3.0 INDIRECT LIQUEFACTION: STATE OF TECHNOLOGY SASOL I AND II

3.1 Introduction

South Africa is currently operating two oil from coal plants based on indirect liquefaction technology and is constructing a third. SASOL I built in the 1950's is a small plant by U.S. standards producing approximately 8,000 BPD of liquid products. SASOL II, however, is a full size commercial plant of about 40,000 BPD liquid product output. Both plants produce synthesis gas by dry-bottom Lurgi gasification followed by Fischer-Tropsch synthesis of the clean synthesis gas using both fixed and fast-fluid bed reactor technology. The main processing steps used in both plants are:

- Coal Handling and Preparation
- Gasification
- Clean Gas Preparation
- F-T Synthesis
- F-T Product Upgrading

3.2 SASOL I:

At SASOL I approximately 8,000 tons/day of coal are gasified in 13 Lurgi Mark III moving bed gasifiers.(2) These gasifiers operate at 350 pounds pressure and are 12 feet in diameter and are 65½ feet high including the coal and ash lock-hopper systems. Their total production of raw gas is about 330 MM SCFD which represents an increase in output of 34% over that obtained in 1967. Gasifier

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availability is high and averages 10.8 from the 13 units. The dry-bottom Lurgi system requires considerable excess steam to keep the moving grate at temperatures that prevent slagging of the coal ash. Thus the tail gas is very wet and contains considerable quantities of tars, phenols, oils, gasifier naphtha as well as the synthesis gas, primary methane and other impurities.

The production of 1000 SCF of raw gas from these units require 156 SCF of oxygen and 42.5 lbs of steam. This represents an oxygen/d.a.f. coal ratio of 0.5 and a steam/d.a.f. coal ratio of 1.5.[3] The height of the coal bed moving through the gasifier is approximately 16 feet and the coal residence time is in the order of one hour. Gas exit temperatures are around 930°F and the maximum temperature in the combustion zone is around 2200°F.

At SASOL I coal utilization requirements are to a large extent governed by the lower acceptable coal size for the Lurgi gasifiers. The final crushed coal product consists of two size fractions, -0.4 inches and +0.4 - 2.0 inches. The smaller size is fed to pulverized fuel boilers for steam and power generation and the larger size is fed to the pressurized lock-hoppers for Lurgi gasification. Almost half of the coal in the plant goes to power generation and the remainder is gasified. The HHV thermal efficiency of the gasifier system is 75.5% if recovery of low pressure steam is included. Omission of this LP steam gives a gasifier efficiency of 67%

The gas cooling and purification system at SASOL is complex, necessitated by the heterogeneous nature of the products from dry-bottom Lurgi gasification. As mentioned, in addition to synthesis gas and methane, there are considerable quantities of organic condensibles, cyanides, sulfur compounds and unreacted coal fines. After cooling the gasifier products in waste heat boilers, tars, oils, tar acids and gas liquor are separated and fed to tar distillation and Phenosolvan plants for recovery. The biologically treated liquor is used for removal and transport of ash from the gasifiers.

The hydrogen to carbon monoxide ratio in the raw gas varies but generally lies in the region of 2. Because of the high H_2/CO ratio requirement of the Synthol F-T Synthesis reactor, about 10% of this raw gas is shifted over sulfur resistant catalysts. The cooled gases are then fed to three Rectisol units each having a capacity of 2 MM SCF/Hr to remove CO_2, COS, H_2S and gum-forming compounds. This process uses a cold (-55°C) methanol wash system and the treated gases emerge with a total sulfur content of less than 0.03 ppm. This requirement is critical as sulfur is a poison to the Fischer-Tropsch catalysts. The acid gases recovered from the Rectisol units are then sent to a Stretford unit for recovery of elemental sulfur.

After purification and raw shift the synthesis gas and primary methane are sent in two separate streams having different H_2/CO

ratios to the F-T synthesis units. Two types of F-T synthesis reactor are available. The Arge fixed bed and the Synthol fast-fluid bed systems.

