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Safety aspects with E85 as a fuel for vehicles

Fire Safety Consideration

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Stockholm (SE), BioFuel Region (SE), Rotterdam (NL), Somerset (UK), Dublin (IE), Basqe County (ES), Madrid (ES), La Spezia (IT), Nanyang (CH), São Paulo (BR)

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Preferace

The BEST project (Bio Ethanol for Sustainable Transport) deals with the introduction and market penetration of bio ethanol as a vehicle fuel, establishment of infrastructure for supply and fuelling of bio ethanol, the introduction and wider use of ethanol cars and flexible fuel vehicles on the market.

During the BEST project, more than 10 000 ethanol cars and 160 ethanol buses will be put in operation and E85 and E95 fuel stations will be opened.

Low blends with petrol and diesel will be developed and tested. Through this, the participating cities and regions aim to prepare a market breakthrough for ethanol vehicles and for bio ethanol and also to inspire and obtain followers.

Participating cities/regions are: BioFuel Region (SE), Dublin (IR), Somerset (UK), Rotterdam (NL), Basque Country and Madrid (ES), La Spezia (IT), Nanyang (China), Sao Paolo (Brazil). Co-ordinating City is Stockholm (SE). Industrial partners are Ford Europe, Saab Automobile and several bio ethanol suppliers.

The project is co-financed within the 6th framework; Sustainable Energy Systems/Alternative Motor Fuels: Bio fuel cities.

Within BEST, Stockholm will transfer the Swedish experiences of ethanol as a vehicle fuel to other cities and stakeholders. Many questions have been raised with regard to safety issues with ethanol. On behalf of the City of Stockholm, Ecotraffic ERD^3 AB has therefore, compiled the Swedish experiences and knowledge in the area of ethanol and safety, comparisons have been made with petrol and diesel. This report has been written by Bengt Sävbark, Egon Larsson, Lars Eriksson, Peter Ahlvik and Åke Brandberg at Ecotraffic ERD^3 AB. Eva Sunnerstedt has been the responsible co-ordinator at the Environment and Health Administration, City of Stockholm.

A somewhat longer version of the report is available in Swedish.

Stockholm in October 2006

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Content

Executive summary

During the last years, the use and availability of E85 (85 % ethanol and 15 % petrol) as a motor fuel on the Swedish market has increased dramatically. At the end of 2006, more than 600 filling stations and 50 000 E85 cars was in operation. The more widespread use of E85 during recent years has led to a debate about the fire hazards of this fuel. The overall conclutions are that there is no increased risk associated with E85 compared with petrol fuel, when it comes to fire and safety aspects. The risks with E85, however, are different from petrol: Combustible vapours of E85 fuel can occur in closed spaces (fuel tank in vehicles and at fillig stations) at higher ambient temperatures – and in a broader temperature interval – than for conventional petrol fuels. The advice and recommendations given by The Swedish Petroleum Institute together with the specila adaptations in todays E85cars can be assessed to be sufficient to compensate for these risks. E85 fires can be assessed to be less damaging to humans and to property as well and are less difficult to extinguish than petrol and diesel fires. Also no serious fire or explotion accidents have occured despite the fact that E85 is now widely used in Sweden. These facts correlate with the author's opinion – there is no increased risk associated with E85 compared with petrol fuel. E 85 acctually has the possibilities to increase safety in general for the whole transport system. The conclutions of this report has been discussed with the responsible fire- and saftey authorities in Sweden.

Besides liquid petrol, a petrol tank also contain a mixture of petrol and air vapour above the surface. Normally (if it not is too cold), this mixture contains too much petrol in relation to air to be able to ignite (too rich mixture). When the temperature drops, the evaporation of petrol decreases. After a while, the evaporation is so low that the fuel/air mixture no longer is too rich – the mixture will be combustible and able to ignite.

Swedish petrol of summer quality has a combustible temperature range from about -45°C, the lean limit, to about -10°C, the rich limit. On the other hand, the combustible range for E85 fuel is defined between about -35°C and up to about several degrees above zero (+5 to +11°C). Combustible vapours of E85 fuel can occur at higher ambient temperatures – and in a broader interval – than for conventional petrol fuels. This fact constitutes the major reason for the safety concerns appearing regarding the possibility of increasing risks for fires and explosions when E85 fuels are to substitute petrol. The limits of the combustible range are not fully clarified and further investigations are strongly recommended. However, it is obvious that E85 vapour (in closed spaces) will be within the combustible temperature range more frequently than petrol vapour (due to the Swedish climate). In Sweden during wintertime, temperatures below –20°C are often experienced, resulting in combustible vapour mixtures also in petrol tanks (below – 10°C for summer and below –20°C for winter petrol).

