HVO Handbook

Guidance on industry conversion to Hydrotreated Vegetable Oil

Issue 1.2 - June 2021

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1.2	09/062021	New 2.3.8.1 - First time inclusion of information on flue goods and acid corrosion classification to BS EN1443.
1.2	09/062021	New 2.3.8.2 – First time inclusion of information relative to the acidity of condensate arising from combustion, including new Annex F.
1.2	09/062021	New 2.4 – First time inclusion of information relative to stoichiometric combustion, including new Annex G

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Figure 1 – Sutherland Tables & Home Heating Carbon Emissions
Figures 2, 3, 7, 8, 10, 11 – Oil Heating Consultancy Services Ltd.
Figures 4, 5, 13 & 14 – Regin Products Ltd.
Figures 6, 9 & 12 – Crown Oil Ltd.
Figure 16 and Tables 5 & 6 – Danfoss Ltd.
Table 4 – SPX Flow – Tigerholm

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Foreword

Around 1.5 million homes in the UK currently rely on liquid fuel heating. However, to tackle the problem of climate change – the biggest challenge the world has ever faced – the fuels we use to heat our homes must change. It is vital that this is done in a way that is fair to consumers and minimises cost and disruption, which are major barriers to progress.

This handbook is a first edition “living document” and provides detailed points of consideration and instruction that are required to convert homes from using the fossil fuels in use today to a new low carbon renewable liquid fuel alternative called Hydrotreated Vegetable Oil (sometimes referred to as Hydrogenated Vegetable Oil or HVO). The content of this document will be updated in line with new learning that will come as more homes transition on to the new fuel.

Industry is committed to introducing this new fuel which, with government support, could make a major contribution to meeting the government’s net carbon zero target.

Paul Rose
Chief Executive – OFTEC

1 Introduction – decarbonisation with liquid fuels

In 2019, the UK government amended the Climate Change Act 2008 to create a legally binding target of achieving net zero emissions by 2050. This change to the legislation broadly follows recommendations from the government's independent statutory advisor, the Committee on Climate Change (CCC).

To achieve net zero, all areas of the economy will need to be transformed. This includes heating which is widely acknowledged to be a difficult challenge. Until now, most progress with decarbonisation has been made through major infrastructure – for example, off-shore wind turbines – but going forward the way we live our lives will increasingly need to change.

To achieve the decarbonisation of heat, we must end the use of fossil fuels such as oil, coal, and gas. How this is achieved is the subject of much debate. However, the government has made it clear that many homes will need to switch to electric heating using heat pumps, although today these are at least three times more expensive to install than conventional boilers.

Off-gas grid homes have been identified as an early priority for decarbonisation during the 2020s, but over half (65%) are difficult to convert because of their very poor energy efficiency which will result in significant additional fabric improvement costs. The CCC has suggested heat pump/biofuel hybrid systems as an alternative for hard-to-treat homes, but these will be very expensive to install and run.

OFTEC and other industry partners believe that many households will prefer to simply replace their existing liquid fuel with a low carbon alternative. Following extensive tests, we believe Hydrotreated Vegetable Oil (HVO) offers the best current solution. HVO can be used in existing appliances following straightforward, inexpensive modification and, at 100% concentration, will reduce an oil heating system's emission by around 88%.

This makes HVO not only a cheaper and easier solution to implement, but one that provides the greatest carbon reductions until at least the mid-2030s. Beyond that date, governments forecast that the carbon intensity of electricity will reduce sufficiently to enable heat pump systems to match and possibly surpass it for those properties where heat pumps can provide a cost effective solution.

1.1 Carbon savings (CO_{2e})

The use of bio-liquids derived from verified waste sources creates overall carbon reductions in the lifecycle analysis of emissions when compared to the use of traditional mineral (fossil) fuels such as Kerosene or Gas Oil.

It is important to note that the use of virgin plant stock as a bio-liquid source is not appropriate for achieving carbon reduction as it provides:

- Less carbon savings compared to liquid fuels derived from waste sources such as Used Cooking Oil (UCO). This is due to the waste product being counted as net carbon zero as its carbon impact on the environment has already been counted during its previous life cycle. This is in contrast to virgin plant feedstocks where the final application emissions additionally have to take account of and include the production, land-use change, cultivation, and initial transportation emissions as part of the lifecycle emissions analysis. By way of example a bio-liquid produced from waste sources should be expected to have an overall CO_{2e} emission rate of less than 50 g CO_{2e}/kWh combusted whereas the use of a virgin plant based feedstock to produce the same bio-liquid fuel would have emissions nearer 200 g CO_{2e}/kWh.[1]

- Uncertainty and concern over land use change away from natural forestation and food production resulting in environmental and socio-economic negative impacts.

Since 2007 OFTEC has been working with industry members and interested external parties on the development of alternative waste derived liquid fuels to initially reduce and ultimately remove from our market our reliance upon fossil fuels. Successful trials and testing proved that alternative liquid fuels could be utilised within our sector to reduce carbon emissions. The 1st stage of carbon reductions and reliance on fossil fuels was proven with a lower carbon fuel blend of 30% FAME (EN 14214) derived from waste sources and 70% Kerosene achieving circa 28% reduction in emissions.

Climate change targets set to achieve net carbon zero emissions by 2050 in the UK have rendered the use and consideration of bio-liquid/fossil fuel blends somewhat obsolete in terms of an industry approach for which political support is required.

Further evaluation works have been undertaken with regards to the use of 100% waste derived FAME in domestic applications which proved unsuccessful due to the properties of the liquid fuel in terms of small-scale combustibility, material compatibility and issues surrounding sub 15 ^{o}C storage. Larger scale applications and use of 100% waste derived FAME with bespoke installations and equipment have however been successfully installed and utilised since circa 2000.

A number of alternative liquid fuels have been considered and evaluated since 2010 for domestic fixed combustion purposes, none of which provided a satisfactory solution for home heat applications as in general terms the alternatives were either unstable and/or incompatible, at a theoretical concept stage only or were derived from fossil fuel source material which could have resulted in even higher emissions than those produced by combusting Kerosene.

Within the mix of alternative fuels evaluated by industry was BS EN 15940 Hydrotreated Vegetable Oil (HVO) developed as an alternative for the automotive diesel market. At the time of initial evaluation of the available HVO liquid fuels in the market the feedstock used to produce this fuel included virgin plant oils such as palm. Although HVO initially appeared to be an ideal alternative to Kerosene in terms of combustion application the inclusion of virgin feedstocks historically debarred it from further evaluation due to the socio economic and environmental impacts associated with virgin feedstock and the associated CO_{2e} emissions of up to circa 200 g CO_{2e}/kWh certainly would not have enabled industry to achieve a net carbon zero fuel source solution.

The pivotal point for our sector was movement away from HVO being produced from virgin feedstocks and the large-scale production and availability of HVO from waste sources such as used cooking oils. See ***Annex A*** – Neste Biofuels Sustainability Statement for HVO.

CO_{2e} Carbon equivalent emission evaluations carried out during 2020 by the Building Research Establishment (BRE)[2] These showed that HVO (when derived from waste sources such as UCO) CO_{2e} emissions for home heat applications could be as low as 25 g CO_{2e}/kWh and overall a generic value for waste derived HVO was established at 36 g CO_{2e}/kWh.

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[1] Source: RED II

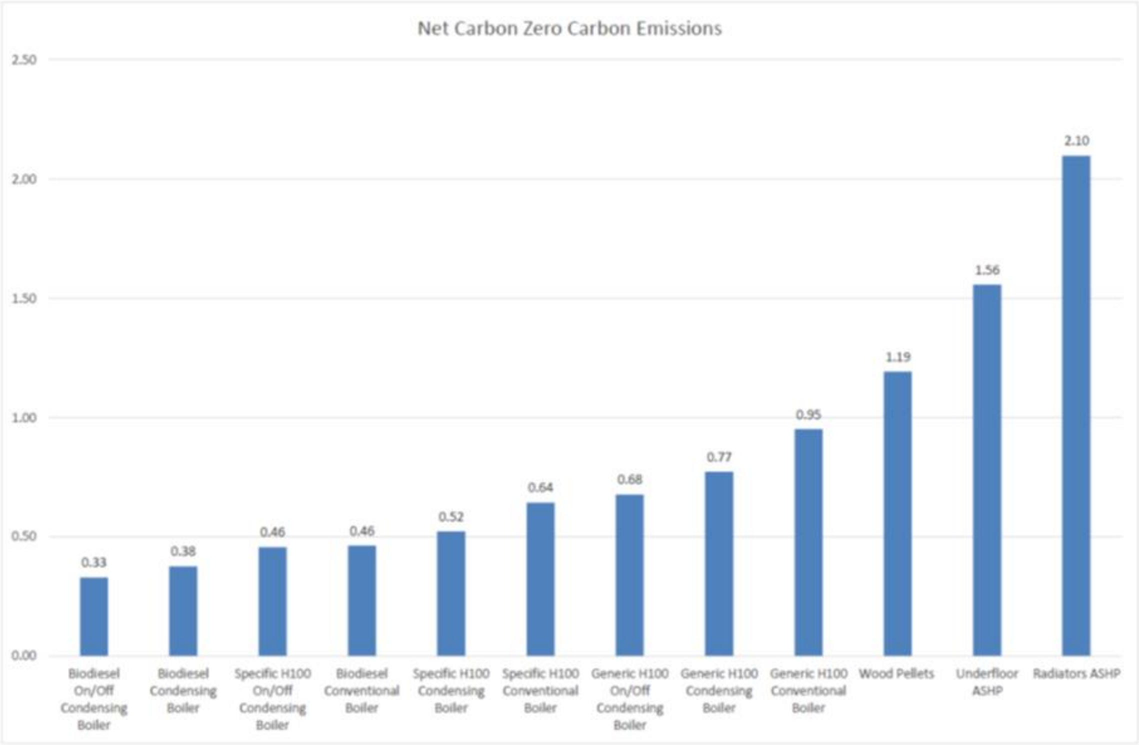
[2] Source: BRE Client Report P117563-1000 Issue 1.1, May 2020

The generic waste derived HVO CO_{2e} value has been compared to those within Table 12 of SAP 10.1[3], (November 2019) and was found to have CO_{2e}/kWh emissions:

- 88% less than Kerosene
- 32% less than biomass (wood pellets)
- 74% less than 2020 future projected electricity

Sutherland Tables were engaged to undertake comparative annual carbon emission indicative modelling works (May 2020) based on their comparative running cost tables but utilising SAP 10.1 Table 12 values available at the time.

Figure 1: 3-bed house Scotland indicative annual carbon emissions (tonnes CO_{2e})



Key: Biodiesel = FAME (waste derived BS EN 14214)
Specific H100 = Crown Oil HVO as evaluated by BRE (waste derived BS EN 15940)
Generic H100 = Generic HVO as evaluated by BRE (waste derived BS EN 15940)

The Sutherland Table's indicative chart, ***Figure 1*** above, clearly demonstrated the real potential for annual carbon emissions savings in comparison to other "Net Carbon Zero" government supported "solutions" achievable to our industry via the adoption of HVO as an alternative domestic home heat liquid fuel and justified further specific and detailed evaluation works to continue.

Elmhurst Energy were also engaged to undertake SAP modelling (The Government's **S**tandard **A**ssessment **P**rocedure for Energy Rating of Dwellings) which reflected similar outcomes but also identified where the then SAP system was somewhat inflexible with regards to the application of new fuels and technologies. Work with BEIS and BRE has addressed these concerns, and when published, SAP 10.2 should enable new fuels and technologies to be applied to the SAP evaluation and ratings of domestic dwelling houses.

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[3] https://www.bregroup.com/wp-content/uploads/2019/11/SAP-10.1-08-11-2019_1.pdf

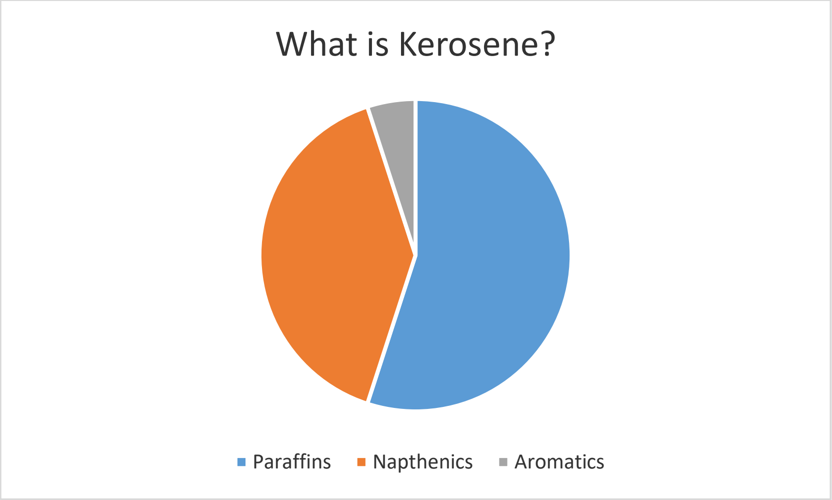
2 Hydrotreated Vegetable Oil for home heat applications

2.1 Introduction

Before industry adopts HVO as an alternative replacement fuel for Kerosene we need to understand what Kerosene predominantly is and then compare HVO to it.

Kerosene as used for domestic heat applications is basically a mix of paraffins, naphthenics and aromatics, see ***Figure 2*** below.

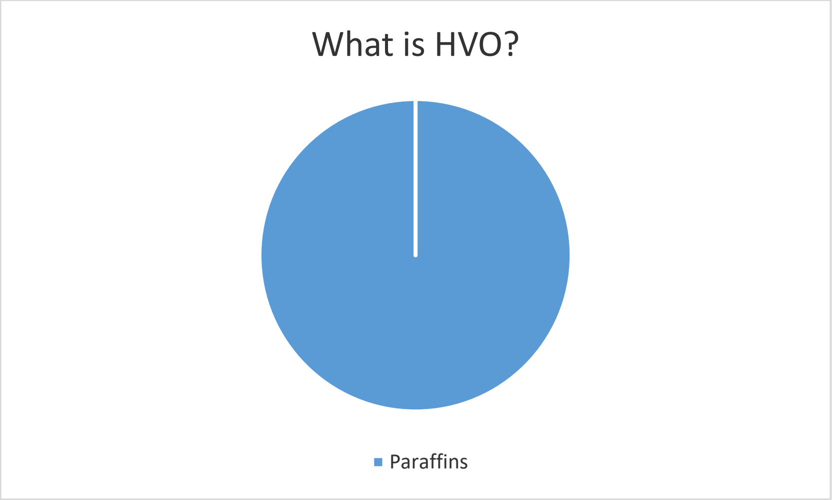
Figure 2: What is Kerosene?



In terms of industry material compatibility issues, it is predominantly the aromatics within the Kerosene which causes our traditional sector problems of leaking seals, failed flexible hoses, etc., as aromatics are good solvents.

So, what is the make-up of HVO?

Figure 3: What is HVO?



As can be seen from ***Figure* 3** above, HVO is 100% paraffins – the best bit of Kerosene!

HVO has been shown to be compatible with nitriles, fluoroelastomers, PTFE, vinyl ester resins, and epoxy resins, etc., due to the lack of aromatic compounds.

To aid industry members in identifying any potential material compatibility issues which may arise as a result of the change of fuels from Kerosene to HVO, OFTEC engaged the services of SMS Analytical Ltd, an independent laboratory, to evaluate and report on the differences between Kerosene and HVO. This report is reproduced in full in ***Annex B***.

2.2 Fuel quality

HVO used for domestic heating purposes should comply with BS EN 15940, be derived from verifiable and sustainable waste sources, and be produced under strict quality assurance systems to achieve consistent quality and properties of the fuel.

For the production of new bio-liquid compatible equipment such as boilers, burners and liquid fuel storage tanks - as well as for the conversion of existing installations and equipment - it is important and necessary that the properties of the fuel to be combusted are not only known but are consistent in supply. To achieve this, only HVO from known, verifiable and proven sources should be utilised and the use of aftermarket/post production additives (other than production additives as necessary to comply with BS EN 15940) such as those containing detergents and dispersants and/or combustion aids should not be used.

2.3 Fuel properties

2.3.1 Materials

The properties of HVO such as density, viscosity and reaction to temperature changes are different from mineral fuels such as Kerosene and can again react differently to different materials. This means that to change from 100% Kerosene mineral fuel to HVO will require formal conversion and re-commissioning of installations and equipment. Older materials such as natural rubber – as found in fuel pump and filter seals that are commonly encountered in mineral fuel installations – should be replaced as they can deteriorate rapidly when used with HVO due to the lack of exposure to aromatics which would have caused the materials to swell and have remained in a swollen state. In simple terms older existing rubber materials could “dry out”, crack and leak when the aromatics are removed.

OFTEC Member manufacturers have started to produce boilers, burners, tanks, and ancillary equipment dedicated to HVO to enable conversion in the field.

Examples of Product Data Sheets for both Kerosene and HVO are reproduced in ***Annex C***.

2.3.2 Safety

The safety issues concerning the transportation, storage, and combustion of Kerosene are dramatically reduced when compared with the properties of HVO.

We can clearly see from the two example tank labels in ***Figure 4*** and ***Figure 5***, reproduced overleaf, the dramatic reduction in warning symbols. The details of which are briefly that HVO is not classed as a flammable liquid nor as a pollutant.

Examples of Material Safety Data Sheets for both Kerosene and HVO are reproduced in ***Annex D***.

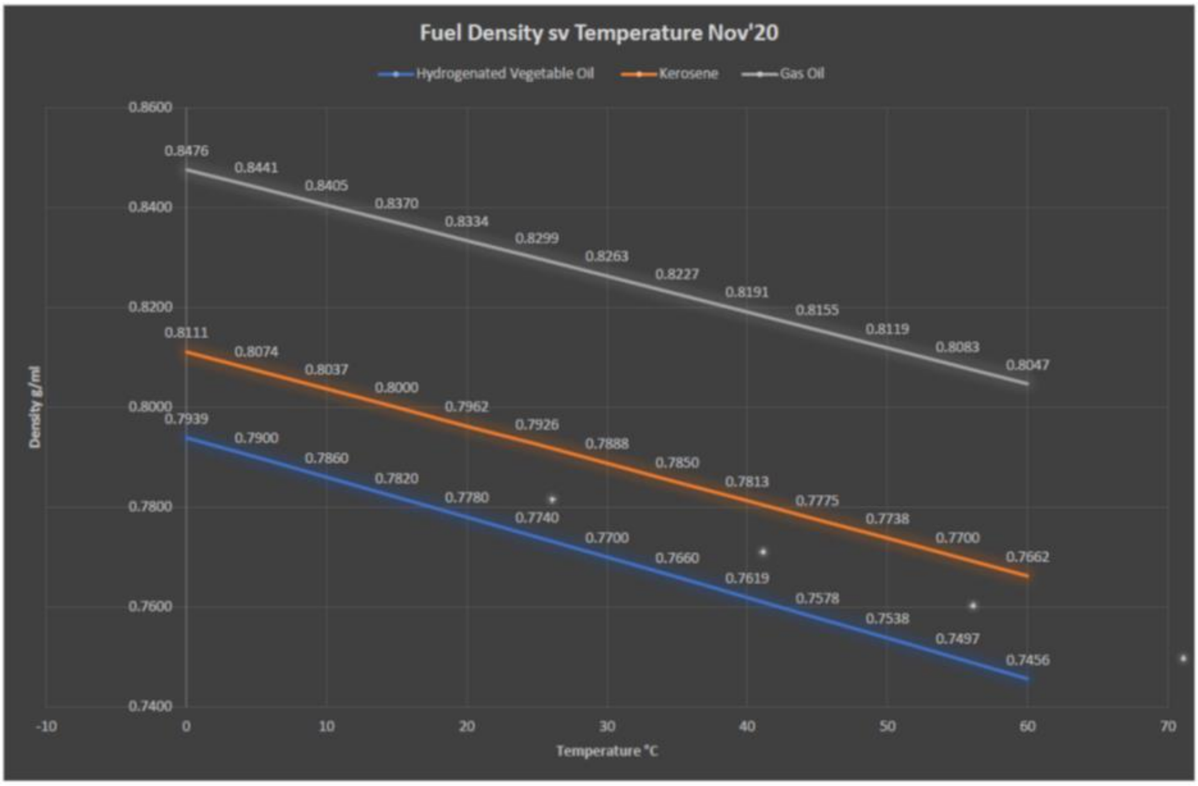
Figure 4: Example tank storage safety label for Kerosene

Figure 5: Example tank storage safety label for HVO

2.3.3 Density

Specific differences between HVO and Kerosene in terms of density, having been identified early on in the evaluation process, led to the need for further detailed evaluation works to be undertaken to enable a full understanding of fuel differences under different climatic conditions. This work was kindly undertaken by the laboratory staff at Crown Oil Ltd.

Figure 6: Comparative densities of fuels V's temperature

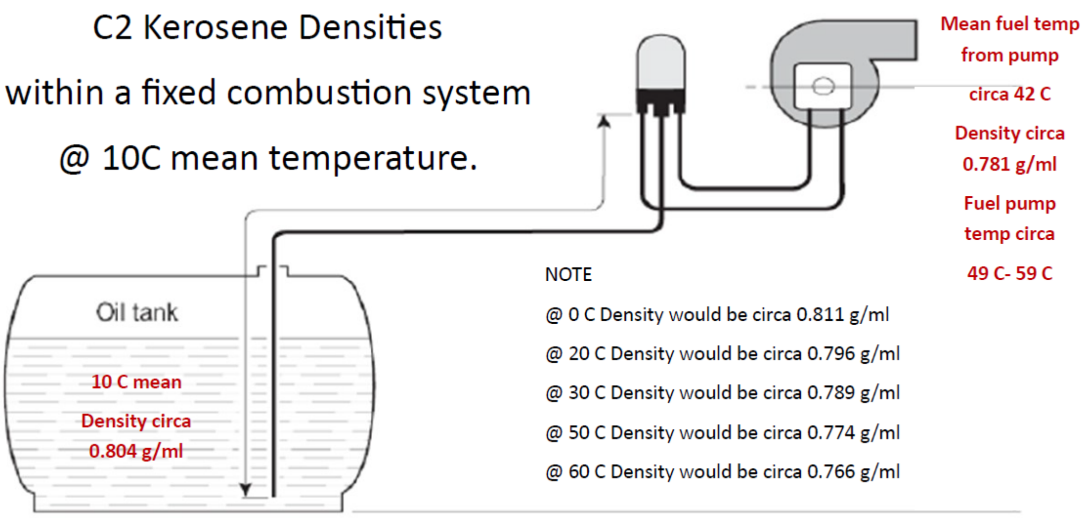


It can be seen from ***Figure 6*** above, HVO although often described as a "diesel" replacement fuel in reality has a density noticeably less than Kerosene and vastly lower than Gas Oil. As density equates to weight this is an important consideration when undertaking suction line sizing and atomising nozzle throughput calculations.

Applying the Crown analysis density results for Kerosene and HVO to field expected mean temperatures within domestic above ground integrally bunded liquid fuel storage tanks shows that where Kerosene would have a mean temperature density of circa 0.804 g/ml, HVO would have a significantly lower mean temperature density of circa 0.786 g/ml, affecting the correct sizing of suction lines on sub gravity supply systems.

At the burner however, applying the Crown analysis density results for Kerosene and HVO to field expected mean operational fuel pump temperatures shows that where Kerosene would have a mean fuel pump temperature density of circa 0.781 g/ml HVO would have a significantly lower mean temperature density of circa 0.762 g/ml, directly affecting the throughputs of Kerosene and Gas Oil calibrated atomising nozzles. An important consideration for appliance, atomising nozzle and fuel pump manufacturers. See ***Figure 7*** and ***Figure 8*** overleaf.

Figure 7: Field application indicative densities – Kerosene



C2 Kerosene Densities
within a fixed combustion system
@ 10C mean temperature.

NOTE

@ 0 C Density would be circa 0.811 g/ml

@ 20 C Density would be circa 0.796 g/ml

@ 30 C Density would be circa 0.789 g/ml

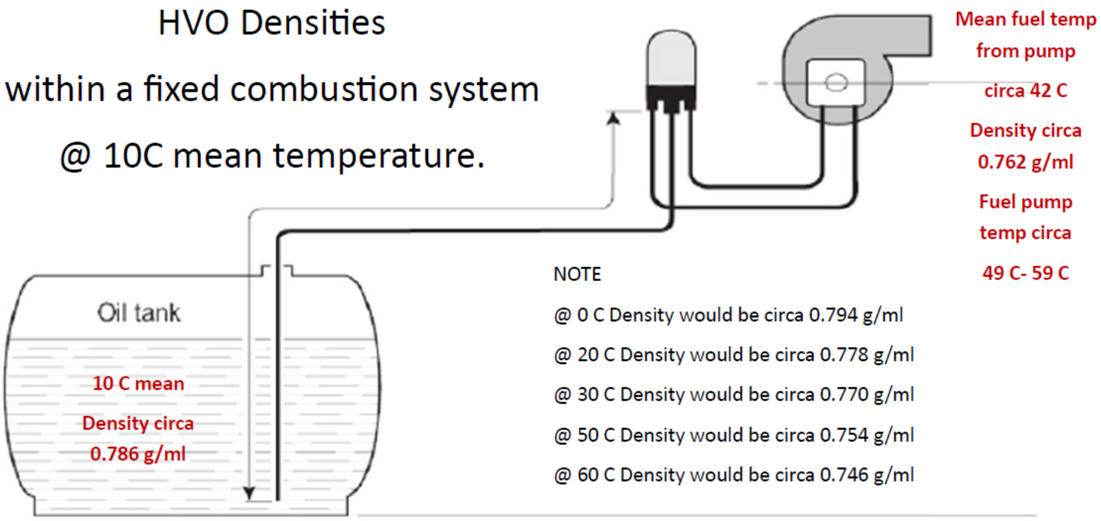
@ 50 C Density would be circa 0.774 g/ml

@ 60 C Density would be circa 0.766 g/ml

Notes

- Mean temperatures taken from OFTEC 2008-2010 B30K trials internal tank temperature monitoring of an above ground domestic integrally bunded oil storage tank.
- Fuel densities provided by Crown Oils from laboratory analysis December 2020
- Fuel pump outlet temperatures taken from KIWA Report 80638 October 2020.

Figure 8: Field application indicative densities – HVO



HVO Densities
within a fixed combustion system
@ 10C mean temperature.

NOTE

@ 0 C Density would be circa 0.794 g/ml

@ 20 C Density would be circa 0.778 g/ml

@ 30 C Density would be circa 0.770 g/ml

@ 50 C Density would be circa 0.754 g/ml

@ 60 C Density would be circa 0.746 g/ml

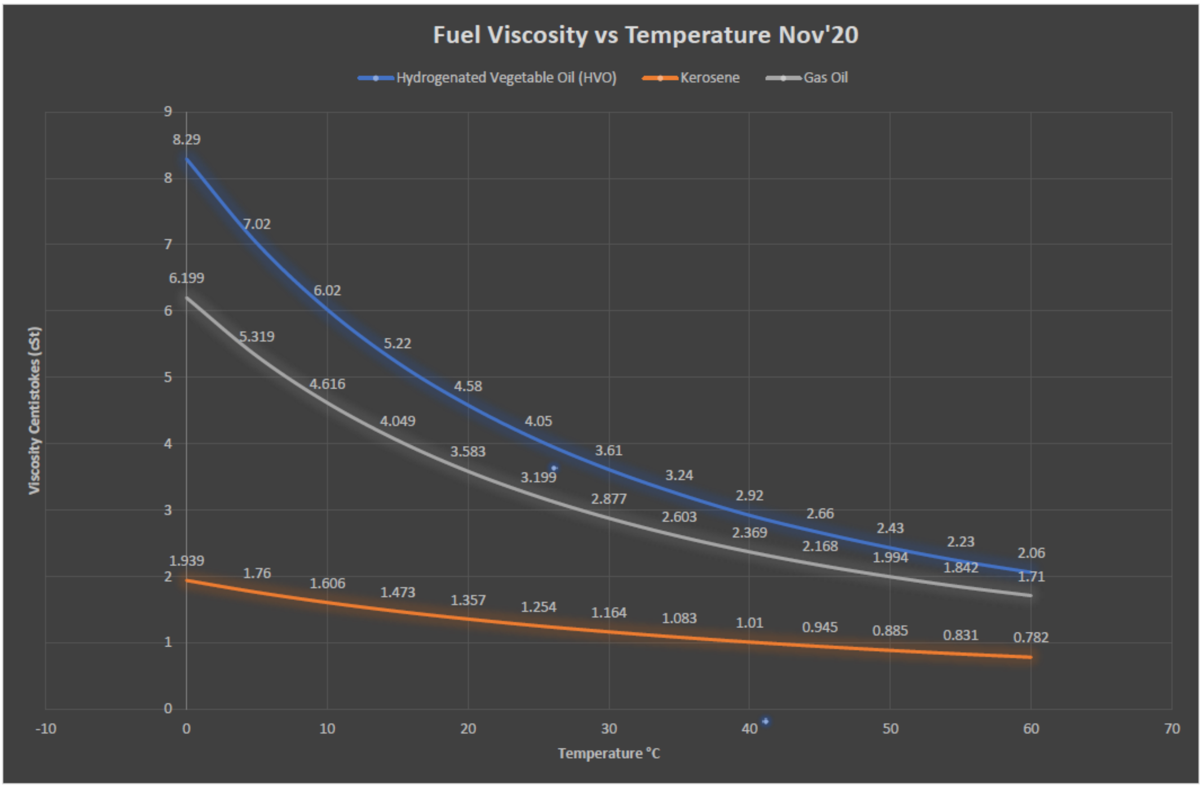
Notes

- Mean temperatures taken from OFTEC 2008-2010 B30K trials internal tank temperature monitoring of an above ground domestic integrally bunded oil storage tank.
- Fuel densities provided by Crown Oils from laboratory analysis December 2020
- Fuel pump outlet temperatures taken from KIWA Report 80638 October 2020.

2.3.4 Viscosity

Specific differences between HVO and Kerosene in terms of viscosity, having been identified early on in the evaluation process, led to the need for further detailed evaluation works to be undertaken to enable a full understanding of fuel differences under different climatic conditions. This work was kindly undertaken by the laboratory staff at Crown Oil Ltd.

Figure 9: Comparative viscosities of fuels V's temperature

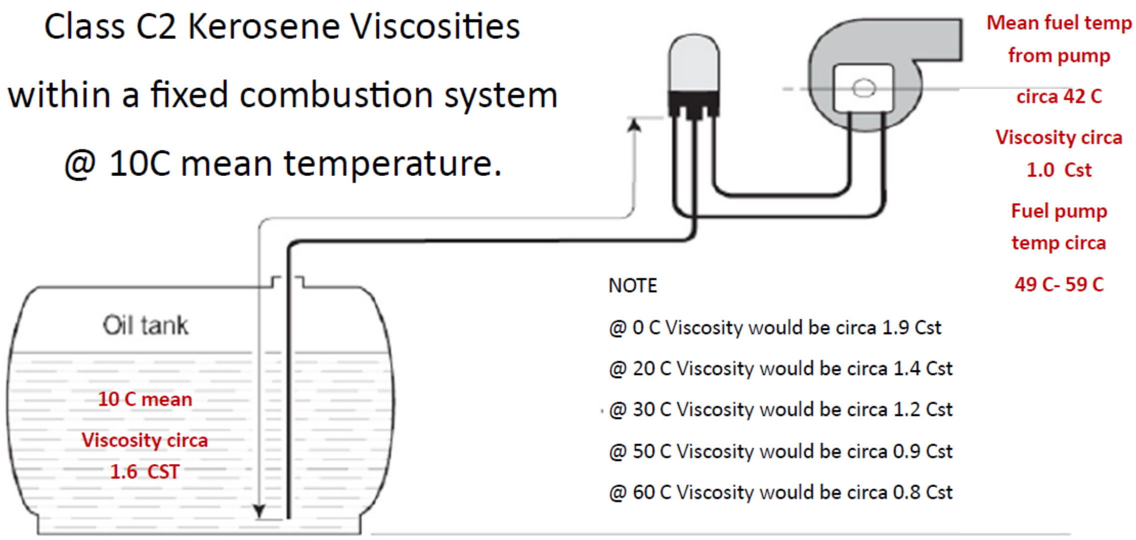


It can be seen from ***Figure 9*** above, HVO although often described as a “diesel” replacement fuel in reality has a viscosity vastly higher than Kerosene and even higher than Gas Oil. As viscosity equates to ability to flow, i.e. how sticky the fuel is, we can see here a major difference in the flow characteristics of HVO compared to Kerosene and even Gas Oil. As with differences in density, viscosity is again a major consideration when undertaking suction line sizing and atomising nozzle throughput calculations.

