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opportunities and costs to upgrade the quality of automotive diesel fuel

Prepared by CONCAWE Automotive Emissions Management Group's Special Task Force on Refinery Processes for Upgrading Diesel Fuel Quality (AE/STF-5)

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ABSTRACT

The results of last year's study of opportunities and costs to upgrade quality of automotive diesel fuel in the EEC were included in CONCAWE Report No. 10/87 "Diesel fuel quality and its relationship with emissions from diesel engines". The purpose of the present report is to record the full study. This investigates three classes of processing options and one non-processing alternative to improve diesel fuel cetane number. The routes described are selective blending of distillate pool components; processing causing significant yield change, e.g. hydrocracking, solvent extraction; hydrogenation with little or no yield change; and use of cetane number improving additives. It is concluded that hydrogenation would be the only processing option suitable to provide significant cetane number increase. It would be capital intensive, whereas the alternative of using additives would be less expensive and more flexible. Such additives could not change other parameters like density and aromaticity.

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SUMMARY

Future automotive diesel fuels are expected to have lower cetane numbers and higher densities than in the past. A survey has been made of possible routes and their costs to increase the quality of diesel fuels.

Three options have been identified:

- Selective blending of distillate pool components
- Processing causing significant yield change, e.g. hydrocracking, solvent extraction
- Hydrogenation with little or no yield change

The hydrogenation process, although not in commercial operation and highly capital intensive, would be the only processing option to produce a significant cetane number increase across the EEC-12 diesel fuel pool. A two cetane number pool improvement would require a capital investment of USD 3.5-4.5 billion, a yearly total cost (including capital charge) of USD 1.3-1.7 billion and an additional hydrocarbon consumption of 3 Mt/yr.

A non-processing alternative viz. the use of an additive to improve cetane number would require some 30 kt/yr of additive for a two cetane number pool improvement and cost USD 42-50 million/year including dosing facilities and testing costs. This latter option is clearly less expensive than the processing route and is more flexible cost-wise in coping with fluctuating situations, but other parameters such as density and aromaticity are not changed.

1. INTRODUCTION

A CONCAWE evaluation of the impact on diesel fuel quality of changing refinery processing routes, crude slates and product demand between 1980 and year 2000 has shown a clear move towards lower cetane numbers (CN) and higher densities in the future. The cause of this trend is the requirement to use more residue conversion capacity to match the ever decreasing fuel oil demand while maintaining the required production of distillate fuels. Conversion processes produce low quality middle distillate components which have to be absorbed into the distillate product pool because the size of the fuel oil market (which varies from country to country) is decreasing relative to distillate demand. An additional factor is the significant increase in demand for high quality diesel fuel while demand for less stringent specification heating and industrial gas oil is decreasing.

In view of the identified lowering of cetane number, CONCAWE has studied what opportunities there would be to improve this property by selective blending and/or refinery processes and to assess the costs thereof. The use and cost of cetane number improvement by additives is also briefly discussed.

It is worth noting that in contrast to motor gasoline, diesel fuel quality is largely resultant from crude oil quality and its distillation and the need to absorb components from conversion processes. Quality trimming is presently achieved by selective blending, and sulphur content is controlled by hydrodesulphurization whereby cetane number improvement is only marginal.

2. QUALITY IMPROVEMENT OPTIONS

Three main classes of improvement options can be identified.

2.1 SELECTIVE BLENDING

In this route there is no overall quality improvement for the pool of components available for blending diesel fuel, domestic heating, industrial and bunker gas oils. Selecting high cetane number components for diesel automatically results in the remaining components being concentrated in the other grades. There is a limit to how much lower quality component can be absorbed in heating/industrial/bunker gas oils and this is normally considered to be when around 40 CN is reached.

The CONCAWE study using LP models to identify the trend to lower cetane numbers has already assumed a 40 CN level for heating/industrial/bunker gas oil. It is concluded, therefore, that there is little or no scope for additionally improving cetane numbers of diesel fuel by selective blending. This conclusion is further supported by the fact that the LP models assume 100% segregation of crude oils and components is possible which is certainly over-optimistic. Moreover, it is widespread practice to manufacture and distribute a dual purpose fuel for both off-road diesel and heating oil. If heating oil quality would be reduced to 40 CN and off-road diesel quality was maintained then clearly a dual purpose grade would not be possible. Creation of a three grade structure would cost additional money for handling facilities.

2.2. PROCESSING WHICH INVOLVES SIGNIFICANT CHANGES IN PRODUCT YIELDS

Two options are available viz.

(i) Extraction of aromatics
(ii) Hydrocracking

Re. (i) Processes are available to remove aromatics by solvent extraction, thus leaving a high cetane number component. So-called light cycle oils which are produced by catalytic crackers are high aromatic gas oil components which could be considered for such a process. However, removal of the aromatics would mean a loss of gas oil which is not acceptable and would present a disposal problem for the aromatics. A solution by exchanging aromatics with middle distillates in the fuel oil pool is considered to be infeasible long-term for fuel oil quality reasons and the lack of suitable middle distillates in the ever-decreasing fuel oil pool. For these reasons this route is not considered to be a viable solution except in highly localized circumstances.

