil 'swapping' normally preclude this option.

Because of the above, the production of a single series of specifications for automotive diesel fuel is particularly difficult, since it is unlikely that more than a very few countries could achieve the most emission-critical requirements for the grades appropriate to the lower emissions standards. The type-approval process should thus be left undisturbed, with the only problem being a supply of the type-approval fuel for reference fuel purposes.

The key parameters that cause these problems are ignition quality (in terms of Cetane Number and Cetane Index) and density. These two properties, together with sulfur content, are the major fuel quality items directly related to emissions (see annex G). Both of these properties are related to the natural chemical composition of the fuel, and, as mentioned earlier, the crude oil. Increasing aromaticity (not aromatics) adversely affects both, increasing the density, and decreasing the ignition quality. Some amelioration of the effect on ignition quality can be achieved with addi tives, but these are organic nitrates, and if used in high proportions (above 0,10 %(V/V), could increase NO_x emissions. They, like lead compounds for motor gasoline, also need extremely rigorous storage, handling and blending facilities, as they are basically explosives.

Density is probably the most difficult property to control, and the most critical property for overall performance and emissions of existing vehicles. The reputed fuel economy of the diesel engine is of course based largely on the higher volumetric specific energy of the fuel, as a higher mass charge is introduced into the engine at a given volumetric injection. This gives more energy (power), but at a given air/fuel ratio, a propensity to less complete combustion and thus more smoke (see annex G). The density range is narrow for optimum performance, power and emissions, and rather like the exercise on gasoline octane numbers, energy balances need to be made between the overall economy/power output to the end-user, and the energy consumed in both the engine and oil manufacturing processes.

Sulfur, to some extent, also falls into this category. Sulfur is emitted either as SO_x or as sulfates, the former contributing to acid attack both directly (on buildings etc) and indirectly by being transported in water either to the atmosphere (acid rain), or to the water table. The latter forms a major part of the particulate emission, increasing in proportion (but not absolute quantity) as lubricant usage in diesel engines declines, and less lubricant is burnt from the engine chamber walls with the fuel (see annex G). Removal of sulfur is a fairly simple oil refinery process, but it is expensive in energy terms, and also results in a disposal problem for the sulfur produced. A recent cost evaluation showed that to reduce the sulfur content of a diesel fuel from 0.25 %(m/m) to 0.05 %(m/m), an additional 19 tonnes of CO_2 are emitted for each 1 tonne of sulfur removed, and that the incremental cost is between US$ 12 and

US$ 18 per tonne of product. Thus again there is a balance between the demerits of different types of pollutants, and the cost-benefits of the fuel improvements.

4.3.3 **2-stroke oils.** The 2-stroke engine, burning a mixture of fuel and lubricant, is inherently a grosser emitter of CO, HC, smoke and particulates than the corresponding 4-stroke gasoline engine. To some extent, these emissions can be controlled by the quality of the oils used, but other factors have an overwhelming influence. The major factor is of course engine design, with maintenance playing an important role, with exhaust ports, manifolds and systems all subject to carbon deposition contributing to a variety of de-optimising engine performance criteria. In addition, the oil/fuel ratio, and means of controlling this at differing power outputs, the oil delivery system, whether within the fuel or separately, contribute to the potential emissions.

The function of the oil is to lubricate the inside walls of the cylinder during the first stroke of the piston, and to be completely burnt during the second, thus providing a clean surface for the next application. This implies a number of properties for the oil, including good thin film lubricity, good 'stickability', good mixing with the fuel, complete combustion within the time period allowed, and low residue. Not all of these are mutually compatible.

In their simplest form, 2-stroke oils consist of base lubricating oil(s), together with a 1spreader', which is generally a kerosine or white spirit type component (usually higher flash point than marketed kerosines or white spirits). In the better formulations, there is more than one base oil to obtain the stickability/lubricity from a heavier material at the minimum overall viscosity (and thus C/H ratio) to aid burn-out. The 'premium' oils contain additives, some of which may be similar to those in crankcase lubricants (anti-rust, detergents, anti-oxidants, etc), but they may also contain anti-smoke additives (see annex G). The major anti-smoke additive used is polybutene (or polyisobutene), although there may also be some residual use of metallic based anti-smoke materials. The use of more sophisticated 2-stroke oils is claimed to reduce the concentration necessary, down to 2 %(V/V) from 5 %(V/V) to 6 % (V/V) for the simplest mineral oils, and technically this is feasible. This concentration however, is also a function of individual engine design.

It is difficult, if not impossible, to write meaningful generic specifications for 2-stroke oils. The approach of crankcase lubricant 'type-approval', where each oil is approved by a range of engine manufacturers, highlights that the requirements are specific to engine model, and are generally not covered by any form of standardised methodology (see 10). Many of the major problems are associated with mis-use, either in type, concentration, or even the re-use of crankcase oil. These are as much infrastructure problems as product quality problems. One approach, which has several attractions, is to disallow the sale of 2-stroke oils, and to restrict the sale of fuel to this market sector to blender pumps dispensing a pre-mixed fuel. One attraction of this approach is that the fuel component of this mixture can tolerate a lower octane number, due to the 2-stroke engine's lower requirements, and thus the overall 'cost' of fuel/ lubricant mixture could be contained. With the demand for higher clear pool octane numbers for passenger cars, this could be attractive to oil suppliers in areas of high 2-stroke engine concentration. Paradoxically, the demand for high quality fuels for passenger cars could otherwise penalise the poorest market sector through rationalisation of the logistics of distribution leading to the removal of the cheapest options.

Harmonisation of emissions standards for the type-approval testing of 2-stroke engined vehicles is possibly the most urgent of all the tasks facing this Project Group. Not only are the ambient air quality factors important, but also potential friction points between countries applying widely different controls, and considerable trans-border traffic, and the relationship with the engine manufacturers and their distributors, provide an urgent incentive for guidance.

5. AUTOMOTIVE FUELS STANDARDS APPROACH.

5.1 General Standard Construction. As a first step, it is important to distinguish between a Standard and a specification. A Standard consists of a number of parts, one of which is the specification of the product(s) being standardised, but many of which deal with the equally important aspects of safety, sampling, packaging, marking, dispute procedure, and special aspects relating to general quality control not directly included in the tables of limiting values. Standardised terminology has been developed for many of these parts of a Standard, and particularly introductory paragraphs of clauses, will be identical in all Standards, or should be, as these expressions have been tested for ambiguity and legal robustness. The Standard will also give guidance on the legal status of the various parts, either by reference to relevant National legislation, or if the Standard is wholly covered, by a statement and reference to this effect.

One of the important parts of a National Standard is the References clause. Here all the documents required for full implementation of the Standard are listed, and if necessary, cross-referenced, and/or annotated. For the purposes of this Project, International Standards Organisation (ISO) references have been used throughout, where available, but locally, either National Standards series, or generic International series such as ASTM, IP, JIS, DIN or AFNOR, may be deemed to be equivalent or acceptable. For legal dispute cases, this clause must clearly indicate the 'referee' Standards for compliance.

'Skeleton' Standards are given in annexes X and Y for motor gasoline and diesel fuel, but these will not necessarily be comprehensive for all countries. The specification clauses in these 'skeletons' are omitted, and dealt with separately in the clauses below.

5.2 Grade Structures. A National Standard does not necessarily cover all the grades of a given product available in the market. Particularly with the increasing tendency to have 'mini-local' environmental requirements, there is often a large number of similar, or even identical, 'performance' grades at differing key pollutant levels. Examples of this are sulfur limits in many fuels, differing in certain urban areas from the general countryside, lead in motor gasoline similarly, or specialised grades for a specific application such as mining. The National Standard may reference these, and should give guidance on how they are to be described, but will not usually provide full specifications for them. The National Standard should concentrate on the major technical performance grades, and give specifications for a minimum number of these in each class, incorporating the environmental limiting values that are applicable across the whole of the area over which the Standard is implemented. Marketing considerations may well lead to higher performance, or lower pollutant level, grades being made available **in addition** to those required by the National Standard. The user and end-use manufacturing industries however, require assurance on **minimum** qualities. The recommendations in these Guidelines are for generic grades only, and will not address these specialised requirements.

5.3 Mandatory and Consensus Options. In many countries, only part of the National Standard has legal status, although it may be that it is indirectly covered by some form of Trades Description legislation for retail sales. In some countries, getting less, it is still allowed to market products that do not conform to the National Standard. This allows for a vast array of difficulties, and it would be strongly recommended that as we move towards more harmonisation of specifications, these specifications themselves are given a more secure basis. The only means of achieving this is to ban the marketing of products that do not meet, or exceed, the minimum requirements of the National Standard, and that the National Standard becomes the baseline in all contracts, both commercial, and by appropriate marking, individual.

This still leaves open the distinction between civil and criminal legislation, and it must be left to each country to decide where to draw the line. Europe has just gone the whole way, in making the whole of EN 228 and EN 590 legally binding by Acts of Parliaments, and thus breaches are criminal. Up till then, only parts of each National Standard were legally binding, mostly the environmental properties, e.g.lead, sulfur and benzene, but also one or two performance or Customs definition limits e.g. RON/MON, Distillation and/or Density, dyes/markers. Other items in the specification were then a matter of contract between buyer and seller, either written, or in the case of retail sales, covered by some form of generic legislation.

It is a difficult decision where to draw this distinction, and these Guidelines can do no more than point out the options. Total coverage, whilst philosophically attractive, may lead to a large number of very small disputes on barely significant quality defects, simply for a commercial advantage, whilst lack of legal protection may leave the individual at the mercy of unscrupulous marketers. It is the resource available to police the system that should determine the extent of coverage.

5.4 Quality Limits and Test Methods. **The result of a test is totally dependent on the method used for the determination and the integrity of the sample examined.** This may seem to be an obvious statement, but unfortunately, is all too often ignored It may seem clear in some cases, such as Water Content, where you get a different answer if you carry it out by distillation or centrifuge and recover only the undissolved water, or you carry it out by Karl Fischer and recover the total, dissolved and undissolved, water. Sometimes it is not clear however. How many people realise that currently, the Octane Numbers (RON and MON) derived in the US (and the Far East) are different to those in Europe, and that this is deliberate? Hopefully, this will change in 1994, but this is the current position, and could only be noticed by extremely close reading of the different methods used.

Many properties show bias when measured by different, even if similar, test methods. Some of these are critical, e.g. sulfur, lead, cetane index, flash point, and often the biases become more pronounced at very low levels. It is therefore absolutely vital that the correct test method is specified, the limiting value is set at the appropriate level, and in the correct reporting units, for that method, and that the test procedures are unambiguous and carried out in the exact manner prescribed.

Unfortunately, the above is not universally applied. Not all test methods are well written, although a tremendous effort has been made in ISO/TC 28 to up-date most of the automotive fuel methods during 1991, 1992 and 1993. All too often, obsolete units are still quoted in specifications, where they are not allowed as reporting units in the test methods, limiting values are not to the precision required by the test method report, and so-called 'equivalent' methods are used, but not reported, for the actual determinations.

There are currently problems in the concepts of petroleum test methodology (common to many other areas), and this makes adherence to the above principles even more important. The problems will not be discussed here, but they relate to calibration (with special problems relating to matrix effects), and to automation (where the principle of measurement is different to that used historically). It is likely therefore, that there may be a proliferation of methodology, which will require different limiting values for what appears to be a similar or identical property. This is already happening for example, with motor gasoline vapour pressure, where the new ASVP methods give a different value to the traditional RVP.

6. QUALITY CONTROL IN THE MARKET.

It is essential that adequate policing of the quality of petroleum fuels is carried out in the market place. The prime reason of course will be safety, since infrastructure and end-use design will rely on certain fuel properties, in particular, flash point, volatility, corrosiveness, and these will be factors in consideration of the siting of facilities, as well as safety distances, venting arrangements etc, within the facilities.

The major quality control issue with regard to this Project however, is the monitoring of quality for conformance to Standard. This is to ensure that the end-use is protected against damage, and that the consumer is assured that he receives the product that is described. It also of course, ensures that environmental regulations, as they apply to fuels, are in compliance.

The exertion of quality control in the market requires a considerable infrastructure, and it is normal for this to be composed of a co-operation between the public and private sectors. Since the National Standard applies at the point of custody transfer of the product to the end-user, in practice this means the external monitoring of product qualities is carried out both at depots/terminals for deliveries to commercial and industrial users, and at retail sites for deliveries to individuals. In addition to a regular monitoring responsibility, the system must also accommodate challenges made by end-users, or in exceptional circumstances, by end-use manufacturers. This demands a number of skills from all those participating in this process, not least being the ability to obtain representative samples of the product(s) being monitored.

Of course, it is totally impracticable to fully monitor any large proportion of sites on a regular basis, and thus some form of statistical approach is necessary, dividing outlets into types both by size and geography, and setting some form of 'random' selection that can be accommodated by the infrastructure in place. Additionally, the test regimes should be rationalised in such a manner to provide the best information within a reasonable budget.

In practice, this means a large number of samples will be collected for a 'short test' examination, looking at a few of the simplest yet most sensitive tests, and a few samples will be subjected to more extensive testing, with a relatively small number actually undergoing a full test against all the properties specified in the National Standard. Obviously, there will need to be facilities for those samples exhibiting defects in the 'short tests' to be further examined, and thus the sample size must be sufficient for this.

Whilst it is not the function of these Guidelines to provide an infrastructure for quality control, it might be helpful if the following general principles were adhered to in all participating countries:

1. Sampling shall be carried out from tanks by trained personnel.

2. Samples from retail outlets shall be generally obtained by purchase, into containers filled from dispensing pumps.

3. Samples shall always be taken into pre-cleaned and dried containers, with appropriate closures.

4. Samples shall be of minimum 2 litres in volume.

5. Gasoline samples shall be chilled to below 10 °C as soon as practicable after sampling, and kept at this temperature until analysis.

6. Samples shall be sealed and clearly labelled immediately after acquisition. Clear records must be kept.

7. Analysis may be carried out by governmental agencies or by accredited laboratories in the private sector. In all cases, the exact methodology and procedures described in the National Standard shall be followed.

A clear focal point for this activity shall be identified, empowered to carry out quality control procedures, its competences, duties and responsibilities specified, and a control and dispute procedure put in place.

Having established an infrastructure for the monitoring of quality, the next stage is to construct a sampling and testing regime, appropriate to the size and complexity of the market. The following suggestions might be appropriate to a medium-size market of say between 1 000 and 5 000 outlets.

A. Sampling should be carried out monthly from retail sites, 'randomly' from between 1 % and 2 % of the retail sites each month, ensuring that within each 6-month period, all grades from all manufacturing sources are examined at least once.

B. Sampling from depots/terminals should be monthly or quarterly depending on their number. The same principle as in B applies.

C. Between 10 % and 20 % of the samples taken from retail sites should be subjected to full analysis against the National Standard. This proportion should rise to between 20 % and 50 % for the samples taken from depots/terminals. The total **number** of samples subject to full analysis each month should be between 5 and 20.

D. Samples exhibiting defects in the 'short tests' should be **added** to those undergoing full examination.

The final decision on structure to be accomplished is the selection of test regime for the 'short tests'. As mentioned earlier, these should be selected on the basis of sensitivity and simplicity, two principles not always mutually compatible. Suggested regimes for gasoline and diesel fuel are given below.

i) **Motor Gasolines.**

a) Density at 15 °C.
b) Vapour Pressure at 37.8 °C.
c) Distillation, E70, E100, E180, FBP.
d) VLI (calculation)
e) Lead Content (in the case of ULG, can be go/no-go).

ii) **Automotive Diesel Fuels.**

a) Appearance/Colour.
b) Density at 15 °C.
c) Distillation, 10 %(V/V), 50 %(V/V), 90 %(V/V), 95 %(V/V).
d) Cetane Index (calculation).
e) Flash Point, PMcc.

There is the difficult decision on the degree of publication of the data, both in terms of its format (coded or named), and in terms of the breadth of publicity. This will be the province of the individual countries, but for the greatest effectiveness, the widest and most open publicity will almost certainly gain the best results. It might be wise however, in the early stages when results may not be as one had hoped, to restrict the results to those directly involved, and, by discussion, eliminate the inevitable 'teething problems'.

7. SPECIFICATION CONSTRUCTION.

In considering the construction of a specification matrix comprising a large number of potential grades and options, it seems reasonable to isolate those properties and limiting values that will be common to all grades, and deal with the 'variables' in a series of sub-tables. As mentioned earlier, a single climate is to be considered for these specifications, and they will be targeted to an ambient temperature of 25 °C to 35 °C. This will certainly simplify the presentation of the specifications, since the climatically dependent properties can be standardised but will obviously not address countries, regions or seasons, when the climate is outside this range.

The target 'premium' quality will be that represented by the quality illustrated in the two major world-wide reference fuels for emission, consumption and power measurement, namely CEC RF-08-A for unleaded premium gasoline, and CEC RF-03-A for automotive diesel fuel, although the compositional restrictions in these specifications will not be applied.

The specifications will be presented in SI units and ISO(or EN) methodology throughout. Only where there is no current appropriate International methodology, will methods be quoted from other series. Users of the specifications may need to translate these into their local preferences, but should ensure that strict equivalence is used. The common practice with most European Standards bodies (IP/BS, DIN and AFNOR) is to adopt the ISO or EN text directly into their standard method by means of re-printing from camera-ready copies available from the issuing authorities.

By constructing tables of 'common' and 'variable' fuel properties, it will be possible to construct a great number of specifications, as the changes in refining upgrading are progressed. It may be possible to implement 'target' variable properties in one area before being able to implement the whole, and this should be encouraged. Some of the most cost-critical items will doubtless be similarly deferred.

The presentation format of the specifications will be to present the target 'premium' specification in full for each category, and to then present tables of 'lowest' and 'intermediate' qualities. The tables of 'intermediate' qualities will be in terms of ranges or steps.

8. SPECIFICATIONS FOR MOTOR GASOLINES.

8.1 General. Specifications are prepared for both leaded and unleaded motor gasoline. For the target grades, all properties apart from octane numbers are the same, and four grades are identified. One of these grades is exclusively for use in 2- and 3-wheeled 2-stroke engined vehicles, and will only be introduced in those countries who have both a substantial population of these vehicles and a strong economic incentive for minimising the cost to the consumer of this product, whilst maintaining controlled quality. The specification represents the quality of motor gasoline before addition of the 2-stroke oil. The top tier grade (Super) is also not recommended as a universal grade, only applying in those countries which have a substantial requirement for older high-requirement engines. For unleaded motor gasoline, this grade is not included.

The vapour pressure limits for all grades are set in terms of the relatively new technique of air saturated vapour pressure (ASVP), not the traditional Reid vapour pressure still widely used. For pure hydrocarbons, ASVP figures, when converted by the DVPE formula given in the method(s), give approximately the same value as Reid vapour pressure, but in the presence of oxygenates, Reid vapour pressure gives erroneous low results. The use of ASVP therefore covers all the options available.

The density range given, even in the target specifications, is wider than would be expected in individual specifications. In general, National Standards should not express a density range of greater than 40 kg/m^3, choosing their position within the overall range with regard to local circumstances.

8.2 Specifications for Leaded Motor Gasoline. The octane requirements for the four target grades are given in table 1, and the general requirements for these grades are given in table 2. Table 3 gives 'lowest' and 'intermediate' qualities for octane requirements, and tables 4 and 5 for other groups of properties

Table 1-Target octane requirements for leaded motor gasoline

Grade / Property	2-stroke	Regular	Premium	Super	Test method
Research octane number, min	82,0	90,0	95,0	98,0	ISO 5164
Motor octane number, min	-	80,0	85,0	87,0	ISO 5163

Table 2-Target common requirements for leaded motor gasoline

Property	Limiting values	Test method
Appearance	Clear and bright	Visual
Density at 15 °C, kg/m^3	725 to 780	ISO 3675 or ISO 12185
Vapour pressure at 37,8 °C, kPa	35 to 70	EN XYZ[1)]

Table 2-continued

Distillation		ISO 3405
E70, %(V/V)	15 to 45	
E100, %(V/V)	40 to 65	
E180, %(V/V), min	85	
FBP, °C, max	215	
Residue, %(V/V), max	2	
VLI (10 VP + 7 E70), max	950	Calculation
Benzene, %(V/V), max	5,0	EN 238 or EN ABC$^{2)}$
Lead, gPb/l, max	0,15	ISO 3830
Sulfur, %(m/m), max	0,05	ISO 8754 or ISO 4260
Oxidation stability, min, min	480	ISO 7536
Gum (solvent washed), mg/100 ml, max	5	ISO 6246
Copper strip corrosion (3h at 50 °C), Class	1	ISO 2160
Oxygenates content		EN PQR$^{3)}$
Ethers (MTBE, ETBE, TAME) %(V/V), max	15	

Notes:

1. Method not yet published. Use IP 394 or ASTM D5191 until publication.
2. Method not yet published. Use ASTM D3606 until publication.
3. Method not yet published. Use ASTM D4815 until publication.

For the properties listed in the following tables, there is no revision to the test methodology, as the relaxed values only apply when tested by the identical methods. For some properties, e.g. Gum, Copper corrosion, Oxygenates, no further relaxations are allowed. In some cases, there is no intermediate position between the 'lowest' recommended quality, and that applicable in the target grades.

The 'lowest' RON octane values can be used as a universal labelling system, providing a guide value below which motor gasoline cannot be labelled as, e.g. 'Premium' or 'Super' quality for retail purposes. This would help consumers in trans-border situations, giving them some help in assessing the fuel necessary for their vehicle.

Table 3-Relaxed octane requirements for leaded motor gasoline

Grade \ Property	Lowest		Intermediate	
	RON	MON	RON	MON
2-stroke	79,0	-	80-81	-
Regular	87,0	77,0	88-89	77-79
Premium	93,0	83,0	94	83-84
Super	97,0	86,0	97,5	86-87

Table 4-Relaxed volatility requirements for leaded motor gasoline

Property	Lowest	Intermediate
Density at 15 °C, kg/m^3	705 to 785	710,720 to 785
Vapour pressure at 37,8 °C, kPa,	35 to 80	75 max.
Distillation		
E70, %(V/V)	15 to 47	15 to 47
E100, %(V/V)	40 to 67	40 to 67
FBP, °C, max.	225	220
VLI	1 000	1 000

Table 5-Relaxed composition requirements for leaded motor gasoline

Property	Lowest	Intermediate
Benzene, %(V/V), max.	10	9 to 6
Lead, gPb/l, max.	0,40	0,35 to 0,25
Sulfur, %(m/m), max.	0,25	0,20 to 0,10
Oxidation stability, min, min.	240	360

8.3 Specifications for Unleaded Motor Gasoline. As stated in 7.1, only a 3-grade structure is proposed for unleaded motor gasoline, and since the 2-stroke grade is optional, it is expected that some countries will have only a 2-grade structure. The target specifications have been designed for use in modern engines with catalytic converters fitted, although they will of course be suitable for all engines with hardened valves and valve seats, with or without converters. The same format of presentation is used as that for the leaded grades.

Table 6-Target octane requirements for unleaded motor gasoline

Grade **Property**	**2-stroke**	**Regular**	**Premium**	**Test method**
Research octane number, min	82,0	90,0	95,0	ISO 5164
Motor octane number, min	-	80,0	85,0	ISO 5163

Table 7-Target common requirements for unleaded motor gasoline

Property	**Limiting values**	**Test method**
Appearance	Clear and bright	Visual
Density at 15 °C, kg/m^3	725 to 780	ISO 3675 or ISO 12185
Vapour pressure at 37,8 °C, kPa	35 to 70	EN XYZ 1)
Distillation		ISO 3405
E70, %(V/V)	15 to 45	
E100, %(V/V)	40 to 65	
E180, %(V/V), min.	85	
FBP, °C, max.	215	
Residue, %(V/V), max.	2	
VLI (10 VP +7 E70), max.	950	Calculation
Benzene, %(V/V), max.	3,0	EN 238 or EN ABC 2)
Lead, mgPb/l, max.	13 4)	EN 237
Sulfur, %(m/m), max.	0,05	ISO 8754 or ISO 4260

Table 7-continued

Phosphorus, mg/l, max.	1,3	ASTM D3231
Oxidation stability, min, min.	480	ISO 7536
Gum (solvent washed), mg/100 ml, max.	5	ISO 6246
Copper strip corrosion, (3h at 50 °C), Class	1	ISO 2160
Oxygenates content Ethers (MTBE, ETBE, TAME) %(V/V), max.	15	EN PQR$^{3)}$

Notes:

1. Method not yet published. Use IP 394 or ASTM D5191 until publication.

2. Method not yet published. Use ASTM D3606 until publication.

3. Method not yet published. Use ASTM D4815 until publication.

4. Although this is a 'target ' value, it is intended that this shall be reduced to 5 mgPb/l when distribution systems are completely free of lead.

The relaxed quality requirements for octane numbers and volatility for the three unleaded grades are identical to those shown in tables 3 and 4 for the appropriate leaded grades. Table 8 gives the relaxed composition requirements, with the exception of oxidation stability, which is the same as that given in table 5.

Table 8-Relaxed composition requirements for unleaded motor gasoline

Property	**Lowest**	**Intermediate**
Benzene, %(V/V), max.	8	7 to 4
Sulfur, %(m/m), max.	0,20	0,15 to 0,10

For lead and phosphorus a transient excursion above the target value to twice this value, can be allowed during the distribution changeover period. Continued presence at these levels will damage catalyst systems. The average level from any outlet shall be below the target values.

9. SPECIFICATIONS FOR AUTOMOTIVE DIESEL FUELS.

9.1 General. Only a single 'premium' grade is considered here, although the properties have been tailored towards only a moderately environmentally sensitive market. The extremes, in terms of environmental severity, of the US West Coast, or Sweden, have not been considered appropriate to any countries participating in this Project.

One of the most important properties of automotive diesel fuel in temperate climates, is the low temperature operability. In many of these, including Europe, Japan, Australasia, and some participants, e.g. Singapore and Hong Kong, Cold Filter Plugging Point (CFPP) is the property used to define this, and that is the practice in these proposed specifications, although climatic variations are not considered. Pour point has no relevance when considering performance in a vehicle, and cloud point is a too severe predictor by itself, and needs great experience to set limits appropriate to climatic conditions, and most importantly, is not conducive to depression by additives. CFPP **can** be used as a direct relationship to daily average minimum temperatures, **unless** excessive additive has been used to achieve a target value (i.e. creating a CFPP/cloud point differential of greater than 10 °C).

Provision has also been made for **both** cetane number and cetane index. This is to allow, but control, the use of ignition improving additives, and to protect the 'base' quality of the fuel being treated.

Sulfur is obviously the difficult property to assess the correct target value. 0,20 %(m/m) has been chosen as basically the lowest level at which a balance between environmental considerations and sesulfurising costs on medium-high sulfur crude oils can be struck. There is not only a monetary cost in this, since as mentioned in 3.3.2 (p.18), there is a strong risk of substituting disproportionate quantities of CO_2 for smaller and smaller reductions in SO_x. It probably has to be accepted that in the long term, sulfur limits will be forced downwards towards 0,05 %(m/m) or even lower, but that has not been considered as a reasonable basis within the lifetime of this Project.

Cleanliness may be another area of difficulty. Historically, sediment and water limiting values have been a nonsense, both in methodology and specified levels. This is being addressed in Europe in particular, but it could prove difficult to implement in the Asia-Pacific region in the short term. New methodology and limiting values are included in the target specification, but it is appreciated that this may take some time to implement, particularly since the limits do depend on clean and dry infrastructure.

9.2 Specification for Automotive Diesel Fuel. The target specification is given in table 9, and the relaxed qualities are given in table 10.

Table 9-Target specification for automotive diesel fuel

Property	Limiting values	Test method
Appearance	Clear and bright at 15 °C	Visual
Density at 15 °C, kg/m^3	820 to 860	ISO 3675 or ISO 12185
Cetane number, min.	49,0	ISO 5165
Cetane index, min.	46,0	ISO 4264
Flash point, PMcc, °C, min.	56,0	ISO 2719
Viscosity at 40 °C, mm^2/s	2,00 to 4,50	ISO 3104
Distillation		ISO 3405
10 %(V/V) rec. at, °C, max.	210	
50 %(V/V) rec. at, °C, max.	295	
85 %(V/V) rec. at, °C, max.	350	
95 %(V/V) rec. at, °C, max.	370	
Sulfur, %(m/m), max.	0,20	ISO 8754
Carbon residue (10 %b), %(m/m), max.	0,30[1)]	ISO 10370
Ash, %(m/m), max.	0,01	ISO 6245
Water, mg/kg, max	250[2)]	ISO 12937
Particulate matter, g/m^3, max.	25	IP PM-BH
Copper corrosion (3h at 50 °C), Class	1	ISO 2160
Oxidation stability, g/m^3, max.	25	ISO 12205
CFPP, °C, max.	10[3)]	EN 116
Neutralisation number		ISO 6618
Acid number, max.	0,20	
Strong acid number	Nil	

Notes:

1. This limit only applies if the method specified is used. Approximate equivalents are 0,20 %(m/m) if ISO 4262 (Ramsbottom) is used, or 0,15 %(m/m) if ISO 6615 (Conradson) is used.

2. This is a measure of total water, and implies only 50 to 100 mg/kg undissolved water (see 4.4).

3. On a 'normal' fuel, with no additives, the average differential between CFPP and cloud point (ISO 3015) will be 2 °C.

Table 10-Relaxed requirements for automotive diesel fuel

Property	Lowest	Intermediate
Density at 15 °C, kg/m^3	815 to 870	865 max.
Cetane number, min.	45,0	46,0 to 48,0
Cetane index, min.	42,0	43,0 to 45,0
Viscosity at 40 °C, mm^2/s	1,50 to 5,50	1,60 to 5,40
Water, mg/kg, max.	500[1]	450 to 300
Particulate matter, g/m^3, max.	80[2]	75 to 30
Sulfur, %(m/m), max.	0,50	0,30

Notes:

1. This is close to the 0,05 %(V/V) level specified in many traditional specifications, when tested by ISO 3733 (distillation).

2. This is close to the 0,01 %(m/m) level specified in many traditional specifications, when tested by ISO 3735 (extraction).

10. DISCUSSION ON 2-STROKE OIL OPTIONS.

As discussed in 3.3.3, the generation of meaningful 2-stroke oil specifications is very difficult, firstly because the 'real' properties required have no standardised methodology, and secondly because a wide range of materials have been found to be suitable. There are some general principles of course, such as a need to have a 'spreader' or 'cosolvent' component to ensure good mixing with the fuel, the need to have a minimum flash point for storage and handling, since it may be handled in uncontrolled conditions, and probably there is an optimum viscosity range, although this is rather wide. Provision for control of basic properties such as sulfur, carbon residue, water content and pour point would also be expected. Most of the other properties will be very dependent on the formulation. For example, it is unreasonable to impose a stringent ash limit, as some ash-containing additives may be effective in reducing either deposits or smoke.

The major assessment of the effectiveness of these 2-stroke oils therefore is likely to be by means of engine tests, and thus via a route of oil type-approval. The engines chosen will be representative of those available locally, since there is a vast amount of manufacturers of these engines, and world-wide coverage is unlikely, and it is likely that at least two, and may be up to five, engines will be required. The reason for the multiplicity of engines is of course because of the different engine sensitivities to the characteristics under examination, and a need to achieve differentiation in the test results. For those countries with substantial 2-stroke engine populations, this does mean an infrastructure of testing facilities, although within the region, it may be possible to achieve some agreement on reciprocal recognition. There should certainly be agreement on base motor gasoline quality for testing (reference fuel), oil/fuel ratio for testing, range of properties required for type approval, and perhaps some form of classification and labelling system. Because of the uncertainty, and poor reproducibility of this type of engine testing, it is normally carried out by parallel examination of candidate oils against a reference oil of known consistent performance. A regional reference oil would certainly aid in acceptance of reciprocal type-approvals.

There are seven major properties that need to be addressed in engine tests, although it is possible that the number of tests can be reduced by examining an engine for a number of these, following a single test sequence. An example of this may be that detergency, ring-sticking and wear, can be assessed on a single engine type, during a single test sequence, if the engine is sensitive to variations in lubricants quality in the same way for a number of different individual quality parameters.

Table 11 gives an outline of these engine related properties, together with a brief commentary, and table 12 gives a basic 'physical' specification for a finished 2-stroke oil.

Table 11-Engine test regime for 2-stroke oils

Characteristic	Commentary
Detergency	Demerit scale required, parallel testing mandatory.

Table 11-continued

Ring-sticking	Can be absolute, e.g. adhesive strength of deposits, but more commonly, parallel tested.
Wear	Can be absolute, e.g. scuff mark diameter, but normally parallel tested.
Lubricity	Can only be assessed against reference oil.
Port blocking	Absolute-measured by power loss, and physical deposits on exhaust ports.
Smoke	Absolute-measured by smoke meter at specified power/time intervals.
Pre-ignition	Absolute-number of failures.

Table 12-Physical requirements for 2-stroke oils

Property	**Limiting values**	**Test method**
Density at 15 °C, kg/m^3	850 to 880	ISO 3675 or ISO 12185
Viscosity		ISO 3104
at 40 °C, mm^2/s	50 to 150	
at 100 °C, mm^2/s	8 to 15	
Viscosity index, min.	96	ISO 2909
Flash point, PMcc, °C, min.	60	ISO 2719
Distillation		ISO 3405
rec. at 320 °C, %(V/V)	15 to 25	
Carbon residue, %(m/m), max.	0,50	ISO 10370
Sulfur, %(m/m), max.	1,0	ISO 8754
Pour point, °C, max.	-6	ISO 3016
Water, mg/kg, max.	300	ISO 12937
Sulfated ash, %(m/m),	Report	ISO 3987

11. OPTIONS FOR SELECTED COUNTRIES.

Whilst it is not possible in these Guidelines to provide country plans for all countries participating in this Project, some indication of the priorities and potential positioning of three countries is looked at with a view to illustrating the suggested upgrading of fuels and 2-stroke oils quality over time. For those items selected for progress by individual countries, the schedule of progress should follow a similar form of logic.

11.1 Environmental Plan. Vehicular emissions of all types, regulated, unregulated and global, are only one component of air quality, and as stated elsewhere in the Guidelines, an emissions inventory is the first step to formulating a strategy for ambient air quality over the longer term. In a graduated approach to emissions strategy, measurement will be the key in all areas, looking at firstly the compliance with such regulations that are imposed, and secondly the effect of these regulations on ambient air quality. With regard to petroleum fuels, this means good statistics on their qualities and usage in all applications, transport, industry and domestic, and a coherent approach to fuels quality and end-use technology in all these areas concurrently, setting the priorities by the immediate impacts of the major contributors to air quality degradation.

When we narrow the field to on-highway tranportation fuels, the vehicles and fuels should be looked at as a single system so that the introduction of more advanced technologies in both oil and motor industries can have the maximum impact on ambient air quality, with the minimum wastage of resource. Part of this consideration needs to be a policy on transportation options, and a view of future transportation usage. This will include a view on the extent of regulation required to direct usage to/from public and private transport, and the control of the gasoline/diesel shares of the market, and for the former, the contribution of small 2-stroke engines within the gasoline sector. Dependent on the overall strategy with regard to greenhouse gases, fuel consumption/engine size for private vehicles, and power/mass ratios for commercial vehicles may also be considered for regulation, or more usually, fiscal encouragement/penalty.

Finally, and not considered in these Guidelines, is the role of alternative fuels, particularly biomass fuels and natural gas. These will never be a major energy producer overall, but may have a beneficial impact in specific locations with use restricted to specific applications.

11.2 China. The Chinese vehicle and fuel market is of considerable interest world-wide at present, not least because of the potential for growth. The indigenous market is both small in per capita terms, and design limited, and thus has a number of real problems in terms of environmental performance, and perhaps as importantly, economic performance. The current average fuel consumptions (and thus CO_2 emissions) are very high across all sectors, and the quality of fuels in the market, particularly the motor gasolines, does not allow for advantage to be taken of newer technologies in the vehicle market. The design of gasoline-engined heavy duty vehicles, dictates both consumption patterns and overall energy balances. Specified unleaded motor gasoline is not available in China, although a significant proportion of the lower octane grades does actually contain no added lead. The quoted lead limits however are very high, and there is no infrastructure segregation. There have been instances of modern vehicles, fitted with catalytic converters and and lambda probes, completely destroyed by the usage of leaded Chinese motor gasoline.

The preferred strategy for China is a very long-term one, and the priorities will not be those for most other countries. The problems are horrendous, and the capital required over say a 10-year period, rather colossal, but failure to start planning now, whilst traffic density is relatively low, would mean much more drastic limitations at a later date. Any strategy derived will require a parallel fiscal policy to direct/coerce the changes necessary for a coherent growing transportation market into the next century, without severe ecological damage. Perhaps, an even more intractable and expensive problem concerns the infrastructure, in particular the road network in major cities, and the distribution and sales of petroleum products.

China has an almost unique opportunity to plan a vehicular policy for the next century without the overhang of a very large existing market dominating for a long period. The forecast is for vehicle population to grow from 7 million in 1992 to 38 million in 2010, and it is the composition of this incremental 31 million vehicles that will determine the emissions

The direct strategy suggested for fuels quality in China, assuming that all factors mentioned above are considered, is based upon:

i) The lead content maxima should be reduced to improve ambient air quality in this respect, but the elimination of lead is not seen as a first priority.

ii) Benzene content should be controlled. A limit of 5 %(V/V) maximum in motor gasoline should be introduced as soon as possible.

iii) Octane values should be raised, and the number of grades reduced to not more than 3.

iv) Density maxima should be introduced for diesel fuels.

v) Over time, at least one diesel fuel of higher ignition quality should be introduced.

vi) Sulfur contents of lower grades of diesel fuel should be reduced.

vii) Viscosity maxima for diesel fuels should be reduced/ rationalised.

All the above depends upon a corresponding improvement in vehicle design, in particular with respect to thermal efficiency (fuel consumption/octane requirement) in passenger cars, and fuel-efficient diesel-engined heavy duty vehicles (TC). Reduced-emission, rather than low-emission should be a **requirement** for all vehicles registered after say 1996. Long term, the introduction of low-emission vehicles and the provision of unleaded gasoline will be required, and a limited availability of unleaded gasoline on main highways may be needed earlier for use by transient vehicles. The quality of this grade(s) must be commensurate with that of the vehicles which will use it (see 8.3), and this will mean a reduced sulfur content from that currently proposed in table 13, even taking into account note 6. Delivery should also be via a 'small' nozzle.

Tables 13 and 14 give an outline of proposed key quality items for a possible motor gasoline and diesel fuel grade structure, and some suggested step-wise improvements with time. It should be emphasised that these limiting values should be implemented at the earliest opportunity, and that they should be regarded as the initial steps on the route towards the 'target' values given in tables 6, 7 and 9.

Table 13-Leaded motor gasoline for China

Grade **Property**		**Low 1)**	**Regular**	**Premium**
Appearance		Clear and bright		
RON	min.	79	90	95
MON	min.	70	80	85
Density at 15 °C, kg/m^3	2)	710 to 785	710 to 785	710 to 780
Vapour pressure at 37,8 °C, kPa	3)	35 to 70(S) 55 to 90(W)		

Table 13-continued

Distillation	3)		
E70, °C			15 to 45(S) 15 to 47(W)
E100, °C			40 to 65(S) 43 to 70(W)
E180, °C		min.	85
FBP, °C		max.	215
Residue, %(V/V),		max.	2
VLI	3)	max.	950(S)---1100(W)
Benzene, %(V/V),	4)	max.	7,0
Lead, gPb/l,	5)	max.	0,40
Sulfur, %(m/m),	6)	max.	0,15
Oxidation stability, min,		min.	360
Gum (solvent washed), mg/100 ml,		max.	5
Copper strip corrosion (3 h at 50 °C), Class			1

Notes:

1. This grade is for existing 4-stroke engined vehicles that can run on it, and small 2-stroke engined vehicles, both existing and new.
2. This range should be narrowed with time towards the 'target' values.
3. More seasonal/regional grades may be required. These limits apply to summer ambient temperatures of around 30 °C, and winter ambient temperatures of around 0 °C.
4. Provision needs to be made for benzene contents to be reduced to 5 %(V/V) as soon as possible, and possibly at later stages to 3 %(V/V) or even 1 %(V/V) in the long term in unleaded motor gasoline when this is introduced.
5. Lead should be reduced in stages to reach 0,15 gPb/l no later than 2000.
6. Sulfur should be reduced to 0,10 %(m/m) as soon as practicable. No further reduction for **leaded** motor gasoline seems to be necessary.

Table 14-Automotive diesel fuels for China

Grade Property			Regular	Premium
Appearance			Clear and bright	
Density at 15 °C, kg/m^3	1)	min.	815 to 880	815 to 870
Cetane number,	2)	min.	45	47
Cetane index,	2)	min.	42	45
Flash point, PMcc, °C,	3)	min.	56	
Viscosity at 40 °C, mm^2/s	3)		1,50 to 5,50	
Distillation	3)			
10 %(V/V) rec. at, °C,		max.	225	215
50 %(V/V) rec. at, °C,		max.	300	295
85 %(V/V) rec. at, °C,		max.	350	
95 %(V/V) rec. at, °C,		max.	370	
Sulfur, %(m/m),	4)	max.	0,50	0,20
Carbon residue (10 %b) %(m/m)	5)	max.	0,40	0,30
Ash, %(m/m)		max.	0,01	
Water, mg/kg,	6)	max.	500	300
Particulate matter, g/m^3,	6)	max.	50	
Copper corrosion (3 h at 50 °C), Class			1	
Oxidation stability, g/m^3,		max.	25	
CFPP, °C,	7)	max.	10(S),	-10(W)
Neutralisation number				
Acid number		max.	0,50	0,20
Strong acid number			Nil	

Notes:

General: A distinction between regular and premium grades may be on the basis of usage, and it is normal to have a fiscal differential also. This relates to the regular grade being duty-exempt/reduced for off-highway applications such as agriculture, construction, airport/port transport etc. In this scenario, the 'regular' grade should be dyed and marked to minimise duty evasion.

1. The density maximum, particularly of the premium grade, should be reduced at the earliest opportunity (see annex G).

2. The ignition quality of the premium grade should be improved towards the 'target' quality over time.

3. This value is that almost universally used in storage and handling regulations for gas oils. At very low ambient temperatures (and thus light product requirements), this may need to be relaxed. In those areas requiring such relaxation, the fuel should be handled as a 'flammable' liquid.

4. The sulfur maximum of the regular grade should be reduced towards 0,20 %(m/m) maximum in steps over time.

5. The limits apply to test method ISO 10370 only (see note 1 to table 9).

6. These limits should be reduced. Regular monitoring should provide an indication of the condition of the distribution system, and where clean-up is required. The limit proposed is an estimated 'starting point'.

7. Many more seasonal/regional grades may be required (see annex B, BS EN 590).

11.3 India. In many respects, India enjoys many commonalities with China in respect of obsolescent vehicle design, domestically produced, poor fuel quality, and in urban areas, a generally insufficient paved road network. However, in respect to emissions and ambient air quality in urban areas, India is significantly worse than China, due largely to its much higher per capita vehicle ownership, and the very high proportion of small 2- and 3-wheeled 2-stroke engined vehicles in this population. In Delhi at least, the absence of any mass transit system mitigates against a rapid improvement in the position.

There has been little investment in the approximately 40 refineries in India over the past 20+ years, in a period of relatively high growth in both the vehicle parc and the general economy, particularly the chemical industry. Refineries are consequently stretched for quantity, with many of the better components for motor gasoline (reformate) being used for chemical intermediates. This leaves the octane pool rather low, and in most areas, the best quality available is well below 'lowest' regular limits, which has the effect of new vehicles needing to be de-tuned considerably, even to run. The fuel consumption and emissions are of course considerably increased by this practice, quite apart from the potential longer-term engine damage. To obtain some control over the emissions from motor gasoline engined vehicles therefore, needs firstly country-wide availability of a fuel suitable for new vehicles to conform to their design fuel consumption and emissions, and secondly, a strategy for 2- and 3-wheeled 2-stroke vehicles that ensures their emissions improvement over time. As for China, the elimination of lead from motor gasoline cannot be a first priority, although the quantity should be contained and then reduced. It seems unlikely that unleaded gasoline of a reasonable quality, on any significant scale, can be made available this century.

The situation is similar for automotive diesel fuel (HSD), where lack of refinery upgrading and constrained feedstock choices leads to a very high sulfur, and in some locations, low ignition quality, product. This, combined with the relatively poorly maintained and elderly vehicle parc, leads in turn to high emissions and poor fuel economy. In the automotive market, sulfur contents of 1,0 %(m/m), with even reported excursions above this, cannot be considered commensurate with any reasonable emissions strategy, and this must be a high priority for attention. Ignition quality is more difficult, depending so highly on feedstock quality, but the absence of a higher ignition quality minimum precludes the introduction of lower emission engined vehicles. In the medium term, ignition-improver additives in some locations may be an economic solution.

Tables 15 and 16 give an outline of a 'first step' improved leaded motor gasoline and automotive diesel fuel specification which should be implemented as soon as possible. Further improvements will need to be planned and implemented at regular intervals, with the objective of at least reaching 'target' leaded fuel limiting values within 10 years.

Table 15-Leaded motor gasoline for India

Grade Property		2-stroke	Regular	Premium
Appearance		Clear and Bright		
RON	min.	79	90	95
MON	min.	-	80	85
Density at 15 °C, kg/m^3 2)		705 to 785	710 to 785	710 to 780
Vapour pressure at 37,8 °C, kPa, 3)		35 to 70		

Table 15-continued

Distillation	3)			
E70, °C		12 to 45		
E100, °C		40 to 65		
E180, °C	min.	85		
FBP, °C,	max.	215		
Residue, %(V/V),	max.	2		
VLI	3)max.	950		
Benzene, %(V/V),	max.	5		
Lead, gPb/l,	4)max.	0,40		
Sulfur, %(m/m),	5)max.	0,25	0,20	0,15
Oxidation stability, min,	min.	360		
Gum (solvent washed) mg/100 ml,	max.	4		
Copper strip corrosion (3 h at 50 °C), Class		1		

Notes:

1. Quality of base gasoline excluding 2-stroke oil. Consideration should be given to supplying this grade pre-mixed only.