Table III-1 shows the operational parameters for both types of Fischer-Tropsch synthesis reactor. The main differences are the higher temperature operation of Synthol and its much higher throughput. Another difference is that Arge can accept a lower H_2/CO ratio and achieves a lower overall conversion.

Five Arge units, four on line and one on standby, are used at SASOL I. They are tubular fixed bed reactors with a diameter of 10 feet and a height of 43 feet. Inside each reactor there are 2000 tubes of 2 inch internal diameter packed with extruded iron catalyst.[4] The exothermic heat of reaction is removed by surrounding the tubes with boiler feed water and controlling the pressure of the generated steam. Reactor throughput per reactor is approximately 550 BPD of liquid products. The Arge reactor operates at 25 bar pressure which makes it compatible with the pressure used during gasification. The low reactor temperature accounts primarily for the product distribution. The products are predominately straight chain high boiling oils and diesel fuel. Only small quantities of gasoline, LPG and oxygenates are produced. Over 50% of the product from the Arge synthesis is wax.

Three Synthol fast-fluid bed reactor units are in operation at SASOL I. The main reactor section is 7' in diameter and the

TABLE III-1

CONVENTIONAL F-T SYNTHESIS REACTOR PARAMETERS

	ARGE) (Fixed Bed)	SYNTHOL (Fast Fluid)
Temperature (^{o}C)	220-225	320-340
Pressure (Bar)	25	23
GHSV	500	--
Fresh Feed Nm^3/H (SCF/H)	$20-22 \times 10^3$ (735×10^3)	$80-110 \times 10^3$ (3.5×10^6)
Recycle: Fresh Feed Ratio	2.2-2.5	2.0
Catalyst Life	6 Months	44 Days
H_2/CO Feed Ratio	1.7	2.8
CO + H_2 Conversion	60-66%	80%
Catalyst Composition		
FE	100	Alkaline Reduced High
CU	5	Grade Magnetite Reduction
K_2O	5	Degree 95%
SiO_2	25	(75% <150 Micron Size)

overall height is circa 120 feet. Figure 3-1 shows a schematic of the operation of this unit. Essentially the reactor is described as a circulating fluidized catalyst system.[4] The incoming synthesis gas carries the catalyst upwards through the reactor at a rapid rate. Approximately 8,000 tons/hr of catalyst is circulated through the reactor. The tail gas is separated from the finely ground catalyst in the disengaging section by cyclones and the catalyst settles out into the hopper and flows down the standpipe to be swept back into the reactor by incoming synthesis gas. The entry temperature of the gas is about 160°C and the exit temperature is circa 345°C. Most of the exothermic heat of reaction is removed by the two sets of coolers. Both the throughput and the percent conversion achieved with the Synthol reactor are much higher than with the Arge system. On the basis of cross-sectional area, production in Synthol is nine times the production of the fixed bed reactor.[4] In SASOL I each reactor produces circa 2000 BPD of liquid products.[3] The Synthol process operates at higher temperatures and produces an entirely different product distribution from the Arge system. Lighter boiling hydrocarbons predominate and if heavy oils are produced problems can arise from catalyst agglomeration with subsequent loss of fluidization.[5]

The Synthol product is mainly low boiling hydrocarbons with small amounts of medium and high boiling components. High selectivity to α-olefins is observed especially in the C_3 and C_4

