EXPERIENCE WITH A NEW TYPE OF REACTOR FOR FISCHER-TROPSCH SYNTHESIS

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Circulating fluidised bed (CFB) reactors have traditionally been used for the high temperature Fischer-Tropsch synthesis–Synthol process. A development program undertaken by Sasol with the assistance of The Badger Company recently led to the successful commissioning of a commercial scale conventional, fixed fluidised bed (FFB) reactor as an alternative to the CFB reactor.

Work was done in a small pilot plant which was followed by work in a 1 m diameter semi-works pilot plant operated in parallel with one of the commercial CFB reactors. Based on the positive results obtained, it was decided to build a commercial scale FFB reactor with a capacity similar to existing commercial reactors at Sasol One. This reactor was successfully commissioned and has been in operation since May 1989.

The reactor is easy to operate and can withstand major plant instabilities. A techno-economic analysis and comparison between the Synthol-CFB and Synthol-FFB reactors indicates significant advantages for the Synthol-FFB reactor, both with respect to capital and operating costs. The results of this analysis and comparison are presented and the significance of the findings discussed in terms of future plants for the conversion of synthesis gas to liquid fuels.

1. Introduction

Fischer-Tropsch synthesis was originally practised in packed bed reactors which were developed into the tubular fixed bed Arge reactors. These reactors have been in use at Sasol since 1955 and operate at about 25 and 45 bar and 220 °C. They predominantly produce diesel and waxlike products which tend to be saturated, non-branched hydrocarbons. The lighter naphtha cuts are also linear and saturated and therefore excellent cracker feedstock.

For the production of gasoline the Synthol circulating fluidised bed (S-CFB) reactor was developed which has also been in use at Sasol since 1955. It operates at about 25 bar and 340 °C. The S-CFB reactor has a much larger capacity than

Selectivity (carbon atom basis) of Sasol processes		
Product	Fixed bed	Synthol (fluidised bed)
CH_4	4	7
C2 to C4 olefins	4	24
C2 to C4 paraffins	4	6
Gasoline	18	36
Middle distillate	19	12
Heavy oils and waxes	48	9
Water soluble oxygenates	3	6

Fig. 1. Product selectivities of Sasol commercial reactors.

the Arge reactor on a volumetric basis and it produces primary products, which are lighter and much more olefinic than that from she Arge reactor. Typical product spectra for the two reactors are shown in fig. 1. Apart from the differences already mentioned, it can be seen that both produce oxygenates but that the high temperature Fischer-Tropsch Synthol reactor produces about twice as much as the low temperature Fischer-Tropsch Arge reactor.

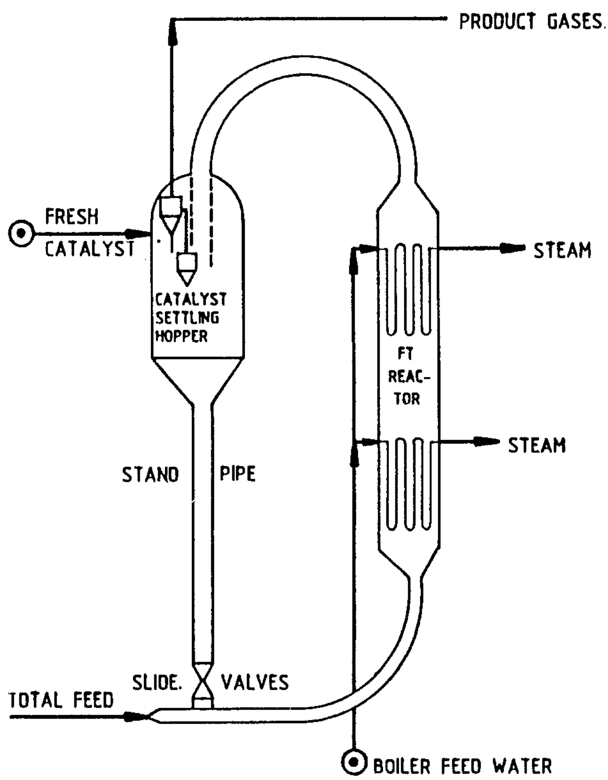

Fig. 2. Synthol circulating fluidised bed reactor (S-CFB).

