residue hydrodesulphurization investment and operating costs

Prepared by the CONCAWE Air Quality Management Group's Special Task Force on Residual Fuel Oil Desulphurization (AQ/STF-28)

R. J. Ellis (Chairman)

R. Arguile
P. L. Bocca
A. Campobasso
A. Cerase
K. Isker
G. J. Waller

G. Origoni (Technical Co-ordinator)

Den Haag
July 1986

ABSTRACTS

In view of the continuing interest in the costs of desulphurization in connection with possible sulphur control strategies, CONCAWE has updated the costs of residue hydrodesulphurization taking account of the latest commercial technological developments and covering a wider number of feedstocks than in previous studies.

Met het oog op de blijvende belangstelling in de kosten van ontzwaveling en in verband met de mogelijk te nemen toekomstige contrôle maatregelen ten aanzien van zwavel emissies, heeft CONCAWE de kosten van waterstof ontzwaveling van residuen. Hierbij is rekening gehouden met de laatste technologische ontwikkelingen en in vergelijking met eerdere studies zijn thans een groter aantal tussen produkten die voor ontzwaveling in aanmerking komen in beschouwing genomen.

Angesichts des nach wie vor bestehenden Interesses an der Entschwefelung von schwerem Heizöl in Verbindung mit einer möglichen gesetzlichen Limitierung des Schwefelgehaltes in flüssigen Kraft- und Brennstoffen, hat CONCAWE die Kosten für die hydrierende Entschwefelung von Rückstandsprodukten auf den neuesten Stand gebracht. Dabei wurden die neuesten technologischen Entwicklungen berücksichtigt and gegenüber früheren Studien eine Reihe zusätzlicher Einsatzprodukte untersucht.

En vue de l'intérêt continu des coûts de désulfuration en liaison avec les stratégies possibles de contrôle des émissions de soufre, le CONCAWE a mis à jour les coûts de la désulfuration des résidus en tenant compte des derniers développements des unités commerciales, et en couvrant un plus grand nombre de charges que dan les études passées.

Teniendo en cuenta que se mantiene el interés sobre el tema de los costos de la desulfuración, relacionado a su vez con las posibles estrategías de control de emisiones de azufre, CONCAWE ha puesto al día los costes de la hidrodesulfúración de los residuos, de acuerdo con los progresos más recientes en el terreno tecnológico y comerical y utilizando una más amplia cobertura de datos que en otros estudios previos.

In considerazione del continuo interesse manifestato per il problema dei costi di desolforazione, in relazione alle strategie praticabili per il controllo delle emissioni di zolfo, il CONCAWE ha aggiornato lo studio sui costi di idrodesolforazione degli olii combustibili tenendo conto degli sviluppi recenti, ed economicamente realizzabili, della tecnologia ed analizzando un numero di materie prime maggiore di quanto era stato fatto negli studi precedenti.

CONTENTS

SUMMARY

Residue hydrodesulphurizations (RDS) costs have been updated to take into account the latest commercial developments in the technology.

The following data are applicable to high sulphur vacuum residues from three crudes. The ranges reflect the average for each feedstock.

- Investment costs are in the range $US 150-215/annual tonnes of 1% sulphur fuel based on 1985 money at Rotterdam. This range reflects differences in the quality of the feedstocks.

  Starting from sulphur contents in the 4-6 wt% range, 1% sulphur in the desulphurized residue is about the lowest that was submitted.

- The operation of the units incur energy and loss requirements in the range 13-19% of 1% sulphur fuel oil.

- Operating costs are in the range $US 68-99/tonnes 1% sulphur fuel with no sulphur/conversion credits or alternatively in the range $US 1830-2070/tonnes of sulphur removed.

- When taking into account possible sulphur and conversion credits from the RDS process these net costs fall into the range $US 47-84/tonnes of 1% sulphur fuel or alternatively $US 1180-1830/tonnes of sulphur removed.

- Depending upon feedstock and credits applicable these operating costs translate into $US 12-21/1% sulphur removed/tonnes of fuel that would have to be recovered from the customer. On the basis of reducing 3.5% sulphur fuel oil to 1% sulphur this would represent a price increase of $US 30-52/tonnes of low sulphur fuel oil, which would make such fuel oil uncompetitive with low sulphur coal and natural gas.

- The significant ranges in costs which are mainly due to the quality of the feedstocks illustrate clearly that there is no one RDS cost and that feedstock and other conditions must be defined when applying such costs.

- As a sensitivity a 50% reduction in the cost of energy and loss would reduce operating costs by only $US 10-17/tonnes of 1% sulphur fuel.

- With the present state of the art cracked residues cannot yet be hydrodesulphurized on a commercial scale.

- Investment costs to desulphurize Kuwait atmospheric residue are some 28% lower than for Kuwait vacuum residue. The corresponding operating costs are 10-15% lower.

However, atmospheric residue normally has a higher value as conversion feedstock than as RDS feedstock and therefore is generally not available for RDS units. Because of the abundance of "clean", low sulphur residue it is unlikely that atmospheric RDS can be economically justified for conversion feedstock preparation.