Applying the Crown analysis viscosity results for Kerosene and HVO to field expected mean temperatures within domestic above ground integrally bunded liquid fuel storage tanks shows that where kerosene would have a mean temperature viscosity of circa 1.6 cSt, HVO would have a vastly higher mean temperature viscosity of circa 6.0 cSt, affecting the correct sizing of suction lines on sub gravity supply systems

At the burner however, applying the Crown analysis viscosity results for Kerosene and HVO to field expected mean operational fuel pump temperatures shows that where Kerosene would have a mean fuel pump temperature viscosity of circa 1.0 cSt, HVO would have a significantly higher mean temperature viscosity of circa 2.8 cSt, directly affecting the throughputs of Kerosene and Gas Oil calibrated atomising nozzles. An important consideration for appliance, atomising nozzle, and fuel pump manufacturers. See ***Figure 10*** and ***Figure 11*** overleaf.

Figure 10: Field application indicative viscosities – Kerosene



NOTE

@ 0 C Viscosity would be circa 1.9 Cst

@ 20 C Viscosity would be circa 1.4 Cst

@ 30 C Viscosity would be circa 1.2 Cst

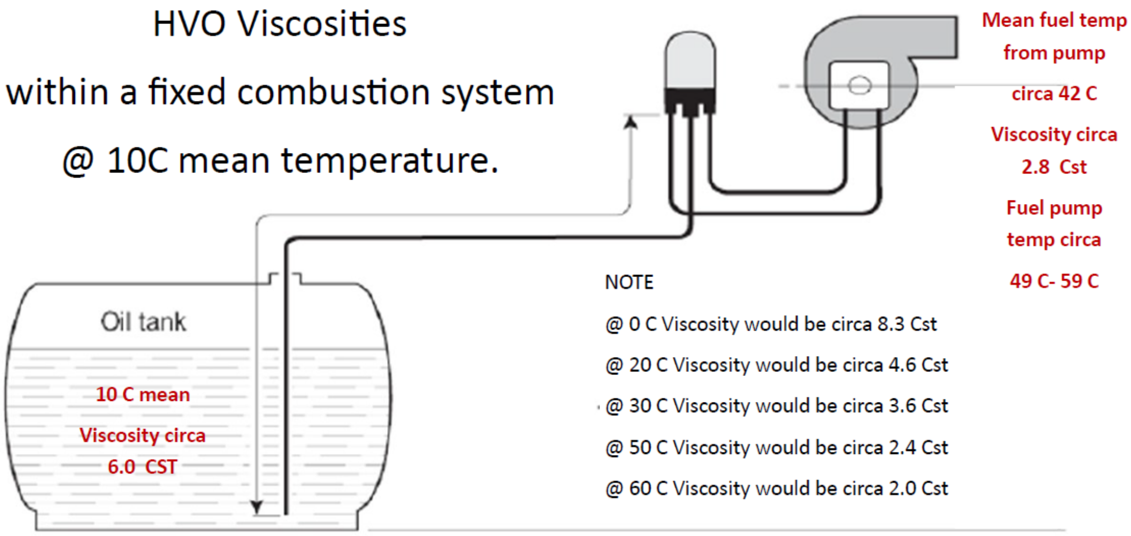
@ 50 C Viscosity would be circa 0.9 Cst

@ 60 C Viscosity would be circa 0.8 Cst

Notes

- Mean temperatures taken from OFTEC 2008-2010 B30K trials internal tank temperature monitoring of an above ground domestic integrally bunded oil storage tank.
- Fuel viscosities provided by Crown Oils from laboratory analysis November 2020
- Fuel pump outlet temperatures taken from KIWA Report 80638 October 2020.

Figure 11: Field application indicative viscosities – HVO



NOTE

@ 0 C Viscosity would be circa 8.3 Cst

@ 20 C Viscosity would be circa 4.6 Cst

@ 30 C Viscosity would be circa 3.6 Cst

@ 50 C Viscosity would be circa 2.4 Cst

@ 60 C Viscosity would be circa 2.0 Cst

Notes

- Mean temperatures taken from OFTEC 2008-2010 B30K trials internal tank temperature monitoring of an above ground domestic integrally bunded oil storage tank.
- Fuel viscosities provided by Crown Oils from laboratory analysis November 2020
- Fuel pump outlet temperatures taken from KIWA Report 80638 October 2020.

2.3.5 Flash Point

Comparative Flash points, initial boiling points and final boiling points for Kerosene, Gas Oil and HVO were provided by Crown Oils as shown in ***Table 1*** below:

Table 1: Comparative flash points and initial & final boiling points of fuels

	Flash Point (ºC)	Initial Boiling Point (ºC)	Final Boiling Point (ºC)
Kerosene	38	165	270
Gas Oil	63	180	360
HVO	78	202	310

As with other fuel properties we can clearly see here distinct differences between the three fuels especially for storage purposes that the flash point of HVO is well in excess of the sub 60 ºC definition point for classification as a flammable liquid.

2.3.6 Calorific Value

Evaluation of the comparative Calorific Values (Specific Energy) of HVO, Kerosene and Gas Oil were undertaken initially from their respective product data sheets available at the time and were found to be as shown in ***Table 2*** below:

Table 2: Comparative Calorific Values (CV) of fuels

	Net CV (MJ/kg)	Gross CV(MJ/kg)
HVO	43.5	46.3
Kerosene	43.0	45.9
Gas Oil	42.8	45.4

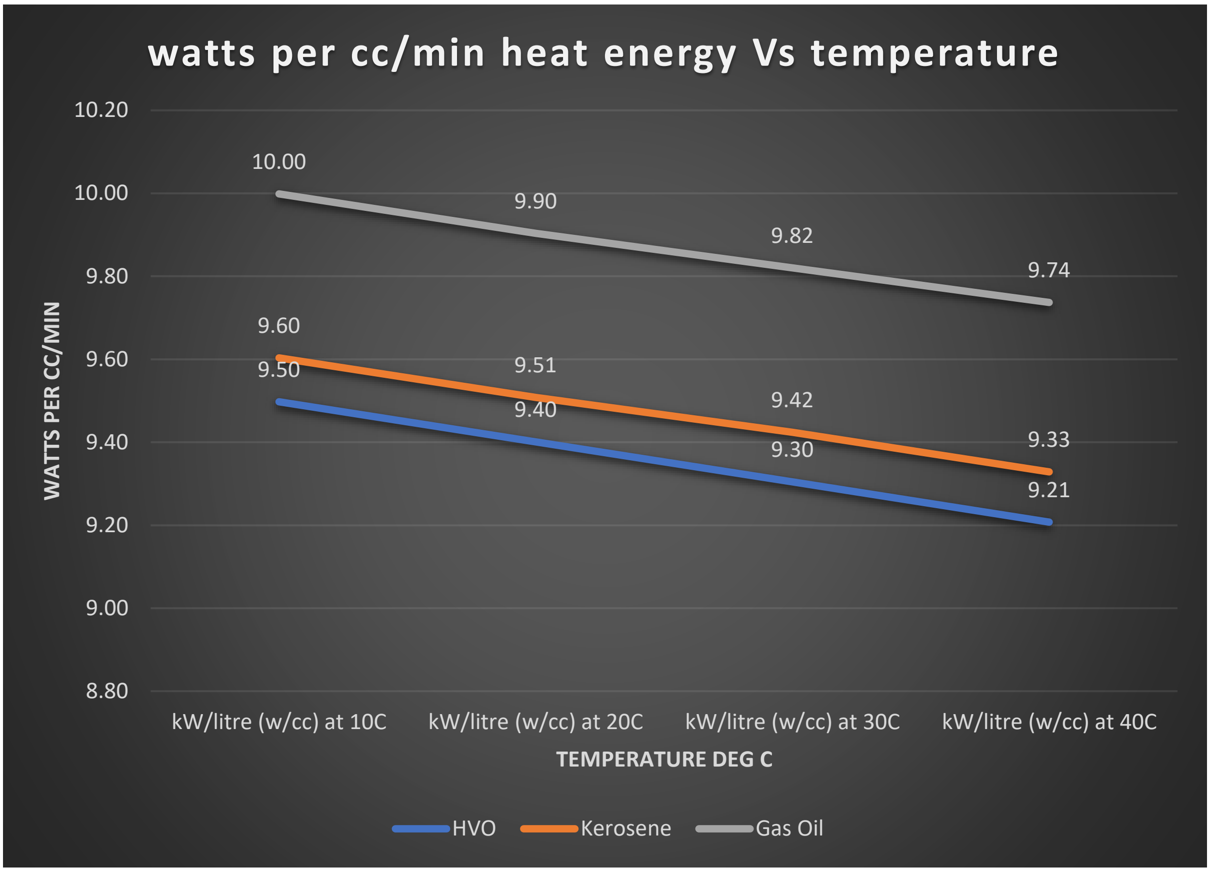
Note: Data provided by Crown Oils.

From the calorific values shown in ***Table 2*** above, when measured by weight we can see that HVO has the highest amount of available heat energy per kg. However, when we take into account the density of the fuel at given temperatures and look at the amount of available heat energy per litre then, the situation reverses. This is illustrated in terms of Net CV in ***Table 3*** below and ***Figure 12*** overleaf.

Table 3: Comparative Net Calorific Values of fuels at a given temperature (40ºC)

	MJ/kg	kW/kg	kW/litre (Watts/cc) @ 40ºC
Gas Oil	42.8	11.89	9.74
Kerosene	43.0	11.94	9.33
HVO	43.5	12.08	9.21

Figure 12: Comparative net heat energy of fuels V's temperature (change in density)



2.3.7 Carbon chain length

When comparing the number of carbon atoms present within Kerosene and HVO (the length of the carbon chain affects atomisation) we can see a noticeable difference between the two liquid fuels.

Typical carbon chain lengths:

Class C2 Kerosene to BS 2869	circa C6 – C16
HVO to BS EN 15940	circa C15 – C18

SMS Analytical were engaged by OFTEC to carry out a comparative chemical analysis of a sample of Kerosene and HVO. See ***Annex B***.

SMS carbon chain length findings:

Class C2 Kerosene to BS 2869	circa C7 – C15
HVO to BS EN 15940	circa C13 – C19

2.3.8 Sulphur content

Environmental and material compatibility concerns with regards to the interaction of liquid fuels in direct contact with components is not the only matter to take into consideration. We also have to take account of the interaction of products of combustion with materials within the combustion process and the discharge of those products of combustion to the atmosphere.

Likewise, with high efficiency condensing liquid fuel boilers we also need to consider the effect on materials and the natural and built environment from the condensate itself.

Typical sulphur levels:

Class C2 Kerosene to BS 2869	200mg/kg
HVO to EN 15940	< 5mg/kg

This clearly demonstrates that HVO contains at worst only 2% of the sulphur content of Kerosene whilst in its liquid state.

2.3.8.1 Flue goods - BS EN 1443

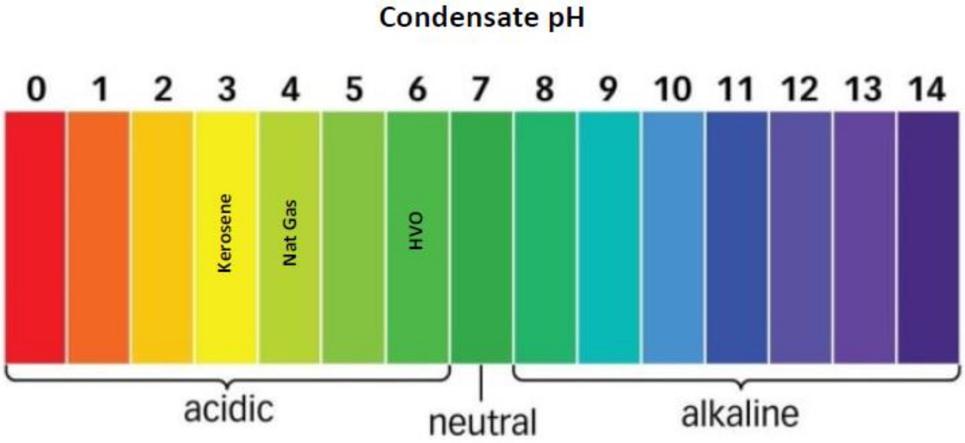
BS EN 1443 was amended in 2019 which resulted in a reclassification of acid corrosion resistance levels, which removed Kerosene as a heating fuel from corrosion resistance class 1 and placed it as per gas oil in corrosion resistance class 2. The changeover point from class 2 corrosion resistance level to class 1 occurs (or would occur if properly recognised within BS EN 1443) at 50 mg/kg sulphur content. In light of the typical sulphur levels of HVO in comparison to Kerosene as shown above, it is quite clear that industry has a robust case to seek amendment to BS EN 1443 so as to recognise that the corrosion resistance class for HVO is recognised as being class 1.

2.3.8.2 Condensate

SMS Analytical carried out analysis of samples of condensate from Kerosene, HVO and natural gas combustion processes as follows:

The pH levels measured from the three samples by SMS were found to be as follows:

- Kerosene pH level 2.9
- Nat Gas pH level 3.9
- HVO pH level 6.1



We can clearly see here the similarity between the pH levels of Kerosene and Nat Gas combustion condensate being only one pH level apart but with Kerosene combustion condensate being more acidic than condensate from Nat Gas combustion.

Comment: **The pH level of condensate from HVO combustion was found to be virtually neutral with a pH level akin to milk.**

The total acidy (mg/l NaOH) of each condensate sample as analysed by SMS were found to be as follows:

Kerosene	176	mg/l NaOH
Nat Gas	132	mg/l NaOH
HVO	<10	mg/l NaOH

This means that in terms of total acidity HVO combustion condensate is:

- > 94% less acidic than condensate from kerosene combustion
- > 92% less acidic than condensate from natural gas combustion

Conclusions:

1. Combustion condensate acidity will be massively reduced when utilising HVO instead of kerosene.

2. HVO combustion condensate should have no greater overall impact in terms of acidity than milk.

N.B. Material compatibility with regards to the chemical (trace paraffinic) composition of HVO condensate and its reaction with materials is required to be ascertained by manufacturers before bringing products to market.

The SMS Analytical report on combustion condensate is in ***Annex F.***

2.4 Stoichiometric Combustion

When ascertaining combustion efficiency for fixed combustion applications it is necessary to have knowledge of the calculated stoichiometric CO2 value expected at 100% combustion efficiency (zero excess air) for any given liquid fuel being combusted.

As Stoichiometric values are the starting point for determining combustion and overall appliance efficiencies and with the industry adoption of lower carbon sustainable liquid fuel alternatives SMS Analytical were tasked with calculating the StoichiometricCO2 values for Class C2 Kerosene, Class D Gas Oil and HVO from current fuel analysis data.

The Stoichiometric CO2 values calculated by SMS were found to be as follows:

Kerosene	14.18% CO2
Gas Oil*	14.22% CO2
HVO	13.68% CO2

* N.B. Gas Oil in the SMS Analytical report in ***Annex G*** is referred to as “Diesel”.

Oil Combustion analysers in common use in our sector typically measure Oxygen and calculate CO2 and have been found to be using Stoichiometric CO2 calculation values of circa 15% -15.5% for kerosene, light oil and gas oil.

Oil combustion analysers are now more readily available which directly measure the level of CO2 in the flue gasses sampled via an infrared sensor.

It is strongly recommended that when converting from kerosene to HVO or when commissioning a dedicated HVO boiler that, due to the differences in Stoichiometric combustion identified analysers which measure CO2 as opposed to calculate CO2 from measured Oxygen are used until such times that combustion analysers become available which have dedicated separate kerosene, HVO and Gas Oil settings which then gives both CO2 and combustion efficiency outputs specifically for each fuel.

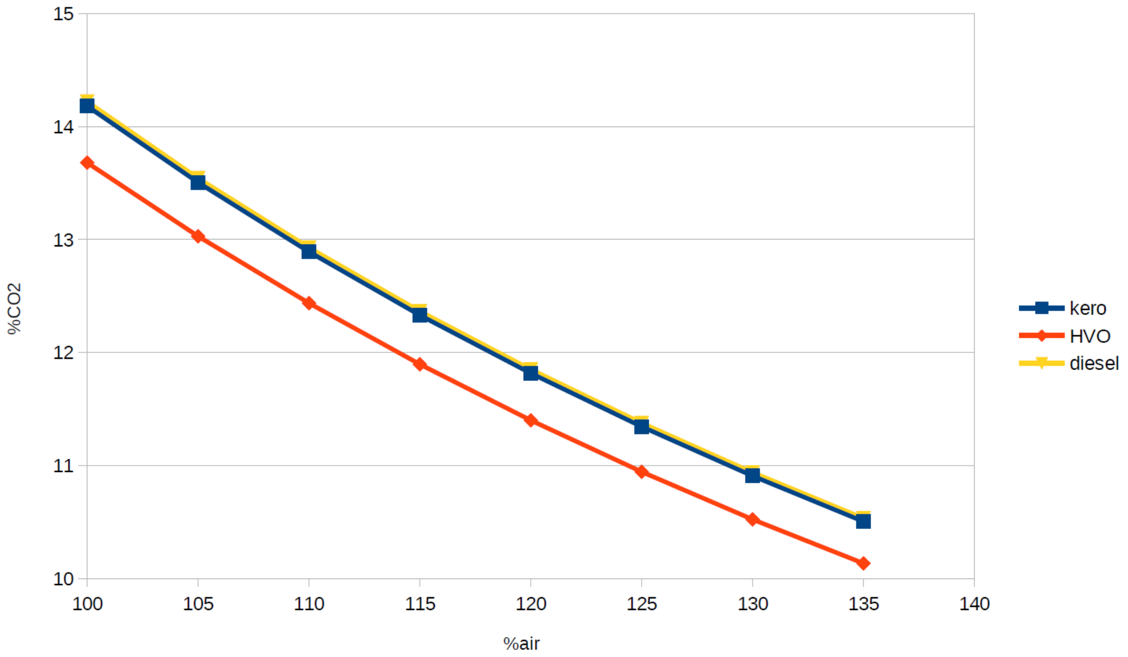


Fig 1 Dilution effect on carbon dioxide concentration with excess air

SMS analytical chart showing dilution effect on CO2 with excess air.

3 Technical requirements

All domestic liquid fuel fired installations for heating, hot water and cooking purposes should satisfy the guidance contained within BS 5410-1 and in addition any specific recommendations given in this document relating to the application and use of HVO as a domestic liquid fuel.

3.1 Fuel storage and supply

Bio-liquids should never be introduced to liquid fuel storage systems that are contaminated as this promotes bacterial growth. Storage tank husbandry is therefore essential in maintaining equipment reliability. Contaminated tanks and systems should be cleaned via fuel conditioning or polishing as a minimum before the introduction of bio-liquids as the consequences will inevitably be blocked filters and inoperative systems. Further information on tank cleaning methods can be found in OFTEC Technical Book 3.

It is strongly recommended that bio-liquids are never introduced to existing storage installations which do not have secondary containment and/or are over 20 years of age.

It is recommended that wherever possible and practicable new integrally bunded fuel storage tanks suitable for bio-liquids are installed. Further information on recommended liquid fuel storage tank capacities for mineral fuels can be found in BS 5410-1.

Supply line ancillary components which contain rubber gaskets or seals should be replaced or renewed prior to the adoption of bio-liquids. Due to the chemical differences identified between HVO and Kerosene HVO can cause older existing rubber seals and gaskets to retract back to their original dimensions (the aromatics in Kerosene having caused them to swell) thus resulting in fuel leakage and loss.

3.2 Fuel storage & supply system guidance points

- Manufacturers of liquid fuel storage tanks need to guarantee their suitability for use with Bio-liquids/HVO prior to purchase and installation.
- All equipment, especially storage tanks, supply line ancillary components and combustion appliances will be required to be clearly and permanently identifiable by non-intrusive means, this being labelled at point of manufacture (or for existing equipment at point of conversion) as (then) only being suitable for HVO. Example labels are shown in
- ***Figure*** 13 and ***Figure 14*** below.

Figure 13: Example appliance conversion label

Regin

HVO

This appliance runs on Hydrotreated Vegetable Oil to BS EN 15940

www.regin.co.uk

REGPL07

Figure 14: Example tank conversion label

Regin

HVO

WARNING

This tank contains Hydrotreated Vegetable Oil to BS EN 15940

www.regin.co.uk

REGPL06

- When converting existing systems, in the first instance all existing liquid fuel storage tanks without secondary containment shall be replaced with new (bio-liquid approved) integrally bunded storage tanks. Existing single skinned storage tanks which are in good condition and are not in excess of 20 years of age should only be considered for reuse when installed within secondary containment systems to CIRIA Report 163, subject to inspection for integrity and having undergone internal cleansing. Existing integrally bunded storage tanks should only be considered for short term use - prior to replacement - subject to inspection for integrity and having undergone internal cleansing and additionally even where they appear to be in reasonably good condition they should be considered to be at end of their useful life at 20 years of age.

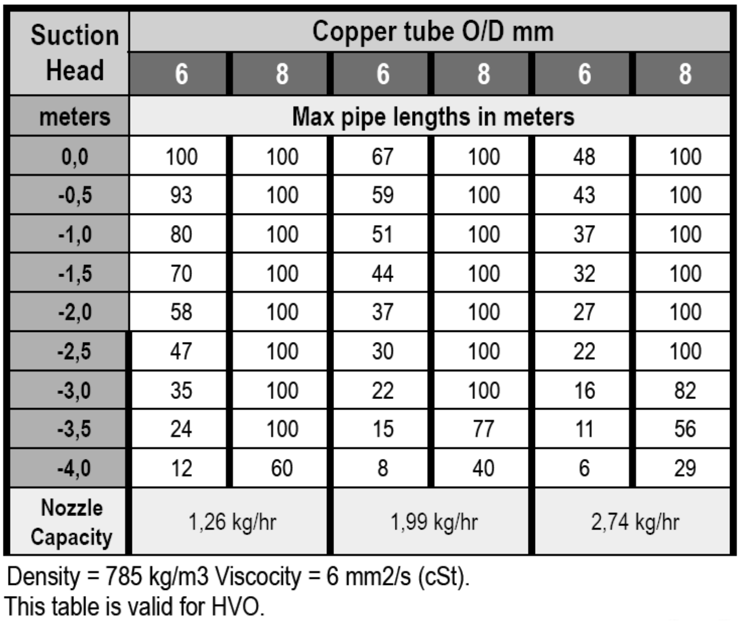
Supply system conversion would commonly require at least the replacement of non-bio compatible:

- Flexible oil lines.
- Filters and/or filter seals.
- De-aerators.
- Remote acting fire valves.
- Lever fuel valves/valves incorporating natural rubber seals.

3.3 Sub-gravity (suction supply line) systems

Attention should also be paid to suction line systems as a correctly sized Kerosene suction line may require an increase in size for example from 6mm to 8mm or even to 10mm due to HVO being more viscous than Kerosene and Gas Oil. HVO suction supply line sizes calculated by SPX Flow – Tigerholm, for OFTEC pilot demonstrator sites, are shown in ***Table 4*** below. The installation instructions for the SPX Flow HVO de-aerator are reproduced in ***Annex E.***

Table 4: Suction supply line sizing for HVO



Suction Head	Copper tube O/D mm					
	6	8	6	8	6	8
meters	Max pipe lengths in meters					
0,0	100	100	67	100	48	100
-0,5	93	100	59	100	43	100
-1,0	80	100	51	100	37	100
-1,5	70	100	44	100	32	100
-2,0	58	100	37	100	27	100
-2,5	47	100	30	100	22	100
-3,0	35	100	22	100	16	82
-3,5	24	100	15	77	11	56
-4,0	12	60	8	40	6	29
Nozzle Capacity	1,26 kg/hr		1,99 kg/hr		2,74 kg/hr	

Density = 785 kg/m3 Viscocity = 6 mm2/s (cSt).
This table is valid for HVO.

Note 1: Density and viscosity at a mean seasonal fuel temperature of 10ºC.

Note 2: The nozzle capacities stated above refer to Danfoss HVO calibrated atomising nozzle throughputs (at their calibration pressure), as provided for the OFTEC pilot demonstrator sites.

3.4 Pressure jet burners

3.4.1 General

Pressure jet appliances and installations can in some cases be converted to run on HVO with relative ease but only where the existing burner has been tested and approved by the manufacturer for use with HVO.

Conversion of an HVO approved pressure jet fired boiler from 100% Kerosene to HVO would commonly require at least the replacement of non-bio compatible:

- Atomising nozzles.
- Fuel pumps.
- Hydraulic rams and actuators.

And in addition, blast tube end cones and or Blueflame combustion tubes may well require replacement with different lengths and designs to achieve clean combustion.

The incorrect conversion of an existing burner can lead to the rapid build-up of carbon deposits on the burner blast tube, as shown in ***Figure 15*** below. The yellow flame burner, converted only some 24 hours previously, remained set for Kerosene and fitted with a Kerosene atomising nozzle, and had simply had HVO supplied to it and the air shutter adjusted to give the correct CO_2 reading.

Figure 15: Carbon deposit build-up on the blast tube of an incorrectly converted burner

Field trial experience has shown that although the burner component changes mentioned above are theoretically sufficient to enable conversion, carbon deposits on fixed head blast tube air veins can form where there is low fan static pressure, as may be found with older yellow flame burners typically found on standard efficiency boilers. Where older yellow flame burners are found on standard efficiency boilers, it is recommended that HVO conversion is achieved by the replacement of the existing Kerosene burner with a new HVO tested and approved burner. However, to conserve energy, fuel and power, to minimise running costs and achieve reduction in the production and release of harmful greenhouse gasses into the atmosphere it is strongly recommended that existing standard efficiency boilers with yellow flame burners are replaced with modern high efficiency condensing boilers with blue flame low

NOx burners. The firing of the appliances themselves should also be managed by weather compensated controls ideally which match the firing rate of the burner to the actual heat load demand at any given time.

Manufacturers of appliances and burners will make available dedicated HVO appliance and burner installation, service and commissioning instruction manuals so that the equipment can be commissioned specifically for HVO including the use of atomising nozzles specifically calibrated and marked for HVO applications.

3.4.2 Pressure jet burner atomising nozzles

Kerosene enhanced specification atomising nozzles and standard Gas Oil atomising nozzles are not recommended for use with HVO due to the differences in both density and viscosity of HVO in comparison to both Kerosene and Gas Oil fuels. Kerosene and Gas Oil atomising nozzles should be replaced with atomising nozzles specifically calibrated and stamped for HVO at 10 bar to OFTEC Bio-Liquid Product Standard BLPS E130 in order to maintain correct atomisation of the fuel to achieve complete combustion. Laboratory testing has identified that to enable appliance efficiencies to be achieved and maintained it is vitally important that the correct burner throughput (firing rate) is achieved to match the appliance's required heat energy input. To enable this to be achieved easily in the field HVO atomising nozzles also have their heat energy throughput (gross) stamped on the atomising nozzle and manufacturers supply atomising nozzle throughput charts as shown in ***Figure 16***,and ***Table 5***, and ***Table 6***.

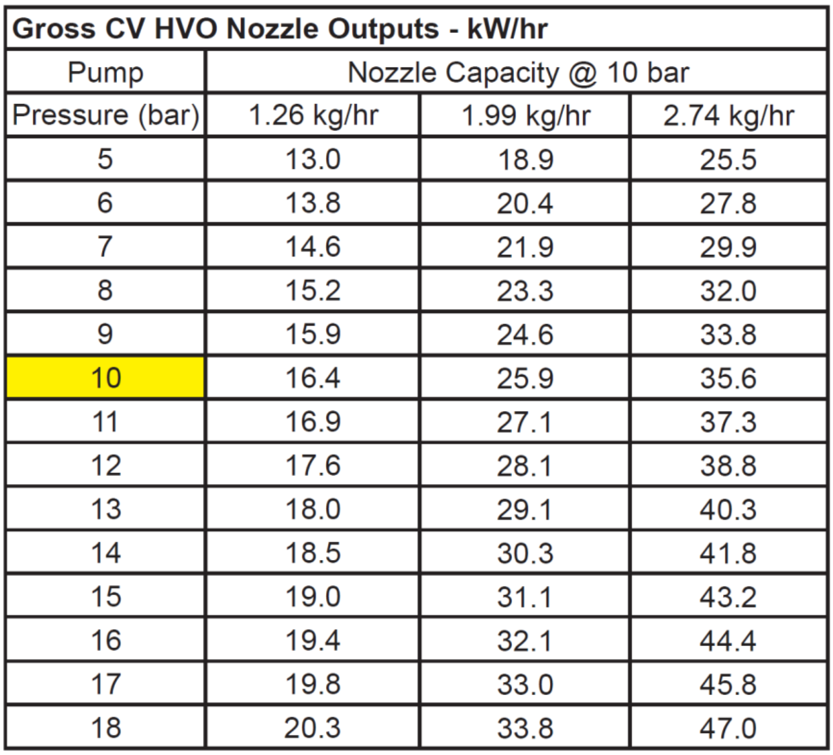
Figure 16: HVO atomising nozzle marking

Danfoss		HVO	kg/hr 1.26	kW/h(g) 16.4	60°S

Danfoss		HVO	kg/hr 1.99	kW/h(g) 25.9	60°S

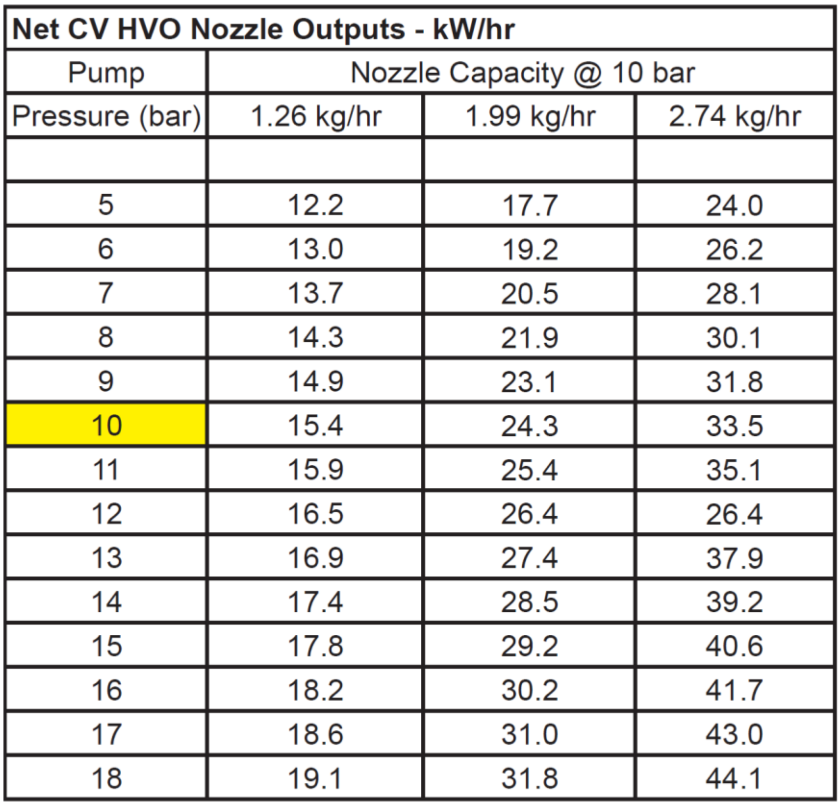
Danfoss		HVO	kg/hr 2.74	kW/h(g) 35.6	60°S

Table 5: HVO atomising nozzle gross energy throughputs for condensing boilers.