2. This range should be narrowed with time.

3. Seasonal/regional grades may be required. These limits apply to ambient temperatures of around 30 °C ± 5 °C.

4. This limit is significantly below existing limits (0,56 gPb/l to 0,80 gPb/l) and should be targeted for early implementation. Further reductions to 0,15 gPb/l should be planned.

5. These limits reflect only a slight improvement on the current values. Reduction to 0,10 %(m/m) maximum should take place as soon as possible.

Table 16-Automotive diesel fuel for India

Property		Limiting values
Appearance		Clear and Bright
Density at 15 °C, kg/m^3	1)	815 to 870

Table 16-continued

Cetane number	2)	min.	45
Cetane index	2)	min.	42
Flash point PMcc, °C	3)	min.	56
Viscosity at 40 °C, mm^2/s	4)		1,50 to 5,50
Sulfur, %(m/m)	5)	max.	0,50
Ash, %(m/m)		max.	0,01
Distillation			
10 %(V/V) rec. at, °C,		max.	220
50 %(V/V) rec. at, °C,		max.	295
85 %(V/V) rec. at, °C,		max.	350
95 %(V/V) rec. at, °C,		max.	370
Carbon residue (10 %b), %(m/m)	6)	max.	0,30
Water, mg/kg,	7)	max.	300
Particulate matter, g/m^3	7)	max.	50
Copper corrosion (3 h at 50 °C),		Class	1
Oxidation stability, g/m^3		max.	25
CFPP, °C,		max.	10
Neutralisation number			
Acid number		max.	0,30
Strong acid number			Nil

Notes:

1. The density range, and in particular the maximum, should be narrowed in steps towards the 'target' value.

2. This is considered to be the minimum quality necessary for use with modern engines, albeit at increased emissions. The CI limit is equivalent to current limiting values, and the CN could be achieved by the use of approximately 0,10 %(m/m) ± 0,05 %(m/m) of organo-nitrate ignition improver.

3. The current value allows the use of light components (for quantity). This should be eliminated in the longer term for performance, emissions, and most importantly, for safety reasons.

4. The current maximum limit is too high for modern fuel pumps. It is probably rarely approached in practice.

5. This is half the current limit, and should be regarded as a start only. Reduction to 0,20 %(m/m) should be planned and implemented over time.

6. The limit applies to test method ISO 10370 only (see note 1 to table 9).

7. See note 6 to table 14.

11.4 Singapore. Of the countries involved in this Project, Singapore is probably the most advanced in terms of the current status of integration of an air quality strategy with emissions, vehicles, and fuels quality. This represents a costly investment, both by State and individuals, and the cost of personal transportation is high. Conversely, public transport is widely available, efficient and cheap. The regulations are tough and effective, with the result that there are virtually no passenger cars more than 7 years old, taxis and heavy-duty vehicles are extremely well maintained, and the indigenous small 2-stroke market is very small.

Of course, Singapore has enormous advantages. It is small, but has one of the largest entrepot oil refinery capacities in the world. This capacity is in terms of the most sophisticated yield-shifting and upgrading design, capable of providing International quality products from a great variety of feedstocks. The impact of high quality demands from the small local Singapore market is thus very limited on the refining capabilities.

The single grade of leaded motor gasoline remaining, is of 'super' quality (98 RON), meeting all the target qualities of tables 1 and 2, and most, if not all, of the marketers incorporating second or third generation additive packages. This grade may soon be severely restricted in availability as the Singapore market approaches 80 % unleaded.

There are two grades of unleaded motor gasoline, one at 98 RON and the other at 92 RON, again both containing advanced additive packages, and exceeding the minimum target requirements of tables 6 and 7, with the possible exception of benzene content.

Because of its size, Singapore unusually has a relatively small diesel vehicle market, with sales of diesel fuel approximately equal to that of motor gasoline. The current automotive diesel fuel does not have quite the same relationship to the target qualities as the motor gasolime, although again there is an advanced additive package included. The main area of divergence is sulfur content, although density and back-end volatility are also not controlled to the target limiting values. Because the major feedstocks to the Singapore refining complex are high sulfur Middle East crude oils and components, and some naphthenic/aromatic Far East crude oils in addition to the highly paraffinic type, the balance required to obtain low sulfur and low density middle distillates is extremely delicate. Since de-sulfurisation is now required for many unleaded motor gasoline components/feedstocks to meet limits of 0,05 %(m/m), the de-sulfurising capacity (hydrogen availability) of even the Singapore refineries, is insufficient to treat all product streams. Thus the current automotive diesel fuel limit of 0,50 %(m/m) is likely to be reduced only slowly with time towards the target of 0,20 %(m/m). For some of the Far East crude oils, although low in sulfur, the density is high and ignition quality low, for conventional automotive diesel fuel distillation ranges. Decreasing density by decreasing the distillation temperatures, correspondingly decreases ignition quality even further. Advanced technology and the availability of new components will with time improve this situation.

ANNEX A (informative)

MAJOR MOTOR GASOLINE SPECIFICATIONS

A.1 CEC LEGISLATIVE FUEL RF-08-A-85.

Type-Premium Gasoline, Unleaded1)2)

Applications-Exhaust Emissions Test (ECE 15)
-Fuel Consumption Test
-Power Measurement Test
-Evaporative Emissions Test

Property		Limiting values	Test method
RON	min.	95,0	ISO 5164
MON	min.	85,0	ISO 5163
Density at 15 °C, kg/m^3		748 to 762	ISO 3675 or ISO 12185
Vapour pressure at 37,8 °C, kPa		56 to 64	ISO 3007
Distillation			ISO 3405
IBP, °C			
10 %(V/V) evap. at, °C		24 to 40	
50 %(V/V) evap. at, °C		42 to 58	
90 %(V/V) evap. at, °C		90 to 110	
FBP, °C		190 to 215	
Residue, %(V/V)	max.	2	
Hydrocarbon analysis			
Olefins, %(V/V)	max.	20	ISO 3837
Aromatics, %(V/V)	max.	45	ISO 3837
Benzene, %(V/V)	max.	5,0	EN 238 3) or EN ABC 3)
Carbon/Hydrogen ratio		Report	
Oxidation stability, min,	min.	480	ISO 7536
Gum (solvent washed) mg/100 ml	max.	4	ISO 6246
Copper corrosion (3 h at 50 °C), Class		1	ISO 2160
Lead, mgPb/l	max.	5	
Sulfur, %(m/m)	max.	0,04	ISO 8754
Phosphorus, mg/l	max.	1,3	ASTM D3231

Notes:

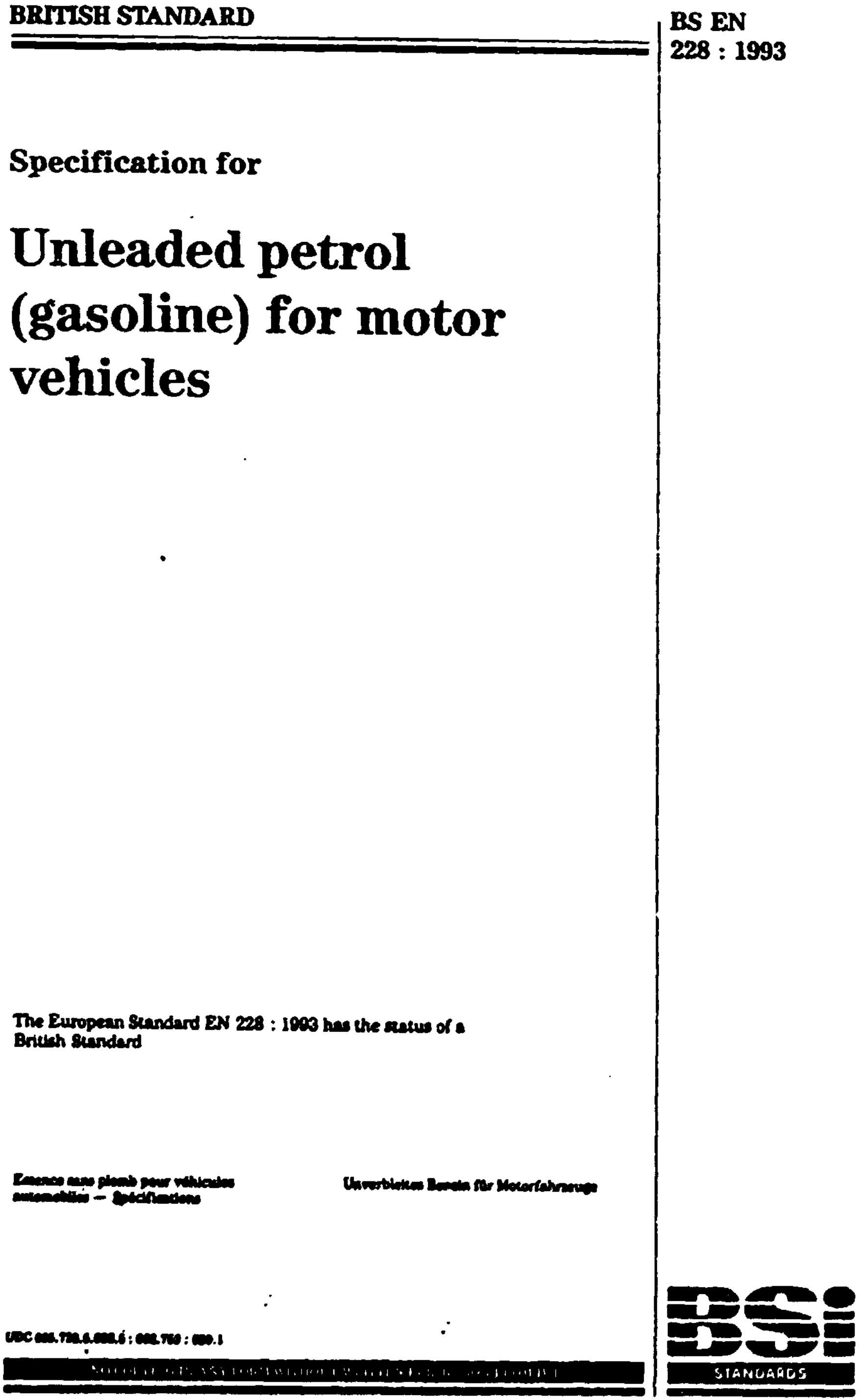
1. The use of oxygenates is prohibited. The blended fuel shall contain only conventional refinery components.

2. The fuel may contain oxidation inhibitors and/or metal de-activators normally used to stabilise refinery gasoline streams. No detergent/dispersant additives or solvent oils are to be added.

3. Pending publication of these methods, ASTM D2267 and ASTM D3606 shall be used as alternatives.

A.2 BS EN 228.

This represents the UK implementation of European Standard EN 228. It is similarly implemented, in English, French or German, by all Member States of EC and EFTA, with their own National Annexes.



BRITISH STANDARD

BS EN
228 : 1993

Specification for

Unleaded petrol (gasoline) for motor vehicles

The European Standard EN 228 : 1993 has the status of a British Standard

Essence sans plomb pour véhicules automobiles — Spécifications

Unverbleites Benzin für Motorfahrzeuge

UDC [illegible]

[illegible]

Cooperating organizations

The European Committee for Standardization (CEN), under whose supervision this European Standard was prepared, comprises the national standards organizations of the following countries:

Austria	Oesterreichisches Normungsinstitut
Belgium	Institut belge de normalisation
Denmark	Dansk Standardiseringsraad
Finland	Suomen Standardisoimisliito, r.y.
France	Association française de normalisation
Germany	Deutsches Institut für Normung e.V.
Greece	Hellenic Organization for Standardization
Iceland	Technological Institute of Iceland
Ireland	National Standards Authority of Ireland
Italy	Ente Nazionale Italiano di Unificazione
Luxembourg	Inspection du Travail et des Mines
Netherlands	Nederlands Normalisatie-instituut
Norway	Norges Standardiseringsforbund
Portugal	Instituto Português da Qualidade
Spain	Asociación Española de Normalización y Certificación
Sweden	Standardiseringskommissionen i Sverige
Switzerland	Association suisse de normalisation
United Kingdom	British Standards Institution

This British Standard, having been prepared under the direction of the Petroleum Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 May 1993

The following BSI references relate to the work on this standard:
Committee reference PTC/11
Draft for comment 91/57147 DC

ISBN 0 580 21468 0

Amendments issued since publication

Amd. No.	Date	Text affected

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National annexes

National foreword

This British Standard has been prepared under the direction of the Petroleum Standards Policy Committee and is the English language version of EN 228 : 1993 *Automotive fuels — Unleaded petrol — Requirements and methods of test*, published by the European Committee for Standardization (CEN).

EN 228 : 1993 was produced as a result of international discussions in which the United Kingdom participated.

BS EN 228 supersedes BS 7070 : 1988, which is withdrawn.

EN 228 : 1993 requires that each country implementing it establishes national annexes detailing requirements for 'Pump marking', 'RON and MON requirements for regular grade', and 'Seasonal volatility'. Also, if the methods for sampling given in ISO 3170 and ISO 3171 are not to be used, a national annex has to detail national requirements. National annex NA of BS EN 228 gives additional requirements on sampling, in particular for sampling from the pump; national annex NB gives details of requirements for 'Pump marking'; national annex NC gives details of the 'RON and MON requirements for regular grade'; and national annex ND gives details of seasonal volatility requirements.

The principal differences between this British Standard and BS 7070 : 1988 include the following.

Phosphorus containing compounds are excluded.

The acidity of fuel ethanol blendstock is limited.

The minimum density is increased to 725 kg/m^3 and a maximum given.

The limit for sulfur content is reduced to 0.10 % (*m/m*) and, from 1995-01-01, to 0.05 % (*m/m*).

The minimum oxidation stability is increased from 240 min to 360 min.

A storage grade with an oxidation stability of 480 min is no longer included.

Oxygenates are now limited by reference to Directive 85/536/EEC.

NOTE. *Testing.* In the laboratory testing of petrol against the requirements of clause 5 of this British Standard it is necessary to use equipment and procedures exactly as laid down in the appropriate test methods. In particular it is essential to use properly inspected and maintained standard CFR[1] engines for the determination of both RON and MON. A useful guide to the satisfactory operation and test precision of a CFR engine can be obtained by including it in the Engine Test Correlation Programme of the Institute of Petroleum. Details of this programme are available from the Institute of Petroleum or the British Standards Institution.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

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[1] Co-operative Fuel Research Committee.

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 228

March 1993

UDC 665.733.5.038.5 : 662.753 : 620.1

Supersedes EN 228 : 1987

Descriptors: Motors vehicles, gasoline, unleaded gasoline, specifications, characteristics, tests, volatility, reference to standards

English version

Automotive fuels — Unleaded petrol — Requirements and methods of test

Carburant pour automobiles — Essence sans plomb — Exigences et méthodes d'essai

Kraftstoffe für Kraftfahrzeuge — Unverbleite Ottokraftstoffe — Mindestanforderungen und Prüfverfahren

This European Standard was approved by CEN on 1993-03-16. CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN
European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. EN 228 : 1993 E

Foreword

This European Standard was drawn up by CEN/TC 19 "Test methods and specifications for petroleum products".

The standard was approved and in accordance with the CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 1993 and conflicting national standards shall be withdrawn at the latest by September 1993.

This European Standard cancels and replaces EN 228 : 1987 in whole. In this second edition of EN 228 provisions for requirements to be set nationally for characteristics designated in the first edition as type B and type C characteristics are deleted. For all relevant characteristics requirements and test methods are now specified in this European Standard. Only for climatically related requirements provisions are included for national bodies to specify seasonal grades from a limited number of grade-options given in this European Standard.

Also in this second edition requirements are included or amended as appropriate to account for the use of oxygenates in unleaded petrol.

This European Standard has been prepared under a mandate given to CEN by the Commission of the European Communities and the European Free Trade Association.

Annex A forms an informative part of this European Standard.

Introduction

As a consequence of the adoption of the request issued to CEN concerning the establishment of a standardization programme in the field of motor vehicle fuels (BC/CEN/8/87) by the Commission of the European Communities, the Commission requested that CEN create two European Standards for unleaded petrol in addition to the existing EN 228. One European Standard was to deal with the characteristics designated in the first edition as type B and type C characteristics, for which national bodies would no longer be allowed to set requirements nationally. The other European Standard was to set or amend requirements as necessary in view of the use of oxygenates in unleaded petrol.

In view of the major effects that these two new European Standards would have on the existing EN 228 and on each other, it was decided by CEN/TC 19 to draft a full new edition of EN 228 in response to these requests.

1 Scope

This European Standard specifies requirements and methods of test for unleaded petrol as marketed and as delivered in the countries of the members of CEN. It is for use in petrol engine vehicles designed to run on unleaded petrol, including those equipped with devices to reduce emitted pollutants.

All requirements apply equally to regular and premium grade unleaded petrol, unless indicated otherwise. The requirements regarding the regular grade apply only if a regular grade unleaded petrol is marketed.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 5	*Determination of existent gum in fuels by jet evaporation*
EN 12	*Liquid petroleum products - Determination of vapour pressure - Wet method*
EN 237[1]	*Liquid petroleum products - Determination of low lead concentrations - Atomic absorption spectrometric method*
EN 238[1]	*Liquid petroleum products - Determination of the benzene content - Infrared spectrometric method*
EN 24260[2]	*Petroleum products and hydrocarbons - Determination of sulfur content - Wickbold combustion method*
ISO 1388-2 : 1981	*Ethanol for industrial use - Method of test - Part 2 : Detection of alkalinity or determination of acidity to phenolphthalein*
ISO 2160 : 1985	*Petroleum products - Corrosiveness to copper - Copper strip test*
ISO 3170 : 1988	*Petroleum products - Liquid hydrocarbons - Manual sampling*
ISO 3171 : 1988	*Petroleum products - Liquid hydrocarbons - Automatic pipeline sampling*
ISO 3405 : 1988	*Petroleum products - Determination of distillation characteristics*
ISO 3675 : 1976	*Crude petroleum and liquid petroleum products - Laboratory determination of density or relative density - Hydrometer method*
ISO 4259 : 1979	*Petroleum products - Determination and application of precision data in relation to methods of test*
ISO 5163 : 1990	*Motor and aviation-type fuels - Determination of knock characteristics - Motor method*
ISO 5164 : 1990	*Motor fuels - Determination of knock characteristics - Research method*
ISO 7536[3]	*Gasoline - Determination of oxidation stability - Induction period method*
ISO 8754 : 1992	*Petroleum products - Determination of sulfur content - Nondispersive X-ray fluorescence method*
ASTM D 4052[4] : 1991	*Test method for density and relative density of liquids by digital density meter*

3 Sampling

Samples shall be taken as described in ISO 3170 or ISO 3171 and/or in accordance with the requirements of national standards or regulations for the sampling of unleaded petrol. The national requirements shall be set out in detail or shall be referred to by reference in a national annex to this standard.

NOTE. It is essential that for sampling of unleaded petrol the containers used to take and store the samples before test are not contaminated with lead.

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[1] These standards are to be published. Pending their publication the following standards may be used.
For EN 237: ASTM D 3237-90: Test methods for lead in gasoline by atomic absorption spectrometry.
For EN 238: ASTM D 2267-88: Test method for aromatics in light naphthas and aviation gasolines by gas chromatography.

[2] To be published. (CEN implementation of ISO 4260 : 1987, to replace EN 41 : 1975, *Determination of the sulphur content of petroleum products by the Wickbold combustion method.)*

[3] To be published.

[4] ASTM D 4052-91 is a joint ASTM/IP method and carries also the designation IP 365/1984 (1986).

4 Pump marking

Information to be marked on dispensing pumps used for delivering unleaded petrol, and the dimensions of the mark shall be in accordance with the requirements of national standards or regulations for the marking of pumps for unleaded petrol. Such requirements shall be set out in detail or shall be referred to by reference in a national annex to this European Standard.

5 Requirements and test methods

5.1 Dyes and markers

The use of dyes and markers is allowed.

5.2 Additives

In order to improve the performance quality the use of additives is allowed.

5.3 Phosphorus

In order to protect automotive catalyst systems, phosphorus containing compounds shall not be included in unleaded petrol.

5.4 Oxygenates content

The limits for the oxygenates content are given in an EC Directive (see Annex A, A1). An EN giving a test method for the determination of the oxygenates content is being developed. For the time being methods as indicated in the relevant EC Directive (see Annex A, A2) shall be used.

5.5 Acidity

To adequately limit the acidity of the petrol, the acidity of fuel ethanol used as a blendstock shall not exceed 0,007 % *m/m* (as acetic acid) when tested in accordance with ISO 1388-2.

5.6 Generally applicable requirements and test methods

When tested in accordance with the test methods indicated in tables 1 and 2, premium grade unleaded petrol and regular grade unleaded petrol respectively shall be in accordance with the limits specified in tables 1 and 2.

Table 1. Generally applicable requirements and test methods for premium grade unleaded petrol

Property	Units	Limits		Test method
		Min.	Max.	
Research octane number, RON		95,0	–	ISO 5164
Motor octane number, MON		85,0	-	ISO 5163
Lead content	g/l	–	0,013	EN 237
Benzene content	% *V/V*	–	5,0	EN 238
Density (at 15 °C)	kg/m^3	725	780	ISO 3675/ASTM D 4052
Sulfur content	% *m/m*	–	0,10[1]	EN 24260/ISO 8754
Oxidation stability	min	360	–	ISO 7536
Existent gum content (solvent washed)	mg/(100 ml)	–	5	EN 5
Copper strip corrosion (3 h at 50 °C)	rating	class 1		ISO 2160
Appearance		clear and bright		Visual inspection

[1] From 1995-01-01 onward the sulfur content shall be: 0,05 % *m/m* max.

Table 2. Generally applicable requirements and test methods for regular grade unleaded petrol

Property	Units	Limits		Test method
		Min.	Max.	
Research octane number, RON		[1]	–	ISO 5164
Motor octane number, MON		[1]	–	ISO 5163
Lead content	g/l	–	0,013	EN 237
Benzene content	% *V/V*	–	5,0	EN 238
Density (at 15 °C)	kg/m^3	725	780	ISO 3675/ASTM D 4052
Sulfur content	% *m/m*	–	0,10[2]	EN 24260/ISO 8754
Oxidation stability	min	360	–	ISO 7536
Existent gum content (solvent washed)	mg/(100 ml)	–	5	EN 5
Copper strip corrosion (3 h at 50 °C)	rating	class 1		ISO 2160
Appearance		clear and bright		Visual inspection

[1] RON and MON shall be specified in a national annex to this European Standard, in accordance with the provisions of the relevant EC Directive(s).

[2] From 1995-01-01 onward the sulfur content shall be: 0,05 % *m/m* max.

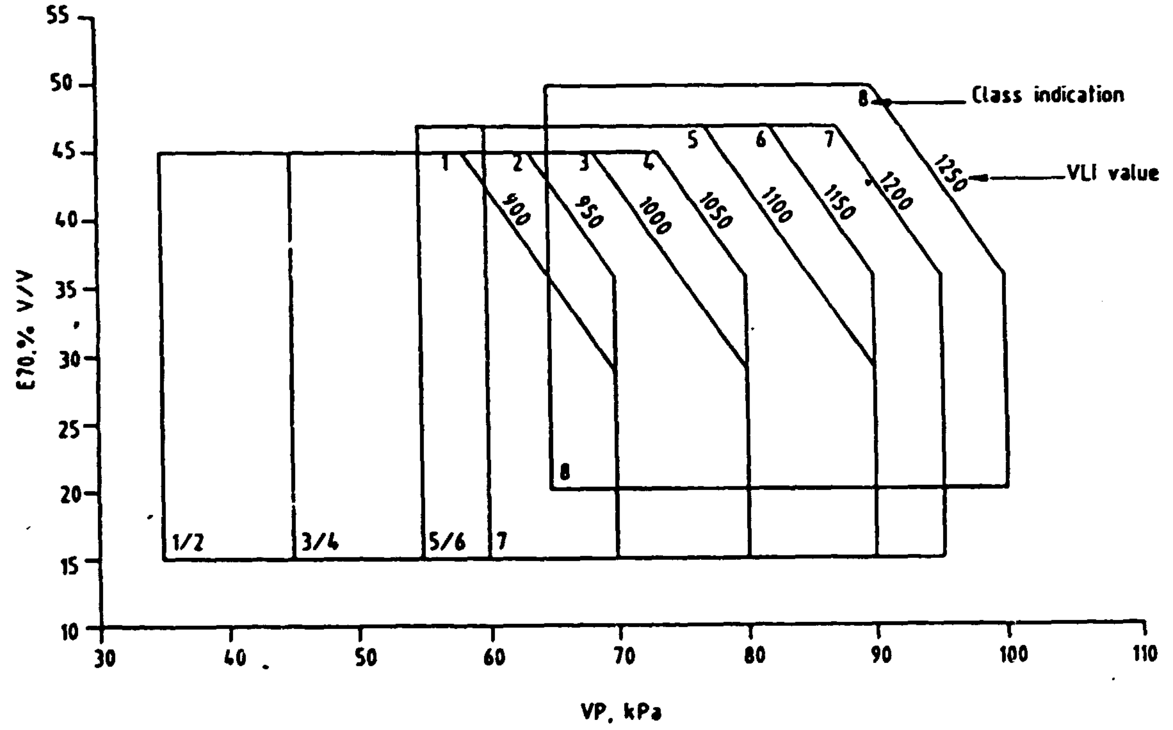


Figure 1. Relation between VP, E70 and VLI for the eight different volatility classes

5.7 Climatically dependent requirements and test methods

5.7.1 *Water tolerance*

Given the known potential for some motor gasolines to absorb water, suppliers shall ensure that no water segregation occurs under the range of climatic conditions experienced in the country concerned. When there is a risk of water separation, anti-corrosion additives shall be incorporated.

5.7.2 *Volatility requirements*

The volatility requirements of petrol shall be controlled by limits on the properties given in table 3.

Table 3. Properties for volatility requirements

Property	Unit	Limits
Vapour Pressure, VP	kPa	min./max.
Percentage evaporated at 70 °C, E70	% *V/V*	min./max.
Percentage evaporated at 100 °C, E100	% *V/V*	min./max.
Percentage evaporated at 180 °C, E180	% *V/V*	min.
Final Boiling Point, FBP	°C	max.
Distillation residue	% *V/V*	max.
Vapour Lock Index, VLI (VLI = 10 VP + 7 E70)		min./max.

To meet the different seasonal and geographical conditions eight volatility classes are defined as given in table 4, and illustrated by figure 1. Each country shall, in a national annex to this European Standard, specify which one of these eight classes applies during a defined period of the year for a defined region of its country.

5.8 Precision and dispute

All the test methods referred to in this European Standard include a precision statement. In cases of dispute, the procedures described in ISO 4259 for resolving the dispute, and interpretation of the results based on test method precision shall be used.

Annex A (informative)

Bibliography

A.1 Directive 85/536/EEC, Council Directive on crude-oil savings through the use of substitute fuel components in petrol

A.2 Directive 87/441/EEC, Commission Directive on crude-oil savings through the use of substitute fuel components in petrol

Table 4. Volatility classes

Property	Units	Limits class 1	class 2	class 3	class 4	class 5	class 6	class 7	class 8	Test method
Vapour pressure	kPa, min. kPa, max.	35 70	35 70	45 80	45 80	55 90	55 90	60 95	65 100	EN 12[1]
% evaporated at 70 °C	% *V/V*, min. % *V/V*, max.	15 45	15 45	15 45	15 45	15 47	15 47	15 47	20 50	ISO 3405
VLI (10VP + 7E70)	max.	900	950	1000	1050	1100	1150	1200	1250	
% evaporated at 100 °C	% *V/V*, min. % *V/V*, max.	40 65	40 65	40 65	40 65	43 70	43 70	43 70	43 70	ISO 3405
% evaporated at 180 °C	% *V/V*, min.	85	85	85	85	85	85	85	85	ISO 3405
FBP	°C, max.	215	215	215	215	215	215	215	215	ISO 3405
Distillation residue	% *V/V*, max.	2	2	2	2	2	2	2	2	ISO 3405

[1] EN 12 is suitable for oxygenates contents meeting column A of the relevant Directive (see Annex A, A1). It is intended to replace EN 12 by a generally applicable method.

National annex NA (normative)

Sampling requirements

NA.1 Introduction

This national annex gives the sampling requirements to comply with clause 3.

NA.2 Sampling

NA.2.1 *Sampling from storage tanks*

For the purposes of this British Standard all sampling shall be carried out in accordance with the relevant procedures of BS 3195 : Part 1 : 1989 and, additionally, as detailed in NA.2.3.

NOTE 1. Attention is drawn to the special precautions needed for samples for the determination of Reid vapour pressure (see BS 2000 : Part 69).

NOTE 2. The method described in NA.2.3 is designed for sampling the bulk of fuel being fed to the offtake point. The examination of equipment, e.g. pumps to detect faulty operation, may require the use of different techniques.

NA.2.2 *Sampling from pipelines*

For the purposes of this British Standard all sampling shall be carried out in accordance with the relevant procedures of either BS 3195 : Part 1 : 1989 or BS 3195 : Part 2 : 1989 and, additionally, as detailed in NA.2.3 (see note 2 to NA.2.1).

BS 3195 : Part 2 : 1989 shall be used in combination with a variable volume receiver which maintains the integrity of the sample.

NA.2.3 *Sampling from petrol pumps*

NA.2.3.1 *Sampling cans of 5 l and 1 l capacity*

The construction of the cans shall conform to the appropriate safety requirements for cans that are to hold highly flammable material. Cans shall be constructed from lead-free material except that lead solder may be used for the attachment of external fittings. They shall be provided with screw caps incorporating a petroleum resistant washer in good condition.

A stock of cans shall be kept solely for the purpose of taking samples of unleaded petrol. Such cans shall be clearly identified and kept separate from cans used for the purpose of taking samples of leaded petroleum in accordance with BS 4040.

NOTE. Attention is drawn to the fact that sampling cans will need to conform to the statutory safety requirements for the classification, packaging and labelling of dangerous substances.

NA.2.3.2 *Preparation of cans*

New cans shall be rinsed with unleaded petrol before being used, to remove any residual traces of oil left during manufacturing operations, and then allowed to dry. Before use, all cans shall be checked to ensure that they are sound and free from leaks.

NA.2.3.3 *Sampling procedure*

From the pump nozzle, 5 l of petrol shall be drawn carefully into a cool 5 l can using a clean dry funnel. Immediately afterwards, this sample shall be decanted carefully into the requisite number of 1 l cans, using a funnel, filling the cans within 15 mm of the brim.

If more than 5 l is needed, the operation shall be repeated immediately and before the pump has been used for any other purpose. The screw caps shall be tightened fully and the cans checked to ensure that there are no leaks.

The sampling procedure shall not be carried out in direct sunlight.

NOTE 1. If carried out in direct sunlight, changes in fuel quality especially octane level, may occur.

NOTE 2. A quantity of 1 l is sufficient for the determination of octane number and certain other tests but it is advisable to provide each laboratory with 2 l of sample in case further work is needed; it is essential that these 2 l be identical material.

NA.2.3.4 *Storage, labelling and transport*

Samples shall be kept in a cool place although it is not necessary to keep them refrigerated.

NOTE 1. If left in direct sunlight there is a danger that the cans will 'balloon'.

Full and legible information relating to the source of the sample shall be attached to the can in such a manner that it will not easily become detached subsequently.

NOTE 2. If required, the sample may be sealed and labelled to maintain the legal integrity.

NOTE 3. If the sample has to be sent to a laboratory by public transport, it will be necessary to comply with the general regulations covering transportation of flammable materials and with the requirements of the transport authority concerned. Information on the appropriate procedures and the type of packaging required should be obtained from the transport authority involved.

NA.3 List of references

NA.3.1 *Normative references*

BS 3195 :	*Methods for sampling petroleum products*
BS 3195 : Part 1 : 1989	*Manual sampling of liquid hydrocarbons*
BS 3195 : Part 2 : 1989	*Automatic pipeline sampling of liquid hydrocarbons*

NA.3.2 *Informative references*

BS 2000 :	*Methods of test for petroleum and its products*
BS 2000 : Part 69 : 1982	*Reid vapour pressure of petroleum products*
BS 4040 : 1988	*Specification for leaded petrol (gasoline) for motor vehicles*

National annex NB (normative)

Pump marking requirements

NB.1 Introduction

This national annex gives the pump marking requirements to comply with clause 4.

NB.2 Requirements

For the purposes of this British Standard the following information shall be marked on each dispensing pump or container used for delivering petrol conforming to this British Standard into the consuming vehicle.

a) The name or mark of the supplier or vendor of the petrol.

b) The grade designation 'Premium' or 'Regular' as defined in 5.6 and displayed as shown in figure NB.1. The minimum dimensions of this mark shall be as shown in figure NB.1 (see note 1) and the colour used for the design and lettering shall be in clear contrast to the background colour (see note 2).

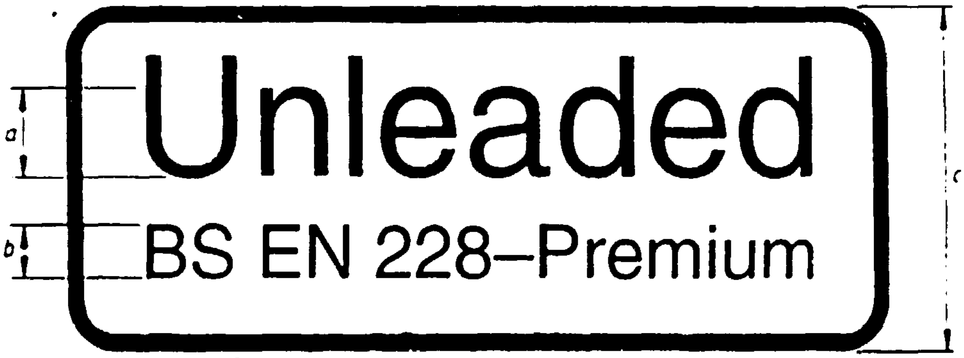
NOTE 1. The minimum dimensions of the mark given in figure NB.1 have been selected to enable its application to pumps of the smallest anticipated dimensions. It is strongly recommended that, in the interests of visibility to the motorist the larger recommended dimensions be used wherever possible.

NOTE 2. It is recommended that the prominent colour should be green. The preferred colour is colour number 216 of BS 381C.

The mark shall be in a prominent position.

NB.3 *Informative reference*

BS 381C : 1988 *Specification for colours for identification, coding and special purposes*



	Recommended mm	Minimum mm
a	25	15
b	15	12
c	100	60

NOTE. For Regular grade, substitute the word 'Regular' for 'Premium'.

Figure NB.1. Form of mark for unleaded petrol, Premium grade

National annex NC (normative)
RON and MON requirements for regular grade

NC.1 Introduction

This national annex gives the RON and MON requirements for regular grade to comply with footnote 1 to table 2.

NC.2 Requirement for anti-knock values

For the purposes of this British Standard unleaded petrol designated as 'regular' shall have anti-knock values expressed as RON and MON not less than the minimum values given in table NC.1 when tested by the methods given in table NC.1.

Table NC.1 Minimum anti-knock values for regular grade

Property	Limit min.	Test method
RON	90.0	BS 2637 : 1991
MON	80.0	BS 2638 : 1991

NOTE 1. The interpretation of single RON and MON test results according to BS 4306 is described in NC.3.

NOTE 2. The details of procedure and equipment for the determination of RON and MON are given in ASTM D 2699-86 : IP 237/69 and ASTM D 2700-86 : IP 236/69 respectively, to which BS 2638 and BS 2637 refer. EEC Directive 85/210/EEC refers for the determination of octane ratings to the 1977 editions of ISO 5163 and ISO 5164, which themselves refer to undated editions of the ASTM methods. BS 2638 and BS 2637 refer to dated editions of the ASTM standards.

NC.3 Interpretation of single RON and MON tests results: testing margin at the recipient

A recipient who has no other source of information on the true value of a characteristic than a single result shall consider that the product fails the specification limit, with 95 % confidence, only if the result X is such that:

$$X < A - \frac{0.84R}{\sqrt{2}}$$

where

R is the reproducibility of the test method given in tables NC.2 and NC.3;

A is the minimum RON and MON for the grade.

NOTE. Reproducibility is a quantitative expression of the random error associated with operators working in different laboratories, each obtaining a single result on a portion of the same sample. It is the difference between two such single and independent results that would be exceeded in the long run in only one case in twenty in the normal and correct operation of the test method. This is known as the 95 % probability level.

Extensive data obtained from consumer and producer laboratories over a number of years for many samples of conventional petrols have shown that the reproducibility of fuel ratings between laboratories varies with octane number level.

Table NC.2. Reproducibility of RON test method

RON	Reproducibility, R
90	0.7
91	0.7
92	0.7
93	0.6
94	0.6
95	0.6
96	0.6
97	0.6
98	0.7
99	0.7
100	0.7

NOTE. Table NC.2 has been calculated from the reproducibility data published in ASTM D 2699-86 : IP 237/69, Section 18 and figure 3a.

Table NC.3. Reproducibility of MON test method

MON	Reproducibility, R
80	1.2
81	1.0
82	1.0
83	1.0
84	0.9
85	0.9
86	0.9
87	1.0
88	1.0
89	1.1
90	1.1

NOTE. Table NC.3 has been calculated from the reproducibility data published in ASTM D 2700-86 : IP 236/69, Section 18 and figure 4a.

NC.4 List of references

NC.4.1 *Normative references*

BS 2637 : 1991

BS 2638 : 1991

NOTE. The titles of these British Standards are listed in national annex NF opposite the entries for ISO 5163 and ISO 5164.

NC.4.2 *Informative references*

BS 4306 : 1981

NOTE 1. See ISO 4259 in national annex NF.

ISO 5163 : 1990

ISO 5164 : 1990

NOTE 2. See national annex NF.

ASTM D 2699-86 : IP 237/69

ASTM D 2700-86 : IP 236/69

National annex ND (normative)

Seasonal volatility requirements

ND.1 Introduction

This national annex gives seasonal volatility requirements to comply with 5.7.2.

ND.2 Requirements

For the purposes of this British Standard the following volatility classes shall apply.

Summer	For deliveries from refineries and import terminals 16 April to 31 August inclusive:	class 4
	For sales from petrol retail outlets petrol pumps 1 June to 31 August inclusive:	class 4
Winter	For deliveries from refineries and import terminals, 1 September to 15 April inclusive:	class 8
	For sales from petrol retail outlet petrol pumps 1 September to 31 May inclusive:	class 8

National annex NE (informative)

Committees responsible

The United Kingdom participation in the preparation of this European Standard was entrusted by the Petroleum Standards Policy Committee to Technical Committee PTC/11, upon which the following bodies were represented:

Association of United Kingdom Oil Independents
Automobile Association
Bus and Coach Council
Chemical Industries' Association
Consumer Policy Committee of BSI
Department of Trade and Industry
Department of Transport
Federation of Petroleum Suppliers
Freight Transport Association
Institute of Petroleum
Institute of Trading Standards Administration
Ministry of Defence
Motor Cycle Industry's Association of Great Britain
Petrol Pump Manufacturers' Association
Petrol Retailers' Association
Road Haulage Association
Royal Automobile Club
Society of Motor Manufacturers and Traders
United Kingdom Petroleum Industry Association
World Wide Fund for Nature

National annex NF (informative)

Cross-references

Publication referred to	**Corresponding British Standard**
EN 5	BS 4348 : 1976 *Determination of existent gum in fuels by jet evaporation*
ISO 2160 : 1985	BS 2000 *Methods of test for petroleum and its products* Part 154 : 1982 *Detection of copper corrosion from petroleum products by the copper strip tarnish test*
ISO 3170 : 1988	BS 3195 *Methods for sampling petroleum products* Part 1 : 1989 *Manual sampling of liquid hydrocarbon*
ISO 3171 : 1988	BS 3195 *Methods for sampling petroleum products* Part 2 : 1989 *Automatic pipeline sampling of liquid hydrocarbon*
ISO 3405 : 1988	BS 7392 : 1990 *Method of determination of distillation characteristics of petroleum products*
ISO 3675 : 1979	BS 4714 : 1980 *Method for laboratory determination of density or relative density of crude petroleum and liquid petroleum products (hydrometer method)*
ISO 4259 : 1979	BS 4306 : 1981 *Method for determination and application of precision data in relation to methods of test for petroleum products*
ISO 5163 : 1990	BS 2637 : 1991 *Method for determination of knock characteristics of motor and aviation-type fuels (motor method)*
ISO 5164 : 1990	BS 2638 : 1991 *Method for determination of knock characteristics of motor fuels (research method)*

A.3 ASTM D4814.

Designation: D 4814 – 92c

An American National Standard

Standard Specification for Automotive Spark-Ignition Engine Fuel[1]

This standard is issued under the fixed designation D 4814; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense

NOTE—Footnotes D, E, and F of Table 4 are currently under ballot for revision.

1. Scope

1.1 This specification guides in establishing requirements of automotive fuels for ground vehicles equipped with spark-ignition engines.

1.2 This specification describes various characteristics of automotive fuels for use over a wide range of operating conditions. It provides for a variation of the volatility and water tolerance of automotive fuel in accordance with seasonal climatic changes at the locality where the fuel is used. For the period May 1 through September 15, the maximum vapor pressure limits issued by the U.S. Environmental Protection Agency (EPA) are specified for each geographical area except Alaska and Hawaii. Variation of antiknock index with seasonal climatic changes and altitude is discussed in Appendix X1. This specification neither necessarily includes all types of fuels that are satisfactory for automotive vehicles, nor necessarily excludes fuels that can perform unsatisfactorily under certain operating conditions or in certain equipment. The significance of each of the properties of this specification is shown in Appendix X1.

1.3 The spark-ignition engine fuels covered in this specification are gasoline and its blends with oxygenates such as alcohols and ethers. This specification does not apply to fuels that contain an oxygenate as the primary component, such as Fuel Methanol (M85). The concentrations and types of oxygenates are not specifically limited in this specification. However, depending on oxygenate type, as oxygenate content increases above some threshold level, the likelihood for vehicle problems also increases. The composition of both unleaded and leaded fuel is limited by economic, legal, and technical consideration, but their properties, including volatility, are defined by this specification. In addition, the composition of unleaded fuel is subject to the rules, regulations, and Clean Air Act waivers of the U.S. Environmental Protection Agency (EPA). With regard to fuel properties, including volatility, this specification can be more or less restrictive than the EPA rules, regulations, and waivers. Refer to Appendix X3 for discussions of EPA rules relating to fuel volatility, lead and phosphorous contents, and use of oxygenates in blends with unleaded gasoline. Contact EPA for the latest versions of the rules and additional requirements.

1.4 This specification represents a description of automotive fuel as of the date of publication. The specification is under continuous review, which can result in revisions based on changes in fuel, automotive requirements, or test methods, or a combination thereof. All users of this specification, therefore, should refer to the latest edition.

NOTE 1—If there is any doubt as to the latest edition of Specification D 4814, contact ASTM Headquarters.

1.5 Tests applicable to gasoline are not necessarily applicable to its blends with oxygenates. Refer to the specific test methods for information on their applicability to gasoline-oxygenate blends. The type of fuel under consideration must first be identified, in order to select applicable tests. A method for identifying gasolines that contain alcohols is described in 5.2. A test method for identifying gasolines that contain alcohols or MTBE is Test Method D 4815.

1.6 The test methods in Annexes A1 through A3 are state-of-the-art; however, they may be revised and eventually balloted for publication as separate standards.

1.7 The values stated in SI units are the standard, except when other units are specified by federal regulation. Values given in parentheses are provided for information purposes.

1.8 The following safety hazard caveat pertains only to the test method portions, Annexes A1, A2, and A3 of this specification. *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 86 Test Method for Distillation of Petroleum Products[2]

D 130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test[2]

D 381 Test Method for Existent Gum in Fuels by Jet Evaporation[2]

D 439 Specification for Automotive Gasoline[3]

D 525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)[2]

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[1] This specification is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.A on Gasoline.

Current edition approved Nov. 15, 1992. Published January 1993. Originally published as D 4814 – 88. Last previous edition D 4814 – 92b.

[2] *Annual Book of ASTM Standards*, Vol 05.01.

[3] Discontinued—See 1990 *Annual Book of ASTM Standards*, Vol 05.01.

TABLE 1 Vapor Pressure and Distillation Class Requirements

Vapor Pressure/ Distillation Class	Vapor Pressure,[A] max, kPa(psi)	Distillation Temperatures, °C(°F), at % Evaporated[B]					Distillation Residue, vol %, max
		10 Vol %, max	50 vol %		90 vol %, max	End Point, max	
			min	max			
AA	54(7.8)	70(158)	77(170)	121(250)	190(374)	225(437)	2
A	62(9.0)	70(158)	77(170)	121(250)	190(374)	225(437)	2
B	69(10.0)	65(149)	77(170)	118(245)	190(374)	225(437)	2
C	79(11.5)	60(140)	77(170)	116(240)	185(365)	225(437)	2
D	93(13.5)	55(131)	77(170)	113(235)	185(365)	225(437)	2
E	103(15.0)	50(122)	77(170)	110(230)	185(365)	225(437)	2

[A] The dry methods described in Test Methods D 4953, D 5190, or D 5191 shall be used for gasoline-alcohol blends (consult EPA for approved test methods for enforcement).