1. INTRODUCTION

In view of the continuing interest in the costs of desulphurization in connection with possible sulphur control strategies, it was decided to update the costs of residue hydrodesulphurization to take account of the latest commercial technological developments and to cover a wider number of feedstocks than in previous studies.

2. OUTLINE OF APPROACH

The results of the last study made by CONCAWE on this subject were published in May 1981 (CONCAWE report No. 5/81 entitled "Direct desulphurization of residual petroleum oil - investment and operating costs"). This study examined in some detail the desulphurization costs of Kuwait atmospheric and vacuum residues. For this update it is appropriate to increase the scope to include vacuum residues from Arabian Light and Heavy crudes. Participating companies were invited to submit data for cracked residual feedstocks but no data was offered from which it can be concluded that commercially proven technology for the direct desulphurization of cracked residual fractions is not yet available.

The procedure followed is similar to that of previous studies, i.e. companies were invited to complete a standard questionnaire which would give cost and desulphurized residue yield and quality data based on the best commercially available technology. The information is first-hand, i.e. submitting companies would be prepared to design and have constructed such plant, if required, in their refineries in the next 5 years.

On the basis of the received data, desulphurization cost to make 1% sulphur fuel oil from the various feedstocks can be calculated.

From the product yield and quality data requested it is possible to address the question of possible economic side-benefits from applying residual desulphurization e.g. the resulting viscosity reduction effect. This aspect must also be viewed against the results of the refinery demand and supply situation in the period up to 2000, which are discussed in the concurrent CONCAWE report dealing with sulphur emissions.

3. DATA COLLECTION

As already indicated in the introduction the desulphurization cost of residues is based on replies of CONCAWE member companies to a questionnaire. In fact relatively few companies have sufficiently developed technology to desulphurize residual material on a commercial basis i.e. within the next 5 years be able to design and build a unit for operation in a refinery. This was made a prerequisite for replying to the questionnaire and the following table shows the extent of the response.

	Kuwait Atmospheric Residue	Kuwait Vacuum Residue	Arabian Light Vacuum Residue	Arabian Heavy Vacuum Residue
Capacity (t/cd)	4000/7600	4000	4000	4000
Company 1	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes
3	-	Yes	-	-
4	Yes	Yes	Yes	Yes
5	-	-	Yes	-

3.1 *FEEDSTOCK AND PRODUCT YIELD AND PROPERTIES*

The data received was based on the latest technology commercially available and the residues were assumed to be desulphurized to the lowest level economically possible. This is a difference with the previous study where the aim was to produce maximum 1% sulphur fuel oil. Desulphurization is carried out at high temperature and pressure in the presence of hydrogen and a catalyst and as a result, particularly with heavy feedstocks there is a significant conversion effect with the production of light material and viscosity reduction of the residue. The economic effect of this will be dealt with in a later section.

3.2 INVESTMENT COSTS

The investments are based on the cost of facilities built in The Netherlands mid 1985. They should therefore be corrected for inflation and location. Capital depreciation and interest on capital investment have been taken as an annual capital charge of 25% of the investment.

The on-site facilities include the costs of the desulphurization unit, the hydrogen plant, fractionation facilities for splitting off light distillates, facilities for tail gas treatment (H_2S recovery) and a Claus unit (SO_2 conversion to sulphur). The off-site facilities are all other facilities such as tankage, utilities and handling facilities. The cost of these will vary from location to location and, therefore, participants decided to use an average investment for off-sites of 35% of on-sites. This percentage takes into account the question of heat integration which will be extremely complex.

3.3 OPERATING COSTS

The operating costs are calculated according to the following scheme.

a) Variable operating costs (excluding energy and loss). These include, catalyst, chemicals, royalties and miscellaneous operating expenses for total complex.

b) Fixed operating costs. These include, salaries, wages, maintenance and overheads for total complex.

c) Energy. This includes direct and indirect (steam, electricity) fuel for total complex.

d) Loss. This includes loss around the whole complex and in particular the loss incurred in the hydrogen unit. (The product of H_2 from hydrocarbon feed involves the production of CO_2 and H_2O and represents a loss of hydrocarbons).

3.4 TOTAL OPERATING COSTS

The total cost of desulphurizing the various feedstocks is built up of the following elements.

A. Capital charge (25% of capex)
B. Operating costs (excluding energy/loss)
C. Energy cost
D. Loss cost

A number of credits can be identified e.g. sulphur recovery, upgrading via conversion in the RDS process and these are subtracted to arrive at the net cost. The following sections deal with these aspects in more detail. The costing of the various hydrocarbon elements is based arbitrarily on Platts' spot prices for Rotterdam October 1985. Attachment 10 refers. Clearly where the perceived situation is different, adjustments will be necessary.

