

Sulphur dioxide emissions from oil refineries and combustion of oil products in Western Europe and Hungary (2002)

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ABSTRACT

This report examines the sulphur balances of European oil refineries and the sulphur contents of oil products based on a CONCAWE survey of 2002 actual data. Comparisons are made with data from the previous CONCAWE survey of 1998 and also in some cases with 1995 sulphur survey data. The distribution of sulphur content between the major oil products groups is highlighted to allow assessment of the impact of regulatory sulphur reduction measures.

Confirming the trend observed since 1992 as reported in earlier CONCAWE reports, there is a continuous significant decrease in the sulphur content of petroleum fuels and with a corresponding increase in the quantity of sulphur recovered by refineries.

To provide further continuity with the previous reports, some data are broken down to show the situation in four different European regions.

KEYWORDS

Combustion, emissions, oil industry, petroleum products, refinery, sulphur, sulphur dioxide, survey, Western Europe, Hungary, crude.

INTERNET

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SUMMARY

In a survey covering the year 2002, forty-seven European refineries, processing about 49% of Western European crude oil throughput, provided comprehensive data on sulphur in crude oil, petroleum products and sulphur emissions to air. These data are compared with previous surveys covering the year 1998 and for some comparisons the year 1995. While the 2002 survey covered a lower percentage of European refineries than the previous surveys, the comparisons with previous years can nevertheless still highlight trends in the industry.

This report shows how European legislation has continued to impact upon product quality and operational emissions from refineries. It also establishes a baseline for comparisons in the future as further legislation affecting refineries and their products is enacted.

Comparative data for 1998 confirm the impact of measures, which are aimed at restricting ultimate emissions from combusting of gas oils and inland fuel oils.

The impact of legislation has resulted in a continuation of the downward trend of sulphur in oil products for combustion seen in the previous survey with a decrease from 36.7% of the total sulphur intake in 1998 to 29.1% in 2002. There was a corresponding increase in sulphur recovery in refineries from 39% of the sulphur input in 1998 to 49% in 2002. It is worth noting that this recovery was only 27% in 1992.

The average refinery fuel SO₂ 'bubble' concentration in the flue gases from all reporting refineries¹ decreased from 1249² mg/Nm³ in 1998 to 800 mg/Nm³ in 2002. This reduction is consistent with the decrease in the average sulphur content of the refinery fuel oil burned from 1.70% in 1998 to 1.42% in 2002. This is also a consequence of fuel substitution and the reduction in the percent of fuel oil burned from 28% in 1998 to 23% in 2002.

The change in the refinery bubble concentrations in the different European regions is also analysed. In North West Europe, the average refinery SO₂ bubble concentration was about 540 mg/Nm³ in 1998 whereas in 2002 the value had dropped to about 480 mg/Nm³. In contrast, the Mediterranean region average was 2060³ mg/Nm³ in 1998 reducing to 1420 mg/Nm³ in 2002. Such regional differences are consistent with the more severe acidification problems in northern Europe compared to southern Europe, which are reflected in the tougher SO₂ ceilings for northern European countries in the recently adopted EU National Emission Ceilings Directive and the UN-ECE Gothenburg Protocol.

¹ Based on total flue gas volumes from all fuels.

² Corrected from 1998 survey result published as CONCAWE report 10/02.

³ See previous footnote.

1. INTRODUCTION

All crude oils contain sulphur compounds, the amounts of which depend on the crude oil source. During refinery processing these compounds are distributed among the various products, with very little appearing in the lighter products such as gases and gasolines, rather more in the intermediate products such as gas oils, and the highest levels remaining in the heavy products such as fuel oils and bitumen.

Most of the energy used by refineries is provided by a portion of their hydrocarbon intake so that part of the feed sulphur leaves the refinery in the form of sulphur oxides in the flue gases from refinery furnaces, boilers and other plants involving combustion of Refinery fuels.

During the past decade, legislation, both at the national and at the European level, has progressively toughened both the limits required in the sulphur content of petroleum products and the maximum permitted concentration limits of sulphur oxides emitted from the combustion of finished petroleum products.

Refineries have therefore been increasing the use of low sulphur crude oils or adopting processes for the removal of sulphur from streams used to blend the finished products. This sulphur is normally recovered as elemental sulphur.

2. THE CONCAWE 2002 SULPHUR SURVEY

This report shows how the intake of sulphur into the Western European and Hungarian refineries in 2002 was distributed among products, by-products and refinery emissions. See section 2.2 for an overview of countries.

2.1. COLLECTION OF DATA

CONCAWE member companies completed a questionnaire regarding the sulphur input and output of their refineries. In preparing the questionnaire, advantage was taken of CONCAWE's experience with previous similar sulphur surveys, carried out in 1979, 1982 [1], 1985 [2], 1989 [3], 1992 [4], 1995 [5] and 1998 [6]. Data requested for 2002 included:

- crude oil and other refinery feedstocks and their sulphur contents;
- quantities and sulphur contents of oil products for combustion;
- quantities and sulphur contents of non- combustion products;
- the quantity of sulphur recovered;
- the type and the sulphur content of the fuels used in the refinery; and
- sulphurous emissions from process sources⁴.

Forty-seven refineries completed the 2002 questionnaire. These refineries accounted for about 49% of refinery crude oil throughput in Western Europe and Hungary in 2002. The number of participating refineries is considerably less than for the 1998 survey where seventy-nine refineries submitted data. The low response rate of the 2002 survey does mean that care must be taken when interpreting the results as the 2002 survey may be less representative than the 1998 one. Looking at the available data for 2002 there does *not* seem to be a bias in terms of refinery size. However, compared to the 1998 results there are some differences in geographical spread of the participating refineries.

Nevertheless the 2002 survey results are still presented here, but as mentioned above the outcomes may be less robust than of previous CONCAWE sulphur surveys.

Estimates of total refinery data for Western Europe and Hungary were made by extrapolation of the available data. These estimates are described in **Section 4**.

In this report the emphasis is on:

1. Showing the effects of existing European legislation; and
2. Establishing a baseline for such comparisons in the future as further legislation affecting refineries and their products is enacted.

⁴ Although the report refers to SO₂ emissions, a few percent may be in the form of SO₃. The data on emissions include all sulphurous emissions.

2.2. FOCUS ON PRODUCTS AND EUROPEAN REGIONS

From 1992, CONCAWE has reported data showing the distribution of sulphur in crude oil and in groups of major oil products, ranging from gas to heavy fuel oil.

Whereas in 1992 most of the data were broken down into four different regions, in a changing Europe with broader European legislation, these are not considered appropriate anymore for all of the data. Nevertheless, to provide continuity with previous reports, limited use is still made of the regional comparison for 2002.

These four regions are used throughout the report and group together countries that are similar in terms of crude supply and product demand patterns. They are:

- Northwest Europe (Belgium, The Netherlands, Germany and Denmark).
- Atlantic (Ireland, United Kingdom, Portugal and the Atlantic coasts of France and Spain).
- Mediterranean (the Mediterranean coasts of Spain and France, Italy and Greece).
- "Others", namely the former EFTA countries (Norway, Sweden, Finland, Austria and Switzerland) and Hungary.

2.3. PRESENTATION AND INTERPRETATION OF DATA

Whilst some data are provided in tabulated form, detailed data are included as frequency distributions in the form of sulphur content plotted against cumulative throughput and production. Emphasis is on the total refinery intake including both crude and other feedstocks and blending components. An example of such a frequency distribution is Figure 4.

In the frequency distributions, the values of the horizontal axis range from 0 to 100% of throughput or production. On the vertical axis the sulphur level of fuels is reported, with the maximum on the scale depending on the reported maximum. The average values are usually also given in the report text. Therefore, it is possible to determine the percent of the throughput or production that lies above or below any particular sulphur level, by simply drawing a horizontal line from the desired level on the vertical axis to the cumulative curve and then reading the resulting percent on the horizontal axis.

Generally, data for total 'CONCAWE' Europe are shown for the 2002 and 1998 surveys.

2.4. STRUCTURE OF THE REPORT

Section 3 contains a mass balance of the sulphur input and output for the refineries surveyed. The total sulphur intake, in crude oil and other intakes, is discussed. The output is quantified in four groups; the sulphur leaving the refineries in oil products destined for combustion and the sulphur in non-combustion products, elemental sulphur recovered or as sulphur emitted as sulphur oxides from gas and oil firing in the refinery process heaters, boilers and process emissions. A detailed analysis of SO₂ emissions and SO₂ stack concentrations at the refineries is also included.

Section 4 reports total Western European refinery sulphur data based on extrapolation from the CONCAWE survey data.

The formats of these two sections of the report are similar to the previous CONCAWE Sulphur Survey Reports of 1979 [1], 1982 [1], 1985 [2], 1989 [3], 1992 [4], 1995 [5] and 1998 [6]. In this report a comparison is made between levels in 2002 and 1998.

Section 5 shows the cumulative distribution of sulphur in crude and in petroleum products destined for combustion.