The Synthol-CFB reactor, as shown in fig. 2, consists of a reactor section and a hopper and standpipe section. Synthesis gas, containing H_2 and CO as reactables, has catalyst added to it from the standpipe as it passes through the lower bend to the bottom section of the reactor. The amount of catalyst added to the gas stream is controlled by a slide valve situated in the lower half of the standpipe. As soon as the catalyst is introduced into the syngas, the reaction commences. The gas which is fed to the system at about 200 ° C, heats up and soon after entering the reactor proper, reaches the reaction temperature of about 340 ° C. The Fischer-Tropsch reaction is highly exothermic and one of the major design characteristics of the Synthol reactor is the way in which the heat is removed. In the latest versions of the Synthol-CFB reactors, of which there are sixteen in the Secunda plants, heat is removed in banks of cooling coils in the reactor section.

The gaseous mixture of products and unreacted syngas, together with the catalyst passes through the top bend into the hopper section where most of the catalyst drops out. 99 + % of the remainder is removed in cyclones through which the gas stream passes before it leaves the synthesis section to the down stream cooling train.

Good temperature control is important for the Fischer-Tropsch reaction as the product spectrum is very sensitive to temperature. Too high a temperature will yield a rather light product with an excess of methane and LPG. An excess of carbon is also deposited on the catalyst. Too low a temperature will lower the conversion rate and in the extreme, produce too much heavy hydrocarbons which, if condensed onto the catalyst, interfere with the fluidisation process, causing slumping of the circulating fluidised bed and reactor shut down.

2. Limitations of the Synthol-CFB reactor

One of the drawbacks of the Synthol-CFB reactor is the physical complexity of a reactor and hopper standpipe system suspended in a complex structure. This complexity leads to high capital cost. The circulation of large tonnages of catalyst means considerable recompression of recycle gas with associated capital and operating cost.

Carbon tends to be deposited on the iron based Fischer-Tropsch catalyst. Carbon formation increases with an increase in temperature and lowering of the P_{H_2}/P_{CO} ratio. Although it does not seriously affect the intrinsic catalytic activity of the catalyst, sooner or later it affects the operation of the Synthol-CFB reactor. Carbon deposition reduces the density of the catalyst and hence the amount of iron catalyst in the reactor. This in turn requires higher circulation rates of catalyst from the hopper-standpipe to the reactor to maintain reaction rates. When this cannot be increased any further, the carbon deposition limits the amount of iron in the catalyst which can be circulated through the slide valve into the reactor. The pressure balance between the reactor and the hopper-standpipe of the Synthol-CFB system is also negatively affected by the reduction in catalyst density in the standpipe. Together the two effects limit the amount of catalyst and hence the reaction rates in the reactor section. This in turn determines the catalyst life.

At any specific time, a major portion of the total catalyst inventory is not being used but held in the hopper-standpipe system.

3. The Synthol-FFB reactor

The limitations to the S-CFB reactor are largely eliminated in a conventional fluidised bed. Conventional fluidised beds were tried for high temperature Fischer-Tropsch synthesis during the late 1940's and early 1950's in a plant at Brownsville, Texas. To the best of our knowledge these attempts were not successful. About a decade ago, Sasol in conjunction with The Badger Company, started to re-investigate conventional fluidisation, which led to the construction and operation of a semi-works pilot plant reactor with a diameter of about 1 metre. This development was successful and Sasol decided to proceed with the construction of a commercially sized reactor which was commissioned in May 1989. It is called a Synthol Fixed Fluidised Bed (S-FFB) reactor (see fig. 3) to differentiate it from the S-CFB reactor. It has nominally the same capacity as the S-CFB reactors at the Sasolburg plant which in turn have about a third of the capacity of our larger S-CFB reactors at Secunda.

