sulphur dioxide emissions from oil refineries and combustion of oil products in western europe and hungary (1998)

Prepared by the CONCAWE Air Quality Management Group Task Force on Refinery Sulphur Survey (AQ/STF 51)

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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 1998 actual data. Comparisons are made with data from the previous CONCAWE surveys of 1992 and 1995. 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, 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

This report is available as an Adobe pdf file on the CONCAWE website (www.concawe.be).

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SUMMARY

In a survey covering the year 1998, seventy-nine European refineries, processing about 87% 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 years 1992 and 1995.

A trend to the closer matching of refinery crude throughput compared to primary distillation capacity is evident from this survey. In the 1992 survey the total crude oil throughput was at about 80% of primary distillation capacity, by 1995 this had risen to 85% while in this 1998 survey, the level was some 94%.

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, 1995 and 1992 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 40.1% of the total sulphur intake in 1995 to 36.7% in 1998. There was a corresponding increase in sulphur recovery in refineries from 36% of the sulphur input in 1995 to 39% in 1998. It is worth noting that this recovery was only 27% in 1992.

The average refinery fuel SO_2 'bubble' concentration in the flue gases from all reporting refineries[1] decreased from 1350 mg/Nm^3 in 1995 to 1125 mg/Nm^3 in 1998. This reduction is consistent with the decrease in the average sulphur content of the refinery fuel oil burned from 2.0% in 1995 to 1.7% in 1998. Also, because of fuel substitution and the reduction in the percent of fuel oil burned fell from some 32% in 1995 to 28.5% in 1998.

The change in refinery bubble concentration is much more marked in refineries in North West Europe. In this region, the average refinery SO_2 bubble concentration was about 860 mg/Nm^3 in 1995 whereas in 1998 the value had dropped to 550 mg/Nm^3. In contrast, the Mediterranean region average was 2060 mg/Nm^3 in 1995 reducing to 1870 mg/Nm^3 in 1998. Such regional differences are consistent with the more severe acidification problems in northern Europe compared to southern Europe, which are reflected in the tougher SO_2 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

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 emissions 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 1998 SULPHUR SURVEY

This report shows how the intake of sulphur into the Western European and Hungarian refineries in 1998 was distributed among products, by-products and refinery emissions.

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] and 1995 [5]. Data requested for 1998 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 sources[2].

Seventy-nine refineries completed the 1998 questionnaire. These refineries accounted for about 87% of refinery crude oil throughput in Western Europe and Hungary in 1998.

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.

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 1998.

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

[2] Although the report refers to SO_2 emissions, a few percent may be in the form of SO_3. The data on emissions include all sulphurous emissions.

- 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.

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 also given. 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 last three surveys and while only limited data for the four separate regions described above are presented.

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 three groups; the sulphur leaving the refineries in oil products destined for combustion, 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 SO_2 emissions and SO_2 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 is similar to the previous CONCAWE Sulphur Survey Reports of 1979 [1], 1982 [1], 1985 [2], 1989 [3], 1992 [4] and 1995 [5]. In this report a comparison is made between levels in 1998 and previous years.

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 AT REFINERIES

3.1. CRUDE OIL INTAKE

For the 79 refineries surveyed, total crude oil throughput in 1998 was 507 Mt corresponding to 94% of their available primary distillation capacity.

As in the 1995 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 1998, this accounted for 48.7 Mt i.e. 8.8% 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 2.8% m/m sulphur, to chemical feedstock containing practically none. The weighted average sulphur content in 1998 was 0.97% m/m in crude oil and 0.69% m/m in the other feeds. The total sulphur intake into refineries in 1998 was some 5.26 Mt, with 4.92 Mt coming from the crude oil and 0.34 Mt from the other feeds (6.4% of total sulphur intake).

Accounting for the sulphur contribution of non-crude feedstocks is essential for obtaining a sulphur mass balance for each refinery. However, as described above, this approach means that the sum of all the individual refinery sulphur intakes will overstate the actual net sulphur intake of all the reporting refineries, because a portion of the other intakes consist of blendstocks and intermediates, which are shipped from one refinery to another, and are double counted albeit to a small degree.

3.3. SULPHUR MASS BALANCE

Sulphur entering a refinery must either leave as products and intermediates or be emitted as SO_2 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 refineries has been accounted for in six categories, as shown in **Table 1**.

Table 1 Distribution of sulphur output

Sulphur output: Category	Output in 1998 (kt)	Fraction of total sulphur intake (%m/m)
SO_2 emissions from refineries (as sulphur)	**387**	**7.4**
Sulphur in products for combustion		
- distillates	599	11.4
- inland fuel oil	785	14.9
- bunkers	548	10.4
Sulphur emitted as SO_2	**2319**	**44.1**
Sulphur in products not used for combustion (e.g. bitumen, chemical feedstocks, lubricants)	742	14.1
Sulphur recovered	2061	39.2
Sulphur retained Sub-total	**2803**	**53.2**
Total Sulphur	**5122**	**97.3**

Total sulphur output was 5122 kt representing 97.3% of the reported intake; a satisfactory balance in view of the scale of the exercise.

In 1998, 39% of the total sulphur intake was recovered as elemental sulphur. This has increased by about 3% from 1995 reflecting the impact of a demand for lower sulphur products, particularly in middle distillates.

36.7% of the total sulphur input went into products for combustion, mainly fuel oils. The continued decreasing trend from previous CONCAWE surveys (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. bitumen and lubricants, which accounted for about 14.1% of input sulphur.

SO_2 emissions from refinery operations accounted for 7.4% of the total input sulphur intake. The downward trend from 1995 (8.6%) 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 SO_2 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 SO_2 EMISSIONS

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

Figure 1 Sources of SO_2 discharged in refineries

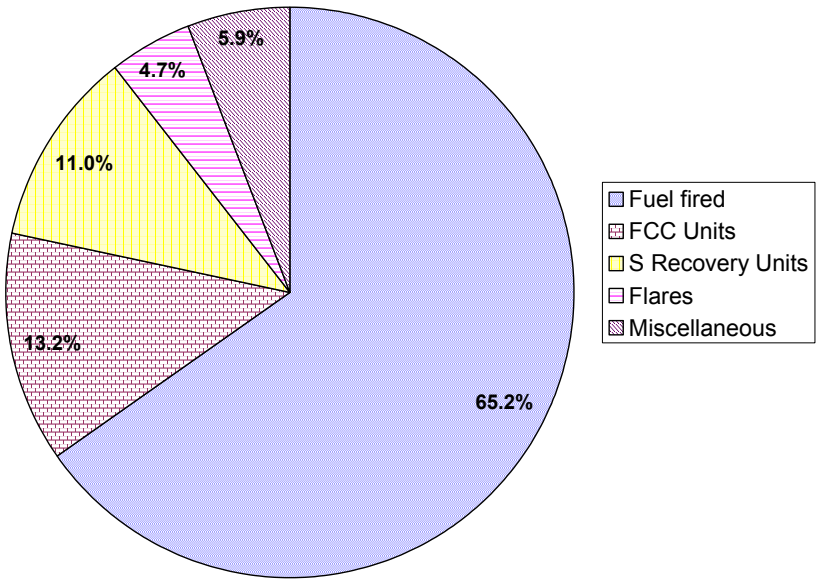


Table 2 SO_2 discharged to atmosphere

	SO_2 emitted (expressed as sulphur) (kt/a)	Percent of refinery SO_2 emissions (%)	Percent of intake sulphur
Fuel fired	252.3	65.2	4.79
FCC Units	51.0	13.2	0.97
S Recovery Units	42.5	11.0	0.81
Flares	18.4	4.7	0.35
Miscellaneous	22.7	5.9	0.43
TOTAL	**386.9**	**100.0**	**7.35**