The conductivity of E85 is much higher compared to petrol. Fuels that have low conductivity tend to accumulate static charge and release the charge through a spark. This has potential to become an ignition source for a fuel fire. The higher the conductivity of the fuel, the more quickly a static charge can dissipate and therefore it is less likely to cause ignition. However, if static charge releases through a spark, the probability for ignition is higher for E85 vapour than for petrol vapour (combustible mixture at a higher number of days compared with petrol). Such a spark could, conceivably, propagate down into the tank, thus causing ignition of the fuel. The fuel distribution system for E85 on Swedish market is modified to handle that extra risk.

Filling stations for E85 are also modified in accordance with safety recommendations from the Swedish Petroleum Institute. An example of a measure is that the pistol valve on refilling pumps for E85 should not be equipped with lock-up mechanism. The reason for that is that it not should be possible to leave the pistol and "build up a personal charge". With the exception

of refilling of FFV cars as designed by Saab, fuel vapours are emitted into open air by fuel refilling of E85 cars at Swedish filling stations. New regulations from the Swedish EPA are expected in the near future to handle this issue.

E85 fuel has about 30 vol-% less energy content compared to petrol, on a volumetric basis. This fact implies that larger volumes of E85 will be consumed for the same transportation work compared to conventional petrol. The effect of this will be that the E85 infrastructure for supplying fuel to the market must be significantly larger than the infrastructure for the conventional fuels, what necessarily would imply greater risk levels in general if E85 were to substitute petrol completely, or to a significant degree, on the motor fuel market. However, there is a surplus of filling stations on the market in Sweden today, whereas no additional stations are needed.

There are several benefits associated with E85 compared with petrol, such as, slower fire propagation, less violent fires that are easier to control than petrol fires.

The objective and ambition of the present report has been to quantify and compare differences between E85 and petrol regarding fire safety aspects. For comparison, also neat ethanol (E100) and diesel fuel are included in the study. The estimates, as depicted below, do not represent any accurate comparison between the various fuels in terms of their associated risk levels. Neither can these figures be added up to a “global estimate of risk” for the various individual fuels.

	Diesel	**Petrol**	**Ethanol**	**E85**
Propensity of ignition Open situation	2	9	4	7
Propensity of ignition Closed situation	5	2	8 (2-4)*	3 (2)*
Risk for damage in case of fire Intensity of fire	8	10	3	4
Risk for damage in case of fire Difficulty of extension	9	10	7	8
Risk for damage in case of fire Visibility of fire	1	1	7	3

1 – 10 There 1 is low- and 10 are extremely high risk.

(*) Following such design changes, which have already been implemented by Saab, Volvo and Ford in their E85 cars. The recommendations as proposed by the Swedish Petroleum Institute (SPI) will also imply the same improvements as estimated with the lower figures within parentheses

During the past 100 years or so, a long experience of handling petrol and neat ethanol in a safe way has been built up in Sweden. Therefore, it is obvious that also mixtures of these components could be handled in a safe manner. The assessments made here (the author’s conclusions) say that E85 fuel cannot be assessed to be more dangerous from a fire and explosion perspective than conventional hydrocarbon fuels. As have been mentioned above, combustible vapours of E85 fuel can occur at higher ambient temperatures – and in a broader interval – than for conventional petrol fuels. Advice and recommendations as given by SPI (Annex 1) can be assessed to be sufficient for improving safety in general for the transport system as a whole when combined with the safety measures, which have already been implemented by the pertinent car industry. E85 fires can be assessed to be less damaging to humans and to property as well and are less difficult to extinguish than petrol and diesel fires.

During the last years, the number of E85 cars and filling station-offering E85 has increased rapidly without any serious fire or explosion accidents. These facts correlate with the author's opinion – there is no increased risk associated with E85 compared with petrol fuel.

Introduction and Background

Recently, the use and availability of E85 as a motor fuel on the Swedish market has increased dramatically. One of the main driving forces behind this development was a Swedish law with an obligation for larger filling stations to distribute bio fuels. Another factor has been the substantial increase in the number of E85 cars during the last year. Increasing environmental awareness and substantial economic incentives for bio fuels and so-called “clean cars” have speeded up this development. For example, the sales of clean cars increased in April 2006 by 500 % compared to April 2005. Similarly, the sale of E85 fuel has also increased considerably. This increase was due to both a significant increase in the sales of E85 cars, as well as an increase in the use of E85 (in relation to petrol) for E85 cars already in use. In addition, the fuel infrastructure for E85 has been further developed and the number of filling stations (providing E85) passed 500 in September 2006.

The question whether the use of E85 as a motor fuel would imply greater risks in terms of fire and explosion hazards has recently been raised in Sweden. The question has come up on the agenda because E85 is associated with a somewhat broader temperature range, within which the formation of a combustible mix of fuel and air is possible, as compared to conventional petrol. Furthermore, this temperature range is shifted towards higher temperatures for E85.