Gross CV HVO Nozzle Outputs - kW/hr			
Pump	Nozzle Capacity @ 10 bar		
Pressure (bar)	1.26 kg/hr	1.99 kg/hr	2.74 kg/hr
5	13.0	18.9	25.5
6	13.8	20.4	27.8
7	14.6	21.9	29.9
8	15.2	23.3	32.0
9	15.9	24.6	33.8
10	16.4	25.9	35.6
11	16.9	27.1	37.3
12	17.6	28.1	38.8
13	18.0	29.1	40.3
14	18.5	30.3	41.8
15	19.0	31.1	43.2
16	19.4	32.1	44.4
17	19.8	33.0	45.8
18	20.3	33.8	47.0

Table 6: HVO atomising nozzle net energy throughputs for standard efficiency boilers.



Net CV HVO Nozzle Outputs - kW/hr			
Pump	Nozzle Capacity @ 10 bar		
Pressure (bar)	1.26 kg/hr	1.99 kg/hr	2.74 kg/hr
5	12.2	17.7	24.0
6	13.0	19.2	26.2
7	13.7	20.5	28.1
8	14.3	21.9	30.1
9	14.9	23.1	31.8
10	15.4	24.3	33.5
11	15.9	25.4	35.1
12	16.5	26.4	26.4
13	16.9	27.4	37.9
14	17.4	28.5	39.2
15	17.8	29.2	40.6
16	18.2	30.2	41.7
17	18.6	31.0	43.0
18	19.1	31.8	44.1

To identify the correct atomising nozzle and pump pressure required is a simple process of matching the nozzle output to the required boiler energy input. Where the energy input is not known but the boiler output is then simply divide the boiler output by the boiler efficiency to obtain the required input as follows:

Example

Standard efficiency boiler output = 21kW

Boiler net efficiency = 82%

Boiler input (burner output) = $\frac{21}{82\%}$

Boiler input (burner output) = 25.6 kW

From the net chart shown in ***Table 6*** we can see that a 1.99 kg/hr HVO atomising nozzle at 11 bar throughput pressure would give the nearest match.

IMPORTANT: ATOMISING NOZZLE THROUGHPUT AND PUMP PRESSURE CALCULATION METHODOLOGY AS CONTAINED IN OFTEC TECHNICAL BOOKS 2 & 7 FOR KEROSENE AND GAS OIL IS NOT SUITABLE FOR HVO THROUGHPOUT CALCULATIONS.

Oil Heating Consultancy Services Ltd (OHCS) initially carried out atomising nozzle throughput test measurements with HVO where the discrepancies between calibrated Kerosene, calibrated Gas Oil and calibrated nozzle throughput calculations were identified.

Following on from these initial findings OFTEC engaged Kiwa Ltd to conduct further atomising nozzle throughput tests in their accredited test house. The Kiwa findings confirmed the initial findings identified by OHCS.

Measured V’s calculated & calibrated nozzle throughput findings[4]:

Atomising nozzles calibrated for Class C2 Kerosene and Class D Gas Oil when utilised with HVO were found to be up to 10% out at calibrated pressures, and up to 20% out at other pressures over the range 5-18 bar.

Pressure jet burner conversion notes

- Boiler/burner manufacturer’s guidance as to spray pattern and angle for HVO should be followed in addition to the use of HVO calibrated atomising nozzles.
- Burners will need to be guaranteed for use with HVO. This includes specific use of new materials for component seals in fuel pumps, hydraulic rams and actuators where applicable and appropriate.
- All equipment, especially storage tanks, oil line and ancillary equipment, and appliances, will be required to be clearly and permanently identifiable by non-intrusive means, this being labelled at point of manufacture (or for existing equipment at point of conversion) as (then) only being suitable for HVO to BS EN 15940.

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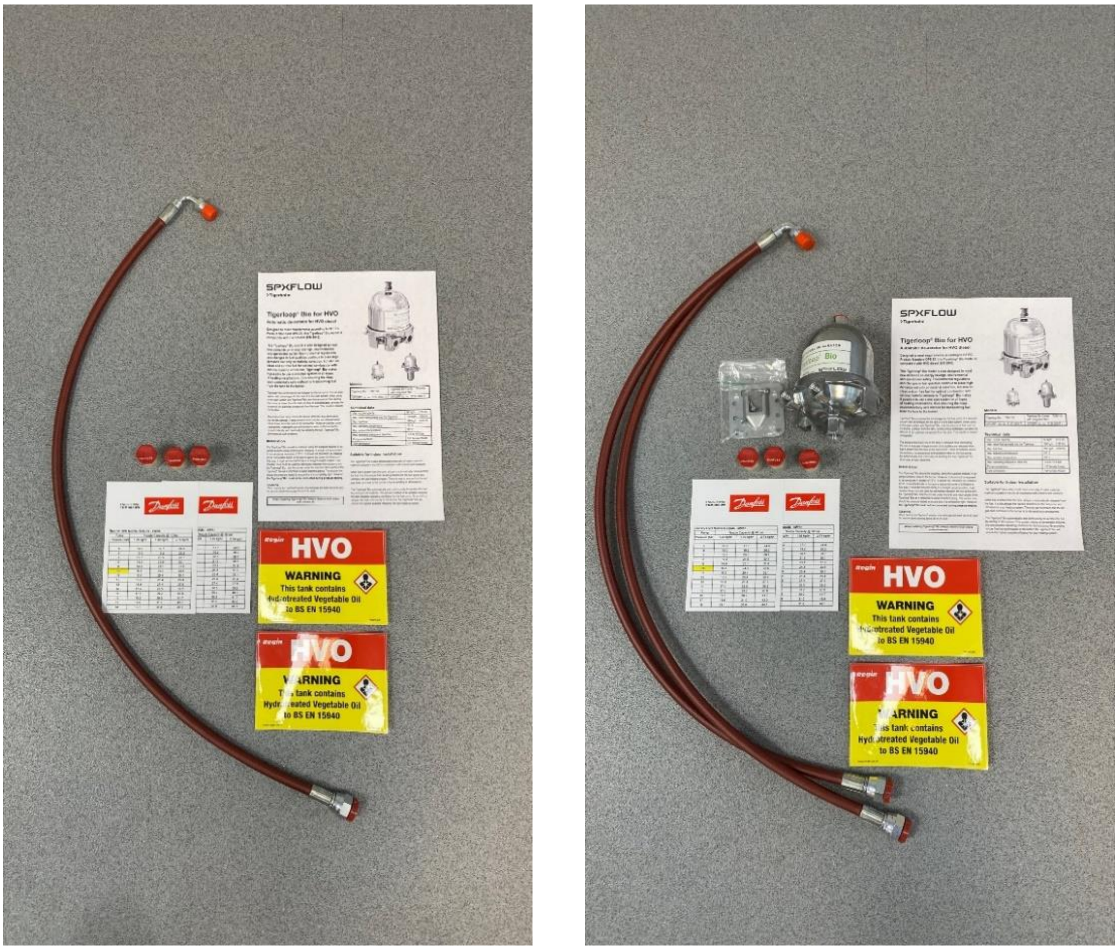
[4] Source: Kiwa Ltd. Client Report 80638, October 2020

Figure 17 illustrates HVO conversion kits provided for OFTEC pilot demonstrator sites comprising HVO calibrated atomising nozzles and throughput charts (Danfoss Ltd.), HVO flexible oil lines (EOGB Energy Products Ltd.), HVO de-aerator with HVO suction line tables (SPX Flow – Tigerholm), and tank & appliance HVO conversion stickers (Regin Products Ltd.).

Figure 17: HVO conversion kits provided for OFTEC pilot demonstrator sites



3.5 Boiler efficiencies

Kiwa Ltd were engaged by OFTEC to compare the combustion and thermal efficiency characteristics of Kerosene and HVO when fired in the same oil boiler when set to give the same thermal output, CO_2 concentration and flue gas temperature. To achieve this the boiler was tested being fired on Kerosene with a dedicated Kerosene pressure jet burner. Once testing was complete the Kerosene pressure jet burner was removed and replaced with an equivalent tested and approved burner and the boiler testing was repeated.

The findings of these tests were that within test regime and apparatus tolerances, the boiler efficiency was unchanged and the measured NO_x (ppm) was very similar.

"Overall, there is very little difference in observed performance between the two fuels."[5]

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[5] Source: Kiwa Ltd. Client Report 80637, November 2020

The caveat with regards to boiler efficiencies here is that the boiler efficiency and emissions only remain consistent when an HVO burner throughput (kW of heat energy fired into the boiler) is correctly matched to the previous Kerosene burner throughput in terms of kW of heat energy fired into the appliance.

For further information on Stoichiometric combustion and the use of combustion analysers please refer to section 2.4.

3.6 Vaporising burners

Vaporising sleeve burners should not have bio-liquid fuels introduced to them. This is down to the increased carbon chain length, differences in viscosity, boiling point, density and calorific value between bio-liquids and Kerosene. It has been proven that bio-liquids in Kerosene can immediately adversely affect combustion and manifest in the rapid onset of premature carboning in vaporising sleeve burner bases - even within hours.

It is recommended that vaporising sleeve burners are converted with appliance manufacturer's (or appliance manufacturer's approved) bio-liquid conversion burners.

Initial tests of firing HVO via a vaporising pot burner developed by Terry Hibbard of Howarth Heating Ltd., some 30 years ago, have proved very encouraging.

This gave rise to the opportunity for industry to be able to convert existing range cookers such as AGA's to HVO from other fuels including Kerosene by the replacement of the Kerosene vaporising sleeve burner with an HVO vaporising pot burner.

Howarth Heating have donated one of their original vaporising pot burners for an OFTEC pilot demonstrator site, and have also provided a replacement Oil Control Valve suitable for HVO along with initial cold flow rate settings. Mitchell & Webber Ltd. have installed and commissioned the HVO conversion, and to date, the converted cooker is performing extremely well.

The original Howarth Heating sketched diagram of the vaporising pot burner, and an image of the conversion kit as supplied to Mitchell & Webber Ltd. for the OFTEC pilot demonstrator site, are shown in ***Figure 19*** below, and ***Figure 19*** overleaf.

Figure 18: Original Harworth Heating sketch diagram of vaporising pot burner

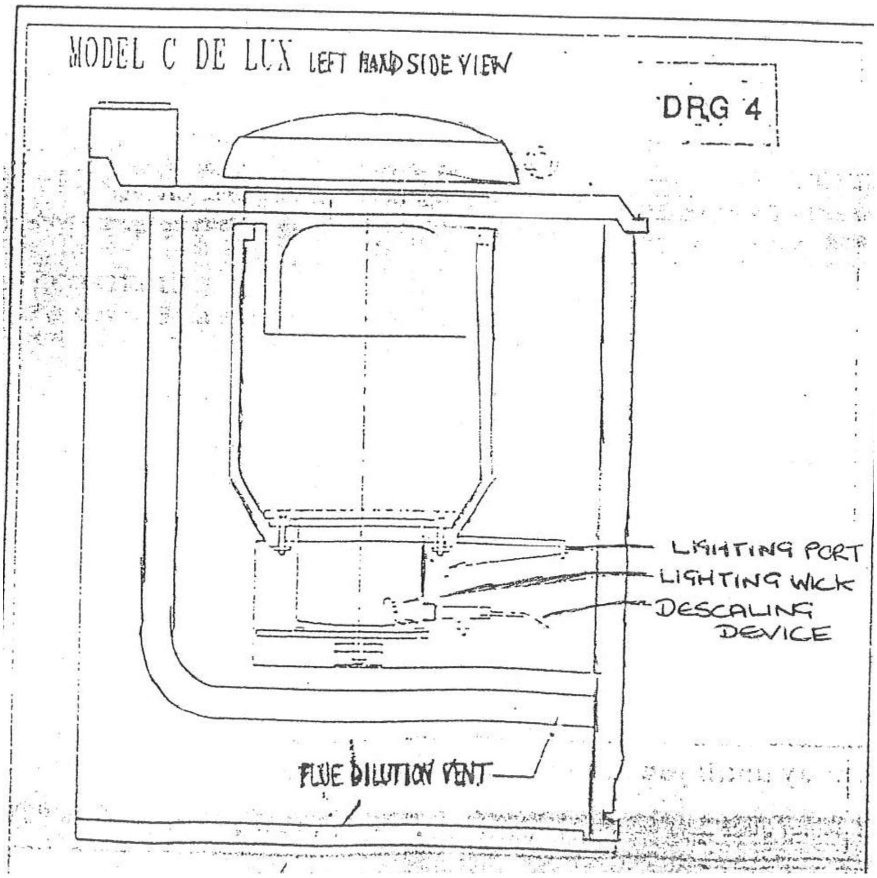


Figure 19: Vaporising pot burner conversion kit as supplied to Mitchell & Webber

4 Maintenance

Combustion testing trials suggest that combustion equipment operating on HVO requires no more maintenance than 100% mineral fuel installations. However, for continued performance and reliability of downstream equipment, a regular maintenance schedule should always be put in place in accordance with BS 5410-1 and equipment manufacturers recommendations. Please also see section 2.4 regarding the use of combustion analysers.

5 Key guidance points

- All fuel carrying components and seals need to be checked for material compatibility with HVO.
- All equipment, especially storage tanks and combustion appliances will be required to be clearly and permanently identifiable by non-intrusive means, this being labelled at point of manufacture (or for existing equipment at point of conversion) as (then) only being suitable for HVO to BS EN 15940.
- Fuel storage tank husbandry is essential.
- Vaporising sleeve burners should not be attempted to run on HVO.
- Measured CO2 combustion analysers are recommended at this time.

Awareness

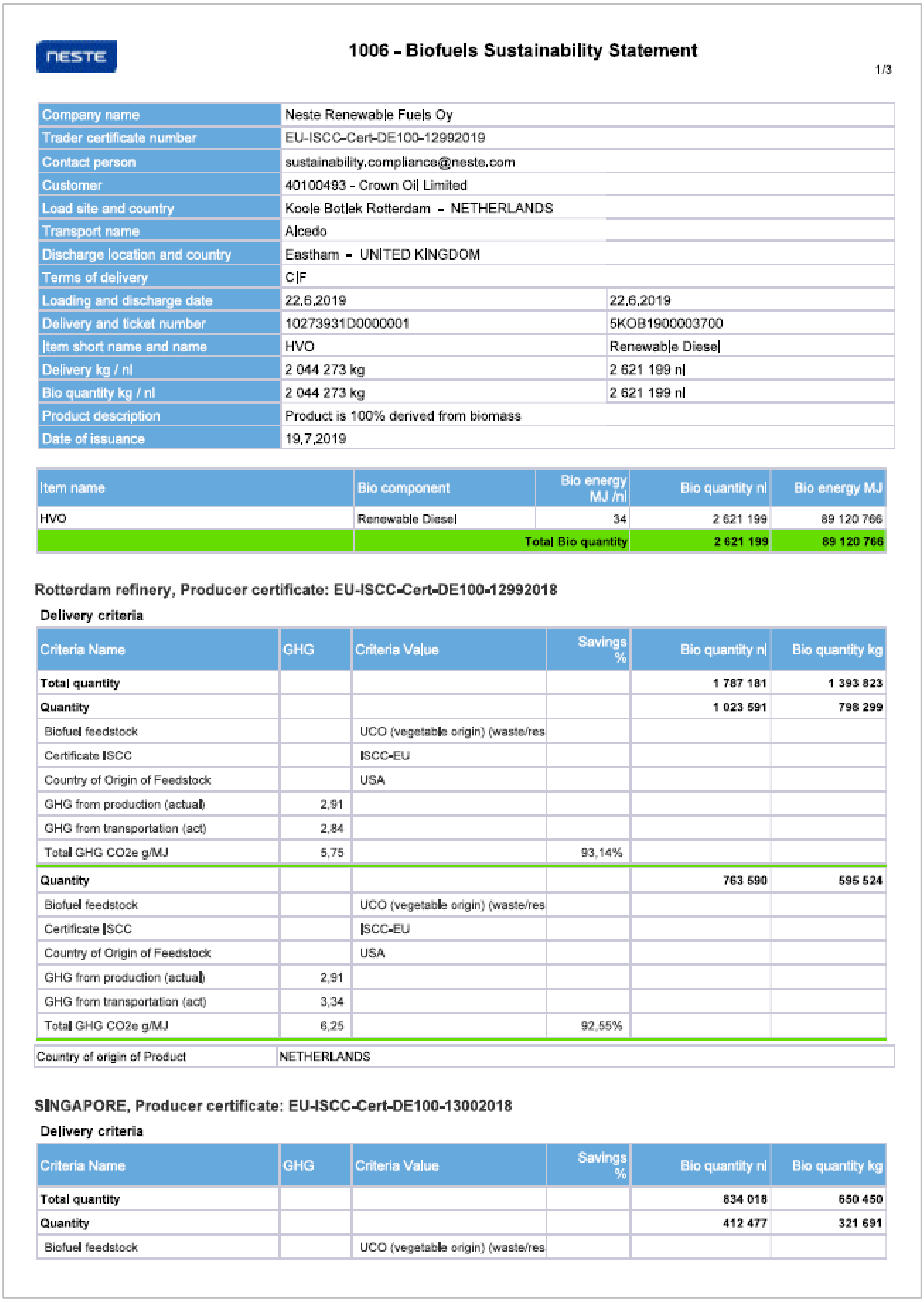
Many of the technical and commercial principles that prevent freely changing mineral fuel types, such as Paraffin, Kerosene, Gas Oil and Diesel in heating installations over the last 40 years are equally applicable when considering combusting bio-liquids.

The real life scenario of a consumer mistakenly filling a diesel car with petrol at a garage forecourt is addressed in the heating sector by the fuel distributor checking that the installation is labelled as being suitable for the grade of fuel which has been requested to be delivered, before any delivery commences, also that no aftermarket additives are applied to the stored fuel consequentially altering the characteristics of the bio-liquid away from the identified and known parameters.

It is vitally important that storage tanks and combustion appliances are clearly labelled as only being suitable for HVO in order to prevent delivery of incorrect fuel, which may give rise to some or all of the following problems:

- Over firing of the burner with resultant damage to blast tube, baffle(s) and heat exchanger.
- Intermittent lock-outs due to the burners inability to establish and/or maintain a flame.
- Fuel pump failure due to lack of lubricity or filter blocking where aftermarket additives have been applied.
- Equipment & system material failures.
- Appliance inefficiency.
- Customer call backs.

Annex A – HVO Sustainability Statement



1006 - Biofuels Sustainability Statement

1/3

Company name	Neste Renewable Fuels Oy	
Trader certificate number	EU-ISCC-Cert-DE100-12992019	
Contact person	sustainability.compliance@neste.com	
Customer	40100493 - Crown Oil Limited	
Load site and country	Koole Botlek Rotterdam - NETHERLANDS	
Transport name	Alcedo	
Discharge location and country	Eastham - UNITED KINGDOM	
Terms of delivery	CIF	
Loading and discharge date	22.6.2019	22.6.2019
Delivery and ticket number	10273931D0000001	5KOB1900003700
Item short name and name	HVO	Renewable Diesel
Delivery kg / nl	2 044 273 kg	2 621 199 nl
Bio quantity kg / nl	2 044 273 kg	2 621 199 nl
Product description	Product is 100% derived from biomass	
Date of issuance	19.7.2019	

Item name	Bio component	Bio energy MJ /nl	Bio quantity nl	Bio energy MJ
HVO	Renewable Diesel	34	2 621 199	89 120 766
		Total Bio quantity	**2 621 199**	**89 120 766**

Rotterdam refinery, Producer certificate: EU-ISCC-Cert-DE100-12992018

Delivery criteria

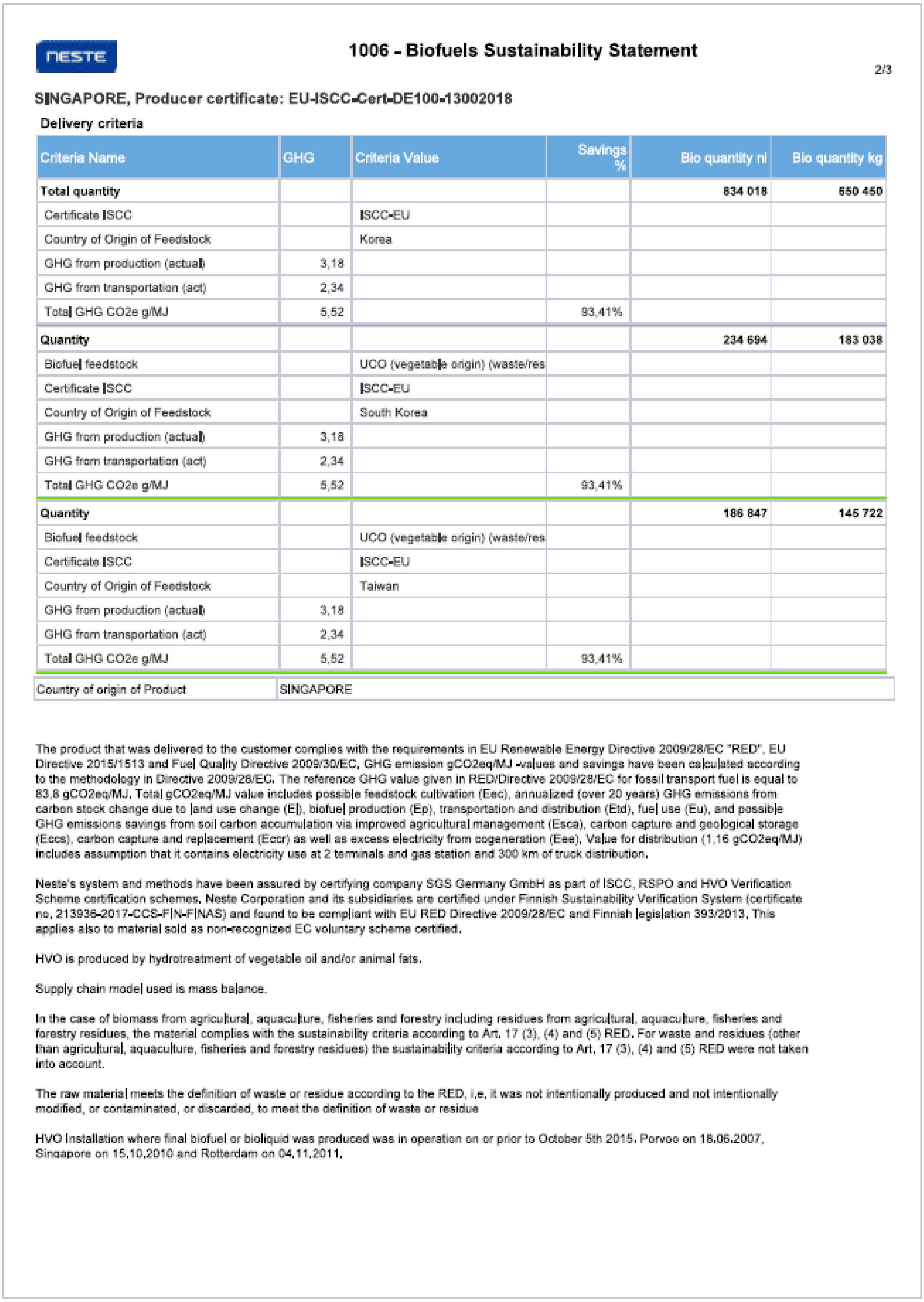
Criteria Name	GHG	Criteria Value	Savings %	Bio quantity nl	Bio quantity kg
Total quantity				**1 787 181**	**1 393 823**
Quantity				**1 023 591**	**798 299**
Biofuel feedstock		UCO (vegetable origin) (waste/res			
Certificate ISCC		ISCC-EU			
Country of Origin of Feedstock		USA			
GHG from production (actual)	2,91				
GHG from transportation (act)	2,84				
Total GHG CO2e g/MJ	5,75		93,14%		
Quantity				**763 590**	**595 524**
Biofuel feedstock		UCO (vegetable origin) (waste/res			
Certificate ISCC		ISCC-EU			
Country of Origin of Feedstock		USA			
GHG from production (actual)	2,91				
GHG from transportation (act)	3,34				
Total GHG CO2e g/MJ	6,25		92,55%		

Country of origin of Product	NETHERLANDS

SINGAPORE, Producer certificate: EU-ISCC-Cert-DE100-13002018

Delivery criteria

Criteria Name	GHG	Criteria Value	Savings %	Bio quantity nl	Bio quantity kg
Total quantity				**834 018**	**650 450**
Quantity				**412 477**	**321 691**
Biofuel feedstock		UCO (vegetable origin) (waste/res			



NESTE

1006 - Biofuels Sustainability Statement

2/3

SINGAPORE, Producer certificate: EU-ISCC-Cert-DE100-13002018

Delivery criteria

Criteria Name	GHG	Criteria Value	Savings %	Bio quantity nl	Bio quantity kg
Total quantity				**834 018**	**650 450**
Certificate ISCC		ISCC-EU			
Country of Origin of Feedstock		Korea			
GHG from production (actual)	3,18				
GHG from transportation (act)	2,34				
Total GHG CO2e g/MJ	5,52		93,41%		
Quantity				**234 694**	**183 038**
Biofuel feedstock		UCO (vegetable origin) (waste/res			
Certificate ISCC		ISCC-EU			
Country of Origin of Feedstock		South Korea			
GHG from production (actual)	3,18				
GHG from transportation (act)	2,34				
Total GHG CO2e g/MJ	5,52		93,41%		
Quantity				**186 847**	**145 722**
Biofuel feedstock		UCO (vegetable origin) (waste/res			
Certificate ISCC		ISCC-EU			
Country of Origin of Feedstock		Taiwan			
GHG from production (actual)	3,18				
GHG from transportation (act)	2,34				
Total GHG CO2e g/MJ	5,52		93,41%		

Country of origin of Product	SINGAPORE

The product that was delivered to the customer complies with the requirements in EU Renewable Energy Directive 2009/28/EC "RED", EU Directive 2015/1513 and Fuel Quality Directive 2009/30/EC. GHG emission gCO2eq/MJ -values and savings have been calculated according to the methodology in Directive 2009/28/EC. The reference GHG value given in RED/Directive 2009/28/EC for fossil transport fuel is equal to 83,8 gCO2eq/MJ. Total gCO2eq/MJ value includes possible feedstock cultivation (Eec), annualized (over 20 years) GHG emissions from carbon stock change due to land use change (El), biofuel production (Ep), transportation and distribution (Etd), fuel use (Eu), and possible GHG emissions savings from soil carbon accumulation via improved agricultural management (Esca), carbon capture and geological storage (Eccs), carbon capture and replacement (Eccr) as well as excess electricity from cogeneration (Eee). Value for distribution (1,16 gCO2eq/MJ) includes assumption that it contains electricity use at 2 terminals and gas station and 300 km of truck distribution.

Neste's system and methods have been assured by certifying company SGS Germany GmbH as part of ISCC, RSPO and HVO Verification Scheme certification schemes. Neste Corporation and its subsidiaries are certified under Finnish Sustainability Verification System (certificate no. 213936-2017-CCS-FIN-FINAS) and found to be compliant with EU RED Directive 2009/28/EC and Finnish legislation 393/2013. This applies also to material sold as non-recognized EC voluntary scheme certified.

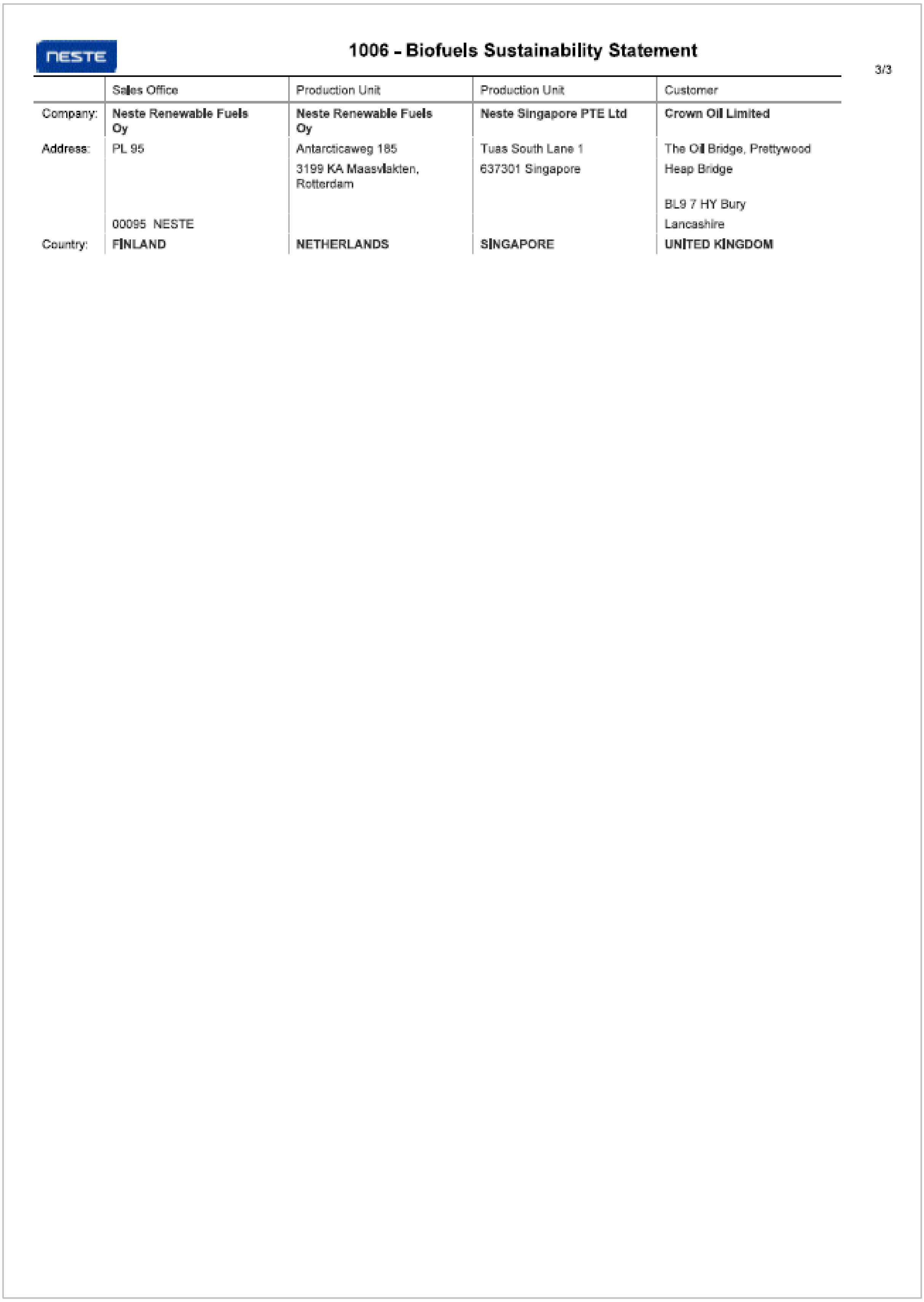
HVO is produced by hydrotreatment of vegetable oil and/or animal fats.

Supply chain model used is mass balance.

In the case of biomass from agricultural, aquaculture, fisheries and forestry including residues from agricultural, aquaculture, fisheries and forestry residues, the material complies with the sustainability criteria according to Art. 17 (3), (4) and (5) RED. For waste and residues (other than agricultural, aquaculture, fisheries and forestry residues) the sustainability criteria according to Art. 17 (3), (4) and (5) RED were not taken into account.

The raw material meets the definition of waste or residue according to the RED, i.e. it was not intentionally produced and not intentionally modified, or contaminated, or discarded, to meet the definition of waste or residue

HVO Installation where final biofuel or bioliquid was produced was in operation on or prior to October 5th 2015. Porvoo on 18.06.2007, Singapore on 15.10.2010 and Rotterdam on 04.11.2011.