The sources grouped together as 'Miscellaneous' include flue gases from residual H_2S 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 SO_2 EMISSIONS BY FUEL TYPE

The 79 refineries surveyed provided data on the quantities and quality of the fuel used in their combustion units. Fuel consumption is summarised in **Table 3**.

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}	867			
> 50 MW_{th}	9,693			
Total fuel oil	**10,560**	**10,560**	**28**	**1.90**
Fuel gas< 50 MW_{th}	3,526			
> 50 MW_{th}	15,946			
Total fuel gas	**19,472**	**25,314**	**66**	**4.56**
SUB-TOTAL	**30,032**	**35,874**		**6.46**
Others < 50 MW_{th}	439			
> 50 MW_{th}	5,280			
Total others	**5,719**	**2,288**	**6**	**0.41**
OVERALL TOTAL	**35,751**	**38,162**	**100**	**6.87**

Fuel Oil Equivalent is defined as the quantity of fuel in metric tons to release 40.24 GJ/t. in other words, it rationalises all fuels to an equivalent net calorific value of 40.24 MJ/kg – a typical fuel oil.

Figure 2 shows the fuel mixes for each of the refineries surveyed. The 'other' fuels represent 6% 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

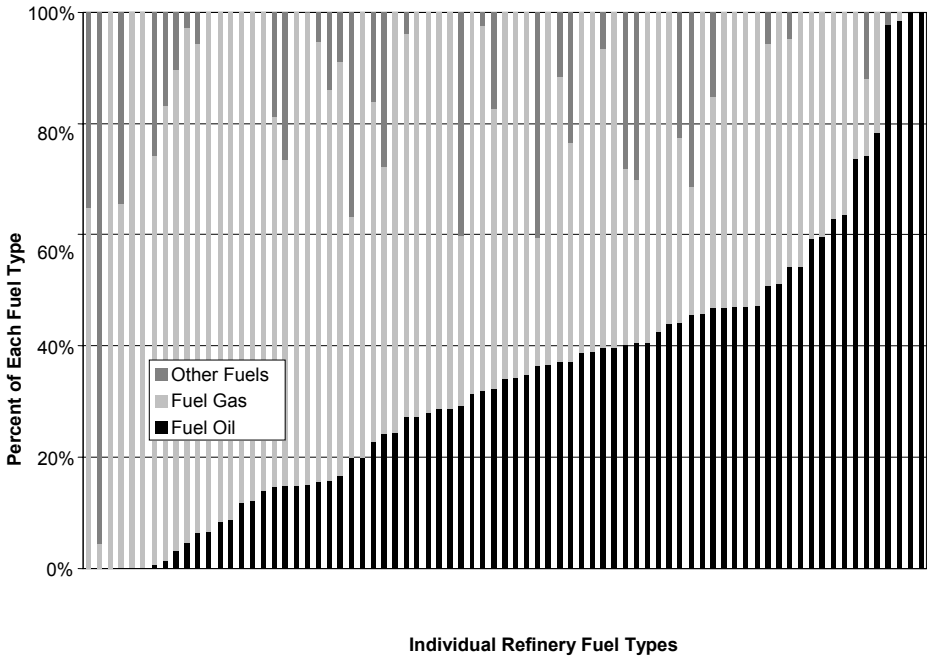
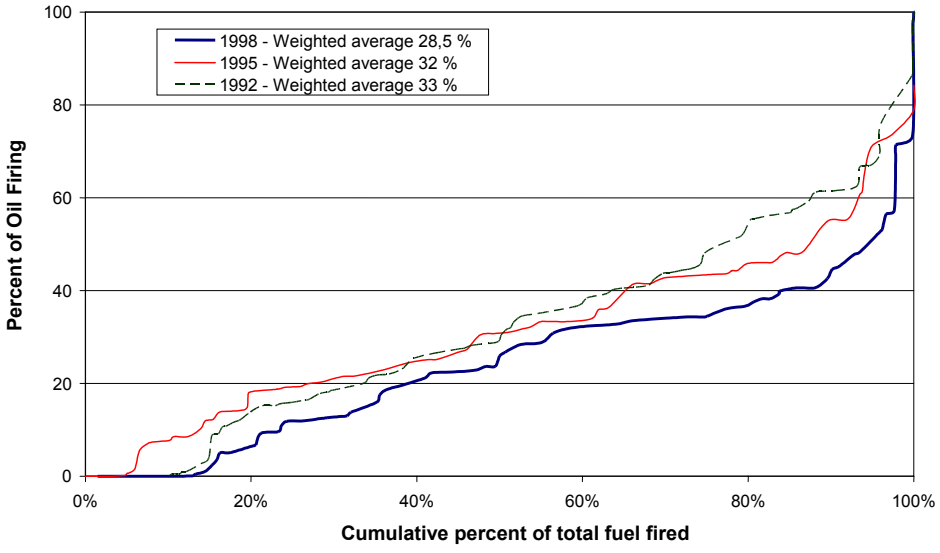


Figure 3 plots the total fuel oil component against the total refinery fuel, both presented on a Fuel Oil Equivalent basis. The results of this survey show a continued shift to less fuel oil burning in the refineries down to 28.5% of the total energy burnt in 1998 compared with 32% in 1995.