Combustion of fuel vapours requires that air is present within certain limits. When the fuel/air ratio corresponds to complete combustion of the fuel/air mixture, the tendency for ignition is at its maximum level. This point represents exact *stoichiometry* of the fuel/air ratio. Outside of the stoichiometric point, the combustibility decreases successively towards the two extreme temperature points, which define the combustible range of temperatures. Beyond these limits, the fuel/air ratio is either *too lean* or *too rich* for flame propagation to occur at all. In the case of petrol with a low volatility, i.e. “summer grade” petrol, the combustible temperature range extends from about -45°C, the lean limit, to about -10°C, the rich limit. On the other hand, the combustible range for E85 fuel is defined between about -35°C and up to about +5°C, what can be said to demonstrate the somewhat wider temperature range and its shift towards higher temperature levels for the latter fuel. It should also be noted, however, that the rich limit of the combustible range of temperatures is shifted towards a higher limiting value when the fuel tank is continuously being emptied. This phenomenon appears both for E85 and for petrol and indicates that none of these fuels is completely safe under all possible conditions. However, the probability of that the tank vapour will be within the mentioned limits will be less for petrol than for E85. Referring to the discussion above – combustible vapours of E85 fuel can occur at higher ambient temperatures – and in a broader interval – than for conventional petrol fuels. This fact constitutes the major reason for the safety concerns appearing regarding the possibility of increasing risks for fires and explosions when E85 fuels are to substitute petrol.

The amount of relevant test data for E85 is poor and the exact value of the upper temperature limit in the combustion range is unknown, indicating that additional tests are required. The upper temperature limit for combustion is, more or less, what the Swedish fire risk debate is all about. In the present work, emphasis is made on those properties of the fuel, which are of significance for the occurence of fire and explosion risks. These are also described and explained in a somewhat simplified manner to which extent these properties are significant. We have deliberately excluded provision of exact definitions (as they appear in textbooks) of concepts used. We have instead tried to explain how these concepts apply in practice just in order to avoid being too abstract.

Important Chemical and Physical properties

In the table below, the most important physical and chemical properties have been summarised. The table below has been compiled using a number of different sources. Some of them are national standards (compatible to EU standards in the petrol case). Since the sources are of different origin, minor differences in comparison to the case for variation of fuel properties on a local base might exist. Note that the diesel fuel is Swedish Environmental Class 1 (EC 1) diesel fuel and not a diesel fuel corresponding to the European standard EN 590. Anyway, the fuel properties of interest in this case are not decisively different between the two diesel fuel qualities. Some values are subject to correction or change as more analyses and experiments are being successively undertaken. Most important for this report is to show orders of magnitudes, and to point out differences between the various fuels as focused on, thereby trying to assess relative safety levels as compared with the conventional fuels.

		Ethanol E100	**E85**	**Petrol**	**Diesel MK1**
Density, liquid	Kg/m^3	794	765 - 785	720 – 775	800 – 820
Density (vapour)	Rel.air	1.6	2-4	3-4	5-6
Boiling point	°C	78.5	>35 – 205	25 - 220	180 – ca330
Conductivity	pS/m	134.500	as E100	> 50	>50
Vapour pressure (DVPE)	KPa	17	35 - 95	45 - 95	0.4
Flash point	°C	12	< - 30	< - 40	(56) 60
Flammability range fuel vapour in air	% in air	3.3 - 19	1.4 - < 19	1 - 8	0.6 – 7.5
Flammability range, summer **winter**	°C	+12 till +40	-33 to +5 -45 to -5	- 45 to -10 -45 to -20	>56
Autoignition temperature	°C	363		250 – 280	220 – 320
Stoichiometric air/fuel ration	kg/kg	9,0	10	14,6	14,8
Heat of vaporisation	kJ/kg	910	825	335	251
Energy of combustion	kWh/lit	5.9	6.3	9.1	9.8
Energy of combustion, LHV	MJ/lit	21,2	22,7	32,8	35,3
Flame spread rate	m/s	2 - 4		4 - 6	0.02 – 0.08
Diffusion coefficient	cm^2/s	0,137	Between petrol and ethanol	0,05	0,05
Energy of ignition	mJ	0.24	Approx. petrol	0.20 – 0.24	0.20 – 0.24

Fire risk

Introduction

As shown in the table in section 2.1, the physical properties vary a lot between different fuels. Each one of these properties plays an important role for assessing the probability of fire risks. Physical properties also indicate expected type of fire and extent of fire. The physical properties of a fuel that affect fire hazards include its volatility, flash point, range of flammability, autoignition temperature and electrical conductivity. Other properties of fuels that affect the potential risk associated with a fuel fire include flame spread rate in liquid pool fires, the heating value of the fuel, flame temperature and thermal radiation emitted from the fire.