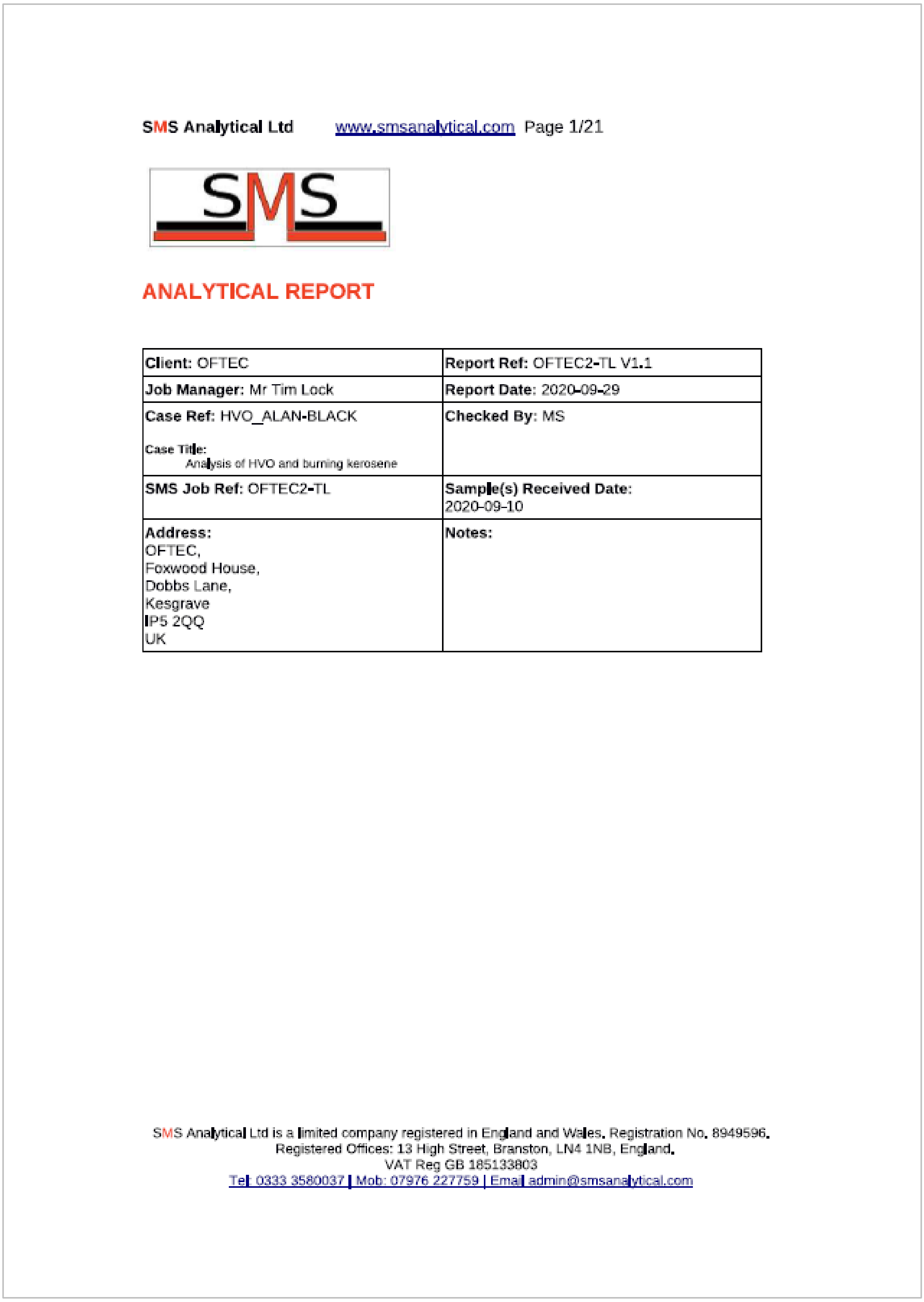


1006 - Biofuels Sustainability Statement

3/3

	Sales Office	Production Unit	Production Unit	Customer
Company:	**Neste Renewable Fuels Oy**	**Neste Renewable Fuels Oy**	**Neste Singapore PTE Ltd**	**Crown Oil Limited**
Address:	PL 95 00095 NESTE	Antarcticaweg 185 3199 KA Maasvlakten, Rotterdam	Tuas South Lane 1 637301 Singapore	The Oil Bridge, Prettywood Heap Bridge BL9 7 HY Bury Lancashire
Country:	**FINLAND**	**NETHERLANDS**	**SINGAPORE**	**UNITED KINGDOM**

Annex B – Comparative Analysis of HVO and Kerosene

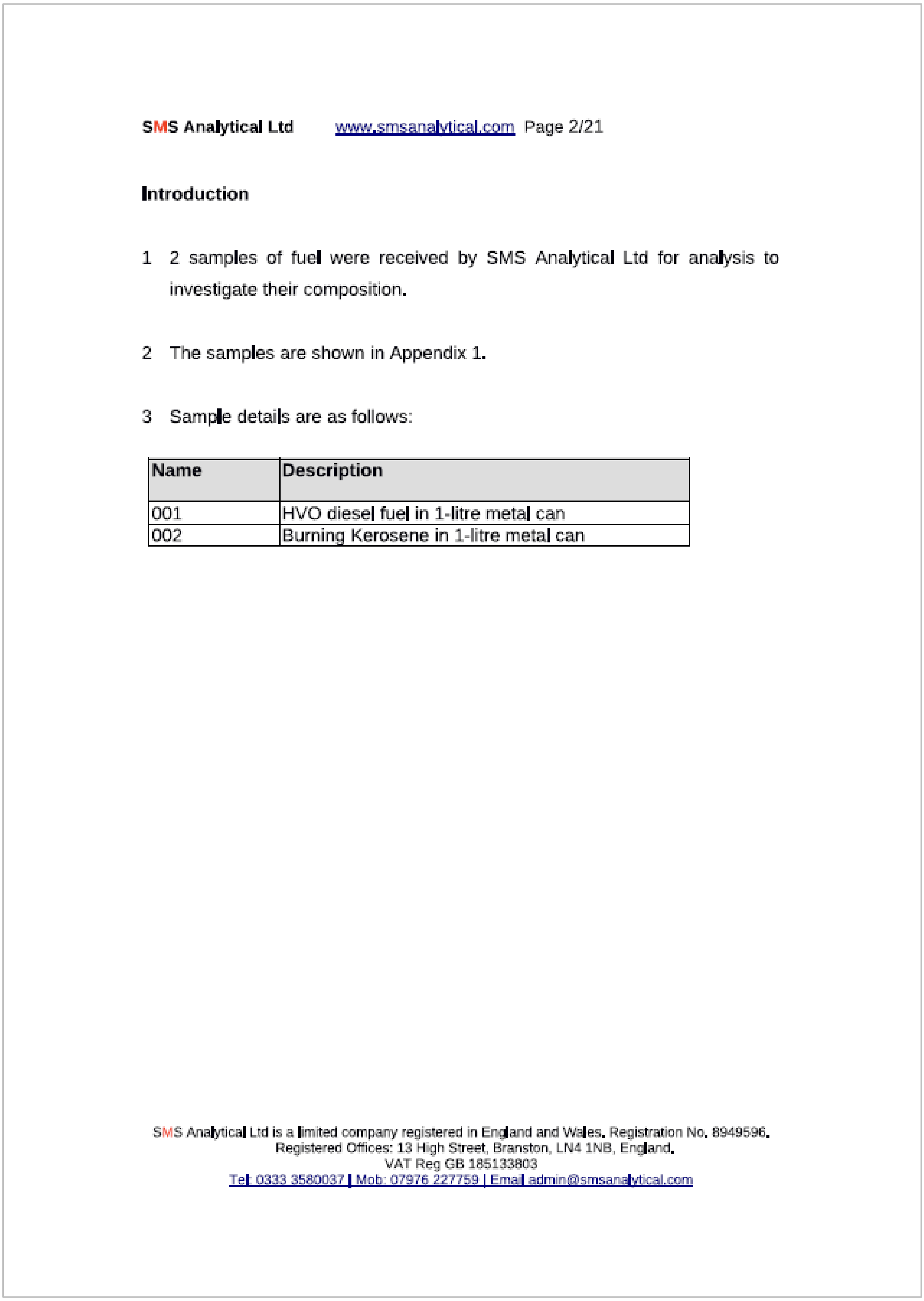


SMS Analytical Ltd www.smsanalytical.com Page 1/21

ANALYTICAL REPORT

Client: OFTEC	**Report Ref:** OFTEC2-TL V1.1
Job Manager: Mr Tim Lock	**Report Date:** 2020-09-29
Case Ref: HVO_ALAN-BLACK **Case Title:** Analysis of HVO and burning kerosene	**Checked By:** MS
SMS Job Ref: OFTEC2-TL	**Sample(s) Received Date:** 2020-09-10
Address: OFTEC, Foxwood House, Dobbs Lane, Kesgrave IP5 2QQ UK	**Notes:**

SMS Analytical Ltd is a limited company registered in England and Wales. Registration No. 8949596.
Registered Offices: 13 High Street, Branston, LN4 1NB, England.
VAT Reg GB 185133803
Tel: 0333 3580037 | Mob: 07976 227759 | Email admin@smsanalytical.com



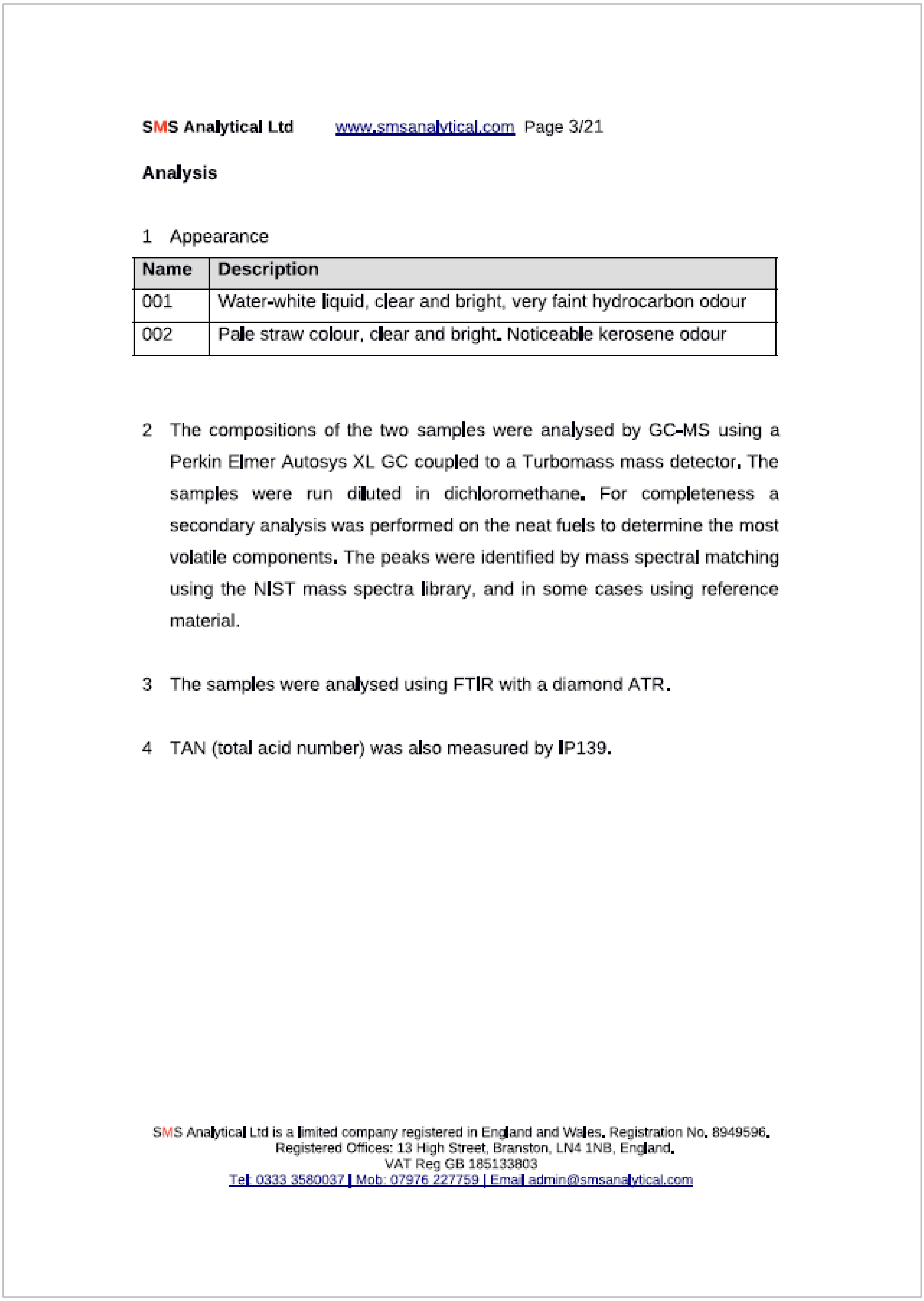
Introduction

1 2 samples of fuel were received by SMS Analytical Ltd for analysis to investigate their composition.

2 The samples are shown in Appendix 1.

3 Sample details are as follows:

Name	Description
001	HVO diesel fuel in 1-litre metal can
002	Burning Kerosene in 1-litre metal can



Analysis

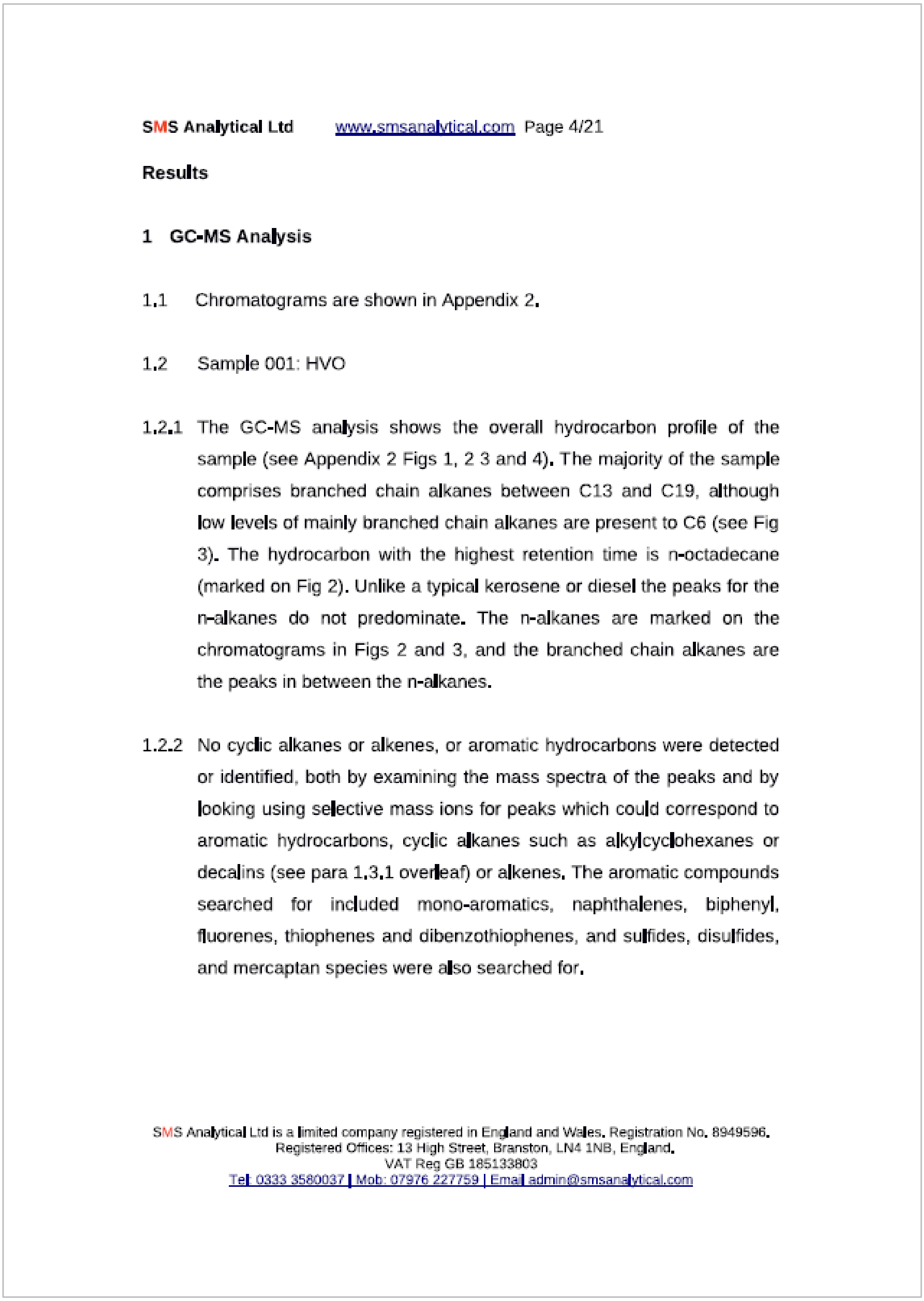
1 Appearance

Name	Description
001	Water-white liquid, clear and bright, very faint hydrocarbon odour
002	Pale straw colour, clear and bright. Noticeable kerosene odour

2 The compositions of the two samples were analysed by GC-MS using a Perkin Elmer Autosys XL GC coupled to a Turbomass mass detector. The samples were run diluted in dichloromethane. For completeness a secondary analysis was performed on the neat fuels to determine the most volatile components. The peaks were identified by mass spectral matching using the NIST mass spectra library, and in some cases using reference material.

3 The samples were analysed using FTIR with a diamond ATR.

4 TAN (total acid number) was also measured by IP139.



Results

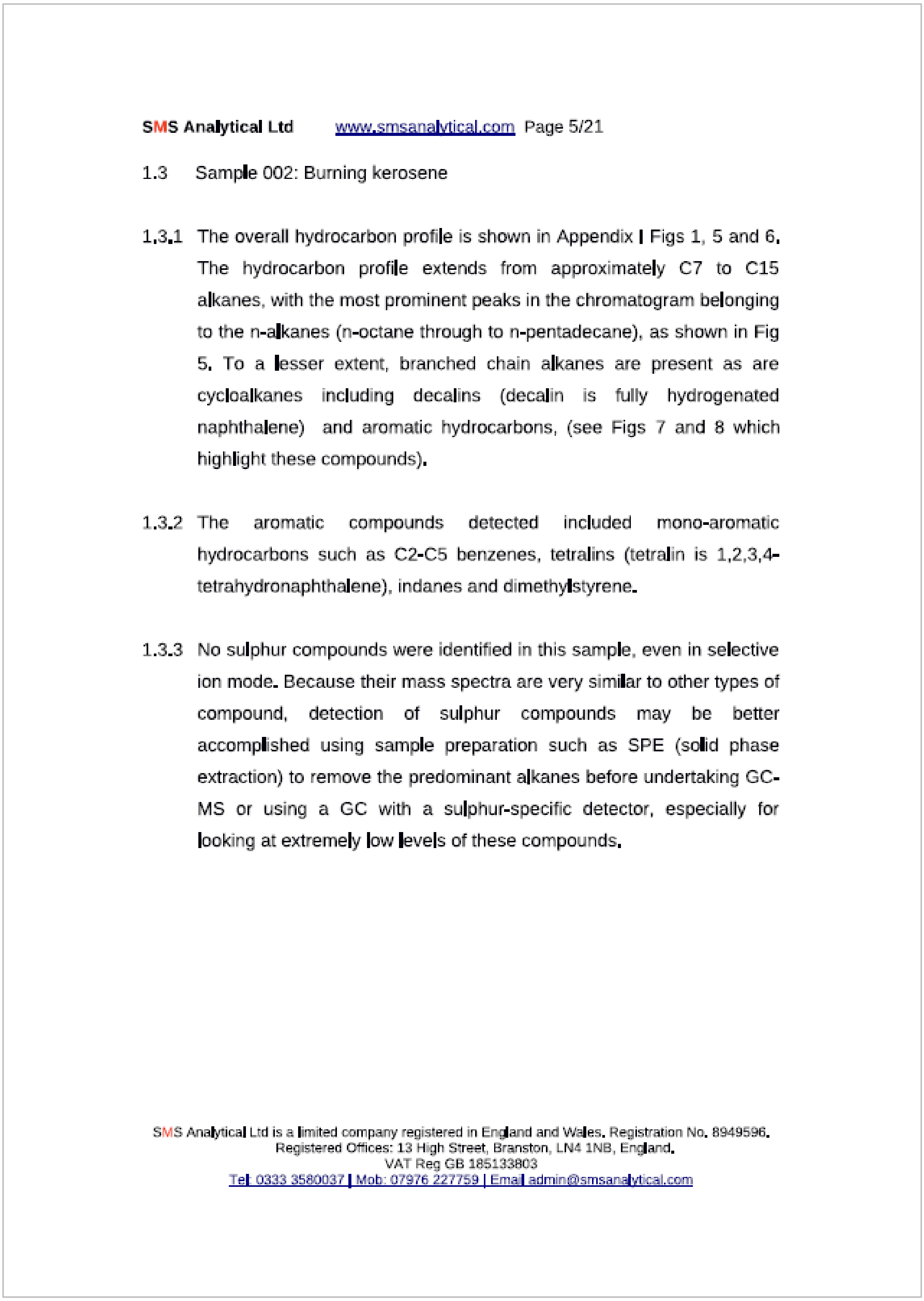
1 GC-MS Analysis

1.1 Chromatograms are shown in Appendix 2.

1.2 Sample 001: HVO

1.2.1 The GC-MS analysis shows the overall hydrocarbon profile of the sample (see Appendix 2 Figs 1, 2 3 and 4). The majority of the sample comprises branched chain alkanes between C13 and C19, although low levels of mainly branched chain alkanes are present to C6 (see Fig 3). The hydrocarbon with the highest retention time is n-octadecane (marked on Fig 2). Unlike a typical kerosene or diesel the peaks for the n-alkanes do not predominate. The n-alkanes are marked on the chromatograms in Figs 2 and 3, and the branched chain alkanes are the peaks in between the n-alkanes.

1.2.2 No cyclic alkanes or alkenes, or aromatic hydrocarbons were detected or identified, both by examining the mass spectra of the peaks and by looking using selective mass ions for peaks which could correspond to aromatic hydrocarbons, cyclic alkanes such as alkylcyclohexanes or decalins (see para 1.3.1 overleaf) or alkenes. The aromatic compounds searched for included mono-aromatics, naphthalenes, biphenyl, fluorenes, thiophenes and dibenzothiophenes, and sulfides, disulfides, and mercaptan species were also searched for.

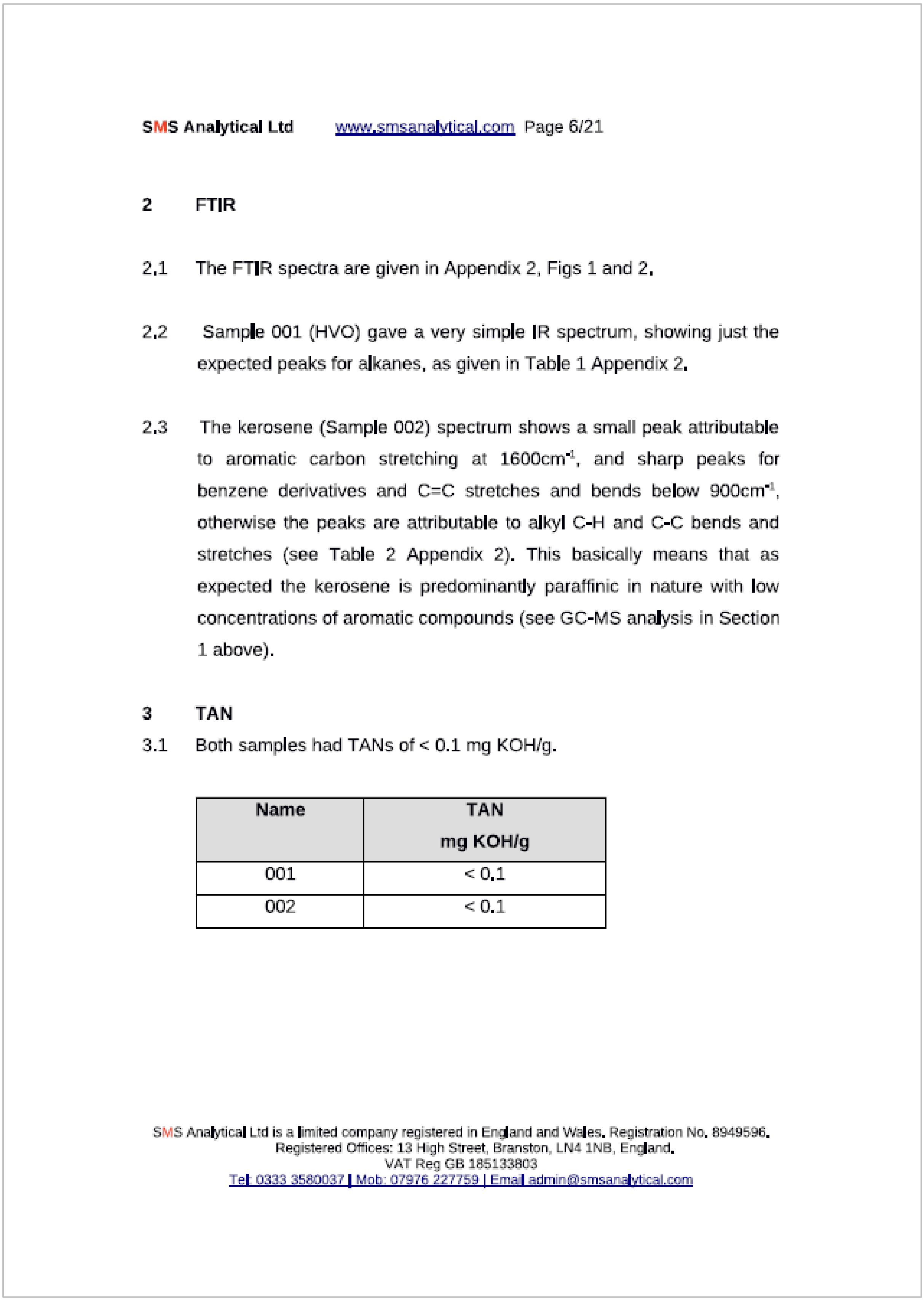


1.3 Sample 002: Burning kerosene

1.3.1 The overall hydrocarbon profile is shown in Appendix I Figs 1, 5 and 6. The hydrocarbon profile extends from approximately C7 to C15 alkanes, with the most prominent peaks in the chromatogram belonging to the n-alkanes (n-octane through to n-pentadecane), as shown in Fig 5. To a lesser extent, branched chain alkanes are present as are cycloalkanes including decalins (decalin is fully hydrogenated naphthalene) and aromatic hydrocarbons, (see Figs 7 and 8 which highlight these compounds).

1.3.2 The aromatic compounds detected included mono-aromatic hydrocarbons such as C2-C5 benzenes, tetralins (tetralin is 1,2,3,4-tetrahydronaphthalene), indanes and dimethylstyrene.

1.3.3 No sulphur compounds were identified in this sample, even in selective ion mode. Because their mass spectra are very similar to other types of compound, detection of sulphur compounds may be better accomplished using sample preparation such as SPE (solid phase extraction) to remove the predominant alkanes before undertaking GC-MS or using a GC with a sulphur-specific detector, especially for looking at extremely low levels of these compounds.



2 FTIR

2.1 The FTIR spectra are given in Appendix 2, Figs 1 and 2.

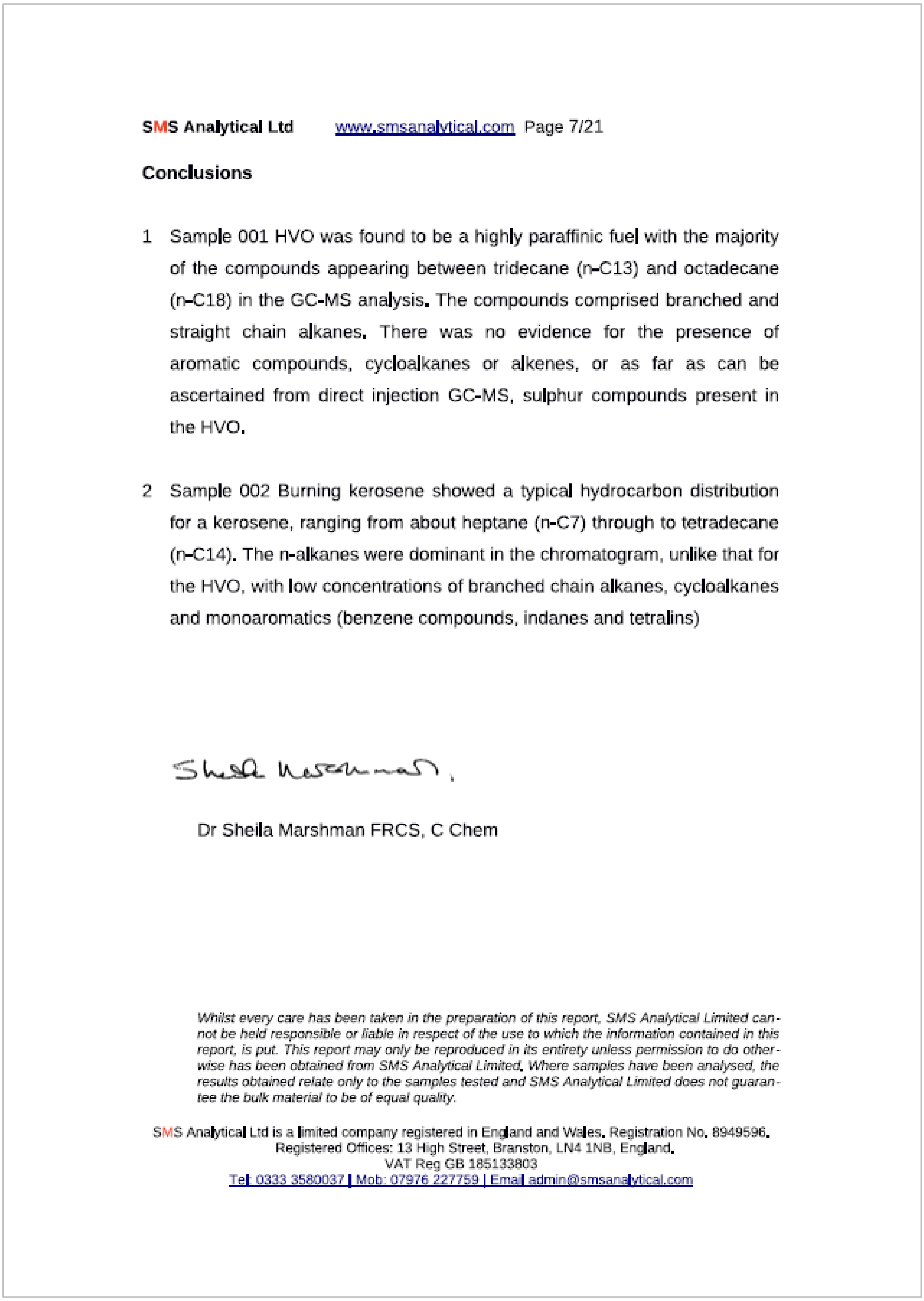
2.2 Sample 001 (HVO) gave a very simple IR spectrum, showing just the expected peaks for alkanes, as given in Table 1 Appendix 2.

2.3 The kerosene (Sample 002) spectrum shows a small peak attributable to aromatic carbon stretching at 1600cm^{-1}, and sharp peaks for benzene derivatives and C=C stretches and bends below 900cm^{-1}, otherwise the peaks are attributable to alkyl C-H and C-C bends and stretches (see Table 2 Appendix 2). This basically means that as expected the kerosene is predominantly paraffinic in nature with low concentrations of aromatic compounds (see GC-MS analysis in Section 1 above).

