SHELL MIDDLE DISTILLATE SYNTHESIS: FISCHER-TROPSCH CATALYSIS IN NATURAL GAS CONVERSION TO HIGH QUALITY PRODUCTS

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1. INTRODUCTION

The importance of natural gas as a source of energy has increased substantially in recent years and is expected to continue to increase. In the recent past many new gas fields were discovered around the world, leading to a large increase in the proven world gas reserves. Proven world gas reserves are now approaching those of oil and, on the basis of the current reserves situation and relative depletion rates, natural gas seems to be set to outlast oil.

The main drawback of natural gas remains its low energy density, which makes its transportation to the point of use expensive and which may even prohibit its exploration and production. Shell and others have therefore been looking at processes that chemically convert natural gas into liquid hydrocarbons. Critical for the viability of each project is the value of its products. The chemical products like ammonia, urea and methanol have shown a high price volatility in the market with a relatively low entry barrier. Production of top quality middle distillate fuels from gas is favoured by recent developments in fuel quality requirements, the ease of transport and distribution of the products, and the enormous market for the products. The middle distillates from SMDS will therefore be well positioned in the market place of quality transportation fuels.

It has been realised that there are many places in the world where gas is available, without a ready market and where, as a consequence, it would have a much lower intrinsic value compared with transportation fuels. It is this difference in value that would drive a synthetic fuel project and provide opportunities for both government and private enterprises.

The present scene in the field of oil and transportation fuels and the prospects for the near and medium term however, call for a careful and selective approach to any synfuel development. At low fuel oil prices almost no alternative energy technology can compete with existing refining. On the other hand, the crises of the early seventies and early eighties provided important lessons: emergencies come at relatively short notice, and, because of the lead times usually involved in technological development, in a crisis the answers to problems always come too late.

Next to the synthetic hydrocarbon transportation fuels, a similar role could be perceived for methanol. However, use of methanol as a transport fuel has considerable drawbacks. These include the required modifications to fuel distribution systems and to the car / engine fuel system. Synthetic hydrocarbons, on the other hand, have the advantage that they can be readily incorporated into existing fuels which can be used in today equipment. In addition, middle distillates manufactured from natural gas have very environmentally friendly properties, upon which we will elaborate in this paper. The cleanliness of natural gas is, as it were, transferred into its products. The middle distillates from SMDS will therefore be extremely well positioned in a market place with an ever increasing quality demand. Natural gas conversion has become an asset for Shell with the construction and successful operation of the first commercial natural gas to transportation fuels conversion plant , SMDS(M) Bintulu.

2. THE PROCESS

The SMDS process combines conventional and well proven technologies with advanced technology using newly developed heterogeneous catalysts.
The overall process starts with the conversion of natural gas into synthesis gas, for which there are several commercial processes available. For the production of predominantly saturated hydrocarbons, $-CH_2-$, the syngas components H_2 and CO, are consumed in a molar ratio of about 2: 1, so a production in about that ratio is desirable. This influences the choice of process, as will be explained below.

The next step of the process, the hydrocarbon synthesis, is, in fact, a modernised version of the classical Fischer-Tropsch (FT) process, with the emphasis on high yields of useful products.

The Fischer-Tropsch process developed by Shell for SMDS favours the production of long chain waxy molecules which, as such, are unsuitable for transportation fuels. The hydrocarbon synthesis step is therefore followed by a combined hydro-isomerisation and hydrocracking step to produce the desired, lighter products. By opting for the production of waxy molecules in the Fischer-Tropsch step, the amount of unwanted smaller hydrocarbons or gaseous products, produced as by-products, is substantially reduced. This means that the process, simply spoken, does not make 'gas' out of gas. Combined with the high selectivity towards middle distillates in the hydrocracking step the overall process shows a high total yield of product in the desired range.

In the final stage of the process, the products, mainly kerosene, gasoil and naphthas, are separated by distillation. By the right operating conditions in the hydrocracking step and the subsequent distillation the product slate can be shifted towards a maximum kerosene mode or towards a maximum gasoil mode depending on market circumstances.