4. RESULTS

4.1 FEEDSTOCK AND PRODUCT YIELD AND PROPERTIES

The details of the data provided are shown in Attachment 1. There is a reasonable agreement on the quality of the feedstocks. Where there are significant differences, these can be traced back to a different cut point for the residue. Companies have preferred to report on known feedstocks in their system rather than estimating on one standardized feedstock.

The range of hydrogen requirement for each feedstock is relatively wide. This reflects the different philosophies used by the companies in developing their technology. Low H_2 requirement points to low desulphurization and/or low rate of conversion. Higher H_2 requirement points to higher desulphurization and/or higher rates of conversion. A good example of the different effects is given by the submissions for Arabian Light vacuum residues. Most of the significant differences on yield and properties of products can be traced back to differences in feedstocks and in the way the technology has been applied.

4.2 INVESTMENT COSTS

The following Table shows the average investment costs per feedstock and the range reported. The results per submission are shown in Attachment 2.

Investment Costs (a)

Feedstock		Kuwait Atmospheric Residue		Kuwait Vacuum Residue	Arabian Lt Vacuum Residue	Arabian Hvy Vacuum Residue
Capacity	t/cd	4000	7600	4000	4000	4000
Total investment Average	$\$US\ 10^6$	177	277	247	231	275
Range	$\$US\ 10^6$	166-188	262-286	230-279	192-254	257-304
$US/year tonne of 1 wt% sulphur fuel		134-147	105-130	154-190	128-169	198-241
$US/year tonne of average sulphur removed		2900-3300	2450-2850	3400-4600	4000-5200	3750-4150

(a) Basis Rotterdam 1985.

The agreement between submissions must be considered good in view of the complexity of the technology. The range is somewhat larger for the vacuum residues which presumably is a reflection of their more difficult nature for desulphurization. This is also the reason why vacuum residue desulphurization requires some 40-50% more capex than for atmospheric residue desulphurization on an intake basis.

4.3 OPERATING COSTS (EXCLUDING ENERGY/LOSS)

Attachment 3 shows a summary of the operating costs submitted.

4.4 ENERGY

The energy requirement for the whole complex i.e. RDS, H_2 unit utilities and other facilities is shown in Attachment 4. It is assumed for the costing of the energy that it will be in terms of 1% sulphur residue based on its own RDS costs plus the price for 3.5% sulphur heavy fuel oil. The individual unit and total energy costs are also given in Attachment 4. Despite differences in unit costs and energy usage, there is good agreement on total energy costs.

4.5 LOSS

Each of the submissions has identified losses around the complex and in particular around the H_2 unit. For this study loss has been calculated as the difference between intake and output each for RDS and H_2 units. Since H_2S/NH_3 are non-hydrocarbon these quantities are also counted as loss. (The question of sulphur credit is dealt with later). The losses are costed at the unit cost of the intakes to the individual RDS and H_2 unit. The results are shown in Attachment 5. Agreement is good between the submissions.

4.6 TOTAL OPERATING COSTS

Attachment 9 shows the total cost made up of the various cost elements for each feedstock and for each complete submission.

4.7 CREDITS

As a result of the RDS process a certain amount of upgrading takes place in terms of conversion of residue to distillates and lighter and viscosity reduction which indirectly results in releasing material that may be suitable for additional middle distillates if required. Also the facilities produce sulphur which can be sold. For this latter aspect a credit of $US 50 per tonne of sulphur recovered has been given. To calculate the tonnes of sulphur recovered it is assumed that 95% of the sulphur removed by the process is actually recovered. Attachment 6 gives the calculated sulphur picture. The sulphur credit is small compared with the costs.

For the upgrading credit the following approach has been applied. The material boiling below 185°C in principle can be used for H_2 production and since in fact additional quantities of the H_2 manufacturing feedstock are physically required it is reasonable to allocate full upgraded value to these by-products. Taking Rotterdam spot prices October 1985, the added value is the difference between value of feedstock and value of product. The results of this calculation are shown in Attachment 7.

The material boiling above 185°C i.e. the 185 plus residue has a significantly lower viscosity than that of the residue feedstock to the RDS unit. Two main situations can be identified viz.

(a) when the feedstock residues would normally require diluent to meet fuel oil viscosity specifications, then the viscosity reduction via the RDS unit can release diluent in the boiling range 185-370°C. The alternative value of this diluent is dependent on two main factors, one, its quality as a marketable distillate, two, the market demand for such material. With respect to quality, this will differ from location to location, but with the generally high level of conversion being applied the released diluent is most likely to have an aromatic/high density character and thus of indifferent quality. With respect to demand for middle distillates up to the year 2000, the concurrent CONCAWE sulphur emission study indicates that there is sufficient existing conversion capacity to meet distillate demand therefore it is unlikely that a high gas oil/fuel differential will exist. However it is likely that some individual locations could have a deficit of middle distillates.

(b) The second situation is either where the operation of a RDS unit would produce unwanted distillates, or where there is insufficient residual feedstocks available to load all units. In both cases the situation could be brought more or less in balance by closure of say visbreaking capacity which would save operational costs.