To achieve a spontaneous ignition, the temperature must be higher than the auto ignition temperature. Examples of ignition sources at lower temperatures may bee a “burning” flame, or static electricity. When assessing the probability of fire, it is normal to look at two types of situations, open and closed space:

- An open space is normally an outdoor situations with good (ventilation (no accumulation)
- A closed space is normally a situation inside a fuel tank or a fuel cistern.

In an open space, the key determining factor for assessing the probability of fire are the fuel volatility and the lower flammability limits, as well as the fuel vapour density, diffusion coefficient and source of ignition. Low volatility makes it difficult to generate sufficient vapour to achieve a combustible mixture. Alcohol fuels are much less likely to ignite in open areas compared to petrol. Since diesel fuel has a very low volatility, the risk for fire in open situations is very low. However, diesel fuel has a relatively low autoignition temperature and this property makes it more likely to achieve ignition if exposed to a hot surface. Under the hood, this might be the case, if the exhaust manifold or the turbine of the turbocharger is hot enough when a fuel leak is experienced. In a closed space, the key factors for assessing the probability of fire are the fuel volatility, flammability limits and ignition properties

Open space

Diesel fuel

Diesel fuel represents the fuel (in this study), which is most difficult to ignite in open spaces. The reason for that is the extremely low volatility at normal temperatures. A combustible vapour mixture will occur only at temperatures above 56°C. To ignite diesel fuel at open spaces and in combination with high ventilation, a flame with relatively high energy must bee used. Diesel fuel has a relatively low autoignition temperature and this property makes it more likely to achieve ignition if exposed to a hot surface.

Petrol

In contrast to diesel, petrol can easily be ignited in open spaces. High vapour pressure gives a high rate of evaporation of the fuel and low diffusion coefficient, in combination with high vapour density, indicates that fuel vapour can be accumulated in “holes” etc. Petrol can also ignite at very low vapour concentrations. As in the diesel case, petrol has a low autoignition temperature – it ignites easily in contact with hot surfaces.

Ethanol (E100)

Neat ethanol is more difficult to ignite than petrol and diesel fuel in open spaces. Some of the reasons for that is:

- Lower vapour pressure compared with petrol
- Lower vapour density and higher diffusion coefficient compared with petrol
- Higher autoignition temperature compared with petrol and diesel (safer in contact with hot surfaces). High concentration (air/fuel ratio) needs for ignition.

E85

The information about risk assessments regarding E85 is still poor. However, fuel properties indicate that E85 may be a better fuel than petrol according to fire risks. Low volatility makes it difficult to generate sufficient vapour to achieve a combustible mixture.

Closed space

Diesel fuel

Fire risks for diesel fuel in closed spaces is low since the lower limit of the combustible range are about 56°C for normal market fuels. Return flow of fuel (from the engine) may, if the fuel level in the tank is low, increase the fuel temperature in the tank. However, most modern diesel cars are equipped with fuel coolers for the return flow, implying that this is very unlikely to occur.

Petrol

The probability for ignition in closed spaces is very low since the high temperature limit of the combustible range is low (about –10 for summer- and –20°C for winter petrol). Temperatures above these limits give too high fuel/air ratios (too rich mixture) for ignition to occur at all.

Ethanol (E100)

Neat ethanol represents – due to fuel properties – the highest risk for ignition (fire and explosion) in closed spaces. Since the combustible temperature range is from +12 to +41°C, there will be combustible vapours in closed spaces during a significant part of the year. Return flows (from the engine) may result in higher fuel temperatures.

E85

The combustible range for E85 fuel is defined between about -35°C and up to about +5°C (according to a Canadian study), what can be said to demonstrate the somewhat wider temperature range and its displacement towards higher temperature values for the E85 compared with petrol fuel. It ought to be noticed, however, that the rich limit of the combustible range of temperatures is displaced towards a higher limiting value when the fuel tank is becoming empty. This phenomenon appears for both E85 and petrol.

The limits of the combustible range (and influence of fuel composition, fuel level etc.) are not fully clarified and further investigations are strongly recommended. However, it is obvious that E85 vapour (in closed spaces) will be within the combustible temperature range more frequently than petrol vapour (due to the Swedish climate).

Measures to increase safety

Introduction

Motor fuels are per definition combustible and can (due to improper use, bad design, wrong material choice etc) of course give rise to serious hazards. As mentioned above, combustible vapours of E85 can occur at higher ambient temperatures – and in a broader interval – than for conventional petrol fuels. Saab, Volvo and Ford have already implemented design changes in their E85 cars. The recommendations, as proposed by the Swedish Petroleum Institute (SPI), will also imply safety improvements.