2.1. Synthesis Gas Manufacture

For the production of synthesis gas in principle two technologies are available, viz., steam reforming and partial oxidation.

Steam Reforming (SMR)

Starting from pure methane, SMR is the most commonly used conversion process for natural gas into synthesis gas, and could theoretically produce a synthesis gas with an H2/CO ratio of about 3. This process has the advantage that it doesn't require an air separation unit for the production of pure oxygen.

For the Fischer-Tropsch process SMR turns out to be less suited since the high H2/CO ratio is a disadvantage for a reaction which is highly exothermic and obeys first order kinetics in hydrogen partial pressure. Two other disadvantages are the large size of the reformer furnace which limits the scale-up potential of this synthesis gas technology and the limitation in pressure of about 30 bar, while the Fischer-Tropsch reaction is preferably carried out at somewhat higher pressures.

On the other hand SMR technology might be favourable for small scale Fischer-Tropsch applications and for feed gases having a high content in CO_2.

Partial Oxidation

A synthesis gas with a H2/CO ratio of about 2, can theoretically be produced by partial oxidation of methane with oxygen. Without much correction such gas is suitable for the production of middle distillates. The oxygen source can be air, or pure oxygen or anything in between. The final selection depends on a number of factors and can be different from project to project. However, generally, economics favour the application of pure oxygen.

For this type of partial oxidation several processes exist amongst which Shell's own Shell Gasification Process (SGP) which has been applied for several decades for the gasification of residual oils and has been chosen for the SMDS plant in Malaysia as the most appropriate synthesis gas manufacturing process.

For the catalytic Fischer-Tropsch synthesis, the synthesis gas must be completely free of sulphur. For this requirement all sulphur components are removed upstream of the partial oxidation step. A number of well-known treating processes are available the application of which is mainly guided by the type and concentration of the sulphur components in the natural gas.

2.2. The Hydrocarbon Synthesis Step

In the Heavy Paraffin Synthesis (HPS) step, the synthesis gas is converted into long chain, heavy paraffins. The paraffinic hydrocarbons produced via the FT reaction are highly linear. The formation of the linear paraffinic molecules can be described with the Anderson Flory Schultz [AFS] distribution model. Relation between model, design, product slate, catalyst and plant operation and economics will briefly be discussed.

During the catalysed reaction of synthesis gas to the primary paraffinic product an appreciable amount of heat is released. For the classical catalyst system this requires a considerable control of the temperature in view of the following constraints:

- The temperature window of stable operation is rather small
- A high space-time yield demands a high temperature
- At only moderately higher temperature a side reaction leading to methane formation becomes more dominant, reducing selectivity and, eventually, stability.

Because of these shortcomings, Shell has developed a new and proprietary catalyst system which establishes substantial improvements in all these areas. Its robustness allows the use of a multitubular fixed bed reactor system at a temperature level where heat recovery, via production of medium pressure steam, leads to an efficient energy recovery. The catalyst self can be regenerated in situ whereby the cycle time depends on a number of factors like process conditions, changes in feedgas composition and production planning.

2.3. Heavy Paraffin Conversion (HPC)

One of the prerequisites for obtaining a high selectivity towards n-middle distillates is a sufficiently high average molecular weight of the raw product. This product, which is predominantly waxy but contains small amounts of olefins and oxygenates, has to be hydrogenated to remove the olefins and oxygenates, has to be hydrocracked into the right molecule lengths for kerosene and gasoil and has to be isomerised to improve the cold flow properties. A commercial Shell catalyst is used in a trickle-flow reactor under rather mild conditions of pressure and temperature. The HPC product is subsequently fractionated in a conventional distillation section. The product fraction which is still boiling above the gas oil range is recycled to the HPC section. By varying the process severity or the conversion per pass one can influence the selectivity towards a preferred product. Hence one may opt for a kerosene mode of operation yielding some 50% kerosene on total liquid product or for a gas oil mode of operation producing up to 60% gas oil.