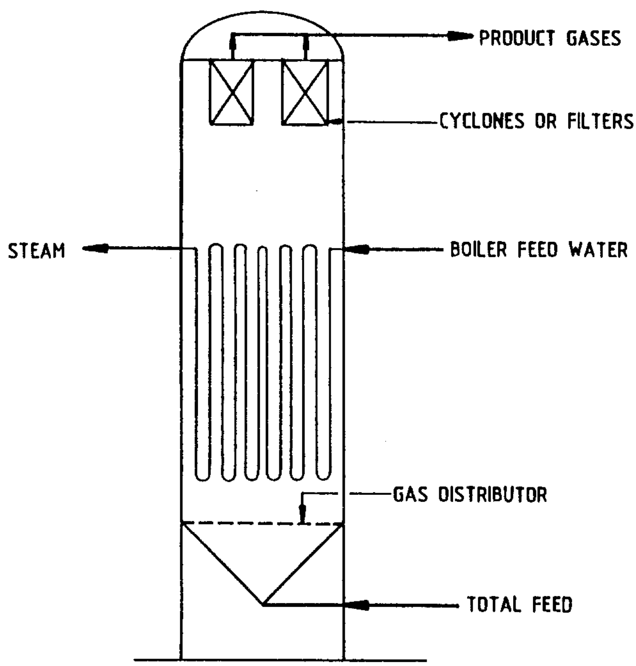

Fig. 3. Synthol fixed fluidised bed reactor (S-FFB).

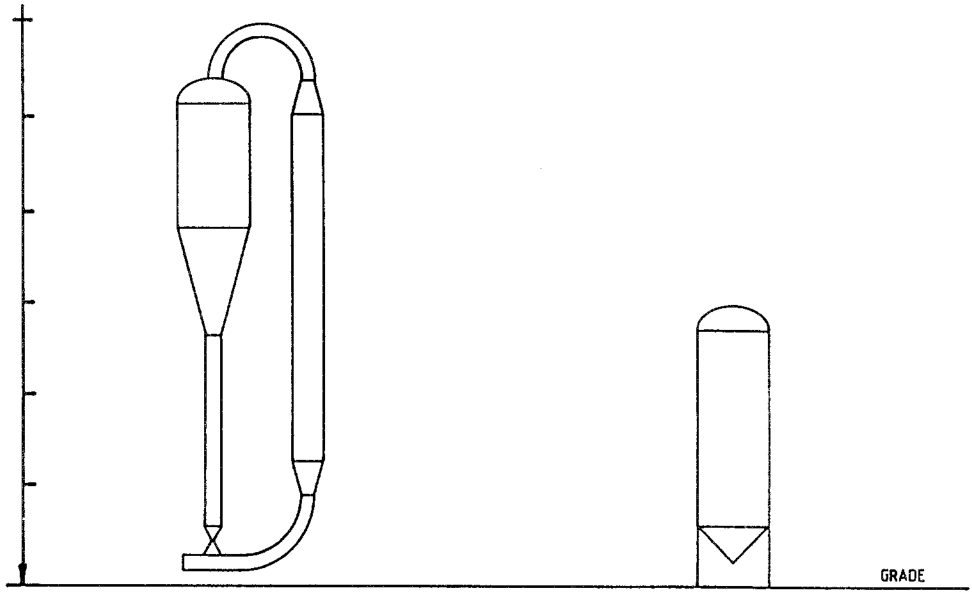

Fig. 4. S-CFB and S-FFB reactor to the same scale (equal capacity).

The Synthol-FFB reactor consists of a vessel with a gas distributor, a fluidised bed containing the catalyst, cooling coils in the bed and a system to separate the catalyst from the gaseous product stream. Sufficient free board is given above the fluidised bed to disengage most of the catalyst and for the present commercial reactor the remainder is practically completely retained and returned through single stage cyclones in the top of the reactor.

The relative sizes of the S-CFB and S-FFB reactors for equal capacities are given in fig. 4. The S-FFB is clearly simpler and much smaller in overall size. This precludes the need for a complex structure for the reactor. The FFB reactor is selfsupporting. For the present commercial reactor a separate structure was provided for operating platforms etc. In future it may be considered to support these platforms from the reactor itself.

Because the diameter of the S-FFB reactor is larger than that of the S-CFB reactor proper (it is roughly that of the S-CFB hopper) it is possible to put more cooling coils in a single bank and in general there is more space for heat exchange surface and for removal of heat from the reactor. This allows for greater conversion capacity, which makes it possible to operate at higher fresh feed concentrations or at higher pressures and flow rates.

The maximum gas flow for the S-CFB and S-FFB reactors at Sasol One is roughly the same and is determined by the need to disengage the catalyst from the gas stream before it enters the cyclones. The lower limit for the S-CFB is determined by the gas flow needed for circulating the catalyst. For the S-FFB reactor the minimum flow is, in practice that determined by the minimum full support velocity for the catalyst. This gives a minimum flow much lower than for the S-FFB reactor. The turndown ratio for the S-FFB is therefore much larger.

4. Operating experience with the S-FFB reactor

At the time of writing the commercial S-FFB reactor had operated for a total of 120 days.