Section 6 provides a commentary on the environmental pressures and legislative developments that are reflected in the trends evident in the CONCAWE sulphur surveys.

3. SULPHUR IN REFINERIES

3.1. CRUDE OIL INTAKE

For the 47 refineries surveyed, total crude oil throughput in 2002 was 331 Mt.

As in the 1998 report, not only crude intake but also other feedstocks were included in order to determine the sulphur entering refineries and to obtain a reliable sulphur mass balance. These 'other intakes' consist of intermediates imported from outside Europe or shipped from one refinery to another for further processing, for blending or for refinery fuel. In 2002, this accounted for 37.4 Mt i.e. 11.3% of total intake.

3.2. SULPHUR INTAKE

All crude oils contain significant amounts of sulphur compounds, the actual concentration being dependent upon the origin of the crude oil. The sulphur content of 'other feedstocks' also varies, from residual fuel oils containing up to 3.3% m/m sulphur, to chemical feedstock containing practically none. The weighted average sulphur content in 2002 was 0.91% m/m in crude oil and 0.54% m/m in the other feeds. The total sulphur intake into the 47 refineries in 2002 was some 2.89 Mt, with 2.69 Mt coming from the crude oil and 0.20 Mt from the other feeds (6.9% of total sulphur intake). Because a portion of the 'other feedstocks' consist of blendstocks and intermediates, which are shipped from one refinery to another there is probably some double-counting here but the effect will be small.

3.3. SULPHUR MASS BALANCE

Sulphur entering a refinery must either leave as products and intermediates or be emitted as SO₂ by the refinery. One of the products leaving the refinery is elemental sulphur, which has been removed from petroleum streams and recovered.

In this study, the sulphur output from the 47 refineries participating in this survey has been accounted for in four main categories, as shown in **Table 1**.

Table 1 Distribution of sulphur output in surveyed refineries

Sulphur output: Category	Output in 2002 (kt sulphur)	Fraction of total sulphur intake (% m/m)
SO ₂ emissions from fuels burned in refineries	155	5.4
Sulphur in products for combustion		
- distillates	150	5.2
- inland fuel oil	330	11.4
- bunkers	365	12.6
Total sulphur emitted as SO₂	1000	34.6
Sulphur in non-fuel products (e.g. bitumen, chemical feedstocks, lubricants)	235	8.1
Sulphur recovered as elemental S	1423	49.2
Sulphur retained sub-total	1658	57.3
Total sulphur	2658	91.9

Total sulphur output was 2658 kt representing 91.9% of the reported intake of 2891 kt; which makes the sulphur balance less good than in the 1998 survey (97%), but it is a reasonably fair balance in view of the scale of the exercise.

In 2002, 49% of the total sulphur intake was recovered as elemental sulphur. This is an increase by about 10 percentage points from the 39% recovery in 1998 reflecting the impact of the demand for lower sulphur products, particularly in middle distillates.

In 2002 29.1% of the total sulphur input went into products for combustion, mainly bunkers. The continued decreasing trend from previous CONCAWE surveys (36.7% in 1998, 40.1% in 1995), reflects the further impact of environmental legislation on emissions to air.

A third category is that of oil products not used for combustion, e.g. chemical feedstocks, bitumen and lubricants, which accounted for about 8.1% of input sulphur.

SO₂ emissions from refinery operations accounted for 5.4% of the total sulphur intake. The downward trend from 1998 (7.4%) again reflects the response to environmental legislation on air emissions. As discussed in **Section 3.6**, there are significant regional differences in this overall trend due to the higher national SO₂ reductions required in Central and Northern Europe as a consequence of the higher vulnerability to acidification in these areas.

The cumulative percent sulphur levels in crude and all products ranging from LPG and light distillates to heavy fuel oils are listed in **Section 5** of the report.

3.4. BREAKDOWN OF REFINERY SO₂ EMISSIONS

Sulphur dioxide is discharged to atmosphere from various refinery emission sources, as shown in **Figure 1** and **Table 2**.

Figure 1 Sources of SO₂ emitted by refineries

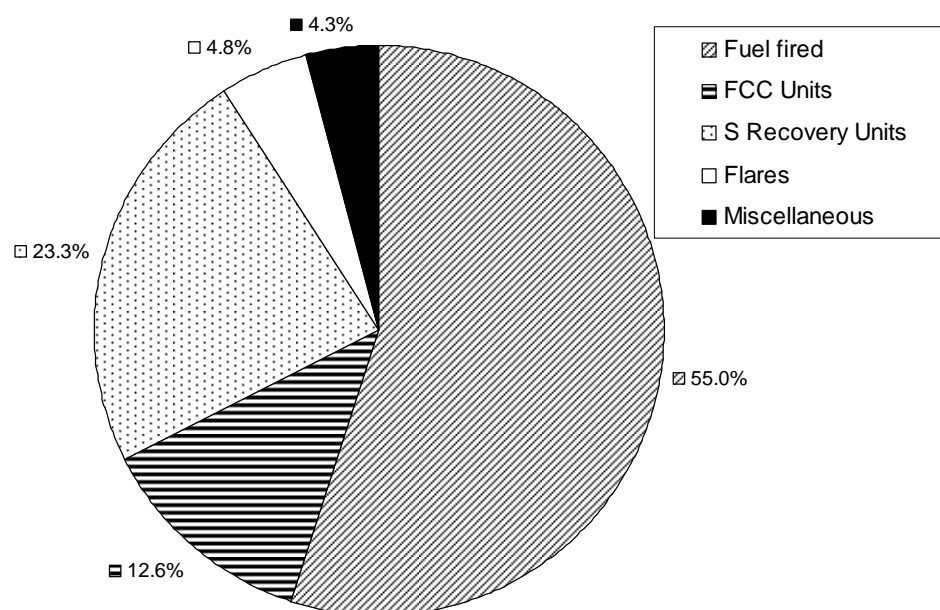


Table 2 SO₂ discharged to atmosphere

	SO ₂ emitted (expressed as sulphur) (kt/a)	Refinery SO ₂ emissions (%)	Percent of intake sulphur
Fuel fired	85.2	55.0	2.95
FCC Units	19.5	12.6	0.68
S Recovery Units	36.1	23.3	1.25
Flares	7.4	4.8	0.26
Miscellaneous	6.6	4.3	0.23
TOTAL	154.9	100.0	5.36

The sources grouped together as ‘Miscellaneous’ include flue gases from residual H₂S and sludge incineration, Sour Water Stripper off-gas and non-FCCU catalyst regeneration. These streams are difficult to quantify and the data reported should be considered approximate only.

3.5. BREAKDOWN OF REFINERY SO₂ EMISSIONS BY FUEL TYPE

The 47 refineries surveyed provided data on the quantities and quality of the fuel used in their combustion units. Fuel consumption is summarised in **Table 3**. The 50 MW_{th} threshold is used because of its relevance to the Large Combustion Plant Directive.

Table 3 Refinery fuel consumption

Fuel Type	Actual quantity (kt/a)	Fuel Oil Equivalent (kt/a)	% FOE	FOE (% on total intake)
Fuel oil < 50 MW _{th}	1,575			
> 50 MW _{th}	3,851			
Total fuel oil	5,426	5,426	23	1.64
Fuel gas < 50 MW _{th}	5,240			
> 50 MW _{th}	7,137			
Total fuel gas	12,377	16,090	69	4.85
SUB-TOTAL	17,803	21,516		6.49
Others < 50 MW _{th}	1,659			
> 50 MW _{th}	2,708			
Total others	4,366	1,747	8	0.53
OVERALL TOTAL	22,169	23,263	100	7.02

Fuel Oil Equivalent (FOE) is defined as the quantity of fuel in metric tons that would release 40.24 GJ/t. In other words, it normalises all fuels to an equivalent net calorific value of 40.24 MJ/kg – which is typical of heavy fuel oil.

Figure 2 shows the fuel mixes for each of the refineries surveyed. The ‘other’ fuels represent 7.5% of the overall total refinery fuel, including coke, waste gas component and a small proportion of very light liquid fuel.