3 TAN

3.1 Both samples had TANs of < 0.1 mg KOH/g.

Name	TAN mg KOH/g
001	< 0.1
002	< 0.1

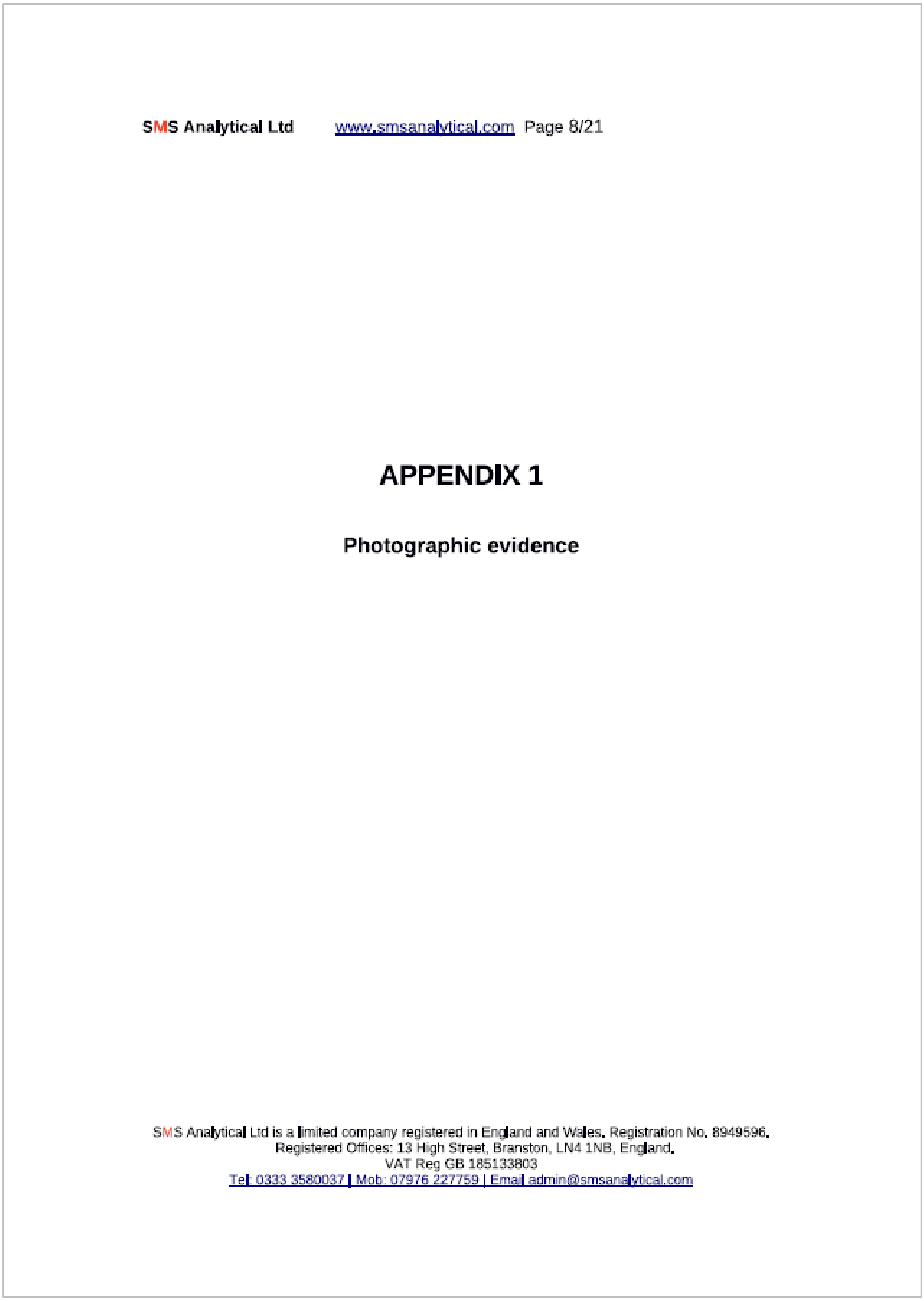


Conclusions

1 Sample 001 HVO was found to be a highly paraffinic fuel with the majority of the compounds appearing between tridecane (n-C13) and octadecane (n-C18) in the GC-MS analysis. The compounds comprised branched and straight chain alkanes. There was no evidence for the presence of aromatic compounds, cycloalkanes or alkenes, or as far as can be ascertained from direct injection GC-MS, sulphur compounds present in the HVO.

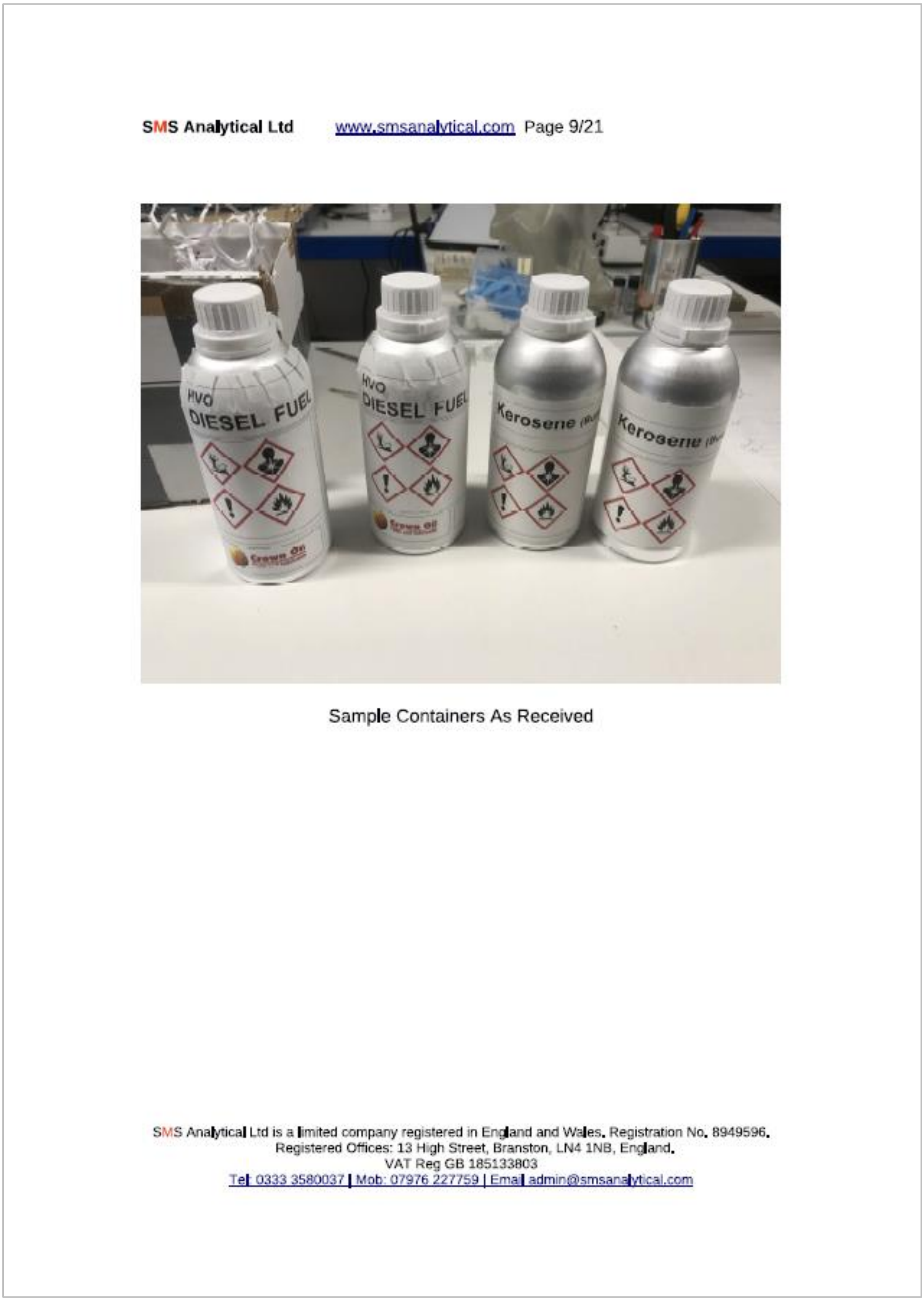
2 Sample 002 Burning kerosene showed a typical hydrocarbon distribution for a kerosene, ranging from about heptane (n-C7) through to tetradecane (n-C14). The n-alkanes were dominant in the chromatogram, unlike that for the HVO, with low concentrations of branched chain alkanes, cycloalkanes and monoaromatics (benzene compounds, indanes and tetralins)

Dr Sheila Marshman FRCS, C Chem



APPENDIX 1

Photographic evidence



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Sample Containers As Received

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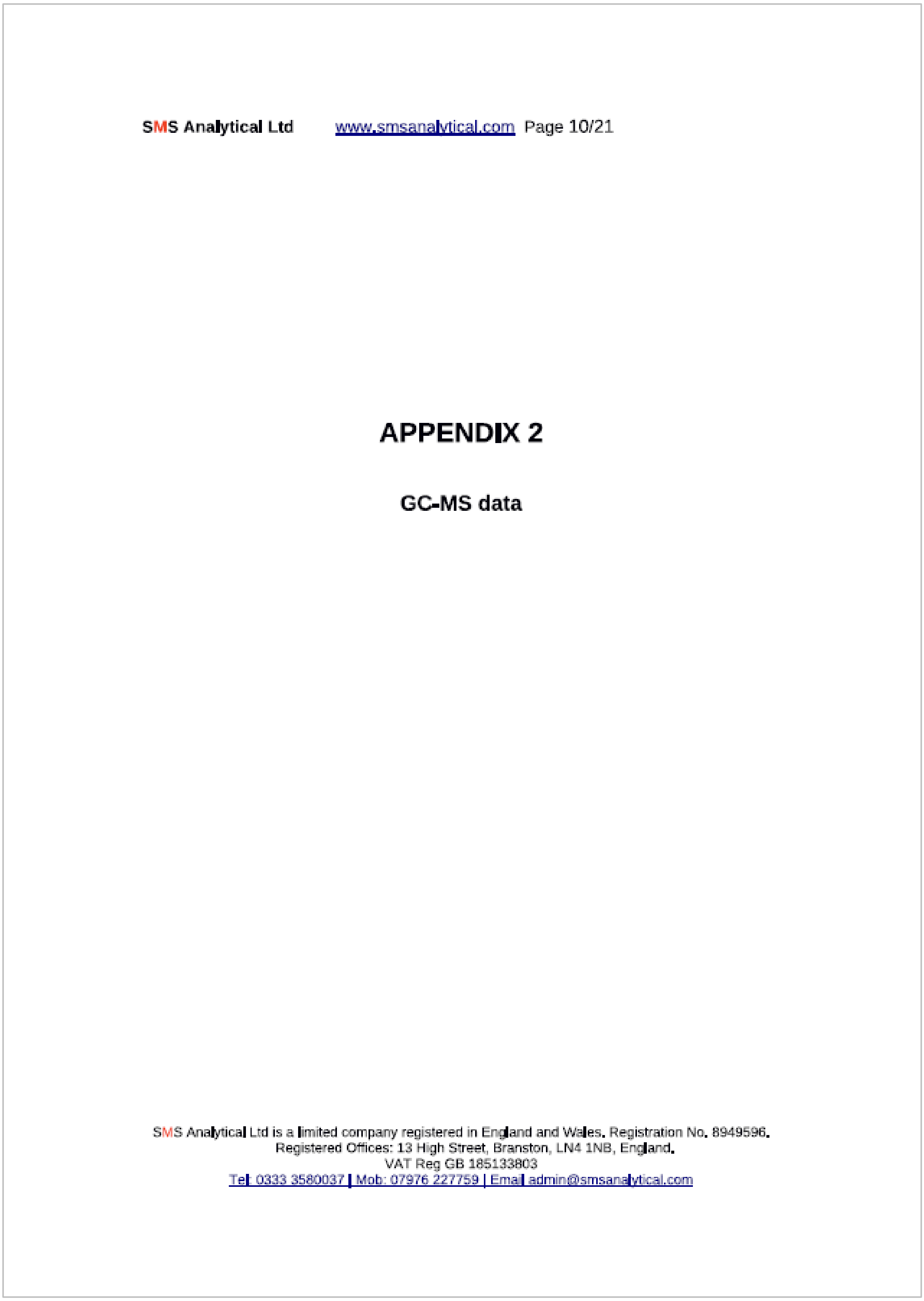

APPENDIX 2

GC-MS data

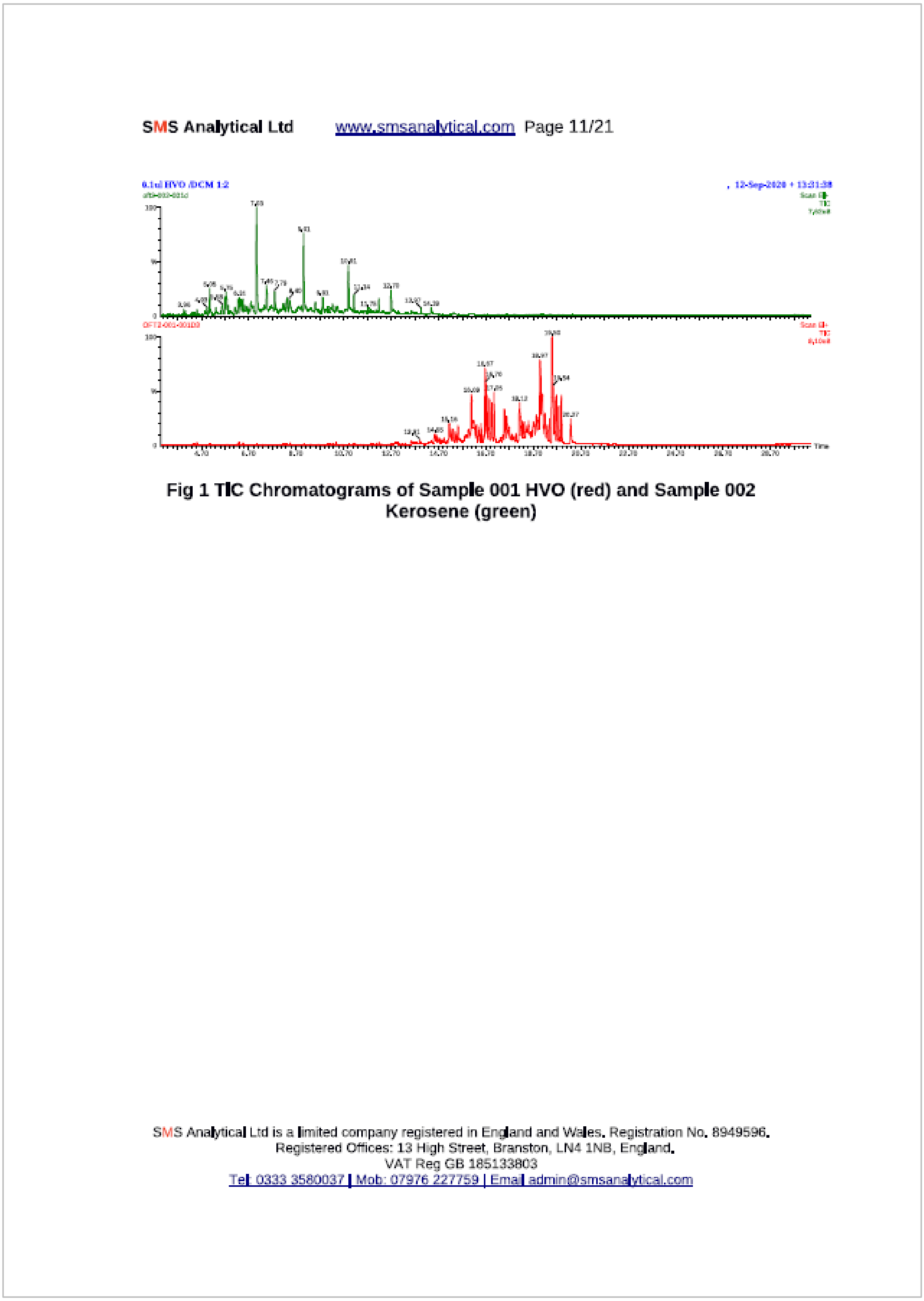

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Fig 1 TIC Chromatograms of Sample 001 HVO (red) and Sample 002 Kerosene (green)

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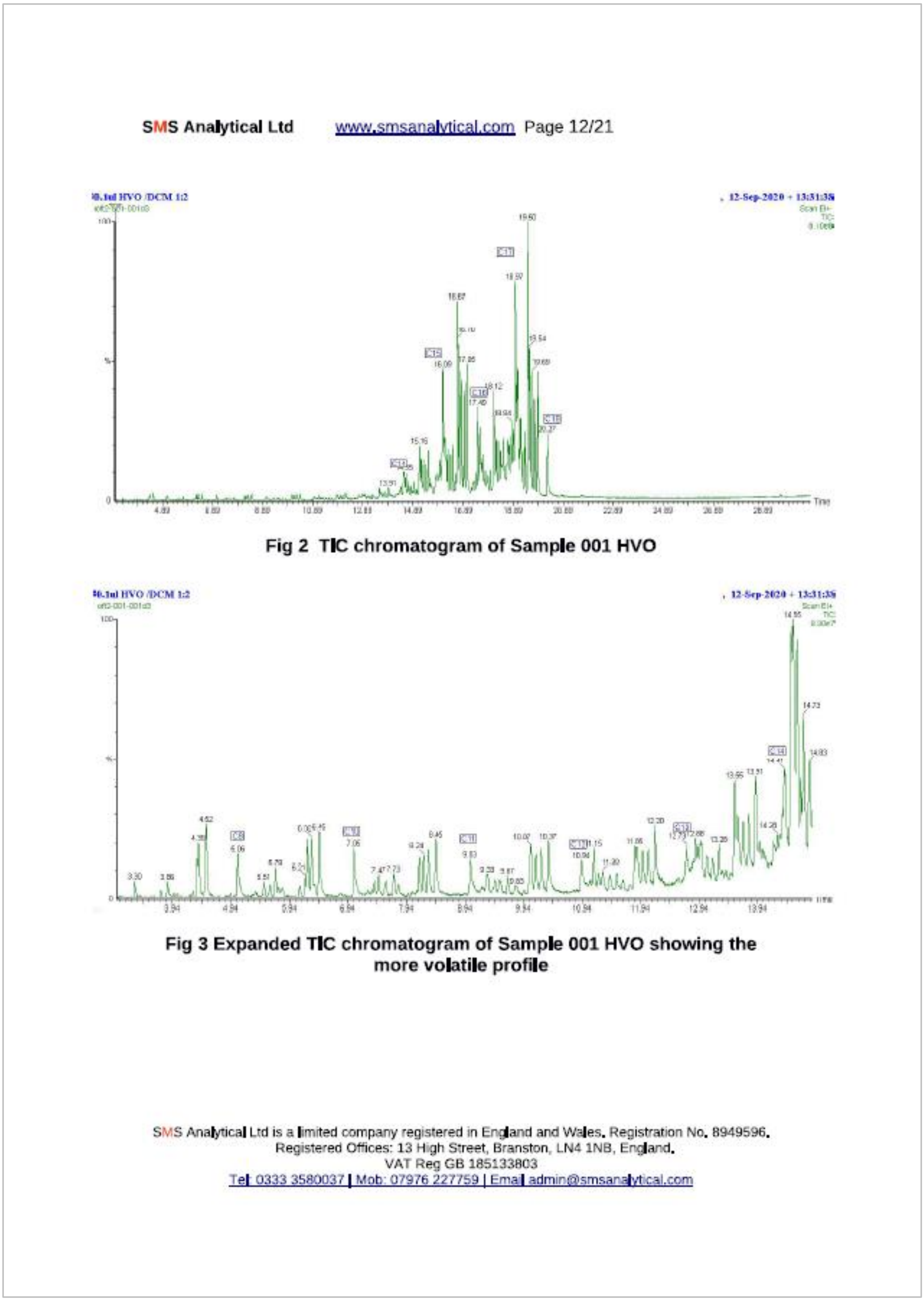

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Fig 2 TIC chromatogram of Sample 001 HVO

Fig 3 Expanded TIC chromatogram of Sample 001 HVO showing the more volatile profile

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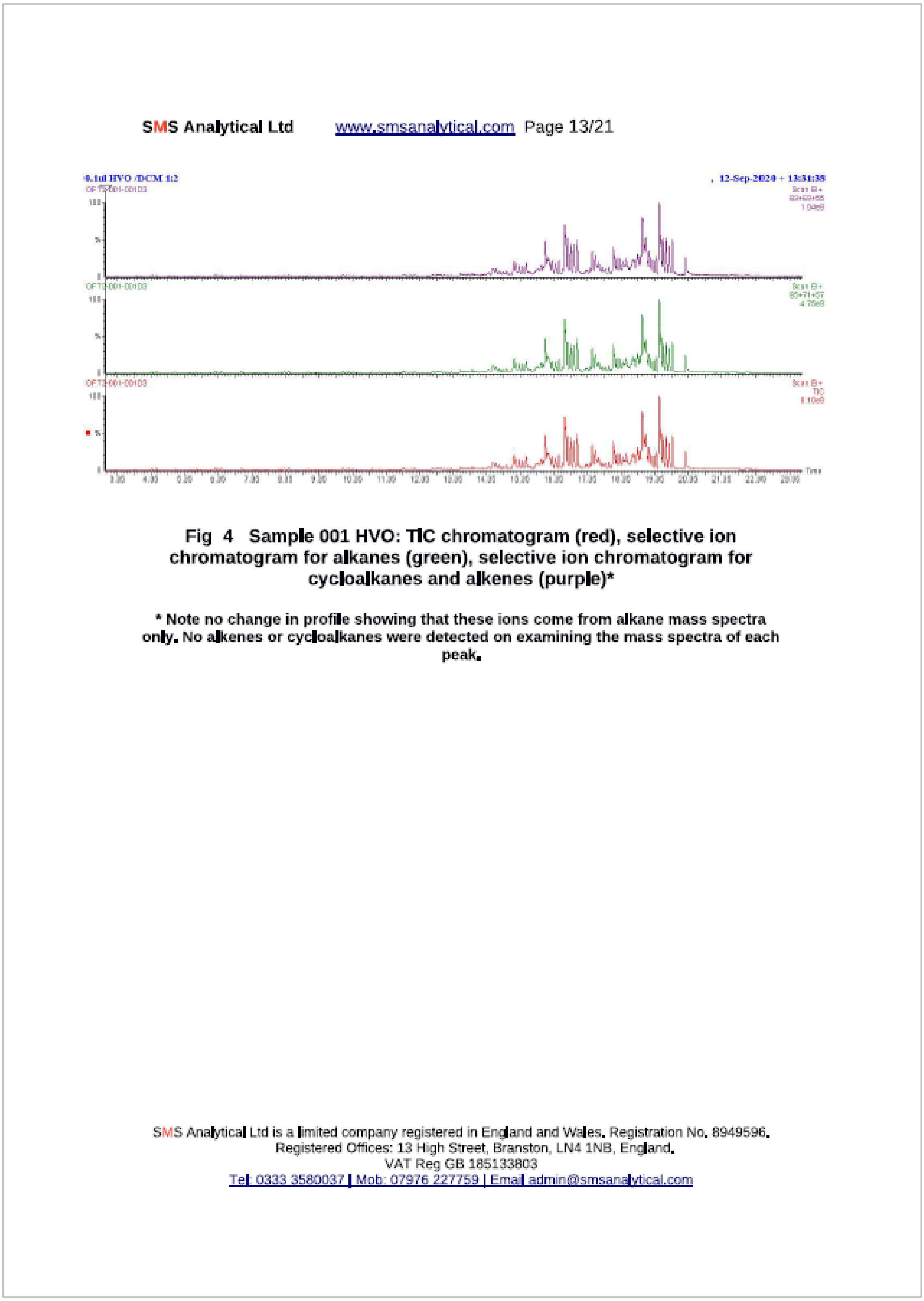

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Fig 4 Sample 001 HVO: TIC chromatogram (red), selective ion chromatogram for alkanes (green), selective ion chromatogram for cycloalkanes and alkenes (purple)*

*** Note no change in profile showing that these ions come from alkane mass spectra only. No alkenes or cycloalkanes were detected on examining the mass spectra of each peak.**

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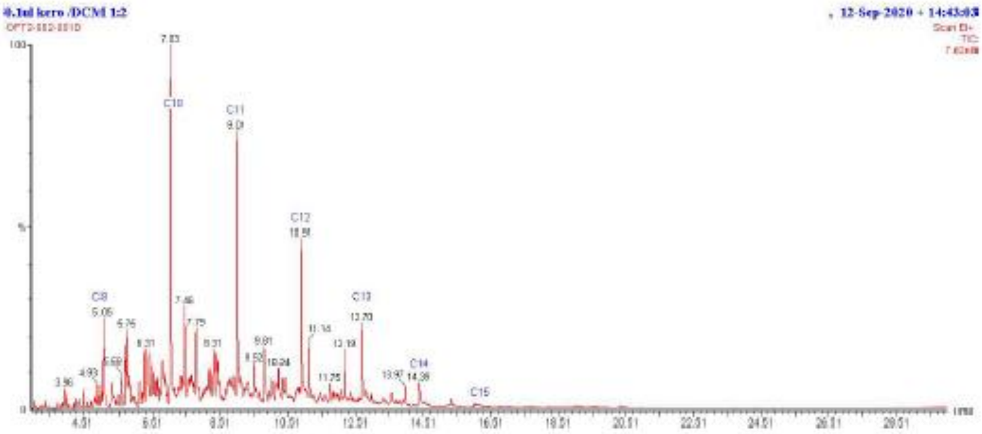

Fig 5 TIC chromatogram of Sample 002 Burning kerosene

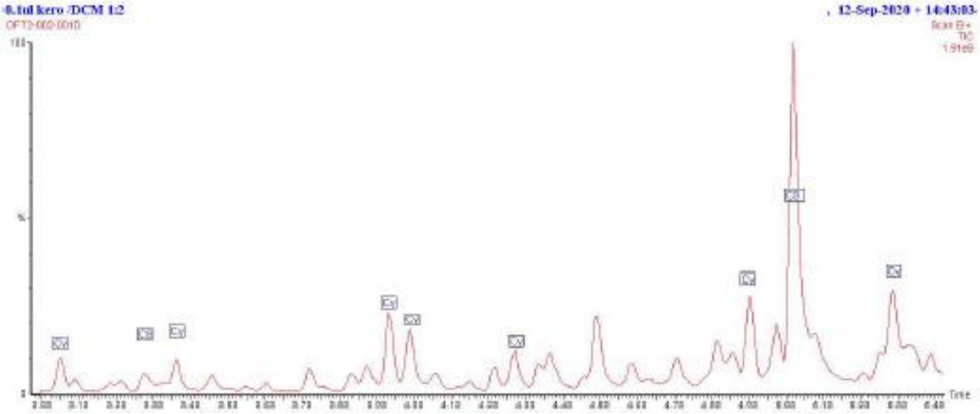

Fig 6 Expanded TIC chromatogram of Sample 002 kerosene showing the more volatile profile

Note: C8 is n-octane, C9 is n-nonane and Cy shows cycloalkanes

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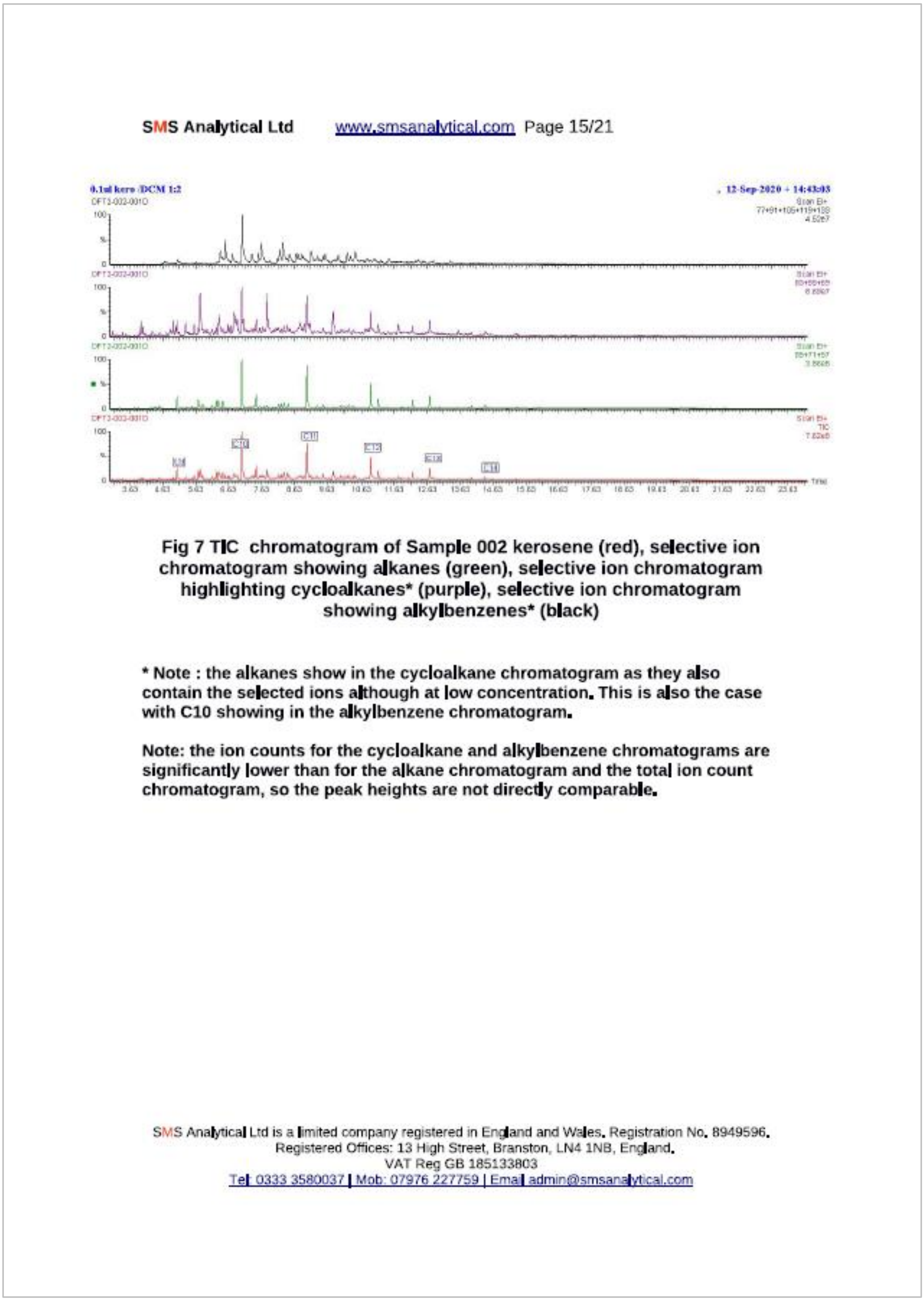

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Fig 7 TIC chromatogram of Sample 002 kerosene (red), selective ion chromatogram showing alkanes (green), selective ion chromatogram highlighting cycloalkanes* (purple), selective ion chromatogram showing alkylbenzenes* (black)

*** Note : the alkanes show in the cycloalkane chromatogram as they also contain the selected ions although at low concentration. This is also the case with C10 showing in the alkylbenzene chromatogram.**

Note: the ion counts for the cycloalkane and alkylbenzene chromatograms are significantly lower than for the alkane chromatogram and the total ion count chromatogram, so the peak heights are not directly comparable.