The principle of combining the length-independent chain growth process (in the HPS) with a selective, chainlength dependent conversion process has been applied to selectively produce middle distillates from synthesis gas. The two stage approach creates flexibility for differentiated product slates since the primary Fischer-Tropsch liquid product can be converted into different product distributions by adjusting the cracking severity in the heavy paraffin conversion step.

For the SMDS Bintulu project, the technology was extended to include the production of specially chemicals. This addition was required to support the economy of a relatively small pioneer project. It takes advantage of the high quality of all the products respectively intermediate streams produced. Linear paraffins of varying length are isolated as solvents, detergent feed stocks and waxes. Isomerised molecules boiling below the gasoil range are worked up into lube oils. Their product properties are discussed below in some more detail. Figure 1 depicts a block diagram of the SMDS Bintulu complex.

3. THE PLANT

The first commercial SMDS plant is located in Bintulu, Malaysia. At this place, in the state of Sarawak, sufficient remote natural gas is available for conversion. About 100 MMSCFD are converted into liquid products whereas a much larger amount is liquefied in the Malaysia LNG plant. As an advanced gas conversion technology, SMDS technology is of great interest for Malaysia with its significant gas reserves. A joint venture were formed by Petronas, Sarawak State, Mitsubishi and Shell. The project was developed by Shell Internationale Petroleum Maatschappij (SIPM today SIOP), constructed by Japan Gasoline Corporation (JGC) and is operated by Shell.

A short history of construction, commissioning and start-up including some useful lessons learnt when bringing new technology into life on an industrial scale will be presented during the presentation.

Plant throughput, availability of the complex and reliability of the process units increased over the last three years. It forms a tremendous source of experience and know-how and represents a valuable basis when entering into the next generation SMDS plants.

4. THE PRODUCTS AND THEIR MARKETS

The Fischer-Tropsch synthesis for transportation fuels has the great disadvantage that first the hydrocarbonaceous feedstock has to be gasified and converted into synthesis gas before the route to the transportation fuels can be taken. On the other hand, it turns into an advantage since the target products are built from their molecular building blocks H2 and CO. As described above, after having converted olefins and oxygenates into paraffins separation into valuable products and further conversion / isomerisation into clean transportation fuels can start. Studies and experimental programmes were undertaken to identify and develop the unique SMDS products. The marketing of these products was and is a challenge, but creates simultaneously many opportunities, for example, legislation related to improvement of air quality. To be able to comply with the regulations, components of the purity provided by SMDS products are welcome and very well accepted in the market place.

In fact, SMDS products are extremely clean. They contain no sulphur, no nitrogen and aromatics at the limit of detection. The SMDS products have impurities that are several orders of magnitude lower than highly refined crude oil derived products. Hence, several normal 'oil impurities' are not detectable by the standard methods. Below some typical properties for the product groups as indicated in Figure 1 are briefly discussed.

4.1. Middle Distillates

Naphtha

The naphtha or C5-C8 fraction from SMDS is highly paraffinic. These paraffins are known to have a rather bad combustion behaviour (expressed in a low octane number), When isomerised (predominantly one methyl branch) the front end components can be used in the automotive gasoline pool whereas the heavier molecules (C7, C8) need further upgrading for the gasoline market. This will become important for future SMDS plants since applications as described below can only absorb a limited amount of these products. However, the transportation fuel market is immense, spread all over the world and expanding in some important areas. Actually, the consumption of gasoline is estimated to about 600 million metric tonnes per year and that of gasoil (diesel) to about 370 million metric tonnes per year.

Besides blending SMDS into the gasoline pool it can be used as chemical feed stock for petrochemicals. Its paraffinic nature makes it an ideal cracker feed stock for ethylene manufacture. The paraffinic nature and the purity of the SMDS naphtha results in about 10 percent higher conventional ethylene yields compared to petroleum-derived naphtha feed stock. Expectations have been met when processing SMDS naphtha on large scale in industrial steam crackers, e.g. in Singapore.