The first startup of the reactor was smoother than any startup ever experienced with a S-CFB reactor. Ever since, the S-FFB reactor has run more stably than the S-CFB reactors. The new reactor has been subjected to several slumps of which some were as long as two weeks, without any ill effects. The restarts after the slumps were smooth and normal. The major reason for the smooth startup and running is the elimination of catalyst recycle. There are no slide valves to control and all of the catalyst is heated up at the same time. The system is much more robust to upsets because there are no standpipes which could potentially block during maloperation. Because all the catalyst is in use all the time and it is well mixed, the reactor is much more isothermal, adding to the stability of the system.

For the same feed and operating conditions, the conversions in the S-FFB have generally been higher at startup and they can be maintained at that level much longer during the run. As indicated above, there is a general decline in catalytic activity with time in the S-CFB because of carbon deposition. In the S-FFB reactor a lowering of catalyst density due to carbon deposition causes an increase in bed height and a concomitant increase in residence time of gas in the fluidised bed. This more than compensates for a possible decline in the intrinsic catalyst activity and a small increase in conversion was noted. The fluidised bed height has been allowed to increase until it started to interfere with the operations of the cyclones. At that stage catalyst is removed without interrupting the operation of the reactor. Due to the high conversion rates, fairly large amounts of catalyst have to be removed before a decline in conversion is noticed. If necessary at a later stage, on-line removal of some of the old catalyst and renewal with fresh catalyst will increase the conversion again.

The catalyst inventory of the S-FFB Is similar or somewhat smaller than that of the S-CFB at startup. The catalyst consumption per ton of product is about 30% less than that of the S-CFB.

The selectivities of the products obtained from the S-FFB reactor are similar to those obtained from the S-CFB. The methane selectivity is marginally lower while a somewhat heavier syncrude is produced.

The improved selectivities are obtained through the excellent isothermal character and temperature control of the S-FFB reactor which together with higher reaction rates allow for operation at somewhat lower temperatures and adjustment of catalyst formulations.

Although this cannot yet be quantified, it is clear that the new reactor will need less maintenance. In general the fluidisation is much less energetic and there are no erosion prone components such as bottom and top bends, standpipes and slide valves needed for the circulation of the catalyst.

5. The use of filters instead of cyclones for the removal of catalyst from product streams

As part of the experimental program in the FFB semi-works pilot plant, the cyclones were replaced by porous metal filters. Although they have not been in use long enough to prove mechanical reliability, the tests have shown that the filters are an improvement from a process point of view. The filters have the advantage that scrubber/quench towers are not required in the downstream condensation and cooling train. Apart from capital savings, this also allows for a more efficient cooling train with a concomitant increase in thermal efficiency of the gasloop.

Another advantage of filters are that no fines are lost from the fluidised bed. In practice the catalytic activity of catalyst particles in high temperature Fischer-Tropsch is inversely proportional to the size of the particle. Reactors with filters therefore tend to give higher conversions than those with cyclones. Small particles however, tend to have a higher proportion of carbon which lead to lower bulk densities for the catalyst bed. In the case of the S-CFB reactors the lowering in average catalyst density will negatively affect the pressure balance between the reactor and the hopper-standpipe system. In the S-FFB reactor these lower bulk densities are more than counteracted by an increase in activity of the catalyst. Whereas it is not clear whether filters will have an advantage for the S-CFB reactors they have an obvious advantage for the S-FFB reactors.

6. Comparison of S-FFB with S-CFB reactor in a natural gas based plant

Using the information gathered from the commercial S-FFB reactor and semi-works pilot plant, the FFB and CFB concepts were compared. A comparison was done for a grassroots Fischer-Tropsch plant, using syngas ($H_2 + CO$) obtained from reforming natural gas, to produce 100 t/h of final products. In order to establish how much more effective high temperature Fischer-Tropsch plants can be built and operated, full use was made of the potential of the FFB concept and filters were used instead of cyclones and scrubber towers to remove catalyst traces from the product gas. A block flowdiagram of the process is shown in fig. 5.