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



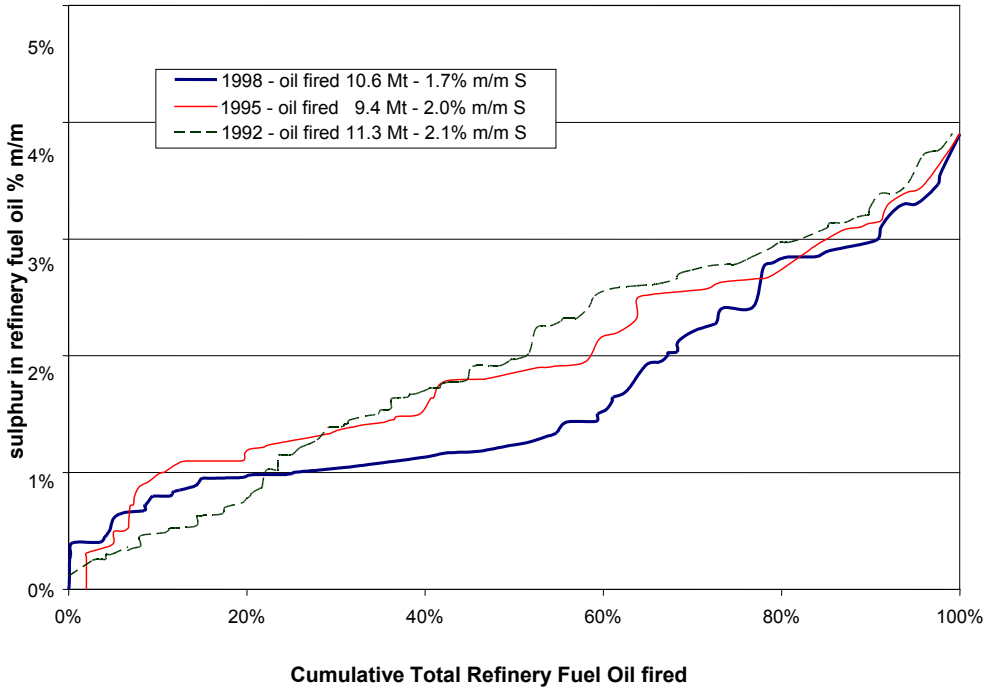
From the data provided, average sulphur contents in refinery fuels and corresponding SO_2 emissions have been calculated, which are presented in **Table 4**.

Table 4 SO_2 emissions (as sulphur) from all reporting refineries

Fuel type	S content % m/m	S emitted kt/a	S emitted %
Fuel oil < 50 MW_{th}	1.73	15	
> 50 MW_{th}	1.69	164	
Total fuel oil	**1.70**	**179**	**74**
Fuel gas < 50 MW_{th}	0.11	4	
> 50 MW_{th}	0.07	11	
Total fuel gas	**0.07**	**15**	**6**
Others fuels< 50 MW_{th}	1.35	6	
> 50 MW_{th}	0.82	44	
Total others fuels	**0.86**	**50**	**20**
TOTAL ALL FUELS	**0.68**	**244**	

The 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 fuel oil for refinery consumption. 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 2.0% in 1995 to 1.7% in 1998. This perhaps reflects the continued impact of the Large Combustion Plant Directive.

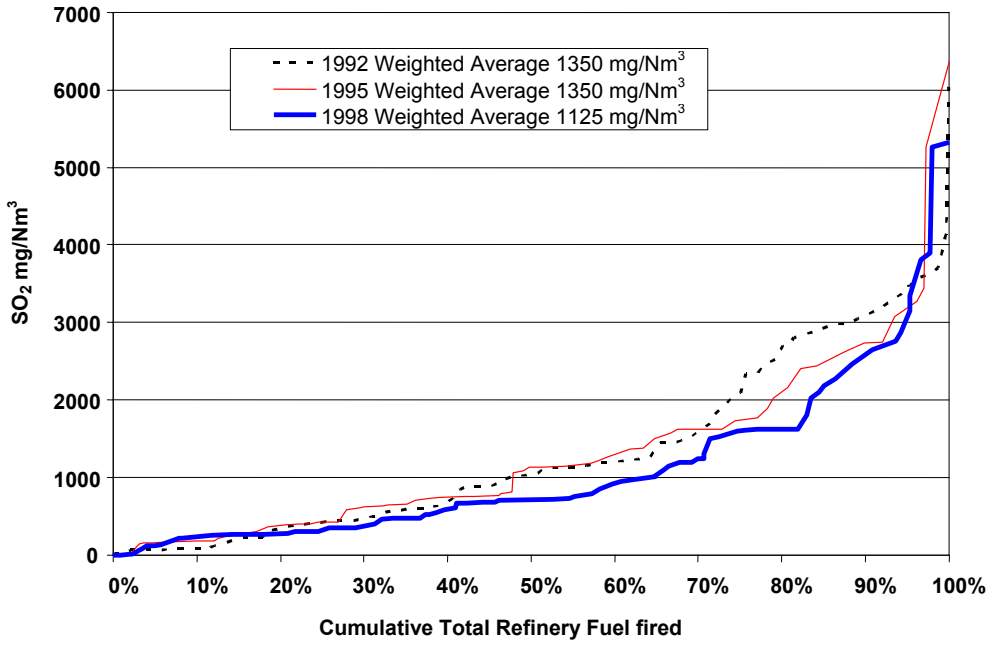
Figure 4 Sulphur in refinery fuel oil, all reporting refineries



3.6. SO_2 CONCENTRATIONS AT REFINERY STACKS

The total SO_2 concentrations from fuel oil and gas firing of the surveyed refineries are presented for the three last surveys in **Figure 5**.

Figure 5 SO_2 concentrations from oil/gas firing, all reporting refineries



The average curve for 1998 shows a significant reduction from the 1995 survey i.e. 1125 mg/Nm^3 compared to 1350 mg/Nm^3 in 1995. This reflects the shift to more gas firing (28.5% from 32% in 1996, see **Figure *3***) and the lowering of sulphur level in refinery fuel oil (1.7% from 2% in 1995, see **Table 4**).

Figure 6 gives an overview of the SO_2 concentrations in 1998 for the four regions defined above. In terms of both absolute levels and change since 1995, 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 SO_2 emission ceilings for north European countries mandated in the EU National Emission Ceilings Directive and in the UN-ECE Protocol.