Figure 2 Fuel Mixes, all reporting refineries

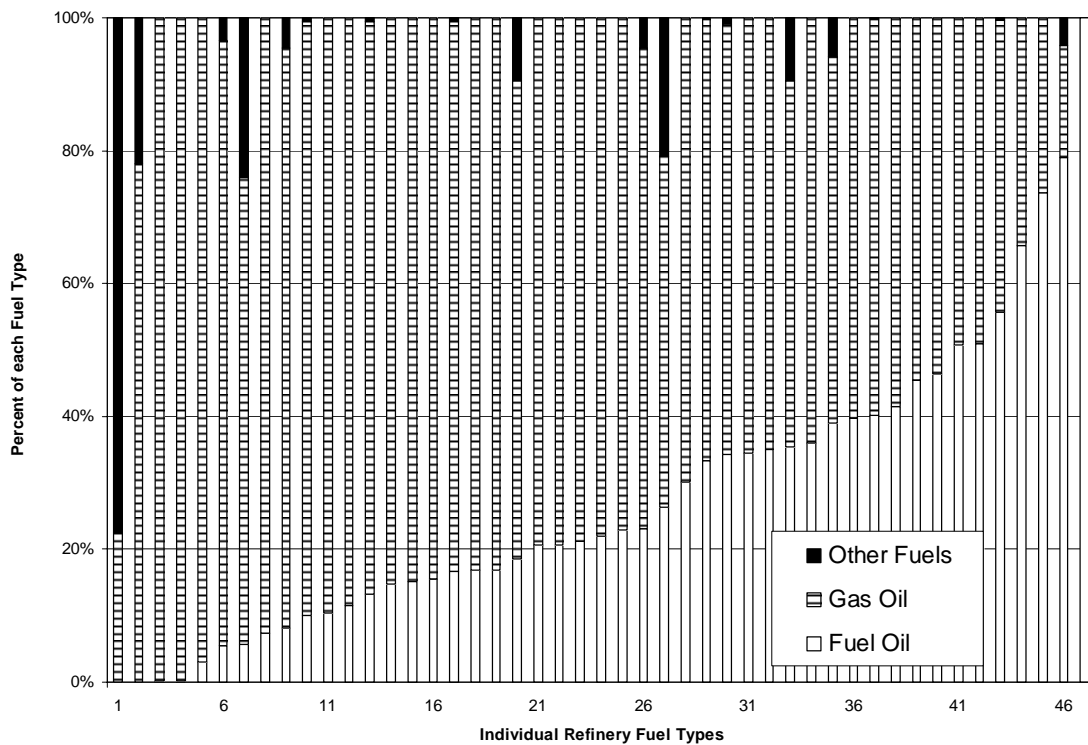
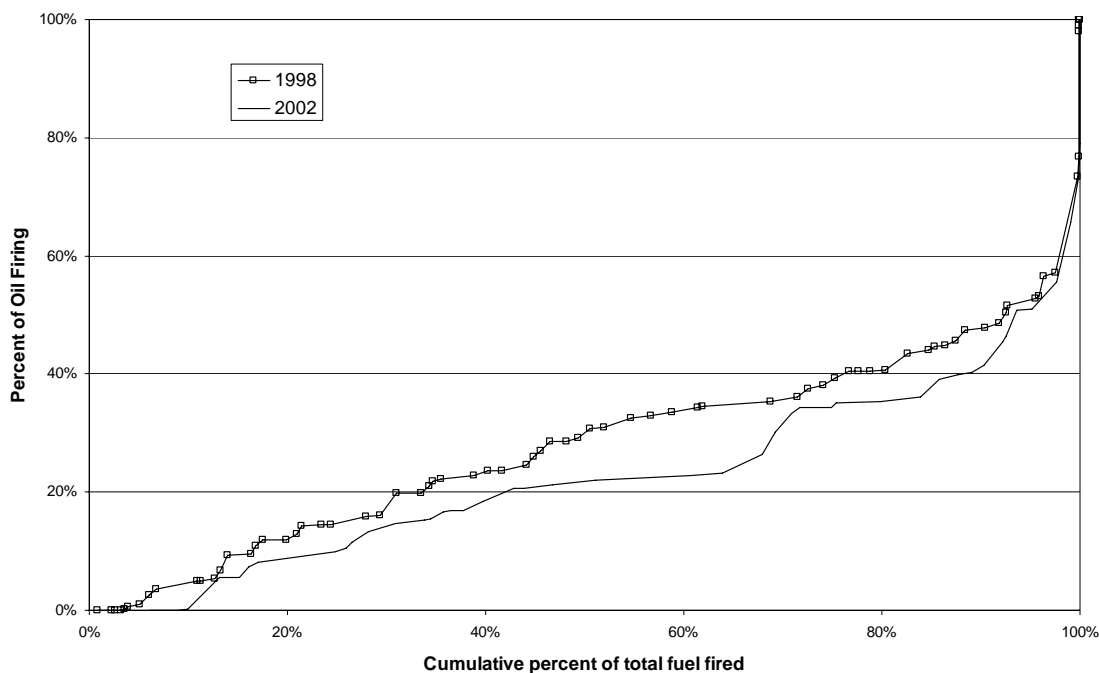


Figure 3 plots the total fuel oil component against the total refinery fuel, both presented on a Fuel Oil Equivalent basis.

The results of this survey show a continued shift to less fuel oil burning in the refineries down to 23% of the total energy burnt in 2002 compared with 28% in 1998 and 32% in 1995.

Figure 3 Percent of all oil firing in refineries, all reporting refineries



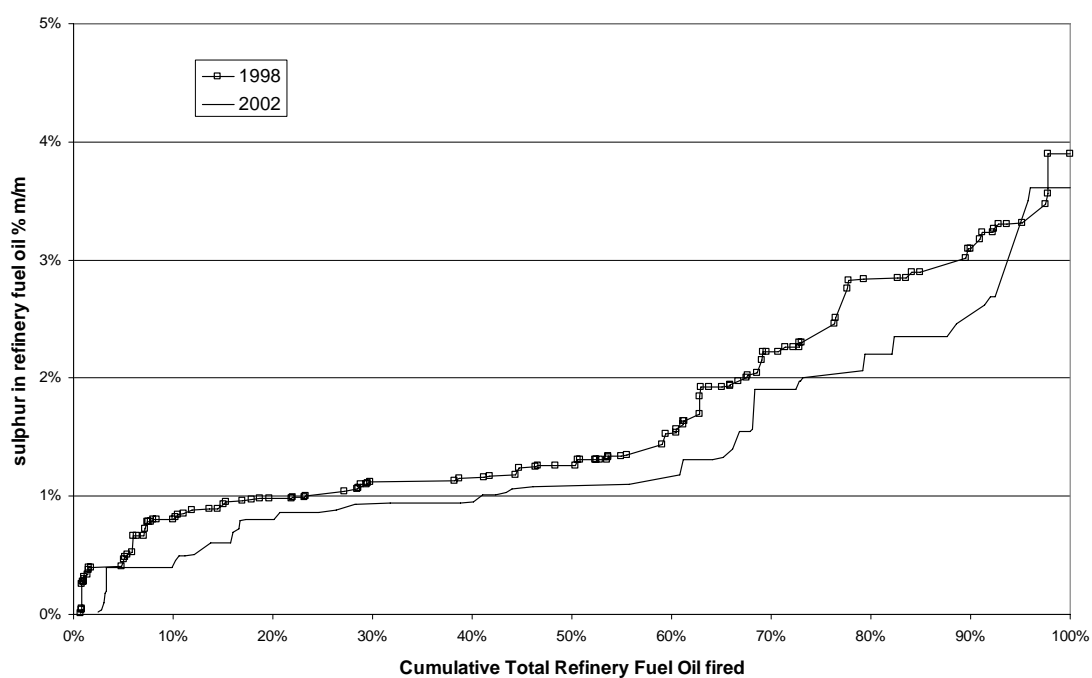
From the data provided, average sulphur contents in refinery fuels and corresponding SO₂ emissions have been calculated, which are presented in **Table 4**.

Table 4 SO₂ emissions (as sulphur) from all reporting refineries

Fuel type	S content % m/m	S emitted	
		kt/a	%
Fuel oil < 50 MW _{th}	0.92	11.8	
> 50 MW _{th}	1.58	60.9	
Total fuel oil	1.42	73	85
Fuel gas < 50 MW _{th}	0.06	1.8	
> 50 MW _{th}	0.05	2.8	
Total fuel gas	0.05	5	5
Others fuels < 50 MW _{th}	0.36	4.6	
> 50 MW _{th}	0.12	3.2	
Total others fuels	0.20	8	9
TOTAL ALL FUELS	0.47	85	100

The fuel oil data provided in **Tables 3 and 4** are presented as a distribution curve in **Figure 4**, which illustrates the wide variation of sulphur content in the refinery fuel oil. The reduction in average sulphur content in refinery fuel oil reflects the impact of European legislation on emissions to air. This overall decrease is much more evident in the fuel oil used in units above 50 MW_{th}, with a decrease in the average sulphur content of fuel oil fired from about 1.70% m/m in 1998 to 1.42% m/m in 2002. This perhaps reflects the continued impact of the Large Combustion Plant Directive.