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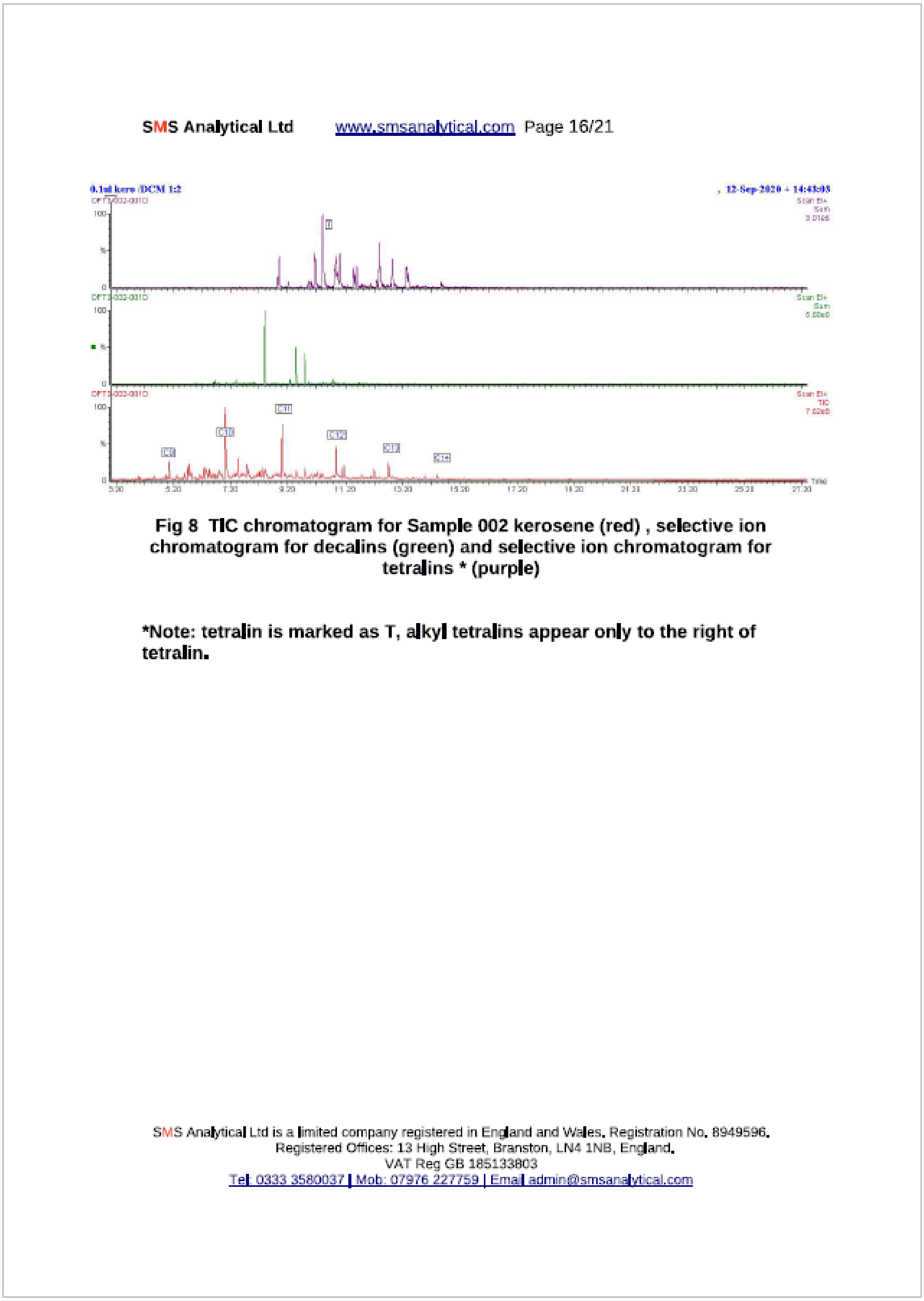

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Fig 8 TIC chromatogram for Sample 002 kerosene (red) , selective ion chromatogram for decalins (green) and selective ion chromatogram for tetralins * (purple)

***Note: tetralin is marked as T, alkyl tetralins appear only to the right of tetralin.**

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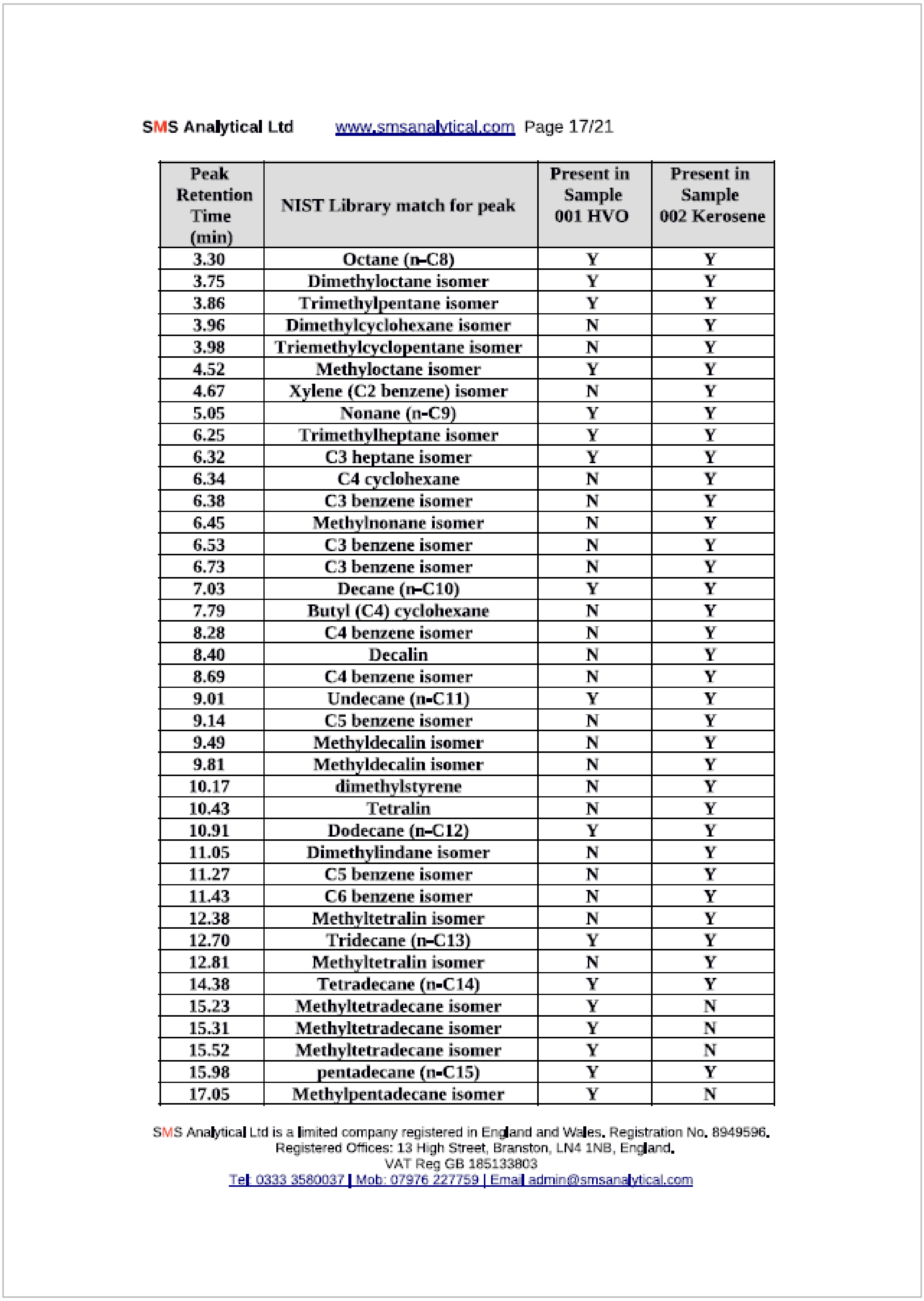

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Peak Retention Time (min)	NIST Library match for peak	Present in Sample 001 HVO	Present in Sample 002 Kerosene
3.30	Octane (n-C8)	Y	Y
3.75	Dimethyloctane isomer	Y	Y
3.86	Trimethylpentane isomer	Y	Y
3.96	Dimethylcyclohexane isomer	N	Y
3.98	Triemethylcyclopentane isomer	N	Y
4.52	Methyloctane isomer	Y	Y
4.67	Xylene (C2 benzene) isomer	N	Y
5.05	Nonane (n-C9)	Y	Y
6.25	Trimethylheptane isomer	Y	Y
6.32	C3 heptane isomer	Y	Y
6.34	C4 cyclohexane	N	Y
6.38	C3 benzene isomer	N	Y
6.45	Methylnonane isomer	N	Y
6.53	C3 benzene isomer	N	Y
6.73	C3 benzene isomer	N	Y
7.03	Decane (n-C10)	Y	Y
7.79	Butyl (C4) cyclohexane	N	Y
8.28	C4 benzene isomer	N	Y
8.40	Decalin	N	Y
8.69	C4 benzene isomer	N	Y
9.01	Undecane (n-C11)	Y	Y
9.14	C5 benzene isomer	N	Y
9.49	Methyldecalin isomer	N	Y
9.81	Methyldecalin isomer	N	Y
10.17	dimethylstyrene	N	Y
10.43	Tetralin	N	Y
10.91	Dodecane (n-C12)	Y	Y
11.05	Dimethylindane isomer	N	Y
11.27	C5 benzene isomer	N	Y
11.43	C6 benzene isomer	N	Y
12.38	Methyltetralin isomer	N	Y
12.70	Tridecane (n-C13)	Y	Y
12.81	Methyltetralin isomer	N	Y
14.38	Tetradecane (n-C14)	Y	Y
15.23	Methyltetradecane isomer	Y	N
15.31	Methyltetradecane isomer	Y	N
15.52	Methyltetradecane isomer	Y	N
15.98	pentadecane (n-C15)	Y	Y
17.05	Methylpentadecane isomer	Y	N

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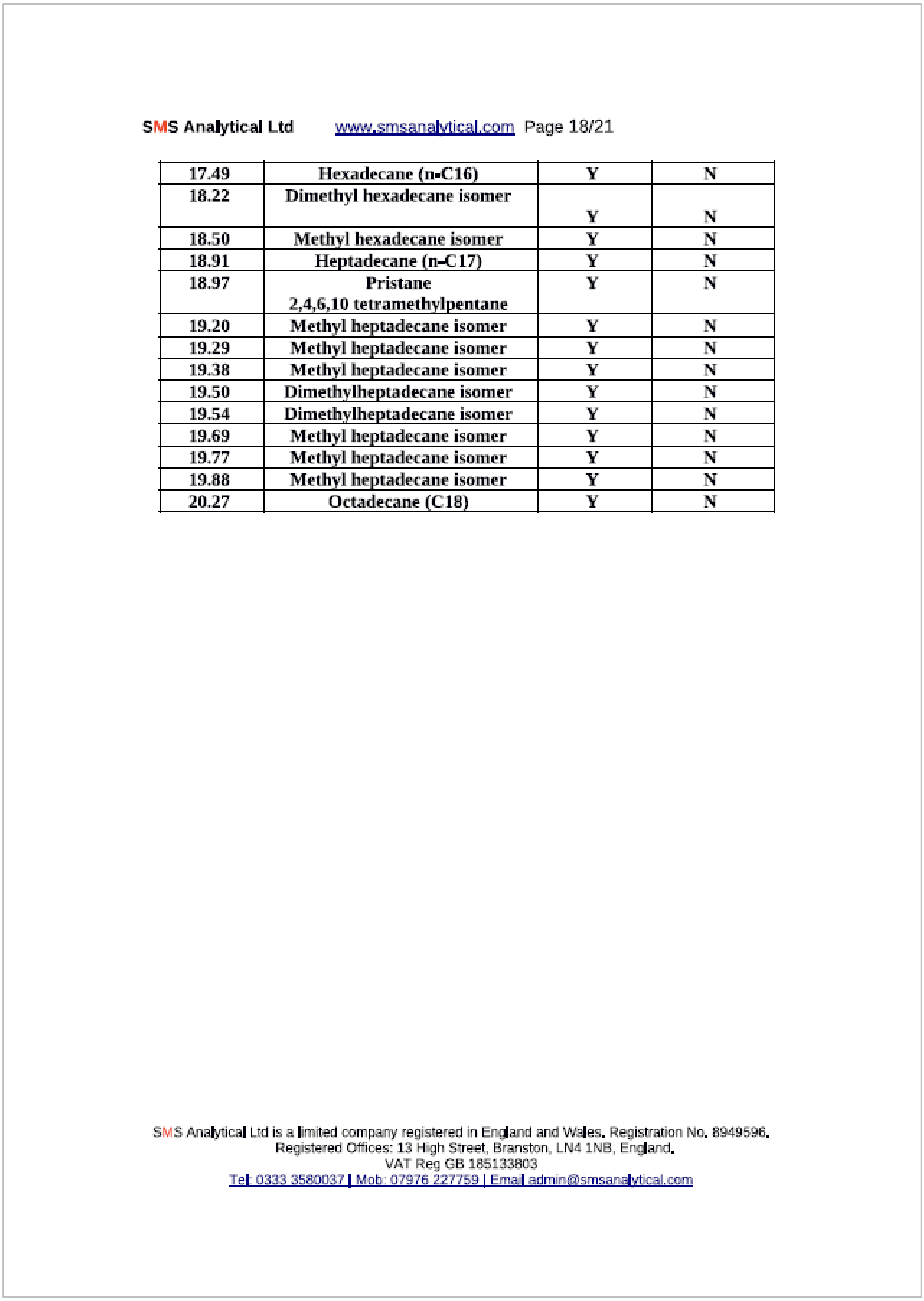
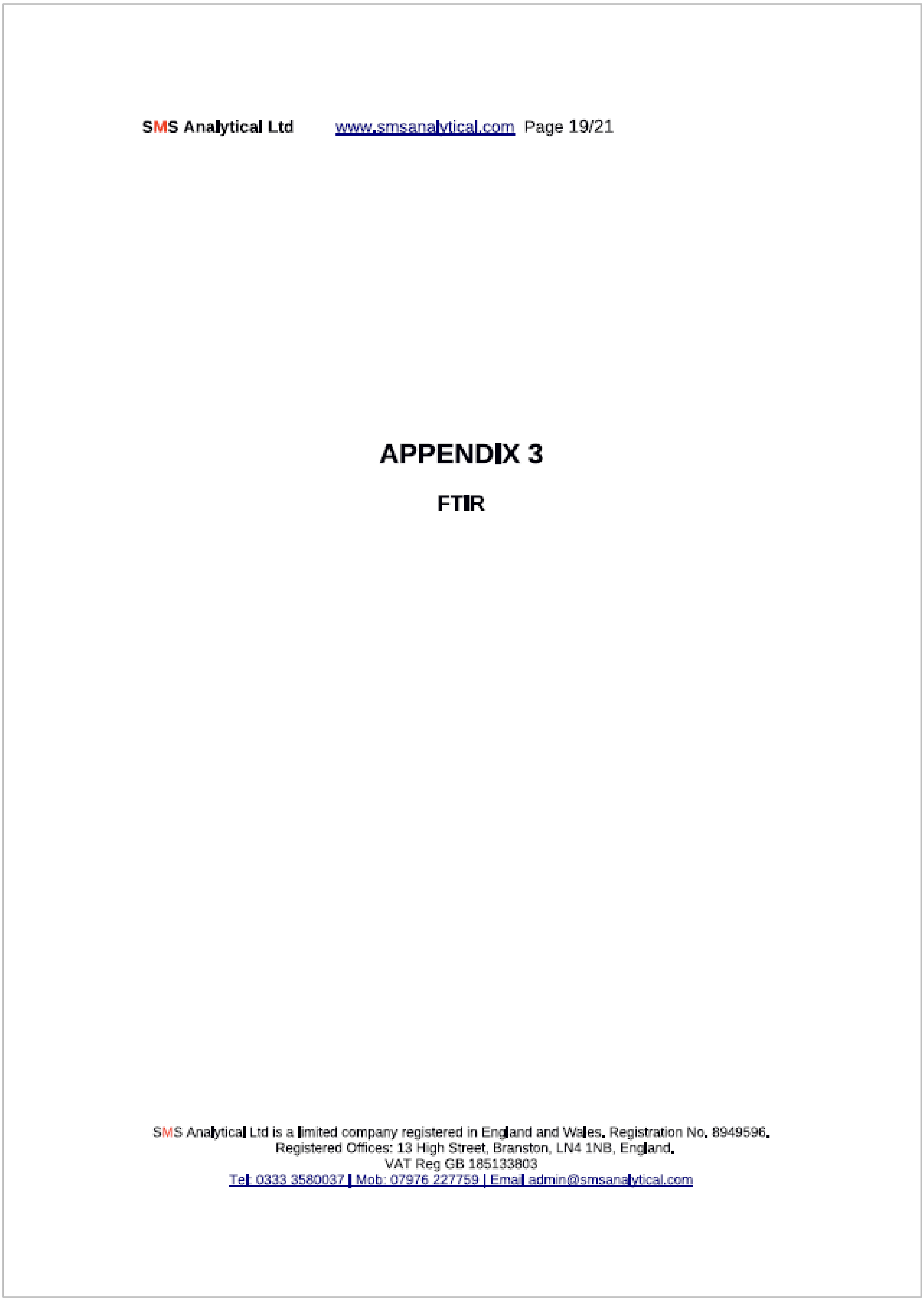


17.49	Hexadecane (n-C16)	Y	N
18.22	Dimethyl hexadecane isomer	Y	N
18.50	Methyl hexadecane isomer	Y	N
18.91	Heptadecane (n-C17)	Y	N
18.97	Pristane 2,4,6,10 tetramethylpentane	Y	N
19.20	Methyl heptadecane isomer	Y	N
19.29	Methyl heptadecane isomer	Y	N
19.38	Methyl heptadecane isomer	Y	N
19.50	Dimethylheptadecane isomer	Y	N
19.54	Dimethylheptadecane isomer	Y	N
19.69	Methyl heptadecane isomer	Y	N
19.77	Methyl heptadecane isomer	Y	N
19.88	Methyl heptadecane isomer	Y	N
20.27	Octadecane (C18)	Y	N



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APPENDIX 3

FTIR

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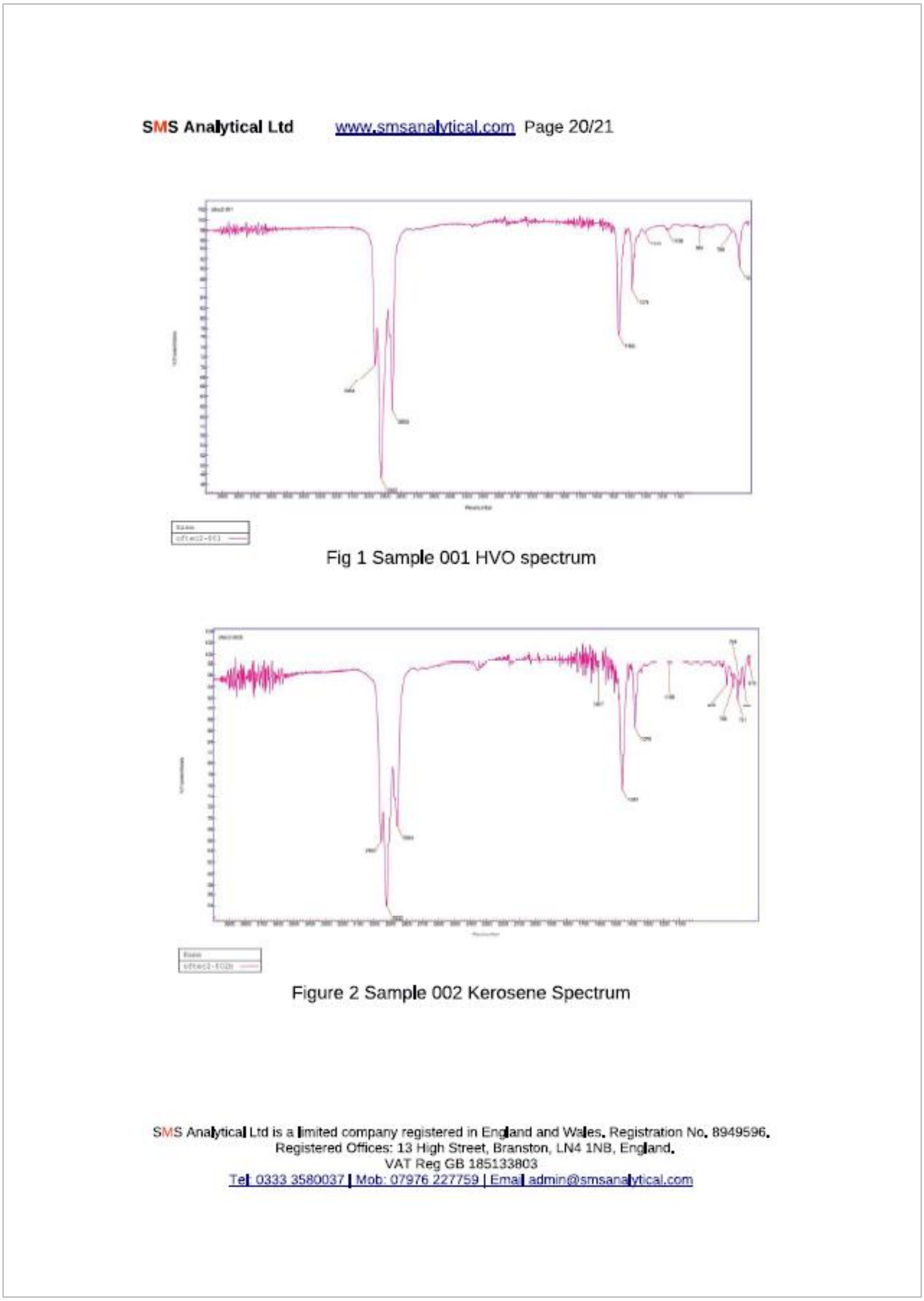

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Fig 1 Sample 001 HVO spectrum

Figure 2 Sample 002 Kerosene Spectrum

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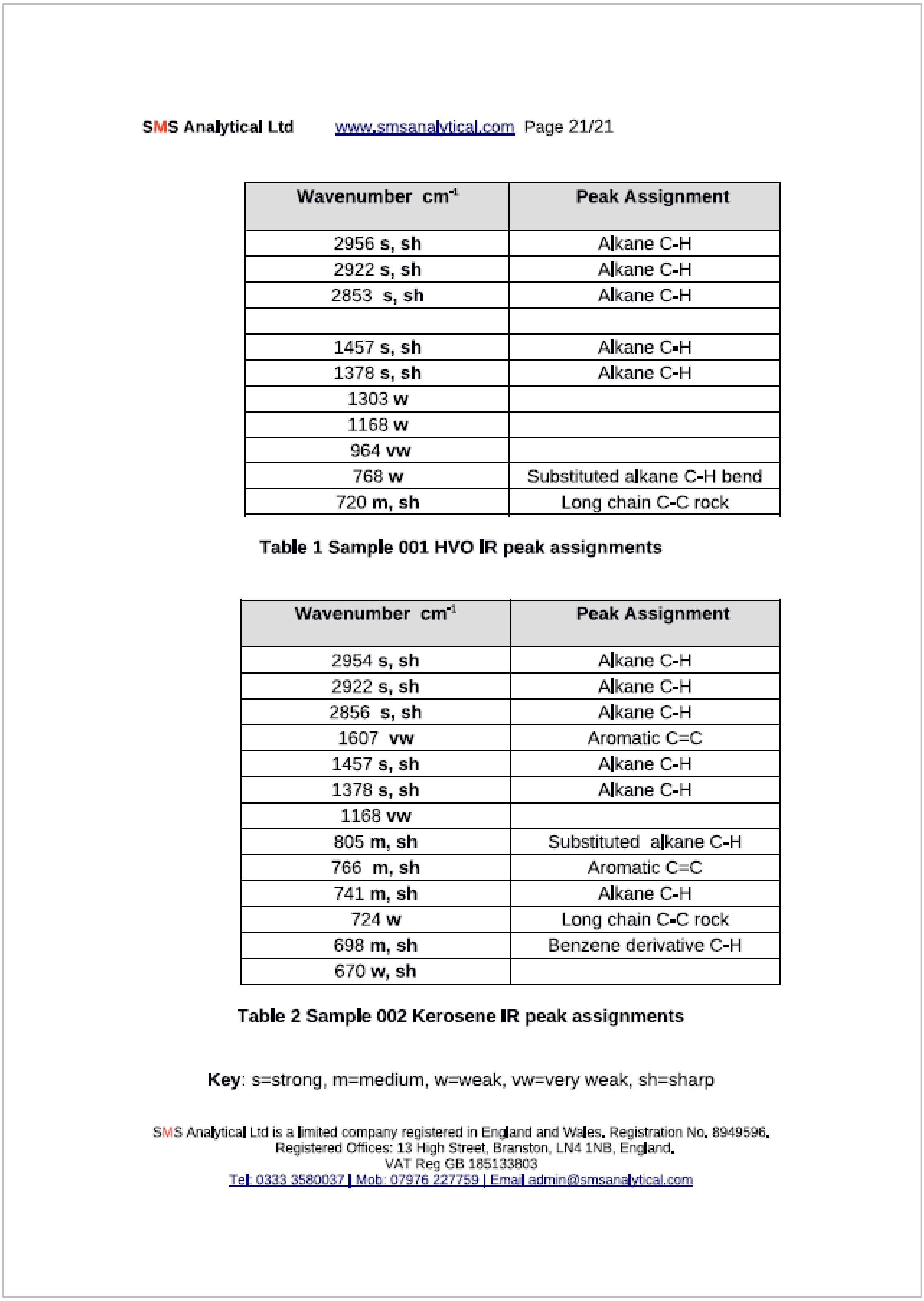

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Wavenumber cm^{-1}	**Peak Assignment**
2956 **s, sh**	Alkane C-H
2922 **s, sh**	Alkane C-H
2853 **s, sh**	Alkane C-H
1457 **s, sh**	Alkane C-H
1378 **s, sh**	Alkane C-H
1303 **w**	
1168 **w**	
964 **vw**	
768 **w**	Substituted alkane C-H bend
720 **m, sh**	Long chain C-C rock

Table 1 Sample 001 HVO IR peak assignments

Wavenumber cm^{-1}	**Peak Assignment**
2954 **s, sh**	Alkane C-H
2922 **s, sh**	Alkane C-H
2856 **s, sh**	Alkane C-H
1607 **vw**	Aromatic C=C
1457 **s, sh**	Alkane C-H
1378 **s, sh**	Alkane C-H
1168 **vw**	
805 **m, sh**	Substituted alkane C-H
766 **m, sh**	Aromatic C=C
741 **m, sh**	Alkane C-H
724 **w**	Long chain C-C rock
698 **m, sh**	Benzene derivative C-H
670 **w, sh**	

Table 2 Sample 002 Kerosene IR peak assignments

Key: s=strong, m=medium, w=weak, vw=very weak, sh=sharp

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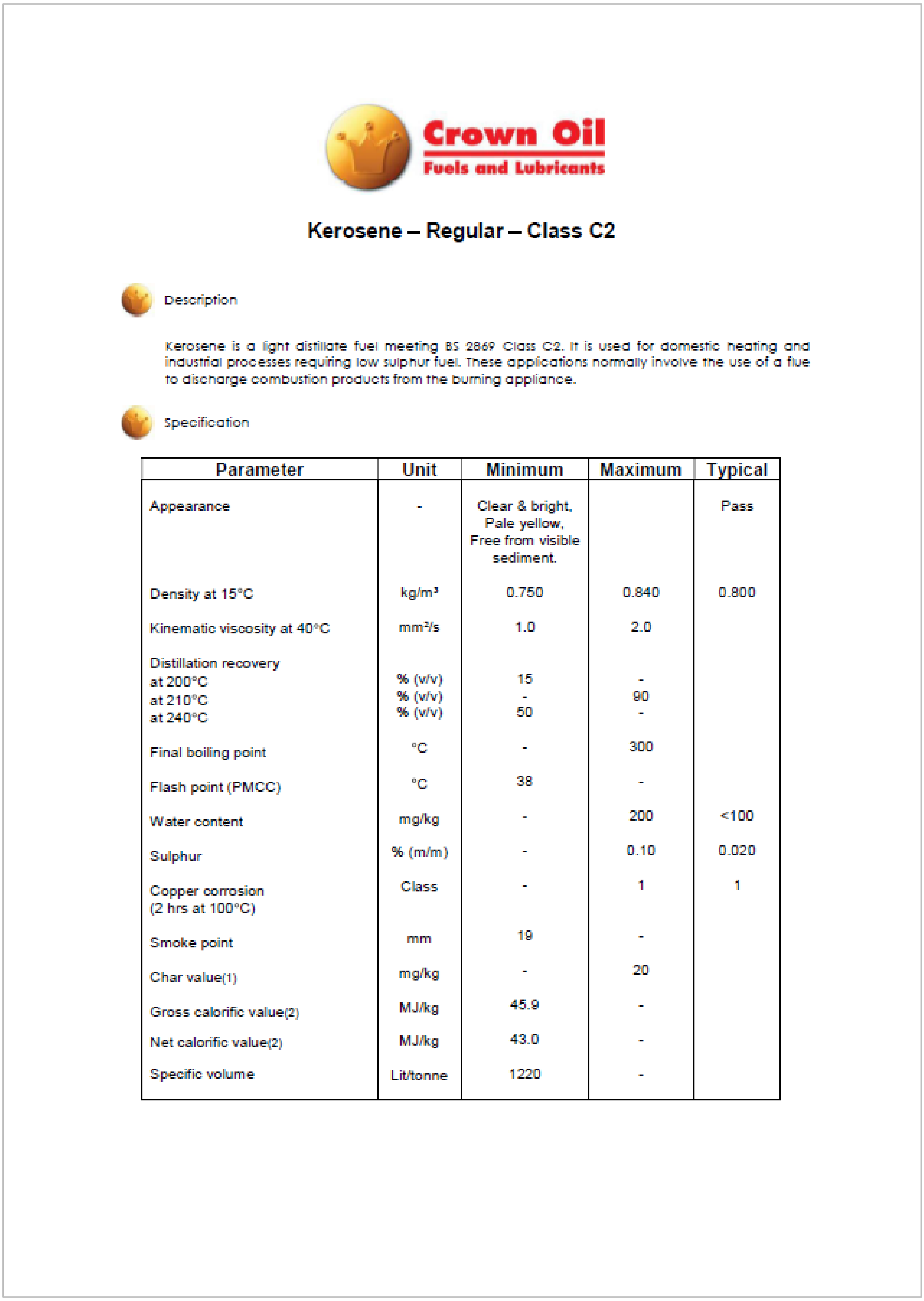
Annex C – Product Data Sheets

C.1 – Kerosene



Crown Oil
Fuels and Lubricants

Kerosene – Regular – Class C2

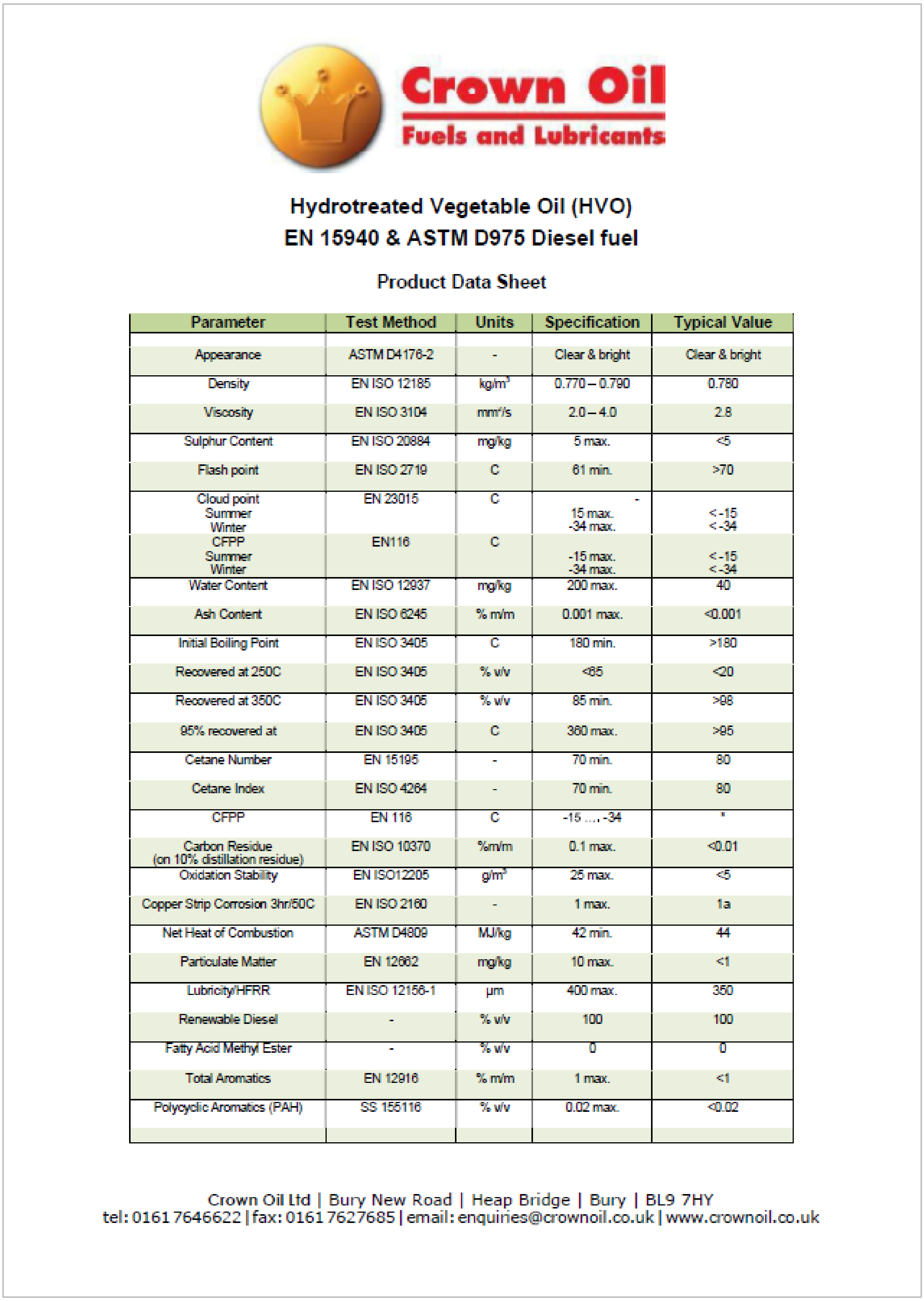
Description

Kerosene is a light distillate fuel meeting BS 2869 Class C2. It is used for domestic heating and industrial processes requiring low sulphur fuel. These applications normally involve the use of a flue to discharge combustion products from the burning appliance.

