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Synthol reactor technology development

Dawid J. Duvenhage*, Terry Shingles

Opportunity Exploration Center, Sasol Technology, Private Bag X 1034, Secunda, 2304 South Africa

Abstract

Since Sasol introduced the Kellogg designed circulating fluidized bed (CFB) reactors at Sasol 1 in the 1950s, the commercial high-temperature Fischer–Tropsch (HTFT) process has had a dynamic ongoing development resulting, recently, in the introduction of Sasol advanced synthol (SAS) reactor operation only at Secunda, 1999. It has reached a stage now where the emphasis has shifted for developing a catalyst tailored to these reactors and current market requirements. This paper follows the development of the reactor technology since the early 1940s, highlighting the major developments and giving indications of the effect thereof on gas throughput and bulk product yields. The paper traces Sasol's journey utilizing the sound, but unproven pilot plant scale-up of Kellogg, to a routine day to day operation and profitable commercial process by means of innovative design changes, general state-of-the-art advances and, importantly, experience! © 2002 Published by Elsevier Science B.V.

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1. Pilot plant to commercial Fischer–Tropsch

1.1. The first pilot plant developments

By 1948 Kellogg, a USA-based company, obtained sufficient data on 4 and 10 cm diameter pilot plant units to do a paper scale-up for a commercial circulating fluidized bed (CFB) unit. (The latter reactor was 13 m tall and included two internal banks of heat exchangers. These were later changed to external jacket cooling. The reactor also had a 7 m long standpipe with an 8 cm diameter.) The project was, however, shelved due to the then increasing cost of natural gas which was the main source of synthesis gas for the commercial units. Significantly, at the time, the decision was taken rather to go for CFB than FFB technology (dense or bubble phase reactor, further on referred to as SAS reactor technology) in keeping with FCC reactor developments.

The decision to build a commercial reactor in South Africa was taken in the late 1940s—crude oil was and still is, undiscovered in the region (in large quantities). Sasol took a decision to commit, at a fair amount of risk, the then commercially unproven CFB Kellogg technology to convert two-thirds of the gas available (designed for) at the Sasolburg site (at the time) to syn fuels—the other third was to be converted using the German fixed bed reactor wax technology used during the second world war. The former decision, although causing much anguish initially, paid off handsomely in the end.

1.2. The first commercial technology wave—SASOL 1 CFB

A 500 times gas throughput scale-up (also see Figs. 1 and 2 with discussion) from the approx. 4–5 bbl/d Kellogg pilot plant unit to the first two commercial CFB units—approx. 2200 bbl/d, at Sasolburg, saw the light in the mid-1950s. The initial

* Corresponding author. Fax: +27-17-619-2798.
E-mail address: duvenhage@tamu.edu (D.J. Duvenhage).

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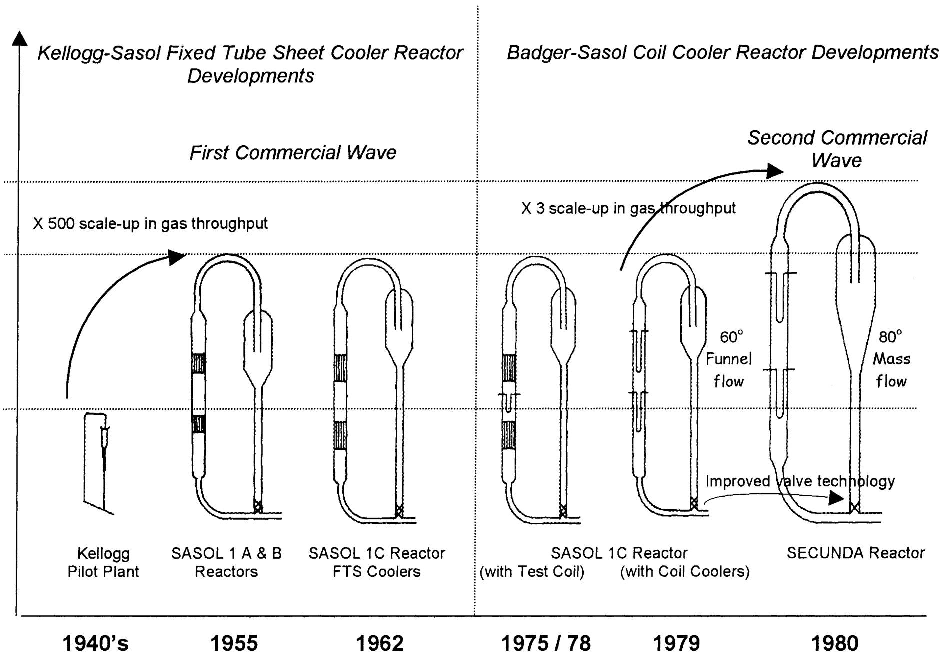

Fig. 1. Synthol CFB reactor development.