A comparison was done for the case where the two types of reactors operate at the normal S-CFB operating pressure of about 25 bar. Another case was worked

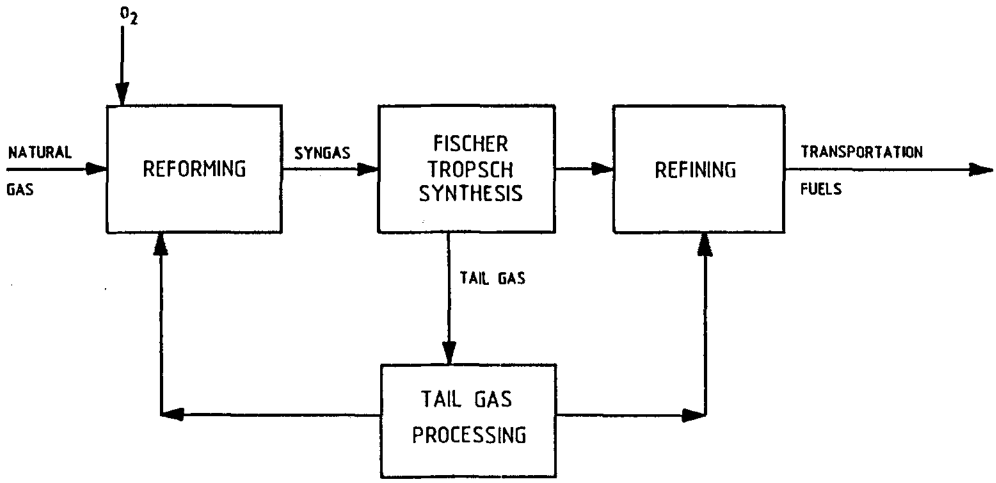

Fig. 5. The Sasol conversion process for natural gas.

out where use is made of the potential of the S-FFB to operate at a higher pressure.

The cost estimates were done for December 1989 which covered all the costs involved in design, procurement and construction, in South Africa, of the S-FFB and S-CFB synthesis units, plus all other related plants required for the production of synfuels from natural gas.

The following results were obtained:

Capital cost comparison:

Type	Number of reactors	Pressure	Relative capital cost		
			Reactors	Gasloop	Total plant
S-CFB (base)	3	normal	1.00	1.00	1.00
S-FFB	2	normal	0.46	0.78	0.87
S-FFB	2	high	0.49	0.71	0.82

If cyclones are used in stead of filters, the capital costs for the S-FFB cases would increase by less than 5%.

Energy efficiencies:

The S-FFB reactor fitted with filters allows for greater recovery of high grade heat from the product gas as heat is not degenerated through quenching. Together with savings obtained from lower compression costs for recycle gas due to lower pressure drops across the gasloop, this leads to higher thermal efficiencies.

For a plant based on natural gas containing about 25% condensate, on an energy basis, for the S-CFB base case with energy flows as shown in fig. 6, the following results are obtained:

Type	Number of reactors	Operating pressure	Energy efficiency (%)	Relative power import
S-CFB (base)	3	normal	61.9	1.00
S-FFB	2	normal	63.6	0.44
S-FFB	2	high	64.7	0.41

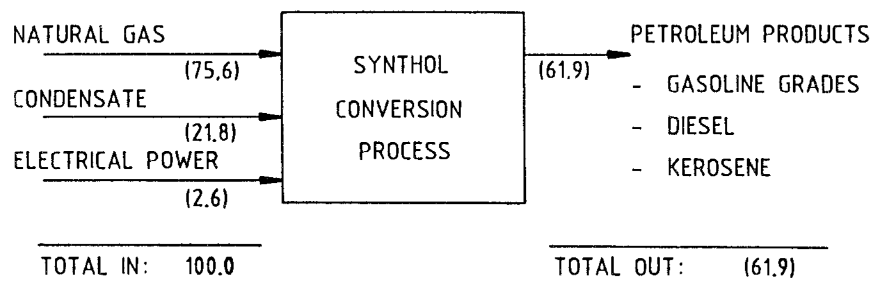

Fig. 6. Sasol conversion process energy flows. Base case: energy efficiency = 61.9%.

7. Conclusion

A techno-economic analysis and experience with a commercially sized S-FFB reactor, indicate important advantages for the S-FFB reactor over the older S-CFB reactor for Fischer-Tropsch synthesis. The S-FFB is considerably cheaper, allows for thermally more efficient gasloops, has lower operating costs and it is much easier to operate.

The S-FFB process is now considered commercially proven and will be employed in any future Sasol synfuels plant. Sasol is now also prepared to license the S-FFB process and provide support services with such a license.