[B] At 101.3 kPa pressure (760 mm Hg)

D 1193 Specification for Reagent Water[4]

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)[2]

D 2500 Test Method for Cloud Point of Petroleum Oils[2]

D 2533 Test Method for Vapor-Liquid Ratio of Spark-Ignition Engine Fuels[2]

D 2599 Test Method for Lead in Gasoline by X-Ray Spectrometry[5]

D 2622 Test Method for Sulfur in Petroleum Products by X-Ray Spectrometry[5]

D 2699 Test Method for Knock Characteristics of Motor Fuels by the Research Method[6]

D 2700 Test Method for Knock Characteristics of Motor and Aviation Fuels by the Motor Method[6]

D 2885 Test Method for Research and Motor Method Octane Ratings Using On-Line Analyzers[6]

D 3116 Test Method for Trace Amounts of Lead in Gasoline[5]

D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry[5]

D 3229 Test Method for Low Levels of Lead in Gasoline by Wavelength Dispersive X-Ray Spectrometry[5]

D 3231 Test Method for Phosphorus in Gasoline[5]

D 3237 Test Method for Lead in Gasoline by Atomic Absorption Spectrometry[5]

D 3341 Test Method for Lead in Gasoline—Iodine Monochloride Method[5]

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[5]

D 4306 Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination[5]

D 4815 Test Method for Determination of C1 to C4 Alcohols and MTBE in Gasoline by Gas Chromatography[7]

D 4953 Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)[7]

D 5059 Test Methods for Lead in Gasoline by X-Ray Spectroscopy[7]

D 5190 Test Method for Vapor Pressure of Petroleum Products (Automatic Method)[7]

TABLE 2 Vapor Lock Protection Class Requirements

Vapor Lock Protection Class	Vapor/Liquid Ratio (V/L)[A,B]	
	Test Temperature, °C(°F)	V/L, max
1	60(140)	20
2	56(133)	20
3	51(124)	20
4	47(116)	20
5	41(105)	20

[A] At 101.3 kPa pressure (760 mm Hg).

[B] The mercury confining fluid procedure of Test Method D 2533 shall be used for gasoline-oxygenate blends. Either glycerin or mercury confining fluid may be used for gasoline. Subcommittee D02.08 is investigating a possible bias of the mercury procedure and the suitability of using glycerin for gasoline-ether blends. The procedure for estimating temperature-V/L (see Appendix X2) may only be used for gasoline

D 5191 Test Method for Vapor Pressure of Petroleum Products (Mini Method)[7]

E 1 Specification for ASTM Thermometers[8]

3. Terminology

3.1 *Definitions:*

3.1.1 *antiknock index, n*—the arithmetic average of the Research octane number (RON) and Motor octane number (MON), that is, (RON + MON)/2.

3.1.2 *gasoline, n*—a volatile mixture of liquid hydrocarbons, containing small amounts of additives, suitable for use as a fuel in spark-ignition, internal combustion engines.

3.1.3 *gasoline-alcohol blend, n*—a fuel consisting primarily of gasoline along with a substantial amount of one or more alcohols.

3.1.4 *gasoline-ether blend, n*—a fuel consisting primarily of gasoline along with a substantial amount of one or more ethers.

3.1.5 *gasoline-oxygenate blend, n*—a fuel consisting primarily of gasoline along with a substantial amount of one or more oxygenates.

3.1.6 *oxygenate, n*—an oxygen-containing, ashless, organic compound, such as an alcohol or ether, which can be used as a fuel or fuel supplement.

3.2 *Applicability*—In order to determine when a fuel contains a substantial amount of an oxygenate, a gasoline-oxygenate blend is defined as a fuel which contains more than 0.35 mass percent oxygen, or more than 0.15 mass percent oxygen if methanol is the only oxygenate. The definitions in this section do not apply to fuels that contain

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[4] *Annual Book of ASTM Standards*, Vol 11.01.

[5] *Annual Book of ASTM Standards*, Vol 05.02.

[6] *Annual Book of ASTM Standards*, Vol 05.04.

[7] *Annual Book of ASTM Standards*, Vol 05.03.

[8] *Annual Book of ASTM Standards*, Vols 05.03 and 14.03.

TABLE 3 Detailed Requirements for all Volatility Classes[A]

Lead Content, max, g/L (g/U.S. gal)[B]		Copper Strip Corrosion, max	Existent Gum, max, mg/100 mL	Sulfur, max, mass %		Oxidation Stability, Minimum, minutes	Water Tolerance
Unleaded	Leaded			Unleaded	Leaded		
0.013(0.05)	1.1(4.2)	No. 1	5	0.10	0.15	240	[C]

[A] See Appendix X1 for information on Antiknock Index.

[B] See Appendix X3 for U.S. EPA maximum limits for lead and phosphorus contents in unleaded gasoline (X3.2.1) and maximum average lead limits for leaded gasoline (X3.2.2)

[C] Water tolerance limits in terms of maximum temperature for phase separation are given in Table 5 (consult Annex A3).

an oxygenate as the primary component; for example, fuel methanol (M85).

NOTE 2—The criteria in 3.2 were selected with consideration given to current oxygenate levels in the marketplace, state labeling practices, and consistency with federal legislation and regulations.

4. Ordering Information

4.1 The purchasing agency shall:

4.1.1 State the antiknock index as agreed upon with the seller,

4.1.2 Indicate the season and locality in which the fuel is to be used,

4.1.3 Indicate the lead level required (Table 1), and

4.1.4 State the concentration and types of oxygenates present as agreed upon with the seller.

5. Performance Requirements

5.1 Some requirements and test methods applicable to automotive spark-ignition engine fuel depend on whether the fuel is a gasoline, or a gasoline-oxygenate blend. If it is not known whether a specific fuel is a gasoline-oxygenate blend, fuels containing more than about 0.1 volume % alcohol can be identified using the test described in 5.2. Once the type of fuel is known, the appropriate requirements and test methods can be identified by reference to Tables 1, 2, 3 and Section 7.

5.2 A simple laboratory test to determine generally whether oxygenates are present in a fuel is not currently available. However, the alcohol detection test using refraction of light through the water extract of the fuel sample (see Annex A1) should be used to determine if a fuel contains alcohol (methanol through butanols). A detectable change in refractivity of the water extract, as defined in Annex A1, indicates the presence of sufficient alcohol to require special precautions, and references in this specification to oxygenates are applicable. This test may not detect small concentrations of alcohol (less than 0.1 volume %), which, however can influence the vapor pressure of the fuel. The test does not detect ethers, such as methyl *tert*-butyl ether (MTBE), and does not detect high-molecular weight (beyond butanol) alcohols. The inability to detect ethers would affect the results of the vapor-liquid ratio (V/L) Test Method D 2533 because MTBE is miscible with one of the confining fluids (glycerin). Because of these limitations, this alcohol detection test should not be used to decide whether to add oxygenates to a fuel of unknown composition. A gas chromatographic analysis is required to ensure that an oxygenate is not introduced into a fuel already containing oxygenates. A gas chromatographic test method, such as Test Method D 4815, can be used to detect ethers as well as determine the presence of alcohols.

5.3 Volatility of fuels is varied for seasonal climatic changes and conformance to U.S. EPA volatility regulations by providing six vapor pressure/distillation classes and five vapor lock protection classes for fuel. Volatility of fuel is specified by an alphanumeric designation that uses a letter from Table 1 and a number from Table 2.

5.3.1 The seasonal and geographic distribution of the combined vapor pressure/distillation-vapor lock classes is shown in Table 4.

5.3.2 The EPA vapor pressure regulations can cause the distillation of the fuel to be less volatile, which for some vehicles, results in poorer warmup driveability performance.

5.3.3 Test Methods D 4953, D 5190, or D 5191 shall be used for determining vapor pressure of gasoline and gasoline-oxygenate blends.

5.3.4 Test Method D 2533 contains procedures for measuring temperature-V/L of both gasoline and gasoline-oxygenate blends. For gasoline-oxygenate blends, the procedure requires that mercury be used as the confining fluid in place of glycerin. Either confining fluid may be used for gasoline. Subcommittee D02.08 is investigating a possible bias of the mercury procedure and the suitability of using glycerin for gasoline-ether blends. An alternative method for measuring temperature-V/L of 20 for gasoline-oxygenate blends, as well as gasoline, using a bomb method is shown in Annex A2. This test method is under development by Subcommittee D02.08. In case of dispute, Test Method D 2533 is the referee method. The method for estimating (see Appendix X2) temperature-V/L is only applicable for gasoline.

5.4 Antiknock index (AKI) is very important to engine performance. The matching of engine octane requirement to fuel octane level (AKI) is critical to the durability and performance of engines; this cannot be accomplished with a single specified minimum level of antiknock index. Appendix X1 includes a discussion of antiknock indexes of fuels currently marketed and relates these levels to the octane needs of broad groups of engines and vehicles. Also discussed is the effect of altitude and weather on vehicle antiknock requirements.

5.5 Additional fuel requirements are shown in Table 3.

5.6 The properties of gasoline-oxygenate blends can differ considerably from those of gasoline. Consequently, additional requirements are needed for gasoline-oxygenate blends. These requirements involve evaluation of compatibility with plastic and elastomeric materials in fuel systems, corrosion of metals, and especially in the case of gasoline-alcohol blends, water tolerance. Requirements for metal corrosion (other than copper) and material compatibility are not given because test methods and appropriate limits are still under development. When these have been developed

TABLE 4 Schedule of Seasonal and Geographical Volatility Classes^A

This schedule, subject to agreement between purchaser and seller, denotes the volatility properties of the fuel at the time and place of delivery to the end user. It also denotes the vapor pressure for finished gasoline tankage at refineries, importers, pipelines, and terminals during May and for the entire distribution system for June 1 to Sept. 15. Shipments should anticipate this schedule.

Where alternative classes are listed, either class or intermediate classes are acceptable, the option shall be exercised by the seller

NOTE—Footnotes D, E, and F of Table 4 are currently under ballot for revision.

State	Jan.	Feb.	Mar.	Apr.	May^B	June	July	Aug.	Sept. 1–15	Sept. 16–30	Oct.	Nov.	Dec.
Alabama	D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-3^D	A-3^D	A-2^E	A-2^E	A-2/C-3	C-3	C-3/D-4	D-4
Alaska	E-5	E-5	E-5	E-5	E-5/D-4	D-4	D-4	D-4	D-4	D-4/E-5	E-5	E-5	E-5
Arizona													
N 34° Latitude and E 111° Longitude	D-4	D-4	D-4/C-3	C-3/A-2	A-2	A-1	A-1	A-1	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4
Remainder of State	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2	A-1^F	A-1^F	A-1^F	A-1^E	A-1	A-1/B-2	B-2/C-3	C-3/D-4
Arkansas	E-5/D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4	D-4/E-5
^{C} California:													
North Coast	E-5/D-4	D-4	D-4	D-4/A-3	A-3	A-3^D	A-2^E	A-2^E	A-2^E	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
South Coast	D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-2^E	A-2^E	A-2^E	A-2^E	A-2/B-2	B-2/C-3	C-3/D-4	D-4
Southeast	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2	A-1^F	A-1^F	A-1^F	A-1^F	A-1	A-1/B-2	B-2/C-3	C-3/D-4
Interior	E-5/D-4	D-4	D-4	D-4/A-3	A-3	A-2^E	A-2^E	A-2^E	A-2^E	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Colorado	E-5	E-5/D-4	D-4/C-3	C-3/A-3	A-3	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Connecticut	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Delaware	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
District of Columbia	E-5	E-5/D-4	D-4	D-4/A-3	A-3	A-3^D	A-3^D	A-3^D	A-3^D	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Florida	D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-3^D	A-3^D	A-3^D	A-3^D	A-3/C-3	C-3	C-3/D-4	D-4
Georgia	D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-3^D	A-3^D	A-2^E	A-2^E	A-2/C-3	C-3	C-3/D-4	D-4
Hawaii	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3
Idaho:													
N 46° Latitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
S 46° Latitude	E-5	E-5/D-4	D-4	D-4/A-3	A-3	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Illinois:													
N 40° Latitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
S 40° Latitude	E-5	E-5	E-5/D-4	D-4/A-3	A-3	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4	D-4/E-5
Indiana	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Iowa	E-5	E-5	E-5/D-4	D-4/A-3	A-3	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Kansas	E-5	E-5/D-4	D-4/C-3	C-3/A-3	A-3	A-2^E	A-2^E	A-2^E	A-2^E	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Kentucky	E-5	E-5/D-4	D-4	D-4/A-3	A-3	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Louisiana	D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-3^D	A-3^D	A-2^E	A-2^E	A-2/C-3	C-3	C-3/D-4	D-4
Maine	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Maryland	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3^D	A-3^D	A-3^D	A-3^D	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Massachusetts	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Michigan	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Minnesota	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Mississippi	D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-3	A-3	A-2	A-2	A-2/C-3	C-3	C-3/D-4	D-4
Missouri	E-5	E-5/D-4	D-4	D-4/A-3	A-3	A-3^D	A-2^E	A-2^E	A-2^E	A-2/C-3	C-3/D-4	D-4	D-4/E-5
Montana	E-5	E-5	E-5/D-4	D-4/A-3	A-3	A-2	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
Nebraska	E-5	E-5	E-5/D-4	D-4/A-3	A-3	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Nevada:													
N 38° Latitude	E-5	E-5/D-4	D-4	D-4/A-3	A-3	A-2^E	A-2^E	A-2^E	A-2^E	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
S 38° Latitude	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2	A-1	A-1	A-1	A-1	A-1	A-1/B-2	B-2/C-3	C-3/D-4
New Hampshire	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
New Jersey	E-5	E-5	E-5/C-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
New Mexico:													
N 34° Latitude	E-5/D-4	D-4	D-4/C-3	C-3/A-2	A-2	A-1	A-1	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4
S 34° Latitude	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2	A-1	A-1	A-1	A-1	A-1/B-2	B-2/C-3	C-3/D-4	D-4
New York	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
North Carolina	E-5/D-4	D-4	D-4	D-4/A-3	A-3	A-3^D	A-3^D	A-2^E	A-2^E	A-2/C-3	C-3/D-4	D-4	D-4/E-5
North Dakota	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
Ohio	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Oklahoma	E-5/D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Oregon:													
E 122° Longitude	E-5	E-5/D-4	D-4	D-4/A-4	A-4	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4	D-4/E-5
W 122° Longitude	E-5	E-5/D-4	D-4	D-4/A-4	A-4	A-3^D	A-3^D	A-3^D	A-3^D	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Pennsylvania	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Rhode Island	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
South Carolina	D-4	D-4	D-4	D-4/A-3	A-3	A-3^D	A-3^D	A-2^E	A-2^E	A-2/C-3	C-3/D-4	D-4	D-4
South Dakota	E-5	E-5	E-5/D-4	D-4/A-3	A-3	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Tennessee	E-5/D-4	D-4	D-4	D-4/A-3	A-3	A-3^D	A-3^D	A-2^E	A-2^E	A-2/C-3	C-3/D-4	D-4	D-4/E-5
Texas:													
E 99° Longitude	D-4	D-4	D-4/C-3	C-3/A-3	A-3	A-3^D	A-2^E	A-2^E	A-2^E	A-2/B-2	B-2/C-3	C-3/D-4	D-4
W 99° Longitude	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2	A-1^F	A-1^F	A-1^F	A-1^F	A-1/B-2	B-2/C-3	C-3/D-4	D-4
Utah	E-5	E-5/D-4	D-4	D-4/A-3	A-3	A-2^E	A-2^E	A-2^E	A-2^E	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Vermont	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Virginia	E-5	E-5/D-4	D-4	D-4/A-3	A-3	A-3^D	A-3^D	A-3^D	A-3^D	A-3/C-3	C-3/D-4	D-4/E-5	E-5

TABLE 4 (Continued)

State	Jan.	Feb	Mar	Apr	May[B]	June	July	Aug	Sept 1-15	Sept 16-30	Oct	Nov	Dec
Washington													
E 122° Longitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
W 122° Longitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
West Virginia	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Wisconsin	E-5	E-5	E-5/D-4	D-4/A-4	A-4	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Wyoming	E-5	E-5	E-5/D-4	D-4/A-3	A-3	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5

[A] For the period May 1 through September 15, the specified vapor pressure classes comply with 1992 U.S. EPA Phase II volatility regulations. EPA regulations allow 1.0 psi higher vapor pressure for gasoline-ethanol blends containing 9 to 10 vol % ethanol for the same period. See Appendix X3 for additional federal volatility regulations.

[B] April classes are permitted for shipments to end users.

[C] Details of State Climatological Division by county as indicated:

California, North Coast—Alameda, Contra Costa, Del Norte, Humbolt, Lake, Marin, Mendocino, Monterey, Napa, San Benito, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Trinity

California, Interior—Lassen, Modoc, Plumas, Sierra, Siskiyou, Alpine, Amador, Butte, Calaveras, Colusa, El Dorado, Fresno, Glenn, Kern (except that portion lying east of Los Angeles County Aqueduct), Kings, Madera, Mariposa, Marced, Placer, Sacramento, San Joaquin, Shasta, Stanislaua, Sutter, Tehama, Tulare, Tuolumne, Yolo, Yuba, Nevada

California, South Coast—Orange, San Diego, San Luis Obispo, Santa Barbara, Ventura, Los Angeles (except that portion north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct)

California, Southeast—Imperial, Riverside, San Bernadino, Los Angeles (that portion north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct), Mono, Inyo, Kern (that portion lying east of the Los Angeles County Aqueduct)

[D] AA-3 for the following ozone nonattainment areas:
(See Federal Register 56, 215, 56694, November 6, 1991, for description of the geographic boundary for each area.)

Alabama—Birmingham
California—Monterey Bay
California—San Francisco-Bay Area
District of Columbia—Washington
Florida—Miami-Fort Lauderdale-West Palm Beach
Florida—Tampa-St. Petersburg-Clearwater
Georgia—Atlanta
Louisiana—Baton Rouge
Louisiana—Lake Charles
Maryland—Baltimore
Maryland—Kent and Queen Anne's Counties
Maryland—Philadelphia-Wilmington-Trenton Area
Maryland—Washington Area
Missouri—Kansas City
Missouri—St. Louis
North Carolina—Charlotte-Gastonia
North Carolina—Greensboro-Winston Salem-High Point
North Carolina—Raleigh-Durham
Oregon—Portland-Vancouver AQMA
South Carolina—Cherokee County
Tennessee—Knoxville
Tennessee—Memphis
Tennessee—Nashville
Texas—Beaumont-Port Arthur
Texas—Dallas-Fort Worth
Texas—Houston-Galveston-Brazoria
Virginia-Norfolk-Virginia Beach-Newport News
Virginia—Richmond-Petersburg
Virginia—Smyth County
Virginia—Washington Area

[E] AA-2 for the following ozone nonattainment areas:
(See Federal Register 56, 215, 56694, November 6, 1991, for description of the geographic boundary for each area.)

Alabama—Birmingham
Arizona—Phoenix
California—Los Angeles-South Coast Air Basin
California—Monterey Bay
California—Sacramento Metro
California—San Diego
California—San Francisco-Bay Area
California—San Joaquin Valley
California—Santa Barbara-Santa Maria-Lompoc
California—Ventura County
Georgia—Atlanta
Kansas—Kansas City
Louisiana—Baton Rouge
Louisiana—Lake Charles
Missouri—Kansas City
Missouri—St. Louis
Nevada—Reno
North Carolina—Charlotte-Gastonia
North Carolina—Greensboro-Winston Salem-High Point
North Carolina—Raleigh-Durham
South Carolina-Cherokee County
Tennessee—Knoxville
Tennessee—Memphis
Tennessee—Nashville
Texas—Beaumont-Port Arthur
Texas—Dallas-Forth Worth
Texas—Houston-Galveston-Brazoria
Utah—Salt Lake City

[F] AA-1 for the following ozone nonattainment areas:
(See Federal Register 56, 215, 56694, November 6, 1991, for description of the geographic boundary for each area.)

Arizona—Phoenix
California—Southeast Desert Modified AQMA
Texas—El Paso

they will be included in this specification. Water tolerance is specified in Table 5.

5.7 Depending on oxygenate type and concentration in the blend, vehicle driveability with gasoline-oxygenate blends can differ significantly from that with gasolines having similar volatility characteristics.

5.8 *Water Tolerance:*

5.8.1 The term water tolerance is used to indicate the ability of a gasoline-oxygenate blend to dissolve water without phase separation. This may not be a problem with gasoline-ether blends, but it is of primary concern for alcohol-containing blends, as blends of gasoline with low-molecular weight alcohols generally will dissolve about 0.1 to 0.7 mass % of water under normal conditions, depending on the nature and amount of the alcohol(s) used, the specific hydrocarbons present, and the temperature of the blend.

TABLE 5 Maximum Temperature for Phase Separation, °C[A]

Temperature Conversion °F = (°C × 1.8) + 32°

State	Jan.	Feb.	March	April	May	June	July	Aug.	Sept	Oct.	Nov	Dec.
Alabama	−4	−3	0	5	10	10	10	10	10	6	0	−4
[B]Alaska:												
Southern Region	−27	−26	−23	−11	1	7	9	7	1	−9	−19	−23
South Mainland	−41	−39	−31	−14	−1	7	9	5	−2	−18	−32	−41
N of 62° Latitude												
Arizona:												
N of 34° Latitude	−11	−7	−7	−2	2	6	10	10	6	1	−6	−9
S of 34° Latitude	−2	−1	2	7	10	10	10	10	10	9	2	−1
Arkansas	−9	−6	−2	6	10	10	10	10	10	4	−2	−6
[C] California												
North Coast	−2	0	1	4	5	8	9	9	8	6	2	−2
South Coast	−2	−1	2	4	7	9	10	10	9	6	1	−2
Southeast	−7	−3	−1	3	8	10	10	10	9	4	−3	−6
Interior	−4	−3	−3	−1	3	9	10	10	10	6	0	−2
Colorado:												
E of 105° Longitude	−14	−12	−9	−3	4	10	10	10	7	1	−8	−11
W of 105° Longitude	−24	−20	−12	−6	−1	4	8	6	1	−6	−14	−21
Connecticut	−14	−13	−8	−1	5	10	10	10	7	1	−4	−12
Delaware	−9	−8	−3	0	8	10	10	10	10	4	−1	−8
District Columbia	−8	−7	−3	3	9	10	10	10	10	5	0	−7
Florida:												
N of 29° Latidue	−1	1	4	9	10	10	10	10	10	9	3	−1
S of 29° Latitude	4	7	8	10	10	10	10	10	10	10	9	5
Georgia	−5	−2	1	6	10	10	10	10	10	6	0	−3
Hawaii	10	10	10	10	10	10	10	10	10	10	10	10
Idaho	−17	−16	−11	−3	−5	4	10	9	3	−2	−11	−15
Illinois:												
N of 40° Latitude	−18	−16	−9	−1	4	10	10	10	7	1	−7	−16
S of 40° Latitude	−15	−12	−7	1	7	10	10	10	9	3	−6	−13
Indiana	−16	−13	−7	−1	4	10	10	10	7	1	−6	−14
Iowa	−23	−19	−13	−3	4	10	10	10	6	0	−12	−20
Kansas	−17	−12	−9	−3	5	10	10	10	7	0	−8	−13
Kentucky	−12	−9	−4	1	8	10	10	10	9	3	−4	−11
Louisiana	−3	0	3	8	10	10	10	10	10	7	2	−1
Maine	−24	−22	−16	−4	1	7	10	8	3	−2	−8	−20
Maryland	−9	−8	−3	3	9	10	10	10	10	4	−2	−8
Massachusetts	−15	−14	−7	−1	4	10	10	10	6	0	−4	−13
[D]Michigan:												
Lower Michigan	−18	−17	−12	−3	1	7	10	9	5	0	−6	−14
Upper Michigan	−21	−20	−15	−6	−1	6	9	9	4	−1	−9	−18
Minnesota	−31	−28	−20	−7	0	6	10	8	1	−3	−16	−28
Mississippi	−3	−1	2	7	10	10	10	10	10	7	1	−3
Missouri	−14	−11	−6	1	8	10	10	10	10	3	−5	−12
Montana	−28	−24	−19	−6	1	5	9	8	1	−5	−17	−23
Nebraska	−19	−14	−11	−3	4	9	10	10	5	−2	−10	−16
Nevada:												
N of 38° Latitude	−18	−13	−8	−3	1	5	9	7	2	−3	−11	−14
S of 38° Latitude	−9	−5	−1	1	9	10	10	10	10	4	−3	−6
New Hampshire	−18	−17	−9	−2	3	9	10	9	3	−1	−6	−16
New Jersey	−10	−9	−4	2	7	10	10	10	10	4	−1	−8
New Mexico:												
N of 34° Latitude	−14	−11	−7	−2	1	7	10	10	7	1	−8	−12
S of 34° Latitude	−7	−5	−1	6	10	10	10	10	10	7	−2	−5
New York:												
N of 42° Latitude	−21	−20	−13	−3	2	9	10	10	4	−1	−6	−18
S of 42° Latitude	−13	−13	−7	1	6	10	10	10	8	2	−3	−12
North Carolina	−9	−7	−3	1	7	10	10	10	8	1	−5	−8
North Dakota	−29	−27	−11	−6	1	8	10	10	3	−2	−17	−24
Ohio	−14	−13	−8	−2	6	10	10	10	7	1	−5	−13
Oklahoma	−12	−6	−5	1	7	10	10	10	10	4	−4	−9
Oregon:												
E of 122° Longitude	−17	−12	−8	−3	0	4	6	6	2	−3	−8	−12
W of 122° Longitude	−5	−3	−1	2	5	8	10	10	7	2	−3	−3
Pennsylvania:												
N of 41° Latitude	−17	−19	−13	−4	1	6	9	8	2	−1	−6	−16
S of 41° Latitude	−13	−14	−9	−1	5	10	10	10	7	2	−4	−12
Rhode Island	−11	−11	−5	1	6	10	10	10	8	3	−2	−10
South Carolina	−3	−2	0	6	10	10	10	10	10	7	1	−3
South Dakota	−24	−21	−16	−4	3	10	10	10	4	−2	−12	−21
Tennessee	−9	−7	−3	2	9	10	10	10	10	2	−3	−8

TABLE 5 *Continued*

	Temperature Conversion °F = (°C × 1.8) + 32°											
State	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Texas												
N of 31° Latitude	−11	−8	−4	2	8	10	10	10	10	5	−3	−7
S of 31° Latitude	−1	1	4	10	10	10	10	10	10	10	3	1
Utah	−15	−11	−7	−2	2	8	10	10	7	2	−11	−12
Vermont	−20	−21	−12	−2	2	9	10	10	5	0	−6	−17
Virginia	−8	−7	−3	3	9	10	10	10	10	4	−2	−7
Washington:												
E of 122° Longitude	−13	−6	−3	1	4	7	10	10	7	1	−5	−7
W of 122° Longitude	−6	−2	−2	1	4	7	9	9	6	2	−2	−2
West Virginia	−13	−12	−7	−2	4	9	10	10	5	−2	−7	−12
Wisconsin	−25	−21	−15	−3	3	8	10	10	5	−1	−11	−21
Wyoming	−23	−17	−14	−6	0	5	10	10	3	−2	−13	−16

[A] A maximum phase separation temperature of 10°C (50°F) is specified, even if the 6-h 10th percentile minimum temperature for the area and month can be higher

[B] The designated areas of Alaska are divided as follows:

Southern Region—The Aleutians, Kodiak Island, the coastal strip East of Longitude 141°, and the Aleskan Peninsula South of Latitude 52°.

South Mainland—The portion of Alaska South of Latitude 62°, except the Southern Region.

North of Latitude 62°—The specification test temperature must be agreed between the vendor and purchaser having regard to equipment design, expected weather conditions, and other relevant factors.

[C] The designated areas of California are divided by county as follows:

North Coast—Alameda, Contra Costa, Del Norte, Humbolt, Lake, Marin, Mendocino, Monterey, Napa, San Benito, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Trinity.

Interior—Lassen, Modoc, Plumas, Sierra, Siskiyou, Alpine, Amador, Butte, Calaveras, Colusa, El Dorado, Fresno, Glenn, Kern (excepting that portion lying east of the Los Angles County Aqueduct) Kings, Madera, Mariposa, Merced, Placer, Sacramento, San Joaquin, Shasta, Stanislaus, Sutter, Tehama, Tulare, Tuolumne, Yolo, Yuba, Nevada.

South Coast—Orange, San Diego, San Luis Obispo, Santa Barbara, Ventura, Los Angeles (except that portion lying north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct).

Southeast—Imperial, Riverside, San Bernadino, Los Angeles (that portion lying north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct), Mono, Inyo, Kern (that portion lying east of the Los Angeles County Aqueduct).

[D] The designated areas of Michigan are divided as follows:

Lower Michigan—That portion of the state lying East of Lake Michigan.

Upper Michigan—That portion of the state lying North of Wisconsin and of Lake Michigan.

When blends are exposed to a greater amount of water than they can dissolve, they separate into an alcohol-rich aqueous phase, the volume of which can be significantly greater than that of the additional water, and an alcohol-poor hydrocarbon phase. As the aqueous phase can be highly corrosive to many metals and the engine cannot operate on it, such separation is very undesirable. Blends containing low-molecular weight alcohols are generally hygroscopic and can eventually absorb enough moisture from ambient air to cause separation. The problem of phase separation can usually be avoided if the fuels are sufficiently water-free initially and care is taken during distribution to prevent contact with water. To help ensure this, gasoline-oxygenate blends shall be tested at the lowest temperatures to which they can be subjected, dependent on the time and place of intended use, as indicated in Table 5. The values in Table 5 are the 10th percentile 6-h minimum temperatures, with each reading specifically defined as the highest temperature of the six coldest consecutive hourly temperature readings of a 24-h day. For April through September (and occasionally October, and year-round for Hawaii), Table 5 specifies a minimum phase separation temperature of 10°C (50°F), even though the 10th percentile 6-h minimum temperature can be higher. Use of this temperature limit also reduces the risk of separation of the fuel in storage tanks where temperatures may be lower than ambient.

NOTE 3—The values in Table 5 are taken from the U.S. Army Belvoir Research Development and Engineering Center's Report No. 316, entitled "A Predictive Study for Defining Limiting Temperatures and Their Application in Petroleum Product Specifications." This can be obtained as Publication AD756-420 from the National Technical Information Service, Springfield, VA 22151.

5.8.2 The test procedure (see Annex A3) consists of cooling the fuel under specified conditions to the appropriate temperature listed in Table 5. It is important to note that when cooling to a low temperature some gasolines and many gasoline-oxygenate blends, especially those containing ethers, can take on a hazy appearance. This haze must be carefully distinguished from the test criterion described in Annex A3 of separation into two distinct phases with a more or less distinct common boundary, and must not be considered grounds for rejection of the fuel. This test also must not be confused with that described in Section 6, which is conducted at 21°C (70°F) or above, and for which the appearance of haze is proper grounds for rejection.

6. Workmanship

6.1 The finished fuel shall be visually free of undissolved water, sediment, and suspended matter; it shall be clear and bright at the ambient temperature or 21°C (70°F), whichever is higher.

6.2 Fuel to be used in this test shall not be cooled below about 15°C (59°F) or its temperature at the time the sample was taken, whichever is lower, as cooling of gasoline-oxygenate blends can produce changes in appearance that are not reversed on rewarming.

7. Test Methods

7.1 The requirements enumerated in this specification shall be determined in accordance with the following methods:

7.1.1 *Distillation*—Test Method D 86.

7.1.2 *Vapor-Liquid Ratio*—Test Method D 2533 has procedures for determining vapor-liquid (V/L) ratios for both gasoline and gasoline-oxygenate blends. Because some oxygenates are miscible with the glycerin used in this procedure, another procedure using mercury as the confining fluid is provided for gasoline-oxygenate blends. Either procedure may be used to determine *V/L* for gasoline, but a possible bias between the two procedures is under investigation by Subcommittee D02.08. An investigation is also underway by Subcommittee D02.08 to determine the suitability of using the glycerin procedure for gasoline-ether blends

7.1.2.1 Annex A2 describes a bomb procedure for determining the temperature at a *V/L* of 20. This test method is under development by Subcommittee D02.08.

7.1.3 *Vapor Pressure*— Test Methods D 4953, D 5190, or D 5191.

7.1.4 *Corrosion, for Copper*, Test Method D 130, 3 h at 50°C (122°F).

7.1.5 *Existent Gum*—Test Method D 381, air jet apparatus.

7.1.6 *Sulfur*—Test Methods D 1266, D 2622, or D 3120. With Test Method D 3120, fuels with sulfur content greater than 100 ppm (0.0100 mass %) must be diluted with *iso*octane. The dilution of the sample may result in a loss of precision. Test Method D 3120 cannot be used when the lead concentration is greater than 0.4 g/L (1.4 g/U.S. gal).

7.1.7 *Lead*—Test Methods D 2599, D 3341, or D 5059 (Test Methods A or B). For lead levels below 0.03 g/L (0.1 g/U.S. gal) use Test Methods D 3116, D 3229, D 3237, or D 5059 (Test Method C)

7.1.8 *Oxidation Stability*—Test Method D 525.

7.1.9 *Alcohol Detection*—Test Method D 4815 or see Annex A1.

7.1.10 *Water Tolerance*—See Annex A3 for a test method.

8. Precision and Bias

8.1 The precision of each required test method with gasoline is included in the standard applicable to each method. In many cases, the precision applicable to gasoline-oxygenate blends has not been established yet.

9. Keywords

9.1 alcohol, alcohol detection; antiknock index; automotive fuel; automotive gasoline, automotive spark-ignition engine fuel; copper strip corrosion; corrosion; distillation; driveability; EPA regulations; ethanol; ether; existent gum, fuel; gasoline; gasoline-alcohol blend; gasoline-ethanol blend; gasoline-oxygenate blend; induction period; lead; leaded fuel; methanol; MTBE; octane number; octane requirement; oxidation stability; oxygenate; phase separation; phosphorous; sulfur; $T_{V/L} = 20$; unleaded fuel; vapor-liquid ratio; vapor lock; vapor pressure volatility; water tolerance

ANNEXES

(Mandatory Information)

A1. TEST METHOD FOR DETECTION OF ALCOHOL IN SPARK-IGNITION ENGINE FUEL (REFRACTION METHOD)

A1.1 Scope

A1.1.1 This test method pertains to the determination of the presence of alcohols (methanol through butanol) in automotive spark-ignition engine fuels. The test results are used to determine which limits and analytical tests of Specification D 4814 are applicable to the fuel tested.

A1.1.2 This test method is state-of-the-art; however, it may be revised and eventually balloted for publication as a separate standard.

A1.2 Summary of Test Method

A1.2.1 A sample of the fuel is shaken, using a standardized technique, with distilled water at room temperature. The mixture is allowed to settle into two phases, and a refractometer is used to obtain a reading of the lower aqueous phase. A minimum specified increase in the refractometer reading over that of distilled water indicates that an alcohol is present.

A1.3 Significance and Use

A1.3.1 Based on the results of a round-robin evaluation, a scale reading of 0.5 or greater was selected to indicate that alcohol is present in a fuel sample. A reading of 0.5 on average is equivalent to 0.05 vol % ethanol, 0.11 vol % methanol, or 50/50 mixture of methanol and *tert-butyl* alcohol (TBA), or 0.13 vol % TBA.

A1.3.2 This test method should not be used for deciding whether to add an oxygenate to a fuel of unknown composition. This method does not determine the type of alcohol and does not detect ethers such as MTBE. A gas chromatographic method, such as Test Method D 4815, must be used to determine the types and concentrations of oxygenates to avoid adding an oxygenate to a blend already containing some type of oxygenate, and to ensure compliance with EPA rules and waivers.

A1.4 Apparatus

A1.4.1 *Graduated Glass Cylinder*, glass-stoppered, 100-mL, with 1-mL graduations

A1.4.2 *Pipet*, 2-mL

A1.4.3 *Pipet Filler or Bulb*.

A1.4.4 *Refractometer*,[9] temperature compensated, hand held, 0 to 10° Brix (1.3330-1.3479).

A1.5 Reagents

A1.5.1 *Purity of Reagents*—Reagent-grade chemicals will be used in all tests. Unless otherwise indicated, it is intended

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[9] The Misco Products Tester Model 10441 Automatic Temperature Compensated Hand Refractometer has been found suitable. Also an equivalent may be used.

that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[10] Other grades may be used, provided it is first ascertained that the reagent is of sufficient purity to permit its use without lessening the accuracy of the determination.

A1.5.2 *Purity of Water*—Unless otherwise indicated, reference to water shall be understood to mean distilled water or water of equivalent purity. See Specification D 1193, Type IV.

A1.5.3 *Acetone*

Note A1.1: *Acetone*—**Warning**—Extremely flammable. Irritating to skin, eyes, and mucous membranes.

A1.5.4 *n-Heptane* conforming to material used in Test Methods D 381, D 2699, and D 2700, or petroleum spirit 60/80 conforming to IP specification or equivalent. Commercial grade quality is adequate for these solvents.

Note A1.2: *n-Heptane*—**Warning**—Flammable. Harmful if inhaled. Skin irritant on repeated contact. Aspiration hazard.

Note A1.3: *Petroleum Spirit (Mineral Spirits)*—**Warning**—Combustible. Skin irritant on repeated contact. Aspiration hazard.

A1.6 Preparation of Apparatus

A1.6.1 Clean the graduated cylinder and pipet thoroughly before carrying out this test. The recommended cleaning procedure is as follows:

A1.6.1.1 Remove traces of oil from the cylinder, stopper, and pipet by flushing with hot tap water, brushing if necessary. Alternatively, remove all traces of oil from the glassware by using either *n*-heptane or the IP solvent 60/80. Rinse with acetone followed by tap water.

A1.6.1.2 Immerse the cylinder, stopper, and pipet in warm detergent solution, follow with tap water, distilled water, and acetone rinses. After the acetone rinse, thoroughly drain and dry the cylinder, stopper, and pipet.

A1.6.2 Open the cover plate of the refractometer and using a soft cloth, or soft tissue paper moistened with water, wipe the prism and cover plate. Dry both surfaces with a soft, dry cloth or tissue. Then close the cover plate. Fill a clean pipet with distilled water using the pipet filler. Tilt the refractometer with the eyepiece up. Place the pipet tip at the top of the cover plate between the hinges and discharge a few drops of distilled water until the prism is at least half covered with liquid. Immediately point the instrument toward a window or other source of light so that the light enters from above. Look through the eyepiece and take the reading at the point where the dividing line between light and dark crosses the scale. This should provide a reading of zero. If not, the water is contaminated or the instrument is out of calibration and shall not be used.

Note A1.4—The dividing line between the light and dark areas of the scale can sometimes be difficult to see. The best way to see it is to hold the refractometer slightly away from the eye. When using a lamp as the light source, the refractometer and observer's head should be positioned 0.3 m (1 ft) away from the lamp so that the light enters from above at 45°. The refractometer and observer's head shall be moved together until optimum contrast on the scale is obtained.

A1.7 Procedure

A1.7.1 Measure 100 mL of the fuel to be tested, at room temperature, into the 100-mL graduated cylinder.

A1.7.2 Add 2 mL of distilled water using the pipet and pipet filler and stopper the cylinder.

A1.7.3 Invert the cylinder, holding the stopper with a finger, and allow the water to flow into the sample. Keeping the cylinder in a horizontal attitude, shake it vigorously for exactly 2 min, two to three strokes per second, using 125 to 250 mm (5 to 10 in.) strokes.

A1.7.4 Immediately place the cylinder in a vertical position on a vibration-free surface and allow the contents to settle undisturbed for 5 min.

A1.7.5 Open the cover plate of the refractometer and using a soft cloth, or soft tissue paper moistened with water, wipe the prism and cover plate. Dry both surfaces with a soft, dry cloth or tissue. Then close the cover plate.

A1.7.6 Air dry the pipet and install the pipet filler. Remove the stopper from the graduated cylinder, tilt the cylinder, and insert the pipet with the tip in the water phase. Squeeze the pipet filler and discharge air through the pipet to purge any fuel that has entered the pipet tip. Draw up into the pipet about one-half of the water phase in the bottom of the cylinder. Try to avoid drawing in any emulsion.

Note A1.5—If the water is totally absorbed into the fuel phase, this indicates that the sample contains a high concentration (greater than 25 volume %) of ethanol or heavier alcohol.

A1.7.7 Remove the pipet from the graduated cylinder, dry the outside of the pipet with tissue to remove any fuel on the surface, and then discharge a few drops of water phase to purge any fuel in the tip. Tilt the refractometer with the eyepiece up. Without lifting the cover plate, place the pipet tip at the top of the cover plate between the hinges and discharge enough of the water phase to cover at least half of the prism.

A1.7.8 Immediately point the instrument toward a window or other source of light so the light enters the prism from above. Look through the eyepiece and take the reading at the point where the dividing line between light and dark crosses the scale.

Note A1.6—Take the reading within 10 s of discharging the water phase onto the refractometer prism. The reading can change with time as constituents evaporate or the sample otherwise changes in composition.

A1.7.9 Record the scale reading.

A1.8 Report

A1.8.1 The report shall include the refractometer scale reading. If the reading is off scale, report 10 +° Brix. If the value is equal to or greater than 0.5° Brix, the sample is to be reported as containing a detectable level of alcohol.

Note A1.7—Testing of a number of commercial gasolines containing no alcohol has shown a change in refractometer reading as much as 0.3° Brix. Before concluding that an alcohol is present, a minimum reading of 0.5° Brix must be observed. However, it is still possible that a sample having a refractometer reading of less than 0.5° Brix contains a low level of alcohol.

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[10] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Analar Standards for Laboratory U.K. Chemicals," BDH Ltd., Poole, Dorset, and the "United States Pharmacopeia."

A1.9 Precision and Bias

A1.9.1 The precision of this test method as determined by statistical examination of interlaboratory results is as follows:

A1.9.1.1 *Repeatability*—The difference between successive test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, and in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

Range	Repeatability
0–1.0 vol % alcohol	0.457 (Refractometer Reading)$^{1/3}$

A1.9.1.2 *Reproducibility*—The difference between two single and independent results, obtained by different laboratories on identical test material would, in the long run, and in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

Range	Reproducibility
0–1.0 vol % alcohol	0.467 (Refractometer Reading)$^{1/3}$

A1.9.2 *Bias*—There being no criteria for measuring bias in these test-product combinations, no statement of bias can be made.

A2. TEST METHOD FOR TEMPERATURE AT A VAPOR/LIQUID RATIO OF 20 FOR SPARK-IGNITION ENGINE FUEL (BOMB METHOD)

A2.1 Scope

A2.1.1 This test method covers a procedure to determine the temperature at which the vapor formed from a liquid fuel in a chamber of a volume 21.0 times that of the original volume of this liquid fuel at 32 to 34°F (0 to 1°C) will have a calculated partial pressure equal to 1 atm. This temperature is considered to be equal to the temperature at which the vapor-liquid ratio of the fuel is equal to 20 as determined by the Test Method D 2533.

A2.1.2 This test method is not applicable to samples having a vapor pressure above 26 psi (180 kPa).

NOTE A2.1—This method is applicable to gasolines and gasoline-oxygenate blends which contain compounds which are soluble in glycerin.

A2.1.3 This test method is state-of-the-art; however, it may be revised and eventually balloted for publication as a standard.

A2.2 Terminology

A2.2.1 *Definition*:

A2.2.1.1 $T(V/L = 20)$ the equilibrium temperature at which the partial pressure of a fuel, under the test conditions, is equal to 1 atm. At these conditions the volume of the vapor is equal to 20.0 times the volume of the liquid sample charged at 32 to 34°F (0 to 1°C) (Notes A2.2 and A2.3).

NOTE A2.2—The actual vapor-liquid ratio under these conditions is not exactly 20.0 since no corrections are made for the following: (*1*) the expansion of the liquid sample with increasing temperature, (*2*) the decrease in liquid sample volume because of partial vaporization, (*3*) the dissolved air in the liquid sample, and (*4*) the effect of the air originally present in the vapor chamber.

NOTE A2.3—In this test method the partial pressure of the fuel is observed as a gage pressure in the presence of air. In Test Method D 2533, on the other hand, the vapor pressure of the fuel is measured as an absolute pressure. Strict correspondence between the temperature at which the vapor-liquid ratio is 20, as determined by the Test Method D 2533, and the $T(V/L = 20)$ as determined by this method, is hence only valid for ideal mixtures. For practical purposes, however, results by these two methods can be expected to be quite comparable.

A2.3 Summary of Test Method

A2.3.1 The fuel chamber of the apparatus, having a volume of approximately 20 mL, is filled with the chilled sample and connected to the air chamber, having a volume 20.0 times the volume of the liquid chamber. The apparatus is immersed in a thermostated water bath and shaken periodically until a constant pressure is observed on the pressure readout device attached to the apparatus. After recording this pressure and the corresponding temperature, the apparatus is moved to another thermostated bath set at a temperature 10 to 30°F (5.6 to 16.7°C) higher than the previous bath. The apparatus is shaken periodically until a constant pressure is observed. This pressure and the corresponding temperature are again recorded.

A2.3.2 Using the equation shown in A2.11.1 the corresponding "V/L ratios" for these temperatures are calculated. The temperature corresponding to a "V/L ratio" of 20.0, is then determined by interpolation. The temperature is also known as $T(V/L = 20)$.

A2.4 Significance and Use

A2.4.1 The $T(V/L = 20)$ is a measure of the tendency of a fuel to vaporize in automotive fuel systems. For high ambient temperatures, one would specify a fuel with a high value of $T(V/L = 20)$, indicating a fuel with a low tendency to vaporize; conversely, for low ambient temperatures a fuel with a low value of $T(V/L = 20)$ would be indicated.

A2.5 Apparatus

A2.5.1 The required apparatus consists of two chambers connected to each other. Connected to the top of the upper chamber is a pressure measuring device.

A2.5.1.1 *Upper Chamber* (also known as the vapor chamber) shall be constructed of stainless steel and have the same dimensions as the air chamber described in Test Method D 4953.

NOTE A2.4—An air chamber of a Test Method D 4953 unit may be used for this test.

A2.5.1.2 *Lower Chamber* (also known as the liquid fuel chamber) shall be a cylindrical vessel constructed of stainless steel as shown in Fig. A2.1.

A2.5.1.3 When the two chambers are coupled together, no liquid fuel shall be lost during the coupling operation, nor shall there be any compression effects caused by the act of coupling. The assembly should also be free of leaks during the conditions of the test.