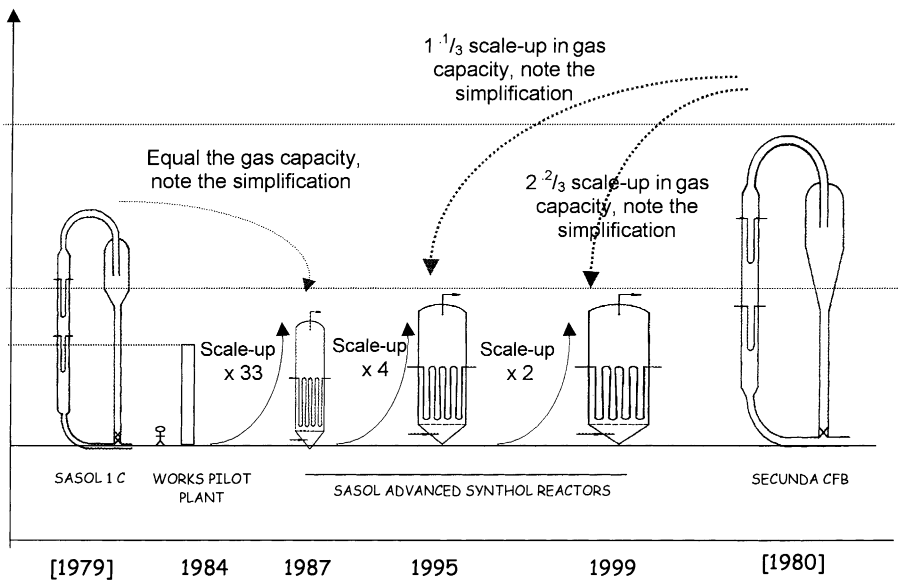

Fig. 2. Synthol reactor development: CFB to SAS.

"conceptual" process description utilized finely divided "reduced" iron oxide catalyst being fed from a "standpipe" through a "slide valve" where it is picked up by the incoming synthesis gas (at ambient temperature) and fed through the reactor section of the CFB unit, which consisted of open reactor sections and two banks of fixed tube sheet coolers. Here, the syngas reacts with the catalyst at approx. 310–330 °C, and is fed with the resulting products through the "goose neck" where, after the gas products and unreacted syngas is separated from the catalyst in a bank of cyclones, discharging the gas to the down stream product cooling unit. The catalyst falls back to the hopper and standpipe, where it is picked up by the reaction gas to take part in the process again. Runs were supposed to last for up to 340 days (this included catalyst addition and withdrawal to maintain equilibrium conditions)—this was, however, never the case as several unforeseen operational and design problems came to light. A positive frame of mind, however, created opportunities for improvement. These changes included the following:

1. Improvement of the inadequate shock absorbing system. The circulation of the high-density catalyst gave rise to excessive movement of the reactors. This issue was addressed by re-viewing the overall design of the shock absorbing system.
2. Waxy catalyst "Cannonball" formation due to lower than required reactor temperatures—this took 5 years to engineer out. The reactor was operated more isothermally by sufficiently preheating the feed gas and the role of alkaline promoters also gradually became better understood.
3. Standpipe catalyst bridging and gas bypassing occurred because of the loss of fine catalyst. The importance of fines for smooth fluidizing was later realized from transparent cold model fluidization studies and from the literature.
4. The catalyst hopper was also suspected of funnel flow (10–30% catalyst hang up), an issue that was only addressed with the installment of the Secunda CFB reactors. This issue was solved, changing the cone angle of the hopper. It was made steeper to induce a wall to wall (mass) flow of catalyst.
5. Typical run lengths of 40 days were the order of the day, as on-line catalyst removal and addition was not a reality till the 1990s, when valve technology improved significantly.
6. The initial fixed tube sheet coolers had a design flaw inherent to two phase flow through parallel paths. Tubes as a result blocked and in some instances, due to the incoming flow angle of the catalyst were cut by the high velocity catalyst. This exposed the hot cooling oil to the highly pyrophoric catalyst, resulting in spectacular shutdowns. The problem was later "engineered" out from the third Sasolburg CFB, by introducing serpentine coil coolers.
7. Low heat removal capacity was addressed by increasing the length of the cooler tubes on the third Sasolburg CFB that came on-line during 1960. The standpipe length was increased. A higher pressure cooling oil system was also introduced. The startup of the new (third) Sasolburg CFB reactor was (relatively) uneventful.
8. The third CFB reactor at Sasolburg was extensively modified in 1979 with Sasol-Badger (Badger now the "Washington Group International") design initiatives. The fixed tube sheet coolers were changed to cooling coils. No major erosion was experienced and there proved to be no problems with heat transfer coefficients and catalyst loading in the reactor side or fast-fluidized bed.

Hence, Sasol took a sound but unproven pilot plant scale-up of Kellogg, to a routine day to day operation and profitable commercial process by means of innovative design changes, general state-of-the-art advances and importantly, experience!