Taking consideration of the likely indifferent quality and the low demand for additional middle distillate it is assumed for this study that a realistic credit for the diluent gain would be in the range of 10 $US/tonnes (basis operating cost saving of visbreakers) to 50 $US/tonnes (value above fuel oil based on low demand and indifferent quality). The results of a calculation of diluent gain and quantity of 1% sulphur fuel produced are shown in Attachment 8.

Attachment 9 gives the complete cost and credit situation for each feedstock and is summarized below.

Summary of Costs of Residue Hydrodesulphurization

	Kuwait Atmospheric Residue		Kuwait Vacuum Residue	Arabian Lt. Vacuum Residue	Arabian Hvy Vacuum Residue
Capacity t/cd	4000	7600	4000	4000	4000
Total investment (average) 10^6 $US	177	277	247	231	275
$US/tonne per year of 1 wt% sulphur fuel (average)	140	116	174	154	214
Tot. op. cost $US/tonne 1 wt% S fuel (average)					
No credits	69	61	82	68	99
Low diluent value	62	54	73	60	84
High diluent value	50	42	58	47	62
$US/tonne S removed					
No credits	1585	1395	1830	2070	1860
Low diluent value	1420	1230	1625	1830	1595
High diluent value	1150	960	1310	1430	1180

5. DISCUSSION OF RESULTS

The results show that RDS costs are feedstock dependent, as between crude type as well as between different residues from the same crude. The costs are also capacity dependent. The consequence of this is that to obtain a good estimate of residue RDS costs, the particular circumstances must be well defined.

Energy and loss required per 100 tonnes of 1% fuel produced ranges from 11 to 23 tonnes and in terms of costs represents $US 20-34/tonnes 1% sulphur fuel. In the extreme case that energy and loss costs would be 50% lower this would reduce RDS costs by $US 10-17/1% sulphur fuel oil.

Any construction of RDS units will almost certainly take place in existing refineries. While investment costs include 35% for off-sites this will be insufficient in general to cover the costs of major integration problems that could occur due to e.g. lack of space, lack of feedstock. Closure of existing units etc.

RDS processing also results in some conversion of the residue to lighter products. The valuation of this effect is highly dependent on the circumstances. The credits that can be allocated are in the range of $US 5-50 per tonne 1% sulphur fuel produced which are significant, although it is expected, based on the conclusions of the CONCAWE sulphur emissions study i.e. sufficient conversion capacity will be available to meet middle distillate demand up to 2000, that the lower end of the range will be applicable. It should be noted that the credits do not affect the amount of capital that has to be laid down for constructing RDS units.

Examination of the results on the vacuum residues shows that Arabian Light vacuum residue is the least expensive on a $US/tonne 1% sulphur fuel basis, but it is the most expensive on a $US/tonne sulphur removed basis.

The least expensive feedstock to desulphurize on a $US/tonne sulphur removed basis is Kuwait atmospheric residue. It is unlikely that significant amounts of this or similar atmospheric residues would be available as RDS feedstock in 2000 since it will have a higher value as feedstock to conversion units either directly or via vacuum distillation.

Although there can be economic benefits to feed low metal, asphaltene and sulphur residues directly to e.g. cat. crackers, the relatively large availability of such residues from low sulphur crudes will, in general, make it difficult to justify investment in RDS for conversion feed preparation.

YIELDS AND PROPERTIES

KUWAIT ATMOSPHERIC RESIDUE

		Submission 1	Submission 2	Submission 4
Feedstock	%	100	100	100
Cut point	°C	370	370	370
Sulphur content	wt%	4.3	4.2	4.3
Viscosity at 100°C	cS	70	70	66
Metals (V + Ni)	ppm	72	60	72
Total nitrogen	ppm	2500	2200	2500
Density	t/m^3	0.973	0.973	0.975
H_2 rate on feed	wt%	1.7	2.1	1.3
Product yield				
$H_2S + NH_3$	%	3.85	3.86	4.2
C_2 minus	%	0.65	0.44	0.2
C_3/C_4	%	1.0	0.43	0.2
C_5/185°C	%	1.3	1.85	0.5
185/370°C	%	15.9	8.24	11.2
370° C plus	%	78.6	86.29	85.0
Total		101.3	101.11	101.3
Properties				
185/370°C				
Sulphur	%	0.04	0.03	0.01
Viscosity at 100°C	cS	1.5	1.4	1.0
Density	t/m^3	0.8653	0.855	0.850
Cetane number		48	38	48
370 + Residue				
Sulphur	%	0.52	0.72	0.5
Viscosity at 100°C	cS	21.5	23	35
Density	t/m^3	0.928	0.904	0.932

