future diesel fuel quality

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CONTENTS

		Page
1.	INTRODUCTION	1
2.	OBJECTIVES OF THIS STUDY	2
3.	BASIS AND ASSUMPTIONS	3
3.1	CRUDE SLATE	3
3.2	PRODUCT DEMAND	3
3.3	PROCESSING CONFIGURATION	4
3.4	PRODUCT QUALITY	4
4.	DISCUSSION OF RESULTS	5
4.1	BASIS AND ASSUMPTIONS	5
4.2	CETANE INDEX	5
4.3	DENSITY	7
4.4	VISCOSITY	7
4.5	DISTILLATION	7
5.	CONCLUSIONS	8
	TABLES	
	Table 1: Crude input and product demands	10
	Table 2: Quality limits of key products	11

1. INTRODUCTION

The Oil and Automobile Industries are facing, in the diesel market, a number of key issues which will become increasingly significant in Europe's attempt to control pollution in the coming years. In particular, the following issues are mainly impacting on the European diesel market:

- the increasing pressure to control the level of exhaust emissions and noise from all vehicles;
- the changing fuel product demand pattern;
- the oil industry changes in crude oil sources and refinery processing routes adopted to continue to supply the European diesel fuel market with the amount of product required, without significantly affecting the differential between mogas and diesel fuel costs, and hence the economics of diesel engines.
- motor industry developments of more efficient diesel engines.

The measures directed towards protection of the environment, ie. emission and noise control, involve design changes in engines or associated equipment, which, in turn, may lead to changed fuel quality requirements of the engines.

On the other hand, the diesel fuel quality changes deriving from changing crude slates and refining processes may affect exhaust emissions and noise levels. There is, therefore, a complex inter-relationship between engine design, diesel fuel quality and environmental control.

To ensure a rational development of this situation, the European Commission encouraged the petroleum and automobile manufacturing industries to conduct a study into these complex relationships, in order to obtain a common planning basis for future legislative actions.

In response to this need, CCMC is providing information regarding fuel quality requirements of diesel engines in relation to engine design characteristics and to emission and noise control. On the other hand, CONCAWE has conducted a study to evaluate the impact on diesel fuel quality of changing refinery processing routes, crude slate and the fuel product demand pattern between now and the year 2000. The purpose of this current report is to describe the basic methodology and the main conclusions of the CONCAWE study.

2. OBJECTIVES OF THIS STUDY

- To study the range of future diesel fuel characteristics which are relevant to engine emissions and performance;
- To take account of anticipated market demand patterns and refinery technology in Europe, by collecting and assessing data on the future demands of relevant products, refinery configurations and resulting diesel fuel quality characteristics;
- To assess the range of diesel fuel quality characteristics likely to be encountered in Europe up to the year 2000.

3. BASIS AND ASSUMPTIONS

Since the objectives of the study demanded detailed estimation and assessment of future crude slates, refinery configurations, throughput and also of production and quality data, it was obvious that Linear Programming (LP) production planning models would need to be used. In particular, the LP models of eight petroleum company members of CONCAWE have been used.

3.1 CRUDE SLATE

The study covers crude of different sulphur and density levels, e.g. high, medium and low. The following base case crudes were respectively selected: Arab Heavy, Arab Light and Brent.

As a sensitivity case, lower ignition quality gas oil from another low sulphur crude was brought into the slate, to simulate a worse but feasible situation. To this end, Nigerian Forcados crude was used, and the low sulphur slate was changed so that one case would assume 100% Brent and another 50/50 Brent/Forcados. This recognises the need to maintain flexibility in crude oil supply.

Three scenarios were adopted to cover high, medium and low throughput situations. The medium case catered for the inclusion of purchased atmospheric residue as feedstock, which is currently a very common practice. All of these assumptions are reported in detail in Table 1.

3.2 PRODUCT DEMAND

The product demands assumed for this study are shown in Table 1. These data reflect both EEC forecasts and projections made by CONCAWE member companies. In general, there was a fairly good agreement among those forecasts. The only exception was the heating gas oil/automotive gas oil ratio (HGO/AGO). As the ratio can have a significant effect on the automotive gas oil quality, two cases have been studied: one with a ratio of 1.08:1 (basic case) as suggested by the European Commission, and one with a ratio of 0.5:1 (low case) to simulate countries having high and low heating gas oil demands, relative to the corresponding automotive gas oil demands.

To satisfy the product demands in a realistic fashion, the LP models were required to:

- meet the demands for mogas and jet fuel;
- maximise other distillate production at both basic and low HGO/AGO ratios;
- allow LPG and naphtha volumes to vary;
- allow total fuel oil volumes to vary, at a given bunker/inland fuels ratio.

3.3 PROCESSING CONFIGURATIONS

Careful consideration was given to the major processing routes available to the oil industry in Europe in the next 15 years. It was felt that diesel fuels produced by the following routes would be typical of what the European market would see in the year 2000:

(1) Atmospheric + vacuum distillation followed by catalytic cracking

(2) (1) + Visbreaking

(3) (1) + Coking

3.4 PRODUCT QUALITY

The quality limits assumed for the key products are reported in Table 2.