The ethylene world market presents about 70 million metric tonnes per annum and is expected to grow with a rate of about 5 % per year in the next 5 to 10 years. The market share of East Asia is estimated to represent about 15 % of the world-wide market by the year 2000. This would represent a doubling of the demand in a relatively short period of time and present opportunities for SMDS naphtha despite the fact that new capacity is planned respectively under construction.

Kerosene

Today, around 90 % of jet-fuel demand is for civil aviation and the remainder for the military sector. In 1992 the world demand for jet fuel was over 125 million tpa. North America accounted for slightly more than half of this, mainly as result of its important domestic aviation market. Outside North America and CIS, civil aviation jet fuel demand has risen between 1982 and 1992 from about 40 million tons to more than 60 million tons. Future growth is predicted at ca 4.5 % per annum. SMDS kerosene can be used to upgrade kerosene fractions having low smoke point and high aromatics, which would otherwise be unsuitable for use in jet fuel.

For the first SMDS plant in Bintulu the produced kerosene is too small to play a significant role in the regional kerosene market. However, a fraction boiling in the kerosene range can be tailored to an iso-paraffinic solvent of high purity. It has a low odour and water-clear appearance and is particularly attractive in applications as printing ink, cosmetics, dry cleaning etc. It is marketed under the tradename SMDS SARASOL 150/200 and some typical properties important for this application are summarised in table 4.

Gasoil/Diesel

Some properties indicating that the SMDS gasoil, too, is of exceptional quality are shown in table 1. Given this quality, the SMDS gasoil is an ideal blending component for upgrading of lower-quality gasoils which don't meet for example the cetane specifications. Alternatively, the SMDS gasoil could enter in a market where premium specifications are valued to meet local requirements. For example, the Californian Air Resources Board (CARB) requires commercial fuels to give lower emissions than a reference fuel, which has a minimum cetane number, low sulphur and aromatics. More details on the environmental impact of SMDS gasoil are described below.

Additionally, SMDS fuels are suitable for special applications, like. high quality lamp oils and e.g. underground truck fuel (in mining), provided that precautions are taken to mitigate the effects of low lubricity and low density. The gasoil has excellent combustion properties, as the typical product data, given in table 3 and compared with important standards, show.

Waxy Raffinate (Base Oils)

The hydrocracker (HPC) in which the linear paraffins are cracked and isomerised to prepare the right boiling range of the middle distillates operates at relatively mild severity. After having distilled the middle distillates a bottom stream remains which is recycled to the hydrocracker. This stream contains a fraction called waxy raffinate which upon solvent dewaxing leads to a stream which combines extremely high viscosity index with very low Noack volatility and forms the main part of a range of wholly synthetic top-tier lubricating oils. These base oils are fit to fulfil ever increasing quality demands like less oil consumption, ability to at higher temperatures and for longer periods, keep modern engines in a better shape.

SMDS Bintulu (Malaysia) presently supplies Shell refineries in France and Japan where SMDS waxy raffinate is processed into finished top-tier motor oils..

4.2 Products on basis of linear paraffins

In Figure 1 it is shown schematically that not all linear paraffins are converted in the HPC into middle distillates. Part of the primary Fischer-Tropsch product which contains a certain percentage of olefins and oxygenates is hydrogenated under such operating conditions that olefins and oxygenates are converted into the corresponding linear paraffins without any isomerisation. The resulting stream of pure, linear paraffins is subsequently separated by distillation to gain access to a range of special products. These products are further characterised below.

Solvents

The C5-C10 SMDS n-paraffins fall into a class of specific solvents. They are completely free of aromatics and sulphur compounds and have a low odour. These solvents fit particularly well into the current environmental requirements since the n-paraffins show the best biodegradability results. The market represents a wide variety of different solvents of which the world-wide demand in aggregate is estimated to be 100,000 tpa. Presently, solvents in this carbon range, particularly hexane and Special Boiling Point (SBP)- types are used in oil-seed extraction, polymerisation and the rubber industry. In view of their application they need to be guaranteed low in aromatics, particularly in benzene. The SMDS solvent cut (and the naphtha fraction too) are suitable for these applications.