YIELDS AND PROPERTIES

KUWAIT VACUUM RESIDUE

		Submission 1	Submission 2	Submission 3	Submission 4
Feedstock	%	100	100	100	100
Cut point	°C	520	566	566	566
Sulphur content	wt%	5.26	5.21	5.1	5.59
Viscosity at 100°C	cS	949	7000	7100	4260
Metals (V + Ni)	ppm	136	150	155	149
Total nitrogen	ppm	4200	3000	4000	4000
Density	t/m^3	1.02	1.037	1.046	1.034
H_2 rate on feed	wt%	2.25	1.68	2.09	1.86
Product yield					
$H_2S + NH_3$	%	5.0	4.58	4.91	5.2
C_2 minus	%	1.12	0.55	1.26	0.35
C_3/C_4	%	1.47	0.56	1.64	0.35
C_5/185°C	%	3.3	0.84	5.63	0.8
185/370°C	%	13.1	4.16	11.0	7.1
370° C plus	%	77.8	90.73	77.53	88.0
Total		101.8	101.4	101.97	101.8
Properties					
185/370°C					
Sulphur	%	0.07	0.09	0.04	0.01
Viscosity at 100°C	cS	1.8	2.0	1.5	1.0
Density	t/m^3	0.855	0.871	0.859	0.850
Cetane number		42	37	42	48
370 + Residue					
Sulphur	%	0.97	1.15	1.0	1.0
Viscosity at 100%	cS	120	70	480	95
Density	t/m^3	0.968	0.968	0.972	0.958

YIELDS AND PROPERTIES

ARABIAN LIGHT VACUUM RESIDUE

		Submission 1	Submission 2	Submission 4	Submission 5
Feedstock	%	100	100	100	100
Cut point	°C	566	566	566	566
Sulphur content	wt%	4.2	4.4	4.2	4.3
Viscosity at 100°C	cS	2400	2000	1625	2000
Metals (V + Ni)	ppm	89	140	114	141
Total nitrogen	ppm	3000	3700	3000	3800
Density	t/m^3	1.028	1.025	1.020	1.022
H_2 rate on feed	wt%	2.05	1.43	1.35	1.87
Product yield					
$H_2S + NH_3$	%	4.00	3.80	3.3	4.09
C_2 minus	%	1.20	0.60	0.4	1.77
C_3/C_4	%	1.15	0.60	0.4	2.17
C_5/185°C	%	2.6	0.71	0.8	7.07
185/370°C	%	12.5	4.26	6.8	20.30
370° C plus	%	80.1	91.16	89.5	66.37
Total		101.6	101.1	101.2	101.8
Properties					
185/370°C					
Sulphur	%	0.1	0.1	0.01	0.25
Viscosity at 100°C	cS	1.80	1.8	1.0	1.2
Density	t/m^3	0.876	0.879	0.868	0.860
Cetane number		42	37	46	44
370 + Residue					
Sulphur	%	0.79	1.11	1.0	1.45
Viscosity at 100°C	cS	125	35	90	20
Density	t/m^3	0.977	0.967	0.962	0.998

YIELDS AND PROPERTIES

ARABIAN HEAVY VACUUM RESIDUE

		Submission 1	Submission 2	Submission 4
Feedstock	%	100	100	100
Cut point	°C	566	566	495
Sulphur content	wt%	5.6	6.0	4.8
Viscosity at 100°C	cS	2500	55000	2720
Metals (V + Ni)	ppm	194	270	244
Total nitrogen	ppm	4200	4800	4640
Density	t/m^3	1.04	1.054	1.030
H_2 rate on feed	wt%	2.25	1.78	2.14
Product yield				
$H_2S + NH_3$	%	4.9	5.52	4.9
C_2 minus	%	0.95	0.64	1.1
C_3/C_4	%	1.00	0.65	1.1
C_5/185°C	%	3.3	0.67	4.6
185/370°C	%	15.8	4.02	18.9
370° C plus	%	75.6	89.91	71.5
Total		101.6	101.4	102.1
Properties				
185/370°C				
Sulphur	%	0.03	0.10	0.01
Viscosity at 100°C	cS	1.75	1.3	0.97
Density	t/m^3	0.85	0.866	0.848
Cetane number		42	37	43
370 + Residue				
Sulphur	%	1.0	1.12	0.6
Viscosity at 100°C	cS	31	80	78
Density	t/m^3	0.959	1.006	0.966

INVESTMENT COSTS
(1985 The Netherlands)

KUWAIT ATMOSPHERIC RESIDUE

	Submission 1	Submission 2	Submission 4
Capacity t/cd	4000	4000	4000
Investment $US million			
On-sites	123	130	139
Off-sites (35%)	43	46	49
Total	166	176	188
$US/t/yr 1% sulphur fuel	138	147	134
Capacity t/cd	7600	7600	7600
Investment $US million			
On-sites	194	212	210
Off-sites (35%)	68	74	74
Total	262	286	284
$US/t/yr 1% sulphur fuel	114	130	105

INVESTMENT COSTS
(1985 The Netherlands)

KUWAIT VACUUM RESIDUE

	Submission 1	Submission 2	Submission 3	Submission 4
Capacity t/cd	4000	4000	4000	4000
Investment $US million				
On-sites	183	207	170	171
Off-sites (35%)	64	72	60	60
Total	247	279	230	231
$US/t/yr 1% sulphur fuel	190	186	164	154