Volvo – Ford – Saab

FFV cars, which have been designed for use of E85 fuel, are presently being sold in relatively large numbers on the Swedish market (existing FFV car models in Sweden can be found by visiting the home page www.miljofordon.se). The technology used on the FFV cars differs significantly from ordinary petrol cars due to the different properties of E85 relative petrol. One aspect is that ethanol fuels are more corrosive than petrol, what makes it necessary to use special materials, which can resist the corrosiveness of ethanol.

There are three car manufactories, which produce and/or sell FFV cars in Sweden. They have all chosen different design solutions and safety measures for their vehicles as explained here below.

Saab has introduced a system, which allows fuel vapours at tank refilling to be taken care of on board the vehicle. That system satisfies American environmental rules, so-called ORVR rules (with the exception of E85 pumps at Swedish filling stations, fuel vapours are in general taken charge of at the filling station itself). Further, Saab uses metal, which is grounded, for the fuel refill piping. The refill pipe is also narrow so as to avoid accidental fuel filling by the wrong type of fuel. When the tank is empty, it contains large amounts of fuel vapour, which is being forced out, by refilling of new fuel, via a large canister with active carbon, which adsorbs the fuel vapours. When the car is then started, air is being sucked through the canister with the effect to empty it of stored hydrocarbons, which are then directed into the engine inlet system to be utilised as fuel. Further, a back valve has been positioned at the spot where the tank fill pipe is ending with the purpose to stop fuel vapours to escape back ways (that is via the tank refill pipe), as they do on all other cars on the Swedish market.

Safety adaptations as undertaken by **Volvo and Ford** are somewhat different. In an interview with a representative from Volvo, it was confirmed that materials have been substituted in large parts of the fuel system of their FFV cars in order to maintain or improve system obligations and life in meeting the special requirements as posed by ethanol. Typical examples of such exchanges of materials are rubber and plastic gaskets in fuel lines and fuel pumps. Further, electrical contacts are being exchanged in order to avoid oxidation, and certain fuel pump components have been exchanged to ensure its compatibility with ethanol. Furthermore, valve seats and valve guides have been modified, and fuel injectors and software for engine control are specific and unique. The fuel system is also so designed as to alleviate risks for electrical spark formation. Volvo also seems to consider the ethanol fuel and conventional petrol to be comparable in regard of their temperature ranges of combustibility. Finally, the fuel tank piping is designed of metal, which is grounded with the body of the car so as to alleviate risks for build up of static electricity. These design principles are inherent in all of the Volvo base engines and, also, in their FFV engines.

Recommendation issued by the Swedish Petroleum Institute

SPI (note 1 and 2) has recently issued recommendations in regard of the safety aspects of E85 fuel. The following safety measures are being proposed:

- In choosing materials for different parts of an E85 facility, it is important to pay attention to the corrosive properties of E85 fuel. Oil companies require that pertinent suppliers shall assign in writing that the materials, which are being used in various parts of the system, are good and pertinent for E85. It is considered proper and expedient to meet this requirement with the aid of certificates, or via some other type of documentation in writing.
- The fuel tank shall be made of suitable material or equipped with an inner surface treatment, which is approved for E85.
- The fuel refill pipe should be made of suitable plastic material or made of warm-galvanized steel. The latter material can be accepted here due to the fact that the refill piping is normally left in an emptied state.
- The distribution line should be made of a suitable plastic material.
- Gaskets and other materials in the metering box should be of material, which is suitable for E85.
- The refill pipe and the pistol valve should also be featured by material, suitable for E85.
- The equipment for over-fill protection of an E85 installation shall be adapted to E85 because the equivalent system for pure petrol is not applicable.

The fuel gas phase in a closed E85 system will have a composition within the combustible temperature range more often than is the case for pure petrol. The following measures are therefore recommended to be undertaken in order to prevent possible ignition to propagate within the system:

- Flame arresters shall be applied to the airing system of the tank in accordance with SÄIFS 1997:9, point 4.2.6. As this requirement refers to new installations, the new rules as based on the ATEX directive require that the flame protection shall be carried out in accordance with the valid EU standard. Flame protection according to class IIB1 is recommended.
- Some form of flame arrester must also to be applied to the refill system of the tank. This arrester may be designed either as flame protection equipment, a well functioning, bolted shut-off tap, or as a liquid lock.
- Static electricity rarely causes fuel fires although smaller fires or weak puffs have been due to such a cause by refilling of cars. In order to alleviate, as far as possible, this risk the pistol valve on refilling pumps for E85 should not be equipped with a looping up mechanism.

Note 1 The American Petroleum Institute (API) issued already back in 1986 recommendations regarding proper handling of ethanol and ethanol blends (for American fuels). These recommendations also include the issue of vapour recovery systems at fuel refill situations (20).

Note 2. A new version of this will be realised by the end of year 2006.