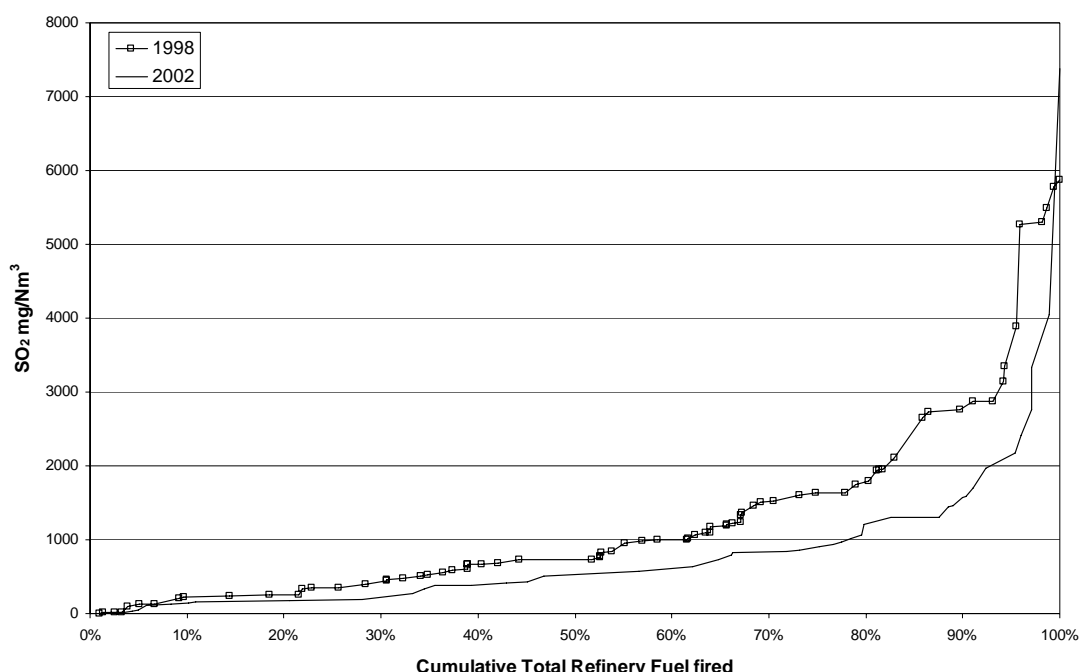
Figure 4 Sulphur in refinery fuel oil, all reporting refineries



3.6. SO₂ CONCENTRATIONS AT REFINERY STACKS

The total SO₂ stack concentrations from fuel oil and gas firing of the surveyed refineries are presented for the two last surveys in **Figure 5**.

Figure 5 SO₂ stack concentrations from oil/gas firing, all reporting refineries



The average concentration of 800 mg/Nm³ for 2002 shows a significant reduction from the 1998 figure of 1249⁵ mg/Nm³ in 1998. This reflects the shift to more gas firing (69% in 2002 from 66% in 1998) and the lowering of sulphur level in refinery fuel oil (1.42% in 2002 from 1.70% in 1998).

Figure 6 gives an overview of the SO₂ concentrations in 2002 for the four regions defined in section 2.2. In terms of both absolute levels and change since 1998, the regional differences reflect the fact that acidification problems are much more serious in northern Europe than in southern Europe. This is evident from the tougher SO₂ emission ceilings for north European countries mandated in the EU National Emission Ceilings Directive and in the UN-ECE Protocol. **Table 5** shows the weighted average SO₂ concentrations for the different regions. This average is higher for the 'Others' region in 2002 compared to 1998 where for all other regions it is smaller. The reason for this is not clear.

⁵ Corrected from 1998 survey result published as CONCAWE report 10/02.

Figure 6 SO₂ concentrations from oil/gas firing, by region

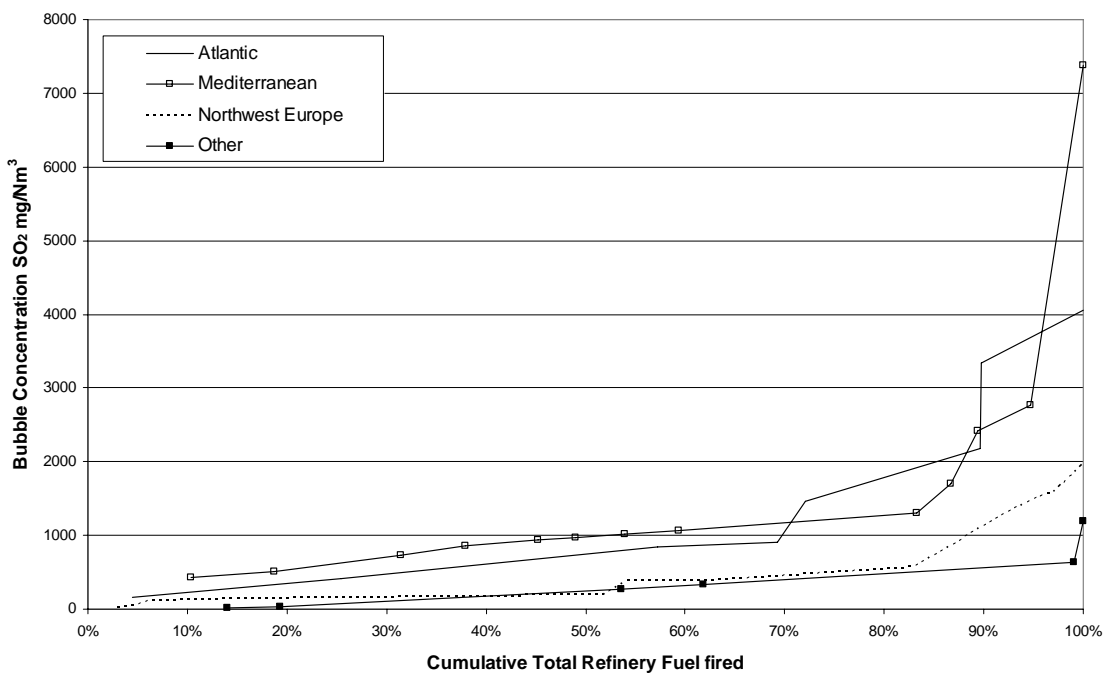


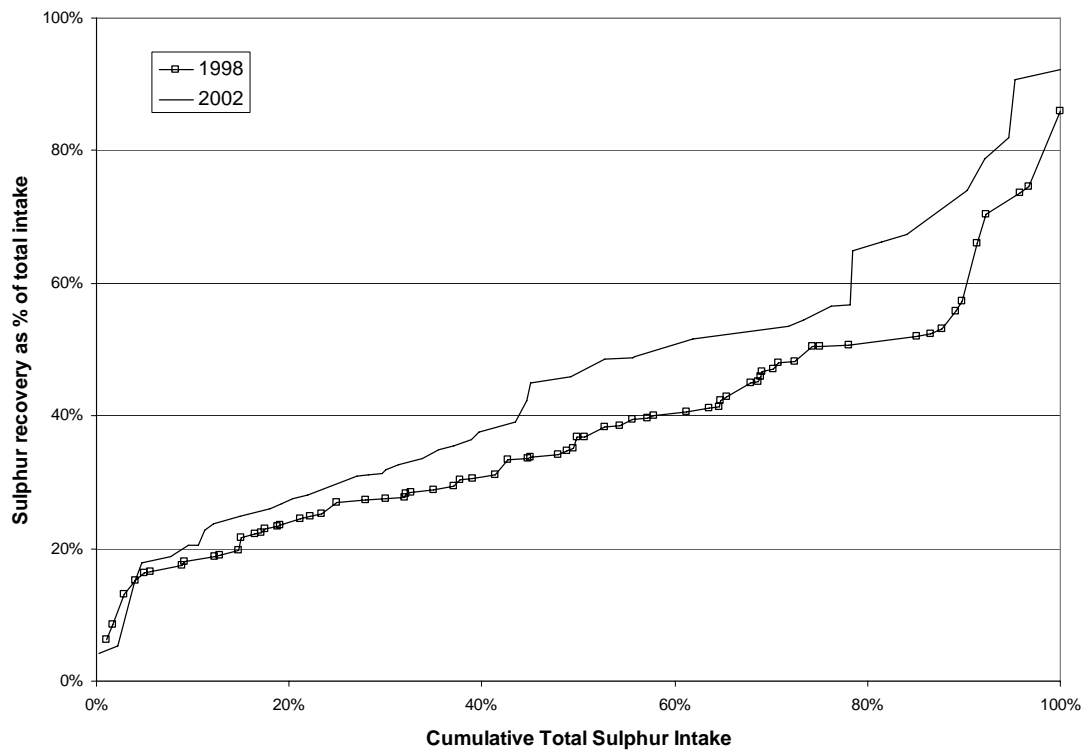
Table 5 Comparison of SO₂ concentrations from oil/gas firing, by region

2002	TOTAL	Northwest Europe	Atlantic	Mediterranean	Others
Total fuel fired in surveyed refineries	18.5 Mt FOE	47%	17%	21%	15%
Weighted Average SO ₂ Concentration (mg/Nm ³)	800	476	1315	1420	371
1998	TOTAL	Northwest Europe	Atlantic	Mediterranean	Others
Total fuel fired in surveyed refineries	32.1 Mt FOE	36%	26%	28%	10%
Weighted Average SO ₂ Concentration (mg/Nm ³)	1249	537	1758	2057	238

3.7. SULPHUR RECOVERY IN REFINERIES

As shown in **Figure 7**, the average sulphur recovery has increased from 39% in 1998 to 49% of total sulphur intake in 2002. This reflects the continued impact of lower sulphur specifications particularly on middle distillates.