4. DISCUSSION OF RESULTS

4.1 BASIS AND ASSUMPTIONS

In line with the assumptions made and the variables chosen for the study, 90 LP model runs were made to simulate various combinations of product demands, crude slate and refinery configurations, within the limits discussed before.

For each LP model run the following diesel fuel quality parameters (which were assumed as variables of this study) were assessed: cetane index, density, viscosity, 10%, 50% and 85% distillation points.

Sulphur content and cloud point were not variables for this study. They were set at 0.3% max. and 0°C respectively. In particular, it must be stressed that the use of lower cloud point levels would directly impact on the conclusions reached related to cetane quality, density and viscosity. In order to quantify the impact on these parameters resulting from the use of different cloud points further LP model studies would be required.

4.2 CETANE INDEX

The LP models used incorporate the latest version of the ASTM calculated cetane Index.

The cetane quality results of the 90 LP model runs are scattered over a relatively large range. This is the result of the large number of situations assessed. In particular, the study parameters which mostly affected the scatter of cetane quality results were the crude slate and the relative demand of diesel fuel compared to other distillates.

It should be recognized that the cases studied represent various real situations and are not a set of alternatives. The market demand for diesel fuel has to be met by individual refineries some of which will be operating outside of the range of conditions represented by these cases.

The distribution of cetane index results which emerged from the study is as follows:

Cetane Level of Automotive Gas Oil	% of LP MODEL Results at or above given Cetane Level
44	92
45	87
46	80
47	67
48	54
49	47
50	38

These results are consistent with trends observed from 1980 onwards of decreasing cetane index and increasing density which reflects the increasing aromatic/naphthenic nature of the gas oil/diesel fuel pool. The main reason for this is the increase in conversion required in refineries to meet the ever decreasing fuel oil demand. The effect is strongest in the year 2000 low throughput cases 5 and 6 (Table 1) where there is the lowest fuel oil demand and where there is less possibility to absorb into fuel oil high density/high aromatic distillates from catatylic crackers running at full capacity to meet mogas demand.

Another important reason for the lower quality can be the processing in increasing amounts of naphthenic low sulphur crude oils. It should be realized that individual refineries can differ significantly depending upon their circumstances.

This reflects average conditions and clearly there are situations where individual refineries will only be capable of producing automotive diesel fuel with a cetane index lower than the average and this will be highly dependant on crude quality, processing capability, gas oil/diesel fuel demand and the ratio between the two, the quality requirement of the gas oil and the possibility to segregate both in the refinery and in the market. In this respect the results shown above give some indication of what may be achievable.

Assuming, in the first approximation, that, within the above relatively narrow range of cetane qualities, the cetane index of a diesel fuel is comparable to its cetane number, the following indications emerge:

- the cetane qualities of only 87% of the cases studied are within the current German specification (45 min.);

- on the other hand, only 38% of the cases studied would be within the current British specification (50 min.);

- a cetane limit of 47 min. (which is representative of other European specifications) would be in line with only 67% of the cases examined.

These results indicate that:

- to ensure adequate availability at acceptable cost, future European diesel fuel specifications should not involve cetane index quality requirements above 44.

  The results are based on a single cloud point level of 0°C. The use of a lower cloud point limit would require the use of lighter fractions which would further reduce the cetane quality.

- significantly higher cetane index values would require very substantial refinery investments in new processes involving large hydrogen-consuming technology for the feedstocks that need correction, and/or would restrict flexibility in selection of crude slates, which would either eliminate the current economic advantage of the diesel fuel versus mogas, or make it impossible to meet future projected diesel fuel volume demands.

4.3 DENSITY

The density results of the LP model runs vary in a range which directionally reflect the cetane index trends reviewed above. In fact, in spite of the different assumptions within each LP model, a good correlation existed (as expected) between the cetane index and the density of the diesel fuel. However, the density results were scattered over a narrower range and it would appear that a density range of 0.040 should be feasible, for a given cloud point level and hence geographical area/season.

This relatively narrow range and the level of results is not surprising, as it was assumed that all diesel fuels would have to meet a cloud point level of 0°C. Of course the assumption of a different cloud point level would involve a different range of densities, and would also affect cetane quality and viscosity levels.

4.4 VISCOSITY

The majority of the LP model viscosity results were included in a range between 3.0 and 6.0 cst. at 20°C. On the basis of these results it would appear that a viscosity range of 3 cst. at 20°C should be feasible for a given cloud point level and hence geographical area/season.

4.5 DISTILLATION

LP model results for three points of the distillation curve (10%, 50%, 85%) were generated. The following trends emerged:

- *10%* point: the majority of the LP model results were within 210°C and 250°C. This is consistent with the current European production.
- 50% point: this fuel characteristic is not part of any European specification but it is used for the calculation of the cetane index. The majority of the results of the LP model runs was between 240°C and 290°C.
- 85% point: the large majority of the results were below 350°C.