Figure 6 SO_2 concentrations from oil/gas firing, by region

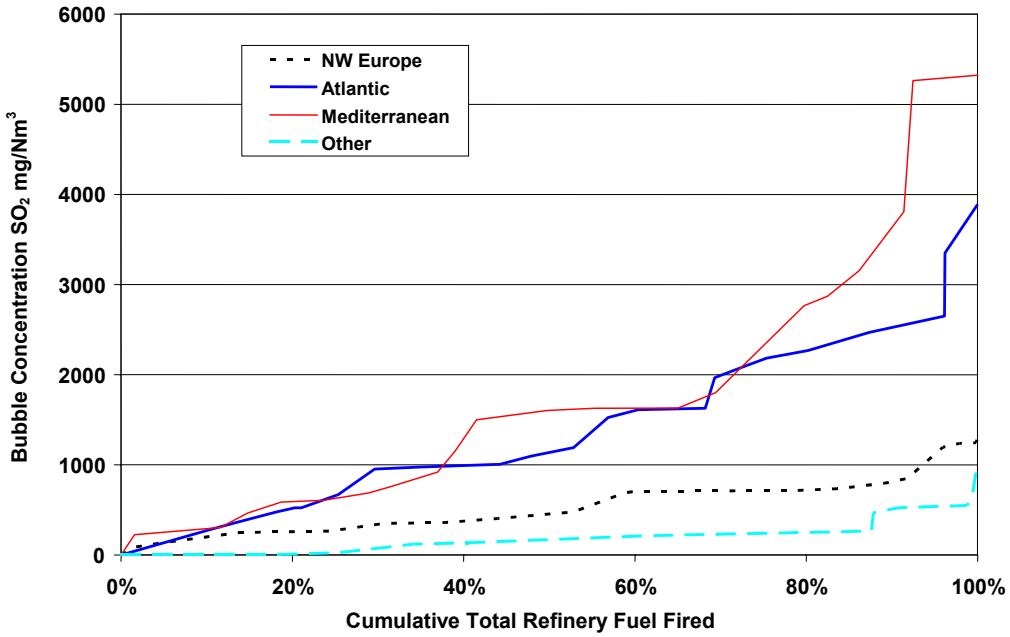


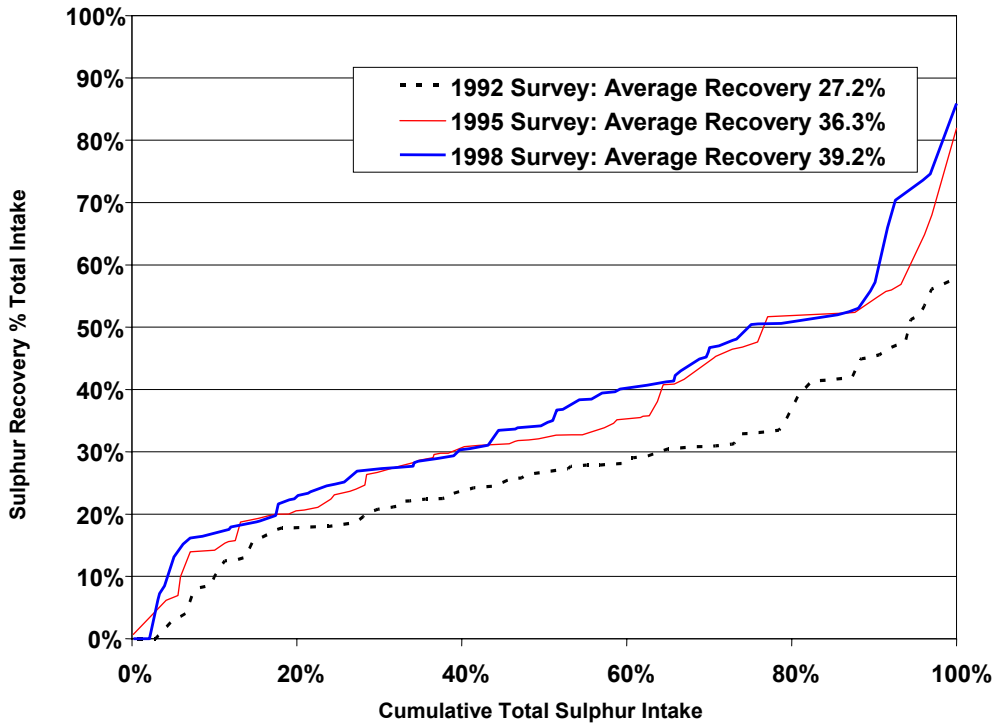
Table 5 Comparison of SO_2 concentrations from oil/gas firing, by region

1998	TOTAL	Northwest Europe	Atlantic	Mediterranean	Others
Total fuel fired in surveyed refineries	38.2 Mt FOE	35%	28%	27%	10 %
Weighted Average SO_2 Concentration (mg/m^3)	1125	550	1460	1870	200
1995	**TOTAL**	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Total fuel fired in surveyed refineries	33.6 Mt FOE	32 %	29 %	29%	10%
Weighted Average SO_2 Concentration (mg/m^3)	1350	862	1531	2064	220

3.7. SULPHUR RECOVERY AT REFINERIES

As shown in **Figure 7**, the average sulphur recovery in 1998 has increased from 36% in 1995 to 39% of total sulphur intake in 1998. 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 SO_2 EMISSIONS 1992-1998

Extrapolation from the CONCAWE data to the total Western European (EU & EFTA countries) situation has been based on refinery throughput. Data have been rounded.

BP-statistics [6] estimate **total** intake of **all** Western European Refineries (crude oil plus other intakes) for 1998 to be 635 Mt. On this basis, crude oil intake for Western Europe and in 1998 is estimated to be 580 Mt.

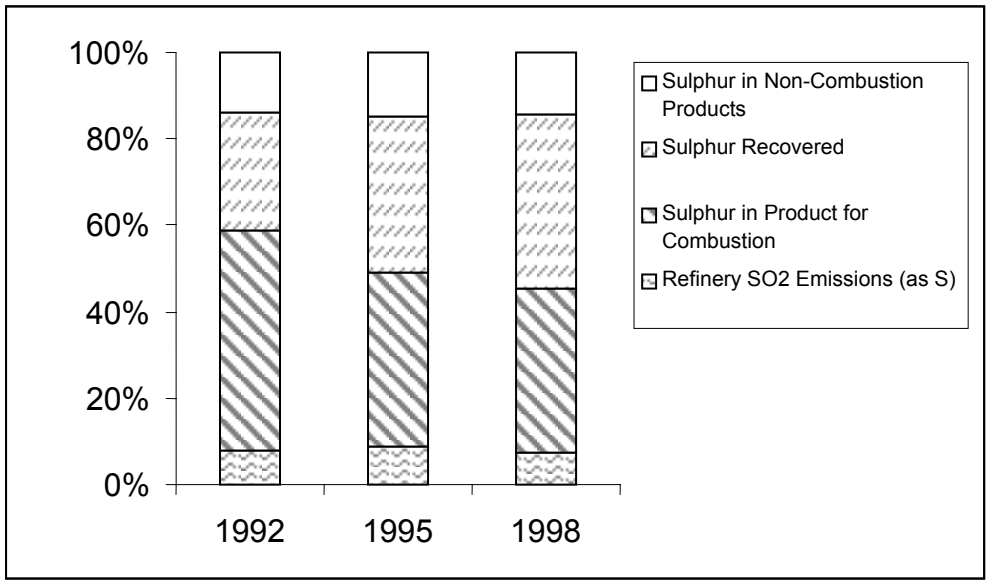
Based on crude oil intake, refineries reporting to CONCAWE represented 87% of total throughput of Western European (plus Hungary).**Table 6** summarises the data extrapolated from the 1998 CONCAWE survey. 1992 and 1995 data, adjusted to the same basis, is also shown.

Table 6 Sulphur balance for Western Europe plus Hungary

	1992			1995			1998		
	Crude	**Other Intake**	**Total Intake**	**Crude**	**Other Intake**	**Total Intake**	**Crude**	**Other Intake**	**Total Intake**
Throughput (Mt/a)	549	75	624	564	73	637	580	55	635
Ratio CONCAWE/ All[3]			0.85			0.77			0.87
Sulphur Content (% m/m)	1.06	1.08	1.06	1.05	0.85	1.03	1.00	0.73	0.97
Sulphur intake (kt/a)	5768	814	6582	5919	622	6541			6021
Refinery SO_2 Emissions (as S) (kt/a)			523			563			443
Sulphur in Products for Combustion (kt/a)			3364			2625			2210
Sulphur Recovered (kt/a)			1782			2370			2358
Sulphur in Non-Combustion Products (kt/a)			887			952			849
Total (kt/a)			6556			6511			5860

[3] Ratio between the throughput for all refineries surveyed by CONCAWE and the total 'all-refinery' throughput for Western Europe plus Hungary as reported in the Oil and Gas Journal for 1998 [7].