Vapour Recovery

The instructions (SNFS 1991:1), as issued by the Swedish Environmental Protection Agency (SEPA), include requirements for gas Vapour Recovery system of motor petrol at fuel filling stations. However, these instructions do not apply to E85 fuelling. With the exception of refilling of FFV cars as designed by Saab, fuel vapours are emitted into open air by fuel refilling of E85 cars at Swedish filling stations.

The vapour recovery system in the petrol distribution chain is divided in two-step:

- Step 1 – Vapour recovery from filling station to tank lorry trucks. The instructions are issued by an EU-directive. New recommendations issued by SPI and (SRSA - Swedish Rescue Services Agency) will be released during end of year 2006.
- Step 2 – Vapour recovery during filling a car. The Swedish EPA issues instructions and new instructions will be released in the near future.

Assessment

The impact of this fact is, generally speaking, that a vapour volume just as large as the total volume of E85 fuel having been refilled at the stations, is being emitted (50 litre fuel = 50 litre gas emitted to open air). It is important from an environmental and health perspective that this problem is addressed as soon as possible. An alternative to step 2 solutions may bee to use (OVRV) On board Vapour Recovery Systems (take care of the vapour on board the cars, in accordance with the solution by Saab).

To introduce both step 2 recoveries and OVRV system is not a good solution, since these systems do not work properly together. Since this question is complex, the oil and car industries must find a joint solution.

In case of fire

The fire hazard associated with a fuel is not only determined by the likelihood of that a fire occurs but also by the behaviour of the fire, once it has occurred. Some important issues may be, how quickly the fire spreads, how easy it is possible to detect, heat release, toxic combustion products, difficulties to extinguish etc.

Difficulty

The "damaging capacity" of a certain fuel does not only depend on the "violence of fire" but also of factors such as heat of combustion and smoke generation.

Diesel fire

Diesel fire starts slowly due to low volatility and low flame spread rate. A combination of high heat of combustion and low heat of vaporisation (ratio 150:1) – results in a fire that will progress rapidly and will burn violently. A diesel fire will also generate a lot of dangerous (and toxic) smoke.

Petrol fire

A high heat of combustion in combination with low heat of vaporisation results in a fire that will progress rapidly and burn violently. The high volatility of petrol results in that a petrol fire will spread 100-fold faster than a diesel fire and progress very rapidly to an uncontrolled state. This in combination with a high heat release, flame temperature and smoke generation places petrol as one of the fuels that has the highest fire hazard of all liquid fuels discussed here.

Ethanol fire

Neat alcohols have the lowest fire hazard of the fuels discussed here (in comparison to diesel and petrol). They have low boiling point, low volatility, and low heat of combustion along with a high heat of vaporisation that gives a fire progress at a slow rate and a fire in a controlled manner. The heat of combustions for ethanol is lower than that of petrol and it has a heat of vaporisation almost three times as high, resulting in a slow rate of fuel vaporisation. Alcohol fires emit much less heat through radiation and therefore spread more slowly to surrounding materials. In case of a great fire, the limited oxygen availability will eventually, cause soot formation with ethanol – although lower than for petrol and diesel fuel – increasing the flame radiation.

E85 fire

An E85 fire starts as a "petrol fire" due to the petrol content in the E85 mixture. However, after some time all "low volatile" petrol component ends up and the fire will more and more become an "ethanol fire" The total generation of smoke and heat radiation is much lower compared to a petrol fire.

Visibility

To be able to limit the harmful effect of a fire, it is of great importance to detect a fire at an early stage. Therefore, the visibility of a fire is an important safety factor. Low visibility gives rise to increased risk for injuries especially for fire fighting personal.

Petrol and Diesel fire

Petrol and diesel fires generate “dark” yellow flames. These types of flames are visible during almost all types of condition.

Ethanol fire

In contrast to petrol and diesel fires, ethanol flames have a low visibility during daylight conditions. In case of using neat alcohols as fuels, it may be necessary to use additives, which are increasing the flame visibility. However, the risk for these types of “clinical fires” must be very low. In practice, there are a lot of surrounding materials in and around a car, such as rubber, wood, textiles, plastic hoses, paint, concrete, asphalt etc.” Also – in case of large fires – there will be suppression of oxygen availability, which will lead to a sooty flame.

E85 fire

Since E85 contain 15 % petrol, it is obvious that the flame will be visible at an initial stage. The flame from E85 fires is yellow blue. However, the petrol content in the fuel decreases continuously and the fire will more and more look like an ethanol fire. The visibility will however, never be low as for neat ethanol since even small amounts of petrol components will result in visible flames.

Difficulty of Extension

All type of fires can cause serious damages to property if they will not be extinguished in time. Therefore, it is necessary to extinct fires as fast as possible and to use effective methods.