5. CONCLUSIONS

Trends in diesel fuel characteristics and the ranges likely to be encountered in Europe have been assessed for the period 1990-2000 using LP planning models. A range of refinery configurations, crude slates, import schemes, product demand patterns, crude throughput and Heating Gas Oil to Automotive Gas Oil demand ratios have been investigated using a total of 90 LP model runs.

THE RESULTS OBTAINED IN THIS STUDY CLEARLY ILLUSTRATE THAT IT WILL NOT BE REALISTIC TO PREPARE A DIESEL FUEL SPECIFICATION WHICH WOULD BE APPLICABLE THROUGHOUT EUROPE; GEOGRAPHICAL AND SEASONAL DIFFERENCES MUST BE TAKEN INTO ACCOUNT WHICH ARE REFLECTED IN THE LOW TEMPERATURE PERFORMANCE PROPERTIES AND THE RELEVANT RELATED CHARACTERISTICS.

Since the study has been based on a single cloud point of 0°C the application of a lower limit would necessitate the use of lower boiling materials which would further reduce cetane level and influence the other relevant properties.

From the study data the following further conclusions can be drawn:

Cetane

- there is a clear trend to lower cetane level up to the year 2000 due to the increased conversion required in European refineries.
- the quality of nearly 90% of the cases studied is within the current German specification (45 min.);
- less than 40% of the cases studied would be within the current British specification (50 min.);
- expensive refinery techniques to improve significantly the cetane level above that expected are not yet commonly available and could eliminate the current economic advantage of diesel fuel versus motor gasoline at current tax structures.

Density

- the results indicate that a density range of 0.040 should be feasible, but the absolute values to be applied will be a function of geographical and seasonal factors.

  As an illustration, at a cloud point of 0°C all of the data generated by the LP runs fall within a range between 0.825 to 0.865; other absolute values will apply for different cloud points.

Viscosity - the results indicate that a viscosity range of 3 cst at 20°C should be feasible.

- the majority of the LP model viscosity results at a cloud point of 0°C are included in a range between 3.0 and 6.0 cst at 20°C;

Volatility - the majority of the 10% point results was within 210°C and 250°C;
- most 85% point results were below 350°C;

TABLE 1

CRUDE INPUT AND PRODUCT DEMANDS

YEAR 2000 (10^6 TONNES)

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
Total Oil Demand	440	440	440	440	380	380
Product Imports	35	35	35	35	70	70
Total Refinery Demand	405	405	405	405	310	310
Feedstocks (Atm. Resid)	-	-	25	25	-	-
Total Crude	405	405	380	380	310	310
Low Sulphur Crude	180 *	90/90**	180 *	90/90**	130 *	65/65**
Medium Sulphur Crude	169	169	150	150	135	135
High Sulphur Crude	56	56	50	50	45	45
<u>Product Demand on Refineries</u>						
LPG	(17.6)	(17.6)	(17.6)	(17.6)	(15.2)	(15.2)
Mogas	91.5	91.5	91.5	91.5	81.6	81.6
Kerosine	22.0	22.0	22.0	22.0	19.0	19.0
Naphtha	(13.8)	(13.8)	(13.8)	(13.8)	-	-
Auto Gas Oil	(68.9)	(68.9)	(68.9)	(68.9)	(51.7)	(51.7)
Heating Gas Oil	(74.8)	(74.8)	(74.8)	(74.8)	(55.7)	(55.7)
Inland Fuel Oil	(50.0)	(50.0)	(50.0)	(50.0)	(38.0)	(38.0)
Bunker Fuel Oil and Black Products	(39.0)	(39.0)	(39.0)	(39.0)	(28.0)	(28.0)

() All figures in brackets are allowed to float to maximise the middle distillate pool.

* 100% Brent

** 50/50 Brent /Nigerian Forcados

Medium Sulphur Crude - Arab Light
High Sulphur Crude - Arab Heavy

TABLE 2

QUALITY LIMITS OF KEY PRODUCTS

Europremium MOGAS (EEC Unleaded Grade)	HEATING GAS OIL	AUTOMOTIVE GAS OIL
RON - 95 min. MON - 85 min.	Rel. Density at 15°C - 0.875 max Sulphur - 0.3%wt. max Cloud - 0°C Mid B. Pt. - To be reported Cetane Index - 40 min Viscosity - 7.5 cSt max at 20°C	Relative Density - To be reported Sulphur - 0.3% wt. max Cloud - 0°C 10% Evap. - To be reported 50% Evap. - To be reported 85% Evap. - To be reported Cetane Index - To be reported Viscosity - To be reported

BUNKER FUEL OIL	INLAND FUEL OIL	IMPORTS
Rel. Density - 0.993 Max Viscosity - 40 cSt max at 100°C Sulphur - 4.0% wt. max	Density - 1.005 max Viscosity - 40 cSt max at 100°C Sulphur - 2.5% wt. max	Atmospheric Residue Density - 0.985 Viscosity - 40 cSt at 100°C Sulphur - 3.5% wt.