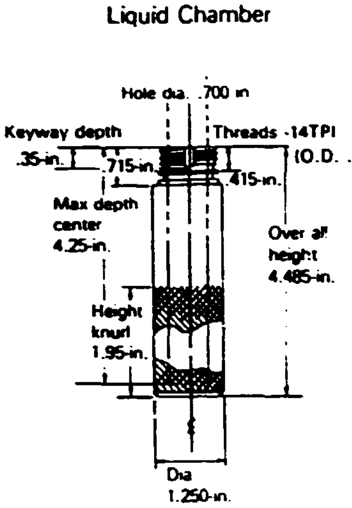

FIG. A2.1 Liquid Chamber

NOTE A2.5—With some commercially available equipment, there is no adequate provisions for avoiding compression effects. Before employing any apparatus, it shall be established that the act of coupling does not compress the air in the air chamber. This may be accomplished by tightly stoppering the gasoline chamber opening and assembling the apparatus with a sensitive pressure readout device attached to the top of the vapor chamber. A pressure increase of more than 0.01 psi (0.07 kPa) is an indication that the apparatus does not adequately meet the specifications of the method. If this problem is encountered, a vent hole may be drilled to ensure atmospheric pressure in the air chamber at the instant of sealing.

A2.5.1.4 The volumetric capacities of both the vapor and the liquid chamber shall be checked to ascertain that the volume ratio of the two chambers is between 19.80 and 20.20. Disconnect the gage from the *V/L* unit and weigh the cleaned and dried vapor chamber and liquid chamber separately. Fill the liquid chamber with water and determine the weight of the water required. Then connect the two chambers together and determine the weight of the water required to fill both units to the seat of the gage connection. The difference in weights shall be the weight of the amount of water corresponding to the vapor chamber (Note A2.6). To the volume of the vapor chamber shall also be added the volume of the pressure gage cavity as determined in A2.5.2.3.

NOTE A2.6—Temperature correction for the expansion of the water is not required if ambient temperature water is used and the temperature is maintained within 1°F (0.5 °C) during these measurements.

A2.5.1.5 Before placing a new apparatus in service and as often as necessary thereafter, the assembled system shall be checked for freedom of leaks by filling with air through the top opening to 50 to 100 psi (350 to 700 kPa) gage pressure and completely immersing the system in a water bath.

A2.5.2 *Pressure Gage:*

A2.5.2.1 The pressure gage can be a Bourdon type spring gage of test gage quality with a passageway of not less than $^3/_{16}$ in. in diameter with a range from 0 to 20 (0 to 140 kPa) or 0 to 25 psi (0 to 175 kPa) and with graduations of not more than 0.2 psi (1 kPa). Only accurate gages shall be used. The gage shall be considered inaccurate if the calibration correction, based on comparison against a Hg manometer or a dead-weight tester, is greater than 0.3 psi (2 kPa).

A2.5.2.2 The pressure gage can also be a pressure transducer which, with the appropriate electronic signal conditioner and display, will have a rated accuracy of 0.1 % of scan or better under the conditions of the test and show a resolution of 0.01 psi or better.

NOTE A2.7—A high resolution is desirable, even though the rated accuracy may be much less, because it will allow the operator to more accurately determine when a system has reached thermal equilibrium during the testing.

NOTE A2.8—Pressure transducers are often quite sensitive to the ambient operational temperature. These transducers should therefore be calibrated prior to use to determine the temperature offset, if any, which will occur because the transducer will be heated up during the measurements. A thermocouple attached to the body of the transducer can be used to determine the temperature of the transducer.

A2.5.2.3 The void volume in the Bourdon tube or in the pressure transducer has to be determined by filling this void volume with water or by calculating the volume from specifications supplied by the manufacturer.

A2.5.3 *Water Bath*—The thermostated bath provided shall be of such a dimension that the *V/L* apparatus can be completely immersed in the vertical position to at least 1 in. (25 mm) above the top of the air chamber. Means shall be provided to control the temperature of the bath in the temperature range of ambient to 180°F (82°C) within 0.2°F (0.1°C) of the setpoint (Note A2.9).

NOTE A2.9—A method to rapidly increase the temperature of a water bath to the desired temperature is to employ live steam introduced directly into the water bath. Ice can be used to rapidly decrease the temperature of the bath.

A2.5.4 *Temperature Indicators:*

A2.5.4.1 Thermometers used to monitor the bath temperature shall have a resolution of 0.1°F (0.05°C) or better and an absolute accuracy of ±0.2°F (0.1°C) as determined by calibration against a standard thermometer. The calibration of this standard should be traceable to the National Institute of Standards and Technology. Although mercury-in-glass thermometers can be used for this purpose, a platinum resistance thermometer with digital readout is more appropriate.

A2.5.4.2 Thermometers used to monitor and to record the ambient temperature of the air in the vapor chamber shall have a resolution of 1°F (0.5°C) or better and a scale error of 1°F (0.5°C) or less. Mercury-in-glass thermometers can be used for this purpose as well as digital temperature indicators with a thermocouple as the sensing element.

A2.5.4.3 A mercury manometer, filled with clean mercury, having a range of at least 20 psi (140 kPa) shall be employed as the primary pressure gage. The manometer scale may be graduated in steps of 1 mm, 0.1 in., 0.05 psi, or 0.001 bar.

A2.6 Reagents

A2.6.1 *Purity of Reagents*—Use reagent grade chemicals in all tests. Unless otherwise indicated, it is intended that all reagents conform to specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.[10] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

A2.6.2 *Acetone*

NOTE A2.10: *Acetone*—**Warning**—Extremely flammable. Irritating to skin, eyes, and mucous membranes

A2.6.3 *Methanol*

NOTE A2.11: *Methanol*—**Warning**—Flammable. Causes eye irritation. Skin irritant on repeated contact

A2.7 Handling of Samples

A2.7.1 The extreme sensitivity of vapor pressure measurements to losses through evaporation and the resulting changes in composition requires the utmost precaution and the most meticulous care in the handling of samples.

NOTE A2.12—Because the liquid volumes used are about five times smaller than in Test Method D 4953, it is even more imperative that great care is taken in the handling of samples to avoid losses of volatile hydrocarbons.

A2.7.2 Sampling shall be performed in accordance with Practice D 4057.

A2.7.3 The size of the sample container from which the sample is taken shall be approximately 1 qt. It shall be filled with 70 to 80 % of sample at 32 to 34°F (0 to 1°C).

A2.7.4 *Precautions:*

A2.7.4.1 This test shall be the first test run on a sample (Note A2.13). For samples with a vapor pressure higher than 13 psi (90 kPa), not more than one sample may be withdrawn from the sample container for this test. For samples with vapor pressures between 10 and 13 psi, not more than two samples may be withdrawn from the sample container for this test. For samples with a vapor pressure less than 10 psi, not more than four samples may be withdrawn from the sample container for this test.

NOTE A2.13—If a vapor pressure determination is required on the same sample, this should be run from a separate sample container. Do not run this test from a sample container after sample has been drawn from that container for a vapor pressure.

A2.7.4.2 Samples shall be protected from excessive heat prior to testing.

A2.7.4.3 Samples in leaky containers shall not be tested. They should be discarded and new samples shall be obtained.

A2.7.4.4 The sample contents shall be cooled to 32 to 34°F (0 to 1°C) before the container is opened. This can be assured by direct measurement of the temperature of a similar liquid in a like container placed in the cooling bath at the same time as the sample.

A2.8 Preparation for Test

A2.8.1 *Verification of Sample Container Filling*—With the sample at a temperature of 32 to 34°F (0 to 1°C), take the container from the cooling bath, unseal it, and examine its ullage. The sample content shall equal 70 to 80 % of the container capacity.

A2.8.1.1 Discard the sample if its volume is less than 70 % of the container capacity.

A2.8.1.2 If the container is more than 80 % full, pour out enough sample to bring the container contents within the 70–80 % range. Under no circumstance may any sample poured out be returned to the container.

A2.8.2 *Air Saturation of Sample in Sample Container:*

A2.8.2.1 With the sample again at a temperature of 32 to 34°F (0 to 1°C), take the container from the cooling bath, unseal it momentarily, reseal it, and shake vigorously. Return it to the bath for a minimum of 2 min.

A2.8.2.2 Repeat A2.8.2.1 twice more. Return the sample to the bath until the beginning of the procedure.

A2.8.3 *Preparation of the Fuel Chamber*—Check that the fuel chamber is clean and dry. Close off the opening with a rubber stopper. Completely immerse the stoppered fuel chamber in the bath at 32 to 34°F (0 to 1°C) for at least 10 min. Wrap the clean and dry sample transfer connection in a plastic bag and place it also in the same bath.

A2.8.4 *Preparation of Air Chamber*—Check that this chamber is clean and dry and that there is no residual liquid left in the pressure cavity of the pressure measurement device. Read and record the room temperature. The chamber should have been at this temperature for at least 15 min prior to charging the sample.

A2.9 Procedure

A2.9.1 *Sample Transfer*—With everything in readiness, remove the chilled sample container and dry off excess moisture. Remove the sample transfer connection from the bath, uncap the container and insert the transfer connection in the container (see Fig. A2.2). Remove the chilled fuel container, wipe the top part dry, remove the cork, and place the fuel chamber in an inverted position, over the sample delivery tube of the transfer apparatus. Invert the entire system rapidly so that the fuel chamber is upright with the end of the delivery tube touching the bottom of the fuel chamber. Fill the fuel chamber to overflowing. Keep the outlet of the transfer tube under the surface of the liquid. Do not splash or slosh during this operation. Withdraw the delivery tube from the fuel chamber while allowing the sample to continue flowing up to the moment of complete withdrawal.

NOTE A2.14: **Caution**—Provisions should be made for suitable restraint and disposal of the overflowing gasoline to avoid fire hazard. Do not inhale gasoline fumes. Carry out the sample transfer in a fume hood if possible.

A2.9.2 *Assembly of Apparatus*—Hold the bottom of the liquid fuel chamber on a flat surface; ensure that the liquid level is flush with the top of the chamber and immediately attach the air chamber to the fuel chamber. Not more than 10 s shall be consumed in coupling the two chambers (Note A2.15).

NOTE A2.15—Sample Transfer and Apparatus Assembly as described in A2.9.1 and A2.9.2 are best performed by two persons working

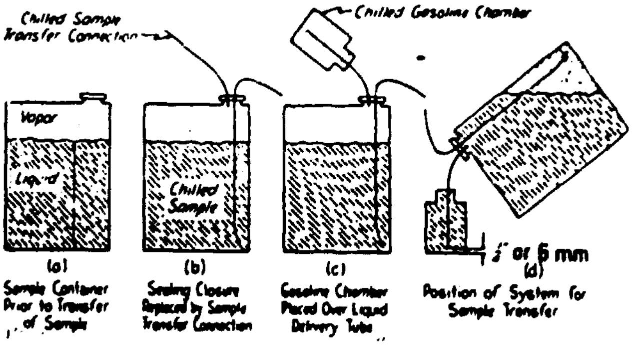

FIG. A2.2 Simplified Sketches Outlining Method of Transferring Sample to Gasoline Chamber from Open-Type Containers together This reduces the time that the sample is exposed to the atmosphere and reduces potential errors in sample handling

A2.9.3 *Introduction of Apparatus into Bath*—Hold the assembled vapor pressure apparatus in the horizontal position to allow a major portion of the sample in the fuel chamber to run into the vapor chamber. With the apparatus still in the horizontal position, shake it vigorously 6 to 8 times in a direction parallel to the apparatus. With the gage end up, immerse the assembled apparatus in a thermostated bath maintained at ±0.2°F (0.1°C) of the desired temperature (Note A2.16). With the connection between the fuel and the vapor chamber under the water level, carefully examine this connection for leaks (Note A2.17). If no leaks are observed, further immerse the apparatus to at least 1 in. (25 mm) above the top of the air chamber. Observe the apparatus for leakage throughout the test. Discard the test at any time a leak is detected.

Note A2.16—For samples with a vapor pressure between 8 and 14 psi (56 and 98 kPa) a good temperature to start is 100°F (37.8°C). For samples with a higher vapor pressure a lower starting temperature is recommended, for example, 90°F. Conversely, a higher starting temperature is indicated for samples with vapor pressures below 8 psi (56 kPa).

Note A2.17—Liquid leaks are more difficult to detect than vapor leaks. Because the coupling between the two chambers is normally in the liquid section of the apparatus, give it particular attention

A2.9.4 *Measurement of Vapor Pressure*:

A2.9.4.1 After the assembled apparatus has been immersed in the bath for at least 5 min, tap the pressure gage or pressure transducer lightly and observe the reading. Withdraw the apparatus from the bath and repeat A2.9.3. At intervals of not less than 2 min, perform A2.9.3 until a total of not less than 5 shakings and gage readings have been made. Continue thereafter if necessary until the last two consecutive gage readings are constant, indicating that equilibrium has been attained. These operations normally require 20 to 30 min. Read the final gage pressure to the nearest 0.05 psi (0.35 kPa) and record this value as the "uncorrected vapor pressure" of the sample.

A2.9.4.2 Have another thermostated bath ready at a temperature 10 to 30°F (6 to 17°C) higher than the previous bath. If only one thermostated bath is available, the temperature can also be changed by adjusting the setpoint of the bath. Increase the temperature by the full 30°F if the observed pressure in the previous run is 9 psig (63 kPa) or less; increase the temperature of the bath by 10°F, if the pressure of the previous run is 13 psig (91 kPa) or more. Decrease the temperature of the bath if the observed pressure of the first run results in a calculated V/L value (see A2.11.1) of more than 20.0.

A2.9.4.3 Repeat steps A2.9.3 and A2.9.4.1. If the observed final gage pressure in the subsequent run is such that the corresponding V/L, as calculated according to A2.11.1 is less than 20, an additional run is required. Repeat steps A2.9.4.2, A2.9.3, and A2.9.4.1 in this case. Repeat until a measurement is obtained where the final gage pressure reading corresponds to a V/L larger than 20, as calculated by Eq A2.1.

A2.9.4.4 After the final gage pressure reading, remove the pressure gage (Note A2.18) and, without attempting to remove any liquid which may be trapped in the gage, check its reading against a manometer while both are subjected to a common steady pressure which is no more than 0.2 psi (1.0 kPa) different from the last recorded gage pressure. If a difference is observed between the gage and the manometer reading, this difference should be added to or subtracted from the uncorrected vapor pressure readings recorded earlier

Note A2.18—The gage pressure should in general be 15 psi (103 kPa) or higher at this point. Cooling the assembly prior to disconnecting the gage will facilitate disassembly and reduce the amount of hydrocarbons released into the atmosphere. In all cases the gage should be disconnected with the relief hole in the bottom of the vapor chamber pointing away from the operator

A2.9.5 *Preparation of Apparatus for Next Test*—Disconnect the vapor and liquid fuel chamber and discard the residual sample. Clean both chambers by rinsing several times with a solvent such as acetone or methanol, allow to drain and then blow dry. Check visually for cleanliness. After disconnecting the pressure gage from its manifold connection with the manometer, remove trapped fluid by repeated centrifugal thrusts. For a Bourdon type pressure gage, this can be accomplished by holding the gage between the palms of the hands with the right hand on the face side and the threaded connection of the gage forward. Extend the arms forward and upward at an angle of 45° with the coupling of the gage pointing in the same direction. Swing the arm downwards through an arc of about 135° so that the centrifugal force aids gravity in removing the trapped liquid. Repeat this operation three times to expel all liquid. For a pressure transducer a similar approach can be used to expel all liquid from the pressure cavity. Purge the pressure gage by directing a small jet of cleaned air into the Bourdon tube or sample cavity for at least 5 minutes

A2.10 Hazards

A2.10.1 Gross errors can be obtained if the prescribed procedures are not followed carefully. It is very important to adhere strictly to the precautions given in this procedure

A2.10.1.1 *Checking the Pressure Gage or Pressure Transducer*—Check the gage or the transducer after each test to ensure high precision and results. Read Bourdon type gages while in the vertical position and after tapping lightly. When a pressure transducer is used, the temperature of the transducer should be monitored to correct for the effect of temperature on the readout.

A2.10.1.2 Shake the sample container vigorously at the beginning of the test to ensure equilibrium of the sample with the air in the container.

A2.10.1.3 Check the apparatus before, during, and after the test for both liquid and vapor leaks.

A2.10.1.4 *Sampling*—Because initial sampling and the handling of the sample will greatly affect the final result, employ the utmost precautions and the most meticulous care to avoid losses through evaporation, splashing, and any other operation which could result in even slight changes in composition.

A2.10.1.5 Thoroughly purge the pressure gage and the two chambers to ensure that they are free from residual sample. This operation is most conveniently performed at the end of each test.

A2.11 Calculation

A2.11.1 For each determination calculate [illegible] vapor-liquid ratio" as follows:

$$V/L = \frac{V_c - V_s}{V_s} \cdot \frac{1}{14.69}\left(P + B\,\frac{T_1 - T_2}{459.6 + T_1}\right) \qquad \text{(A2.1)}$$

where:

V_c = total void volume of the apparatus, ml (Note A2.19),

V_s = volume of the liquid fuel chamber, mL,

P = corrected pressure gage reading, psig (Note A2.20),

B = barometric pressure, psi,

T_1 = air temperature in vapor chamber at charging, °F (Note A2.21), and

T_2 = air temperature at equilibrium, °F.

NOTE A2.19—The total void volume is the sum of the vapor chamber, the liquid fuel chamber, the dead volume in the pressure gage, and the volume of the connection between the pressure gage and the vapor chamber.

NOTE A2.20—If the pressure readings are in mm Hg, substitute 760 for the 14.69 in the equation; if the pressure readings are in kPa, substitute 101.3 for 14.69 in the equation.

NOTE A2.21—If the temperature readings are in °C, substitute 273.13 for 459.6 in the formula.

A2.11.2 Plot the experimental results in the form of "vapor/liquid ratio" versus temperature on graph paper, which can be read easily to 0.1 V/L and 0.2°F (0.1°C). Read from the plot the temperature corresponding to the V/L ratio equal to 20.0 (Note A2.22). This is the desired value of $T(V/L = 20)$.

NOTE A2.22—This temperature can also be calculated mathematically from the following:

$$\begin{aligned} T(V/L &= 20) \\ &= T_a + (T_b - T_a)(20.0 - (V/L)_a)/((V/L)_b - (V/L)_a) \end{aligned} \qquad \text{(A2.2)}$$

where T_a and $(V/L)_a$ are the temperature and the corresponding value of the "vapor/liquid ratio" from the first experimental point and T_b and $(V/L)_b$ are the temperature and the corresponding value of the "vapor/liquid ratio" from the second experimental point.

A2.11.3 Extrapolation is not permitted to calculate the value of $T(V/L = 20)$. If necessary, perform an additional measurement to ensure that the desired temperature can be calculated by interpolation. The calculated value of $T(V/L = 20)$ shall also be less than 10°F (5.6°C) away from a measured data point. If this is not the case, perform an additional measurement at a temperature close to the expected value of $T(V/L = 20)$ (Note A2.23).

NOTE A2.23—If more than 2 data points are obtained, these will not lie on a straight line. To determine the desired $T(V/L = 20)$, consider only the two closest experimental points bracketing this value.

A2.12 Precision and Bias

A2.12.1 *Precision*—Precision is still to be determined.

A2.12.2 *Bias*—There being no criteria for measuring bias in these test-product combinations, no statement of bias can be made.

A3. TEST METHOD FOR WATER TOLERANCE (PHASE SEPARATION) OF SPARK-IGNITION ENGINE FUEL

A3.1 Scope

A3.1.1 This test method determines the ability of gasoline-oxygenate blends to retain water in solution or in a stable suspension at the lowest temperature to which they are likely to be exposed in use.

A3.1.2 The values stated in SI units are standard.

A3.1.3 This test method is state-of-the-art; however, it may be revised and eventually balloted for publication as a separate standard.

A3.2 Summary of Test Method

A3.2.1 The sample of fuel is cooled at a controlled rate to its expected use temperature and is periodically observed for both haze and phase separation. The apparatus of Test Method D 2500 or a dry ice-isopropyl alcohol bath may be used. A maximum cooling rate of 2°C (4°F)/min is specified because phase separation in gasoline-oxygenate blends has a relatively long but unpredictable induction period.

A3.3 Significance and Use

A3.3.1 Some oxygenate-containing fuels, and gasoline-alcohol blends in particular have a very limited ability to retain water in solution or in stable suspension, and if the amount of water in the blend exceeds this limit, the fuel will separate into a lower oxygenate-rich aqueous phase and an upper oxygenate-lean hydrocarbon phase. The most important factor governing the ability of a specific fuel to retain water without such separation is its temperature. This method is intended to determine the maximum temperature at which the fuel will separate. The 10th percentile 6-h minimum temperature, or 10°C (50°F) whichever is lower, for the time of year and geographic area of the United States in which the fuel may be used, are tabulated in Table 3 of Specification D 4814. The temperatures represent the maximum temperatures above which the fuel must not separate into two distinct phases.

A3.3.2 Note that in this test, actual separation of the sample into two distinct phases is the criterion for failure. The following are indications of phase separation:

A3.3.2.1 The formation of droplets large enough to be detected by the unaided eye. They can be either clinging to the sides of the container or collect on the bottom.

A3.3.2.2 The formation of two layers separated by either a common boundary, or a layer of emulsion.

A3.3.3 Formation of haze without one of these indications of separation is not cause for rejection.

A3.4 Apparatus

A3.4.1 *Test Container*—The container may be as specified in the apparatus section of Test Method D 2500, but any glass container of about 100 mL capacity may be used. This container may be marked at the level of 40 mL.

A3.4.2 *Thermometers*, meeting the requirements of Specification E 1. ASTM thermometer 6C (range −80 to +20°C, 1°C graduations, 76 mm immersion. Thermometer 6F is the Fahrenheit equivalent of 6C) spans the necessary range of temperatures. A thermometer must be provided for each container, mounted to pass through the stopper.

A3.4.3 *Viton Rubber Stopper*—to fit sample container, bored centrally for the test thermometer.

A3.4.4 *Cooling Bath*—May be of similar dimensions to those specified in 6.7 of Test Method D 2500 and provided with a jacket, disk, and gasket as specified in the apparatus section, filled with an equal-volume mixture of water and "permanent" antifreeze and provided with refrigeration coils capable of reducing its temperature to −40°C (−40°F). Alternatively, a dry ice-isopropyl alcohol bath may be used.

A3.5 Sampling and Handling

A3.5.1 Draw samples in accordance with the instructions in Practice D 4057, specifically 7.8.3, 7.9.1, and 10.3, except that water displacement, 10.3.1.8, shall not be used.

A3.5.2 Draw the samples in steel cans that have been solvent washed in accordance with 6.3.3.1 of Practice D 4306.

A3.5.3 Store the samples in a refrigerator (2 to 7°C, 35 to 45°F) whenever not actually transferring sample.

A3.5.4 Because gasoline-alcohol blends are hygroscopic as well as volatile, minimize contact with the atmosphere by keeping sample containers tightly closed except when transferring sample.

A3.6 Procedure

A3.6.1 Warm the sample to 15°C (59°F) and shake, to redissolve any water that may have settled out at the refrigerator temperature.

A3.6.2 Cool the test containers to 10 to 15°C (50 to 59°F). Carry out steps A3.6.3 through A3.6.5 as promptly as possible to minimize vaporization losses and absorption of water from the atmosphere.

A3.6.3 Rinse out the cooled test container with some of the sample to be tested. Drain.

A3.6.4 Pour about 40 mL of the sample into the test container. The precise amount is not critical, but it must be enough to submerge the thermometer bulb adequately, without being so much as to require an excessive amount of cooling time. If the sample has separated, as defined in A3.3.2, terminate the test.

A3.6.5 Seal the test container with the rubber stopper. Locate the thermometer bulb approximately at the center of the fuel sample.

A3.6.6 Cool the sample by intermittent immersion in or circulation of the coolant. The sample is not to be swirled or shaken while in the cooling bath. Starting at a cooling bath temperature not higher than 10°C (50°F), or 16°C (30°F) above the test temperature, cool the sample at a maximum rate of 2°C (4°F)/minute until phase separation occurs, or the test temperature is reached.

A3.6.7 At 2°C (4°F) intervals, remove the test container from the cooling bath and shake vigorously for 5 to 10 s. Wipe the exterior of the sample container with a towel moistened with isopropyl alcohol to remove any condensation, and observe the condition of the sample for no more than 5 s against a light colored, illuminated background.

A3.6.8 It is likely that the sample will get hazy prior to actual phase separation as defined in A3.3.2. Record the sample temperature at the first indication of haze (when cooling); and the temperature when the haze disappears (warming).

A3.6.9 Record the temperature of phase separation (A3.3.2). Then allow the sample to warm at ambient temperature. Shake the sample vigorously after a temperature rise of 2°C (4°F), and observe. Record a "warming" phase recombination temperature, and haze disappearance temperature. Average these "cooling" and "warming" temperatures to determine the actual phase separation and haze point temperatures. Repeat this process for improved accuracy.

A3.7 Report

A3.7.1 Report the following information:

A3.7.1.1 Report the averaged haze point and phase separation temperatures found in A3.6.9.

A3.8 Precision and Bias

A3.8.1 *Precision*—The precision of this test method has not been determined.

A3.8.2 *Bias*—There being no criteria for measuring bias in these test-product combinations, no statement of bias can be made.

APPENDIXES

(Nonmandatory Information)

X1. SIGNIFICANCE OF ASTM SPECIFICATION FOR AUTOMOTIVE SPARK-IGNITION ENGINE FUEL

X1.1 General

X1.1.1 Antiknock rating and volatility define the general characteristics of automotive spark-ignition engine fuel. Other characteristics relate to the following: limiting the concentration of undesirable components so that they will not adversely affect engine performance and ensuring the stability of fuel as well as its compatibility with materials used in engines and their fuel systems.

X1.1.2 Fuel for spark-ignition engines is a complex mixture composed of relatively volatile hydrocarbons that vary widely in their physical and chemical properties and may contain oxygenates. Fuel is exposed to a wide variety of mechanical, physical, and chemical environments. Thus, the properties of fuel must be balanced to give satisfactory engine performance over an extremely wide range of operating conditions. The prevailing standards for fuel represent compromises among the numerous quality and performance requirements. This ASTM specification is established on the basis of the broad experience and close cooperation of producers of fuel, manufacturers of automotive equipment, and users of both.

X1.2 Engine Knock

X1.2.1 The fuel-air mixture in the cylinder of a spark-ignition engine will, under certain conditions, autoignite in localized areas ahead of the flame front that is progressing from the spark. This is engine spark knock which can cause a ping that may be audible to the customer.

X1.2.2 The antiknock rating of a fuel is a measure of its resistance to knock. The antiknock requirement of an engine depends on engine design and operation, as well as atmospheric conditions. Fuel with an antiknock rating higher than that required for knock-free operation does not improve performance.

X1.2.3 A decrease in antiknock rating may cause vehicle performance loss. However, vehicles equipped with knock limiters can show a performance improvement as the antiknock quality of the fuel is increased in the range between customer audible knock and knock-free operation. The loss of power and the damage to an automotive engine due to knocking are generally not significant until the knock intensity becomes very severe. Heavy and prolonged knocking may cause power loss and damage to the engine.

X1.3 Laboratory Octane Number

X1.3.1 The two recognized laboratory engine test methods for determining the antiknock rating of fuels are the Research method (Test Methods D 2699 or D 2885) and the Motor method (Test Methods D 2700 or D 2885). The following paragraphs define the two methods and describe their significance as applied to various equipment and operating conditions.

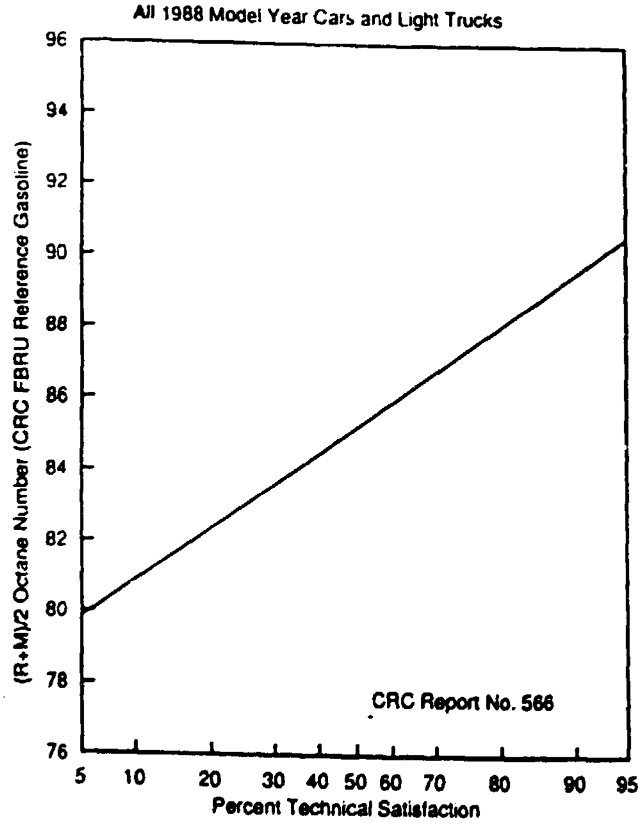

FIG. X1.1 An Example of the Statistical Distribution of Vehicle Antiknock Requirements

TABLE X1.1 Automotive Spark-Ignition Engine Fuel Antiknock Indexes in Current Practice

Antiknock Index[B,C,D,E] (RON + MON)/2	Application
Unleaded Fuel[A] (for vehicles that can or must use unleaded fuel)	
87	Designed to meet antiknock requirements of most 1971 and later model vehicles
89	Satisfies vehicles with somewhat higher antiknock requirements
91 and above	Satisfies vehicles with high antiknock requirements
Leaded Fuel (for vehicles that can or must use leaded fuel)	
Antiknock Index[B,C,D,E] (RON + MON)/2	Application
88	For most vehicles that were designed to operate on leaded fuel

[A] Unleaded fuel having an antiknock index of at least 87 should also have a minimum Motor octane number of 82 in order to adequately protect those vehicles that are sensitive to Motor octane quality.

[B] Reductions in vehicle antiknock requirements for altitude are shown in Fig. X1.2.

[C] Reductions in vehicle antiknock requirements for seasonal variations are shown in Fig. X1.3.

[D] Not all antiknock index levels listed in this table are available at all locations.

[E] The Federal Trade Commission requires octane posting and certification in accordance with 16 CFR Part 306.

X1.3.2 Research octane number is determined by a method that measures fuel antiknock level in a single-cylinder engine under mild operating conditions; namely, at a moderate inlet mixture temperature and a low engine speed. Research octane number tends to indicate fuel antiknock performance in engines at wide-open throttle and low-to-medium engine speeds.

X1.3.3 Motor octane number is determined by a method that measures fuel antiknock level in a single-cylinder engine under more severe operating conditions than those employed in the Research method; namely, at a higher inlet mixture temperature and at a higher engine speed. It indicates fuel antiknock performance in engines operating at wide-open throttle and high engine speeds. Also, Motor octane number tends to indicate fuel antiknock performance under part-throttle, road-load conditions.

X1.4 Road Octane Number

X1.4.1 The road octane of a fuel is the measure of its ability to resist knock in customers' vehicles, and is ultimately of more importance than laboratory octane numbers. Since road octanes are difficult to measure and interpret, the industry has agreed to use ASTM laboratory engine tests to estimate the road octane performance of spark-ignition engine fuel in vehicles.

X1.4.2 The antiknock index (AKI) is the arithmetic average of the Research octane number (RON) and Motor octane number (MON):

$$AKI = (RON + MON)/2 \quad (X1.1)$$

This value is called by a variety of names, in addition to antiknock index, including:

Octane rating
Posted octane
(R + M)/2 octane

X1.4.3 The AKI is posted on retail gasoline dispensing

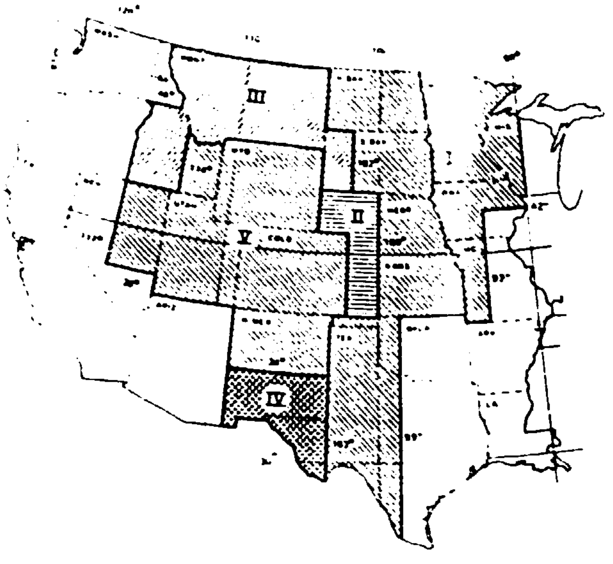

FIG. X1.2 Reduction in Vehicle Antiknock Index Requirements for Altitude[A] [B]

Area	Less than 89 AKI	89 AKI or Greater
I	0.7	0.5
II	1.5	1.5
III	2.2	1.5
IV	3.0	2.0
V	4.5	3.0

[A] Fuel may be marketed using these reductions, but actual antiknock index minimums must be posted.

[B] While the reductions in this table apply to most pre-1985 vehicles, the control technology on many newer vehicles may cause them to have little or no reduced antiknock requirement at higher altitude.

pumps in the United States and is referred to in car owners' manuals. The AKI is also required for certification at each wholesale fuel transfer and is referred to in United States federal law as "Octane Rating."[11]

X1.4.4 The most extensive data base that relates the laboratory engine test methods for Research and Motor octane to actual field performance of fuel in vehicles is the annual Coordinating Research Council (CRC)[12] Octane Number Requirement Survey conducted for new light-duty vehicles. Analysis of these data shows that the antiknock performance of a fuel in some vehicles may correlate best with Research octane number, while in others, it may correlate best with Motor octane number. These correlations also differ from model year-to-model year or from vehicle population-to-vehicle population, reflecting changes in engine designs over the years.

X1.4.5 The antiknock index of a fuel approximates the CRC road octane ratings for many vehicles. However, the user must be guided also by experience as to which fuel is most appropriate for an individual vehicle. The antiknock index formula is reviewed periodically and may have to be adjusted in the future as engines and fuels continue to evolve. The present (RON + MON)/2 formula is an estimate and is not an absolute measure of fuel antiknock performance in general or in any specific vehicle.

X1.4.6 Car antiknock requirements vary, even within a single model, so the statistical distribution of the octane needs of any car population are usually shown in graphical form, as shown in Fig. X1.1. As antiknock index increases, larger and larger fractions of the car population in question will be free of knock, that is, be "satisfied" with the octane

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[11] Details of this regulation can be found in Code of Federal Regulations Title 16, Chapter I, Subchapter C, part 306 (16 CFR306), U.S. Government Printing Office, Superintendent of Documents, Washington DC 20402.

[12] Coordinating Research Council, Inc., 219 Perimeter Center Parkway, Atlanta, GA 30346.

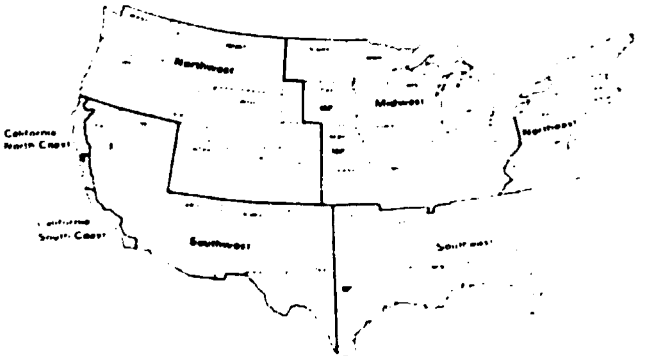


FIG. X1.3 Reduction in Vehicle Antiknock Requirements for Weather[A]

	J	F	M	A	M	J	J	A	S	O	N	D
Northeast	1.0	0.5	0.5	0	0	0	0	0	0	0.5	0.5	1.0
Southeast	0.5	0	0	0	0	0.5	0.5	0.5	0.5	0	0	0.5
Midwest	1.0	0.5	0.5	0	0	0	0	0	0	0	0.5	1.0
Northwest	1.0	1.0	0.5	0.5	0	0	0	0	0	0.5	1.0	1.0
Southwest	1.0	0.5	0	0	0	0	0	0	0	0	0.5	1.0
California[B]												
No Coast	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0	0.5	0.5
So Coast	0	0	0.5	0.5	1.0	1.0	1.0	0.5	0.5	0	0	0
Alaska	1.0	1.0	0.5	0.5	0	0	0	0	0	0.5	1.0	1.0
Hawaii	0	0	0	0	0	0	0	0	0	0	0	0

[A] Fuel may be marketed using these reductions, but actual antiknock index minimums must be posted.

[B] Details of California coastal areas are shown in Footnote A of Table 2.

quality of fuels at or above that level of ck index. The data in Fig. X1.1 are for new model c l trucks sold in the United States in the model year 19 are included as an example of the antiknock requirement distribution, not as a data reference.

X1.4.7 According to the winter 1988–1989 motor gasoline survey published by the National Institute for Petroleum and Energy Research, unleaded fuel antiknock indexes in current practice range from a low near 84 in the mountain areas to a high of near 94. Companies typically market two or three unleaded grades of fuel, one of which usually has a minimum antiknock index of 87, for which most post-1971 vehicles are designed. Most companies also market a higher octane fuel with an antiknock index of 91 or above. This fuel is intended to satisfy those vehicles with a higher octane requirement. Some companies offer three grades of unleaded fuel. The third grade usually has an antiknock index of 89. Leaded fuel is still available in some markets and usually has an antiknock index of 88 or 89.

X1.4.8 Marketers set the grades and octane based on their perception of the technical and competitive needs in the market.

X1.4.9 Antiknock indexes of fuel sold in current practice in the United States are shown in Table X1.1 for both unleaded and leaded fuels.

X1.5 Precision and Bias of Antiknock Index

X1.5.1 The following statements apply to the precision and bias of antiknock index of fuel, which is a composite quantity not addressed in any other standard.

X1.5.2 The precision of the antiknock index, (RON + MON)/2, is a function of the individual precisions of Research (Test Method D 2699) and Motor (Test Method D 2700) octane numbers. The repeatability and reproducibility variances for these test methods are summed and divided by four to obtain the variance of the antiknock index.

X1.5.2.1 *Repeatability*—The difference between two sets of antiknock index determinations, where two test results by each octane number method were obtained by one operator, with the same apparatus under constant operating conditions on identical test material would, in the long run, and in the normal and correct operation of the test methods, exceed the values in the following table in only one case in twenty.

X1.5.2.2 *Reproducibility*—The difference between two independent sets of antiknock index determinations, obtained by different operators working in different laboratories on identical test material would, in the long run, and in the normal and correct operation of the test methods, exceed the values in the following table in only one case in twenty.

Antiknock Index	Repeatability Limits, Antiknock Index Units	Reproducibility Limits, Antiknock Index Units
83	0.2	0.7
85	0.2	0.7
87	0.2	0.7
89	0.2	0.6
91	0.2	0.6
93	0.2	0.6
95	—	0.6
97	--	0.7

NOTE X1.1—These precision limits were calculated from Research and Motor octane number results obtained by member laboratories of the ASTM National Exchange Group (NEG) participating in a cooperative testing program. The data obtained during the period 1980 through 1982 have been analyzed in accordance with RR:D02-1007, "Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants," Spring, 1973.

X1.5.2.3 *Bias*—Since knock ratings are determined by the conditions of the empirical test methods involved, bias cannot be determined.

X1.6 Altitude and Weather Octane Adjustments

X1.6.1 The octane requirement (the octane number of fuel required for satisfactory vehicle operation with respect to knock) of vehicles decreases as altitude increases, primarily because of the reduction in mixture density caused by reduced atmospheric pressure. However, altitude does not affect octane requirements of all cars uniformly.

X1.6.2 The adjustments to antiknock index for altitude are given in Fig. X1.2. Boundaries of the areas defined and the corresponding antiknock index reductions were established to protect cars driven from a high to a lower altitude (and, hence, higher octane requirement) area while using fuel obtained in the high altitude area.

X1.6.3 Tests by the CRC and other organizations have shown that the decrease in octane requirements with altitude is larger for most models between 1971 and 1984, designed to use a fuel with an antiknock index of 87, than for pre-1971 cars. Generally, the pre-1971 cars have high compression ratios and use fuels with an antiknock index of 88 and higher. Fuels with antiknock indexes below 89 are adjusted by a larger reduction factor than those with an antiknock index of 89 or greater.

X1.6.4 Recent data indicate that vehicles with modern control technology do not respond to altitude in the same way as earlier vehicles. In fact, the antiknock index requirement in high altitude regions may be the same as at sea level. This control technology began to be used extensively around 1984 and is now used in the majority of new vehicles. As post-1984 vehicles replace older vehicles in the population, the antiknock corrections in Fig. X1.2 will become inappropriate.

X1.6.5 Vehicle octane requirements, on the average, rise with increasing atmospheric temperature by 0.097 MON per degree Celsius (0.054 MON per degree Fahrenheit), and decrease with increasing specific humidity by 0.245 MON per gram of water per kilogram of dry air (0.035 MON per grain of water per pound of dry air). Because temperature and humidity of geographical areas are predictable throughout the year from past weather records, octane levels can be seasonally adjusted to match seasonal changes in vehicle octane requirements. Fig. X1.3 defines the boundaries of areas and the seasonal variations recommended for antiknock index variations.

X1.7 Leaded Versus Unleaded Fuel Needs

X1.7.1 In addition to selecting the appropriate antiknock index to meet vehicle antiknock needs, a choice must be made between leaded and unleaded fuel. Vehicles that must use unleaded fuel are required by Environmental Protection Agency regulation to have permanent labels on the instrument panel and adjacent to the fuel tank filler inlet reading "Unleaded Fuel Only." Most 1975 and later model passenger cars and light trucks are in this category. Most 1971–1974 vehicles can use leaded or unleaded fuel. Pr[illegible] vehicles were designed for leaded fuel; however, u[illegible]l fuel of suitable antiknock index may generally b[illegible] in these vehicles, except that leaded fuel should be us[illegible]riodically (after a few tankfuls of unleaded fuel have been used). Leaded fuel may be required in some vehicles, particularly trucks, in heavy-duty service and some farm equipment. Instructions on fuel selection are normally provided in publications of vehicles manufacturers (for example, owner's manuals, service bulletins, etc.). Antiknock agents other than lead alkyls may be used to increase the antiknock index of fuels, and their concentrations may also be limited due to either performance or legal requirements.

X1.8 Volatility

X1.8.1 In most spark-ignition internal combustion engines, the fuel is metered in liquid form through the carburetor or fuel injector, and is mixed with air and partially vaporized before entering the cylinders of the engine. Consequently, volatility is an extremely important characteristic of motor fuel.

X1.8.2 At high operating temperatures, fuels can boil in fuel pumps, lines, or carburetors. If too much vapor is formed, the fuel flow to the engine can be decreased, resulting in loss of power, rough engine operation, or engine stoppage. These conditions are known as "vapor lock." Conversely, fuels that do not vaporize sufficiently can cause hard starting of cold engines and poor warm-up performance. These conditions can be minimized by proper selection of volatility requirements, but cannot always be avoided. For example, during spring and fall a fuel of volatility suitable for satisfactory starting at low ambient temperatures can cause problems in some engines under higher ambient temperature operating conditions.

X1.8.3 Six vapor pressure/distillation classes and five vapor lock protection (vapor-liquid ratio) classes of fuel are provided to satisfy vehicle performance requirements under different climatic conditions and to comply with U.S. EPA vapor pressure limits for the control period of May 1 through September 15. Class A and Class AA specify the EPA maximum vapor pressure limits of 9.0 psi and 7.8 psi, respectively. Volatility of fuel is specified by an alphanumeric designation. The letter specifies the vapor pressure/distillation class and the number specifies the vapor lock protection class. The vapor pressure/distillation classes are needed to comply with the EPA vapor pressure regulations and are not based on vehicle performance during the EPA control period. The separate vapor lock protection classes are provided because under most ambient conditions the EPA regulations specify a lower vapor pressure than would be required to prevent hot fuel handling problems. If the corresponding and unnecessarily more restrictive vapor-liquid ratios were specified when the EPA regulations are in effect, it could result in reduced fuel production, manufacturing hardships, and increased fuel costs. The schedule for seasonal and geographical distribution indicates the appropriate alphanumeric volatility requirement or requirements for each month in all areas of the United States, based on altitude and expected air temperatures, and on EPA vapor pressure regulations. Volatility limits are established in terms of vapor-liquid ratio, vapor pressure, and distillation properties.

X1.8.4 For sea-level areas outside of the United States where vapor pressure requirements are not as restrictive as those specified by EPA, the following ambient temperatures are for guidance in selecting the appropriate alphanumeric designation:

Alphanumeric Volatility Designation	10th Percentile 6-h Minimum Daily Temperature °C (°F)	90th Percentile Maximum Daily Temperature °C (°F)
A-1	16 (60)	≥43 (110)
B-2	10 (50)	<43 (110)
C-3	4 (40)	<36 (97)
D-4	−7 (20)	<29 (85)
E-5	≤ −7 (20)	<21 (69)

The 6-h minimum temperature is the highest temperature of the six coldest consecutive hourly temperature readings of a 24-h day. The 6-h minimum temperature provides information on the cold-soak temperature experienced by a vehicle. The 10th percentile of this temperature statistic indicates a 10 % expectation that the 6-h minimum temperature will be below this value during a month. The 90th percentile maximum temperature is the highest temperature expected during 90 % of the days, and provides information relative to peak vehicle operating temperatures during warm and hot weather. For areas above sea level, the 10th percentile 6-h minimum temperature should be increased by 3.6°C/1000 m (2°F/1000 ft) of altitude, and the 90th percentile maximum should be increased by 4.4°C/1000 m (2.4°F/1000 ft) of altitude before comparing them to the sea level temperature. These corrections compensate for changes in fuel volatility caused by changes in barometric pressure due to altitude.

X1.9 Vapor Pressure

X1.9.1 The vapor pressure of fuel must be sufficiently high to ensure ease of engine starting, but it must not be so high as to contribute to vapor lock or excessive evaporative emissions and running losses.

X1.9.2 Test Methods D 4953, D 5190, or D 5191 provide procedures for determining the vapor pressures of gasoline or gasoline-oxygenate blends.