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



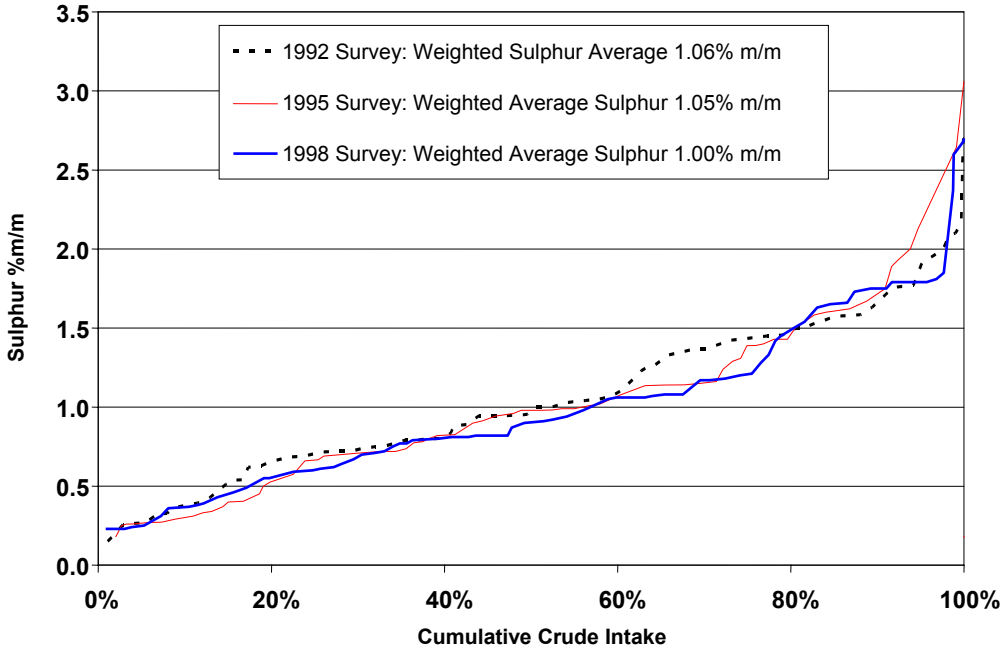
In 1998, total sulphur intake has declined over 1995 and also with a decline in the average sulphur content from 1.03% m/m to 0.97% m/m. Sulphur Recovery has been maintained. The refinery SO_2 emissions show a 20% reduction over 1995 levels, reflecting the impact of European/National legislation. The impact of legislation on the sulphur content in products for combustion is also seen in the further reduction of some 2.6% of total sulphur intake in this category compared to the 1995 survey.

5. SULPHUR CONTENT OF CRUDE OIL AND PRODUCTS

5.1. SULPHUR IN CRUDE OIL

Figure 9 shows a comparison between the 1992, 1995 and 1998 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 since 1992. However, a reduction in the average crude sulphur level is clearly apparent in this survey. 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 Northwest Europe.

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

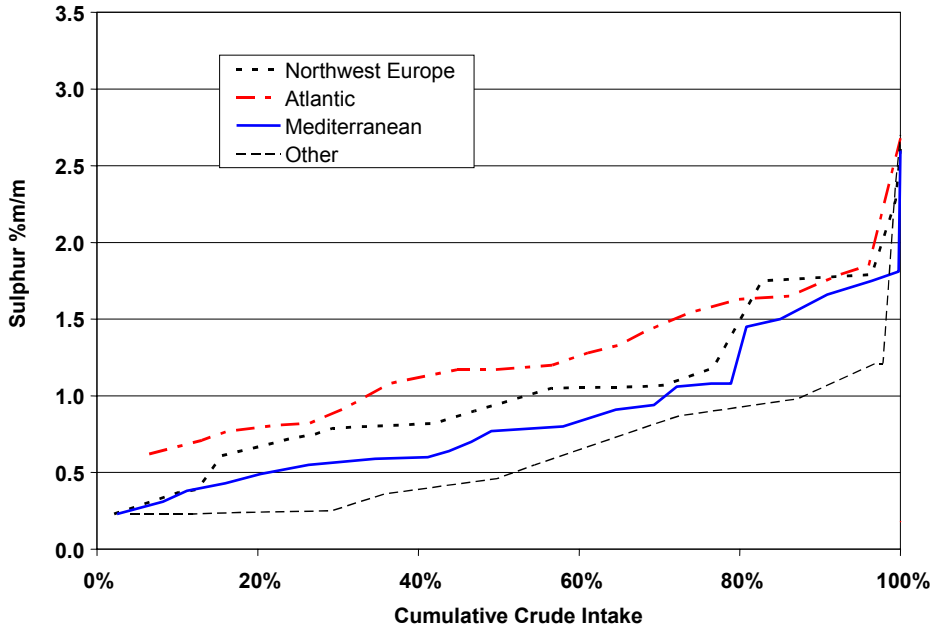


Table 7 Comparison of sulphur levels in crude oil, by region

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
1995	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Crude % of total	36	31	24	9
Weighted average sulphur content (% m/m)	1.17	0.91	1.20	0.64

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 1995 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 1.17% to 1.07% 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 1998, 1995 and 1992 distribution of sulphur in liquefied petroleum gases and naphtha produced in the surveyed refineries. There is a clear reduction over the three surveys.