ARABIAN LIGHT VACUUM RESIDUE

	Submission 1	Submission 2	Submission 4	Submission 5
Capacity t/cd	4000	4000	4000	4000
Investment $US million				
On-sites	175	188	142	180
Off-sites (35%)	61	66	50	63
Total	236	254	192	243
$US/t/yr 1% sulphur fuel	157	169	128	162

ARABIAN HEAVY VACUUM RESIDUE

	Submission 1	Submission 2	Submission 4
Capacity t/cd	4000	4000	4000
Investment $US million			
On-sites	196	225	190
Off-sites (35%)	69	79	67
Total	265	304	257
$US/t/yr 1% sulphur fuel	241	203	198

OPERATING COST (EXCLUDING ENERGY/LOSS)

	Kuwait atmospheric residue		Kuwait vacuum residue	Arabian light vacuum residue	Arabian heavy vacuum residue
Capacity t/cd	4000	7600	4000	4000	4000
Operating cost (excluding energy/loss) $US 10^6/year					
Submission 1	8	12	13	13	15
Submission 2	15	21	18	18	28
Submission 4	13	20	16	12	16

TOTAL ENERGY CONSUMPTION

Feedstock		Kuwait atmospheric residue		Kuwait vacuum residue	Arabian light vacuum residue	Arabian heavy vacuum residue
Capacity	t/cd	4000	7600	4000	4000	4000
Submission 1						
Total energy	t/cd	210	406	294	273	294
Energy cost	$US/t	175	170	171	153	165
Tot. energy cost	$\$US/10^6$	13.4	25.9	18.4	15.2	17.7
Submission 2						
Total energy	t/cd	251	475	285	277	278
Energy cost	$US/t	183	176	186	175	187
Tot. energy cost	$\$US/10^6$	16.8	30.5	19.3	17.7	19.0
Submission 4						
Total energy	t/cd	221	419	269	209	305
Energy cost	$US/t	187	180	203	194	209
Tot. energy cost	$\$US/10^6$	15.1	27.5	20.0	14.8	23.3

LOSS POSITION

KUWAIT ATMOSPHERIC RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
	10^6 t/yr	10^6 t/yr	10^6 t/yr
Intake			
Residue to HDS	1.46	1.46	1.46
LPG to H_2-unit	0.07	0.053	0.048
Total	1.53	1.513	1.508
Output			
H_2S/NH_3	0.056	0.056	0.061
C_2 minus	0.009	0.006	0.003
C_3/C_4	0.015	0.006	0.003
C_5/185	0.019	0.027	0.007
185 plus residue	1.38	1.38	1.404
Total	1.479	1.475	1.478
Loss	0.051	0.038	0.03
H_2S/NH_3	0.056	0.056	0.061
Total loss	0.107	0.094	0.091
Total cost $US million/year	17.5	14.9	16.1

LOSS POSITION

KUWAIT ATMOSPHERIC RESIDUE (7600 t/cd)

	Submission 1	Submission 2	Submission 4
	10^6 t/yr	10^6 t/yr	10^6 t/yr
Intake			
Residue to HDS	2.774	2.774	2.774
LPG to H_2-unit	0.137	0.101	0.091
Total	2.911	2.875	2.865
Output			
H_2S/NH_3	0.105	0.107	0.116
C_2 minus	0.018	0.012	0.005
C_3/C_4	0.028	0.012	0.005
C_5/185	0.036	0.051	0.014
185 plus residue	2.621	2.622	2.669
Total	2.808	2.804	2.809
Loss	0.103	0.071	0.056
H_2S/NH_3	0.105	0.107	0.116
Total loss	0.208	0.178	0.172
Total cost $US million/year	34.2	28.4	30.6

LOSS POSITION

KUWAIT VACUUM RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
	10^6t/yr	10^6t/yr	10^6t/yr
Intake			
Residue to HDS	1.46	1.46	1.46
LPG to H_2-unit	0.094	0.076	0.070
Total	1.554	1.536	1.53
Output			
H_2S/NH_3	0.073	0.067	0.076
C_2 minus	0.016	0.008	0.005
C_3/C_4	0.022	0.008	0.005
C_5/185	0.048	0.012	0.012
185 plus residue	1.327	1.385	1.388
Total	1.486	1.48	1.486
Loss	0.068	0.056	0.044
H_2S/NH_3	0.073	0.067	0.076
Total loss	0.141	0.123	0.12
Total cost $US million/year	20.5	17.4	21.6

LOSS POSITION

ARABIAN LIGHT VACUUM RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
	10^6t/yr	10^6t/yr	10^6t/yr
Intake			
Residue to HDS	1.46	1.46	1.46
LPG to H_2-unit	0.085	0.062	0.05
Total	1.545	1.522	1.51
Output			
H_2S/NH_3	0.058	0.055	0.048
C_2 minus	0.018	0.009	0.006
C_3/C_4	0.017	0.009	0.006
C_5/185	0.038	0.011	0.012
185 plus residue	1.352	1.393	1.406
Total	1.483	1.477	1.478
Loss	0.062	0.045	0.032
H_2S/NH_3	0.058	0.055	0.048
Total loss	0.12	0.100	0.080
Total cost $US million/year	17.8	14.2	15.2