Figure 7 Sulphur recovery, all reporting refineries



4. TOTAL WESTERN EUROPEAN REFINERY SO₂ EMISSIONS 1995-2002

Extrapolation from the CONCAWE data to the total Western European (EU & EFTA countries) situation has been based on refinery throughput. Data have been rounded. Clearly for the 2002 results this extrapolation procedure is less robust than for the earlier years where the survey response rate was significantly higher.

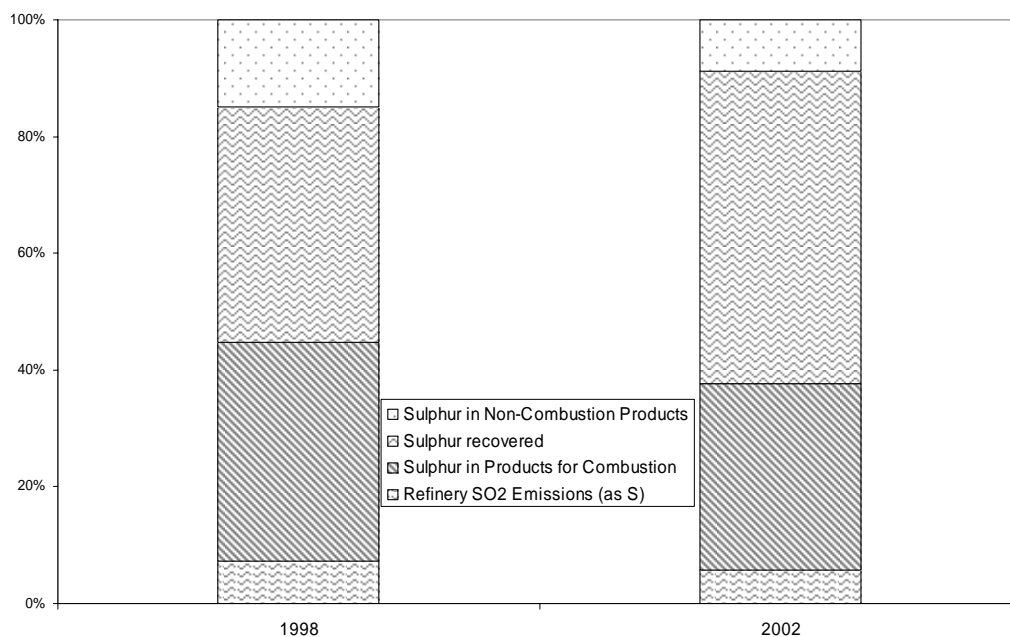
IEA Statistics [7] give a **total** intake of 682 Mt for **all** OECD Europe Refineries (crude oil plus other intakes) for 2002. The crude oil intake for Western Europe and Hungary in 2002 is given as 594 Mt. This is calculated by using the IEA figures for 'OECD Europe' and then subtracting the figures for Czech Republic, Poland, Slovak Republic and Turkey.

Based on crude oil intake, refineries that reported to CONCAWE on 2002 data represented 49% of total throughput of Western European (plus Hungary). **Table 6** summarises the data extrapolated from the 2002 CONCAWE survey by prorating the survey results to 100% of the region intake. The 1995 and 1998 data, adjusted to the same basis, is also shown. Again the declining trend is clearly noticeable, in average sulphur contents, total sulphur intake as well as in SO₂ emissions and sulphur in products. The amount of sulphur recovered has increased.

Table 6 Sulphur balance for Western Europe plus Hungary

	1995			1998			2002		
	Crude	Other Intake	Total Intake	Crude	Other Intake	Total Intake	Crude	Other Intake	Total Intake
Throughput (Mt/a)	564	73	637	580	55	635	594	88	682
Ratio CONCAWE/ All			0.77			0.87			0.49
Sulphur Content (% m/m)	1.05	0.85	1.03	1.00	0.73	0.97	0.91	0.54	0.87
Sulphur intake (kt/a)	5919	622	6541			6021			5840
Refinery SO ₂ Emissions (as S) (kt/a)			563			443			313
Sulphur in Products for Combustion (kt/a)			2625			2210			1707
Sulphur Recovered (kt/a)			2370			2358			2874
Sulphur in Non-Combustion Products (kt/a)			952			849			440
Total (kt/a)			6511			5860			5334

Figure 8 Sulphur distribution as % of total sulphur intake, all reporting refineries.



In 2002, total sulphur intake has declined over 1998 and also with a decline in the average sulphur content in the crude from 1.00% m/m in 1998 to 0.91% m/m in 2002. The sulphur content of the total intake has declined from 0.97% m/m in 1998 to 0.87% m/m in 2002.

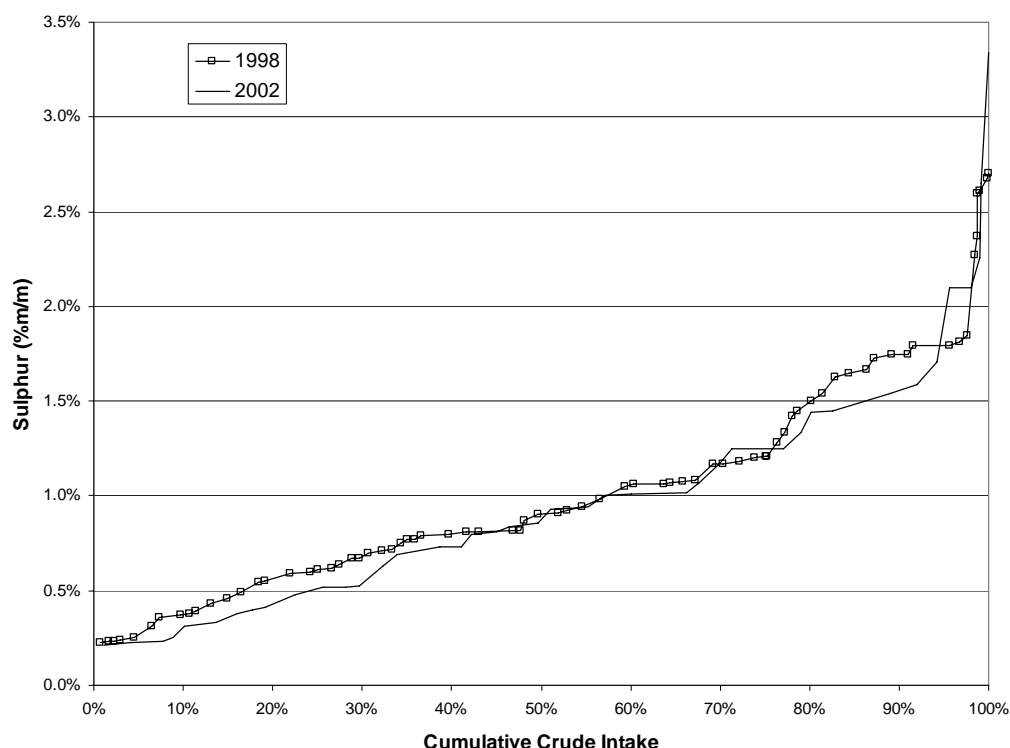
Sulphur Recovery has increased from 39% in 1998 to 49% in 2002. The refinery SO₂ emissions show a 29% reduction over 1998 levels, reflecting the impact of European/National legislation. The impact of legislation on the sulphur content in products for combustion is also seen in the further reduction of some 23% of sulphur in this category compared to the 1998 survey.

5. SULPHUR CONTENT OF CRUDE OIL AND PRODUCTS

5.1. SULPHUR IN CRUDE OIL

Figure 9 shows a comparison between the 1998 and 2002 values of the distribution of crude sulphur content as a function of cumulative crude intake.

Figure 9 Sulphur in crude oil, all reporting refineries



At the overall European level, the shape of the curve has not changed significantly. However, a reduction in the average crude sulphur level seems apparent in this survey. The weighted average sulphur level in the crude is 1.05% m/m in 1995, 1.00% m/m for 1998 and 0.91% m/m for 2002.

However, it must be noted that this decline in average crude sulphur level since 1998 is not in line with the trend for European refiners to process more and more sour crudes as reported by other sources. It could well be that our survey is not representative here in terms of the sulphur in crude trend. A bias in geographical spread of the refineries participating in this current survey could cause this unexpected trend.

The distribution of sulphur in crude oil among the four regions is shown in **Figure 10**. These indicate more significant shifts in sulphur level of crudes processed particularly in the Atlantic. **Table 7** shows the weighted average crude oil sulphur content for the different European regions.