Figure 11 Sulphur in LPG and naphtha, all reporting refineries

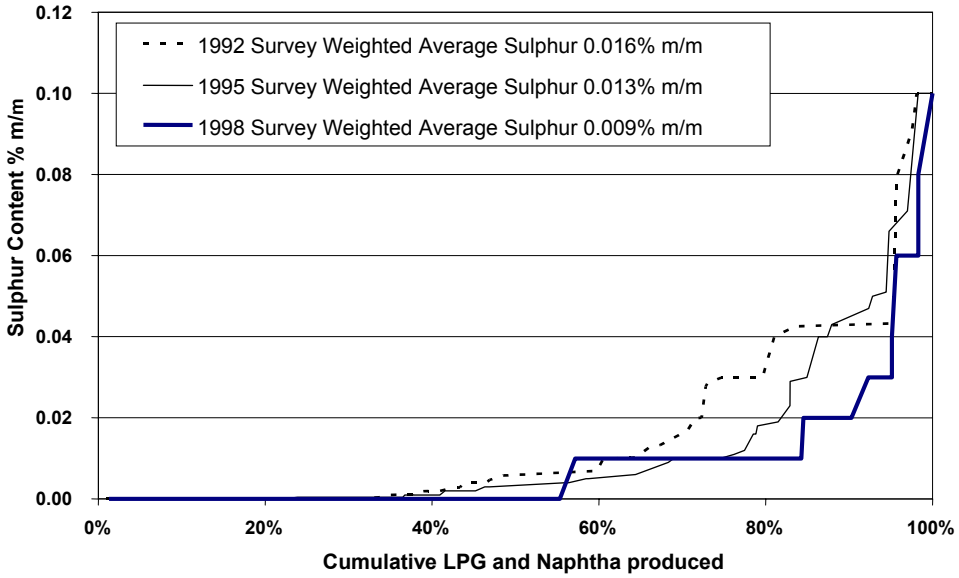
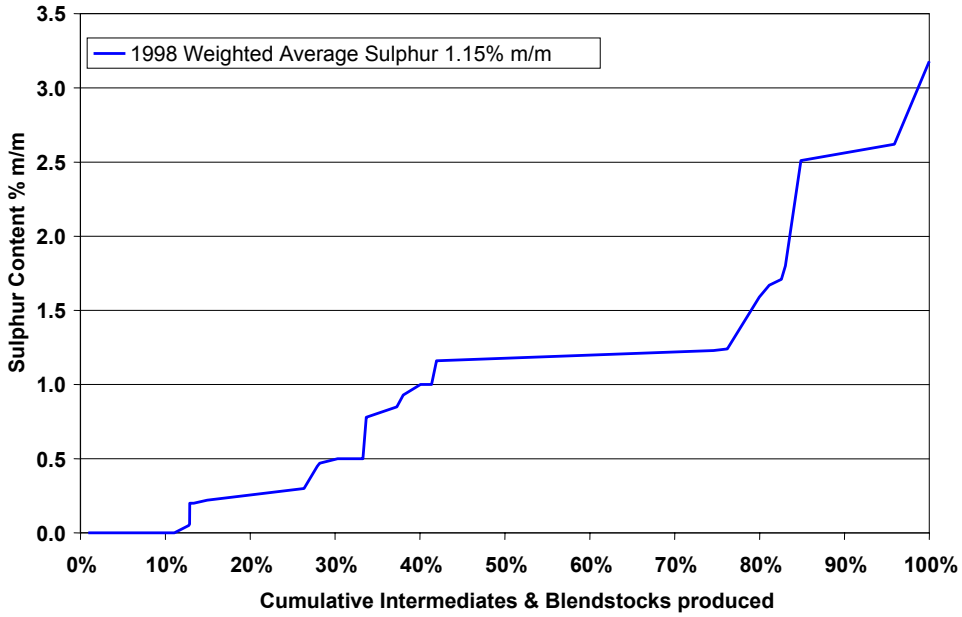


Figure 12 shows that for intermediates and blendstocks, which can range from naphtha to residual oil, the average as well as the maximum value, can be high.

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 1998, 1995 and 1992.

Figure 13 Sulphur in gasoline, all reporting refineries

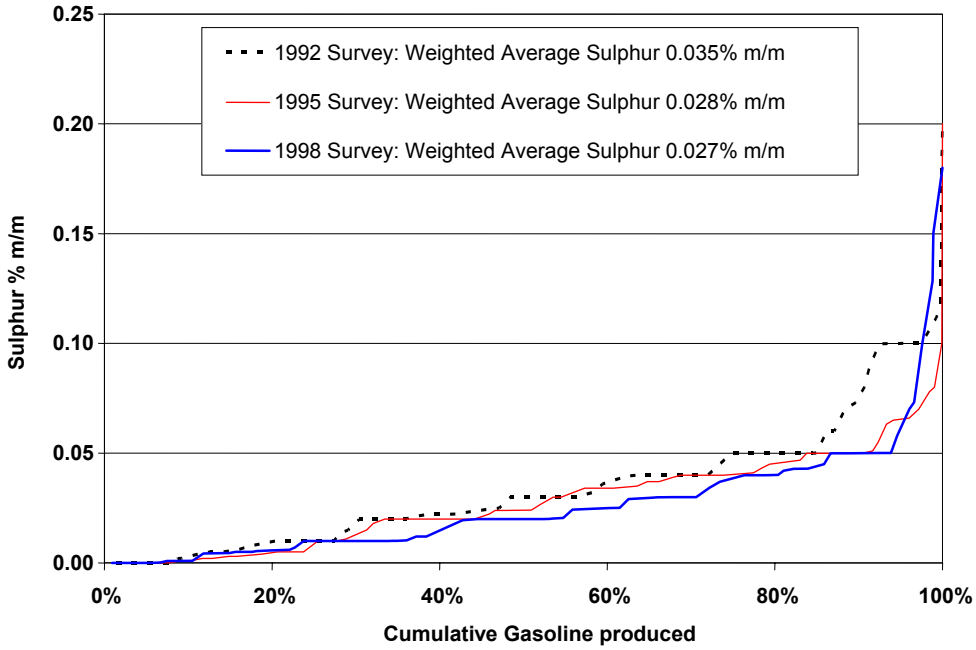


Table 8 Comparison of sulphur levels in gasoline, by region

1998	Northwest Europe	Atlantic	Mediterranean	Others
Gasoline produced in surveyed refineries (% of total)	28	35	22	16
Weighted average sulphur content (% m/m)	0.020	0.029	0.041	0.012

5.4. JET FUEL / KEROSINE

Jet fuel and kerosene are intermediate fractions, mainly obtained by atmospheric distillation of the crude oil.

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 is the ceiling of the sulphur cumulative percent curve (**Figure 14**). Data are presented for years 1998, 1995 and 1992 for comparison. In this case there is a clear reduction in product sulphur concentration over the three surveys.

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

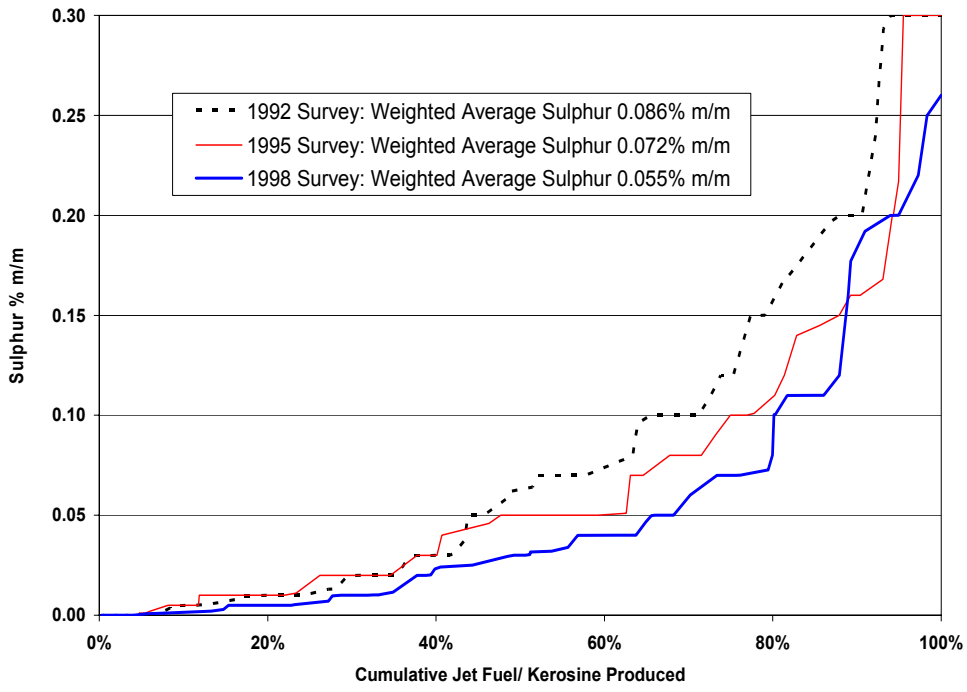


Table 9 Comparison of sulphur levels of jet fuel / kerosene, by region

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
1995[4]	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Jet fuel / kerosene produced in surveyed refineries (% of total)	24	39	22	8
Weighted average sulphur content (% m/m)	0.096	0.055	0.081	0.023

