CONSIDERATIONS IN THE SELECTION OF A FISCHER-TROPSCH REACTOR FOR SYNFUELS PRODUCTION

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ABSTRACT

Since Sasol was founded 40 years ago, substantial development took place with respect to the reactor systems used for the Fischer-Tropsch reaction. Currently three reactor types are in commercial use at Sasol, namely the circulating fluidized bed, the conventional stationary fluidized bed and the fixed bed. A fourth, the slurry bed, is in an advanced stage of development.

In this presentation some major considerations for the selection of a reactor are reviewed. The market demand and potential product price structure should typically be the starting point for a project evaluation. The selectivity and conversion is strongly determined by temperature for a given catalyst. The temperature, as well as exothermic heat of reaction have a bearing on the reactor system. Other considerations include the feed gas composition, the nature of the catalyst and gas recycle ratio.

When optimizing a Fischer-Tropsch reactor for synfuels production, the desirable gasoline to diesel final product ratio is a major consideration. When a balanced gasoline to diesel ratio is required, an iron based fluidized catalyst system operating at about 340°C would be preferable. Should diesel be the predominant product, lower synthesis temperatures (about 220°C) in a fixed bed or slurry phase reactor are more suitable.

Some cost figures for a base case modern Fischer-Tropsch fluidized bed reactor plant are discussed.

INTRODUCTION

At a meeting like the Indirect Liquefaction Contractors' Review Meeting, it is not necessary to convince the audience of the relevance and importance of indirect liquefaction. The title of the meeting suggests indirect liquefaction as contrasted to direct liquefaction and both these terms have traditionally been seen as coal conversion processes. Coal will be, from a strategic point of view, a dominant energy carrier after gas and oil reserves have diminished. However, the utilisation of coal for synfuels production relies on gasification to produce syngas. Syngas is therefore a key factor in the discussion of indirect liquefaction.

The choice of producing syngas from coal or from natural gas is based on the prevailing economic and logistic considerations for a given site. In many localities natural gas is still available in significant quantities to be economically converted to synfuels. Furthermore the options of using flared gases from oil wells or nitrogen containing natural gases could be considered. In most localities liquefaction based on natural gas would be economical before indirect coal liquefaction would be. The further focus of this paper will therefore be on the use of syngas, regardless of its origin.

FISCHER-TROPSCH VERSUS METHANOL

The two main routes for syngas conversion to synfuels are via Fischer-Tropsch synthesis or via methanol synthesis. I shall not cover the pros and cons of these two options, but it is worth noting that the Mossgas project selected Fischer-Tropsch in favour of the methanol route. This choice was still based on the circulating fluidized bed reactor, and the recently developed advanced fluidized bed provides even greater technological and economical advantages for synfuel production.

REACTOR TYPES

Of the various reactor configurations possible, Sasol has commercialised three types and a fourth is in an advanced stage of development. The figures give a schematic outline of the main features of the reactors. In this paper I shall limit my comments on the technical aspects of the two fluidized reactors, since that is dealt with in a separate paper.

In general, both the slurry bed and the advanced fluidized bed have the advantage of isothermal operation and simple construction. For both units the performance of the catalyst separation/recycle system is a key area to ensure success. Stable operation and significant flexibility regarding process parameters give advantages above the older fixed bed reactor or circulating fluidized bed reactor which have been in operation for over 35 years at Sasol. Continuous catalyst addition and withdrawal is practiced with the circulating fluidized bed and it is also a feature of the advanced fluidized reactor as well as the slurry reactor. Scale up of the slurry bed and fluidized bed is relatively straight forward, also for higher pressure operation.

The slurry bed has been the subject of investigation over many years (eg Kölbel, Mobil and MIT). Typically this unit is seen as an alternative to the fixed bed (Arge) system. It typically operates at temperatures favouring longer chain paraffins and lower selectivities of oxygenates than the fluidized systems. The high degree of isothermicity of the slurry bed should give narrower selectivities than the fixed bed, where a greater spread of temperature is experienced radially in the tubes packed with catalyst. This effect has not yet been fully substantiated in the 1 metre diameter slurry pilot plant which was recently commissioned.

CONSIDERATIONS IN SELECTION OF REACTORS

A number of interdependent factors influence the nett product yield of a Fischer-Tropsch reactor. The major ones are briefly discussed. In practice, an economical optimal combination of factors usually requires compromises on individual factors.