X1.10 Vapor-Liquid Ratio

X1.10.1 Vapor-liquid ratio (V/L) is the ratio of the volume of vapor formed at atmospheric pressure to the volume of fuel tested in Test Method D 2533. The V/L increases with temperature for a given fuel. Because some oxygenates are miscible with the glycerin confining fluid, Test Method D 2533 has been modified so mercury can also be used as a confining fluid. Either confining fluid may be used for determining V/L of gasoline, but a possible bias between the two fluids is under investigation by Subcommittee D02.08. The mercury confining fluid must be used for gasoline-oxygenate blends. Subcommittee D02.08 is also investigating the suitability of using glycerin for gasoline-ether blends. A test method shown in Annex A2 describes a bomb procedure for measuring the temperature for V/L of 20 which is under development by Subcommittee D02.08.

X1.10.2 The temperature of the fuel system and the V/L that can be tolerated without vapor lock vary from vehicle to vehicle and with operating conditions. The tendency of a fuel to cause vapor lock, as evidenced by los[illegible]er during full-throttle accelerations, is indicated by [illegible]oline temperature at a V/L of approximately 20. A [illegible]ar relationship for gasoline-oxygenate blends has also been determined. The temperature at which the maximum V/L is specified for each gasoline volatility class is based on the ambient temperatures and the altitude associated with the use of the class.

X1.11 Vapor-Liquid Ratio (Estimated)

X1.11.1 Three techniques for estimating temperature-V/L values using vapor pressure (Test Methods D 4953, D 5190, or D 5191) and distillation (Test Method D 86) results are given in Appendix X2; they apply to gasoline only.

X1.12 Distillation

X1.12.1 Test Method D 86 for distillation provides another measure of the volatility of fuels. Table 1 designates the limits for end-point temperature and the temperatures at which 10 %, 50 %, and 90 % by volume of the fuel is evaporated. These distillation characteristics, along with vapor pressure and V/L characteristics, affect the following vehicle performance characteristics: starting, driveability, vapor lock, dilution of the engine oil, fuel economy, and carburetor icing.

X1.12.2 The 10 % evaporated temperature of fuel should be low enough to ensure starting under normal temperatures.

X1.12.3 Fuels having the same 10 % and 90 % evaporated temperatures can vary considerably in driveability performance because of differences in the boiling temperatures of the intermediate components, or fractions. Driveability and idling quality are affected by the 50 % evaporated temperature. The 90 % evaporated and end-point temperatures should be low enough to minimize dilution of the engine oil.

X1.13 Corrosion

X1.13.1 Fuels must pass the copper strip corrosion test to minimize corrosion in fuel systems due to sulfur compounds in the fuel. Some fuels corrode fuel system metals other than copper, but there are no ASTM test methods to evaluate corrosion of these metals. Depending on the type and concentration of oxygenate, gasoline-oxygenate blends can corrode metals such as zinc, magnesium, aluminum, steel, and terne. However, at this time there is no test method with a known correlation to field performance. Consequently, additional corrosion tests are needed.

X1.14 Existent Gum

X1.14.1 The test for existent gum measures the amount of residue after evaporation of the fuel and after a heptane wash. The heptane wash removes the heptane-soluble material such as additives and nonvolatile oils, which can have been added to the fuel. Excess existent gum can cause harmful carburetor, engine intake manifold and intake valve deposits.

X1.15 Sulfur

X1.15.1 The limit on sulfur content is included to protect against engine wear, deterioration of engine oil, and corrosion of exhaust system parts.

X1.16 Oxidation Stability

X1.16.1 The induction period as measured in the oxidation stability test is used as an indication of the resistance of fuel to gum formation in storage. Experience indicates that fuels with an induction period equal to or greater than that in Table 1 generally have acceptable short-term storage stability. However, correlation of the induction period with the formation of gum in storage can vary markedly under different storage conditions and with different fuels.

X2. ESTIMATING TEMPERATURE-V/L VALUES FOR GASOLINE

X2.1 Scope

X2.1.1 Three techniques are presented here for estimating temperature-V/L data from vapor pressure and distillation test results[13] on gasolines only. They are provided for use as a guideline when V/L data measured by Test Method D 2533 are not available. One method is designed for computer processing, one is a simpler linear technique, while the other is a nomogram form of this linear equation.

X2.1.2 These techniques are not optional procedures for measuring V/L. They are supplementary tools for estimating temperature-V/L relationships with reasonable accuracy when used with due regard for their limitations.

X2.1.3 Test Method D 2533 is the referee V/L procedure and shall be used when calculated values are questionable.

X2.1.4 These techniques are not intended for, nor are they necessarily applicable to, fuels of extreme distillation or chemical characteristics such as would be outside the range of normal commercial motor gasolines. Thus, they are not applicable in all instances to gasoline blending stocks or specially blended fuels.

X2.2 Computer Method

X2.2.1 *Summary*—The values of four intermediate functions, *A*, *B*, *C*, and *D*, are derived from the gasoline vapor pressure and distillation temperatures at 10, 20, and 50 % evaporated. Values for *A*, *B*, *C*, and *D* can be obtained either from equations or from a set of charts. Sections X2.2.2.1 through X2.2.2.3 provide *A*, *B*, *C*, and *D* values using SI units; X2.2.2.6 through X2.2.2.8 provide *A*, *B*, *C*, and *D* values using inch-pound units. Estimated temperatures at a V/L of 4, 10, 20, 30, and 45 are then calculated from *A*, *B*, *C*, and *D*. Estimated temperatures at an intermediate V/L can be obtained by interpolation.

X2.2.2 *Procedure:*

X2.2.2.1 Establish input data from vapor pressure (Test

---

[13] A correlation of temperature-V/L ratio data with vapor pressure and distillation data was developed in 1943 and restudied in 1963 by panels of the Coordinating Research Council, Inc. See "Correlation of Gasoline Vapor Forming Characteristics with Inspection Test Data," *CRC Report No. 159*, Jan. 28, 1943 (or SAE Transaction, Vol 52, August 1944, pp. 364-367) and "Study of CRC Calculated Temperature-V/L Technique," *CRC Report No. 370*, February 1963. The CRC correlation was modified by a task group of Subcommittee A of Committee D-2 to adapt it for computer processing, as well as the linear equation and the nomogram.

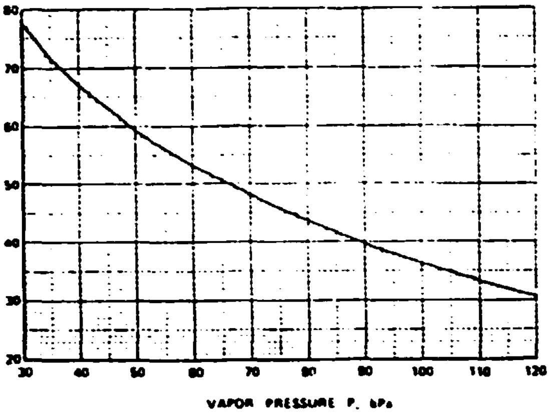


FIG. X2.1 Function *A* versus Vapor Pressure *P*

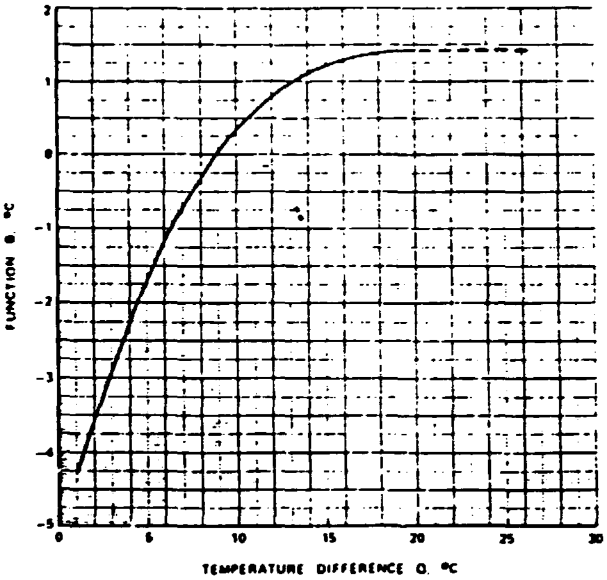


FIG. X2.2 Function *B* versus Distillation Temperature Difference *Q*

Methods D 4953, D 5190, or D5191) and distillation (Test Method D 86) test results as follows:

E = distillation temperature, °C at 10 % evaporated,
F = distillation temperature, °C at 20 % evaporated,
G = distillation temperature, °C at 50 % evaporated,
$H = G - E$, °C, (X2.1)
P = vapor pressure, kPa,
$Q = F - E$, °C, and (X2.2)
$R = H/Q$, except that if H/Q is greater than 6.7, make $R = 6.7$. (X2.3)

X2.2.2.2 If *A*, *B*, *C*, and *D*, are to be calculated use the following equations:

$$A = 102.859 - 1.36599P + 0.009617\,P^2 - 0.000028281P^3 + 207.0097/P \quad (X2.4)$$

$$B = -5.36868 + 0.910540Q - 0.040187\,Q^2 + 0.00057774Q^3 + 0.254183/Q \quad (X2.5)$$

$$S = -0.00525449 - 0.3671362/(P - 9.65) - 0.812419/(P - 9.65)^2 + 0.0009677R - 0.0000195828R^2 - + 3.3502318R/P^2 + 1241.1531R/P^4 - 0.06630129R^2/P + 0.00627839R^3/P + 0.0969193R^2/P^2 \quad (X2.6)$$

$$C = 0.34205P + 0.55556/S \quad (X2.7)$$

$$D = 0.62478 - 0.68964R + 0.132708R^2 + - 0.0070417R^3 + 5.8485/R \quad (X2.8)$$

X2.2.2.3 If *A*, *B*, *C*, and *D*, are to be obtained from charts, read them from Figs. X2.1, X2.2, X2.3, and X2.4, respectively.

X2.2.2.4 Calculate the estimated temperature (°C or °F) at *V/L* ratios 4, 10, 20, 30, and 45 from the following equations:

$$T4 = A + B \quad (X2.9)$$

$$T45 = F + 0.125H + C \quad (X2.10)$$

$$T10 = T4 + 0.146341\,(T45 - T4) + D \quad (X2.11)$$

$$T20 = T4 + 0.390244\,(T45 - T4) + 1.46519D \quad (X2.12)$$

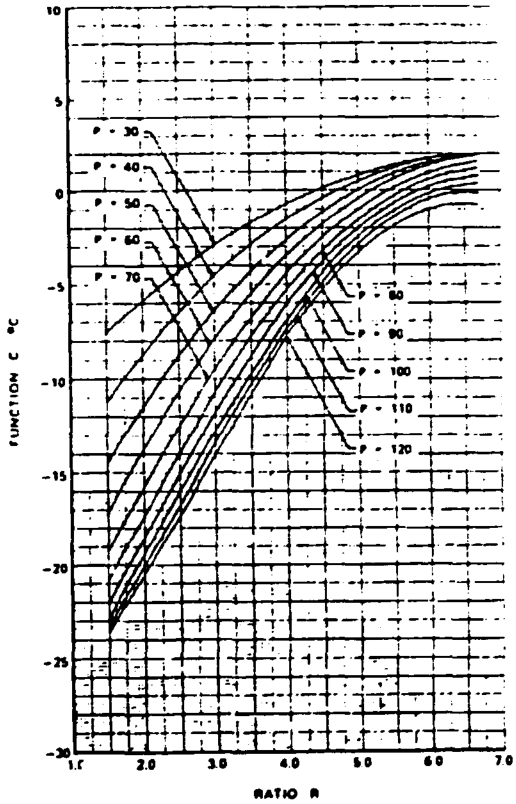


FIG. X2.3 Function *C* versus Ratio *R* and Vapor Pressure *P*

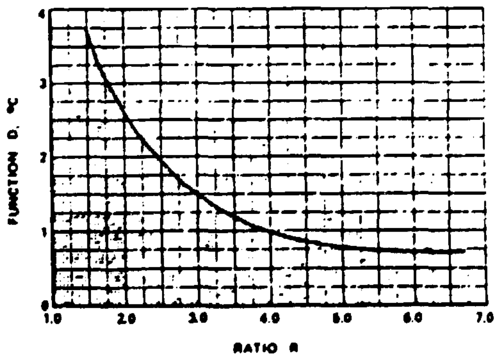


FIG. X2.4 Function *D* versus Ratio *R*

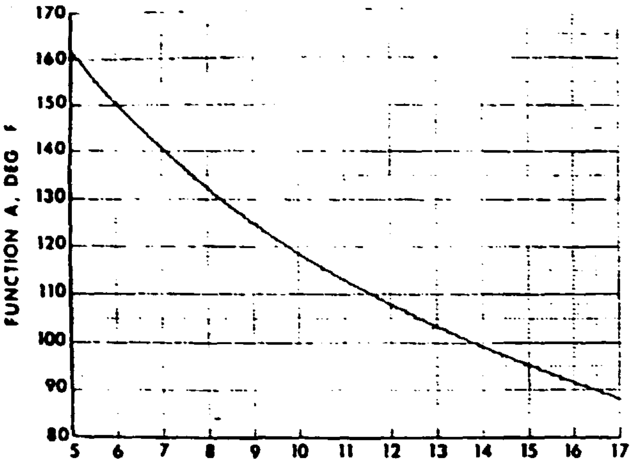


FIG. X2.5 Function *A* versus Vapor Pressure *P*

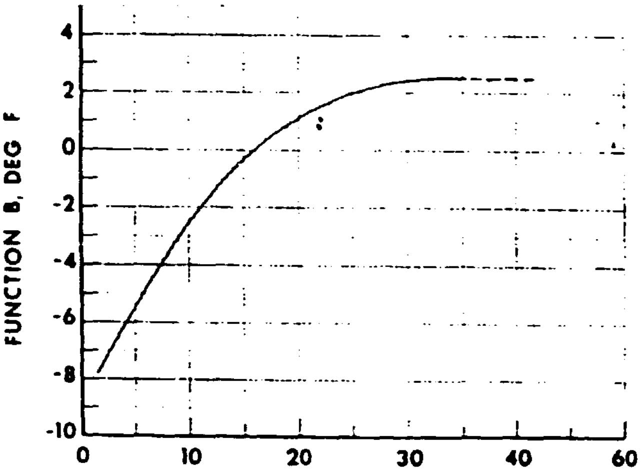


FIG. X2.6 Function *B* versus Distillation Temperature Difference *Q*

$$T30 = T4 + 0.634146\,(T45 - T4) + D \qquad \text{(X2.13)}$$

where:

*T*4, *T*10, *T*20, *T*30, and *T*45 are estimated temperatures at *V*/*L* ratios, 4, 10, 20, 30, and 45.

X2.2.2.5 If the temperature at an intermediate *V*/*L* ratio is to be estimated, either plot the values calculated in X2.2.2.4 and read the desired value from a smooth curve through the points, or use the Lagrange interpolation formula as follows:

$$\begin{aligned} TX = {} & T4\left(\frac{X-10}{4-10}\times\frac{X-30}{4-30}\times\frac{X-45}{4-45}\right) \\ & + T10\left(\frac{X-4}{10-4}\times\frac{X-30}{10-30}\times\frac{X-45}{10-45}\right) \\ & + T30\left(\frac{X-4}{30-4}\times\frac{X-10}{30-10}\times\frac{X-45}{30-45}\right) \\ & + T45\left(\frac{X-4}{45-4}\times\frac{X-10}{45-10}\times\frac{X-30}{45-30}\right) \end{aligned} \qquad \text{(X2.14)}$$

where:

X = the desired *V*/*L* ratio between 4 and 45, and

TX = the estimated temperature at *V*/*L* ratio *X*.

X2.2.2.6 If inch-pound units are used, establish input data from vapor pressure (Test Methods D 4953, D 5190, or D 5191) and distillation (Test Method D 86) test results as follows:

E = distillation temperature, °F, at 10 % evaporated,
F = distillation temperature, °F, at 20 % evaporated,
G = distillation temperature, °F, at 50 % evaporated,
$H = G - E$, °F (X2.15)
P = vapor pressure, psi,
$Q = F - E$, °F, and (X2.16)
$R = H/Q$, except that if H/Q is greater than 6.7, make $R = 6.7$. (X2.17)

X2.2.2.7 If *A*, *B*, *C*, and *D* are to be calculated in inch-pound units, use the following equations:

$$A = 217.147 - 16.9527P + 0.822909P^2 - 0.0166849P^3 + 54.0436/P \qquad \text{(X2.18)}$$

$$B = -9.66363 + 0.910540Q - 0.0223260Q^2 \qquad \text{(X2.19)}$$

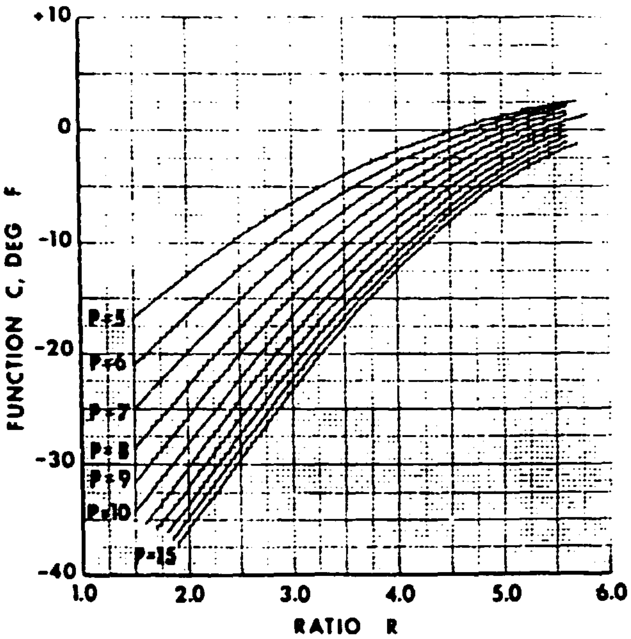


FIG. X2.7 Function C versus Ratio *R* and Vapor Pressure *P*

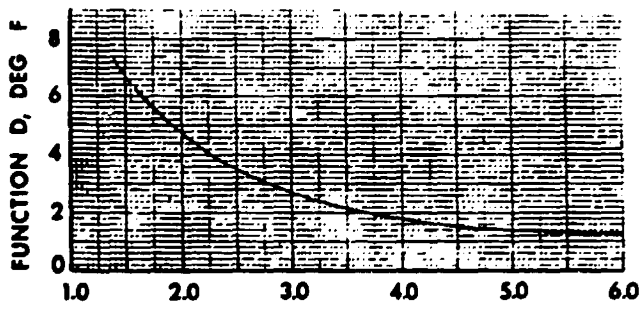
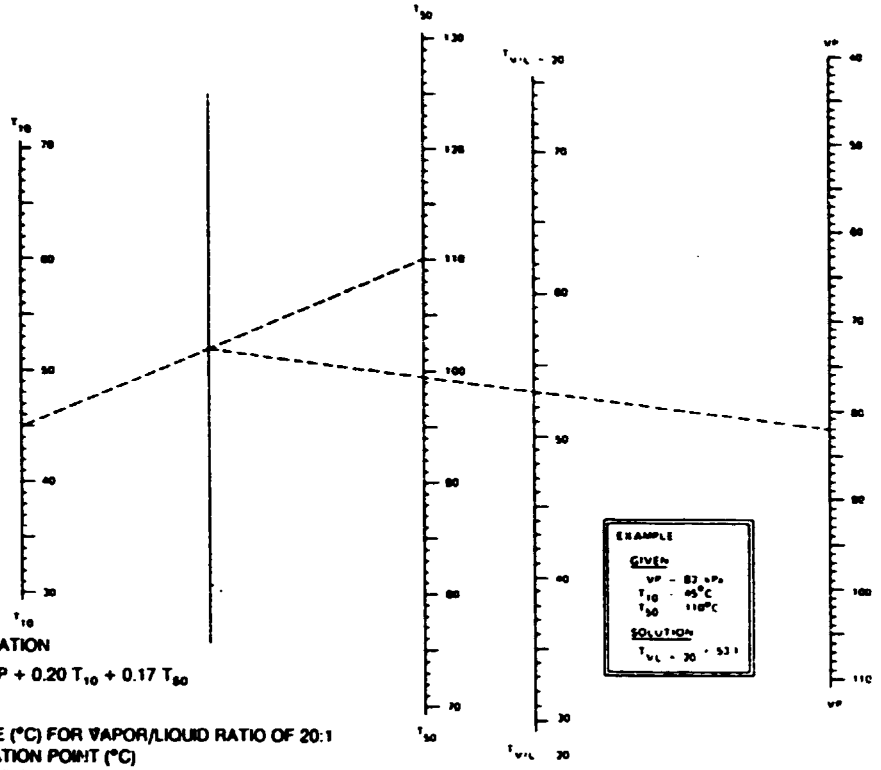


FIG. X2.8 Function *D* versus Ratio *R*



NOMOGRAM SOLVES EQUATION

$T_{V/L=20}$ = 52.47 − 0.33 VP + 0.20 T_{10} + 0.17 T_{50}

where:

$T_{V/L=20}$ = TEMPERATURE (°C) FOR VAPOR/LIQUID RATIO OF 20:1
T_{10} = 10 % EVAPORATION POINT (°C)
T_{50} = 50 % EVAPORATION POINT (°C)
VP = VAPOR PRESSURE (kPa)

FIG. X2.9 Relationship Between Gasoline Volatility and Temperature for V/L Ratio at Sea Level—SI Units

$$+ 0.000178314Q^3 + 0.823553/Q$$

$$\begin{aligned} S = {} & -0.00525449 - 0.0532486/(P - 1.4) \\ & - 0.0170900/(P - 1.4)^2 + 0.0009677R - \\ & 0.0000195828R^2 - 0.0704753R/P^2 + 0.549224R/P^4 \\ & - 0.00961619R^2/P + 0.000910603R^3/P \\ & + 0.00203879R^2/P^2 \end{aligned} \quad (X2.20)$$

$$C = 4.245P + 1.0/S \quad (X2.21)$$

$$D = 1.12460 - 1.24135R + 0.238875R^2 - 0.0126750R^3 + 10.5273/R \quad (X2.22)$$

X2.2.2.8 If *A*, *B*, *C*, and *D* are to be obtained from charts in inch-pound units, read them from Figs. X2.5, X2.6, X2.7, and X2.8 respectively.

X2.2.2.9 Calculate the estimated temperatures, °F, at *V/L* ratios 4, 10, 20, 30, and 45 using the equations in X2.2.2.4 and X2.2.2.5.

X2.3 Linear Equation Method

X2.3.1 *Summary*—As given, these two equations provide only the temperatures (°C or °F) at which a *V/L* value of 20 exists. They make use of two points from the distillation curve, T_{10} and T_{50} (°C or °F), and the vapor pressure (kPa or psi) of the gasoline with constant weighting factors being applied to each. Experience has shown that data obtained with these simple linear equations generally are in close agreement with those obtained by the computerized version given above. The limitations pointed out in X2.1.1 through X2.1.4 must be kept in mind when use is made of this procedure.

X2.3.2 *Procedure*—Obtain 10 % evaporated and 50 % evaporated points from the distillation curve (Test Method D 86) along with the vapor pressure value (Test Methods D 4953, D 5190, or D 5191); apply these directly in the equation.

$$T_{V/L=20} = 52.47 - 0.33\,(VP) + 0.20\,T_{10} + 0.17\,T_{50} \quad (X2.23)$$

where:

$T_{V/L=20}$ = temperature, °C, at *V/L* of 20:1,
VP = vapor pressure, kPa,
T_{10} = distillation temperature, °C, at 10 % evaporated, and
T_{50} = distillation temperature, °C, at 50 % evaporated.

or in the inch-pound customary unit equation:

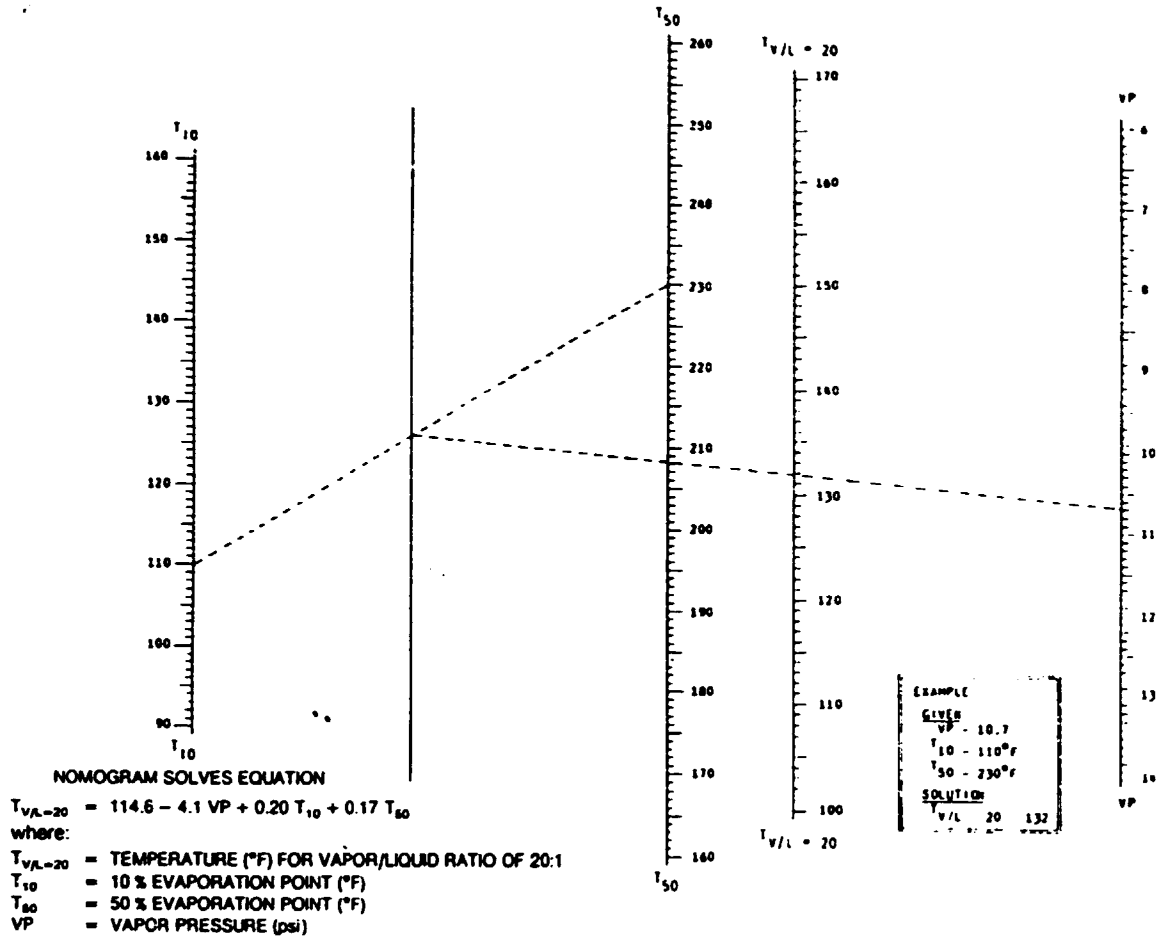
$$T_{V/L=20} = 114.6 - 4.1\,(VP) + 0.20\,T_{10} + 0.17\,T_{50} \quad (X2.24)$$

where:

$T_{V/L=20}$ = temperature, °F, at *V/L* of 20:1,
VP = vapor pressure, psi,
T_{10} = distillation temperature, °F, at 10 % evaporated, and
T_{50} = distillation temperature, °F, at 50 % evaporated.

X2.4 Nomogram Method

X2.4.1 *Summary*—Two nomograms have been developed and are included herein (Figs. X2.9 and X2.10) to provide the same function as the linear equations procedure outlined above. Figure X2.9 is in SI units and Fig. X2.10 is in inch-pound units. The nomograms are based on the two equations and the same limitations apply to their use in estimating *V/L* (20) temperatures.



NOMOGRAM SOLVES EQUATION

$T_{V/L=20}$ = 114.6 − 4.1 VP + 0.20 T_{10} + 0.17 T_{50}

where:

$T_{V/L=20}$ = TEMPERATURE (°F) FOR VAPOR/LIQUID RATIO OF 20:1
T_{10} = 10 % EVAPORATION POINT (°F)
T_{50} = 50 % EVAPORATION POINT (°F)
VP = VAPOR PRESSURE (psi)

FIG. X2.10 Relationship Between Gasoline Volatility and Temperature for V/L Ratio of 20 at Sea Level—Inch-Pound Units

X2.4.2 *Procedure*—Obtain 10 % evaporated and 50 % evaporated points from the distillation curve (Test Method D 86) along with the vapor pressure value (Test Methods D 4953, D 5190, or D 5191). Select the SI unit (Fig. X2.9) or inch-pound unit (Fig. X2.10) nomogram based on the units of T_{10}, T_{50}, and VP. Using a straightedge, locate the intercept on the line between the "T_{10} and T_{50}" scales after selecting the applicable T_{10} and T_{50} values. From this intercept and the proper point on the "VP" scale, a second intercept can be obtained on the "$T_{V/L=20}$" scale to provide the desired value directly.

X2.5 Precision

X2.5.1 The precision of agreement between temperature-V/L data estimated by any one of these three techniques and data obtained by Test Method D 2533 has not been established.

X3. SUMMARY OF EPA REGULATIONS APPLICABLE TO SPARK-IGNITION ENGINE FUEL

X3.1 EPA Applicable Vapor Pressure Standards

X3.1.1 Under authority of the Clean Air Act, the U.S. Environmental Protection Agency (EPA) issued, effective May 1992, vapor pressure control standards for leaded and unleaded gasoline and leaded and unleaded gasoline-oxygenate blends. Some states, notably California, have more restrictive vapor pressure limits.

X3.1.2 Details of the EPA regulations and test methods are available in Part 80 of Title 40 of the Code of Federal Regulations (40 CFR Part 80). For specific state vapor pressure regulations, the state of interest should be contacted.

X3.1.3 The EPA maximum vapor pressure limits of 7.8 psi and 9.0 psi are shown in Table 1 as Classes AA and A, respectively. The EPA requirements for each distribution area are shown in Table 4 for the period May 1 through September 15. For the month of May, the EPA limits only apply to finished gasoline and gasoline-oxygenate blend tankage at refineries, importers, pipelines, and terminals. For the period June 1 through September 15, the EPA limits apply to all locations of the distribution system. Footnotes D through F of Table 4 indicate the ozone nonattainment areas which are limited to 7.8 psi maximum and the appropriate vapor lock protection class. California has controls that vary for the different air basins from as early as March 1 at refineries through as late as October 31. There are no EPA vapor pressure limits for the states of Alaska or Hawaii.

X3.1.4 EPA regulations allow 1.0 psi higher values for gasoline-ethanol blends than the EPA limits shown in Tables 1 and 4 for the period May 1 through September 15. To qualify, the gasoline-ethanol blends must contain 9 to 10 volume % ethanol. Higher vapor pressure limits for gasoline-ethanol blends under state regulations vary for other time periods, and specific states of interest should be contacted to determine if higher limits apply.

X3.2 EPA Lead and Phosphorus Regulations

X3.2.1 *Unleaded Fuel*—The intentional addition of lead or phosphorus compounds to unleaded fuel is not permitted by EPA. EPA regulations limit their maximum concentrations to 0.05 g lead per U.S. gallon (0.013 g/L) and 0.005 g of phosphorus per U.S. gallon (0.0013 g/L) (see Test Method D 3231), respectively.

X3.2.2 *Leaded Fuel*—EPA regulations limit the lead concentration in leaded fuel to no more than 0.10 g per U.S. gallon (0.026 g/L) averaged per calendar quarter for each refinery. There is no EPA lead limit for any individual gallon of leaded fuel.

X3.3 EPA Oxygenate Regulations Applicable to Unleaded Gasoline-Oxygenate Blends

X3.3.1 *Substantially Similar" Rule:*

X3.3.1.1 Section 211(f) (1) of the Clean Air Act prohibits introducing into commerce or increasing the concentration in use of, any fuel or fuel additive, which is not substantially similar to any fuel or fuel additive utilized for emissions certification of any model year 1975, or subsequent model year vehicle or engine, unless a waiver is obtained from the EPA.

X3.3.1.2 Gasoline-oxygenate blends are considered "substantially similar" if the following criteria are met.

(1) The fuel must contain carbon, hydrogen, and oxygen, nitrogen, or sulfur, or combination thereof, exclusively, in the form of some combination of the following:

(*a*) Hydrocarbons;
(*b*) Aliphatic ethers;
(*c*) Aliphatic alcohols other than methanol;
(*d*) (i) Up to 0.3 volume % methanol;
 (ii) Up to 2.75 volume % methanol with an equal volume of butanol, or higher molecular weight alcohol;

(2) The fuel must contain no more than 2.0 mass % oxygen except fuels containing aliphatic ethers and/or alcohols (excluding methanol) must contain no more than 2.7 mass % oxygen.

(3) The fuel must possess, at the time of manufacture, all of the physical and chemical characteristics of an unleaded gasoline as specified by Specification D 4814 – 88 for at least one of the Seasonal and Geographical Volatility Classes specified in the standard.

NOTE X3.1—Opinion varies as to whether the EPA "substantially similar" rule requires unleaded gasolines that do not contain oxygenates to meet ASTM specifications.

X3.3.2 *Waivers:*

X3.3.2.1 EPA has issued waivers for blends of gasoline and ethanol (gasohol), gasoline and ethanol with cosolvents, and gasoline and methanol with cosolvents that are less limiting than the "substantially similar" rule. For the latest listing of waviers, EPA should be contacted.

X3.3.2.2 Gasoline-ethanol blends are not required by EPA to meet Specification D 4814 volatility limits (see X3.1.4 for vapor pressure limits). EPA has specified in all other waivers that the volatility of the finished gasoline-oxygenate blend must comply with Specification D 439 or D 4814 climatic and geographical limits.

ANNEX B (informative)

MAJOR AUTOMOTIVE DIESEL FUEL SPECIFICATIONS

B.1 CEC LEGISLATIVE FUEL RF-03-A-84

Type-Diesel Fuel[1]

Applications-Emissions Test (ECE 24, ECE 15)
-Fuel Consumption Test (ECE 15)
-Power Measurement Test (ECE 15)

Property	Limiting values	Test method
Cetane number	49 to 54	ISO 5165
Density at 15 °C, kg/m^3	835 to 845	ISO 3675 or ISO 12185
Distillation		ISO 3405
50 %(V/V) rec. at, °C min.	245	
90 %(V/V) rec. at, °C	320 to 340	
FBP, °C max.	370	
Flash point, PMcc, °C min.	56	ISO 2719
CFPP, °C max.	-5	EN 116
Viscosity at 40 °C, mm^2/s	2,50 to 3,50	ISO 3104
Sulfur, %(m/m) max.	0,30[2]	ISO 8754
Copper corrosion (3 h at 50 °C), Class	1	ISO 2160
Carbon residue (10 %b), %(m/m) max.	0,20	ISO 6615
Ash, %(m/m) max.	0,01	ISO 6245
Water, %(m/m) max.	0,05	ASTM D1744
Acid number max.	0,20	ISO 6618
Oxidation stability, g/m^3 max.	25	ISO 12205

Notes:

1. The fuel shall consist of straight-run and cracked hydrocarbon distillates only, with desulfurisation as necessary. It shall not contain metallic additives or ignition improvers.

2. The sulfur content will be reduced to 0,20 %(m/m) maximum on 01-01-93, and to 0,05 %(m/m) maximum on 01-10-95.

B.2 BS EN 590

As for BS EN 228 (see A.2), this is the English language implementation of European Standard EN 590. It is implemented in 18 countries of the EC and EFTA.

BRITISH STANDARD

BS EN 590 : 1993

Specification for

Automotive diesel fuel

The European Standard EN 590 : 1993 has the status of a British Standard

Carburants pour automobiles — Combustibles pour moteurs diesel (gazole) — Exigences et méthode d'essai

Kraftstoffe für Kraftfahrzeuge — Dieselkraftstoff — Mindestanforderungen und Prüfverfahren

UDC [illegible].7 : 662.753 : [illegible].1

[illegible]

STANDARDS

Cooperating organizations

The European Committee for Standardization (CEN), under whose supervision this European Standard was prepared, comprises the national standards organizations of the following countries:

Austria	Oesterreichisches Normungsinstitut
Belgium	Institut belge de normalisation
Denmark	Dansk Standardiseringsraad
Finland	Suomen Standardisoimisliito, r.y.
France	Association française de normalisation
Germany	Deutsches Institut für Normung e.V.
Greece	Hellenic Organization for Standardization
Iceland	Technological Institute of Iceland
Ireland	National Standards Authority of Ireland
Italy	Ente Nazionale Italiano di Unificazione
Luxembourg	Inspection du Travail et des Mines
Netherlands	Nederlands Normalisatie-instituut
Norway	Norges Standardiseringsforbund
Portugal	Instituto Português da Qualidade
Spain	Asociación Española de Normalización y Certificación
Sweden	Standardiseringskommissionen i Sverige
Switzerland	Association suisse de normalisation
United Kingdom	British Standards Institution

This British Standard, having been prepared under the direction of the Petroleum Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 October 1993

The following BSI references relate to the work on this standard:
Committee reference PTC/11
Draft for comment 91/57146 DC

ISBN 0 580 22314 0

Amendments issued since publication

Amd. No.	Date	Text affected

Contents

National foreword

This British Standard has been prepared under the direction of the Petroleum Standards Policy Committee and is the English language version of EN 590 : 1993 *Automotive fuels — Diesel — Requirements and methods of test*, published by the European Committee for Standardization (CEN). EN 590 : 1993 was produced as a result of international discussions in which the United Kingdom participated.

BS EN 590 supersedes BS 2869 : Part 1 : 1988, which is withdrawn.

EN 590 requires that each country implementing it establish national annexes detailing requirements for pump marking and summer and winter grades. Also, if the methods for sampling given in ISO 3170 and ISO 3171 are not to be used, a national annex has to detail national requirements. National annex NA of BS EN 590 gives additional requirements on sampling, in particular for sampling from the pump; national annex NB gives details of requirements for pump marking; and national annex NC gives details of requirements for summer and winter grades.

The principal differences between this British Standard and BS 2869 : Part 1 : 1988 are as follows:

- maximum carbon residue increased from 0.2 % (*m/m*) to 0.3 % (*m/m*);
- maximum water content reduced from 0.05 % (*V/V*) to 200 mg/kg;
- introduction of quantitative requirements for particulate matter;
- viscosity range reduced to 2.00 mm^2/s to 4.50 mm^2/s;
- minimum cetane number increased from 48 to 49;
- change of density range to 820 kg/m^3 to 860 kg/m^3;
- no limit for temperature for recovery to 50 % (*V/V*) of the distillate;
- no requirement for sediment but in its place a requirement for the quantitative determination of particulate matter has been introduced;
- the maximum cold filter plugging point for summer grade reduced from - 4 °C to - 5 °C.

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 590

March 1993

UDC 665.7 : 662.753 : 620.1

Descriptors: Motor vehicles, automotive fuels, liquefied petroleum, requirements, tests

English version

Automotive fuels — Diesel — Requirements and methods of test

Carburants pour automobiles — Combustibles pour moteurs diesel (gasoil) — Exigences et méthode d'essai

Kraftstoffe für Kraftfahrzeuge — Dieselkraftstoff — Mindestanforderungen und Prüfverfahren

This European Standard was approved by CEN on 1993-03-16. CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. EN 590 : 1993 E

Foreword

This European Standard was drawn up by CEN/TC 19, Test methods and specifications for petroleum products.

The standard was approved and, in accordance with the CEN/CENELEC International Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 1993, and conflicting national standards shall be withdrawn at the latest by September 1993.

This European Standard has been prepared under a mandate given to CEN by the Commission of the European Communities and the European Free Trade Association.

Annex A forms an informative part of this European Standard.

1 Scope

This European Standard specifies requirements and test methods for automotive diesel fuel as marketed and as delivered in the countries of the members of CEN. It is applicable to automotive diesel fuel for use in diesel engine vehicles designed to run on automotive diesel fuel.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

The references given below reflect the state of affairs at the date of issue of this European Standard. Further information on developments regarding the standards referred to is given in annex A.

EN 116[1]	*Diesel and domestic heating fuels — Determination of cold filter plugging point*
EN 24260[2]	*Petroleum products and hydrocarbons — Determination of sulfur content — Wickbold combustion method*
EN 26245[1]	*Petroleum products — Determination of ash*
ISO 2160 : 1985	*Petroleum products — Corrosiveness to copper — Copper strip test*
ISO 2719 : 1988	*Petroleum products and lubricants — Determination of flash point — Pensky-Martens closed cup method*
ISO 3015 : 1992	*Petroleum products — Determination of cloud point*
ISO 3104 : 1976	*Petroleum products — Transparent and opaque liquids — Determination of kinematic viscosity and calculation of dynamic viscosity*
ISO 3170 : 1988	*Petroleum liquids — Manual sampling*
ISO 3171 : 1988	*Petroleum liquids — Automatic pipeline sampling*
ISO 3405 : 1988	*Petroleum products — Determination of distillation characteristics*
ISO 3675 : 1976	*Crude petroleum and liquid petroleum products — Laboratory determination of density or relative density — Hydrometer method*
ISO 4259 : 1979	*Petroleum products — Determination and application of precision data in relation to methods of test*
ISO 4264[1]	*Petroleum products — Distillate fuels — Calculation of cetane index*
ISO 5165[3] : 1992	*Diesel fuels — Determination of ignition quality — Cetane method*
ISO 8754 : 1992	*Petroleum products — Determination of sulfur content — Non-dispersive X-ray fluorescence method*
ISO 10370[1]	*Petroleum products — Determination of carbon residue (micro method)*
ASTM D 1744 : 1983	*Test method for water in liquid petroleum products by Karl Fischer reagent*
ASTM D 2274 : 1988	*Test method for oxidation stability of distillate fuel oil (Accelerated method)*
ASTM D 4046 : 1987	*Test method for alkyl nitrate in diesel fuels by spectrophotometry*
ASTM D 4052[4] : 1991	*Test method for density and relative density of liquids by digital density meter*
DIN 51 419 : 1983	*Determination of total contamination in highly fluid petroleum products*

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[1] To be published.

[2] To be published (CEN implementation of ISO 4260 : 1087, to replace EN 41 : 1975, *Determination of the sulfur content of petroleum products by the Wickbold combustion method*.

[3] See also 5.5.2.

[4] ASTM D 4052-91 is a joint ASTM/IP method and carries also the designation IP 365 : 1984 (1986).

3 Sampling

Samples shall be taken as described in ISO 3170 or ISO 3171 and/or in accordance with the requirements of national standards or regulations for the sampling of automotive diesel fuel. The national requirements shall be set out in detail or shall be referred to by reference in a national annex to this European Standard.

In view of the sensitivity of some of the test methods referred to in this European Standard, particular attention shall be paid to compliance with any guidance on sampling containers which is included in the test method standard.

4 Pump marking

Information to be marked on dispensing pumps used for delivering automotive diesel fuel, and the dimensions of the mark shall be in accordance with the requirements of national standards or regulations for the marking of pumps for automotive diesel fuel. Such requirements shall be set out in detail or shall be referred to by reference in a national annex to this European Standard.

5 Requirements and test methods

5.1 Dyes and markers

The use of dyes or markers is allowed.

5.2 Additives

In order to improve the performance quality, the use of additives is allowed.

5.3 Generally applicable requirements and related test methods

5.3.1 Generally applicable requirements are given in table 1. When tested by the methods given in table 1, automotive diesel fuel shall comply with the limiting requirements specified in that table.

5.3.2 The limiting value for the carbon residue given in table 1 is based on product prior to addition of ignition improver, if used. If a value exceeding the limit is obtained on finished fuel in the market, ASTM D 4046 shall be used as an indicator of the presence of a nitrate-containing compound. If an ignition improver is thus proved present, the limit value for the carbon residue of the product under test cannot be applied. The use of additives does not exempt the manufacturer from meeting the requirement of max. 0,30 % *m/m* of carbon residue prior to addition of additives.

5.3.3 The limit for the water content shall be 200 mg/kg max. (see table 1) with the following exception: a limit value of 500 mg/kg max. may be specified until 31 December 1995 by those countries where regulations and/or codes of practice result in inherently wet distribution systems.

5.4 Climatically dependent requirements and related test methods

5.4.1 For climatically dependent requirements options are given to allow for seasonal grades to be set nationally. The options are for temperature climates six CFPP (cold filter plugging point) grades and for arctic climates five different classes.

Climatically dependent requirements are given in table 2. Table 2 is divided into two sections, one for temperate climates (table 2a) and one for arctic climates (table 2b).

When tested in accordance with the methods of test indicated in tables 2a and 2b, automotive diesel fuel shall be in accordance with the requirements specified in these tables.

5.4.2 In a national annex to this European Standard each country shall detail requirements for a summer and winter grade and may include (any) intermediate and/or regional grade(s) which shall be justified by national meteorological data.

5.4.3 In a national annex to this European Standard each country shall detail date ranges for summer, winter and, where appropriate, intermediate grades.

5.4.4 Arctic classes (see table 2b) may exhibit poor lubricity characteristics and corrective measures may have to be taken.

5.5 Precision and dispute

5.5.1 All the test methods referred to in this European Standard include a precision statement. In cases of dispute, the procedures described in ISO 4259 for resolving the dispute, and interpretation of the results based on test method precision shall be used.

5.5.2 The test methods referred to in this European Standard are, with one exception, those to be used in cases of dispute. For the determination of the cetane number alternative methods may also be used in cases of dispute provided that these methods originate from a recognized method series, and have a valid precision statement, derived in accordance with ISO 4259, which demonstrates precision at least equal to that of the referenced method. The test result, when using an alternative method, shall also have a demonstrable relationship to the result obtained when using the referenced method.