[4] Data in this table corrected from 1995 Survey published as Concawe Report 3/98

5.5. GAS OIL

Gas oil is a distillate, heavier than kerosene and therefore with a higher natural sulphur content. Refinery processing of gas oil streams can reduce the sulphur levels of the product to meet the specifications.

Since the 1995 survey, the requirements of the update of the EU Fuels Directive, from October 1996 set a different legal maximum specification limit of 0.05 %m/m sulphur in automotive gas oil. 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 1992, 1995 and 1998 surveys are given as **Figure 15**.

Figure 15 Sulphur in gas oil pool, all reporting refineries

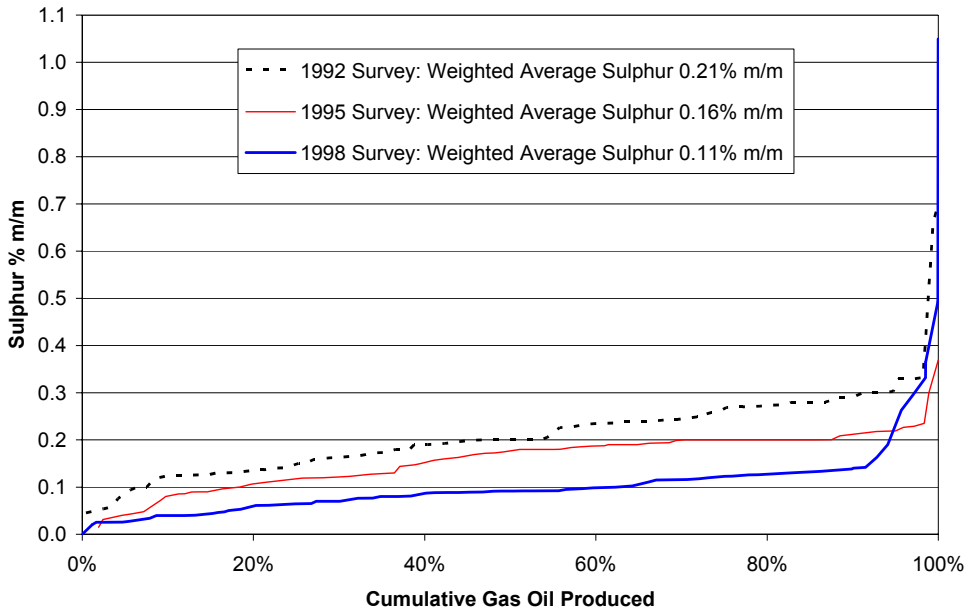


Table 10 Comparison of sulphur levels in gas oil, by region

1998	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Gas oil produced in surveyed refineries (% of total)	22	33	29	16
Weighted average sulphur content (% m/m)	0.049	0.064	0.127	0.062
1995	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Gas oil produced in surveyed refineries (% of total)	30	30	25	14
Weighted average sulphur content (% m/m)	0.139	0.181	0.195	0.082

5.6. INLAND FUEL OIL

Fuel oil is the residue of crude oil processing and its sulphur content depends strongly on the sulphur in the crude oil.

The cumulative percent curve at the European level for 1998 **(Figure 16)** shows no overall decrease compared to 1995 data.

Figure 16 Sulphur in inland fuel oil, all reporting refineries

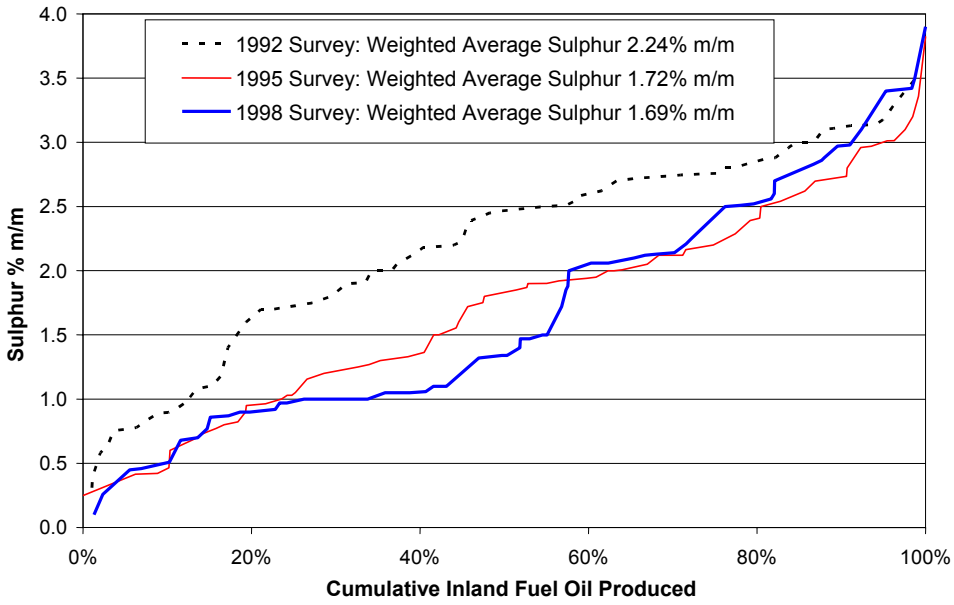


Table 11 Comparison of sulphur levels in fuel oil, by region

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
1995	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Total fuel oil produced in surveyed refineries (% of total)	29%	25%	30%	16%
Weighted average sulphur level (% m/m)	1.32	2.16	2.12	1.02
1992	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Total fuel oil produced in surveyed refineries (% of total)	19%	40%	33%	7%
Weighted average sulphur level (% m/m)	1.82	2.43	2.53	0.93

The 1998 survey continues to highlight the effect of environmental pressure on the sulphur content of heavy fuel oil in the North West region with the average sulphur content falling from 1.8% m/m in 1992 to below 1% m/m in 1998. This trend is likely to be replicated in the future in most of the EU as refiners respond to the requirement of the Sulphur in Liquid Fuels Directive, which enters into force in 2003.