Catalyst

This paper does not deal with the catalysis of Fischer-Tropsch reactions, but clearly the nature (and cost) of a catalyst will have a bearing on the reactor design and has a decisive impact on the selectivity. The more exotic metal catalysts require a different operating philosophy as compared to the cheaper iron based catalysts which can be discarded after use. The selectivity patterns and thus the associated work-up required, determine the cost of the refinery. Although a great flexibility can be achieved by varying the process parameters for a given catalyst, the down-stream process units generally cannot be designed to take care of this wide flexibility, since this would be economically prohibitive. The careful matching of catalyst and market requirements is therefore a must.

Heat of Reaction

The exothermic heat of reaction needs to be withdrawn from the reaction zone. From a thermodynamic efficiency point of view, steam raising is favoured since this steam (at Sasol 40 bar) can be used to drive rotating equipment in the plant complex. The use of serpentine coils gives ample temperature control to ensure optimal temperatures to match the type and average age of the catalyst.

Operating Parameters : Temperature

The dominant operating parameter is the temperature. For the conventional Sasol iron based catalyst systems the temperatures are limited due to coke formation (and thus plugging) if the upper limit in the fixed bed is exceeded. For the fluidized bed a lower limit exists where waxy products start forming, leading to a loss of fluidization. With the slurry bed, it is possible to raise the temperature higher than in the fixed bed, provided the solids separation step can take care of any carbon which was formed.

The selectivity patterns of the fixed bed and fluidized bed have been well published by Dry and others. In this context, it is important to note some key differences in product selectivity for synfuels production. For high temperatures (at Sasol 340°C) the product spectrum is very suitable for branched chain products in the gasoline range, giving good octane numbers and the quantities of non-acid oxygenates which form, can be well accommodated in the gasoline. The lighter olefins can be readily oligomerized to products in the diesel range. The process lends itself to be a predominant gasoline producer, but at Sasol around 40% of the spectrum was at times in the diesel range.

The lower temperature operation (220°C) tends to form more primary products. This leads to longer straight chain paraffins and even waxes, much less oxygenates than the higher temperature and virtually no aromatics (the higher temperature yields around 7% aromatics). This product gives a very superior diesel with cetane number of about 75. However, the cut in the gasoline range is also highly paraffinic with a low octane number. It is a very good feedstock for a cracker, but would need extensive refining to meet gasoline specifications.

Operating parameters : Recycle and Pressure

Depending on the optimal conversion for a required selectivity, it may be necessary to recycle tail gases from the reactor. This decreases thermal efficiency due to compression costs but serves the further function of acting as a mechanism for temperature control. In the slurry bed and the advanced fluidized bed units, the latter function becomes less crucial. The main condideration would then be the economics of the alternative use of the tailgas versus the cost of recycling. The ratio of hydrogen to carbon monoxide in the feed gas (combined syngas and recycle gas) is an important ratio from a kinetic point of view. The "usage ratio" of the gases as well as water gas shift activity of the catalyst have to be optimised in the light of the feed gas hydrogen to carbon monoxide ratio. If reforming is used to produce the syngas, the recycle is especially important for the right hydrogen to carbon monoxide ratio.

The effect of methane and carbon dioxide (both formed during synthesis) must be carefully considered in the overall process configuration. Not only the thermodynamic efficiency, but also the economics can be markedly improved if the methane stream can be used at fuel value instead of being reformed.

The gas throughput of a reactor is proportional to the pressure, whereas the cost is more than proportional to the pressure. It is therefore a case of weighing up the advantages of higher throughput against higher costs. This affects the total system pressure and not merely the reactor. The negative effect of higher pressure on catalyst performance is in our experience negligible. The practical limits of size is set by field construction or transport constraints for the selected reactor.

Products

As indicated above, the temperature and catalyst are major factors in determining the product spectrum. Many studies have been made to steer the Fischer-Tropsch selectivity pattern in a particular direction and some interesting results have in fact been reported. Not only selectivity but also conversion, ie tons of marketable products over the whole spectrum must be taken into consideration.

This meeting is focussing on energy needs, and a synfuels plant with automotive fuels as main products can be viable as will be indicated later. However, if markets for chemicals like ethylene, propylene, acetone, alcohols and similar products can be serviced logistically, it will undoubtedly add significantly to the profitability of such a plant to produce such chemicals together with the fuels.

The market demands and total product price structure is thus one of the first considerations in the selection of a reactor for a Fischer-Tropsch plant.

Reactors for synfuels

Having considered the various reactor types and variables influencing their performance, one can conclude that when automotive fuels in a balanced proportion of gasoline and diesel are to be produced, the advanced fluidized bed reactor would be a logical choice. A capacity of 16 500 bbl/day per reactor is currently considered feasible for this reactor. However, if predominantly high quality diesel is the aim, a lower temperature synthesis would be preferable, and the slurry bed reactor would be the recommended system. Due to the lower temperature, the rate of reaction is less than in the fluidized bed and thus the yield of products per reactor volume will be less. The potential of derivative olefinic and oxygenate chemicals will also be less for the slurry bed reactor.