Specification

Parameter	Unit	Minimum	Maximum	Typical
Appearance	-	Clear & bright, Pale yellow, Free from visible sediment.		Pass
Density at 15°C	kg/m^3	0.750	0.840	0.800
Kinematic viscosity at 40°C	mm^2/s	1.0	2.0	
Distillation recovery				
at 200°C	% (v/v)	15	-	
at 210°C	% (v/v)	-	90	
at 240°C	% (v/v)	50	-	
Final boiling point	°C	-	300	
Flash point (PMCC)	°C	38	-	
Water content	mg/kg	-	200	<100
Sulphur	% (m/m)	-	0.10	0.020
Copper corrosion (2 hrs at 100°C)	Class	-	1	1
Smoke point	mm	19	-	
Char value(1)	mg/kg	-	20	
Gross calorific value(2)	MJ/kg	45.9	-	
Net calorific value(2)	MJ/kg	43.0	-	
Specific volume	Lit/tonne	1220	-	

C.2 – HVO



Crown Oil
Fuels and Lubricants

Hydrotreated Vegetable Oil (HVO)
EN 15940 & ASTM D975 Diesel fuel

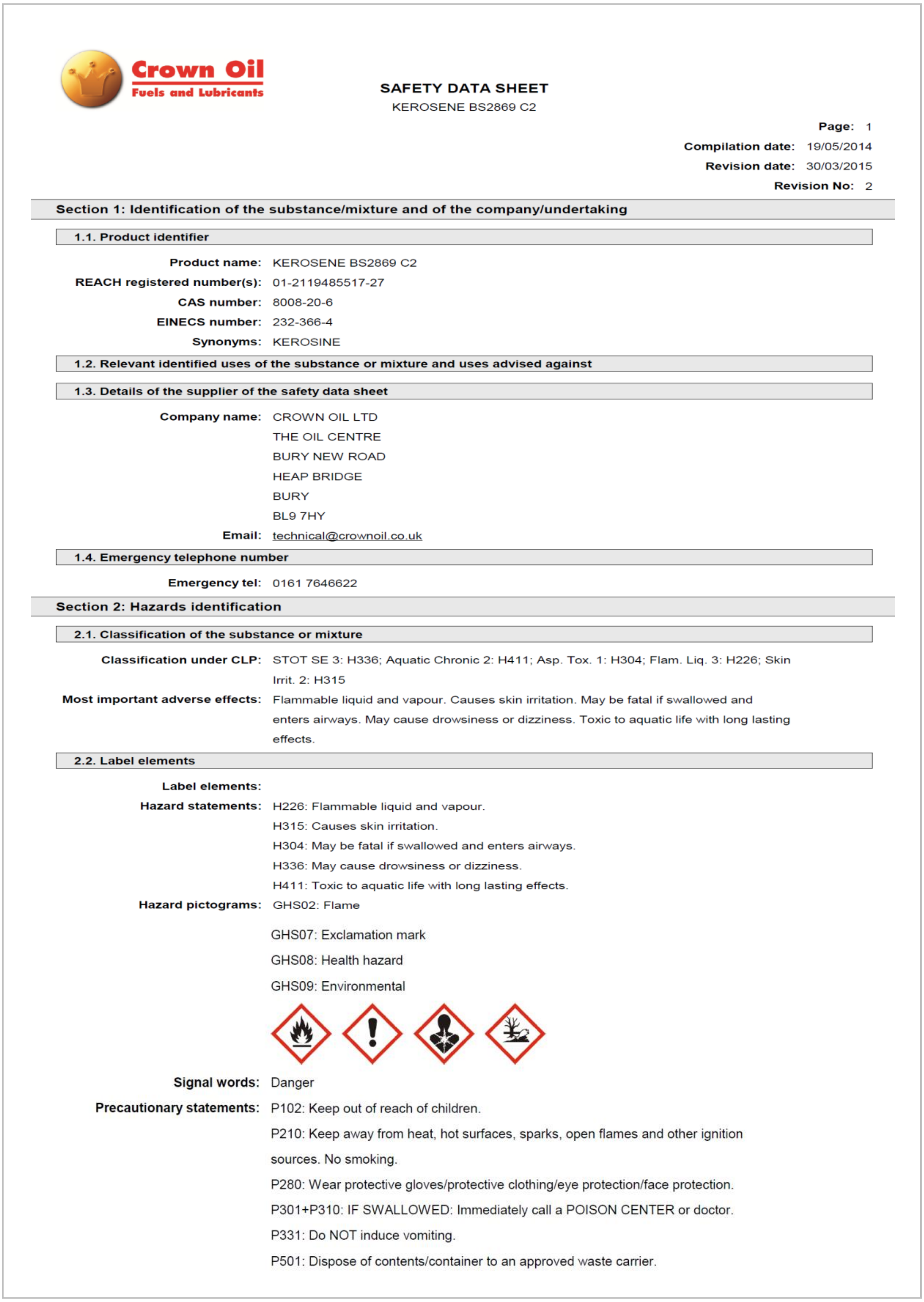
Product Data Sheet

Parameter	Test Method	Units	Specification	Typical Value
Appearance	ASTM D4176-2	-	Clear & bright	Clear & bright
Density	EN ISO 12185	kg/m^3	0.770 – 0.790	0.780
Viscosity	EN ISO 3104	mm^2/s	2.0 – 4.0	2.8
Sulphur Content	EN ISO 20884	mg/kg	5 max.	<5
Flash point	EN ISO 2719	C	61 min.	>70
Cloud point Summer Winter	EN 23015	C	- 15 max. -34 max.	< -15 < -34
CFPP Summer Winter	EN116	C	-15 max. -34 max.	< -15 < -34
Water Content	EN ISO 12937	mg/kg	200 max.	40
Ash Content	EN ISO 6245	% m/m	0.001 max.	<0.001
Initial Boiling Point	EN ISO 3405	C	180 min.	>180
Recovered at 250C	EN ISO 3405	% v/v	<65	<20
Recovered at 350C	EN ISO 3405	% v/v	85 min.	>98
95% recovered at	EN ISO 3405	C	360 max.	>95
Cetane Number	EN 15195	-	70 min.	80
Cetane Index	EN ISO 4264	-	70 min.	80
CFPP	EN 116	C	-15 ..., -34	*
Carbon Residue (on 10% distillation residue)	EN ISO 10370	%m/m	0.1 max.	<0.01
Oxidation Stability	EN ISO12205	g/m^3	25 max.	<5
Copper Strip Corrosion 3hr/50C	EN ISO 2160	-	1 max.	1a
Net Heat of Combustion	ASTM D4809	MJ/kg	42 min.	44
Particulate Matter	EN 12662	mg/kg	10 max.	<1
Lubricity/HFRR	EN ISO 12156-1	µm	400 max.	350
Renewable Diesel	-	% v/v	100	100
Fatty Acid Methyl Ester	-	% v/v	0	0
Total Aromatics	EN 12916	% m/m	1 max.	<1
Polycyclic Aromatics (PAH)	SS 155116	% v/v	0.02 max.	<0.02

Crown Oil Ltd | Bury New Road | Heap Bridge | Bury | BL9 7HY
tel: 0161 7646622 | fax: 0161 7627685 | email: enquiries@crownoil.co.uk | www.crownoil.co.uk

Annex D – Example Material Safety Data Sheets

D.1 – Kerosene



Crown Oil
Fuels and Lubricants

SAFETY DATA SHEET
KEROSENE BS2869 C2

Page: 1
Compilation date: 19/05/2014
Revision date: 30/03/2015
Revision No: 2

Section 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Product name: KEROSENE BS2869 C2
REACH registered number(s): 01-2119485517-27
CAS number: 8008-20-6
EINECS number: 232-366-4
Synonyms: KEROSINE

1.2. Relevant identified uses of the substance or mixture and uses advised against

1.3. Details of the supplier of the safety data sheet

Company name: CROWN OIL LTD
THE OIL CENTRE
BURY NEW ROAD
HEAP BRIDGE
BURY
BL9 7HY
Email: technical@crownoil.co.uk

1.4. Emergency telephone number

Emergency tel: 0161 7646622

Section 2: Hazards identification

2.1. Classification of the substance or mixture

Classification under CLP: STOT SE 3: H336; Aquatic Chronic 2: H411; Asp. Tox. 1: H304; Flam. Liq. 3: H226; Skin Irrit. 2: H315

Most important adverse effects: Flammable liquid and vapour. Causes skin irritation. May be fatal if swallowed and enters airways. May cause drowsiness or dizziness. Toxic to aquatic life with long lasting effects.

2.2. Label elements

Label elements:

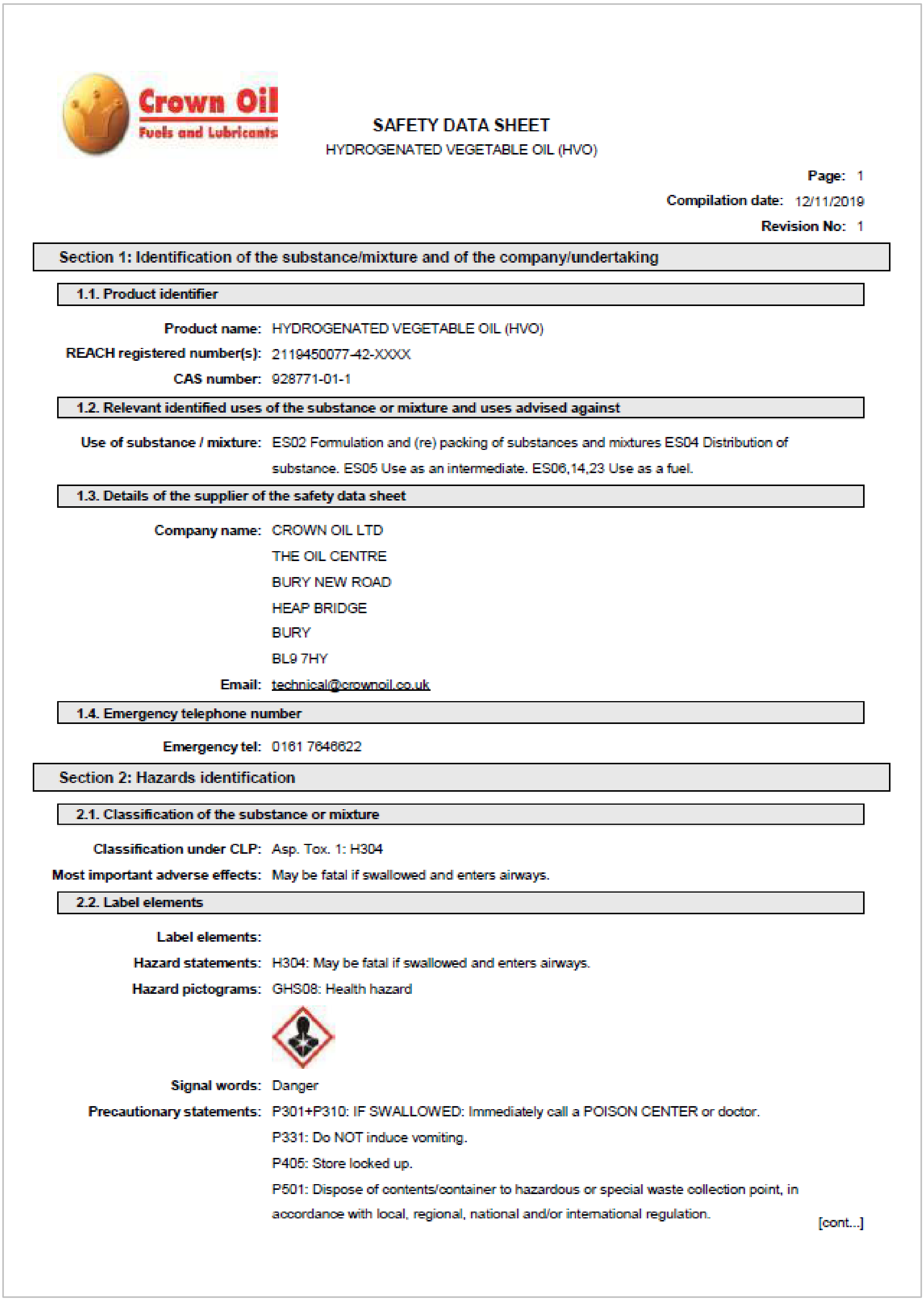
Hazard statements: H226: Flammable liquid and vapour.
H315: Causes skin irritation.
H304: May be fatal if swallowed and enters airways.
H336: May cause drowsiness or dizziness.
H411: Toxic to aquatic life with long lasting effects.

Hazard pictograms: GHS02: Flame
GHS07: Exclamation mark
GHS08: Health hazard
GHS09: Environmental

Signal words: Danger

Precautionary statements: P102: Keep out of reach of children.
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P280: Wear protective gloves/protective clothing/eye protection/face protection.
P301+P310: IF SWALLOWED: Immediately call a POISON CENTER or doctor.
P331: Do NOT induce vomiting.
P501: Dispose of contents/container to an approved waste carrier.

D.2 – HVO



Crown Oil
Fuels and Lubricants

SAFETY DATA SHEET

HYDROGENATED VEGETABLE OIL (HVO)

Page: 1
Compilation date: 12/11/2019
Revision No: 1

Section 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Product name: HYDROGENATED VEGETABLE OIL (HVO)
REACH registered number(s): 2119450077-42-XXXX
CAS number: 928771-01-1

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of substance / mixture: ES02 Formulation and (re) packing of substances and mixtures ES04 Distribution of substance. ES05 Use as an intermediate. ES06,14,23 Use as a fuel.

1.3. Details of the supplier of the safety data sheet

Company name: CROWN OIL LTD
THE OIL CENTRE
BURY NEW ROAD
HEAP BRIDGE
BURY
BL9 7HY
Email: technical@crownoil.co.uk

1.4. Emergency telephone number

Emergency tel: 0161 7646622

Section 2: Hazards identification

2.1. Classification of the substance or mixture

Classification under CLP: Asp. Tox. 1: H304
Most important adverse effects: May be fatal if swallowed and enters airways.

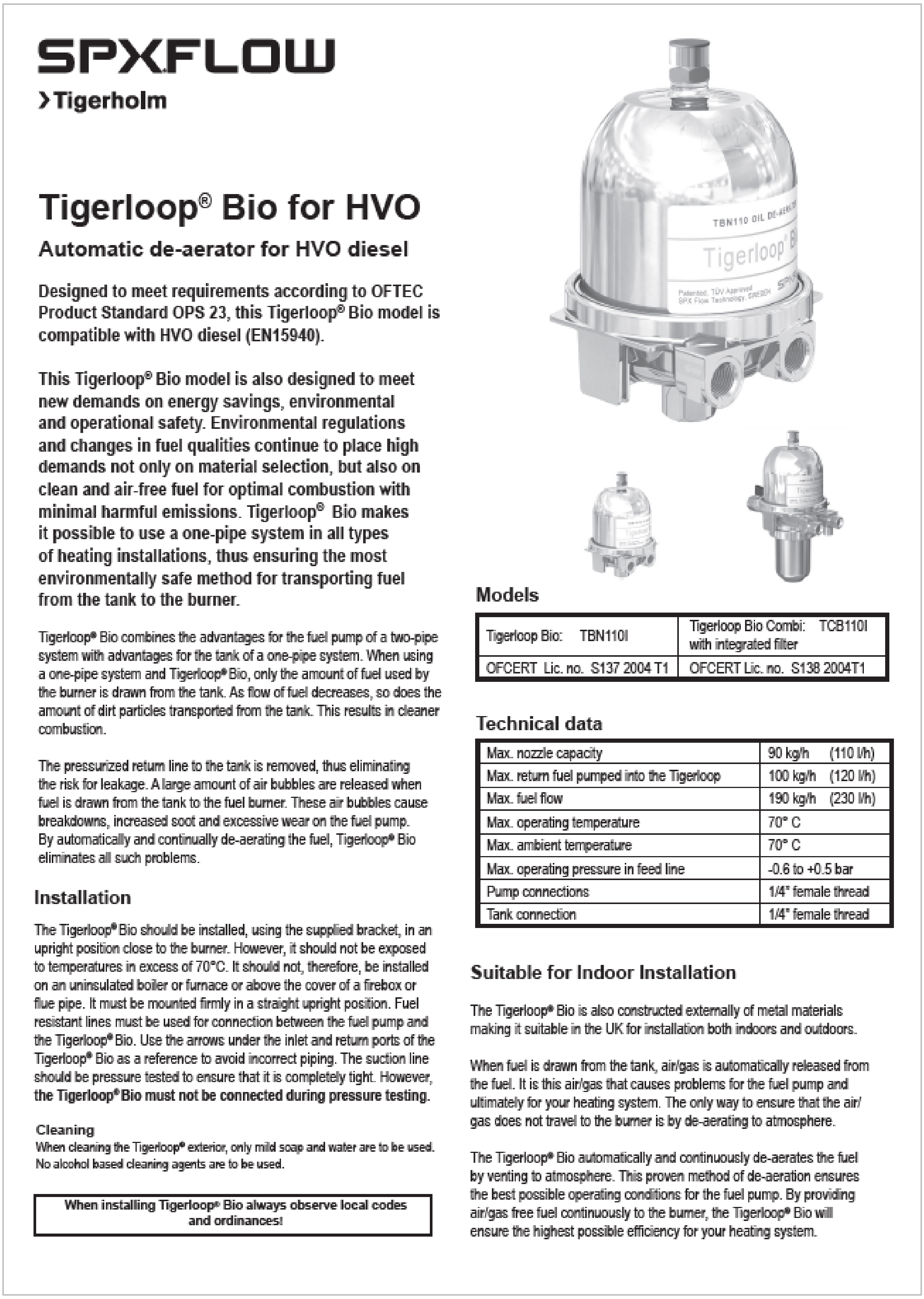
2.2. Label elements

Label elements:
Hazard statements: H304: May be fatal if swallowed and enters airways.
Hazard pictograms: GHS08: Health hazard

Signal words: Danger
Precautionary statements: P301+P310: IF SWALLOWED: Immediately call a POISON CENTER or doctor.
P331: Do NOT induce vomiting.
P405: Store locked up.
P501: Dispose of contents/container to hazardous or special waste collection point, in accordance with local, regional, national and/or international regulation.

[cont...]

Annex E – SPX Flow HVO de-aerator instructions



SPXFLOW
›Tigerholm

Tigerloop® Bio for HVO

Automatic de-aerator for HVO diesel

Designed to meet requirements according to OFTEC Product Standard OPS 23, this Tigerloop® Bio model is compatible with HVO diesel (EN15940).

This Tigerloop® Bio model is also designed to meet new demands on energy savings, environmental and operational safety. Environmental regulations and changes in fuel qualities continue to place high demands not only on material selection, but also on clean and air-free fuel for optimal combustion with minimal harmful emissions. Tigerloop® Bio makes it possible to use a one-pipe system in all types of heating installations, thus ensuring the most environmentally safe method for transporting fuel from the tank to the burner.

Tigerloop® Bio combines the advantages for the fuel pump of a two-pipe system with advantages for the tank of a one-pipe system. When using a one-pipe system and Tigerloop® Bio, only the amount of fuel used by the burner is drawn from the tank. As flow of fuel decreases, so does the amount of dirt particles transported from the tank. This results in cleaner combustion.

The pressurized return line to the tank is removed, thus eliminating the risk for leakage. A large amount of air bubbles are released when fuel is drawn from the tank to the fuel burner. These air bubbles cause breakdowns, increased soot and excessive wear on the fuel pump. By automatically and continually de-aerating the fuel, Tigerloop® Bio eliminates all such problems.

Installation

The Tigerloop® Bio should be installed, using the supplied bracket, in an upright position close to the burner. However, it should not be exposed to temperatures in excess of 70°C. It should not, therefore, be installed on an uninsulated boiler or furnace or above the cover of a firebox or flue pipe. It must be mounted firmly in a straight upright position. Fuel resistant lines must be used for connection between the fuel pump and the Tigerloop® Bio. Use the arrows under the inlet and return ports of the Tigerloop® Bio as a reference to avoid incorrect piping. The suction line should be pressure tested to ensure that it is completely tight. However, **the Tigerloop® Bio must not be connected during pressure testing.**

Cleaning

When cleaning the Tigerloop® exterior, only mild soap and water are to be used. No alcohol based cleaning agents are to be used.

When installing Tigerloop® Bio always observe local codes and ordinances!

Models

Tigerloop Bio: TBN110I	Tigerloop Bio Combi: TCB110I with integrated filter
OFCERT Lic. no. S137 2004 T1	OFCERT Lic. no. S138 2004T1

Technical data

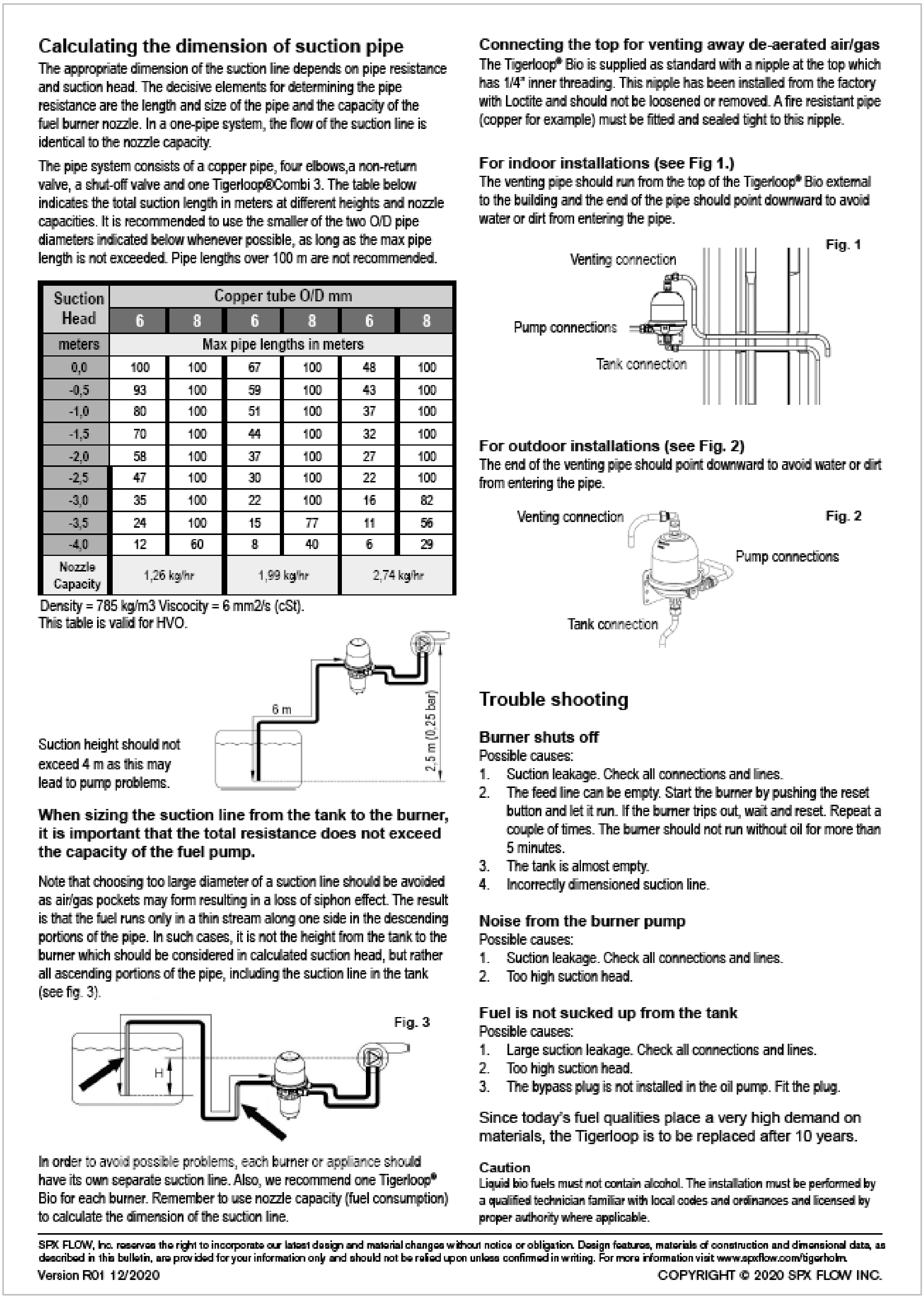
Max. nozzle capacity	90 kg/h (110 l/h)
Max. return fuel pumped into the Tigerloop	100 kg/h (120 l/h)
Max. fuel flow	190 kg/h (230 l/h)
Max. operating temperature	70° C
Max. ambient temperature	70° C
Max. operating pressure in feed line	-0.6 to +0.5 bar
Pump connections	1/4" female thread
Tank connection	1/4" female thread

Suitable for Indoor Installation

The Tigerloop® Bio is also constructed externally of metal materials making it suitable in the UK for installation both indoors and outdoors.

When fuel is drawn from the tank, air/gas is automatically released from the fuel. It is this air/gas that causes problems for the fuel pump and ultimately for your heating system. The only way to ensure that the air/gas does not travel to the burner is by de-aerating to atmosphere.

The Tigerloop® Bio automatically and continuously de-aerates the fuel by venting to atmosphere. This proven method of de-aeration ensures the best possible operating conditions for the fuel pump. By providing air/gas free fuel continuously to the burner, the Tigerloop® Bio will ensure the highest possible efficiency for your heating system.



Calculating the dimension of suction pipe

The appropriate dimension of the suction line depends on pipe resistance and suction head. The decisive elements for determining the pipe resistance are the length and size of the pipe and the capacity of the fuel burner nozzle. In a one-pipe system, the flow of the suction line is identical to the nozzle capacity.

The pipe system consists of a copper pipe, four elbows,a non-return valve, a shut-off valve and one Tigerloop®Combi 3. The table below indicates the total suction length in meters at different heights and nozzle capacities. It is recommended to use the smaller of the two O/D pipe diameters indicated below whenever possible, as long as the max pipe length is not exceeded. Pipe lengths over 100 m are not recommended.

Suction Head	Copper tube O/D mm					
	6	8	6	8	6	8
meters	Max pipe lengths in meters					
0,0	100	100	67	100	48	100
-0,5	93	100	59	100	43	100
-1,0	80	100	51	100	37	100
-1,5	70	100	44	100	32	100
-2,0	58	100	37	100	27	100
-2,5	47	100	30	100	22	100
-3,0	35	100	22	100	16	82
-3,5	24	100	15	77	11	56
-4,0	12	60	8	40	6	29
Nozzle Capacity	1,26 kg/hr		1,99 kg/hr		2,74 kg/hr	

Density = 785 kg/m3 Viscocity = 6 mm2/s (cSt).
This table is valid for HVO.

Suction height should not exceed 4 m as this may lead to pump problems.

When sizing the suction line from the tank to the burner, it is important that the total resistance does not exceed the capacity of the fuel pump.

Note that choosing too large diameter of a suction line should be avoided as air/gas pockets may form resulting in a loss of siphon effect. The result is that the fuel runs only in a thin stream along one side in the descending portions of the pipe. In such cases, it is not the height from the tank to the burner which should be considered in calculated suction head, but rather all ascending portions of the pipe, including the suction line in the tank (see fig. 3).

Fig. 3

In order to avoid possible problems, each burner or appliance should have its own separate suction line. Also, we recommend one Tigerloop® Bio for each burner. Remember to use nozzle capacity (fuel consumption) to calculate the dimension of the suction line.

Connecting the top for venting away de-aerated air/gas

The Tigerloop® Bio is supplied as standard with a nipple at the top which has 1/4" inner threading. This nipple has been installed from the factory with Loctite and should not be loosened or removed. A fire resistant pipe (copper for example) must be fitted and sealed tight to this nipple.

For indoor installations (see Fig 1.)

The venting pipe should run from the top of the Tigerloop® Bio external to the building and the end of the pipe should point downward to avoid water or dirt from entering the pipe.

Fig. 1

For outdoor installations (see Fig. 2)

The end of the venting pipe should point downward to avoid water or dirt from entering the pipe.

Fig. 2

Trouble shooting

Burner shuts off

Possible causes:

1. Suction leakage. Check all connections and lines.
2. The feed line can be empty. Start the burner by pushing the reset button and let it run. If the burner trips out, wait and reset. Repeat a couple of times. The burner should not run without oil for more than 5 minutes.
3. The tank is almost empty.
4. Incorrectly dimensioned suction line.

Noise from the burner pump

Possible causes:

1. Suction leakage. Check all connections and lines.
2. Too high suction head.

Fuel is not sucked up from the tank

Possible causes:

1. Large suction leakage. Check all connections and lines.
2. Too high suction head.
3. The bypass plug is not installed in the oil pump. Fit the plug.

Since today's fuel qualities place a very high demand on materials, the Tigerloop is to be replaced after 10 years.