LOSS POSITION

ARABIAN HEAVY VACUUM RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
	10^6 t/yr	10^6 t/yr	10^6 t/yr
Intake			
Residue to HDS	1.46	1.46	1.46
LPG to H_2-unit	0.094	0.078	0.08
Total	1.554	1.538	1.54
Output			
H_2S/NH_3	0.072	0.081	0.072
C_2 minus	0.014	0.009	0.016
C_3/C_4	0.015	0.009	0.016
C_5/185	0.048	0.010	0.067
185 plus residue	1.334	1.371	1.320
Total	1.483	1.480	1.491
Loss	0.071	0.058	0.049
H_2S/NH_3	0.072	0.081	0.072
Total loss	0.143	0.139	0.121
Total cost $US million/year	19.8	18.2	22.9

SULPHUR CREDIT

	Submission 1	Submission 2	Submission 4
Kuwait atmospheric residue intake 4000 t/cd			
sulphur removed x 1000 t/yr	57	53	57
sulphur recovered x 1000 t/yr	54	50	54
sulphur credit* $US million/year	2.7	2.5	2.7
Kuwait atmospheric residue intake 7600 t/cd			
sulphur removed x 1000 t/yr	107	100	107
sulphur recovered x 1000 t/yr	102	95	102
sulphur credit* $US million/year	5.1	4.8	5.1
Kuwait vacuum residue intake 4000 t/cd			
sulphur removed x 1000 t/yr	65	61	68
sulphur recovered x 1000 t/yr	62	58	65
sulphur credit* $US million/year	3.1	2.9	3.3
Arabian light vacuum residue intake 4000 t/cd			
sulphur removed x 1000 t/yr	52	49	48
sulphur recovered x 1000 t/yr	49	47	46
sulphur credit* $US million/year	2.5	2.4	2.3
Arabian heavy vacuum residue intake 4000 t/cd			
sulphur removed x 1000 t/yr	71	73	64
sulphur recovered x 1000 t/yr	67	69	61
sulphur credit* $US million/year	3.4	3.5	3.1

* $US 50/tonne sulphur recovered

CREDIT FOR 185° C MINUS MATERIAL

		Submission 1	Submission 2	Submission 4
Kuwait atmospheric residue intake 4000 t/cd				
Total 185 minus product	million t/yr	0.043	0.039	0.013
Added value	$US/t	88	103	92
Total credit	$US million	3.8	4.0	1.1
Kuwait atmospheric residue intake 7600 t/cd				
Total 185 minus product	million t/yr	0.082	0.075	0.024
Added value	$US/t	88	103	92
Total credit	$US million	7.2	7.7	2.2
Kuwait vacuum residue intake 4000 t/cd				
Total 185 minus product	million t/yr	0.086	0.028	0.022
Added value	$US/t	118	116	109
Total credit	$US million	10.1	3.2	1.9
Arabian light vacuum residue intake 4000 t/cd				
Total 185 minus product	million t/yr	0.073	0.029	0.024
Added value	$US/t	122	116	92
Total credit	$US million	8.9	3.4	1.8
Arabian heavy vacuum residue intake 4000 t/cd				
Total 185 minus product	million t/yr	0.077	0.028	0.099
Added value	$US/t	129	122	113
Total credit	$US million	9.9	3.4	9.3

NET GASOIL GAINS
1% SULPHUR FUEL OIL PRODUCTION

	Kuwait atmospheric residue				Kuwait vacuum residue		Arabian light vacuum residue		Arabian heavy vacuum residue	
Capacity t/cd	4000		7600		4000		4000		4000	
	gasoil gain	1% S fuel produced	gasoil gain	1% S fuel produced	gasoil gain	1% S fuel produced	gasoil gain	1% S fuel produced	gasoil gain	1% S fuel produced
	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)	(10^6 t/yr)
Submission 1	0.46	1.2	0.87	2.3	0.47	1.3	0.58	1.5	0.83	1.1
Submission 2	0.33	1.2	0.63	2.24	0.64	1.5	0.54	1.5	0.77	1.5
Submission 4	0.31	1.4	0.59	2.7	0.42	1.5	0.37	1.5	0.58	1.3

OPERATING COSTS

KUWAIT ATMOSPHERIC RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
Costs	($US million)	($US million)	($US million)
Capital charge	41.5	44	47
Operating costs (excluding energy/loss)	8.0	15	13
Energy costs	13.4	16.8	15.1
Loss	17.5	14.9	16.1
Total costs	80.4	90.7	91.2
Credits			
Sulphur	2.7	2.5	2.7
185° C minus	3.8	4.0	1.1
Gasoil gain a/b	23/4.6	16.5/3.3	15.6/3.1
Total credit	29.5/11.1	23/9.8	19.4/6.9
Net cost	50.9/69.3	67.7/80.9	71.8/84.3
1% S fuel product 10^6 t	1.2	1.2	1.4
Net cost $US/t 1% S	42/58	56/67	51/60
Sulphur removal 10^6 t/yr	0.057	0.052	0.057
Net cost $US/t sulphur	893/1216	1302/1556	1260/1479

a) at $US 50/t
b) at $US 10/t

OPERATING COSTS

KUWAIT ATMOSPHERIC RESIDUE (7600 t/cd)