Detergent Feedstocks

The next distillation cuts are the C10-C13 and the C14-C18 fractions which are used in further processing steps to obtain industrial detergents and flame retardant materials. The purity of the products satisfies all the performance requirements in the production of linear alkyl benzene, chlorinated paraffins and paraffin sulphonates. The C10-C13 fraction (LDF) is used most widely in laundry applications where its higher than normal C13 content gives the improved detergency. The C14-C18 fraction (HDF) is used in making chloroparaffins of exceptional quality in terms of heat stability and colour. The biodegradability, which is critical in such applications, has been demonstrated to be fully satisfactory since the limited amount of branching present is mostly biodegradable methyl groups (in the alpha position). Some typical properties of the chemicals are shown in table 4.:

Waxes

Linear paraffins above C20 belong to the world of the waxes. Four fractions are separated in Bintulu called SX30, SX50, SX70 and SX100 were SX stands for Sarawax and the figure indicates the typical congealing point of that material. Typical properties of the waxes are given in table 5. Special precautions have been taken to conserve the purity even of the heaviest wax streams. For example, Wiped Film Evaporators (WFEs) are applied to separate the heaviest wax grades. The WFEs operate at a vacuum of about a factor 500-1000 below what is conventional high vacuum technology in standard refinery processing. The low pressure allows a rather mild distillation temperature which together with a very short residence time avoids thermal degradation of the products. Possible ingress of air and formation of unwanted oxygenates can be counteracted by a subsequent final hydrofinishing step. The resulting products (especially SX70 and SX100) are applied in industry segments where extreme purity, high Sayboldt colour quality, thermal stability and specific viscosity behaviour are required. Applications are diverse and vary from candles, paper & packaging, rubber, cosmetics and medicines, electrical use to various outlets, like chewing gum.

The total world paraffin wax consumption is about 3 million tonnes per annum and has over the last 15 years displayed an average annual growth of little over 4 %. Particular growth areas are Asia and Western Europe.

Important markets for waxes are the USA, the central European countries, the Pacific Basin, Japan and Taiwan, India, Brazil and South Africa.

5. ENVIRONMENTAL ASPECTS

The use of the SMDS products as transportation fuels has minimal impact on the environment, based on the excellent product properties. In some countries, notably in the USA, legislation has been proposed, which aims at limiting particulate and sulphur dioxide emissions originating from the combustion of transportation fuels by restricting their aromatics and sulphur levels. From product properties described above it is obvious that SMDS kerosene and gasoil meet such requirements without any problem. In the following section fuel quality aspects of SMDS gasoil will be highlighted, although it should be remembered that engine design and maintenance have an equally important or even greater impact on overall emissions:

Fuel Quality Effects on Vehicle Exhaust Emissions

Extensive work in and outside Shell Laboratories has established the effect of fuel properties on vehicle exhaust emissions.

For example, fuel sulphur has a dominant effect on particulate levels The conversion of fuel sulphur to particulate sulphur is engine dependant but within a relatively narrow range of 1-2%. Thus reduction to 0.05% m from earlier levels of 0.20 %, or higher in some countries, produces a significant emission reduction but further reduction below 0.05%m has only a relatively small influence.

Fuel density has been identified as an important parameter in particulate emissions. Lower density usually gives lower emission. Changes of emission properties in the Federal Test Procedure cycle caused by density changes arise from effects introduced by transient conditions. For example, air/fuel mixture excursions are caused by turbo charger lag during periods of hard acceleration. Reduction in fuel density increases the volumetric fuel consumption at all loads, although the increase in the fuel H2 to C ratio counterbalances the effect to some extent.

Aromatics content has been examined very carefully inside and outside Shell and it has been shown that "total aromatics" have no influence on particulate emissions. In some engines the addition of polyaromatics produces small increases in particulate emissions.

Cetane number is the fuel property having the greatest influence on regulated gaseous emissions (NO., hydrocarbons, and CO) and having a large influences on the cold start performance of an engine. Higher cetane numbers give better performance. However, the benefit in regulated gaseous emissions by increasing the ignition quality through an increase in cetane is limited by the possible steps the markets would and can accept.