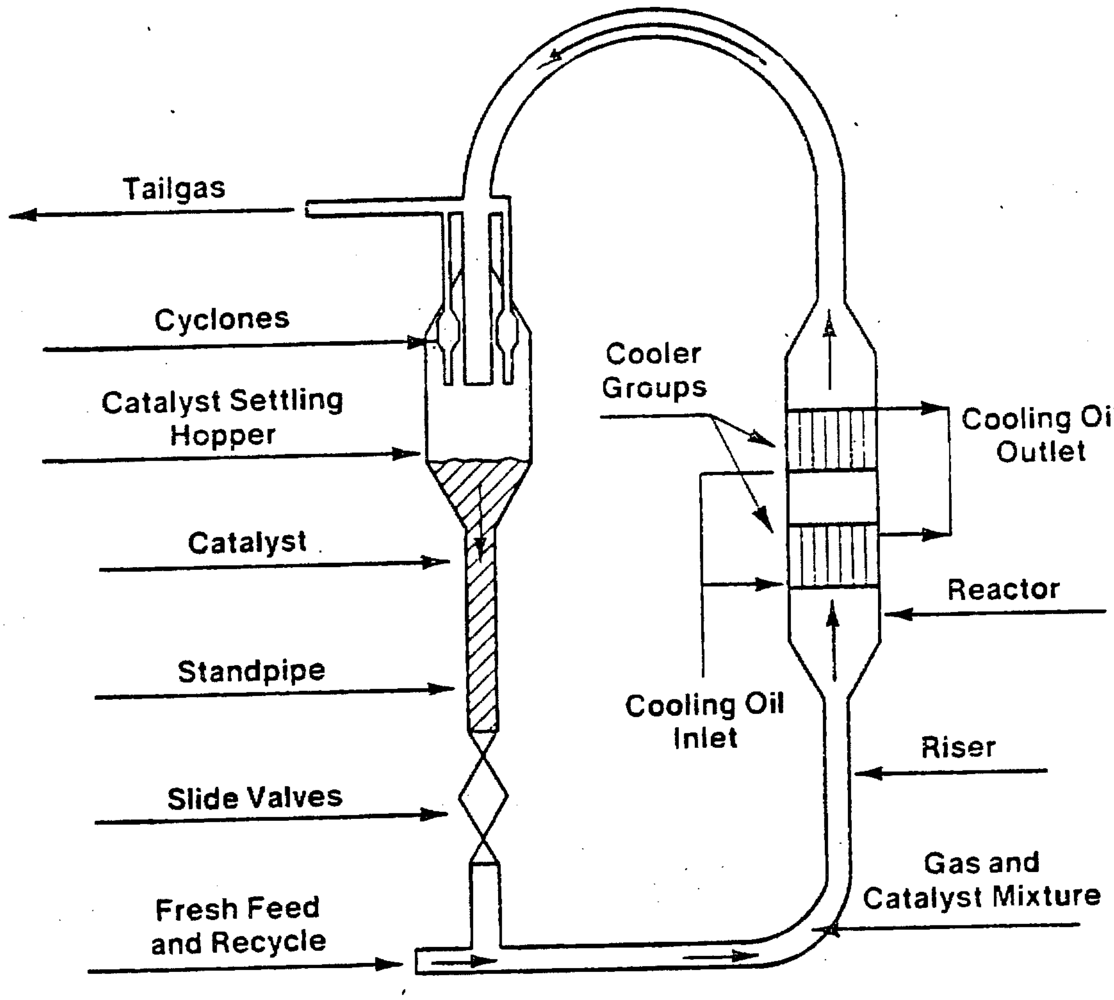

FIGURE 3-1
THE SYNTHOL REACTOR

range. These propylenes and butylenes are later dimerized and trimerized to produce catalytically polymerized gasoline. The raw Synthol liquids have high olefin contents and a small percentage of aromatics.

Table III-2 shows the product distributions from the two reactor systems. The predominence of heavier oils and waxes in the fixed bed system is illustrated. Table III-3 shows the properties of the liquid products from the two systems with respect to their componential analysis. Notice the much higher olefin content from the Synthol reactor.

The raw liquid Fischer-Tropsch products produced from both Arge and Synthol units do not generally meet consumer product specifications for transportation fuels and further refining is necessary. The primary gasoline from the Synthol process has an octane number of only 55 ROM.[(3)] This material is refined by catalytic reforming and by blending with catalytic poly gasoline and C_5/C_6 isomerate. The diesel fraction from the Arge system has a high cetane number and is of excellent quality.