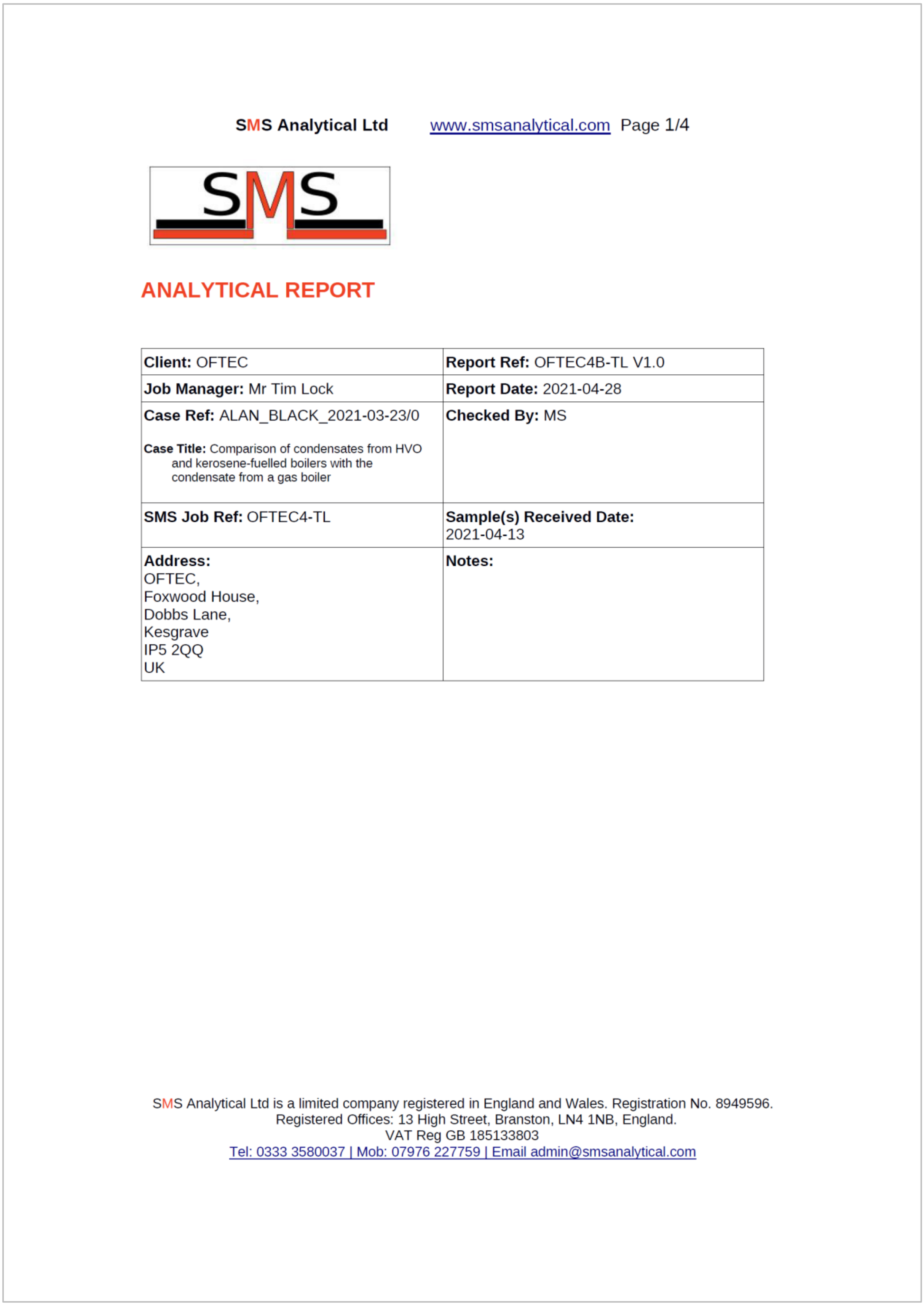
Caution

Liquid bio fuels must not contain alcohol. The installation must be performed by a qualified technician familiar with local codes and ordinances and licensed by proper authority where applicable.

Version R01 12/2020

Note: ***Suction line tables are here matched to Danfoss HVO demonstrator site atomising nozzle sizes at nozzle calibration pressure throughputs***

Annex F – SMS Analytical report on combustion condensate

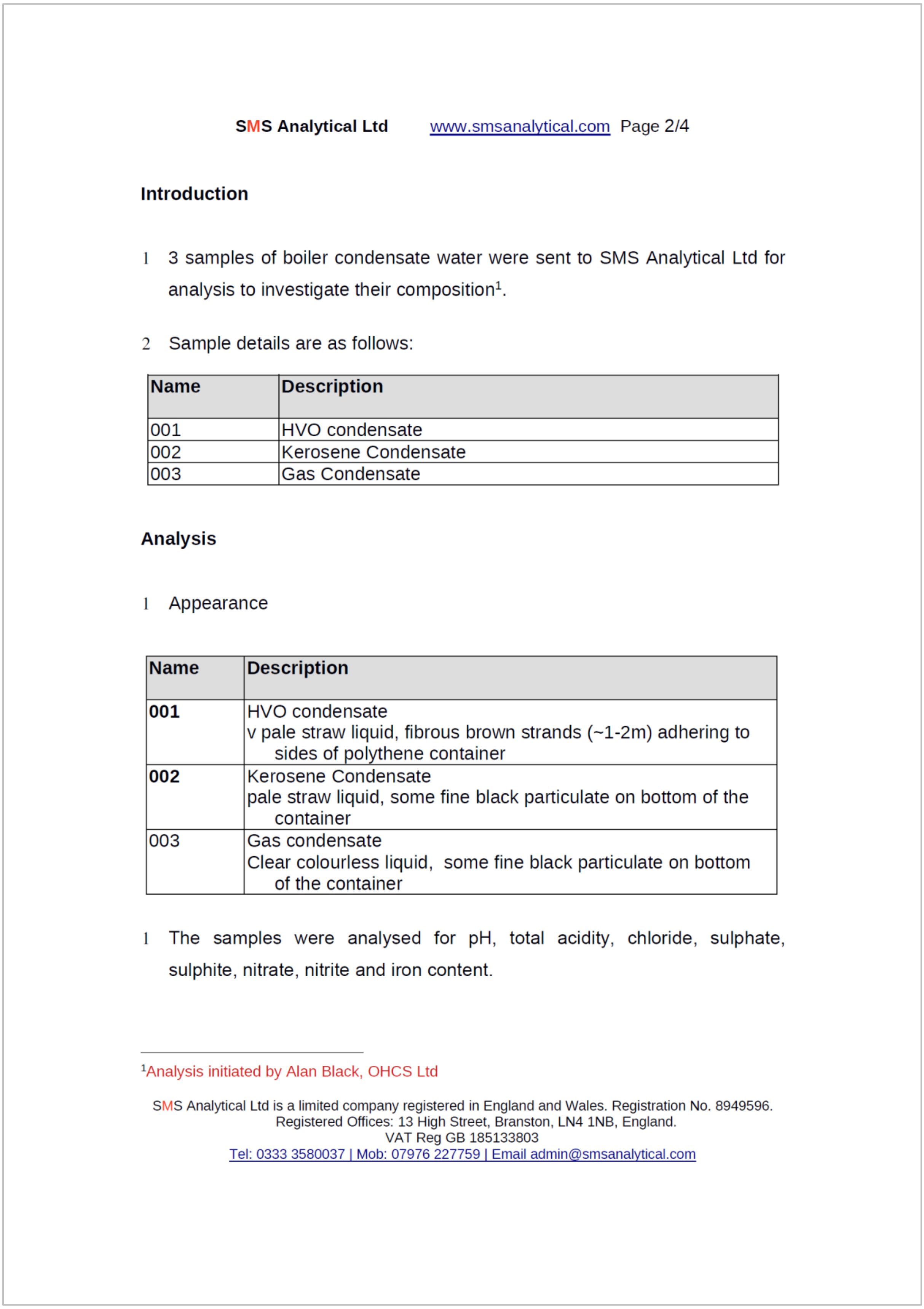


SMS Analytical Ltd www.smsanalytical.com Page 1/4

ANALYTICAL REPORT

Client: OFTEC	**Report Ref:** OFTEC4B-TL V1.0
Job Manager: Mr Tim Lock	**Report Date:** 2021-04-28
Case Ref: ALAN_BLACK_2021-03-23/0 **Case Title:** Comparison of condensates from HVO and kerosene-fuelled boilers with the condensate from a gas boiler	**Checked By:** MS
SMS Job Ref: OFTEC4-TL	**Sample(s) Received Date:** 2021-04-13
Address: OFTEC, Foxwood House, Dobbs Lane, Kesgrave IP5 2QQ UK	**Notes:**

SMS Analytical Ltd is a limited company registered in England and Wales. Registration No. 8949596.
Registered Offices: 13 High Street, Branston, LN4 1NB, England.
VAT Reg GB 185133803
Tel: 0333 3580037 | Mob: 07976 227759 | Email admin@smsanalytical.com



Introduction

1 3 samples of boiler condensate water were sent to SMS Analytical Ltd for analysis to investigate their composition[1].

2 Sample details are as follows:

Name	Description
001	HVO condensate
002	Kerosene Condensate
003	Gas Condensate

Analysis

1 Appearance

Name	Description
001	HVO condensate v pale straw liquid, fibrous brown strands (~1-2m) adhering to sides of polythene container
002	Kerosene Condensate pale straw liquid, some fine black particulate on bottom of the container
003	Gas condensate Clear colourless liquid, some fine black particulate on bottom of the container

1 The samples were analysed for pH, total acidity, chloride, sulphate, sulphite, nitrate, nitrite and iron content.

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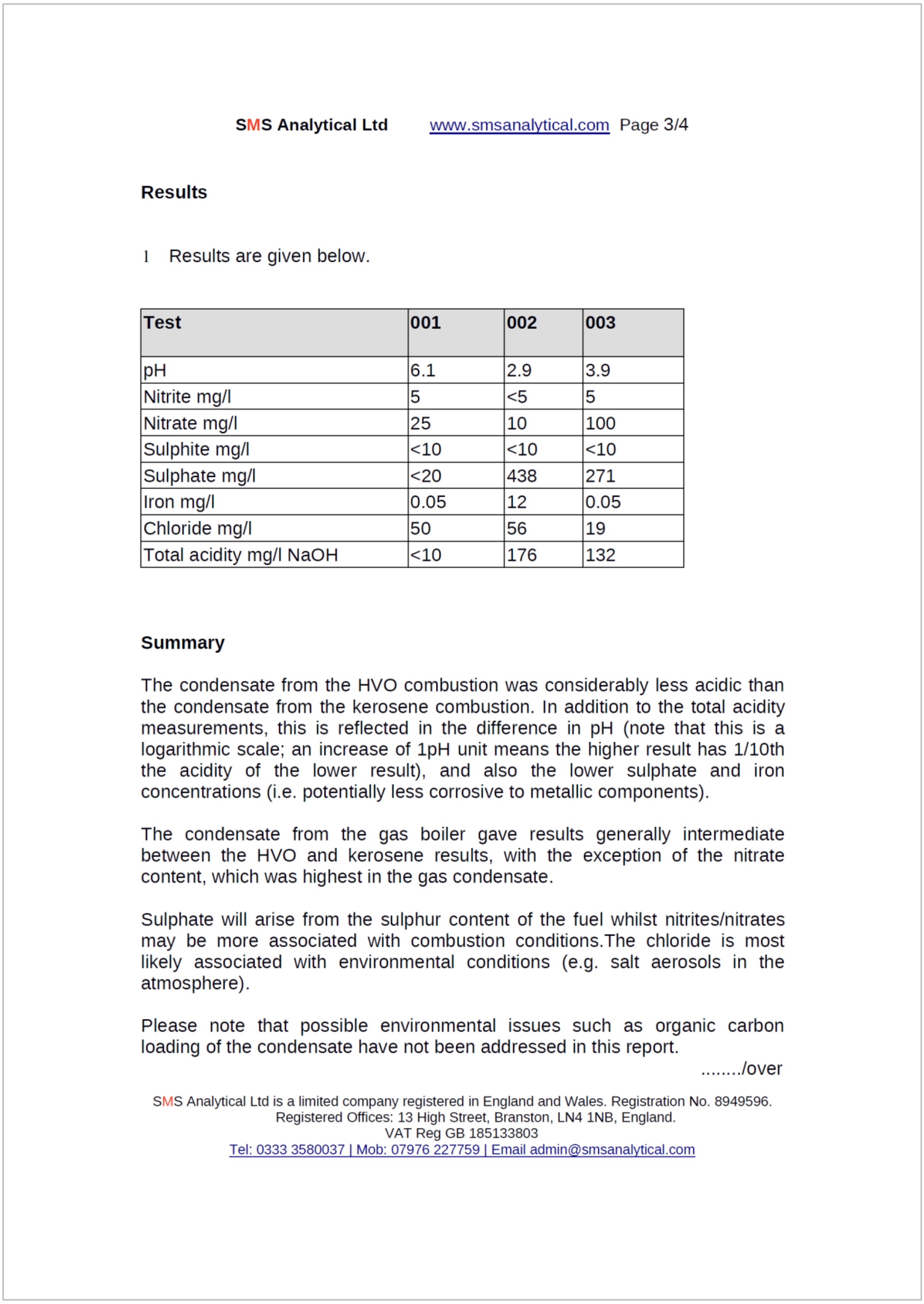
[1] Analysis initiated by Alan Black, OHCS Ltd



Results

1 Results are given below.

Test	001	002	003
pH	6.1	2.9	3.9
Nitrite mg/l	5	<5	5
Nitrate mg/l	25	10	100
Sulphite mg/l	<10	<10	<10
Sulphate mg/l	<20	438	271
Iron mg/l	0.05	12	0.05
Chloride mg/l	50	56	19
Total acidity mg/l NaOH	<10	176	132

Summary

The condensate from the HVO combustion was considerably less acidic than the condensate from the kerosene combustion. In addition to the total acidity measurements, this is reflected in the difference in pH (note that this is a logarithmic scale; an increase of 1pH unit means the higher result has 1/10th the acidity of the lower result), and also the lower sulphate and iron concentrations (i.e. potentially less corrosive to metallic components).

The condensate from the gas boiler gave results generally intermediate between the HVO and kerosene results, with the exception of the nitrate content, which was highest in the gas condensate.

Sulphate will arise from the sulphur content of the fuel whilst nitrites/nitrates may be more associated with combustion conditions.The chloride is most likely associated with environmental conditions (e.g. salt aerosols in the atmosphere).

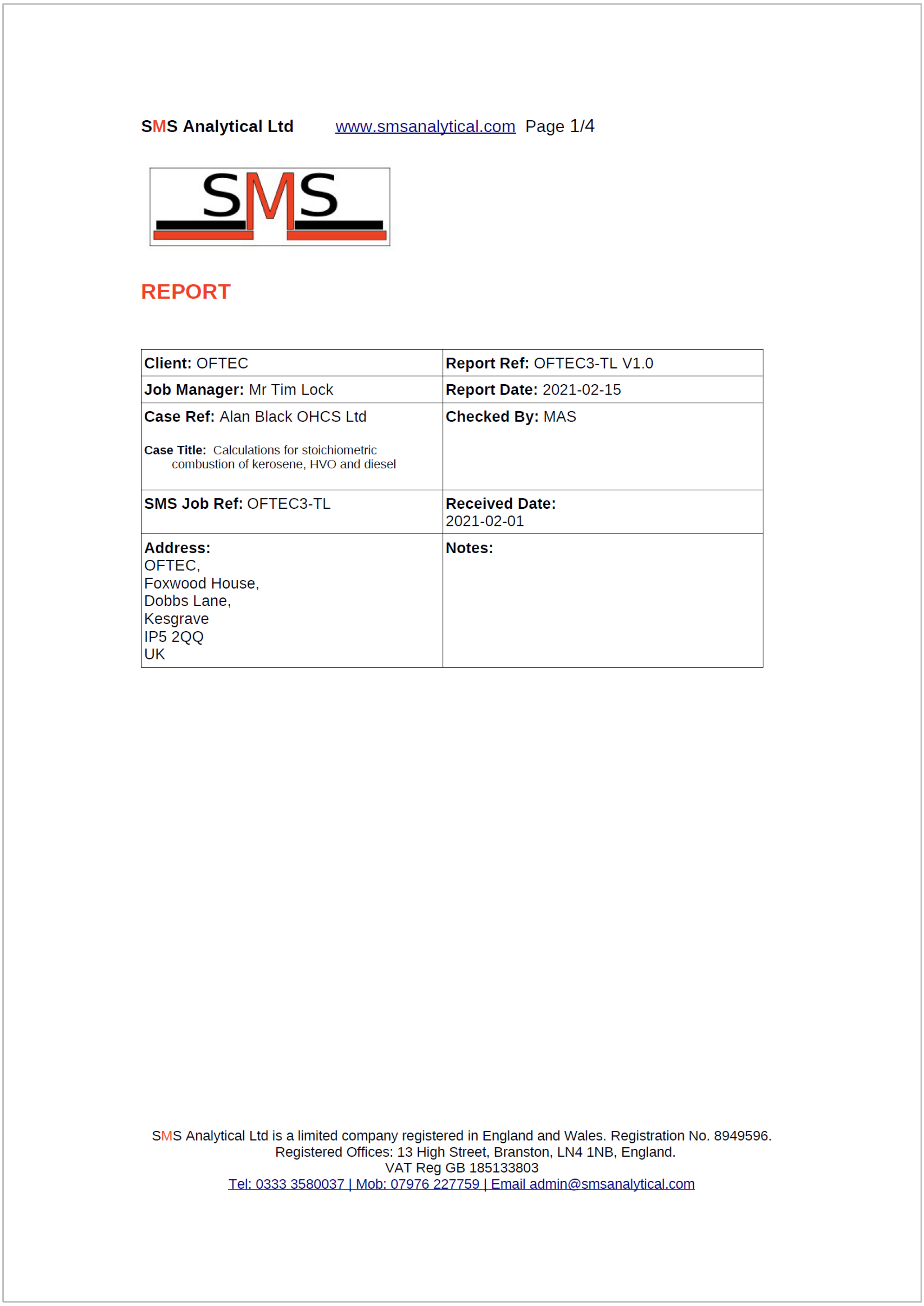
Please note that possible environmental issues such as organic carbon loading of the condensate have not been addressed in this report.

......../over

Sheila Marshman.

Dr Sheila Marshman FRCS, C Chem

Annex G – SMS Analytical report on stoichiometric combustion



SMS Analytical Ltd www.smsanalytical.com Page 1/4

REPORT

Client: OFTEC	**Report Ref:** OFTEC3-TL V1.0
Job Manager: Mr Tim Lock	**Report Date:** 2021-02-15
Case Ref: Alan Black OHCS Ltd **Case Title:** Calculations for stoichiometric combustion of kerosene, HVO and diesel	**Checked By:** MAS
SMS Job Ref: OFTEC3-TL	**Received Date:** 2021-02-01
Address: OFTEC, Foxwood House, Dobbs Lane, Kesgrave IP5 2QQ UK	**Notes:**

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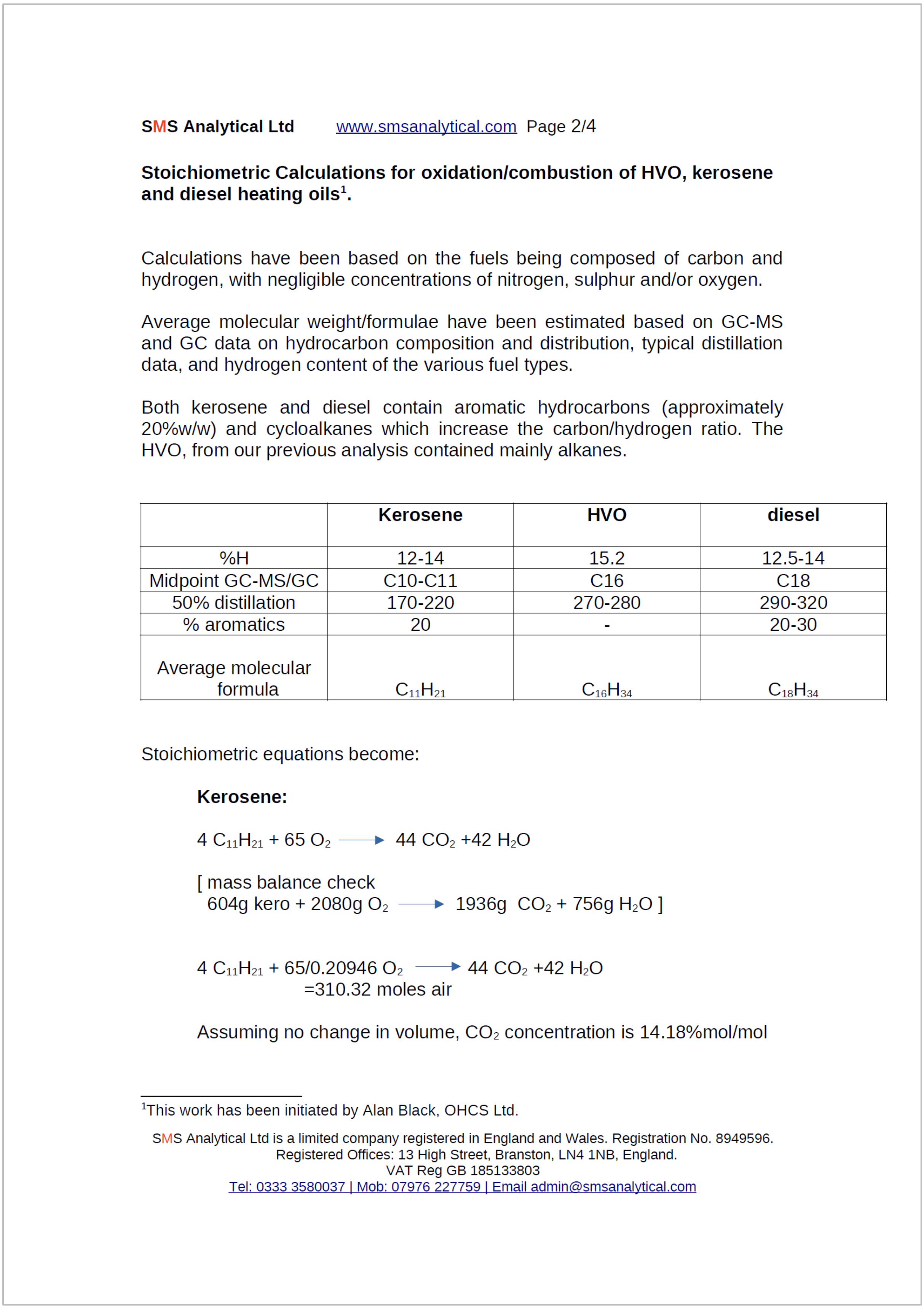

Stoichiometric Calculations for oxidation/combustion of HVO, kerosene and diesel heating oils[1].

Calculations have been based on the fuels being composed of carbon and hydrogen, with negligible concentrations of nitrogen, sulphur and/or oxygen.

Average molecular weight/formulae have been estimated based on GC-MS and GC data on hydrocarbon composition and distribution, typical distillation data, and hydrogen content of the various fuel types.

Both kerosene and diesel contain aromatic hydrocarbons (approximately 20%w/w) and cycloalkanes which increase the carbon/hydrogen ratio. The HVO, from our previous analysis contained mainly alkanes.

	Kerosene	**HVO**	**diesel**
%H	12-14	15.2	12.5-14
Midpoint GC-MS/GC	C10-C11	C16	C18
50% distillation	170-220	270-280	290-320
% aromatics	20	-	20-30
Average molecular formula	$C_{11}H_{21}$	$C_{16}H_{34}$	$C_{18}H_{34}$

Stoichiometric equations become:

Kerosene:

$$4\ C_{11}H_{21} + 65\ O_2 \longrightarrow 44\ CO_2 + 42\ H_2O$$

[mass balance check

$$604g\ \text{kero} + 2080g\ O_2 \longrightarrow 1936g\ \ CO_2 + 756g\ H_2O\ ]$$

$$4\ C_{11}H_{21} + 65/0.20946\ O_2 \longrightarrow 44\ CO_2 + 42\ H_2O$$

=310.32 moles air

Assuming no change in volume, CO_2 concentration is 14.18%mol/mol

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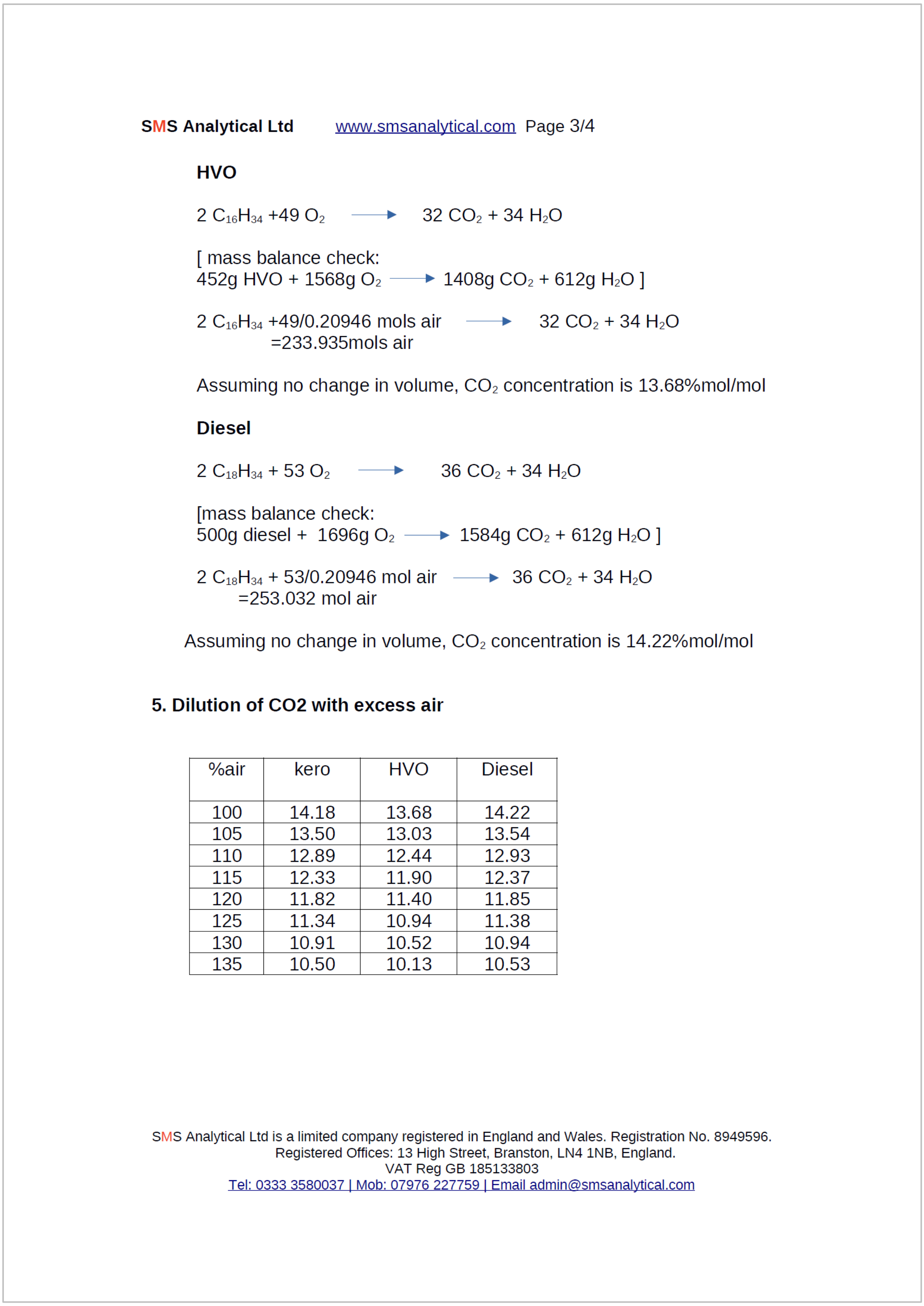
[1] This work has been initiated by Alan Black, OHCS Ltd.



HVO

$2\ C_{16}H_{34} + 49\ O_2 \longrightarrow 32\ CO_2 + 34\ H_2O$

[mass balance check:
452g HVO + 1568g $O_2 \longrightarrow$ 1408g CO_2 + 612g H_2O]

$2\ C_{16}H_{34}$ +49/0.20946 mols air $\longrightarrow$ $32\ CO_2 + 34\ H_2O$
=233.935mols air

Assuming no change in volume, CO_2 concentration is 13.68%mol/mol

Diesel

$2\ C_{18}H_{34} + 53\ O_2 \longrightarrow 36\ CO_2 + 34\ H_2O$

[mass balance check:
500g diesel + 1696g $O_2 \longrightarrow$ 1584g CO_2 + 612g H_2O]

$2\ C_{18}H_{34}$ + 53/0.20946 mol air $\longrightarrow$ $36\ CO_2 + 34\ H_2O$
=253.032 mol air

Assuming no change in volume, CO_2 concentration is 14.22%mol/mol

5. Dilution of CO2 with excess air

%air	kero	HVO	Diesel
100	14.18	13.68	14.22
105	13.50	13.03	13.54
110	12.89	12.44	12.93
115	12.33	11.90	12.37
120	11.82	11.40	11.85
125	11.34	10.94	11.38
130	10.91	10.52	10.94
135	10.50	10.13	10.53

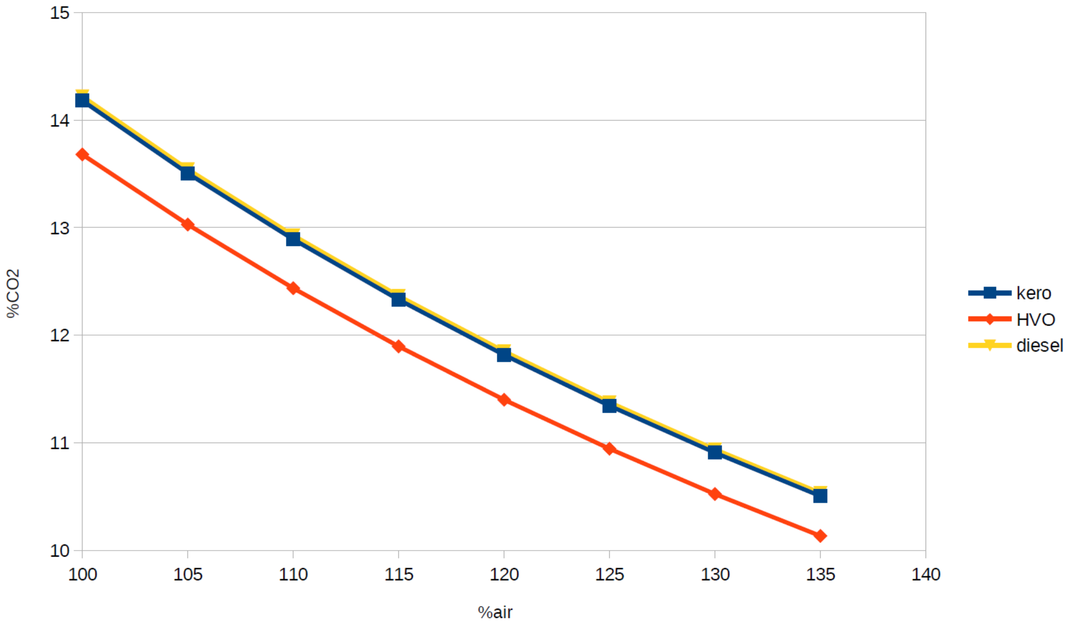


Fig 1 Dilution effect on carbon dioxide concentration with excess air

Sheila Marshman.

Dr Sheila Marshman FRCS, C Chem

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For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

BS 2869, *Fuel oils for agricultural, domestic and industrial engines and boilers – Specification*

BS 5410-1, *Code of practice for liquid fuel firing – Part 1: Installations for space heating and hot water supply purposes for domestic buildings*

BS EN 14214, *Liquid petroleum products – Fatty acid methyl esters (FAME) for use in diesel engines and heating applications – Requirements and test methods*

BS EN 15940, *Automotive fuels – Paraffinic diesel fuel from synthesis or hydrotreatment – Requirements and test methods*

Other publications

OIL FIRING TECHNICAL ASSOCIATION LTD. OFTEC Technical Book 2 – Domestic & light commercial servicing and commissioning – Requirements for oil fired systems – Pressure jet appliances.

OIL FIRING TECHNICAL ASSOCIATION LTD. OFTEC Technical Book 3 – Domestic & commercial requirements for oil storage & supply equipment serving fixed combustion appliances.

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