	Submission 1	Submission 2	Submission 4
Costs	($US million)	($US million)	($US million)
Capital charge	65.5	71.5	71
Operating costs (excluding energy/loss)	12	21	20
Energy costs	25.9	30.5	27.5
Loss	34.2	28.4	30.6
Total costs	137.6	151.4	149.1
Credits			
Sulphur	5.1	4.75	5.1
185° C minus	7.2	7.7	2.2
Gasoil gain a/b	43.5/8.7	31.5/6.3	29.7/5.9
Total credit	55.8/21.0	43.95/18.75	37.0/13.2
Net cost	81.8/116.6	107/132.65	112.1/135.9
1% S fuel product 10^6 t	2.3	2.2	2.7
Net cost $US/t 1% S	36/51	49/60	42/50
Sulphur removal 10^6 t/yr	0.107	0.10	0.107
Net cost $US/t sulphur	764/1089	1070/1327	1048/1270

a) at $US 50/t
b) at $US 10/t

OPERATING COSTS

KUWAIT VACUUM RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
Costs	($US million)	($US million)	($US million)
Capital charge	62	70	58
Operating costs (excluding energy/loss)	13	18	16
Energy costs	18.4	19.3	20.0
Loss	20.5	17.4	21.6
Total costs	113.9	124.7	115.6
Credits			
Sulphur	3.1	2.9	3.3
185° C minus	10.1	3.2	1.9
Gasoil gain a/b	23.5/4.7	32/6.4	20.9/4.2
Total credit	36.7/17.9	38.1/12.5	26.1/9.4
Net cost	77.2/96	86.6/112.2	89.5/106.2
1% S fuel product 10^6 t	1.3	1.5	1.5
Net cost $US/t 1% S	59/74	58/75	60/71
Sulphur removal 10^6 t/yr	0.065	0.061	0.068
Net cost $US/t sulphur	1188/1477	1420/1839	1316/1562

a) at $US 50/t
b) at $US 10/t

OPERATING COSTS

ARABIAN LIGHT VACUUM RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
Costs	($US million)	($US million)	($US million)
Capital charge	59	63.5	48
Operating costs (excluding energy/loss)	13	18	12
Energy costs	15.2	17.7	14.8
Loss	17.8	14.2	15.2
Total costs	105.0	113.4	90.0
Credits			
Sulphur	2.5	2.4	2.3
185° C minus	8.9	3.4	1.8
Gasoil gain a/b	29/5.8	27/5.4	18.7/3.7
Total credit	40.4/17.2	32.8/11.2	22.8/7.8
Net cost	64.6/87.8	80.6/102.2	67.2/82.2
1% S fuel product 10^6 t	1.5	1.5	1.5
Net cost $US/t 1% S	43/59	54/68	45/55
Sulphur removal 10^6 t/yr	0.052	0.049	0.048
Net cost $US/t sulphur	1242/1688	1645/2086	1400/1713

a) at $US 50/t
b) at $US 10/t

OPERATING COSTS

ARABIAN HEAVY VACUUM RESIDUE (4000 t/cd)

	Submission 1	Submission 2	Submission 4
Costs	($US million)	($US million)	($US million)
Capital charge	66	76	64
Operating costs (excluding energy/loss)	15	28	16
Energy costs	17.7	19	23.3
Loss	19.8	18.2	22.9
Total costs	118.5	141.2	126.2
Credits			
Sulphur	3.4	3.5	3.1
185° C minus	9.9	3.4	9.3
Gasoil gain a/b	41.5/8.3	38.5/7.7	28.8/ 5.8
Total credit	54.8/21.6	45.4/14.6	41.2/18.2
Net cost	63.7/96.9	95.8/126.6	85.0/108
1% S fuel product 10^6 t	1.1	1.5	1.3
Net cost $US/t 1% S	58/88	64/84	65/83
Sulphur removal 10^6 t/yr	0.071	0.073	0.064
Net cost $US/t sulphur	897/1365	1312/1734	1328/1688

a) at $US 50/t
b) at $US 10/t

PLATT'S QUOTATIONS ROTTERDAM
Average Barge FOB (October 1985)

PRODUCTS	$US/tonne
<LPG	216
Premium Mogas	276.5
Naphtha	250.5
Kerosene	271
Gasoil	251.5
Fuel oil 1% S	155.5
Fuel oil 3.5% S	140
Arabian Light Crude (FOB)	202.8 (27.64 $US/bbl)
Freight	7.06