Figure 10 Sulphur in crude oil, all reporting refineries, by region

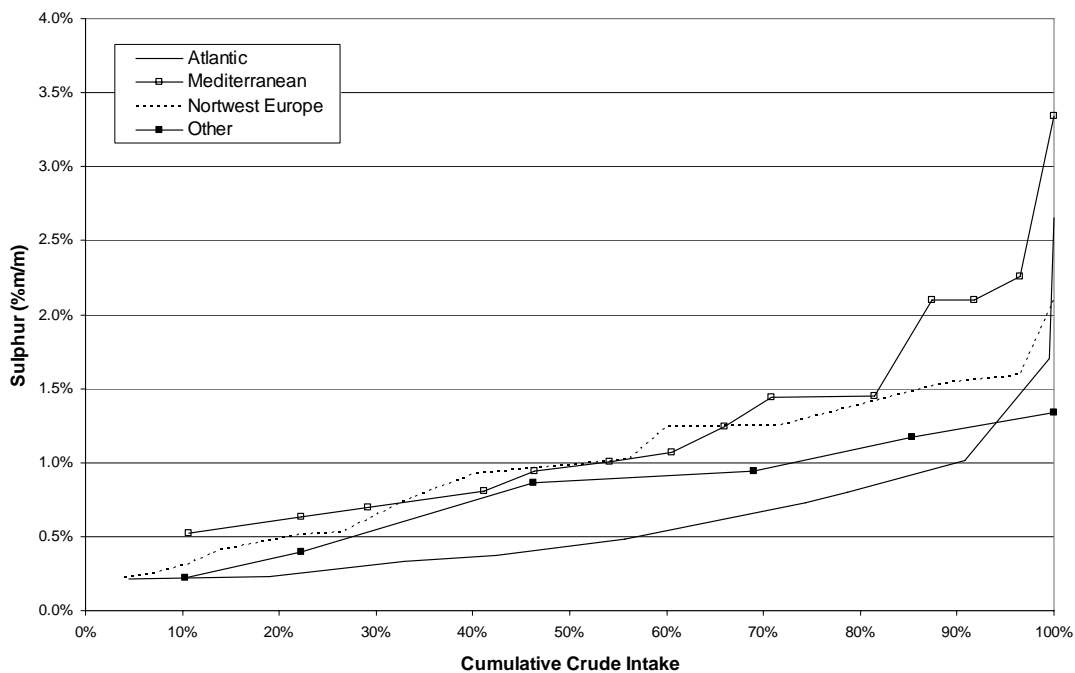


Table 7 Comparison of sulphur levels in crude oil, by region

2002	Northwest Europe	Atlantic	Mediterranean	Others
Crude % of total	38%	25%	23%	13%
Weighted average sulphur content (% m/m)	1.03	0.64	1.20	0.88
1998	Northwest Europe	Atlantic	Mediterranean	Others
Crude % of total	30%	34%	23%	13%
Weighted average sulphur content (% m/m)	1.07	0.88	1.26	0.66

These curves illustrate the relative dependence on Middle East crudes in the various regions. In the 'Others' region the sulphur level in crude is low due to the high level of light low-sulphur North Sea crude being processed in most Scandinavian refineries. This is also reflected in the Atlantic region, which has a higher component proportion of North Sea Crude. The Mediterranean region, with its much higher dependence on medium/high sulphur crudes sourced from the Middle East, has the highest overall sulphur levels.

Comparison with the 1998 survey highlights the impact of environmental pressures on crude sourcing, particularly in the North West Europe region. The shift from an average crude sulphur level of 1.07% to 1.03% reflects the pressures on the sulphur content of the middle to heavy end of the product barrel.

5.2. LPG, NAPHTHA, INTERMEDIATES AND BLENDSTOCKS

Figure 11 shows the 2002 and 1998 distribution of sulphur in liquefied petroleum gases and naphtha produced in the surveyed refineries. There is a clear reduction over the two surveys.

Of course the sulphur content in LPG is in the ppm range so results in Figure 11 are actually for naphtha.

Figure 11 Sulphur in LPG and naphtha, all reporting refineries

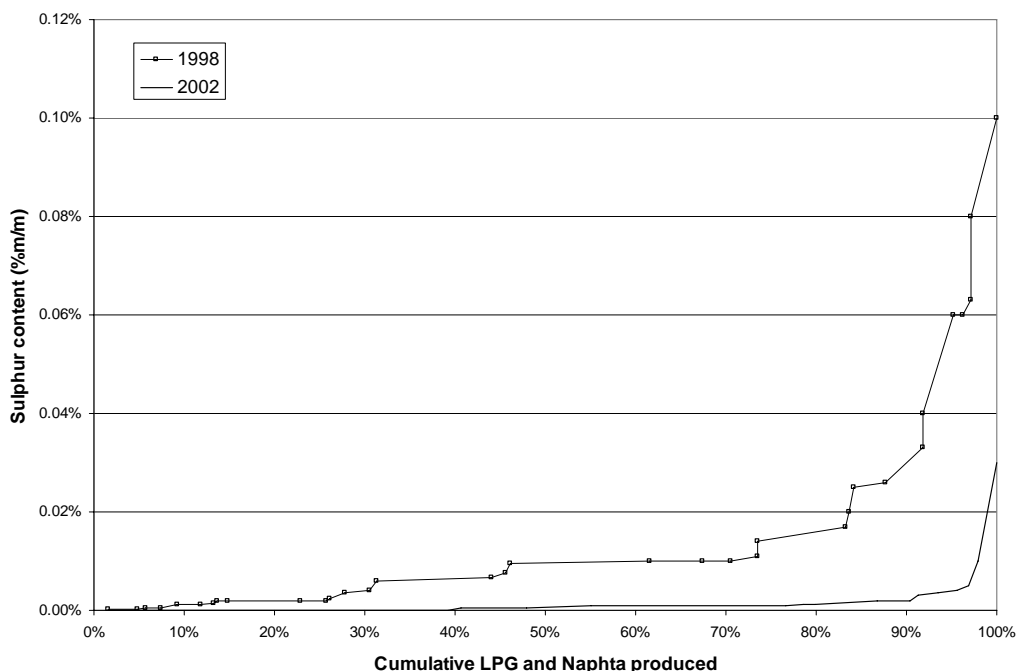
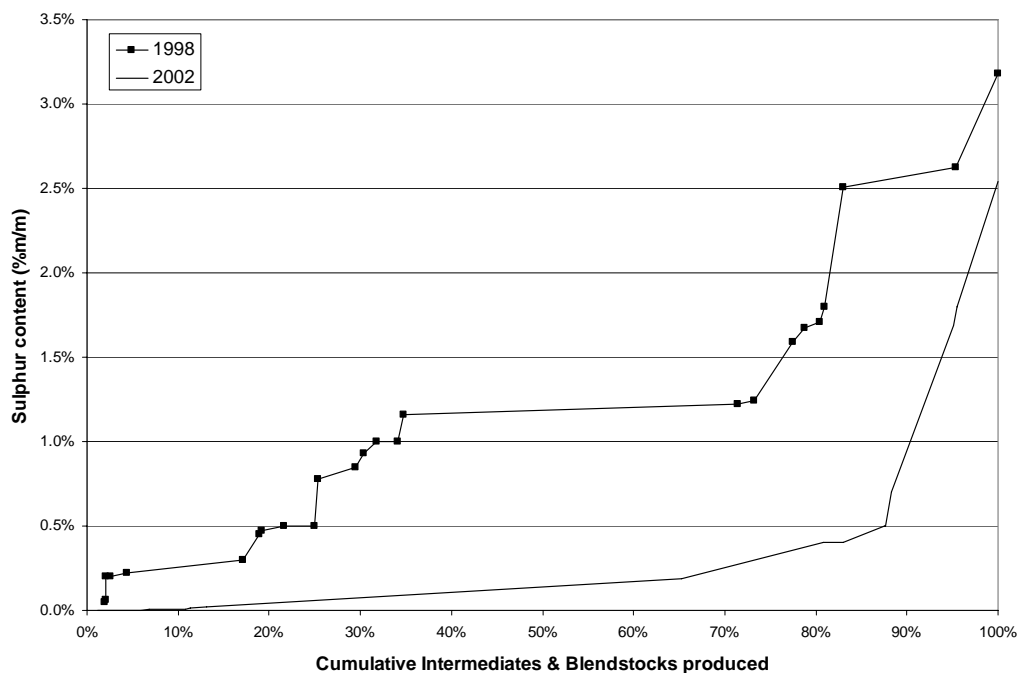


Figure 12 shows that for intermediates and blendstocks, which can range from naphtha to residual oil, the average as well as the maximum value, can be high.

Figure 12 Sulphur in intermediates/blend stocks, all reporting refineries



5.3. GASOLINE

Figure 13 shows the cumulative sulphur contents of gasoline for the refineries in the survey for 2002 and 1998. The weighted average for 1998 is 0.028% m/m and for 2002 it is 0.006% m/m. This is in line with the change of EU sulphur specification from 0.05% m/m (max.) in 1998 to 0.015% m/m (max.) in 2002 (with already some lower sulphur grades produced in some countries). Table 8 gives the weighted average sulphur content in gasoline for the different European regions.