In California regulations are quite advanced in controlling exhaust emissions. However, compliance can be achieved in several ways. Application of SMDS gasoil can present an advantage in several of these options depending on the specific market situation and specific conditions in the refineries. Especially where cetane enhancement is required SMDS gasoil can act as cetane improver additives.

6. OUTLOOK

It is not surprising that the conversion of natural gas into middle distillates for the transportation fuel market has by the nature of the process a disadvantage compared to the manufacture of transportation fuels via crude oil distillation : part of the energy content of the feedstock is consumed for the conversion process itself. Moreover, the feedstock (natural gas) itself has alternatives to reach the market, i.e. by pipeline or by liquefaction. On the other hand, the SMDS technology can provide the bridge between vast reserves of natural gas and the large transportation fuel market. This bridge can be built already today if some specific factors come together :

- the investment has to be reasonably low
- the alternative value of the natural gas should be low
- the products fit into the longer market trends.

Above we have shown in detail that every product produced with the SMDS technology provides by the way of its manufacture from the molecular building blocks top quality and fits into increasing efforts of conserving the environment.

If a natural gas reserve cannot be exploited by pipeline or by liquefaction it can be left in the ground or used in a conversion plant. In that case a reasonable natural gas price would be about US$ 0.5 per MMBTU (equivalent to a feedstock cost element in the product of about US$ 5/bbl) to make the products competitive in the transportation fuel market. The total fixed and other variable operating costs are estimated at a further US$ 5/bbl. The total required selling price for the product will depend on numerous factors, including fiscal regimes, local incentives, debt/equity ratio, type of loans and corporate return requirements. The premium that may be realised for the high quality products can be anything between 0 and 8 US$/bbl over and above the normal straight run middle distillate value depending on local circumstances.

An important factor when realising a natural gas to middle distillate conversion complex are the capital costs. These are highly dependent on location. At a location with an industrial infrastructure available specific capital cost would be around US$ 30,000 per daily barrel, whereas for a similar plant in a remote location and on a greenfield site the cost could be substantially higher.

In addition to these factors, the capacity of the plant is of great importance. Especially for remote locations, where self-sufficiency of the plant is essential, larger plants, in the 25,000 to 50,000 bbl/d range, have a much better economy of scale.

Whilst the process is ready for commercialisation, further developments are underway, directed at increasing the efficiency of the process and reducing the capital cost. An important area for these efforts is the synthesis gas manufacturing plant, which constitutes more than 50% of the total process capital cost. Other fields of interest include further catalyst improvement, the design of the synthesis reactors and general process integration within the project. Here the factor 'moving up the learning curve' is of pivotal importance: construction and several years of operation of the SMDS Bintulu complex has provided an extensive know-how which will be applied the next time. It is expected that know-how combined with further improvements for larger size plants, will bring the specific capital costs for remote areas further down.

SMDS technology has been developed to a stage where it can be considered as technically proven and, subject to local circumstances, commercially viable. Installation of SMDS plants can bring significant national benefits to countries with uncommitted gas reserves, either through export from the plant or inland use of the products, thereby reducing the need to import oil and oil products and saving on foreign exchange,

The successful application of the technology in Bintulu presents an important advance in the commercialisation of SMDS conversion technology and an asset in Shell's portfolio of technologies to make natural gas transportable. It provides exciting opportunities in terms of marketing hydrocarbon products of a quality that fits ideally in a business environment, requiring increasingly higher performance standards.