Re.(ii) Hydrocracking produces good quality gas oils and acceptable feedstocks for further upgrading to finished gasoline. The feedstock is vacuum distillate and/or heavy cycle oil from catalytic crackers. CONCAWE Report No. 5/86 has shown that with presently planned and installed conversion capacity the fuel oil and distillate demand as presently foreseen can be met up to year 2000. If additional hydrocracking capacity were to be constructed to produce good quality gas oil, this would create a surplus of distillates requiring the shut down of existing conversion capacity and the need to construct gasoline upgrading capacity e.g. catalytic reforming. Therefore, this is not a generally economically acceptable solution. However, there may be special local circumstances where additional hydrocracking capacity may be required for distillate demand reasons and any gas oil components produced from such a plant would have a positive effect on cetane number.

2.3 PROCESSING WHICH INVOLVES HYDROGENATION OF AROMATICS WITH ONLY MARGINAL CHANGE IN PRODUCT YIELDS

Gas oil hydrodesulphurization (HDS) processes operate typically at relatively low pressure e.g. up to 25 bar H_2 partial pressure and as such have only a small effect on aromaticity. Conventional desulphurization processes only increase cetane number of the feedstock by 1-2 CN. It is assumed that up to year 2000, all of the aromatic light cycle oils (LCO) will be treated to satisfy storage stability requirements which will also reduce sulphur content. Therefore, any small cetane number improvement will already have been accounted for. If new units were to be considered for treating LCO, then higher pressure could be used whereby more hydrogenation and larger cetane number improvement would be achieved. The following table gives some typical data for medium and high pressure hydrogenation units based on proven technology and existing catalysts although it must be emphasized that no such units have yet been built for this purpose.

Table Cetane number increase by hydrogenation processes. (Costs-basis North West Europe 1986, 1 USD = 1.0 ECU)

		Medium pressure (50 bar H_2 partial pressure)	High pressure (100 + bar partial pressure)
Feedstock		LCO	LCO
Yield gas oil	% wt	91-99 (a)	85-99 (a)
Hydrogen consumption	% wt	1.8-2.25	3-4.5
Capacity	t/sd	1500	1500
Capital expenditure (b)	M $	64-86	120-130
Total annual cost (c)	M $/yr	25-30	46-48
Cetane number improvement		8-10	10-25 (d)
Cost/CN ton improvement	$	5-7.5	3.7-9.6

(a) Range reflects differences in technologies available.

(b) Includes hydrogen production facilities.

(c) Includes 25% capital charge, direct/indirect fuel

(d) This large range is because the improvement is dependent upon the cetane number of the feedstock, e.g. starting at either 15 or 30 CN both improve to around 40 CN.

2.4 THE USE OF CETANE NUMBER IMPROVING ADDITIVES

Additives can be used to give a cetane number increase. Many different compounds have been studied as diesel fuel ignition improvers, the most common being nitrate esters. Peroxides and other reactive compounds have generally been discarded in view of their hazardous nature and/or ability to promote harmful side effects in the fuel. As a consequence virtually all currently available improvers are based on 2-ethylhexylnitrate or mixed octylnitrates. Based on third quarter 1987 information, bulk deliveries of cetane improvers in Western Europe are in the price range USD 1250 to 1500 per ton.

If cetane number of diesel fuels is boosted to successively higher levels, the response to cetane improvers decreases and hence additive concentration per unit of cetane improvement increases exponentially. A typical additive response for a 45 CN diesel fuel is 0.017% volume per unit of cetane number improvement.

3. DISCUSSION

It can be concluded from Section 1.3 that new investment in medium and high pressure hydrogenation processing of light cycle oil are conceivable options for cetane number improvement. Such hydrogenation reduces density and viscosity. If it is assumed that a 2 CN improvement could be required across the EEC-12 diesel fuel pool which is expected to increase to 75 Mt/yr in year 2000, this would represent 150 million CN tons upgrading. Some 15 Mt/yr of LCO is available from the catalytic cracker capacity which means a cetane number improvement of 10 per ton LCO would be required.

Assuming that the high pressure hydrogenation process variant would be required for such an improvement, the capital costs for EEC-12 countries based on unit capacities of 1000-1500 t/d would be USD 3.5 to 4.5 billion for some 30-45 units. The annual costs including 25% capital charge and direct/indirect fuel would be USD 1.3-1.7 billion/year. In addition some 3 Mt/yr extra hydrocarbons would be required for energy and hydrogen manufacture.

In practice this size of upgrading unit would sometimes be too large for available LCO in a refinery, which would either mean a smaller unit with loss of economy of size or transfer of LCO from other refineries thus incurring transport costs.

A comparable cost calculation can be made for the use of cetane improver additive based on data in Section 2.4 and the expected EEC-12 diesel fuel consumption of some 75 Mt/yr by year 2000.
A cetane improvement of 2 CN would require 30 kt/yr of additive giving a cost of USD 38 to 45 million per year.

Costs would also be incurred for storage and handling of the additive, for the provision of a cetane number test engine according to ASTM D-613 and for the manpower to operate and maintain the engine. It is estimated that this would increase the cost of a 2 CN improvement by additive treatment to USD 42 to 50 million per year.

Clearly the additive route is less expensive than hydro-processing, but other quality parameters such as density and aromaticity are not changed. On the other hand, additive dosage can be easily adjusted for fluctuating cetane levels which may occur in refineries because of crude oil changes, seasonal demand variations, etc. Capital intensive processing is, by contrast, a continuing cost situation largely independent of requirement.