Table 1. Generally applicable requirements and test methods

Property	Units	Limits Min.	Limits Max.	Test method
Flash point	°C	above 55		ISO 2719
Carbon residue (on 10 % distillation residue)	% m/m		0,30[1]	ISO 10370
Ash content	% m/m		0,01	EN 26245
Water content	mg/kg		200[2]	ASTM D 1744
Particulate matter	mg/kg		24	DIN 51 419
Copper strip corrosion (3 h at 50 °C)	rating	class 1		ISO 2160
Oxidation stability	g/m³		25	ASTM D 2274
Sulfur content	% m/m		0,20[3]	EN 24260/ISO 8754

[1] See also 5.3.2.

[2] See also 5.3.3.

[3] NOTE. Directive 87/219/EEC, article 2.1 sets a maximum of 0,30.

Table 2. Climatically related requirements and test methods

Table 2a. Temperate climates

Property	Units	Limits		Test method
		Min.	Max.	
CFPP	°C		+ 5	EN 116
CFPP grade A			0	
CFPP grade B			− 5	
CFPP grade C			− 10	
CFPP grade D			− 15	
CFPP grade E			− 20	
CFPP grade F				
Density at 15 °C	kg/m³	820	860	ASTM D 4052
Viscosity at 40 °C	mm²/s	2,00	4,50	ISO 3104
Cetane number		49		ISO 5165
Cetane index		46		ISO 4264
Distillation[1,2]	% *V/V*		< 65	ISO 3405
% *V/V* recovered at 250 °C	% *V/V*	85		
% *V/V* recovered at 350 °C	% *V/V*	95		
% *V/V* recovered at 370 °C				

Table 2b. Arctic climates

Property	Units	Limits					Test method
		class 0	class 1	class 2	class 3	class 4	
CFPP	° C max.	− 20	− 26	− 32	− 38	− 44	EN 116
Cloud point	° C max.	− 10	− 16	− 22	− 28	− 34	ISO 3015
Density at 15 °C	kg/m³min.	800	800	800	800	800	ISO 3675
	kg/m³ max.	845	845	840	840	840	ASTM D 4052
Viscosity at 40 °C	mm²/s min.	1,50	1,50	1,50	1,40	1,20	ISO 3104
	mm²/s max.	4,00	4,00	4,00	4,00	4,00	
Cetane number	min.	47	47	46	45	45	ISO 5165
Cetane index	min.	46	46	46	43	43	ISO 4264
Distillation[1,2]							
% *V/V* recovered at 180 °C	% *V/V* max.	10	10	10	10	10	ISO 3405
% *V/V* recovered at 340 °C	% *V/V* min.	95	95	95	95	95	

[1] The limits for distillation at 250 °C and 350 °C are included for temperate climate diesel fuel in line with EEC Common Customs Tariff. EEC Common Customs Tariff definition of gas oil does not apply to the grades defined for use in arctic climates.

[2] It should be noted that for the calculation of the cetane index the 10 % *V/V* and 50 % *V/V* recovery points are also needed.

Annex A (informative)

Information on referenced standards

This annex gives information on developments regarding the standards referred to in this European Standard.

EN 116 :

Alternative methods to define vehicle low temperature operability are under investigation. If one of these is shown to predict performance to a better precision than the CFPP, this method, together with the appropriate limits will replace EN 116 in this European Standard.

EN 26245 :

It is intended to implement ISO 6245 as EN without alternation (thus becoming EN 26245). ISO 6245 is presently under revision; the CEN implementation procedure will be launched upon publication of the new edition of ISO 6245. Pending publication of the revised ISO 6245, EN 7 may be used.

EN 7 will be withdrawn upon publication of EN 26245.

ISO 4264 :

ISO 4264 is still in preparation, at present at the stage of Draft International Standard. Pending publication of ISO 4264, ASTM D 4737 IP 380, on which ISO 4264 is based may be used.

ISO 10370 :

ISO 10370 is still in preparation, at present at the stage of Draft International Standard. Pending publication of ISO 10370, ASTM D 4530, on which ISO 10370 is based may be used.

ASTM D 2274 :

Alternative techniques are being evaluted. A method based on ASTM D 2274 IP 388 has been submitted to ISO as a new work item. The ISO reference will be inserted as soon as it is available.

DIN 51 419 :

An alternative to DIN 51 419, IP PM-BH, with possibly different limits, will be considered for adoption.

National annex NA (normative)

Sampling requirements

NA.1 Introduction

This national annex gives the sampling requirements to comply with clause 3.

NA.2 Sampling

NA.2.1 *Sampling from storage tanks*

For the purposes of the British Standard, all sampling shall be carried out in accordance with the relevant sections of BS 3195 : Part 1 : 1989 and additionally as detailed in 2.3

NOTE. The method described in 2.3 is designed for sampling the bulk of the fuel being fed to the offtake point. The examination of equipment (e.g. pumps) to detect faulty operation may require the use of different techniques.

NA.2.2 *Sampling from pipelines*

For the purposes of this British Standard all sampling shall be carried out in accordance with the relevant procedures of either BS 3195 : Part 1 : 1989, or BS 3195 : Part 2 : 1989 and, additionally, as detailed in 2.3 (see note to NA.2.1). BS 3195 : Part 2 : 1989 shall be used in combination with a variable volume receiver which maintains the integrity of the sample.

NA.2.3 *Sampling from fuel lines*

NA.2.3.1 *Sampling cans*

Sampling cans shall be of 5 l capacity.

NOTE. Attention is drawn to the fact that sampling cans will need to comply with the statutory safety requirements for the classification, packaging and labelling of dangerous substances

NA.2.3.2 *Preparation of cans*

A stock of cans shall be kept solely for the purpose of taking fuel samples. Before use, all cans shall be checked to ensure that they are sound and free from leaks. A fuel-resistant sealing washer in good condition shall be in position in the cap.

NA.2.3.3 *Procedure*

From the offtake point, 5 l of the fuel to be tested shall be carefully drawn into a 5 l can using a clean dry funnel. The screw cap shall be fully tightened and the can checked to ensure that there are no leaks.

If more than 5 l are needed, the operation shall be repeated immediately and before the pump has been used for any other purpose.

NA.2.3.4 *Labelling and transport*

Full and legible information relating to the source of the sample shall be attached to the can in such a manner that it will not easily become detached subsequently.

NOTE 1. If required, the sample may be sealed and labelled to maintain its legal integrity

NOTE 2. If the sample has to be sent to the laboratory by public transport it will be necessary to comply with the general regulations covering transportation of flammable materials, where appropriate, and with the requirements of the transport authority concerned. Information on the appropriate procedures and type of packaging required should be obtained from the transport authority involved

National annex NB (normative)

Pump marking requirements

NB.1 Introduction

This national annex gives the pump marking requirements to comply with clause 4.

NB.2 Requirements

For the purposes of this British Standard the following information shall be marked on each dispensing pump or container used for delivering diesel fuel complying with this British Standard into the consuming vehicle:

a) the name or mark of the supplier or vendor of the diesel fuel.

b) the designation displayed as shown in figure NB.1. The minimum dimensions of this mark shall be as shown in figure 1 (see note 1) and the colour used for the design and lettering shall be in clear contrast to the background colour (see note 2).

NOTE 1. The minimum dimensions of the mark given in figure NB.1 have been selected to enable its application to pumps of the smallest anticipated dimensions. It is strongly recommended that, in the interests of visibility to the motorist, the larger recommended dimensions be used wherever possible.

NOTE 2. It is recommended that the prominent colour should be black

The mark shall be in a prominent position.

National annex NC (normative)

Climatically dependent requirements

NC.1 Introduction

This annex gives the climatically dependent requirements to comply with 5.4.

NC.2 Requirement

For the purposes of this British Standard the following shall apply at the retail pump.

Summer (16 March to 21 October inclusive): CFPP grade C.

Winter (22 October to 15 March inclusive): CFPP grade E.

NOTE. The date for the change from summer grade to winter grade will be reviewed in the light of experience

	Recommended	Minimum
a	25	15
b	15	12
c	100	60

Dimensions in millimetres

Figure NB.1 Form of mark for automotive diesel

National annex ND (informative)

Committees responsible

The United Kingdom participation in the preparation of this European Standard was entrusted by the Petroleum Standards Policy Committee (PTC/-) to Technical Committee PTC/11, upon which the following bodies were represented:

Association of United Kingdom Oil Independents
Automobile Association
Bus and Coach Council
Chemical Industries Association
Consumer Policy Committee of BSI
Department of Energy
Department of Transport
Federation of Petroleum Suppliers
Freight Transport Association
Institute of Petroleum
Institute of Trading Standards Administration
Ministry of Defence
Motor Cycle Industry's Association of Great Britain
Petrol Pump Manufacturers' Association
Petrol Retailers' Association
Road Haulage Association
Royal Automobile Club
Society of Motor Manufacturers and Traders
United Kingdom Petroleum Industry Association
World Wide Fund for Nature

National annex NE (informative)

Cross-references

Publication referred to	Corresponding British Standard
EN 116 : 1981	BS 6188 : 1982 *Method for determination of cold filter plugging point of diesel and domestic heating fuels*
ISO 2160 : 1985	BS 2000 *Methods of test for petroleum and its products*
	Part 154 : 1993 *Petroleum products. Corrosiveness to copper. Copper strip test*
ISO 2719 : 1988	BS 6664 *Flashpoint of petroleum and related products*
	Part 5 : 1990 *Method for determination of flashpoint by Pensky-Martens closed tester*
ISO 3015 : 1992	BS 2000 *Methods of test for petroleum and its products*
	Part 219 : 1993 *Petroleum products. Determination of cloud point*
	BS 3195 *Methods for sampling petroleum products*
ISO 3170 : 1988	Part 1 : 1989 *Manual sampling of liquid hydrocarbons*
ISO 3171 : 1988	Part 2 : 1989 *Automatic pipeline sampling of liquid hydrocarbons*
ISO 3405 : 1988	BS 7392 : 1990 *Method for determination of distillation characteristics of petroleum products*
ISO 3675 : 1976	BS 4714 : 1980 *Method for laboratory determination of density or relative density of crude petroleum and liquid petroleum products (hydrometer method)*
ISO 4259 : 1979	BS 4306 : 1981 *Method for determination and application of precision data in relation to methods of test for petroleum products*

B.3 ASTM D975

Designation: D 975 – 92a

An American National Standard

Standard Specification for Diesel Fuel Oils[1]

This standard is issued under the fixed designation D 975; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers five grades of diesel fuel oils suitable for various types of diesel engines. These grades are described as follows:

1.1.1 *Grade Low Sulfur No. 1-D*—A special purpose, light distillate fuel for automotive diesel engines requiring low sulfur fuel and requiring higher volatility than that provided by Grade Low Sulfur No. 2-D.[2]

1.1.2 *Grade Low Sulfur No. 2-D*—A general-purpose, middle distillate fuel for automotive diesel engines requiring low sulfur fuel. It is also suitable for use in non-automotive applications, especially in conditions of varying speed and load.[2]

1.1.3 *Grade No. 1-D*—A special-purpose, light distillate fuel for automotive diesel engines in applications requiring higher volatility than that provided by Grade No. 2-D fuels.

1.1.4 *Grade No. 2-D*—A general-purpose, middle distillate fuel for automotive diesel engines, which is also suitable for use in non-automotive applications, especially in conditions of frequently varying speed and load.

1.1.5 *Grade No. 4-D*—A heavy distillate fuel, or a blend of distillate and residual oil, for low- and medium-speed diesel engines in non-automotive applications involving predominantly constant speed and load.

NOTE 1—A more detailed description of the grades of diesel fuel oils is given in Appendix X1.2.

1.2 This specification, unless otherwise provided by agreement between the purchaser and the supplier, prescribes the required properties of diesel fuels at the time and place of delivery.

1.2.1 Nothing in this specification shall preclude observance of federal, state, or local regulations which may be more restrictive.

NOTE 2—The generation and dissipation of static electricity can create problems in the handling of distillate diesel fuel oils. For more information on the subject, see Guide D 4865.

1.3 Values are stated in SI units and are regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

D 56 Test Method for Flash Point by Tag Closed Tester[3]

D 86 Test Method for Distillation of Petroleum Products[3]

D 93 Test Method for Flash Point by Pensky-Martens Closed Tester[3]

D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)[3]

D 130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test[3]

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)[3]

D 482 Test Method for Ash from Petroleum Products[3]

D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products[3]

D 613 Test Method for Ignition Quality of Diesel Fuels by the Cetane Method[4]

D 976 Test Methods for Calculated Cetane Index of Distillate Fuels[3]

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)[3]

D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Absorption.[3]

D 1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)[3]

D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)[3]

D 1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)[3]

D 2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)[3]

D 2276 Test Method for Particulate Contaminant in Aviation Fuel[3]

D 2500 Test Method for Cloud Point of Petroleum Oils[3]

D 2622 Test Method for Sulfur in Petroleum Products by X-Ray Spectrometry[5]

D 2880 Specification for Gas Turbine Fuel Oils[5]

D 3117 Test Method for Wax Appearance Point of Distillate Fuels[5]

D 3120 Test Method for Trace Quantities of Sulfur in Light Petroleum Hydrocarbons by Oxidative Microcoulometry[5]

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[5]

D 4294 Test Method for Sulfur in Petroleum Products by Non-Dispersive X-Ray Fluorescence Spectrometry[5]

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[1] This specification is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.E on Burner, Diesel, and Gas Turbine Fuels.

Current edition approved Oct. 15, 1992. Published December 1992. Originally published as D 975 – 48 T. Last previous edition D 975 – 92.

[2] This fuel complies with 40 CFR Part 80—Regulation of Fuels and Fuel Additives: Fuel Quality Regulations for Highway Diesel Fuel Sold in 1993 and Later Calendar Years.

[3] *Annual Book of ASTM Standards*, Vol 05.01.

[4] *Annual Book of ASTM Standards*, Vol 05.04.

[5] *Annual Book of ASTM Standards*, Vol 05.02.

TABLE 1 Detailed Requirements for Diesel Fuel Oils[A]

Property	ASTM Test Method[B]	Grade Low Sulfur No. 1-D	Grade Low Sulfur No. 2-D	Grade No. 1-D[C]	Grade No. 2-D[C]	Grade No. 4-D[C]
Flash Point, °C, min.	D 93	38	52 (125)	38	52	55
Water and Sediment, %vol, max	D 1796	0.05	0.05	0.05	0.05	0.50
Distillation Temperature, °C 90 % %vol Recovered	D 86					
min		...	282[D]	...	282[D]	...
max		288 (550)	338	288 (550)	338	...
Kinematic Viscosity, mm²/S at 40°C	D 445					
min.		1.3	1.9	1.3	1.9	5.5
max	...	2.4	4.1	2.4	4.1	24.0
Ash % mass, max	D 482	0.01	0.01	0.01	0.01	0.10
Sulfur, % mass, max[E]	D 2622[F]	0.05	0.05	...	...	...
	D 129	...	...	0.50	0.50	2.00
Copper strip corrosion rating max 3 h at 50°C	D 130	No. 3	No. 3	No. 3	No. 3	...
Cetane number, min[G]	D 613	40[H]	40[H]	40[H]	40[H]	30[H]
One of the following properties must be met						
(1) Cetane index, min.	D 976[G]	40	40	...	...	...
(2) Aromaticity, %vol, max	D 1319[F]	35	35	...	...	...
Cloud point, °C, max	D 2500	[I]	[I]	[I]	[I]	[I]
Ramsbottom carbon residue on 10 % distillation residue, % mass, max	D 524	0.15	0.35	0.15	0.35	...

[A] To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller and manufacturer.

[B] The test methods indicated are the approved referee methods. Other acceptable methods are indicated in 4.1.

[C] Grades No. 1-D, No. 2-D and No. 4-D are required to contain a sufficient amount of 1,4-dialkyl amino anthraquinone (blue dye) so its presence is visually apparent.

[D] When a cloud point less than −12°C is specified, the minimum viscosity at 40°C shall be 1.7 mm²/s and the minimum 90 % recovered temperature shall be waived.

[E] Other sulfur limits can apply in selected areas in the United States and in other countries.

[F] These test methods are specified in CFR 40 Part 80.

[G] Where cetane number by Test Method D 613 is not available, Test Method D 4737 can be used as an approximation.

[H] Low ambient temperatures as well as engine operation at high altitudes may require the use of fuels with higher cetane ratings.

[I] It is unrealistic to specify low temperature properties that will ensure satisfactory operation at all ambient conditions. However, satisfactory operation should be achieved in most cases if the cloud point (or wax appearance point) is specified at 6°C above the tenth percentile minimum ambient temperature for the area in which ambient temperatures for U.S. locations are shown in Appendix X2. This guidance is general. Some equipment designs or operation may allow higher or require lower cloud point fuels. Appropriate low temperature operability properties should be agreed upon between the fuel supplier and purchaser for the intended use and expected ambient temperatures

D 4737 Test Method for Calculated Cetane Index by Four Variable Equation[6]

D 4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems[6]

D 5186 Test Method for Determination of Aromatic Content of Diesel Fuels by Supercritical Fluid Chromatography[6]

2.2 Other Document

40 CFR Part 80 Regulation of Fuels and Fuel Additives

3. Requirements

3.1 The grades of diesel fuel oils herein specified shall be hydrocarbon oils conforming to the detailed requirements shown in Table 1.

4. Test Methods

4.1 The requirements enumerated in this specification shall be determined in accordance with the following methods:

4.1.1 *Flash Point*—Test Methods D 93, except where other methods are prescribed by law. For Grades Low Sulfur No. 1-D, Low Sulfur No. 2-D, No. 1-D, and No. 2-D, Test Method D 56 can be used as an alternate with the same limits, provided the flash point is below 79°C and the viscosity is below 5.5 mm²/s at 40°C. This test method will give slightly lower values. In cases of dispute, Test Methods D 93 shall be used as the referee method.

4.1.2 *Cloud Point*—Test Method D 2500. Test Method D 3117 can also be used since the two are closely related. In case of dispute, Test Method D 2500 shall be the referee method.

4.1.3 *Water and Sediment*—Test Method D 1796.

4.1.4 *Carbon Residue*—Test Method D 524.

4.1.5 *Ash*—Test Method D 482.

4.1.6 *Distillation of Low Sulfur No. 1-D, Low Sulfur No. 2-D, No. 1-D, and No. 2-D Fuel Oils*—Test Method D 86.

4.1.7 *Viscosity*—Test Method D 445.

4.1.8 *Sulfur*—Test Method D 2622 is used for Grades Low Sulfur No. 1-D and Low Sulfur No. 2-D. Test Methods D 1266, D 3120 and D 4294 are also suitable for determining up to 0.05 % sulfur in diesel fuels. Test Method D 129 is used for Grades No. 1-D, No. 2-D and No. 4-D. Test Methods D 1552, D 2622, and D 4294 can also be used for these grades. In addition, Test Method D 1266 can be used for Grade No. 1, but only with samples having sulfur contents of 0.4 mass percent and less (down to 0.01 %). In case of dispute, Test Method D 2622 is the referee sulfur test method for Grades Low Sulfur No. 1-D and Low Sulfur No. 2-D. Test Method D 129 is the referee sulfur test method for Grades No. 1-D, No. 2-D and No. 4-D.

4.1.9 *Corrosion*—Test Method D 130, 3 h test at 50°C.

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[6] *Annual Book of ASTM Standards*, Vol 05.03.

4.1.10 *Cetane Number*—Test Method D 613.

4.1.11 *Cetane Index*—Method D 976 – 80.

4.1.12 *Aromaticity*—Test Method D 1319. This test method provides an indication of the aromatics content of fuels. For fuels with a maximum final boiling point of 315°C this method is a measurement of the aromatic content of the fuel.

5. Keywords

5.1 diesel; fuel oil; petroleum and petroleum products; specification

APPENDIXES

(Nonmandatory Information)

X1. SIGNIFICANCE OF ASTM SPECIFICATION FOR DIESEL FUEL OILS

X1.1 Introduction

X1.1.1 The properties of commercial fuel oils depend on the refining practices employed and the nature of the crude oils from which they are produced. Distillate fuel oils, for example, may be produced within the boiling range of 150 and 400°C having many possible combinations of various properties such as volatility, ignition quality, viscosity, and other characteristics.

X1.2 Grades

X1.2.1 This specification is intended as a statement of permissible limits of significant fuel properties used for specifying the wide variety of commercially available diesel fuel oils. Limiting values of significant properties are prescribed for five grades of diesel fuel oils. These grades and their general applicability for use in diesel engines are broadly indicated as follows:

X1.2.2 *Grade Low Sulfur No. 1-D*—Grade Low Sulfur No. 1-D comprises the class of low sulfur, volatile fuel oils from kerosine to the intermediate distillates. Fuels within this grade are applicable for use in high-speed engines which require low sulfur fuel and in services involving frequent and relatively wide variations in loads and speeds, and also for use in cases where abnormally low fuel temperatures are encountered.

X1.2.3 *Grade Low Sulfur No. 2-D*—Grade Low Sulfur No. 2-D includes the class of low sulfur distillate gas oils of lower volatility than Grade Low Sulfur No. 1-D. These fuels are applicable for use in high-speed engines which require low sulfur fuels and in services involving relatively high loads and uniform speeds, or in engines not requiring fuels having the higher volatility or other properties specified for Grade Low Sulfur No. 1-D.

X1.2.4 *Grade No. 1-D*—Grade No. 1-D comprises the class of volatile fuel oils from kerosine to the intermediate distillates. Fuels within this grade are applicable for use in high-speed engines in services involving frequent and relatively wide variations in loads and speeds, and also for use in cases where abnormally low fuel temperatures are encountered.

X1.2.5 *Grade No. 2-D*—Grade No. 2-D includes the class of distillate gas oils of lower volatility. These fuels are applicable for use in high-speed engines in services involving relatively high loads and uniform speeds, or in engines not requiring fuels having the higher volatility or other properties specified for Grade No. 1-D.

X1.2.6 *Grade No. 4-D*—Grade No. 4-D covers the class of more viscous distillates and blends of these distillates with residual fuel oils. These fuels are applicable for use in low- and medium-speed engines employed in services involving sustained loads at substantially constant speed.

X1.3 Selection of Particular Grade

X1.3.1 The selection of a particular diesel fuel oil from one of these three ASTM grades for use in a given engine requires consideration of the following factors:

X1.3.1.1 Fuel price and availability,

X1.3.1.2 Maintenance considerations,

X1.3.1.3 Engine size and design,

X1.3.1.4 Emission control systems,

X1.3.1.5 Speed and load ranges,

X1.3.1.6 Frequency of speed and load changes, and

X1.3.1.7 Atmospheric conditions. Some of these factors can influence the required fuel properties outlined as follows:

X1.4 Cetane Number

X1.4.1 Cetane number is a measure of the ignition quality of the fuel and influences combustion roughness. The cetane number requirements depend on engine design, size, nature of speed and load variations, and on starting and atmospheric conditions. Increase in cetane number over values actually required does not materially improve engine performance. Accordingly, the cetane number specified should be as low as possible to assure maximum fuel availability.

X1.5 Distillation

X1.5.1 The fuel volatility requirements depend on engine design, size, nature of speed and load variations, and on starting and atmospheric conditions. For engines in services involving rapidly fluctuating loads and speeds as in bus and truck operation, the more volatile fuels may provide best performance, particularly with respect to smoke and odor. However, best fuel economy is generally obtained from the heavier types of fuels because of their higher heat content.

X1.6 Viscosity

X1.6.1 For some engines it is advantageous to specify a minimum viscosity because of power loss due to injection pump and injector leakage. Maximum viscosity, on the other hand, is limited by considerations involved in engine design and size, and the characteristics of the injection system.

X1.7 Carbon Residue

X1.7.1 Carbon residue gives a measure of the carbon depositing tendencies of a fuel oil when heated in a bulb under prescribed conditions. While not directly correlating with engine deposits, this property is considered an approximation.

X1.8 Sulfur

X1.8.1 The effect of sulfur content on engine wear and deposits appears to vary considerably in importance and depends largely on operating conditions. Fuel sulfur can affect emission control systems performance. In order to assure maximum availability of fuels, the permissible sulfur content should be specified as high as is practicable, consistent with maintenance considerations.

X1.9 Flash Point

X1.9.1 The flash point as specified is not directly related to engine performance. It is, however, of importance in connection with legal requirements and safety precautions involved in fuel handling and storage, and is normally specified to meet insurance and fire regulations.

X1.10 Cloud Point

X1.10.1 Cloud point is of importance in that it defines the temperature at which a cloud or haze of wax crystals appears in the oil under prescribed test conditions which generally relates to the temperature at which wax crystals begin to precipitate from the oil in use.

X1.11 Ash

X1.11.1 Ash-forming materials may be present in fuel oil in two forms: (*1*) abrasive solids, and (*2*) soluble metallic soaps. Abrasive solids contribute to injector, fuel pump, piston and ring wear, and also to engine deposits. Soluble metallic soaps have little effect on wear but may contribute to engine deposits.

X1.12 Copper Strip Corrosion

X1.12.1 This test serves as a measure of possible difficulties with copper and brass or bronze parts of the fuel system.

X1.13 Aromaticity

X1.13.1 This test is used as an indication of the aromatic contents of diesel fuel. Aromatic content is specified to prevent an increase in the average aromatics in Grades Low Sulfur No. 1-D and Low Sulfur No. 2-D fuels. Increases in aromatic content of fuels over current levels may have a negative impact on emissions.

X1.14 Cetane Index

X1.14.1 Cetane Index is specified as a limitation on the amount of high aromatic components in Grades Low Sulfur No. 1-D and Low Sulfur No. 2-D.

X2. TENTH PERCENTILE MINIMUM AMBIENT TEMPERATURES FOR THE UNITED STATES (EXCEPT HAWAII)

X2.1 Introduction

X2.1.1 The tenth percentile minimum ambient temperatures shown on the following maps (Figs. X2.1 through X2.12) were derived from an analysis of historical hourly temperature readings recorded over a period of 15 to 21 years from 345 weather stations in the United States. This study was conducted by the U.S. Army Mobility Equipment Research and Development Center (USAMERDC), Coating and Chemical Laboratory, Aberdeen Proving Ground, MD 21005. The tenth percentile minimum ambient temperature is defined as the lowest temperature which will occur 90 % of the time. In other words, there is only a 10 % expectation

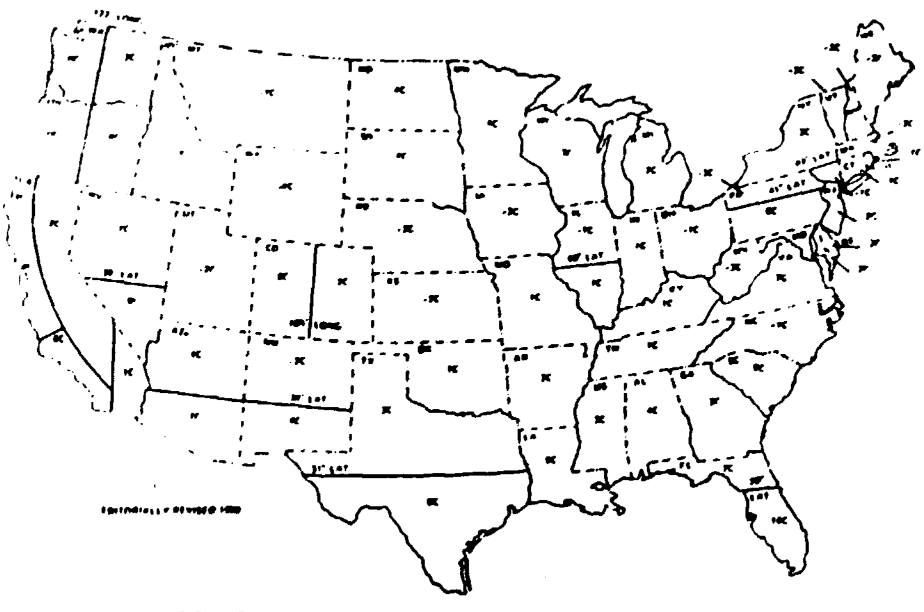


FIG. X2.1 October—10th Percentile Minimum Temperatures

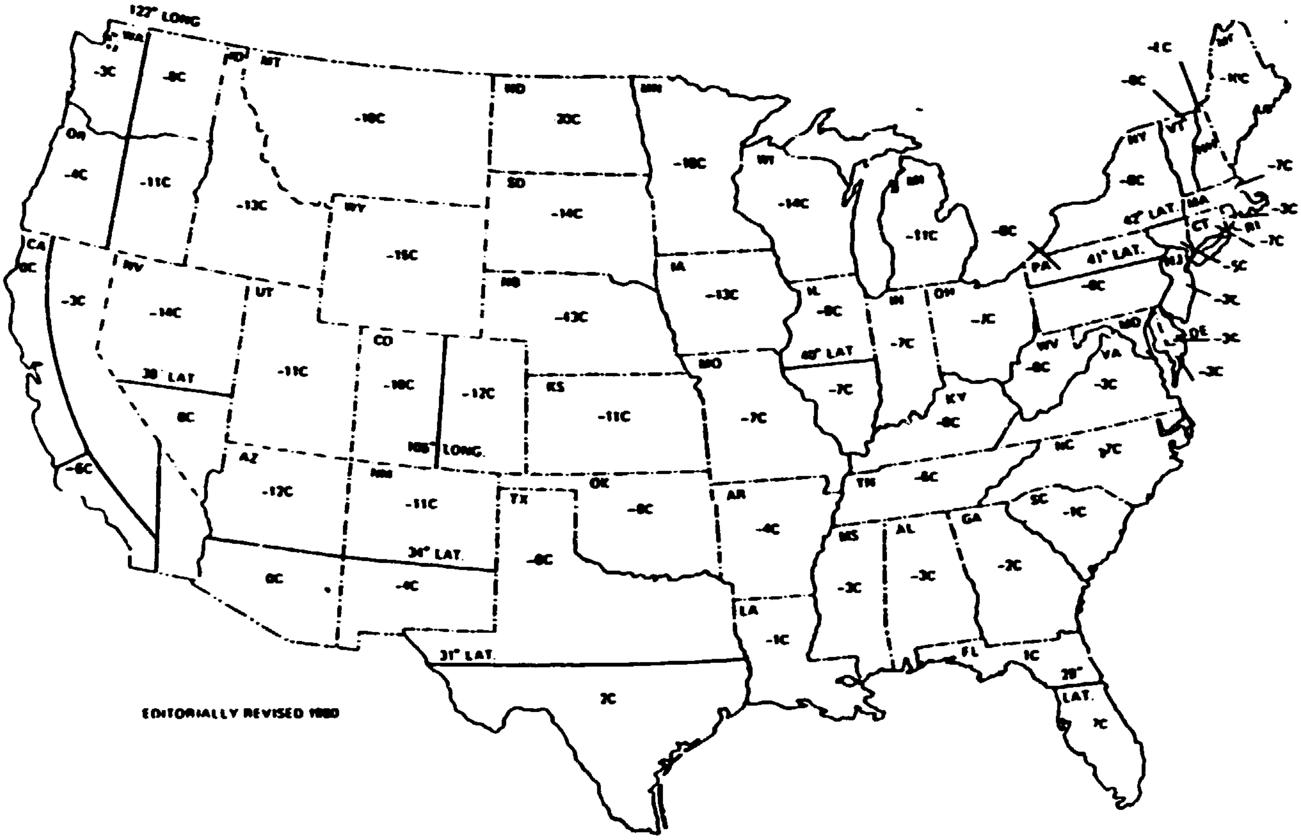


FIG. X2.2 November—10th Percentile Minimum Temperatures

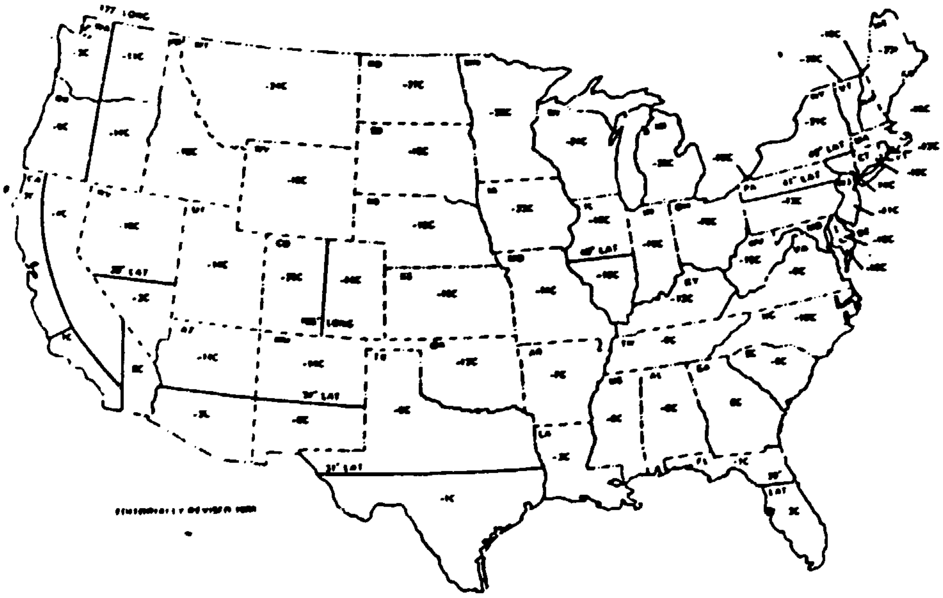


FIG. X2.3 December—10th Percentile Minimum Temperatures

that the minimum daily temperature will be lower than the tenth percentile minimum temperature.

X2.1.2 It is recommended that these data be used to estimate the temperature to be used in specifying low temperature operability requirements. In establishing these low-temperature operability requirements, consideration should be given to fuel system design, normal equipment protection for cold weather operation, type of operation, use

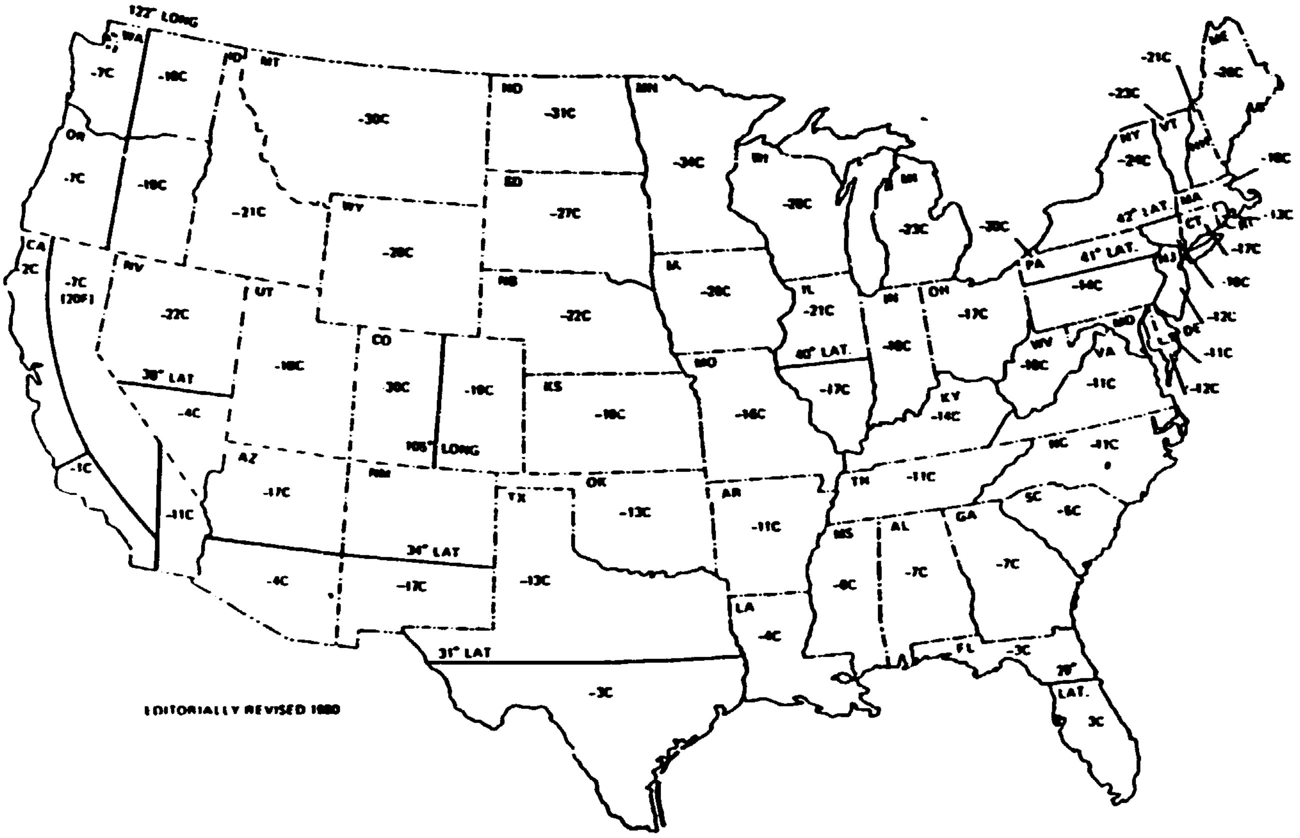


FIG. X2.4 January—10th Percentile Minimum Temperatures

of fluidity improver additives, area in which the fuel will be used and any unusual weather or operating conditions, or a combination thereof, which may make low temperature operability more or less severe than normal.

X2.2 Maps

X2.2.1 The maps in the following figures were derived from CCL Report No. 316, "A Predictive Study for Defining Limiting Temperatures and Their Application in Petroleum Product Specifications," by John P. Doner. This report was

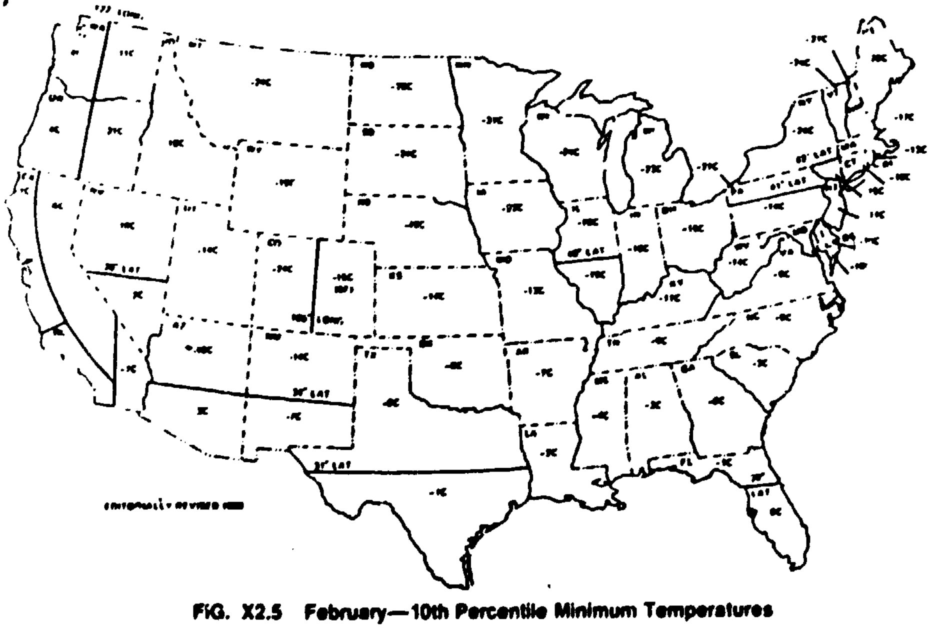


FIG. X2.5 February—10th Percentile Minimum Temperatures

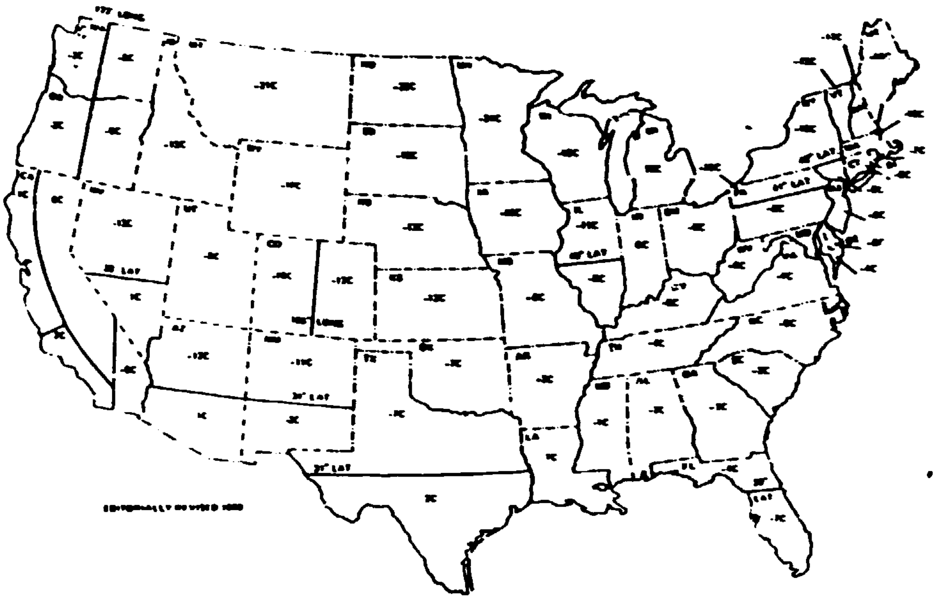


FIG. X2.6 March—10th Percentile Minimum Temperatures

published by the U.S. Army Mobility Equipment Research and Development Center (USAMERDC), Coating and Chemical Laboratory, and it is available from the National Technical Information Service, Springfield, VA 22151, by requesting Publication No. AD756-420.

X2.2.2 Where states are divided the divisions are noted on the maps with the exception of California, which is divided by counties as follows:

California, North Coast—Alameda, Contra Costa, Del Norte, Humbolt, Lake, Marin, Mendocino, Monterey, Napa, San Benito, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Trinity.

California, Interior—Lassen, Modoc, Plumas, Sierra, Siskiyou, Alpine, Amador, Butte, Calaveras, Colusa, El Dorado, Fresno, Glenn, Kern (except that portion lying east of the Los Angeles County Aqueduct), Kings, Madera, Mariposa, Merced, Placer, Sacramento, San Joaquin, Shasta, Stanislaus, Sutter, Tehama, Tulare, Tuolumne, Yolo, Yuba, Nevada.California, South Coast—Orange, San Diego, San Luis Obispo, Santa Barbara, Ventura, Los

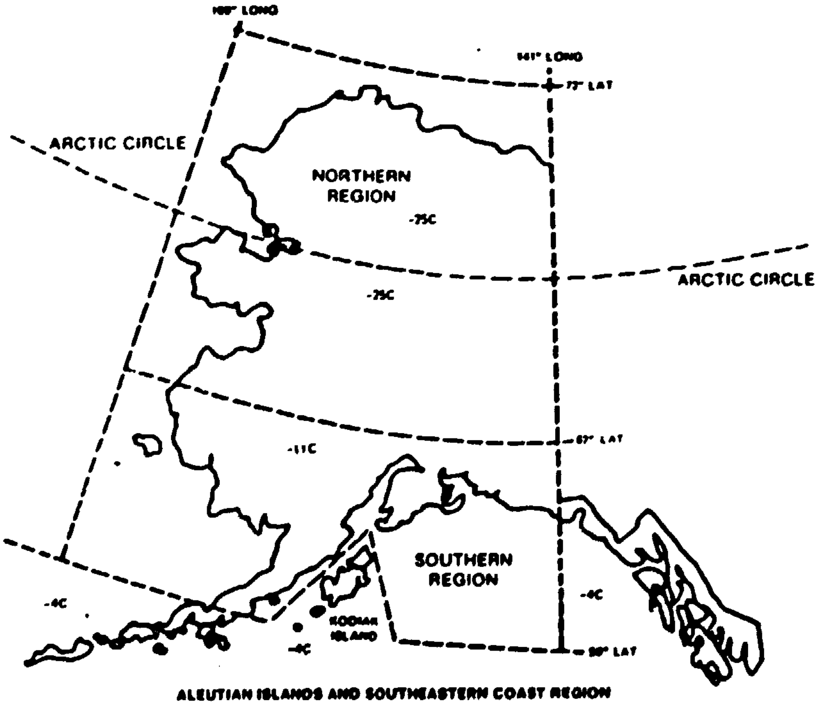


FIG. X2.7 October—10th Percentile Minimum Temperatures

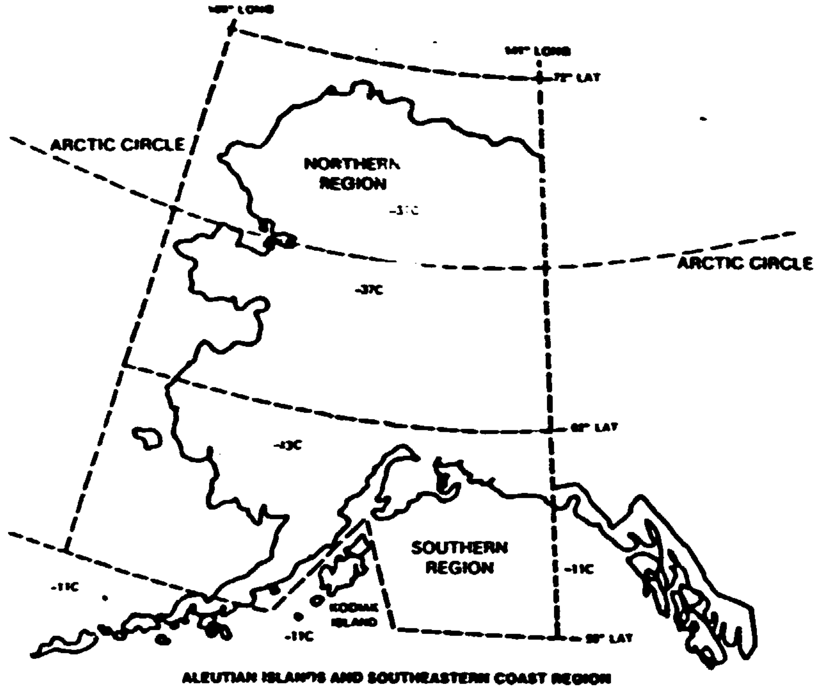


FIG. X2.8 November—10th Percentile Minimum Temperatures

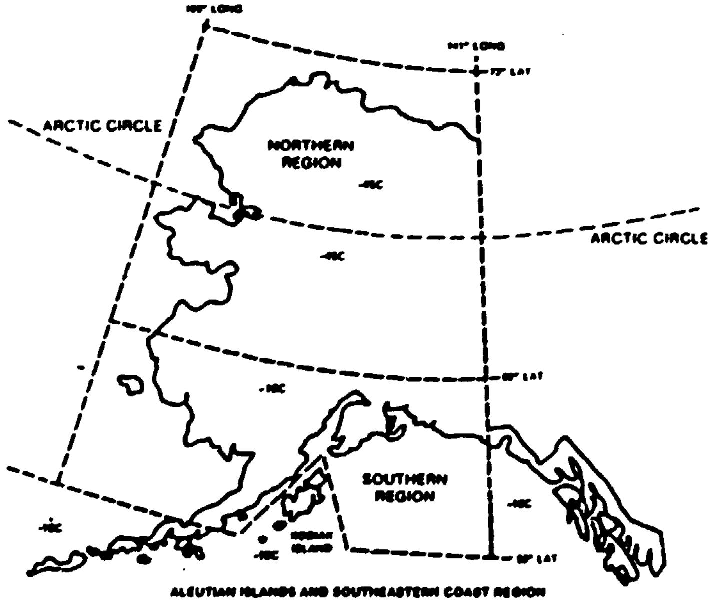


FIG. X2.9 December—10th Percentile Minimum Temperatures

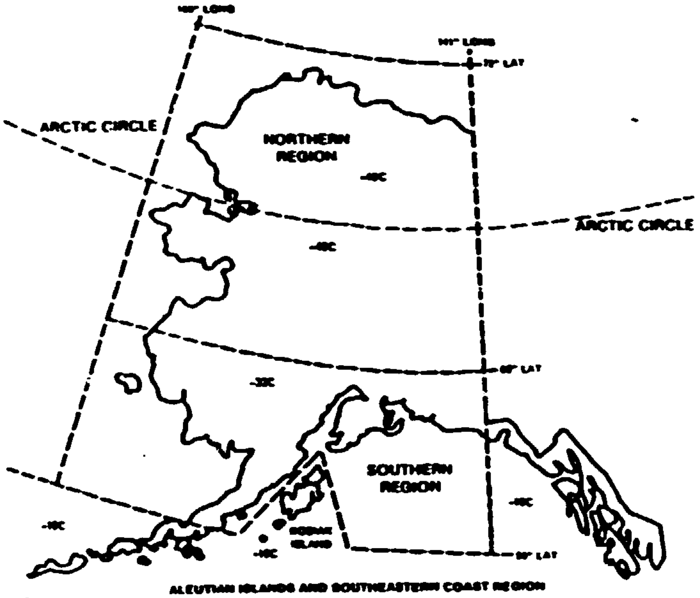


FIG. X2.10 January—10th Percentile Minimum Temperatures

Angeles (except that portion north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct).