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Table 1 Typical properties of SMDS Middle Distillates

Property		Unit	**Naphtha**	**Kerosene**	**Gasoil**	method
Density (at 15 oC)		lkg/m3	690	740	780	ASTM D1298
Saybolt colour		-	+30	+30	n/a	ASTM D156
Distillation range	IBP	°C	40	150	200	ASTM D86
	FBP	°C	160	200	360	
Sulphur		PPM	b.d.l.	b.d.l.	b.d.l.	ASTM D1266
Cetane number		-	n/a	60	75	ASTM D976
Smoke point		mm	n/a	>> 50	n/a	ASTM D1322
Flash point		°C	n/a	40	90	ASTM D93
Aromatics		% vol	b.d.l.	b.d.l.	b.d.l.	ASTM D5186

b.d.l. = below detection limits n/a = not applicable

Table 2 Typical properties of Detergent Feedstocks from SMDS

Property	unit	LDF	HDF	Method
Saybolt colour		+30	+30	ASTM D156
Bromine index	mg Br / 100 g	5	6	ASTM D2710
Sulphur		b.d.l.	b.d.l.	ASTM D3120
Carbon distribution				by GC
C9- / C13-	% m	0	1	
C13- / C17-	% m	99.3	99	
C14+ /	% m	0.7		
..... / C18+	% m		0.2	
N-paraffins content	% m	96	95	

b.d.l. = below detection limit

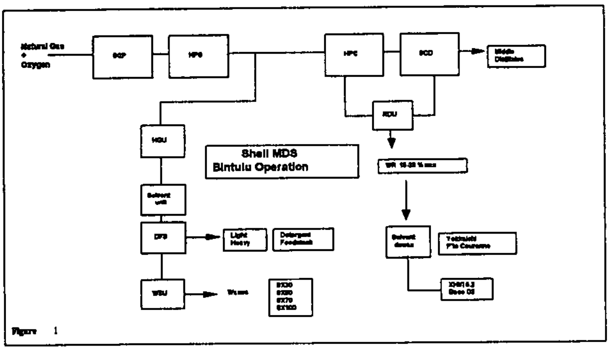

Figure 1

Table 3 **Gasoil Properties compared to CARB specifications**

Gasoil	SMDS product	Californian CARB	CEN Specs
	Commercial Spec.	Reference fuel Spec.	
Cetane number	76	48 min	49 min
Density (kg/m3)	780	N/S	820-860
Sulphur (ppmm)	n/d	500	500 (1996)
Aromatics (% m/m)	n/d	10 max.	N/S
Cloud point oC	1	-5	N/S
CFPP oC	-2	N/S	+5 to -20*
90 % recovery (oC)	340	288-338	
95 % recovery (oC)	350		370 max.

N/S = No Specification * depend on regional application

Table 4 **Typical Properties of SMDS normal paraffin products**

Property	Unit	SARAP AR 059	SARAP AR 103	SARAP AR 147	SARASOL 150/200	Method
Saybolt colour		+30	+30	+30	+30	ASTM DI56
Bromine index	mg Br/ 100g	10	5.0	5.5	20	ASTM D2710
Sulphur	PPM	zero	zero	zero	zero	ASTM 3120
Carbon distr.	% m					GC
n-C5		10				
n-C6		17				
n-C7		19			1	
n-C8		19			3	
n-C9		18			7	
n-C10		8	9		20	
n-C11			30		12	
n-C12			30		8	
n-C13			27	<1	1	
n-C14			<1	26		
n-C15				27		
n-C16				25		
n-C17				17		
n-C18				<1		
N-paraffins tot	% m	91	96	95	50	
Avg. mol. mass		122	167	213	166	
Density	kg/m3	690	750	775	735	ASTM D4052
Distillation	IBP °C	35	190	250	155	
	FBP °C	160	230	280	195	
Flash Point	°C	N/A	75	110	43	ASTM D93
Aniline Point	QC	70	83	93	82	ASTM D611
Pour Point	°C	N/A	-20	5	-35	ASTM D97
Visc. 25 OC	mm/s	0.6	1.7	3.3	1.5	ASTM D445

Table 5 **Typical Wax Properties**

Property	Unit	**SX30**	**SX50**	**SX70**	**SX100**	Method
Congealing point	oC	31	50	70	98	ASTM D938
Saybolt colour	-	+30	+30	+30	+30	ASTM D196
Odour		1.5	. 1.0	0.5	0.5	ASTM D1833
Oil content (-32 oC)	% m	5	2.5	0.4	0.1	ASTM D721
UV absorptivity		< 0.01	< 0.01	< 0.01	< 0.01	ASTM D2008