The tail gas leaving the F-T Synthol reactors is very rich in methane. This is because of the high initial methane make in the Lurgi dry-bottom gasifier and the methane produced during Fischer-Tropsch synthesis. In SASOL I this tail gas is processed for absorption of low molecular weight hydrocarbons excluding C_1 and C_2. Most of the Synthol tail gas is reformed using the Lurgi

TABLE III-2

COMPARISON OF FIXED BED AND SYNTHOL PROCESSES [4]

		Fixed Bed	Synthol
CH_4		2.0	10.0
C_2H_4		0.1	4.0
C_2H_6		1.8	4.0
C_3H_6		2.7	12.0
C_3H_8		1.7	2.0
C_4H_8		2.8	9.0
C_4H_{10}		1.7	2.0
Petrol	C_5-C_{11}	18.0	40
Diesel	C_{12}-C_{18}	14.0	7
Heavy Oil	C_{19}-C_{23}	7.0	
and	C_{24}-C_{35}	20.0	4
Wax	$>C_{35}$	25.0	
	NAC*	3.0	5.0
	Acids	0.2	1.0
		100.0	100.0

* Non-acid chemicals

TABLE III-3

COMPONENTIAL ANALYSIS OF F-T LIQUIDS (5)

	ARGE		SYNTHOL	
	C_5-C_{12}	C_{13}-C_{18}	C_5-C_{10}	C_{11}-C_{14}
% Paraffins	53	65	13	15
% Olefins	40	28	70	60
% Aromatics	0	0	5	15
% Alcohols	6	6	6	5
% Carbonyls	1	1	6	5
% n Paraffin	95	93	55	60

partial oxidation process and the resulting CO and H_2 is recycled to the Synthol units. The product gases not treated in this way are utilized in the Gaskor town gas system and piped to industrial areas of the Witwatersrand. Thus SASOL I produces a coal derived gas as well as transportation fuels and a wide spectrum of chemicals. The pipeline gas has a heating value of 500 Btu/SCF and amounts to a daily production of approximately 65 MM SCF.[(4)]

3.3 SASOL II

The SASOL II facility has recently been constructed at Secunda and is not operating at full capacity at this time. The technology used at SASOL II is almost identical to that of SASOL I. The main difference is one of scale. Thirty-six Mark IV Lurgi gasifiers are available to process 31,000 TPD of coal to produce 1,500 MM SCFD of raw gas.[(5)] The coal utilization pattern is different for this plant in that 70% of the mined coal is sent to gasification while 30% is used for steam generation. There may be problems in utilizing all of the fines produced during the coal mining operation because of the combination of long wall mechanized mining techniques and a more friable coal than that of SASOL I.

Sulfur is again removed by the Stretford process and ammonia is recovered as anhydrous ammonia while at SASOL I the ammonia vapor is reacted with sulfuric acid to produce fertilizer grade ammonium sulphate.[(6)]

Since the SASOL II plant is intended to be primarily a gasoline producer, only Synthol F-T synthesis units are used. Although there are some design improvements over those used at SASOL I, they are essentially similar. The main difference is that the 8 reactors are 2½ times the capacity of the SASOL I units.

Unlike the SASOL I operation the F-T tail gas is cryogenically separated to yield C_2 and 99% purity hydrogen stream for refining purposes.[6] Methane in the tail gas is autothermally reformed and the synthesis gas recycled to the F-T reactors. Presently the plant is designed for all liquids operation although provision is made for production of 500 Btu/SCF pipeline gas if required. The refining of the liquid products is almost identical in both plants.

Figure 3-2 shows a schematic of the SASOL II plant and the total products produced per annum is shown. Table III-4 gives a breakdown of this total output figure into its component parts. This table shows expected outputs once full production capacity has been achieved.