California, Southeast—Imperial, Riverside, San Bernardino, Los Angeles (that portion north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct), Mono, Inyo, Kern (that portion lying east of the Los Angeles County Aqueduct).

X2.2.3 The temperatures in CCL Report No. 316 were in degrees Fahrenheit. The degree Celsius temperatures in X2 were obtained by converting the original degree Fahrenheit temperatures.

X3. LONG-TERM STORAGE OF DISTILLATE FUELS

X3.1 Scope

X3.1.1 This appendix provides guidance for consumers of distillate fuels who may wish to store quantities of fuels for extended periods. Fuels containing residual components are excluded. Consistently successful long-term fuel storage requires attention to fuel selection, storage conditions, and monitoring of properties prior to and during storage.

X3.1.2 Normally produced fuels have adequate stability

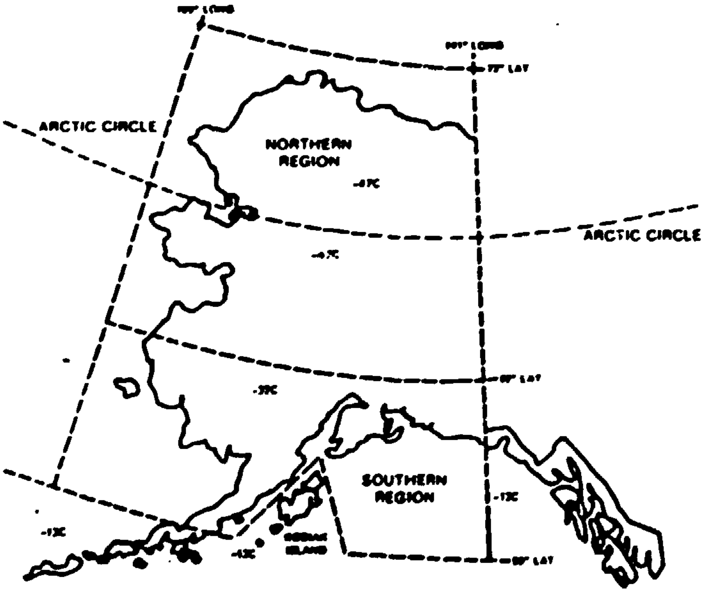


FIG. X2.11 February—10th Percentile Minimum Temperatures

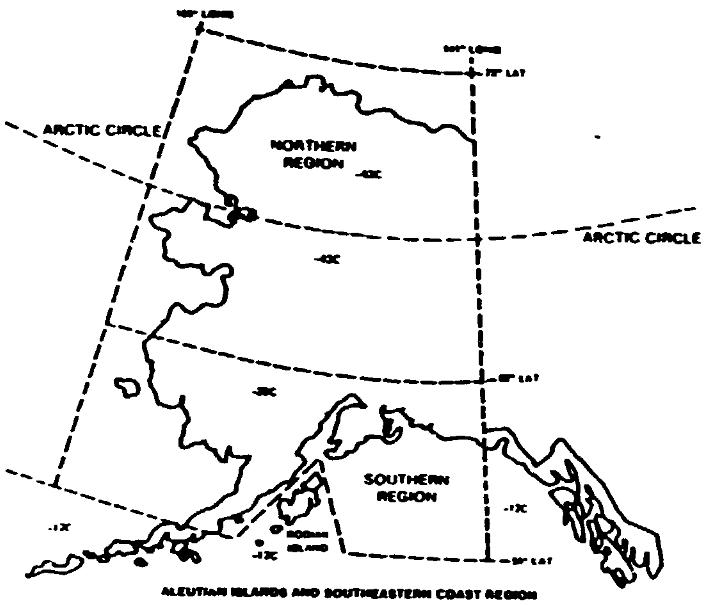


FIG. X2.12 March—10th Percentile Minimum Temperatures

properties to withstand normal storage without the formation of troublesome amounts of insoluble degradation products. Fuels that are to be stored for prolonged periods should be selected to avoid formation of sediments, which can overload filters or plug combustor nozzles or injectors. Selection of these fuels should result from supplier-user discussions.

X3.1.3 These suggested practices are general in nature and should not be considered substitutes for any requirements imposed by the warranty of the distillate fuel equipment manufacturer or by federal, state, or local government regulations. Although they cannot replace a knowledge of local conditions or good engineering and scientific judgment, these suggested practices do provide guidance in developing an individual fuel management system for the distillate fuel user. They include suggestions in the operation and maintenance of existing fuel storage and handling facilities and for identifying where, when, and how fuel quality should be monitored.

X3.2 Definitions

X3.2.1 *long-term storage*—storage of fuel for longer than 12 months after it is received by the user.

X3.2.2 *bulk fuel*—fuel in the storage facility.

X3.2.3 *combustor fuel*—fuel entering the combustion zone of the burner or engine after filtration or other treatment of bulk fuel.

X3.2.4 *fuel contaminants*—foreign materials that make fuel less suitable or unsuitable for the intended use. Fuel contaminants include materials introduced subsequent to the manufacture of fuel and fuel degradation products.

X3.2.5 *fuel-degradation products*—those materials which are formed in fuel during extended storage. Insoluble degradation products may combine with other fuel contaminants to reinforce deleterious effects. Soluble degradation products (soluble gums) are less volatile than fuel and may carbonize to form in fuels due to complex interactions and oxidation of small amounts of olefinic, sulfurous, oxygenated, and nitrogenous compounds present in fuels. The formation of degradation products may be catalyzed by dissolved metals, especially copper salts.

X3.3 Fuel Selection

X3.3.1 Certain distilled refinery products are generally more suitable for long-term storage than others. The stability properties of distillates are highly dependent on the crude oil sources, severity of processing, and whether additional refinery treatment has been carried out.

X3.3.2 The composition and stability properties of distillate fuels produced at specific refineries may be different. Any special requirements of the user, such as long-term storage, should be discussed with the supplier.

X3.3.3 Blends of fuels from various sources may interact to give stability properties worse than expected based on the characteristics of the individual fuels.

X3.4 Fuel Additives

X3.4.1 Available fuel additives can improve the suitability of marginal fuels for long-term storage but may be unsuccessful for fuels with markedly poor stability properties. Most additives should be added at the refinery or during the early weeks of storage to obtain maximum benefits.

X3.4.2 Biocides or biostats destroy or inhibit the growth of fungi and bacteria which can grow at fuel-water interfaces to give high particulate concentrations in the fuel. Available biocides are soluble in both the fuel and water or in the water phase only.

X3.5 Tests for Fuel Quality

X3.5.1 At the time of manufacture, the storage stability of fuel may be estimated by Test Method D 2274. However, correlation of this test with actual storage stability can vary significantly, depending upon field conditions and fuel composition.

X3.5.2 Performance criteria for accelerated stability tests that assure satisfactory long-term storage of fuels have not been established.

X3.6 Fuel Monitoring

X3.6.1 A plan for monitoring the quality of bulk fuel during prolonged storage is an integral part of a successful program. A plan to replace aged fuel with fresh product at established intervals is also desirable.

X3.6.2 Stored fuel should be periodically sampled and its quality assessed. Practice D 4057 provides guidance for sampling. Fuel contaminants and degradation products will usually settle to the bottom of a quiescent tank. A "Bottom" or "Clearance" sample, as defined in Practice D 4057, should be included in the evaluation along with an "All Level" sample.

X3.6.3 The quantity of insoluble fuel contaminants present in fuel can be determined using Test Method D 2276, Procedure A.

X3.6.4 Other quality tests like fuel color (Test Method D 1500) and stability tests (Test Method D 2274) after storage may have value. Correlations of these tests with fuel suitability are tenuous.

X3.7 Fuel Storage Conditions

X3.7.1 Contamination levels in fuel can be reduced by storage in tanks kept free of water, and tankage should have provisions for water draining on a scheduled basis. Water promotes corrosion, and microbiological growth may occur at a fuel-water interface. Underground storage is preferred to avoid temperature extremes; above-ground storage tanks should be sheltered or painted with reflective paint. High storage temperatures accelerate fuel degradation. Fixed roof tanks should be kept full to limit oxygen supply and tank breathing.

X3.7.2 Copper and copper-containing alloys should be avoided. Copper can promote fuel degradation and may produce mercaptide gels. Zinc coatings can react with water or organic acids in the fuel to form gels which rapidly plug filters.

X3.7.3 Appendix X3 of Specification D 2880 discusses fuel contaminants as a general topic.

X3.8 Use of Degraded Fuels

X3.8.1 Fuels that have undergone mild-to-moderate degradation can often be consumed in a normal way, depending on the fuel system requirements. Filters and other cleanup equipment can require special attention and increased maintenance. Burner nozzle or injector fouling can occur more rapidly.

X3.8.2 Fuels containing very large quantities of fuel degradation products and other contaminants or with runaway microbiological growth require special attention. Consultation with experts in this area is desirable. It can be possible to drain the sediment or draw off most of the fuel above the sediment layer and use it with the precautions described in X3.8.1. However, very high soluble gum levels or corrosion products from microbiological contamination can cause severe operational problems.

ANNEX G (normative)

The Relationship of Fuels Quality with Pollutant Emissions from Motor Vehicles

G.1 GENERAL.

The objective of this annex is to give a background on the impact of fuel properties on pollutant emissions from motor vehicles equipped with both spark-ignition (SI) and compression-ignition (CI) engines. This annex provides supplemental information for the explanation and justification of views presented, and recommendations given, in the Guidelines.

Many fuel properties are closely inter-related and interdependent, and their impact on emissions in respect of both direction and magnitude depends on vehicle design features and operating variables. There are differences in sensitivity to fuel quality between uncontrolled, reduced-emission and low-emission engines, and this makes assessment of the effect of fuel characteristics and, in particular, its quantification, very difficult. Fuel characteristics can affect pollutant emissions;

i) **directly**, by influencing the working processes in the engine, e.g. the mixture formation and combustion in the case of exhaust emissions, or

ii) **indirectly**, by influencing, e.g. engine cleanliness and wear, which in turn will have an impact on emissions.

This overview is concentrated on so-called regulated (or controlled) pollutants, which are:

- CO, total HC and NO_x for SI engined vehicles, and
- CO, total HC, NO_x, PM and smoke for CI engined vehicles.

However, fuel properties, in particular composition, impact also emissions of many unregulated pollutants, e.g. benzene, aldehydes, polyaromatic hydrocarbons (PAH), as well as smog-forming or photochemically reactive emission products which considerably affect air quality, and are of growing concern. The impact of fuel quality on unregulated emissions is often higher than on those regulated.

To achieve the best compromise between many, sometimes contradictory, requirements to be met by vehicles, the engine design and the setting of production engines, are finalised using a fuel quality apporiate to the market. In order to make it possible for in-use vehicles to maintain their performance, including emissions, close to design, fuels in the market should be manufactured to tolerances which allow little variation in fuel quality. However, in practice, the situation where fuel characteristics do not match vehicle requirements is common, e.g. imported technologies not sufficiently adapted to local conditions, or imported, both new and second-hand vehicles, designed for fuels different to those locally available.

In this connection, two cases should be considered when the effect of fuel properties on vehicle performance, including emissions, is analysed:

i) the design and setting of the engine is adjusted to a given market fuel properties, and

ii) the design and settings remain unchanged, and there is a deviation of market fuel properties from those optimum.

Case ii) is typical for in-use vehicles, where, in practice, only very limited modifications of their adjustment are feasible. The effect of fuel properties on emissions is usually higher in this case than in i).

In principle, every fuel specification property affects, to some degree, pollutant emissions. In this overview emphasis is laid on properties thought to be most significant. These key properties for vehicles equipped with SI engines are:

- lead content,
- benzene content,
- density,
- volatility.

The effect of lead and benzene content is obvious (see 3.2.1), and does not require any supplementary comments.

For vehicles equipped with CI engines, the key properties are thought to be:

- ignition quality (cetane number/index),
- density,
- back-end volatility,
- viscosity,
- sulfur content.

The above characteristics are not listed in any order of magnitude of effect.

G.2 VEHICLES EQUIPPED WITH SI ENGINES.

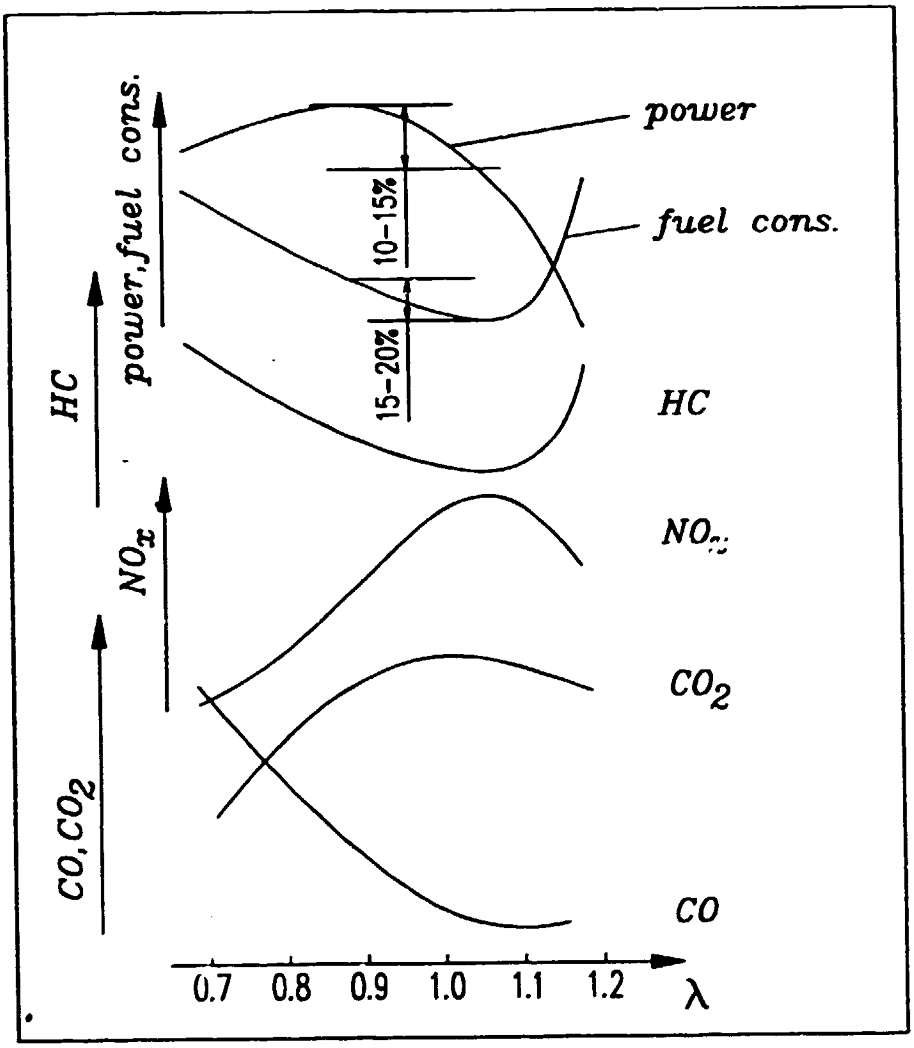
G.2.1 Exhaust emissions. The level of regulated, and some of the unregulated exhaust emissions from SI engines depends upon the mixture formation and combustion processes, and is affected by many engine design and operating variables. The predominant role is played by air-fuel equivalence ratio (called also mixture strength) of the fresh charge supplied to the engine (λ). With lambda equal to 1, the engine is receiving a stoichiometric air-fuel mixture. The effect of air-fuel equivalence ratio,λ, on engine performance and pollutant emissions is shown in a simplified qualitative manner in figure G.1. The major characteristic to note is that the individual parameters reach their extremum (maximum or minimum) values at a different mixture strength, which makes it difficult to optimise for all regulated pollutants.

The engine power output is maximum at a mixture richer by about 10 % to 15 % than stoichiometric, i.e. at lambda equal to about 0,85 to 0,90. Both mixture enrichment and enleanment from this point results in power drop, particularly noticeable with enleanment. The minimum fuel consumption occurs at a mixture considerably leaner than this, and at an optimum lambda of 1,00 to 1,20. Thus maximum powe and minimum fuel consumption are incompatible, and depending on the compromise or priority chosen, engines will operate 5 % to 20 % from optimum conditions on one or both of these.

As regards emissions, carbon monoxide emissions decrease with increasing lambda, as do hydrocarbon emissions, but only to the 'lean limit'. When this limit is exceeded, they increase steeply due to incomplete flame propagation and misfire. This increase is accompanied by unstable engine operation , resulting in surge and poor driveability. This precludes the use of such lean operation. The effect of mixture strength on NO_x emissions is to some extent, the reverse. The maximum NO_x emission occurs at lambda of 1,05 to 1,10, and falls from here with both increasing and decreasing lambda.

Trends cocerning the effect of air-fuel equivalence ratio on engine parameters, shown in figure G.1, are typical of all SI engines, including 2-stroke, irrespective of their design and operating variables. However, these variables affect concrete characteristic values of lambda at which extremum values of power, fuel consumption, HC and NO_x occur. Moreover, they affect the rate of change of these parameters as a function of lambda. It is worth noting that CO and CO_2 cocentrations in the exhaust gas depend relatively little on variables other than lambda.

Figure G.1-Effect of air-fuel equivalence ratio on SI engine parameters.



There is a significant difference between vehicles not equipped with three-way catalytic converters, and those so equipped. When not equipped, the mixture strength is the result of a compromise between requirements related to different parameters, e.g. power, fuel economy, driveability, emissions, etc, whereas when not equipped, the emission aspect is decisive. To achieve the optimum efficiency of the converter, and to meet emission standards, the air-fuel equivalence ratio must be stoichiometric (within very close tolerances) under most operating conditions. It is because of these close tolerances of lambda acceptable to catalytic converters, that carburetted engines are not now acceptable for low-emission vehicles. Carburetion often, if not generally, led to a maldistribution of fuel-air mixture between the individual cylinders, which in turn meant erratic composition of the exhaust gases. Thus carburetors are no longer fitted to vehicles in North America, Japan or Europe, with new car production exclusively fuel injected, with electronic engine management systems. The consistency of engine conditions, and the response obtainable from electronic engine management systems, makes their application desirable even without catalytic converters, on the grounds of driveability and emissions.

The air-fuel equivalence ratio depends largely on the fuel system setting, but is affected by some fuel properties. By definition, the air-fuel equivalence ratio, λ , is equal to:

$$\lambda = \frac{m_A}{m_P\, L}$$

where:

m_A is the air mass flow rate, kg/h,

m_P is the fuel mass flow rate, kg/h,

L is the stoichemetric air-fuel ratio, kg/kg

The above formula shows that λ , which is a function of mixture, depends on air-fuel stoichiometric ratio L, which is a property of the fuel. L can be calculated from the formula:

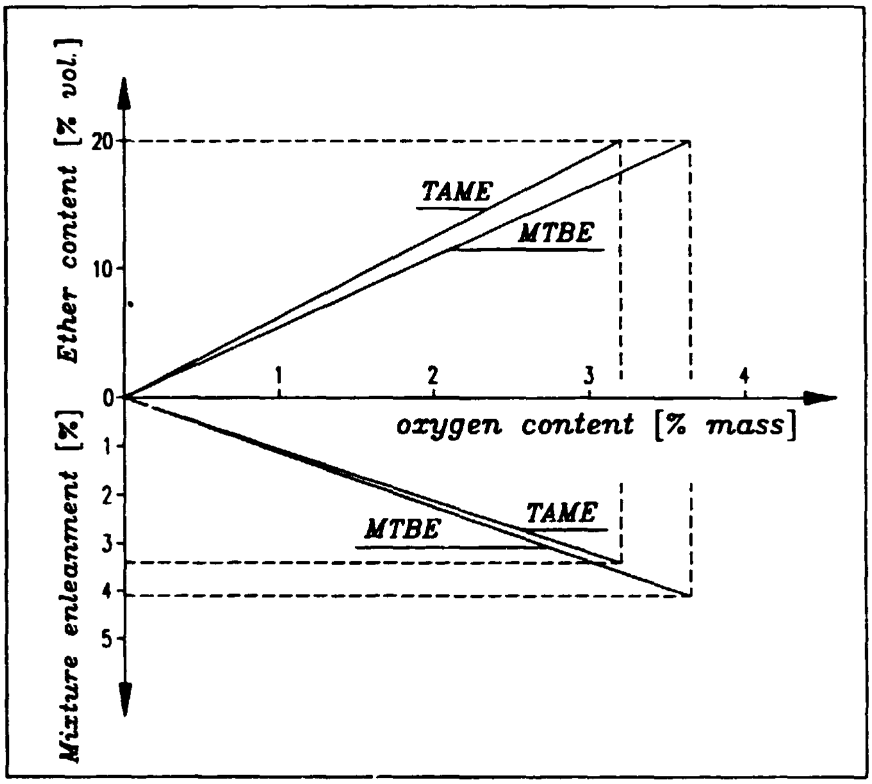
$$L = 11{,}51C + 34{,}55H + 4{,}31S + 4{,}32O$$

where C, H, S, and O are respectively the mass share of carbon, hydrogen, sulfur and oxygen in the fuel.

The hydrocarbon composition of motor gasoline, within reasonable limits, has little effect on the stoichiometric ratio. For hydrocarbon fuels it is in the order of 14,7 to 14,9. However, this ratio is considerably affected by the addition of oxygenates. A fuel oxygen content of 1 %(m/m) reduces it by about 0,2. As alcohols are not recommended (see 3.3.1), the relationship between ether content and oxygen content in fuel is shown in figure G.2.

If the setting of the fuel system is adjusted to maintain a constant value of lambda (by increasing the fuel mass flow rate, m_P), the effect of oxygenates on emissions is relatively small. Some changes result from the fact that in some engines the addition of oxygenates shifts the lean limit towards the lean side, and improves the combustion. However, if the setting of the fuel system remains unchanged, mixture enleanment occurs when oxygenates are added. This is shown in figure G.2. A fuel oxygen content of 1 %(m/m) results in a mixture enleanment of about 1,4 %. The total impact of oxygenates on emissions may be considerable, due to an interplay between all the factors. However, the role of enleanment is dominant. The total effect varies from vehicle to vehicle and mainly depends on the initial mixture strength which in turn, is influenced by the level of emission control.

Figure G.2-Effect of addition of ethers on air-fuel equivalence ratio



In all vehicles, the effect of enleanment on emissions is significant until the lean limit is reached (see figure G.1) and the **percentage** change is similar for CO and HC for uncontrolled-, reduced- and low-emission vehicles, although of course, the absolute change in terms of g/km will reduce with increasing control. For NO_x, there is still some uncertainty. For uncontrolled- and reduced-emission vehicles, NO_x tends to increase slightly with enleanment, but for low-emission vehicles, NO_x is broadly unaffected. The general range of change in emissions for a fuel with 1 %(m/m) oxygen content, as a percentage of the emissions from the same engine on hydrocarbon fuel, is;

- for CO - from 6 % to 12 % decrease;
- for HC - from 2 % to 5 % decrease;
- for NO_x - from 4 % increase to 4 % decrease.

Because of the lean limit threshold, there is a maximum oxygen content that should be in marketed fuels supplied to a vehicle parc essentially designed for hydrocarbon fuels. This limit may be as low as 2,5 %(m/m) oxygen, and even at this level, a small amount of vehicles adjusted to operate close to the lean limit may experience driveability problems, and require re-adjustment.

Density changes can also have an effect on emissions in a similar manner. Density is related to air-fuel equivalence ratio by the general formula:

$$\lambda = \frac{k}{\sqrt{D}}$$

where;

k is a constant;

D is the density, kg/m^3.

A range of 100 kg/m^3 in density corresponds to about 6 % change in air-fuel equivalence ratio, if all other factors affecting λ remain constant.

Since increasing densities result in increasing volumetric specific energy, there is a benefit in fuel economy to the user from higher densities. This is of the order of 0,7 % to 0,9 % for every 10 kg/m^3 increase. The effect on emissions in vehicles with fuel systems not adjusted to maintain a constant value of lambda, is that higher densities cause enrichment and thus an increase in CO and HC emissions, and a lower density an enleanment and thus a reduction. This change is relatively small however, being between 1,0 % and 2,5 % for CO, and between 0,5 % and 1,0 % for HC, for every 10 kg/m^3 change in density from the vehicle setting target. For vehicles with fuel systems adjusted to maintain a constant value of lambda, and for low-emission vehicles fitted with catalytic converters, the effect of fuel density on emissions is very much lower.

Overall, the major density related factors influencing emissions are;

- the average (weighted) density of each of the motor gasoline grades in the market, and the deviation of this value from the value for which vehicle fuel systems were set;
- the scatter of density values around this average in each grade (see figure G.3).

Volatility has an impact on emissions, which is particularly severe under cold weather and hot weather conditions. In cold weather, inadequate volatility increases engine cranking times, and since the air-fuel mixture is extremely rich, contributes to high HC emissions. During warm-up, lack of volatility causes enleannent at the beginning of acceleration, and if the vehicle has been set close to the lean limit, can cause driveability problems due to intermittent periods of fuel-air mixture being outside the flammable range. During these periods, HC emissions increase, and possibly CO emissions also. For vehicles with manual chokes, the driveability problems may be assuaged by increased choke perhaps for a longer period, but this gives more mixture enrichment and thus increased HC and CO emissions.

In hot weather, probably of more interest to most of the countries participating in this Project, it is the maximum volatility that is critical during the early vehicle operation. The major problem is vapour lock, caused by excessive fuel evaporation in the fuel pump and lines, leading to back-pressure restricting the flow of fuel to the carburetor or injectors. This either leads to enleanment, and higher HC emissions and poor driveability, or in extreme cases, to the engine stopping. In vehicles fitted with carburetors, high volatility can also lead to boiling of the fuel in the float chamber, leading to a very rich fuel-air mixture being supplied to the cylinders, and thus a rise in CO and HC emissions. This phenomenon is known as 'carburetor percolation'.

The control of this maximum volatility is achieved by one of two measures. In North America, a vapour-liquid ratio (V/L) temperature is used, whereby a maximum temperature for a specified V/L, usually 20, is set. The V/L temperature is either determined, or calculated from a combination of vapour pressure and distillation characteristics. Outside North America, the normal control is a vapour lock index (VLI), which is a function of vapour pressure and the percentage of fuel evaporated at 70 °C, given by;

$$VLI = 10VP + 7E70$$

where;

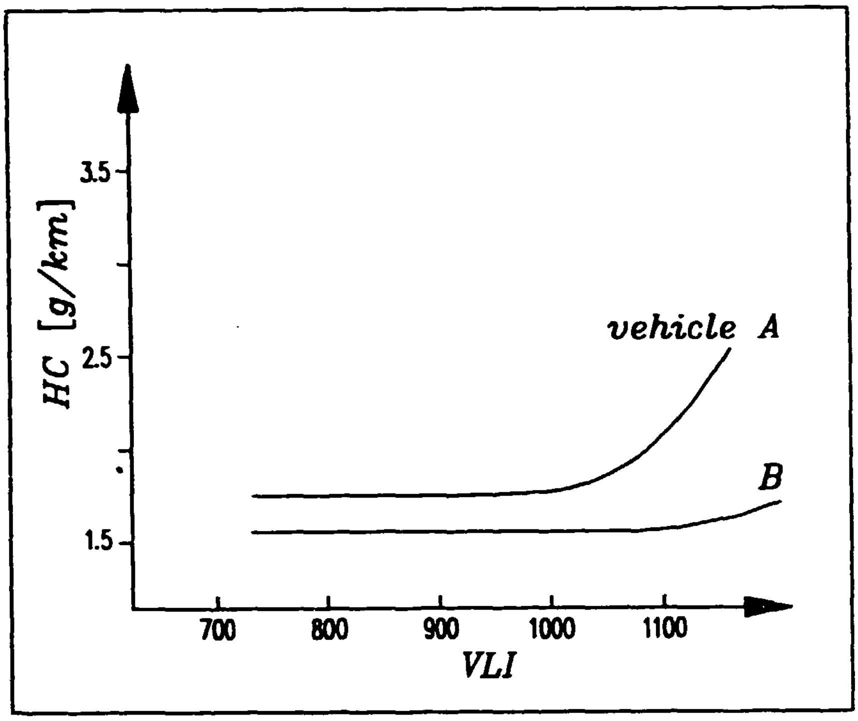
VP is the vapour pressure, kPa;

E70 is the fuel evaporated at 70 °C, %(V/V).

The latter control is used for the specifications given in 8.2.

The actual effect of fuel volatility on emissions is difficult to quantify, but figure G.3 gives some test results on two vehicles moderately sensitive to changes in volatility.

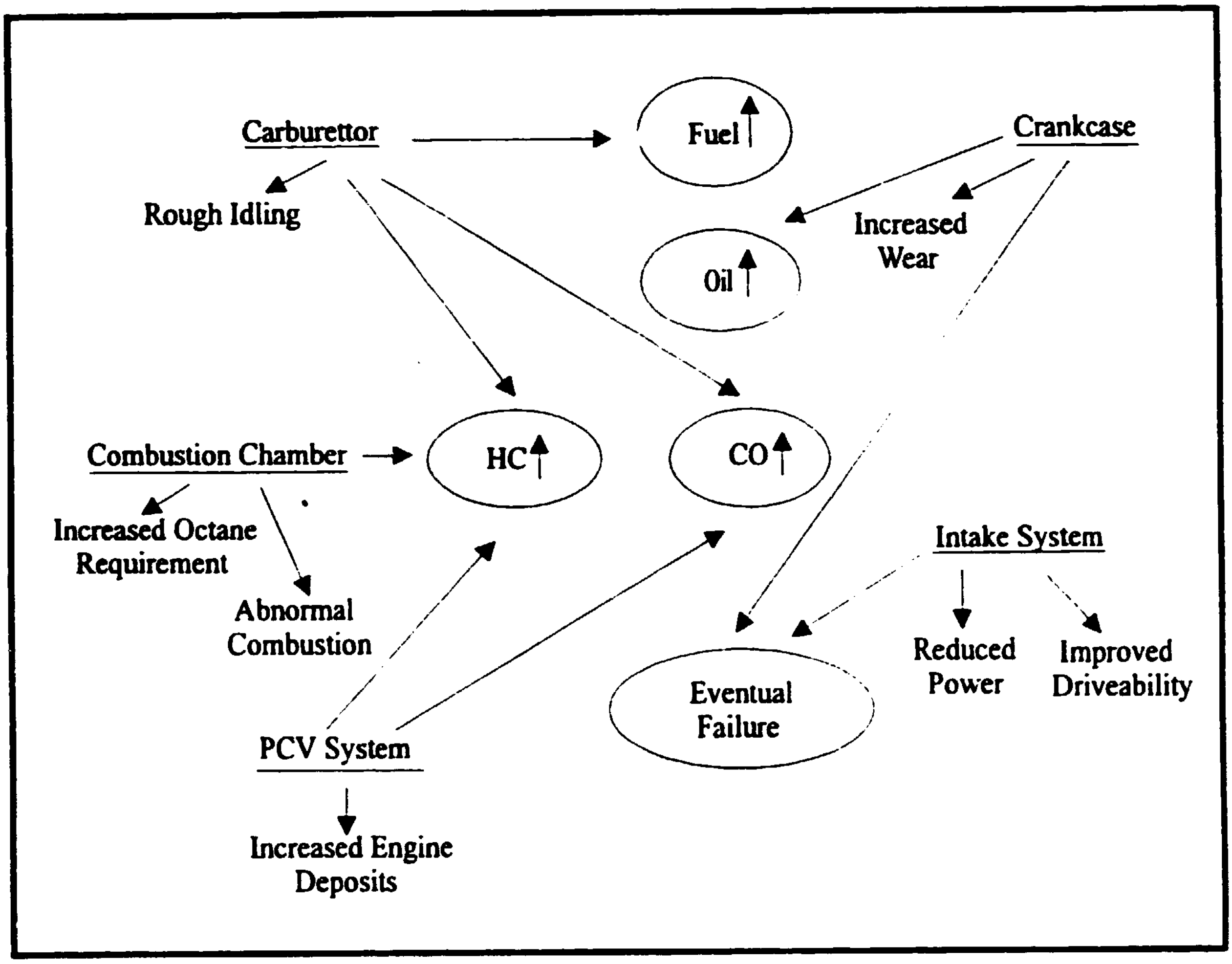
Figure G.3-Effect of volatility on HC emissions under hot weather conditions



An aspect of the fuel quality affecting emissions is the susceptibility to deposit formation, particularly on the intake manifold and valves, and/or the fuel injectors/carburetors. The oxidation stability (induction period) test gives only partial protection to this susceptibility in modern engines with high under-bonnet temperatures, and multi-point injectors, and although overall uncontrolled-, carburetted engines are more prone to deposits, low-emission engines are more sensitive to them. Figure G.4 gives an indication of the effect of deposits on vehicle operation and performance.

Deposits affect emissions by affecting the mixture strength, mainly during starting and warm-up, and and in injectors of course, affecting the flow and atomisation efficiency. The increase in regulated emissions can be as high as 15 % to 30 % for carburetted engines or, as a percentage, even higher for low emission vehicles fitted with electronic engine management systems. Figure G.5 gives some indication of the increase in emissions related to intake valve deposits.

Figure G.4-Effect of deposits on vehicle operation and performance

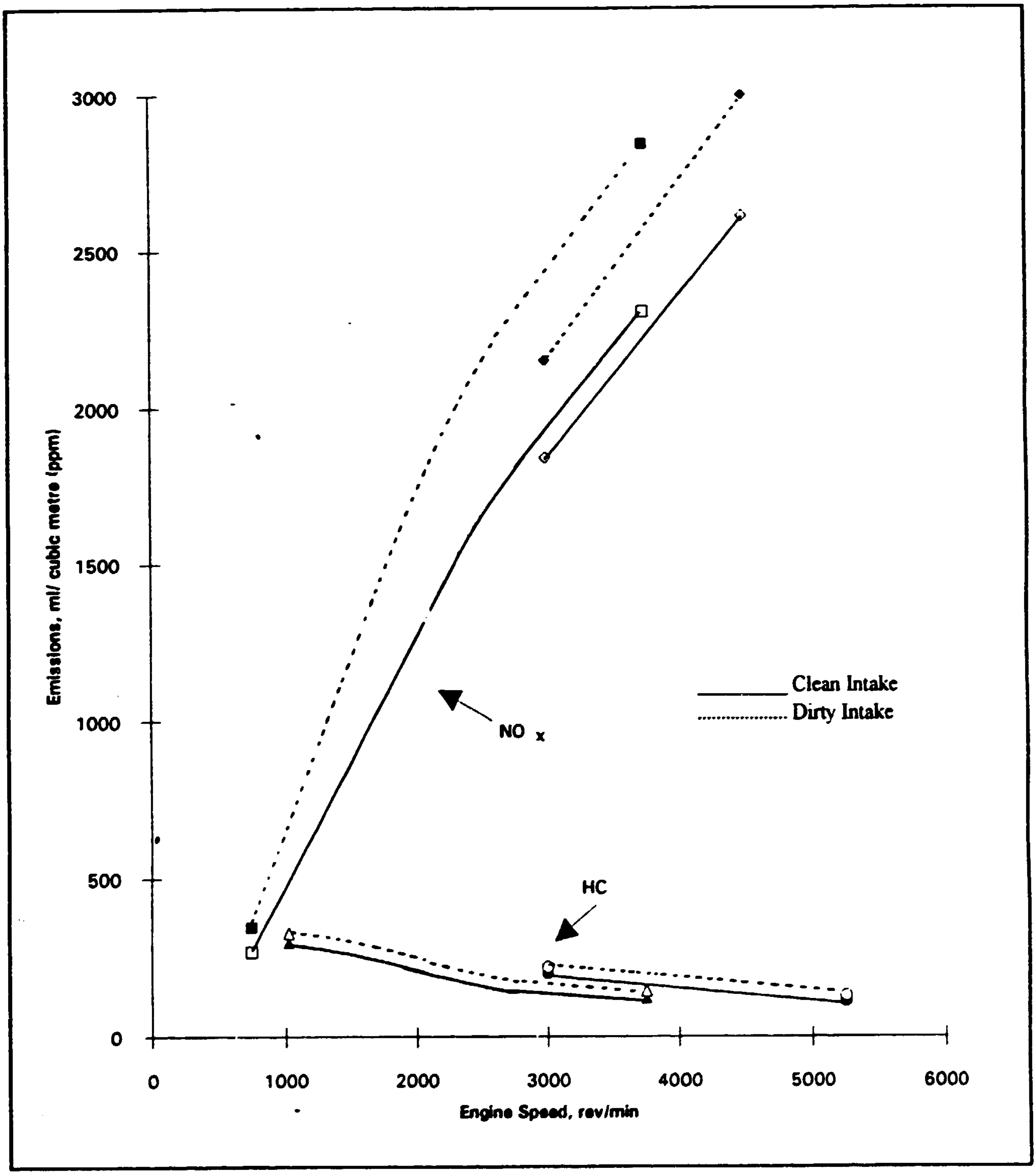


There are a variety of additives available, at different levels of efficiency, and for different target engine system deposits. These are effective, and are included in most 'top tier' motor gasolines marketed by the major oil companies. Various standardised engine test regimes are available for the assessment of these additives, but there is no requirement for their use in any National Standard (see X.10).

G.2.2 2-stroke engines. The conventional 2-stroke engine has inherent defects which lead to poor fuel economy and high emissions of HG and white/blue smoke. The main reasons for the high HC emissions are:

i) high fuel losses in the exhaust, due to the scavenging of fresh air-fuel mixture;
ii) misfiring in the cylinder;
iii) incomplete combustion of the 2-stroke oil.

Figure G.5-Emissions versus intake valve deposits

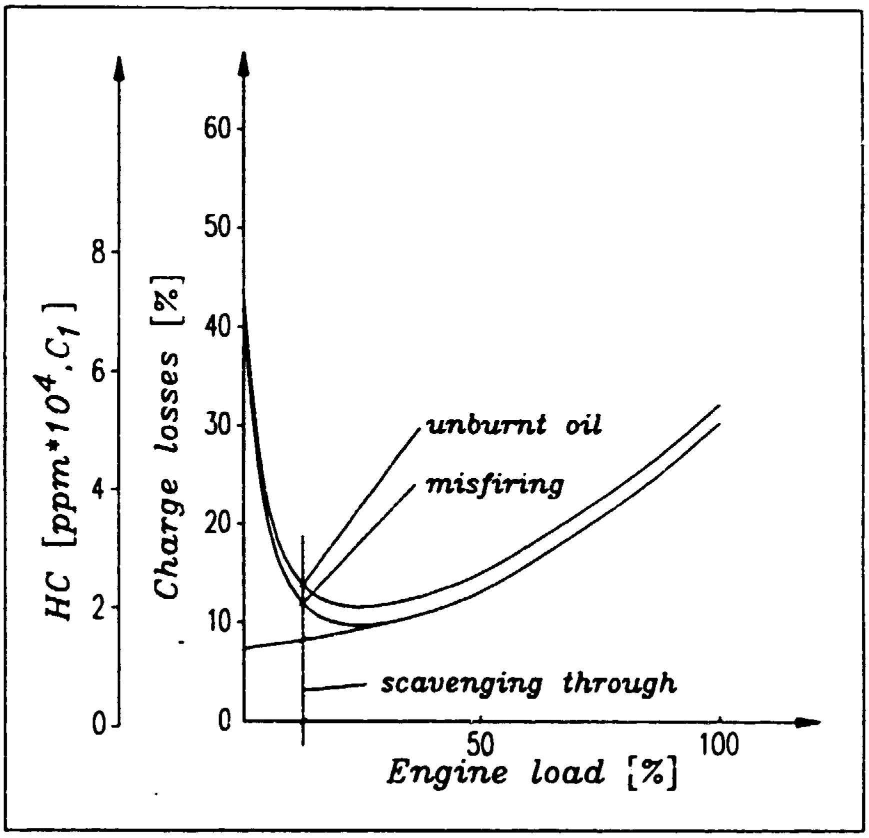


The scavenging occurs when fresh air-fuel mixture is partially mixed with the burnt gases from the previous cycle, and partially exhausted into the open exhaust ports. During idle and low load operation, about 5 % to 10 % of the fuel supplied to the cylinder may be lost in this manner, but at high load, this can rise to above 30 %. In addition to the losses, the mixing of air-fuel mixture with the exhaust gases can, particularly at low load, cause misfiring, which in turn results in even more unburnt fuel being exhausted. In some engines, under this combination, over 65 % of the supplied fuel may be unburnt and exhausted as HC.

The current HC emissions limits in Japan recognise this fact, and set generous limits for HC emissions at idle for small 2-stroke engines (in Japan, the limit is equivalent to about 50 % of supplied fuel), but this of course, exerts little control.

The incomplete combustion of the 2-stroke oil may be as high as 25 % to 50 % of the oil supplied, but still only generally accounts for 5 % to 10 % of the total HC emissions. Both the quality and quantity of 2-stroke oil used, and the engine operating variables, can have a considerable effect on these figures. Figure G.6 gives an overview of the contribution of the various factors to HC emissions from 2-stroke engines.

Figure G.6-2-stroke engine emissions as a function of load



The function of anti-smoke additives is to firstly complete the combustion of the 2-stroke oil, and secondly, to reduce the droplet size of unburnt, or partially burnt, fuel/oil in the exhaust gases. The actual reduction in HC emissions is likely to be small, below 10 %, but there is an effect on the colour, visibility and odour of the smoke. Small droplets, below 0,8 μm diameter, appear to be blue in colour, whereas larger droplets appear white, are more visible to coventional opacity meters, and are more odorous. Although unpleasant, the health effects of these emissions are not yet clarified. Table G.1 gives some data on the effect of one additive on three engines under different operating conditions.

Table G.1-Effect of anti-smoke additive on smoke emissions

Vehicle / **Operating conditions**	**Relative smoke level, % of neat fuel**		
	$1^{1)}$	$2^{2)}$	$3^{3)}$
A (75 cc)	70	55	50
B (150 cc)	90	45	45
C (175 cc)	70	40	40

Notes:

1. Warm-up period, full throttle acceleration in highest gear.
2. Warmed-up vehicle, full throttle acceleration in highest gear.
3. Warmed-up vehicle, constant speed, 60 km/h.

G.2.3 Evaporative emissions. Evaporative emissions **from the fuel system**, excluding re-filling losses, occur from:

a) running losses which occur when the vehicle is being driven;

b) hot soak losses which occur after the warmed-up vehicle has been stopped and its engine switched off;

c) tank diurnal breathing losses.

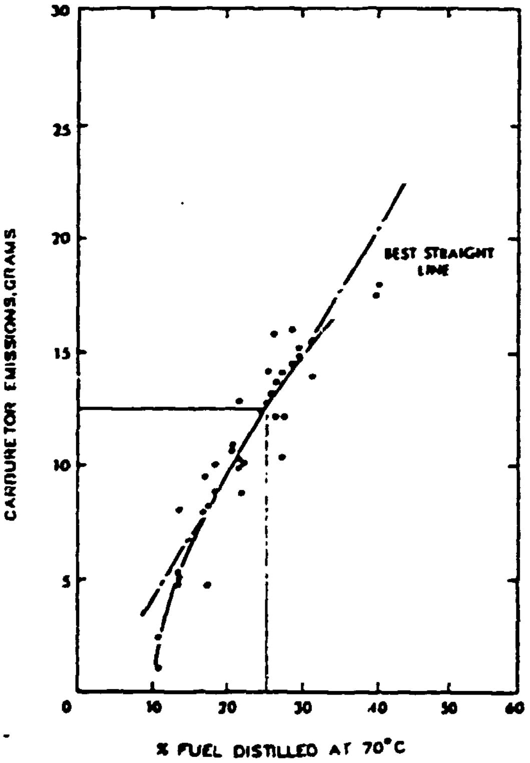
These emissions can be split into two main sources:

i) fuel system losses, from pumps, lines, and particularly carburetors

ii) fuel tank losses.