Figure 13 Sulphur in gasoline, all reporting refineries

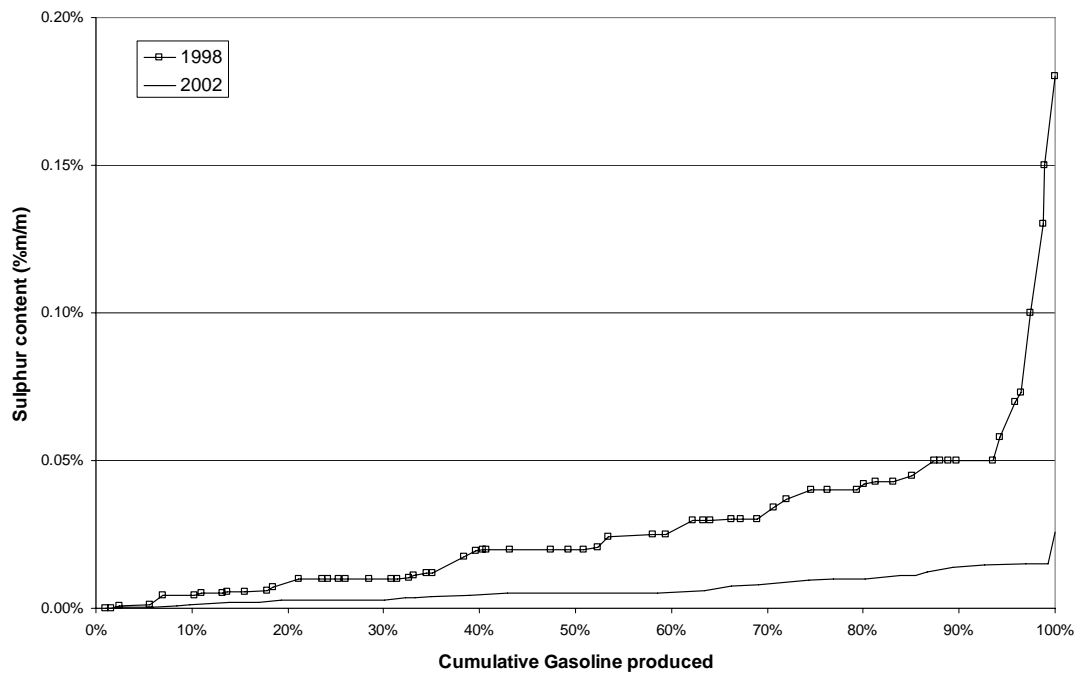


Table 8 Comparison of sulphur levels in gasoline, by region

2002	Northwest Europe	Atlantic	Mediterranean	Others
Gasoline produced in surveyed refineries (% of total)	27%	29%	30%	14%
Weighted average sulphur content (% m/m)	0.005	0.007	0.009	0.003

5.4. JET FUEL/KEROSENE

The sulphur level in kerosene depends on the sulphur level in the crude being run in the refinery and may be reduced by hydrodesulphurisation, whereas the alternative chemical sweetening processes have no effect on the total sulphur content of the stream.

The world-wide specification limit of 0.30% m/m (max.) is the ceiling of the sulphur cumulative percent curve (**Figure 14**). Data are presented for years 2002 and 1998 for comparison. The weighted average for 1998 is 0.059% m/m and for 2002 it is 0.048% m/m. **Table 9** gives the weighted average sulphur contents in jet fuel/kerosene for the different European regions. The value of this average for 'Others' is higher in 2002 than in 1998, while for the other regions it is lower. The reason for this is not clear.

Figure 14 Sulphur in jet fuel/kerosene, all reporting refineries

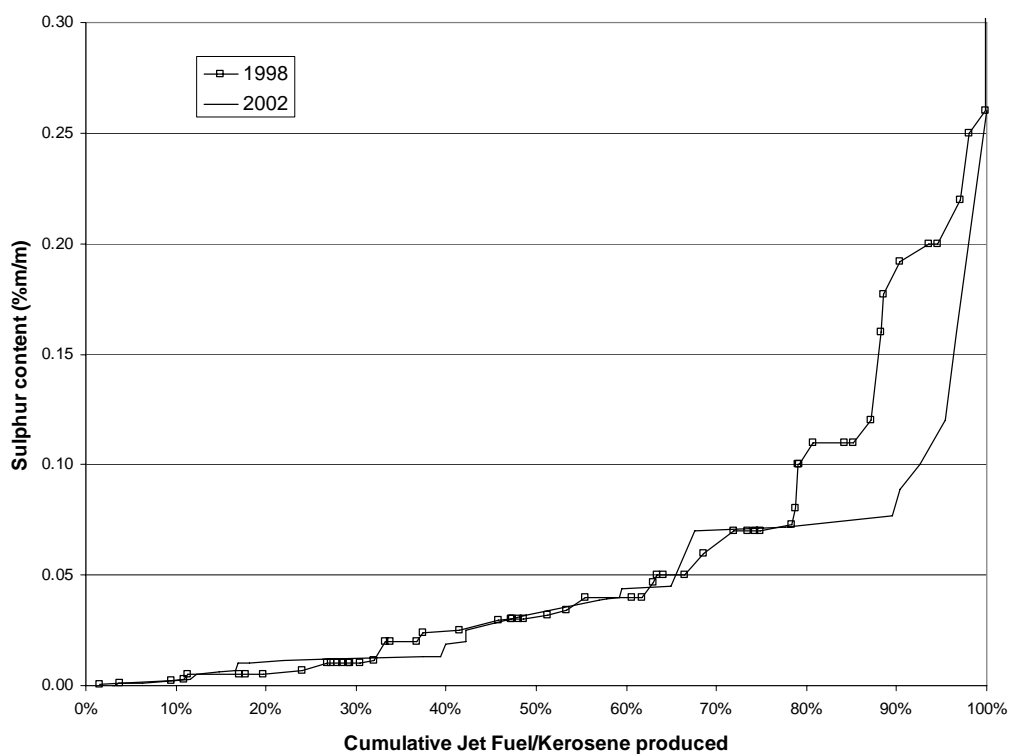


Table 9 Comparison of sulphur levels of jet fuel/kerosene, by region

2002	Northwest Europe	Atlantic	Mediterranean	Others
Jet fuel / kerosene produced in surveyed refineries (% of total)	39%	32%	24%	5%
Weighted average sulphur content (% m/m)	0.040	0.052	0.055	0.044
1998	Northwest Europe	Atlantic	Mediterranean	Others
Jet fuel / kerosene produced in surveyed refineries (% of total)	27%	44%	21%	8%
Weighted average sulphur content (% m/m)	0.054	0.060	0.061	0.020

5.5. GAS OIL

The generic name of "gasoil" includes several different grades mostly automotive diesel fuel, heating oil, industrial gasoil and marine diesel fuel.

The data submitted by individual refineries in this survey and in the previous years have not enabled a reliable split to be made between automotive gas oil and other gas oils. In this survey we have therefore only presented data for the overall gas oil pool. The cumulative distribution curves for the 1998 and 2002 surveys are given as **Figure 15**. The weighted average for 1998 is 0.11% m/m and for 2002 it is 0.09% m/m. Although sulphur in automotive diesel fuel has been significantly reduced between the two surveys (specification reduced from 0.05 to 0.035% m/m (max.)), the full effect is masked by the other grades. **Table 10** again shows the weighted average sulphur contents per region. The different trends between the regions may be caused by a difference in product slate between these regions.