Petrol and Diesel fire

Petrol fires are more violent than diesel fires and therefore more difficult to extinguish. The extinguish methods are however similar for these kind of fires. For “small” fires, CO_2 or fire extinction foams are preferable to use by fire fighting. For bigger fires, it is better to use extinction foams than water spray. For extremely large diesel and petrol fires, it is sometimes not possible to extinguish the fire at all. Diesel and petrol cannot be solved in water resulting in a separation (two phases), where diesel or petrol will accumulate in the upper phase. Other hazard aspects are the violent fire and the high heat release from the fire. These factors make it difficult for fire fighting personal to reach the fire. High generation of black smoke is another complicating factor when fighting these kinds of fires.

Alcohol fire

Ethanol fires can be extinguished with similar methods as for fire fighting petrol and diesel fires. Alcohols can easily dissolve in water (and will not float on the water surface). However, even mixtures of low concentration of alcohol in water are combustible. Therefore, water is not the best solution for fire fighting of ethanol fires – the best solution may be alcohol resistant extinction foams. Alcohol fires emit much less heat through radiation and therefore spread more slowly to surrounding material. Low heat radiation makes it possible for fire fighting personal to come closer to the fire compared with the situation for petrol or diesel fire. One complication with alcohol fires may be that low visibility (of burning flames) gives rise to increased risk for injuries especially for fire fighting personal getting too close to the fire.

The extinguish methods for E85 are similar as for neat ethanol fires. However, water is even more unsuitable as a fire extinction agent than for fire fighting of neat ethanol fires. The reason for that is that, besides the risk for phase separation, there will also be an extra risk since water/alcohol mixtures are combustible even at low concentrations. E85 fires generate relatively small amount of smoke. In contrast to neat ethanol, the burning flames will be visible during most conditions.

Example of accidents

Fuel fires can appear during refuelling and the ignition source can be static electricity. Between the years 1995 to 2005, 162 petrol fires caused by static electricity have been reported in the USA. The total number of filling (situations) is about 11 – 12 billion per year indicating that this kind of fires is very uncommon.

The conductivity of E85 is much higher compared to petrol. Fuels that have low conductivity tend to accumulate static charge and release the charge through a spark. This has potential to become an ignition source for a fuel fire. The higher the conductivity of the fuel, the more quickly a static charge can dissipate and therefore it is less likely to cause ignition.

The most common reason for static electricity (built up) is when the loop up mechanism on the pistol valve is used. The person leaves the filling pump and gives him/her a possibility to get charged (during a lot of different types of activities). This is the reason why looping up mechanism is not used at Swedish filling stations offering E85 fuel. However, there are also a lot of other sources for static electricity, such as, friction between liquids and hoses, different electrical potential levels etc.

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Annex – SPI recommendations for handling of E85 fuel on filling stations

Prerequisites

It is increasingly popular in Sweden to choose and drive cars for E85 fuel. The effect of this trend is that an increasing number of filling stations are being supplied with particular pump and storage equipment with the objective to supply the new E85 fuel to the customers. This trend is expected to increase significantly in the short time perspective.

The objective of the present recommendations is to provide instructions about which special measures are in need of being implemented, from a safety point of view, at petrol stations selling E85 fuel. A risk assessment of E85 relative petrol has been carried out to provide foundation for the recommendations.

The recommendations have been produced by the Swedish Petroleum Institute (SPI) in concert with the Swedish Rescue Services Agency. The objective is to address the oil branch and the communities as licensing and supervising authorities. If these recommendations are honoured, the Swedish Rescue Services Agency, will consider the handling of E85 as safe, thereby meeting the legal obligations for handling goods which are prone to fire and explosion. In case other technical solutions would be preferred, the owner of an E85 installation must demonstrate, by carrying through a specific risk investigation, that his choice of particular solutions will ensure equally safe handling of the products regarding fire and explosion risks. When new installations are being built the present recommendations can be directly obeyed. Already existing facilities must be completed, as soon as possible, in accordance with these recommendations in regard of flame arresters, gas vapour Recovery system and fuel level indication. However, adaptation to the prescriptions of the present recommendations regarding materials and surface treatments as utilised in the already existing facilities ought to be allowed, from a safety point of view, to be performed somewhat later in time.

Legal requirements

In Sweden it is necessary to acquire a license for handling with fire-prone products at filling stations. Further, a license permit having been received for conventional petrol is not automatically valid also for E85 fuel. Such a license must, accordingly, be completed with an additional license for E85, and an E85 installation is, furthermore, not allowed to be used prior to its having been controlled and declared to meet the technical requirements for safe handling. These rulings are applicable also for the erection of a new installation exclusively for E85 or for E85 as combined with sales of petrol. E85 fuel has been assigned, as is also the case for petrol, as a fire-prone liquid product according to safety class 1 with applicable rules in SÄIFS 1997:9 and in SRVFS 2004:7. The classification schemes, which have to be established for every filling station and which determine the selection of equipment, are the same independent of whether petrol are to be handled exclusively or together with E85 properties of E85 differ relative to petrol, what make it recommendable to apply certain, additional fuel. When applying these rules it should be taken into consideration that the product precautions for the E85 installations. Accordingly, the following differences are of importance in this respect:

It is necessary to take the corrosion properties for E85, which differ from those of petrol, into consideration by selection of various parts of an installation. Aluminium, Zink, and brass are examples of unsuitable materials together with E85. E85 also affects certain materials, made of plastic and rubber, in a different way than petrol.