Many of the details of the SASOL II operation are considered proprietary and thus only a brief outline of the plant has been given. In the following section a much more detailed analysis of the process is disclosed based upon information from a Mobil Study conducted under a grant from the DOE.[1]

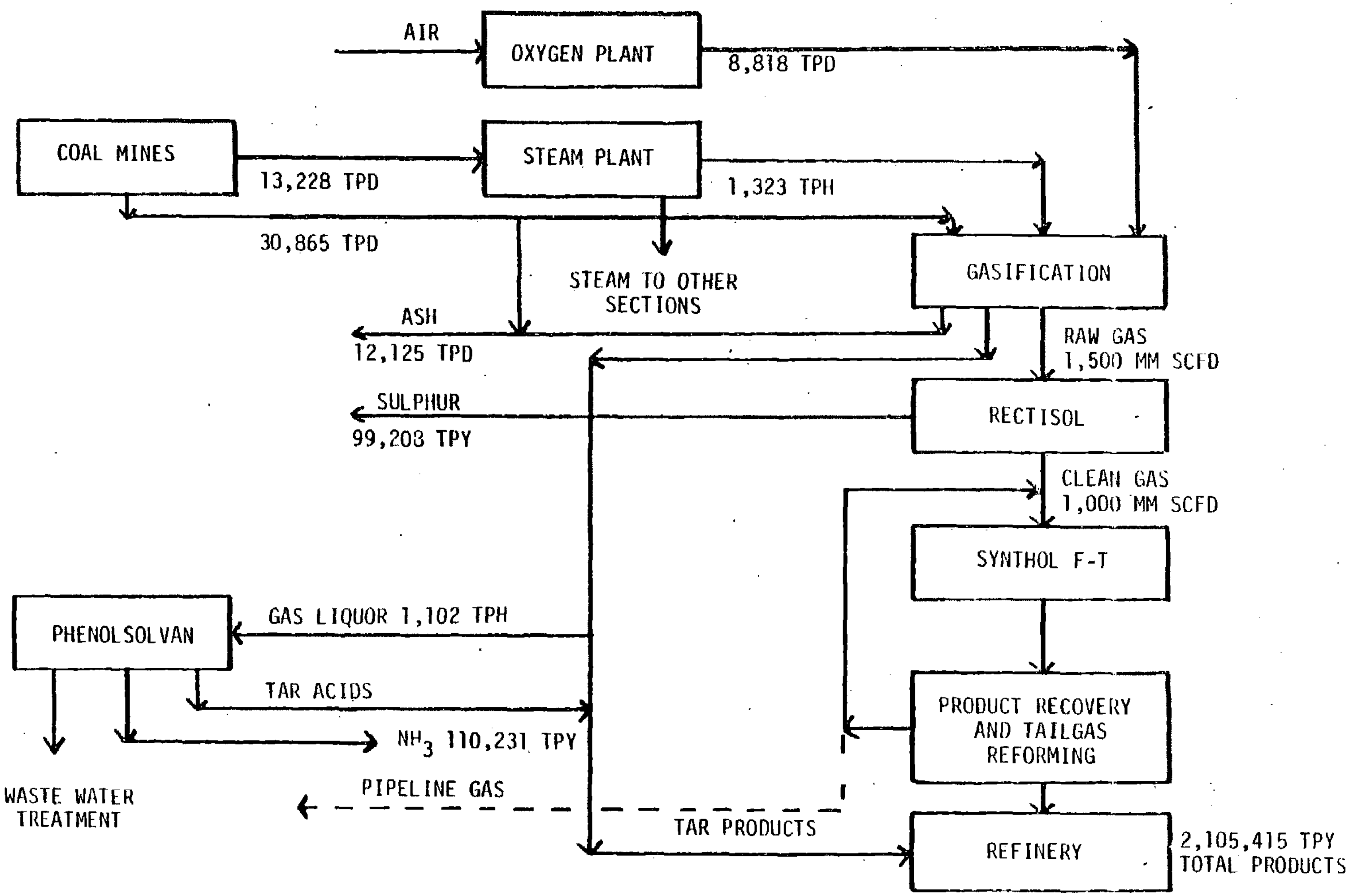

FIGURE 3-2
SASOL II FLOWSHEET

TABLE III-4

EXPECTED PRODUCT BREAKDOWN FOR SASOL II [5]

Motor Fuels	1,653,000 TPY
Ethylene	176,000
Chemicals	55,000
Tar Products (including tar acids)	220,000
Ammonia	110,000
Sulfur	99,000