5.7. BUNKER FUEL OIL

Bunker fuel oil, i.e. heavy fuel oil used in ships, 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 not submitted to the same restrictions in terms of sulphur content.

The cumulative percent curve at the European level for 1995 **(Figure 17)** shows a small reduction in sulphur content versus the 1992 and 1995 data. The bulk of the production lies between 2% m/m and 4% m/m.

Figure 17 Sulphur in bunker fuel oil, all reporting refineries

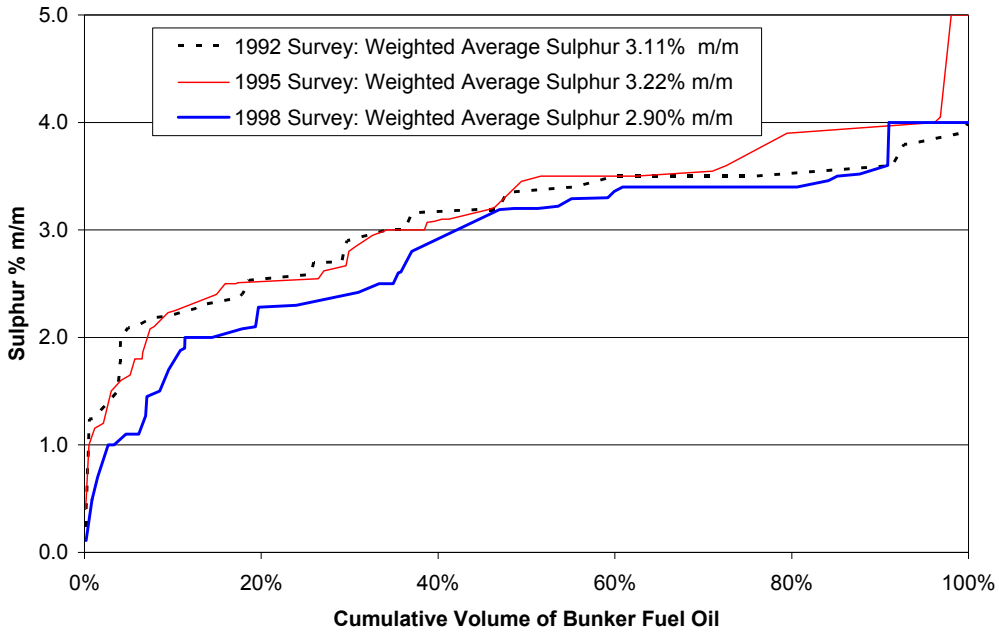


Table 12 Comparison of sulphur levels in bunker fuel oil, by region

1998	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Total bunker fuel oil produced in surveyed refineries (% of total)	52%	13%	25%	10%
Weighted average sulphur level (% m/m)	3.1	2.7	2.9	2.0
1995	**Northwest Europe**	**Atlantic**	**Mediterranean**	**Others**
Total bunker fuel oil produced in surveyed refineries (% of total)	54%	17%	24%	5%
Weighted average sulphur level (% m/m)	3.5	2.9	2.8	2.7

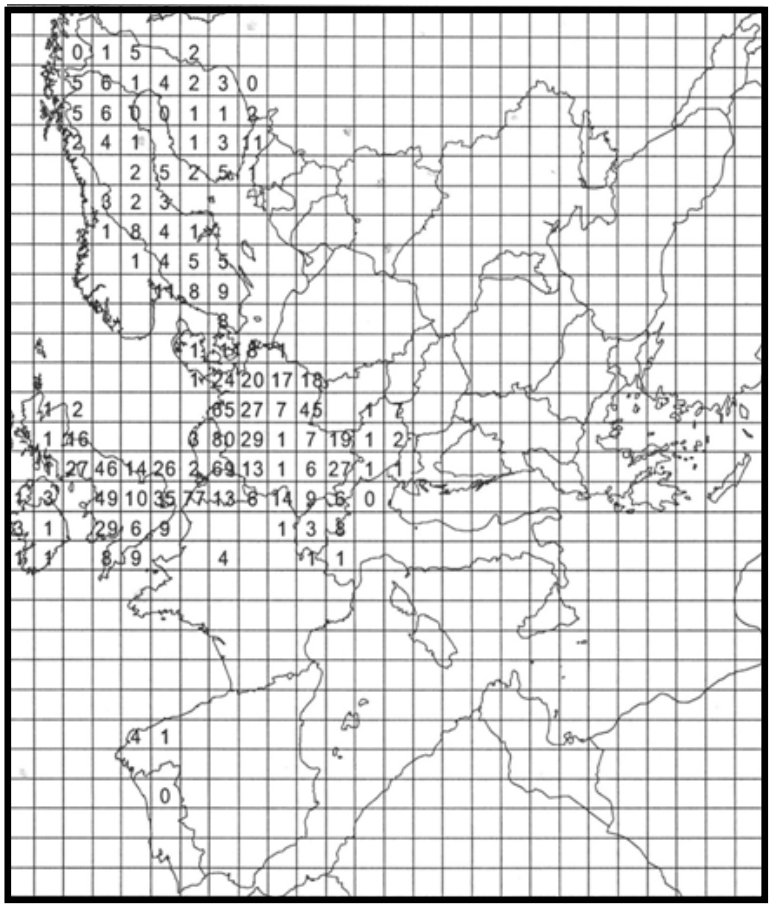
6. SULPHUR IN PRODUCTS AND ENVIRONMENTAL PROTECTION

In Europe there is continued pressure for environmental legislation to reduce SO_2 emissions and therefore the sulphur content of petroleum-derived fuels intended to be burned. The main drivers for such legislation are air quality improvement and the control of acidification. Given the general attainment within Europe of the air quality standards for SO_2 designed to protect public health, the more important of these two concerns is acidification.

In response to concerns over acidification the European Union recently adopted into European law the National Emission Ceilings Directive (NECD) and formally ratified the UN-ECE the multi-pollutant/multi effects Protocol known as the Gothenburg Protocol.

The technical work underpinning both the NECD and Gothenburg Protocol highlighted the significant differences in the severity of acidification problems across Europe. In particular this showed that northern Europe experiences much more severe problems than southern Europe due to their more vulnerable ecosystems. This is clear from **Figure 18**, which shows the percent of ecosystems that are foreseen still to be exceeding their acid critical loads in 2010 assuming legislated measures (pre-NECD/Gothenburg) are implemented.

Figure 18 Percent of Ecosystems exceeding their Acid Critical Load in 2010 [8]



This ‘north-south’ divide is clearly seen in the more demanding emission ceilings for northern European countries in both the NECD and Gothenburg Protocol.

This geographical difference is also reflected in the regional differences in SO_2 emissions from refineries included in this survey. The lower regional SO_2 bubble concentrations in Northwest Europe and the other regions are largely in response to the demand for more significant reductions in SO_2 emissions in these regions required to attain compliance with acid deposition targets. Such a perspective also accounts for the regional differences in the sulphur levels of heavy fuel oil for inland use.

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