The combustible temperature range are different for ethanol and petrol. The consequence of this fact is that an explosive vapour mixture of E85 and air can be formed inside a closed cistern/tank within a wider temperature range for E85, which is also displaced towards higher temperatures than is the case for petrol. There are somewhat diverging information available regarding which temperature ranges are to be applied for formation of combustible fuel vapour mixes for the two different fuels here considered. However, according to SAE paper 950401 ("flammability tests of Alcohol/petrol vapours"), the temperature ranges for combustible fuel vapour mixes to be formed are given as -41 ^{o}C up to -10 ^{o}C for petrol and from -33 ^{o}C up to +11 ^{o}C for E85. However, the shaping of the practical, extra precautionary safety measures as here recommended to be undertaken for E85 fuel is independent of the exact definition of the combustible temperature ranges.

Design of petrol stations for E85 fuel

Selection of materials.

In the selection of material for construction of various parts of an installation, the corrosive properties of E85 must be taken into consideration. It is of importance for the oil companies that possible suppliers will assign the materials, which have been used in various parts of the facility, to be suitable for E85. This can be fulfilled by a certificate or via some other form of documentation in writing. Accordingly,

The cistern shall be constructed of a suitable material or be furnished with an inner surface treatment having been approved for E85 fuel. Bottoms of cisterns for petrol are often surface treated up to one third of their physical sizes. However, such a measure is deemed not to be sufficient for E85. Instead, the entire cistern shall be constructed of a material, which is approved for E85.

The refill pipe ought to be made of a suitable plastic material or of warm-galvanized steel. The latter material here mentioned can be accepted in this case, due to the fact that the refill pipe is normally empty.

The distribution piping should be of suitable plastic material.

Packings and other materials in the case for measuring equipment shall be made of materials suitable for E85.

The pipe and pistol valve shall be of material suitable for E85.

The equipment for securing against over-filling shall be adapted for E85. The type of over-filling equipment for petrol is not applicable to E85.

Enhanced risk for ignition

The fuel vapour mixture in a closed E85 system will have, more often than is the case for petrol, a composition which falls within the temperature range for explosion risk. Therefore, the following measures are recommended to be implemented in order to prevent any ignition to propagate into the system:

A flame arrester shall be applied on the airing system of the cistern in accordance with SÄIFS 1997:9, point 4.2.6. As this requirement refer to new installations, the new rules as based on the ATEX directive require that the flame protection shall be carried out in accordance with the valid EU standard. Flame protection according to class IIB1 is recommended.

Some form of flame arrester ought also to be applied to the refill system of the cistern. This arrester may be designed either as a flame protection equipment, a well functioning, bolted shut-off tap, or as a liquid lock.

Static electricity rarely causes fuel fires although smaller fires or weak puffs have been due to such a cause by refilling of cars. In order to alleviate, as far as possible, this risk the pistol valve on refilling pumps for E85 should not be equipped with a looping up mechanism.

Vapour recovery system

The instructions (SNFS 1991:1) as issued by the Swedish State Authority for Environmental Protection (SNV) includes requirements for gas recovery of motor petrol at fuel filling stations. However, these instructions do not apply to E85 fuelling. With the exception of refilling of FFV cars as designed by Saab, fuel vapours are emitted into open air by fuel refilling of E85 cars at Swedish filling stations.

The vapour recovery system is usually divided in two steps. In the first step vapours from the cistern are refluxed to the depot for reuse. In the second step the vapours are being refluxed to the cistern for refilling cars. When this vapour recovery system is connected to an E85 installation, it is important to take the associated special safety risks into consideration. It is also recommended not to connect the second step to the vapour recovery system until this problem has been investigated further. Prior to connecting E85 to the first step, the person in charge of the installation should secure, in concert with the supplier of the vapour recovery system of his facility, that no safety risk is appearing and that it keeps on functioning. This is also to be appropriately documented.

Levelling procedures

The increased risk for ignition to occur is to be taken into account while levelling manually. As an additional precaution a wooden stick should be used and, further, the procedure shall be carried through in accordance with written instructions. However, it would, from a safety perspective, be preferable to utilize an automatic method for fuel level determination (an “ATM” method).

Means of fire extinction

According to the opinion of the “Rescue Organisation” in Sweden special alcohol resistant fire extinction foams are preferably to be used by fire fighting of an E85 fire.

Stockholm October 3rd 2005