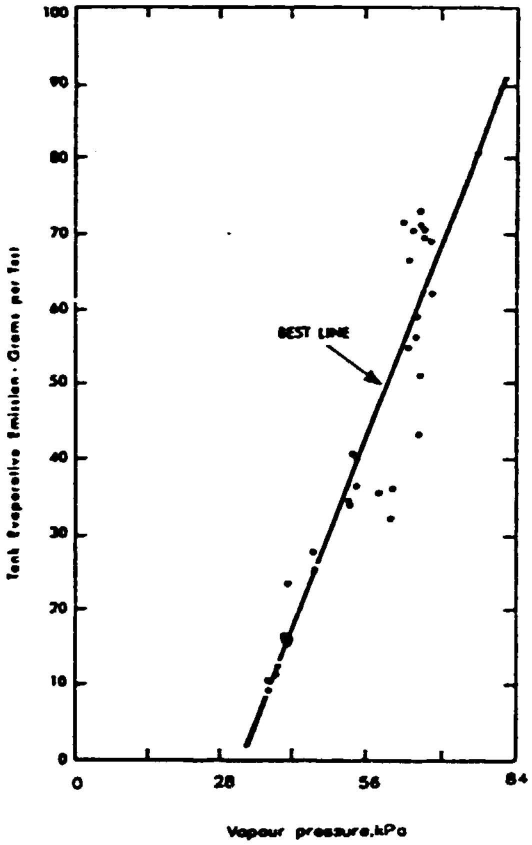
The fuel system losses occur from normal imperfections in the sealing of fuel systems, but in the case of carburetors, there are the extra possibilities due to a supply of fuel being present in the float chamber both during running, and particularly after engine switch-off. Vehicles fitted with carburetors with unbalanced float chambers (most 2-stroke engines) can experience a considerable rise in HC emissions when excess fuel-air mixture generated by the carburetor is vented directly to the atmosphere. After engine switch-off, the fuel in the carburetor is still warm, and partially evaporates, and in general 5 g to 30 g is lost for each hot soak period. All fuel system losses are loosely correlated with the components of VLI, vapour pressure and front-end volatility, but with different functions for the different areas of loss. Carburetor hot soak losses are more strongly correlated with E70, and this is illustrated in figure G.7.

Figure G.7-Carburetor hot soak losses versus volatility



Tank losses, apart from those that occur during refilling, occur either from fuel temperature fluctuations due to ambient conditions (diurnal) or engine system operating conditions (hot soak). A rise in fuel temperature increases vaporisation which displaces air-fuel mixture into the atmosphere. When the fuel temperature falls, condensation and contraction of the fuel draws fresh air into the tank for the cycle to be repeated. Diurnal tank losses correlate most closely with vapour pressure, and this is illustrated in figure G.8.

Figure G.8-Diurnal tank losses versus volatility

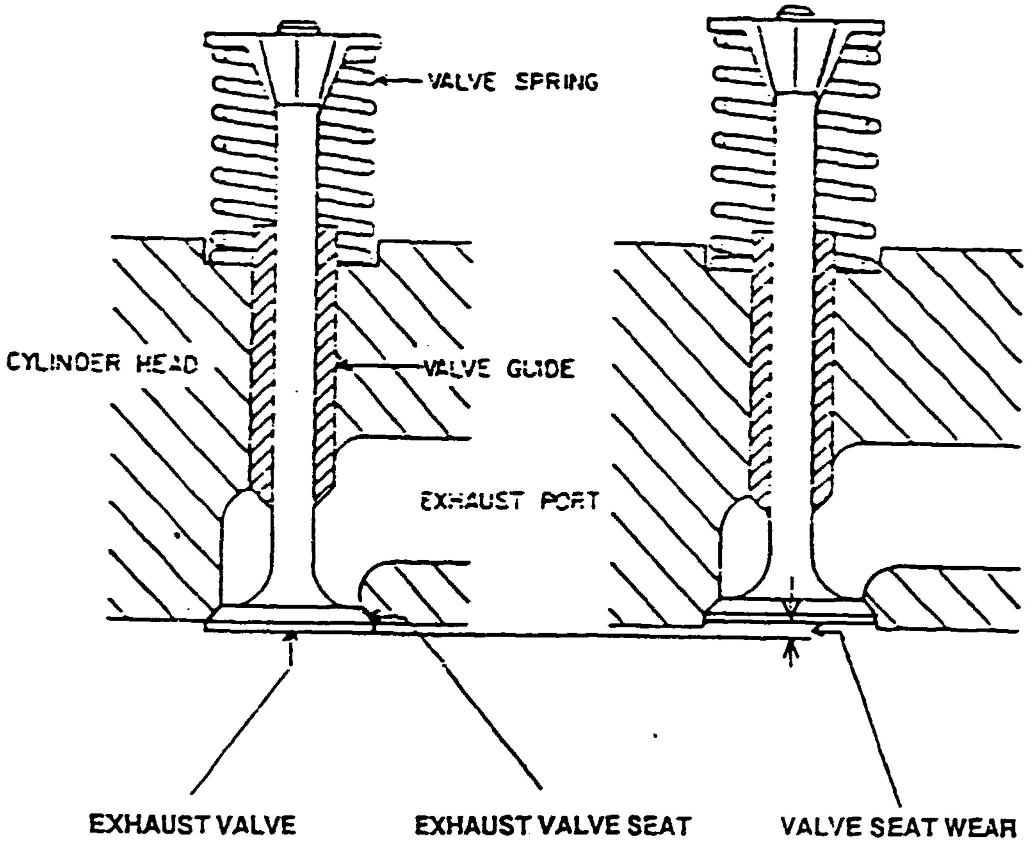


The composition of the vapours generated will depend on the light blending components used in the motor gasoline manufacture, and will comprise largely that fraction boiling below about 60 °C, i.e. with a carbon number of 6 (hexane) or lower.

G.2.4 <u>Valve seat problems.</u> Engines which have unhardened exhaust valves and valve seats require a lubricant to prevent wear on these parts, which can in extreme cases cause engine failure. Figure G.9 gives an illustration of this.

Recession is wear on the valve seat which increases the contact area between the valve and seat, and therefore reduces the contact pressure, and reduces the seal. This is progressive until tappet clearances are taken up and the valve is

Figure G.9-Valve seat recession



NEW CYLINDER HEAD

WITH RECESSED VALVE SEAT

permanently partially open, allowing gases to escape whilst combustion is not complete. This leads to a drop in power and fuel economy, and a rise in HC emissions.

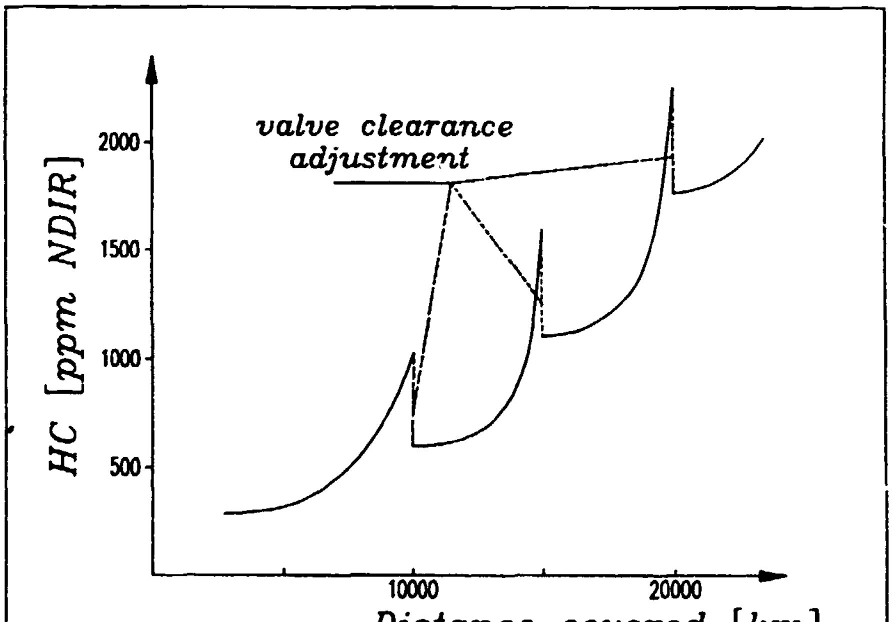
Organic lead compounds have very high lubricity properties (lead compounds were used in many EP lubricants), and a lead content of somewhere between 30 mgPb/l and 50 mgPb/L is sufficient to give seat protection. Unleaded motor gasoline therefore requires hardened materials for exhaust valves and valve seats. Some figures illustrating the effect of low lead levels required to achieve a 1 mm valve seat recession are given in table G.2, but these can be regarded as illustrative only, as there is an effect of engine load and speed.

Table G.2-Valve seat recession as a function of lead content and distance

Lead content, mgPb/l	Distance, km
less than 5	7 500
10 to 13	18 000
50 to 80	above 75 000

Valve seat recession leads to higher HC emissions, and this is illustrated in figure G.10 for the vehicle used in table G.2 running at raised idle speed on motor gasoline with 10 mgPb/l to 13 mgPb/l lead content.

Figure G.10-HC concentration as a function of distance



Alternatives to lead for the avoidance of valve seat recession are available, but are generally unacceptable in modern vehicles fitted with catalytic converters because they contain other elements that interfere, e.g. manganese, phosphorus, alkali metals. Environmentally concious consumers in markets where both leaded and unleaded motor gasolines are marketed, and who own vehicles unsuited to run on unleaded motor gasoline, are generally recommended to alternate their tank filling to the extent that the **average** lead level seen by the engine is kept above 50 mgPb/l, but minimised. This of course requires both the publicity of prevailing lead levels in the various motor gasoline grades, and a consistency of this.

G.3 VEHICLES EQUIPPED WITH CI ENGINES

G.3.1 General. The major problem with the assessment of diesel engine exhaust emissions is the vast range of engine types/sizes, and the individual cylinder/piston designs. Conclusions for one type (DI) may not be applicable to another (IDI), but more confusingly, the response of different engines to changes in fuel quality may not only be different in magnitude, but are often even different in direction. This is particularly the case in respect of NO_x emissions. The following discussion therefore can only be regarded as an 'average trend' indication in respect of many of the properties discussed, and individual vehicles, driven over separate test cycles, may well exhibit a different relationship.

G.3.2 Particulate and smoke emissions. The emissions of vehicles equipped with diesel (CI) engines include, besides the gaseous components of CO, HC and NO_x, particulates (PM) and smoke. Figure G.11 gives an overview of these exhaust emissions.

Particulate emissions are of particular concern because of their aspiration potential and chemical constitution, which combined, is thought to be a severe hazard to health, even to the extent of being carcinogenic.
Diesel particulates are generally composed of the following components:

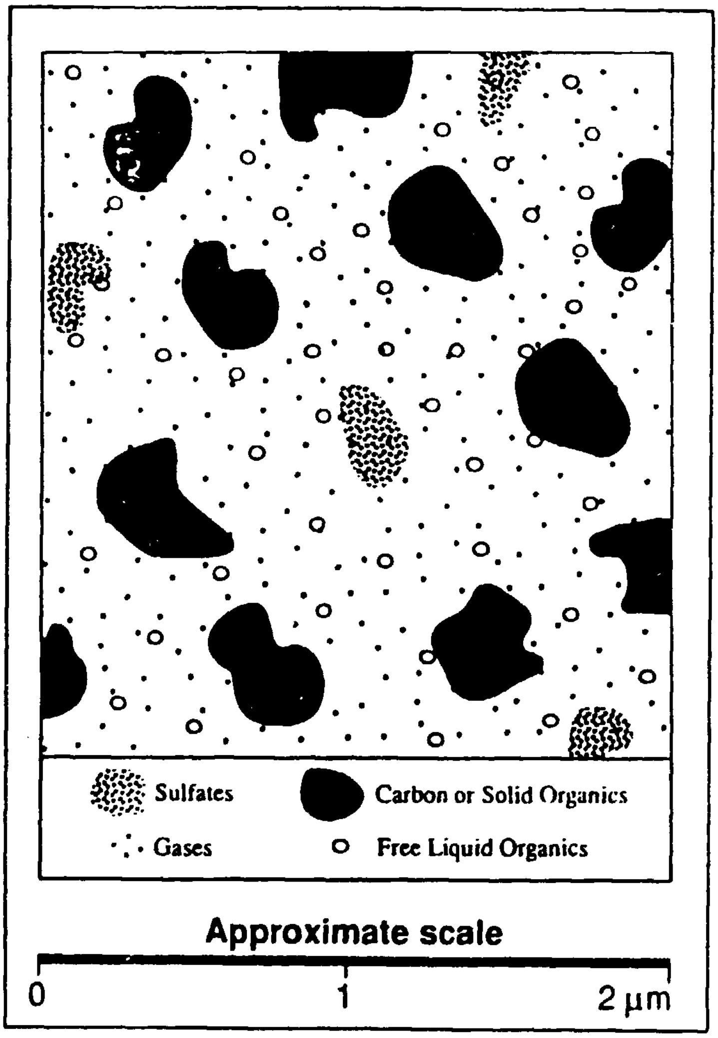
- **soot**- irregularly shaped, agglomerated fine carbon particles, usually less than 2 µm in size, formed from the hydrocarbon fuel in the combustion process under high temperature conditions in the absence, or insufficiency, of oxygen,

- **soluble organic fraction (SOF)**- unburnt and partially burnt fuel or lubricant which condenses on the exhaust walls, form aerosols or absorb soot,

- **sulfates**- formed during the combustion process mainly from the sulfur contained in the fuel,

- **bonded water.**

Figure G.11-Diesel exhaust gas schematic



The same components of the diesel exhaust gas form smoke, often referred to as 'visible emission'. The smoke is composed of particles, including aerosols, suspended in the engine exhaust stream which obscure, reflect and/or refract light. The smoke is usually divided into two categories:

- **black** smoke which mainly consists of soot,
- **white/blue** smoke mainly composed of liquid fuel and lubricant droplets.

Design features of the diesel engines are the prime factor in the quantitative emissions of PM and smoke, but fuel factors do have an effect on the quantity of emissions, but, more directly, on the quality (composition) of PM. Possibly the major physical fuel property affecting the PM emissions ia density, since as for fuel-injected SI engines, this determines the mass delivery rate through volumetric metering. A simplified illustration of the effect of fuel delivery rate on emissions is shown in figures G.12, G.13 and G.14.

Figure G.12-Engine parameters versus fuel delivery

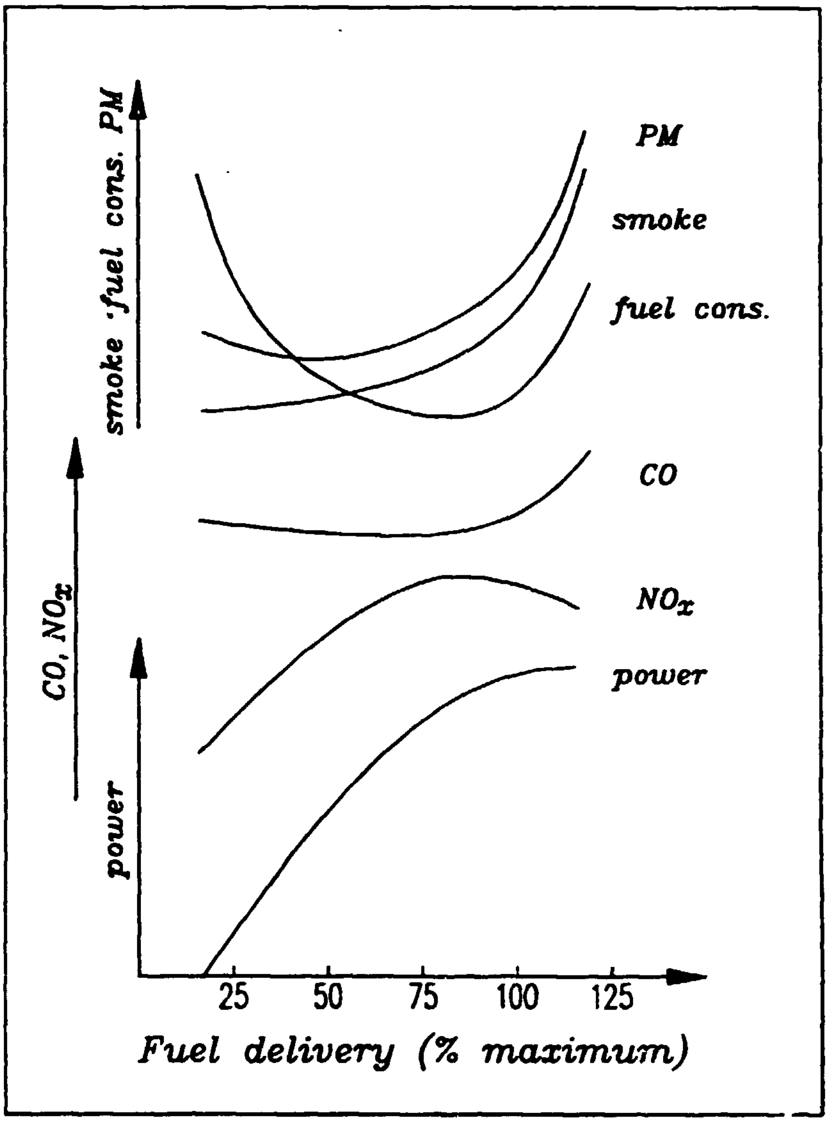


Figure G.13-Effect of density variation on emissions

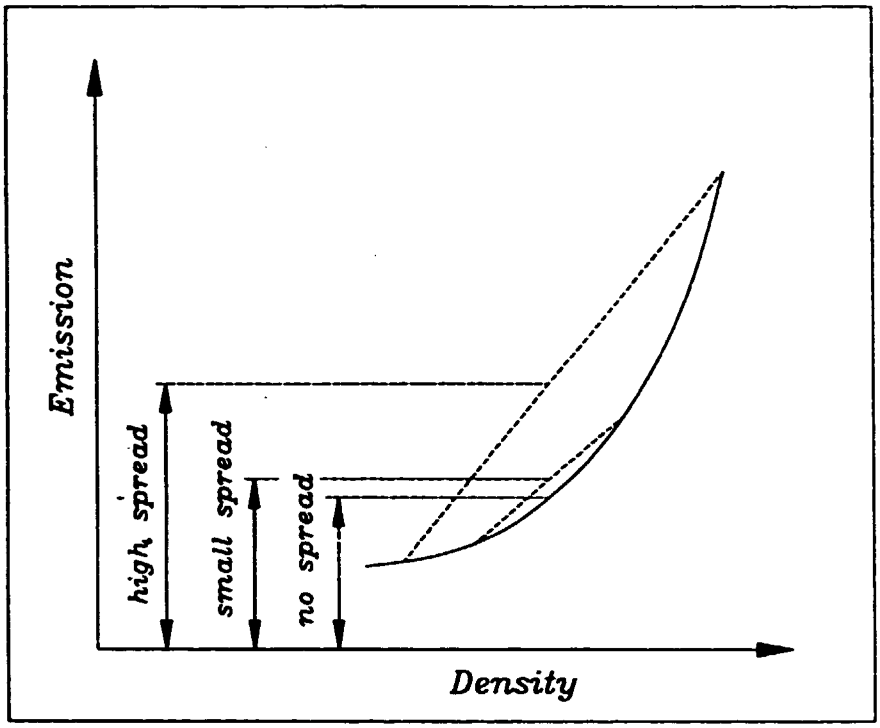
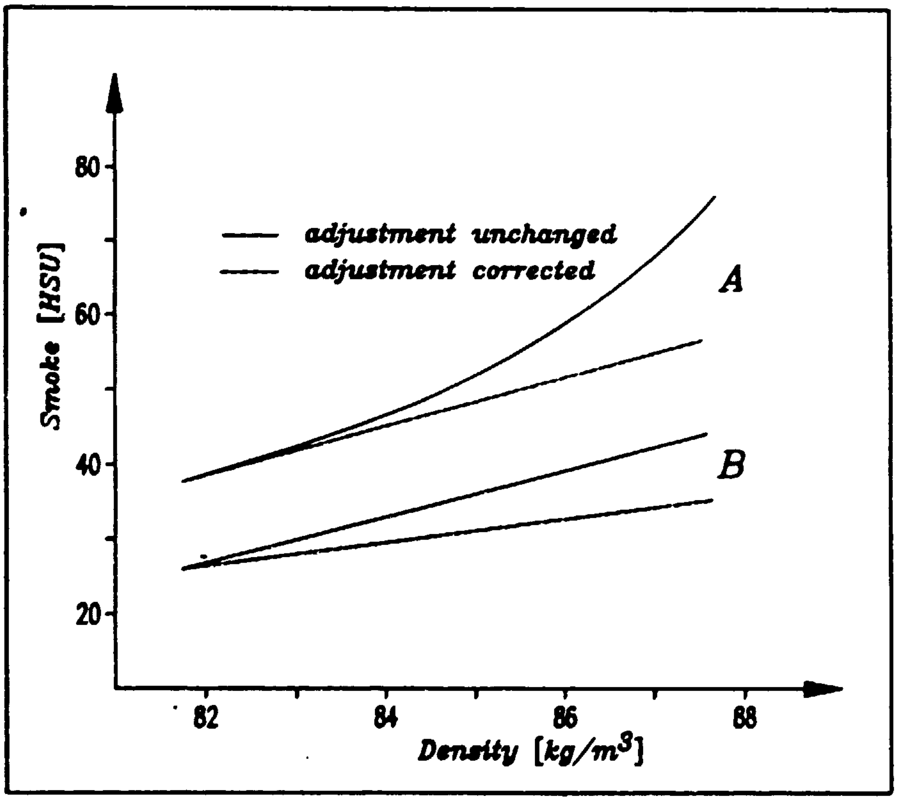


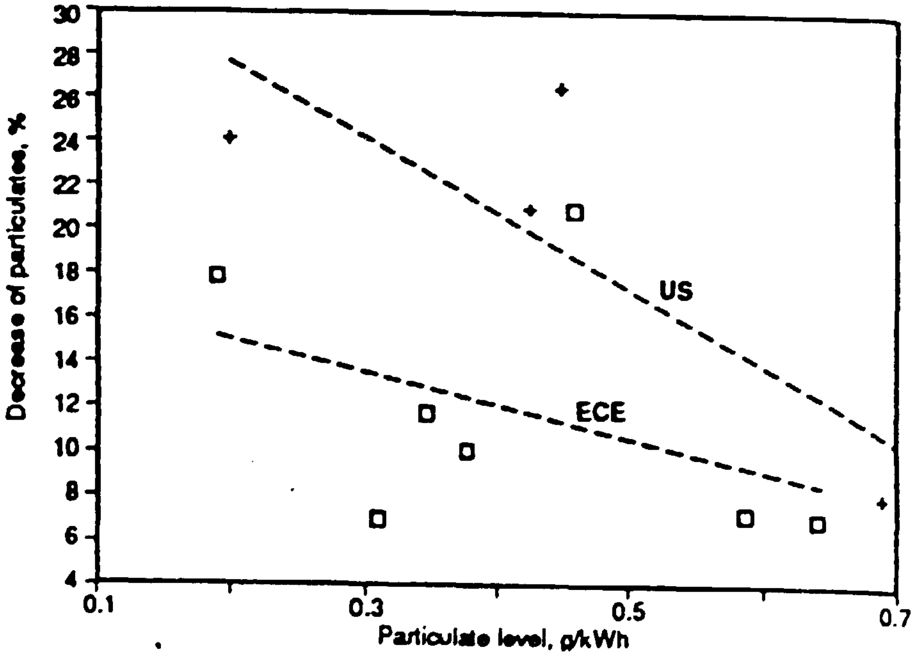
Figure G.14-Effect of density on smoke emissions



For smoke, low delivery rates result in low intensity (invisibility), in the order of 7 HSU to 15 HSU or 0,7 °B to 1,5 °B. One point to make for temperate or colder climates is that the real density, and thus the delivery rate at full power, increases at lower fuel temperatures, and this is a major factor contributing to white smoke at cold starts. If, as is normal, the setting of the injection pump is not adjusted to maintain a constant mass delivery rate, increases in density result in an increase in smoke intensity under full load conditions, which is likely to increase in rate of change with increasing density (see fig. G.13). In all cases, the increase in soot content is far greater than smoke intensity due to the non-linear relationship between this property and opacity readings (either HSU or °B).

When the setting of the injection pump is not adjusted for mass flow, the results of emissions tests for PM become sensitive to the test cycle, particularly the share of full load of the total cycle time. This is illustrated in figure G.15 for the ECE and US cycles.

Figure G.15-Particulate decrease as a function of test cycle

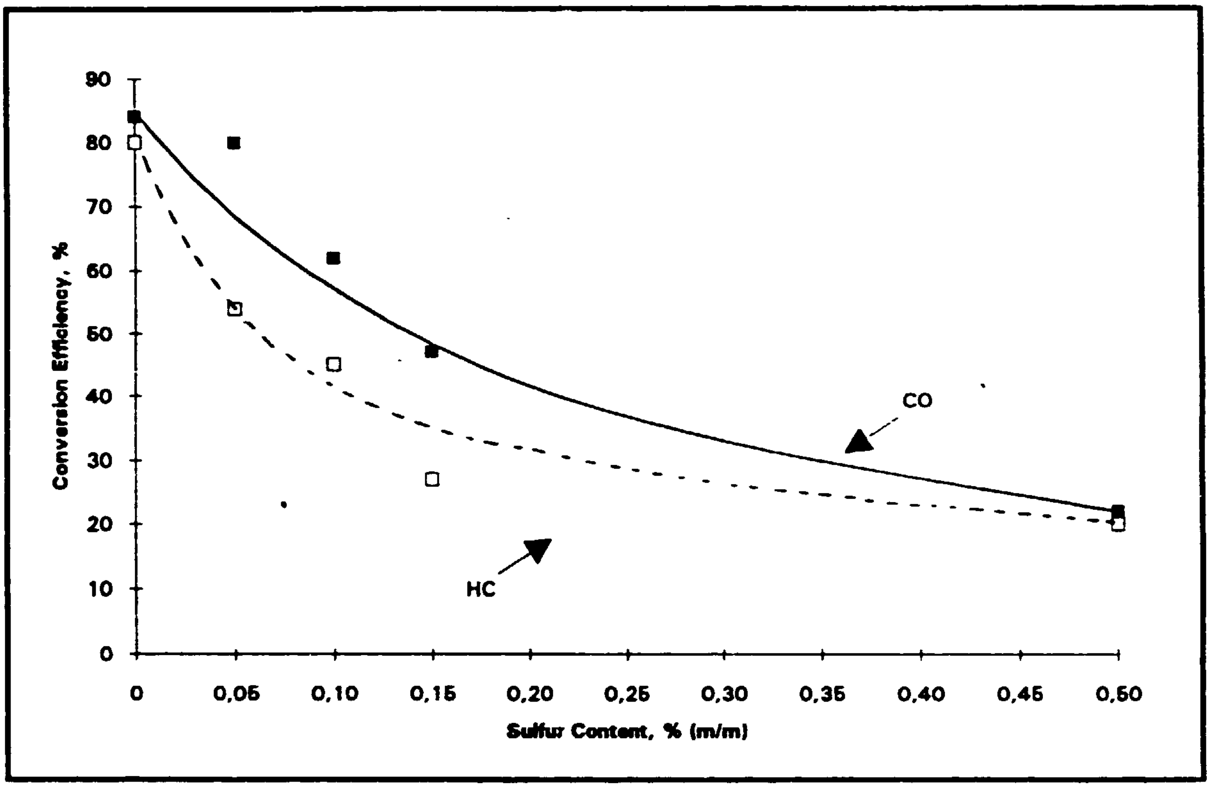


This accounts partially for the different results obtained particularly between light duty and medium/heavy-duty vehicles, and between engine models/vehicle masses, since the share of full load is a function of power/mass ratio, not speed or engine size alone. For medium/heavy duty engines, where most engine tests are carried out on the bench, the share of individual test modes on full load is strictly defined (e.g. 17 % in Japanese, and 35 % in ECE 13-mode tests), and this results in an increase in fuel density contributing a significant rise in PM emissions, possibly exceeding 3 % to 5 % per 10 kg/m^3 rise in density. The results from bench tests do however, have a more tenuous relationship with real conditions because of the power/mass considerations of the final vehicle.

The next most important fuel property affecting PM emissions is ignition quality, and this also has a contribution to HC emissions, particularly in light-duty IDI engines. The ignition quality determines the delay time between injection and combustion, and thus affects the rate of pressure rise in the cylinder. The lower the ignition quality (cetane number), the less time there is available for complete combustion, and the higher the peak temperature obtained. This results in an increase in pyrolised particles (PM and smoke) in addition to the unburnt fuel (HC) exhausted. For the most sensitive vehicles, a decrease of 6 in cetane number can increase PM and smoke emissions by 45 %. It is difficult to orthaganolise ignition quality from other fuel properties when examining a fuel matrix, since it is generally interrelated with density and volatility, and there are 'trade-offs' to some degree with these, but a trend can be established which, over the range 42 to 52 cetane number, gives an average of about 3 % to 5 % increase in PM and smoke emissions per cetane number decrease. Another effect of ignition quality, not covered under the emissions in these Guidelines, is the noise. Engine noise is almost directly affected by ignition quality, particularly close to a threshold which is individual for a single engine type, and also particularly during the start-up and warm-up phases of engine operation.

Sulfur has a direct relationship with particulate emissions, although the total sulfates plus SO_x emitted from motor vehicles is normally only a small proportion of total sulfur emissions in a given environment. Over the whole range of sulfur contents [0,01 %(m/m) to 1,0 %(m/m)] the conversion of sulfur to sulfates is fairly constant at 1 % to 2 %, although there is evidence that DI engines tend to have a slightly higher average conversion rate than IDI engines. However, as PM emissions have reduced, the percentage of the particulate comprising sulfate has risen, and this is particularly true for low-emission vehicles. One of the major factors contributing to this fall in PM emissions is the drastic reduction in lubricant usage in diesel engines. Sulfur content does have an effect on the conversion efficiency of oxidation catalysts, and the corresponding emission of HC and CO. Figure G.16 gives data on sulfur content reduction versus conversion efficiency for DI engines.

Figure G.16-Effect of sulfur content reduction on conversion efficiency



Other fuel properties that have a second-order effect on PM emissions (more particularly to smoke) are volatility and viscosity. Front-end volatility has a small effect on white smoke at start-up due to 'ignitability', i.e. sufficient vapour present for instant ignition, whereas mid-range and back-end volatility contribute to black smoke during warmed-up operation. The effect of back-end volatility on regulated PM emissions is still inconclusive, and more studies are currently underway. Engine effects are overwhelming here. Viscosity is important, perhaps more in terms of a consistent range than an absolute maximum value. The viscosity interrelates with the fuel pump pressure and injector design to give a specified droplet size and spray pattern. Changes in this, affect combustion efficiency and burn-out, and thus emissions.

G.3.3 Nitrogen oxide emissions. NO_x emissions are naturally higher from CI engines than from SI engines of equivalent capacity, and few fuel properties have any effect on these. The contribution of fuel nitrogen within small ranges (100 mg/kg to 500 mg/kg) is small, at less than 10 % of total NO_x, but some fuel components such as those from coking, or even some from catalytic cracking, can start to be significant contributors. As mentioned in 3.3.2, excessive use of organic nitrate ignition improvers can also start to make a contribution. The only fuel property significantly affecting NO_x emissions is ignition quality, and even here the effect is relatively small, although fairly consistent across the engine types. An increase in 3 cetane number may decrease NO_x emissions by 20 % to 30 % in critical engines. There is some evidence of an effect of mid-range volatility on NO_x emissions, but at present it is somewhat inconclusive.

G.3.4 Other gaseous emissions. CO and HC emissions from diesel vehicles are low, and are again only affected by ignition quality amongst the fuel properties. In the case of these emissions however, the effect is significant, particularly if the market cetane number is low (below 47 cetane number) (see G.3.2).

G.3.5 Injector fouling/additives. Injector fouling caused by both carbonaceous and metallic deposits on the injector tip has long been a problem with diesel engines. The metallic components came from metals dissolved by the relatively aggressive (acid) older diesel fuels attacking Group II metals, particularly copper, zinc and cadmium, and depositing these on the injectors. This phenomenon has largely disappeared from developed markets due to the better metallurgy used in diesel fuel systems, and the increasing desulfurisation of diesel fuels which has the side-benefit of also decreasing acidity.

The incidence of 'coking' deposits however has increased, with higher injector pump pressures, smaller injector orifices, and higher temperatures at the injectors. The effect of these deposits has also increased, and they possibly account for the highest influence on emissions from diesel vehicles. Table G.3 gives an example of the relative effect on performance and emissions in an ECE 13-mode test, between injectors in good condition (100 %) and coked injectors.

Table G.3-Effect of injector coking on engine performance

Characteristic	**Value (% relative)**
Maximum power	94
Fuel consumption	96
Smoke[1)]	210
HC	170

Table G.3-continued

CO	170
NO_x	97
PM	161

Note 1-Expressed as g soot/m^3 exhaust gas at full load.

As for SI engines (see G.2.1), effective additives, largely detergent-type, are available, and these do also have some effect on dirty injectors, which may lead to a temporary increase in emissions, which is probably negligible in proportion to the overall longer-term beneficial effects.

G.3.6 <u>Summary of fuel property effects on CI engine emissions.</u> Overall, the fuel quality effects of diesel fuel are smaller, less well defined, and far more dependent on engine design, than those identified for SI engines. The strong interrelation of many of the fuel properties makes definitive statements difficult, and potentially erroneous. The best example of such a problem is the proposal, very well supported in the period 1988 to 1992, that aromatics had a direct effect on PM emissions. This has now been shown to be a false conclusion (but we still have legislative limits in California and Sweden), and aromatics as compounds, have no effect beyond that which is already predictable from a combination of density and cetane number (which combined give a function of 'aromaticity'), although there may be some contribution from di- and tri-aromatics on the composition of PM (and perhaps on quantity if present in high proportions). Many of the trends shown in table G.4 may not apply to all individual engines, and for some combinations, results are inconclusive, and/or more work is currently being done in this area.

Table G.4-Trends of fuel quality change effects on CI engine performance and emissions

Fuel modification	Max. power	Fuel cons.	Black smoke	White smoke	HC	CO	NO_x	PM
Reduce density	↓↓	↑0	↓↓	↓0	0	0	0	↓0
Reduce T10	0	0	0	↓↓	?	0	0	0
Reduce T50	0	0	↓↓	↓?	0	0	0	?
Reduce T90/95	0	0	↓?	0	?	?	0	?
Increase cetane number	↑0	↓0	↓0	↓↓	↓↓	↓↓	↓0	↓0
Reduce sulfur	0	0	0	0	0	0	0	↓↓
Reduce di- and tri-aromatics	0	0	?	0	0	0	?	?

Key:
↓↓ - Strong effect
0↑ or 0↓ - Slight effect
0 - No significant effect
? - Inconclusive, more work needed/underway

ANNEX X (informative)

Skeleton Standard for motor gasoline

X.1 Title. The title of the Standard shall be as unambiguous as practicable, within the limits of brevity, but should include the main elements of the content and scope of the Standard.

X.1 Foreword. This clause (usually un-numbered, but may be designated '0') deals with the construction procedure of the Standard. It details who was involved, what Standard(s) are superceded, and may highlight some radical changes from previous Standards. It is **not** part of the Standard.

X.3 Introduction. This is an optional clause, normally omitted, but may be included if there is some discussion items not included in the Foreword.

X.4 Scope. This is the first mandatory clause, and needs to be unambiguous, brief and comprehensive. A suggested outline is:- 'This Standard specifies requirements and methods of test for *leaded/unleaded** motor gasoline at the point of custody transfer. It specifies requirements for *n** grades of motor gasoline, and it is the responsibility of the user to ensure that the grade appropriate to his requirements is specified. For retail sales, it is the responsibility of the seller to ensure that the requirements for quality and grade identification, given in this Standard, are in compliance.'

X.5 Normative references. This clause defines the referee methods of test and other reference requirements. A decision is needed as to whether dated or undated references are to be used, and the introductory part of this clause should indicate the conditions of whichever is chosen. Alternative methodology should **not** be incuded here, unless specific reference is made in the text of the Standard, but should be included in an annex, which can be normative if alternatives are accepted as technically idendical, or informative if they are technically equivalent or worse. It is strongly recommended that the primary references are selected from annex Z.

X.6 Sampling. For motor gasoline, this clause shall give full details of the sampling requirements from tanks, pipelines and from retail dispensing pumps. It shall pay particular attention to the containers, and the conditions of storage, labelling and transport. It may reference other sampling procedures (specifically those such as ISO 3170 and ISO 3171), but usually will include local enhancement. Within the body of the Standard, it is quite usual to reference a normative annex giving further details.

X.7 Grade marking. This shall contain the requirements for the marking of dispensing pumps, and may in addition include requirements for the labelling of tanks, pipelines and bulk vehicles (road and rail). As for X.6, the detailed requirements may be set out in a normative annex.

X.8 **Retail dispensing requirements.** This shall include requirements for dispensing hose marking or colours (it has become customary to identify unleaded gasoline with green hoses, and leaded gasoline with red hoses), and most importantly, nozzle diameters. The recommended nozzle diameters are 23,6 mm **max.** for unleaded, and 26,4 mm **min.** diameter for hoses dispensing leaded gasoline.

X.9 **Fiscal requirements.** Requirements for fiscal grade identification shall be set out in this clause. In particular, it will contain requirements for specific grade colours and the use of trace markers.

X.10 **Additives.** The policy on additives, excluding lead compounds, shall be stated in this clause, and the scope of allowable and disallowable additives set out. In general, the current philosophy is to 'allow' the use of performance-enhancing additives (without definition) in National Standards, with perhaps other bodies 'endorsing' specific products or marketers. Modern engines certainly obtain benefits from the best of modern additives.

X.11 **Quality requirements.** This clause, immediately preceding the specification table(s), gives additional requirements for either the finished fuel or components. For motor gasoline, it will normally contain further requirements on the quality of oxygenates for blending (if used), and requirements for water tolerance and/or avoidance of water contamination. Some Standards may include fairly detailed specifications for the oxygenate qualities as annexes.

The presentation of the specification table(s) is optional, although it is logical to separate the general requirements from those that are grade specific. If more than one volatility grade is required, either geographical or seasonal or both, it is recommended to separate the volatility requirements (vapour pressure, distillation, VLI) into a separate table, with possibly illustrative figures.

X.12 **Precision and dispute.** Immediately following the specification table(s) shall be a clause detailing the basis of assessment for challenge and dispute. It is strongly recommended that this reference is based on ISO 4259, which describes procedures which relate to the precision of the test method.

X.13 **Normative annexes.** These annexes, if included, are part of the Standard, and have the same legal and fiscal status as the body of the text. They generally contain more detailed information on, for example, sampling or grade marking, or secondary specifications for components that are mandatory. In some cases, seasonal and regional grades are included in normative annexes, particularly if they are very complex (such as in the US), and in many cases, dates for grade changes, or variations from statements made in the main text are the subject of normative annexes.

X.14 Informative annexes. These annexes are not part of the Standard, although their inclusion may be necessary for universal application of the Standard. They usually consist of 'translations', such as referenced standards given their local or customary equivalents (with appropriate caveats if not identical), or conversions from referenced units/methods to customary. They may also contain extensions to the Foreword by giving more details of the construction process of the Standard, and they may contain a bibliography of documents, not specifically included in the Standard, but considered useful to the user.

ANNEX Y

Skeleton standard for automotive diesel fuel

Y.1 **General.** The outline for this Standard should be identical to that given in annex X for motor gasoline, with only those changes relating to the different product being made. Only elements of major change will be detailed in this annex.

Y.2 **Scope.** The suggested wording for this clause is:- 'This Standard specifies requirements and methods of test for automotive diesel fuel for use in vehicles for on-highway duty, at the point of custody transfer. This Standard does not apply to off-highway vehicles, and diesel engines used in other applications. It is the responsibility of the user to ensure that this product is appropriate to his requirements, and it is the responsibility of the seller to ensure that the requirements for quality and grade identification, given in this Standard, are in compliance.

Y.3 **Sampling.** This clause shall be a simpler version of that given in annex X for motor gasoline. It would be satisfactory for reference to ISO 3170 or ISO 3171 (or local equivalents) to be made, with some enhancement for sampling from dispensing pumps.

Y.4 **Grade marking and retail dispensing requirements.** A simplified version of a combined X.7 and X.8 will suffice here. Normal black hose and the large nozzle diameter may be specified.

Y.5 **Quality requirements.** It is unlikely that there will be much detailed requirement in addition to the specification table(s) here. There may be however, a discussion on alternative low temperature operability measurements, either here, or more conveniently, referenced here and included in eithr a normative or informative annex. Since, in this region, regional/ seasonal grades, if applied, are likely to be within a fairly narrow temperature range, low temperature operability is the only property likely to be affected. Only if ambient temperatures fall below -20 °C, will other constraints need to be considered. These may include a small relaxation in ignition quality, a relaxation in minimum density, and perhaps a relaxation in minimum viscosity (this may require some protection for lubricity). In this event, treatment of low temperature properties as a group, should be approached in the same manner as motor gasoline volatility.

ANNEX Z (normative)

Bibliography of Standards

Z.1 ISO STANDARDS.

ISO 2049:1994	*Petroleum products-Determination of colour.*
ISO 2160:1985	*Petroleum products-Corrosiveness to copper-Copper strip test.*
ISO 2719:1988	*Petroleum products and lubricants-Determination of flash point-Pensky-Martens closed cup method.*
ISO 2909:1981	*Petroleum products-Calculation of viscosity index from kinematic viscosity.*
ISO 3007:1994	*Petroleum products-Determination of vapour pressure-Reid method.*
ISO 3012:1991	*Gasoline, kerosine and distillate fuels-Determination of mercaptan sulfur-Potentiometric method.*
ISO 3015:1992	*Petroleum products-Determination of cloud point.*
ISO 3016:1994	*Petroleum products-Determination of pour point.*
ISO 3104:1994	*Petroleum products-Transparent and opaque liquids-Determination of kinematic viscosity and calculation of dynamic viscosity.*
ISO 3170:1988	*Petroleum liquids-Manual sampling.*
ISO 3171:1988	*Petroleum liquids-Automatic pipeline sampling*
ISO 3405:1988	*Petroleum products-Determination of distillation characteristics.*
ISO 3675:1993	*Crude petroleum and liquid petroleum products -Laboratory determination of density or relative density-Hydrometer method.*
ISO 3830:1993	*Petroleum products-Determination of lead content of gasoline-Iodine monochloride method.*
ISO 3987:1994	*Petroleum products-Lubricating oil and additives-Determination of sulfated ash.*
ISO 4259:1992	*Petroleum products-Determination and application of precision data in relation to methods of test.*

ISO 4260:1987	*Petroleum products and hydrocarbons-Determination of sulfur content-Wickbold combustion method.*
ISO 4264:1993	*Petroleum products-Distillate fuels-Calculation of cetane index.*
ISO 5163:1990	*Motor and aviation-type fuels-Determination of knock characteristics-Motor method.*
ISO 5164:1990	*Motor fuels-Determination of knock characteristics-Research method.*
ISO 5165:1992	*Diesel fuels-Determination of ignition quality-Cetane number.*
ISO 6245:1993	*Petroleum products-Determination of ash.*
ISO 6246:1994	*Petroleum products-Determination of the gum content of distillate fuels-Jet evaporation method.*
ISO 6618:1987	*Petroleum products and lubricants-Neutralisation number-Colour-indicator titration method.*
ISO 7536:1993	*Petroleum products-Determination of the oxidation stability of gasoline-Induction period method.*
ISO 8754:1992	*Petroleum products-Determination of sulfur content-Energy-dispersive X-ray fluorescence method.*
ISO 10370:1993	*Petroleum products-Determination of carbon residue (micro method).*
ISO 12185 1)	*Crude petroleum and petroleum products-Determination of density-Digital density meter method.*
ISO 12205:1994	*Petroleum products-Determination of the oxidation stability of distillate fuels.*
ISO 12937 1)	*Petroleum products-Determination of water-Coulometric Karl Fischer titration method.*
ISO 13759 1)	*Petroleum products-Determination of alkyl nitrate in diesel fuels-Spectrometric method.*

1) In course of preparation.

Z.2 EN STANDARDS.

EN 12	*Liquid petroleum products-Determination of vapour pressure-Wet method.*
EN 116	*Diesel and domestic heating fuels-Determination of cold filter plugging point.*
EN 237	*Liquid petroleum products-Determination of low lead concentrations-Atomic absorption spectrometric method.*
EN 238	*Liquid petroleum products-Determination of benzene content-Infrared spectrometric method.*
EN ABC	*Liquid petroleum products-Determination of benzene content-Gas chromatographic method.*
EN PQR	*Liquid petroleum products-Petrol-Determination of organic oxygenate compounds and total oxygen content by gas chromatography.*
EN XYZ	*Petroleum products-Determination of air saturated vapour pressure (ASVP).*

Z.3 ASTM AND IP STANDARDS.

ASTM D3231	*Phosphorus in gasoline.*
ASTM D3606	*Benzene and toluene in finished motor and aviation gasoline by gas chromatography.*
ASTM D4046	*Alkyl nitrate in diesel fuels by spectrophotometry.*
ASTM D4052/ IP 365	*Density and relative density of liquids by digital density meter.*
ASTM D4815	*Determination of* C_1 *to* C_4 *alcohols and MTBE in gasoline by gas chromatography.*
ASTM D5191/ IP 394	*Determination of air saturated vapour pressure (ASVP)-Mini method.*
IP PM-BH	*Determination of particulate content of gas oils.*