TECHNO-ECONOMIC CONSIDERATIONS

Due to the much greater simplicity of the advanced fluidized bed reactor, substantial capital and operating cost reductions are achieved in comparison with the circulating fluidized reactor alone. On the capital cost of the reactor a reduction of at least 50% is obtained. The significant savings on maintenance cost and the higher on-stream factor than the previous units, can only be fully quantified after a few years' operation. These savings will also be very substantial.

Few topics generate so much heated debate as process economics. One of the reasons is that every person evaluating a process has an own frame of reference and thus the set of assumptions differ from evaluation to evaluation. At Sasol we experienced it when people took the cost figures for Sasol Two or Three and simply expressed that as a capital cost per barrel of product without taking cogniscance of the nature or complexity of the plant in relation to the real nature of the final products, the degree of refining and the total product spectrum.

Experience has taught us, and other process developers, that the eventual costs of projects using new technology are notoriously under-estimated, until commercial scale of operation has been reached and accurate data is available.

Also regarding thermal efficiency, a lot of half-truths can cause skewed perceptions. Only when a plant is fully described does the comparison with a real alternative, also fully described, lead to meaningful conclusions. For instance, in the field of direct liquefaction, thermal efficiencies of around 75% over a reactor system can be achieved, but when a fully integrated self sustaining plant is considered, it could drop to 55%. As a further example, the choice between own power generation versus purchased power, can have a significant impact on the thermodynamic efficiency of the complex. In the process design, a few percentage points of thermal efficiency can easily be offset by inadequate considerations regarding utilities or the economic advantages due to higher efficiency can be forfeited if, for instance, excessive control systems costs are incurred. Maximum profitability requires attention to a multitude of details during design, construction and operation.

As a licensor of the Synthol process, Sasol is willing to make process and process economic details available to serious potential clients. Such information can be provided for the specific conditions prevailing at the chosen locality.

Clearly, the process economics differ greatly between starting from coal or from natural gas. Furthermore, the availability of suitable infrastructure or the proximity of potential clients for chemicals can make a meaningful difference in the viability of a project.

Another factor, as referred to above, is the marketing of chemicals. Should one be able to service a developed chemical market, around one third of the products could be channelled into chemical applications, adding substantially to the viability of such a project. Additional capital would be required for chemicals purification, but the added value above fuel value is generally attractive enough to justify the expenditure provided the total capacity of the Fischer-Tropsch plant is adequate to ensure a good economy of scale.

EXAMPLE: SYNTHOL USING NATURAL GAS

A major study was completed to assess the process economics for a base case using 410 million SCFD dry natural gas as feedstock to a 50 000 bbl/d Synthol plant. If an air separation plant,carbon dioxide removal, a reformer and basic product work-up is included up to the point of providing a syncrude, the capital cost of the complex would be about $1300 million (IBL), excluding utilities and offsites. After adding allowances for utilities and offsites, the plant could be economic at a crude oil price above $23/bbl. Three advanced fluidized bed reactors would be required. The thermodynamic efficiency for such an integrated plant can be between 62 and 65%.

It should be noted that the nature of this syncrude actually deserves a premium in terms of its suitability as a material for modern automotive fuels. It is free of sulphur, low in aromatics and the oxygenates co-produced in the Fischer-Tropsch synthesis and can be readily used as alcohols or converted to ethers. It has also been proven that particulate emissions from Fischer-Tropsch diesels are less than for crude oil based diesels.

CONCLUSION

For a synfuels plant, the advanced Synthol reactor is commercially proven. Furthermore, from an technical and economical point of view, serious consideration can be given to an advanced Synthol reactor as a refinery processing unit in a normal refinery. Benefits of such a unit would lie in factors such as the desirable gasoline and diesel blending properties of the products, the potential chemicals, the utilisation of refinery gas which could be converted to syngas and the generation of 40 bar steam from the exothermic heat of reaction. Again, a proper techno-economic assessment needs to be done for a specific application.

The advanced Synthol process is technically sound and economically competitive to produce fuels to conform to modern requirements. The advanced fluidized bed Synthol technology has an techno-economical leadership position in the synfuels field.

FISCHER - TROPSCH REACTOR TYPES

LOW TEMPERATURE		HIGH TEMPERATURE (SYNTHOL)	
FIXED BED (ARGE)	SLURRY BED	CIRCULATING FLUIDIZED BED	ADVANCED FLUIDIZED BED
COMMERCIAL SINCE 1955	DEVELOPMENT 1 METRE ID	COMMERCIAL SINCE 1955	COMMERCIAL SINCE 1989