Figure 15 Sulphur in gas oil pool, all reporting refineries

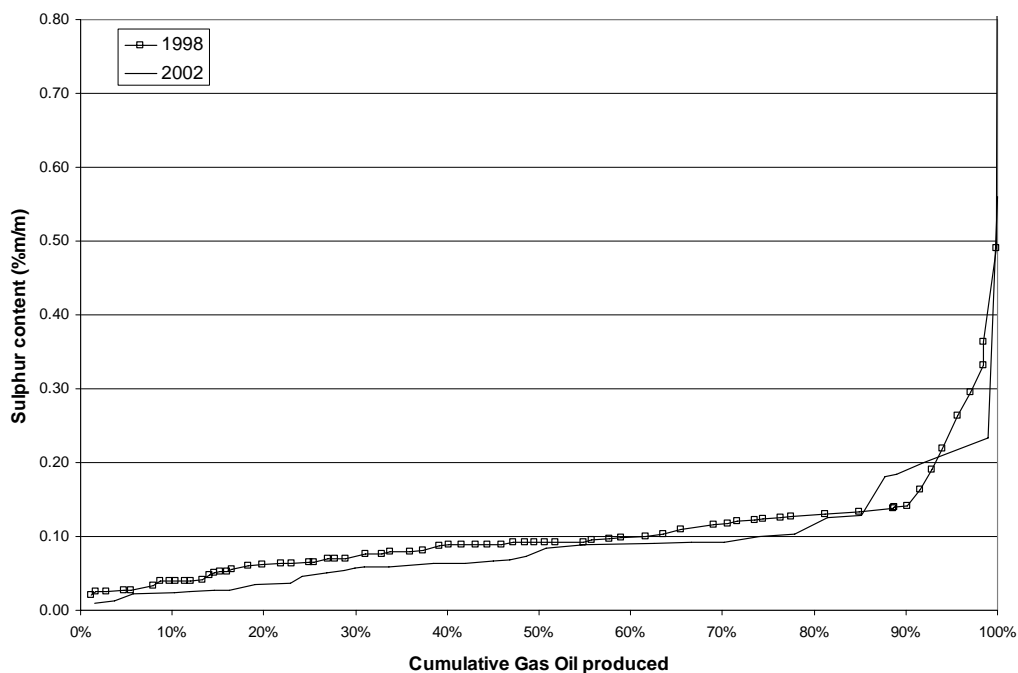


Table 10 Comparison of sulphur levels in gas oil, by region

2002	Northwest Europe	Atlantic	Mediterranean	Others
Gas oil produced in surveyed refineries (% of total)	33%	22%	29%	16%
Weighted average sulphur content (% m/m)	0.108	0.079	0.114	0.047
1998⁶	Northwest Europe	Atlantic	Mediterranean	Others
Gas oil produced in surveyed refineries (% of total)	33%	28%	24%	16%
Weighted average sulphur content (% m/m)	0.108	0.084	0.157	0.070

⁶ Data in this table corrected from 1998 survey results published as CONCAWE report 10/02.

5.6. INLAND FUEL OIL

Fuel oil is primarily made from the heavy, non-converted part of the crude oil and its sulphur content depends strongly on the sulphur in the crude oil.

The cumulative percent curve at the European level for 2002 (**Figure 16**) shows some change compared to 1998 data. The weighted average sulphur content is 1.75% m/m for 1998 and 1.57% m/m for 2002.

Figure 16 Sulphur in inland fuel oil, all reporting refineries

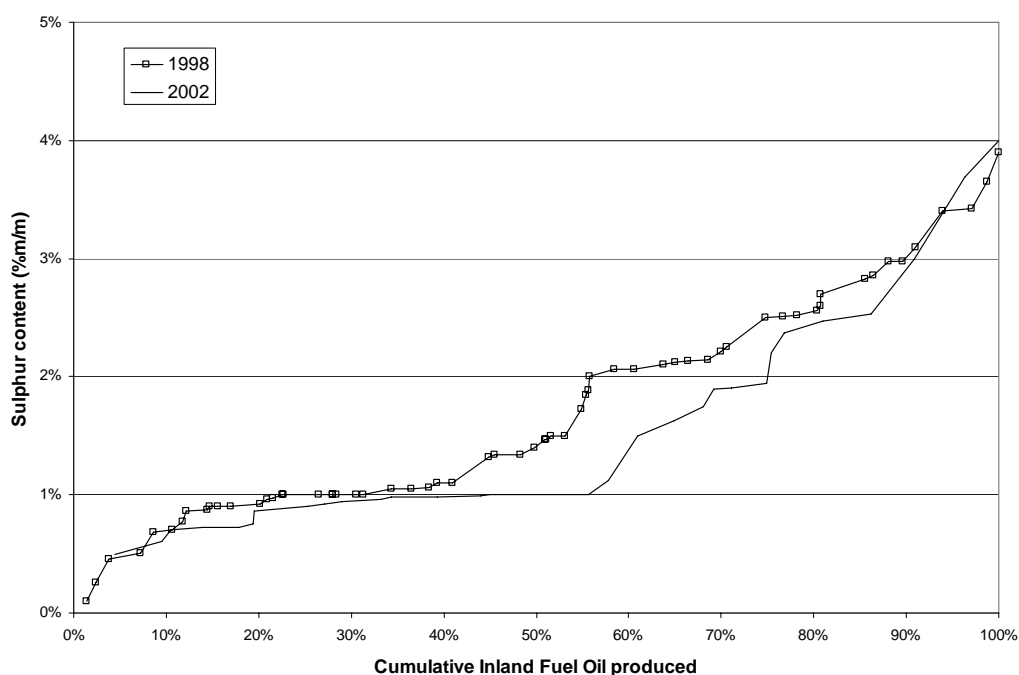


Table 11 Comparison of sulphur levels in fuel oil, by region

2002	Northwest Europe	Atlantic	Mediterranean	Others
Total fuel oil produced in surveyed refineries (% of total)	15%	29%	39%	17%
Weighted average sulphur level (% m/m)	0.99	1.32	2.29	0.78
1998	Northwest Europe	Atlantic	Mediterranean	Others
Total fuel oil produced in surveyed refineries (% of total)	14%	40%	26%	19%
Weighted average sulphur level (% m/m)	0.96	1.96	2.15	1.02

As can be seen from the table above, the values for the sulphur levels in 2002 are either comparable to or lower than the 1998 values. The differences between 1998

and 2002 figures for Northwest Europe and for the Mediterranean Sea are not significant and can be explained by the different survey sample sizes.

5.7. BUNKER FUEL OIL

Bunker fuel oil, i.e. heavy fuel oil used in ships (Residual Marine Fuel Oil), is not produced by all refineries, due to constraints in logistics, product demand and customer quality needs. It is a product similar to heavy fuel oil for inland combustion but it is submitted to other restrictions in terms of sulphur content and other specifications.

The cumulative percent curve at the European level for 2002 (**Figure 17**) shows a clear reduction in sulphur content versus the 1998 and 2002 data. The weighted average sulphur content decreases from 2.85% m/m in 1998 to 2.53% m/m in 2002. The 1995 weighted average was 3.22% m/m. For 2002 the bulk of the production lies between 1.5% m/m and 3% m/m. **Table 12** shows the weighted average sulphur contents in bunker fuel for the European regions.

Figure 17 Sulphur in bunker fuel oil, all reporting refineries

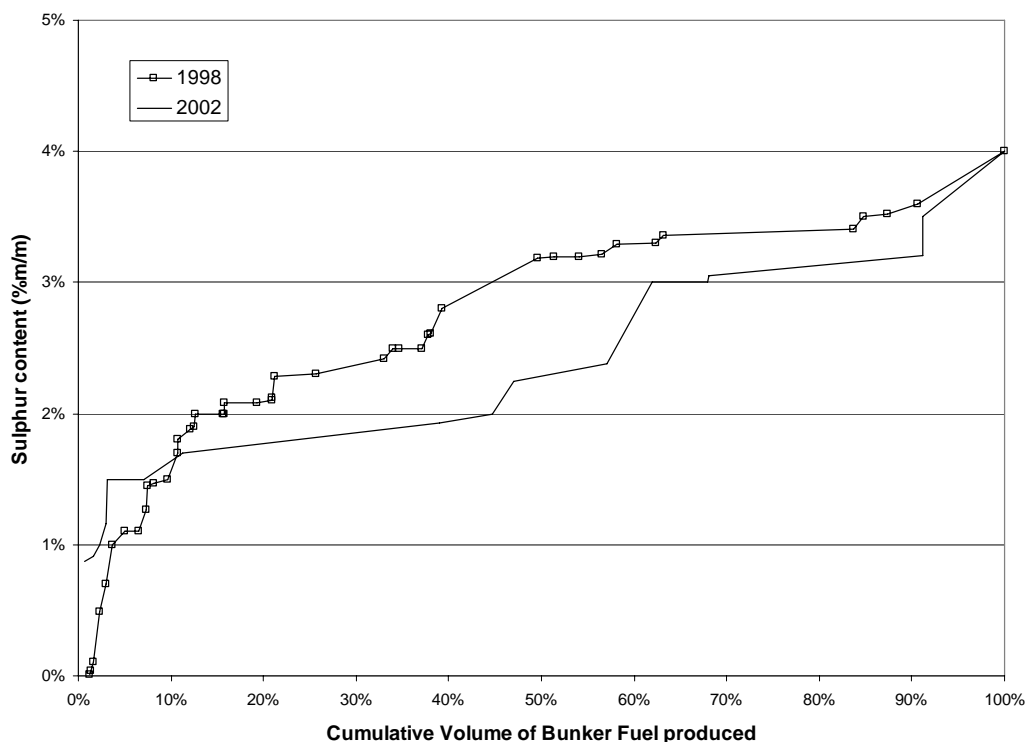


Table 12 Comparison of sulphur levels in bunker fuel oil, by region

2002	Northwest Europe	Atlantic	Mediterranean	Others
Total bunker fuel oil produced in surveyed refineries (% of total)	62%	9%	18%	11%
Weighted average sulphur level (% m/m)	2.7	2.1	2.3	2.3
1998	Northwest Europe	Atlantic	Mediterranean	Others
Total bunker fuel oil produced in surveyed refineries (% of total)	54%	13%	23%	11%
Weighted average sulphur level (% m/m)	3.1	2.7	2.8	2.0

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