1.3. The second commercial technology wave—Sasol 2 and 3 CFB

OPEC's oil embargo of the early 1970s overnight turned Sasol into a production/development orientated company and in 1974, the decision was made to build the Sasol 2 CFB-based plant. With the help of Badger a major development effort was undertaken and the end result was eight huge 60 m tall CFB reactors, allowing for approx. 3.5× scale-up of gas throughput—compared to Sasol 1. Before Sasol 2 (now Sasol West) started-up, the decision was made to expand the initial concept and add an identical complex next door—hence the birth of Sasol 3 (now Sasol East). Sasol 2 started up on schedule in 1980, and Sasol 3 2 years later in 1982. Compared to the 1955 start-up of Sasol 1, the 1982 start-up of Sasol 3 went very smoothly with all reactors being brought up to full design conditions very quickly. The operation of these reactors was relatively smooth and the Sasol-Badger developments minimized standpipe bridging, catalyst hang-up in the hopper and cooler blockages were eliminated. Initially, the reactors were still operated on a batch process basis, but during 1994/1995 further development work led to the introduction of on-line catalyst removal and addition, changing the process to a continuous operation between plant shutdowns.

1.4. The third commercial technology wave—Sasol advanced synthol (SAS)

As already mentioned above, dense phase turbulent bed reactors were unsuccessfully operated at Brownsville, Texas, in the 1950s. Many problems were evident at the time, Sasol however re-investigated this technology as an alternative and potentially cheaper option to CFB operation. The SAS technology uses a less-expensive reactor without the CFB complexity of the reactor–hopper–standpipe system suspended in a complex structure. The installed capital cost for a SAS is less than three-quarters of that of a CFB and maintenance costs are greatly reduced. Furthermore, a 50% lower pressure drop across the SAS unit also results in a saving in both the capital and operating cost of the gas compressors. Recompression of recycle gas to circulate the large tonnages of catalyst also adds to capital and operational costs.

During the SAS development stages at Sasolburg, a semi-works demonstration reactor (90 bbl/d) was run in parallel to a commercial CFB reactor. Initial operational problems of the test unit included blockages of the solid separation units, i.e. cyclone and diplegs. This problem was solved with the help of an equipment vendor.

In May 1989, on completion of the research program, a 33× scale-up to a 5.0 m diameter commercial SAS unit (3000 bbl/d) took place and was successfully operated in Sasolburg. The unit was relatively easy to operate and could withstand major plant upsets. The reactor, for equal processing capacity is simpler and much smaller in overall size, when compared to a CFB reactor. It is structurally self-supporting, hence eliminating additional cost for an expensive support structure. The SAS unit also houses more cooling coils in a bank due to its larger diameter and also has more space for heat exchange. This allows for greater conversion capacity.

Other advantages of the SAS unit above the CFB units includes:

- higher per pass conversions, thus necessitating lower recycle ratios;
- slightly smaller catalyst inventory at start-up for equivalent size reactors;
- lower catalyst consumption (by 50%/ton) of product;
- similar overall product selectivity, with the product spectrum slightly towards the heavier hydrocarbon numbers (thus marginally lower methane selectivity);
- excellent isothermal characteristics and temperature control;
- less maintenance;
- greater run stability;
- fluidization is less energetic thus giving less erosion on critical components and less catalyst attrition;
- no standpipe and no need to build-up pressure to circulate the catalyst.

During 1995, a further 4× capacity scale-up to a 8.0 m diameter SAS (11000 bbl/d) or SAS reactor took place, and was successfully commissioned and operated at the Secunda Sasol 2 plant. In 1998/1999, the whole of Sasol 2 and Sasol 3, i.e. 16 CFB reactors, were converted to four 10.7 m and four 8.0 m SAS reactors. The 10.7 m reactor (22000 bbl/d) was a further 2× scale-up from the 8.0 m reactor, which in fact is a 10× scale-up from the initial Sasol 1C reactor processing capacity.

1.5. Epilogue

To decrease unit costs and improve performance, Sasol strived to increase fuel volumes per fluidized reactor unit, and as already indicated above, the production per unit increased from approx. 2000 bbl/d (SASOL 1C) to 11 000 bbl/d (SAS 8.0 m) and 22 000 bbl/d (SAS 10.7 m). At the same time, the focus broadened even further to chemicals and Sasol is at present a major supplier of, e.g., alpha olefins, with a pool amounting to approx. 1.8 million tons of alpha olefins/annum still to be exploited (February 2000).

However, it is unlikely (although the idea cannot be excluded) that future increases in throughput capacity would be associated with larger reactor units. The focus is now shifting towards optimizing the current SAS operation. Specifically, areas like the process/production environment and catalyst optimization/development, towards tailoring the product spectrum, are receiving serious attention. There is scope to address both the volume aspect and the drive to market competitive chemicals by this route.

It can in conclusion, be stated that Sasol has covered an interesting journey since the early 1950s, implementing the sound, but unproven pilot plant scale-up of Kellogg, to a routine day to day operation and profitable commercial process by means of innovative design changes, general state-of-the-art advances and, importantly, experience! The journey still continues today.

For further reading see [1–7].

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